

**THE SYSTEMATICS AND PALEOBIOLOGY OF HETTANGIAN AMMONITES  
FROM THE ALLOCHTHONOUS TERRANES OF BRITISH COLUMBIA**

by

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## ABSTRACT

The Hettangian is a poorly understood 3 million year time interval following the Triassic-Jurassic mass extinction during which the biosphere struggled to rebuild its diversity.

Hettangian ammonite faunas are examined from the two key areas of the terranes of British Columbia, Taseko Lakes and the Queen Charlotte Islands (QCI). In total, 90 different species or taxonomic groups are described representing 32 genera. Thirteen new species are recognized. Stratigraphic ranges are identified for each taxon and the North American Zonation is updated so that it is more representative of Canadian sequences. Except for the definitive occurrence of the Spelae Zone, all Hettangian zones of the North American Zonation are present in the BC terranes.

A section on Kunga Island in the QCI demonstrates a spectacular radiolarian turnover across the Triassic-Jurassic transition interval (T-J boundary), provides a radiometric date to constrain the boundary, contains ammonites which permit correlations with other areas and can be correlated with a carbon curve which shows a distinct negative excursion just below the radiolarian turnover. This section is proposed as a potential Global Stratotype Section and Point for the basal Jurassic if radiolarians are selected as the primary standard for defining the T-J boundary or as a parastratotype section to assist with characterizing the interval if radiolarians are not selected.

Detailed correlations are suggested between the Hettangian and lower Sinemurian of the terranes and other areas of North America, South America, New Zealand, western and eastern Tethys, and northwest Europe.

The lateral distribution of ammonite faunas suggest there may have been some longitudinal separation between the craton and the Cadwallader, Wrangellia and Peninsular terranes during



the Hettangian. They also support a significant northward displacement for Wrangellia relative to the craton since Early Jurassic time and suggest that the Hispanic Corridor connecting the Panthalassa and Tethys oceans may have been open during the Hettangian.

Sexual dimorphism is recognized in several Hettangian genera including *Kammerkarites*, *Eolytoceras*, *Sunrisites* and *Badouxia*. Asymmetries in the vertical position of the internal elements of the phragmocone of *B. columbiae* were assessed for a potential counterbalance mechanism using computer modeling. No counterbalance mechanism was recognized.

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## **DEDICATION**

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## CO-AUTHORSHIP STATEMENT

This thesis results from the work and leadership of Louise Longridge. Louise is principally responsible for performing the research and data analyses including the majority of the ammonite systematics. Apart from the exceptions discussed below, Louise is responsible for virtually all manuscript content. This research produced papers co-authored with 7 other scientists. The extent and scope of this collaboration was as follows:

1. The work was carried out under the supervision of Paul Smith as part of his research program dealing with Jurassic extinction, radiation and biogeography, funded by NSERC. Smith initiated the project and provided scientific guidance in the field and in the laboratory, as well as editorial input.
2. The late Howard Tipper of the Geological Survey of Canada provided fossil collections, stratigraphic information and scientific guidance regarding ammonite biostratigraphy.
3. Elizabeth Carter is completely responsible for all aspects of the radiolarian studies which form part of Chapters 2 and 3 and had editorial input in other portions of these chapters.
4. Jozsef Pálffy performed the original systematic work on the latest Hettangian faunas from the Queen Charlotte Islands. This data was updated by Louise and is included in Chapter 4. He also completed the initial systematics on one of the *Sunrisites* species included in Chapter 6 and provided editorial input on Chapters 4 and 6.
5. James Haggart of the Geological Survey of Canada contributed content and had editorial input on Chapter 3.
6. Bill Rawlings and Voytek Klapotocz worked in close consultation with Louise to construct the computer ammonite models and perform the analyses in Chapter 8.

# 1 INTRODUCTION

## 1.1 Introductory Statement

This thesis research addresses 4 broad questions:

1. How does the Canadian succession of Hettangian ammonites contribute to our understanding of the recovery of this group directly following their near demise during the Triassic-Jurassic extinction?

The recovery of the ammonites in the Hettangian Stage represents the beginning of one of the most spectacular adaptive radiations in the fossil record. This study provides insight into how this major group recovered and flowered to become a dominant force throughout the following hundred and thirty-five million years. Hettangian ammonites occur in several of the tectonostratigraphic terranes that make up western Canada (Fig. 1.1). The two most important areas are the Queen Charlotte Islands (QCI), which contain a virtually complete Hettangian succession, and Taseko Lakes, which contains a diverse and well preserved late Hettangian fauna.

2. How does the Canadian succession potentially contribute to a) the definition of the Triassic-Jurassic boundary, b) recognition of the Triassic-Jurassic transition elsewhere in the world, and c) time scale calibration?

The mass extinction at the end of the Triassic is one of the “big five” mass extinctions in the Phanerozoic. Despite its importance, this extinction is relatively poorly understood due in part to the small number of continuous sections spanning the Triassic-Jurassic boundary (T-J boundary) as a result of eustatically low sea level at the time. This problem has also led to difficulties in choosing a global stratotype section and point (GSSP) to define the boundary. Ammonites are usually chosen as index fossils in the Jurassic, but the low diversity and rare occurrence of earliest Jurassic ammonites make

them imperfect for use as the primary standard. The QCI have the potential to assist with boundary definition primarily because two sections from the area contain a diverse and complete radiolarian record which shows a spectacular turnover across the T-J boundary.

Although ammonites were widespread in Early Jurassic seas, significant endemism and provincialism existed within the faunas. This led to Taylor *et al.* (2001) establishing a regional zonation for the Hettangian and Sinemurian of western North America (Fig. 1.2). However, this zonation is incomplete and inaccurate with respect to the fauna from the Canadian terranes. The unusual biogeographic setting of the terranes means the Canadian fauna maximizes correlation potential with other regions because it contains east-Pacific, Tethyan and rare Boreal forms. These correlations are of added importance, because fossiliferous strata are often interbedded with ash beds in North America, permitting the calibration of biochronologic and geochronologic time scales.

3. What was the relationship between paleobiogeography and plate tectonics during and subsequent to the Hettangian?

Fossils are essential to understanding the tectonically complex history of western North America. Ammonites from British Columbia (BC) provide useful data for testing previous hypotheses of terrane movements and the possible existence during the Hettangian of the Hispanic Corridor, a trans continental seaway linking the Panthalassa and Tethyan oceans (Smith 1983; Fig. 1.3).

4. What insights can be gained concerning the paleobiology of the ammonites during this critical phase of their evolution?

Sexual dimorphism is relatively poorly documented in Hettangian forms yet is common in several genera from the BC terranes. Furthermore, it is common for Hettangian ammonites to have asymmetries in the elements of their phragmocone. This

raises the question as to whether a counterbalance mechanism was in effect, allowing the animal to remain upright in the water column.

## 1.2 Previous Work

### 1.2.1 Systematics

Work on Hettangian ammonite systematics has been underway in numerous parts of the world for many years. Previous studies have revealed that Hettangian ammonites are not cosmopolitan but are restricted to two faunal provinces. The Boreal Province occupies the northern part of the Northern Hemisphere, while the Tethyan Province occupies the rest of the world (*sensu* Westermann 2000). The two faunal realms were separated by a gradational boundary which fluctuated in position through time (Smith and Tipper 1986; Smith 1999; Cecca and Westermann 2003).

#### 1.2.1.1 Faunas from the allochthonous terranes of BC (Fig. 1.1).

Although no comprehensive taxonomic studies exist, preliminary studies of some Hettangian ammonites from the allochthonous terranes of BC have been published.

Frebold (1951, 1967) completed the first systematic studies of the upper Hettangian ammonite succession of the Taseko Lakes area. These works documented important genera such as *Paracaloceras* and *Eolytoceras* and identified the first *Psiloceras canadense* (now *Badouxia canadensis*). A taxonomic study of the Schlotheimiid fauna was completed by Smith and Tipper (2000).

In the Queen Charlotte Islands (QCI), preliminary lists of the main taxa were given by Tipper and Carter (1990), Tipper and Guex (1994), Tipper *et al.* (1994) and Carter *et al.* (1998). Pálffy (1991) studied the latest Hettangian faunas as part of his unpublished Master's thesis but only a biostratigraphic summary is in print (Pálffy *et al.* 1994).

Frebold and Tipper (1970) and Frebold and Poulton (1977) listed taxa from Morehead Creek in the Quesnel Lake area under the names *Psiloceras canadense* Frebold and *Paracaloceras* sp.

Frebold and Tipper (1970) and Frebold and Poulton (1977) listed *Schlotheimia* cf. *S. montana* (Wöhner) from the Mount Waddington Area.

Frebold and Tipper (1970) listed the occurrence of *Eolytoceras* cf. *E. tasekoi* Frebold from the Babine Lake area, although this claim was not supported in Frebold and Poulton (1977).

A fossiliferous section occurs in Holberg Inlet on northern Vancouver Island; however, fossils are rare and specimens poorly preserved. Identification is often difficult even at the generic level, although possible *Discamphiceras*, *Saxoceras*, *Franziceras* and *Pleuroacanthites* may be present in the middle Hettangian while *Badouxia* and *Schlotheimia* may occur in upper Hettangian strata.

Three specimens that may be of Hettangian age were described from the Salmo area of southeast BC under the names ammonite gen. et sp. indet. 1, ammonite gen. et sp. indet. 2 and *Gyrophioceras* (?) sp. indet (Frebold and Little 1962). Poor preservation makes confident identification impossible even at the generic level (Frebold and Little 1962; Frebold and Tipper 1970; Taylor *et al.* 1984).

In the Iskut River map area, Frebold and Tipper (1970) listed *Psiloceras canadense* from the Unuk River. Nadaraju (1993) included descriptions of taxa under the names *Badouxia* cf. *canadensis* (Frebold), *Alsatites* (?) cf. *proaries* (?) (Neumayr), *Canavarites* sp. indet., *Paracaloceras* cf. *rursicostatum* Frebold, *P.* cf. *multicostatum* Frebold, *P.* cf. *coregonense*? (Sowerby) and *P.* sp. indet from several different localities as part of her unpublished Master's thesis. Jakobs and Pálffy (1994) listed taxa from the area under the names *Metophioceras* cf. *rursicostatum*, *Paracaloceras* sp., *P.* cf. *cordieri*, *Eolytoceras* sp. *Badouxia canadensis*, *Sulciferites* cf. *marmoreus* and *S.* cf. *trapezoidalis*.

Frebold (1958, 1964*b*) described a collection from the Telegraph Creek area under the name *Psiloceras canadense* Frebold.

#### 1.2.1.2 Faunas from other areas of North America

Imlay (1981) documented Hettangian faunas across Alaska, whereas Pálffy *et al.* (1999) published a more local study of the ammonites from Puale Bay in southern Alaska.

The Yukon has yielded isolated specimens of generally poorly preserved material that is probably of Hettangian age (Lees 1934; Frebold 1964*a*; Frebold and Tipper 1970; Frebold and Poulton 1977; Poulton 1991), although the majority of the material is too poor for species level identification.

A fauna of early to late Hettangian age was described from the BC craton in the Williston Lake area (Fig. 1.1; Tozer 1982; Hall and Pitaru 2004).

A single specimen of *Discamphiceras* was found in Alberta (Hall *et al.* 2000).

In Nevada and Oregon, several areas yield well preserved sequences of Hettangian ammonites (Guex and Taylor 1976; Guex 1980, 1982, 1995; Taylor 1988, 1990, 1998, 2000; Guex *et al.* 1998, 2002; Taylor and Guex 2002).

González-León *et al.* (1996, 2000) and Taylor *et al.* (2001) documented late Hettangian ammonites from Sonora in northern Mexico.

#### 1.2.1.3 Faunas from other areas of the world

In South America, Hettangian ammonites are present in Peru, Chile and Argentina (e.g., Tilmann 1917; Cecioni and Westermann 1968; Geyer 1979; Hillebrandt 1981*a*, 1988, 1990, 1994, 2000*a, b*; Corvalan 1982; Prinz 1985; Quinzio Sinn 1987; Riccardi *et al.* 1988, 1991).

Many detailed taxonomic studies have been published on the Boreal faunas of northwest Europe (e.g., Sowerby 1812-1846; Wright 1879; Reynés 1879; Spath 1922, 1924; Elmi and Mouterde 1965; Bloos 1979, 1981, 1983, 1988, 1994, 1999; Lange 1941, 1951; Donovan 1952; Schlegelmilch 1976; Hodges 1986; Guerin-Franiatte 1990; Kment 2000; Bloos and Page 2000).

Extensive taxonomic studies have also been completed on the Tethyan successions of the Mediterranean area (e.g., Gümbel 1861; Neumayr 1879; Wähner 1882-1898; Canavari 1888; Lange 1952; Blind 1963; Rakús 1975, 1993*a, b*, 1999; Rakús and Lobitzer 1993; Bloos 1979, 1983, 1988, 1994; Braga *et al.* 1984; Venturi 1985; Donovan 1958; Dommergues *et al.* 1995; Böhm *et al.* 1999; Pálffy and Dosztály 2000; Kment 2000; Bertinelli *et al.* 2004).

Hettangian faunas also occur in several other areas of the world including New Caledonia, Timor and New Zealand (Spath 1923; Krumbeck 1923; Avias 1953; Stevens 2004), China (Yin *et al.* 1999, 2007; Yin and Enay 2000), and the Russian Federation (e.g., Repin 1977, 1984; Dagys 1996).

### **1.2.2 North American Zonation**

Northwest European ammonite successions (e.g., Dean *et al.* 1961; Mousterde and Corna 1997; Page 2003) are considered the primary standard for Early Jurassic biochronology (Callomon 1984). In 1961, Dean *et al.* erected the Planorbis, Liasicus and Angulata zones for the region (Fig. 1.2). Correlation of these three classic zones with North America has been difficult because key European index genera and species are missing. Early Jurassic ammonites in North America have more in common with Tethyan successions from Mediterranean countries than the Boreal successions found in northwest Europe. In addition, a high number of endemic forms in the eastern Pacific further complicates this issue. For these reasons, a separate zonation for the Hettangian and Sinemurian of the Western Cordillera of North America was established by Taylor *et al.* (2001) (Fig. 1.2). Unfortunately, this zonation is inaccurate and incomplete with respect to the Canadian forms.

### **1.2.3 Correlations between Canadian successions and other areas**

Similar to the situation with northwest Europe, endemism and provincialism make correlations difficult between North American successions and those of South America, New Zealand, and western and eastern Tethys. Correlations with other areas are of particular



significance because interbedded volcanic and fossiliferous marine rocks in Canada and Alaska permit the calibration of geochronological and biochronological time scales (Pálffy *et al.* 1999, 2000a, b).

#### **1.2.4 Triassic-Jurassic boundary**

##### 1.2.4.1 Date of T-J boundary

Until recently, a date of  $199.6^{+/-0.3}$  was used to constrain the T-J boundary (Pálffy *et al.* 2000a, b). This date, obtained using multi-grain zircon analysis from an ash bed on Kunga Island, is now considered too young, and further work is underway to refine its accuracy (Pálffy and Mundil 2006). A date of  $201.27 \pm 0.27$  Ma was obtained for the T-J boundary from a Central Atlantic Magmatic Province (CAMP) flow in Nova Scotia, Canada using single-crystal zircon analysis (Schoene *et al.* 2006).

##### 1.2.4.2 End-Triassic mass extinction

The Hettangian is the first stage in the Jurassic. Thus, it falls directly after the mass extinction which defines the T-J boundary. This extinction is commonly cited as one of the five most severe mass extinctions in the Phanerozoic. Approximately 22% of marine families, 53% of genera and 80% of species became extinct (Sepkoski 1996; Pálffy 2003), and there was also a significant extinction in the terrestrial realm at this time (e.g. Visscher and Brugman 1981; Fowell *et al.* 1994; Hallam and Wignall 1997). Despite significant progress (Hesselbo *et al.* 2007), the end-Triassic event is one of the most poorly understood and least researched in the Phanerozoic (Twitchett 2006).

A large volume of literature exists on the groups affected by high extinction rates in the latest Triassic, and only a brief summary is provided here. Brachiopods, bivalves, reef organisms, ammonoids, nanofossils, palynomorphs, ostracodes, foraminifera, radiolarians, conodonts, plants and vertebrates are all affected (e.g., Hallam 1996, 2002; Hallam and Wignall 1997; Pálffy 2003; Tomašových and Siblík 2007; Hillebrandt *et al.* in press; and references therein). Some

taxa show a marked turnover at the boundary. The radiolarians demonstrate a distinct change where rich and diverse Triassic forms were mostly replaced by a low diversity basal Hettangian fauna composed of very simple forms (Carter 1994, 1998; Carter *et al.* 1998; Carter and Hori 2005; Longridge *et al.* 2007). Although not evident in all cases, a clear extinction is also recognized in palynomorph assemblages (e.g., Visscher and Brugman 1981; Fowell *et al.* 1994; Hallam and Wignall 1997; Gómez *et al.* 2007; Kuerschner *et al.* 2007; Whiteside *et al.* 2007). In addition, extinction rates were probably high in bivalves, brachiopods, reef biota and possibly plants at the boundary (Laws 1982; McRoberts and Newton 1995; Hallam 2002; Pálffy 2003; McRoberts 2004; and references therein). Other groups exhibit more gradual extinction in the Late Triassic including ammonites, conodonts and land vertebrate taxa (Benton 1991; Taylor *et al.* 2000; Hallam 2002; Pálffy 2003; Tanner *et al.* 2004; and references therein).

Kiessling *et al.* (2007) analyzed the abundance and diversity patterns of marine benthic organisms such as sponges, corals, bivalves, gastropods and brachiopods across the T-J boundary using data from the Paleobiology Database. Despite the gradual extinction pattern of some groups, they found these groups have elevated extinction rates and reduced origination rates in the Rhaetian and suggest that the end-Triassic does qualify as a true mass extinction when considered against Middle Triassic or Middle Jurassic background levels.

Environmental changes recognized over the T-J boundary interval include global warming, a widespread regression/transgression couplet, oceanic anoxia and widespread aridification (e.g., Tucker and Benton 1982; Hallam and Wignall 1997, 2000; McElwain *et al.* 1999; Hallam 1997, 2001; Hesselbo *et al.* 2004; Tanner *et al.* 2004; and references therein). There was also a significant perturbation to the global carbon cycle across the boundary interval. Negative isotope anomalies have been identified in marine strata in BC, Nevada, England, Austria, Italy, China and Hungary (McRoberts *et al.* 1997; Pálffy *et al.* 2001; Ward *et al.* 2001, 2004, 2007; Hesselbo *et al.* 2002; Guex *et al.* 2003, 2004, 2007; Galli *et al.* 2005; Hillebrandt 2006; Yin *et*

*al.* 2006; Williford *et al.* 2007; Kuerschner *et al.* 2007; Lucas *et al.* 2007) and in terrestrial strata in Greenland and China (Hesselbo *et al.* 2002, 2006). Tanner *et al.* (2004) suggest that the biotic turnover in the latest Triassic may be caused by a combination of gradualistic and catastrophic mechanisms of environmental change such as long term ecological degradation from sea-level fluctuation or climate change in addition to more abrupt events like flood basalt volcanism or bolide impact.

Flood basalt volcanism of the CAMP is currently the most favored trigger for the environmental perturbations and biotic crisis at the end-Triassic (e.g., Marzoli *et al.* 1999, 2004; Pálffy *et al.* 2002; Hesselbo *et al.* 2002, 2007; Pálffy 2003; Knight *et al.* 2004; Golonka 2007). The flood basalt, brought about by the beginning of the rifting of Pangea in the latest Triassic, extends over  $7 \times 10^6 \text{ km}^2$  (Marzoli *et al.* 1999). This event may have been responsible for environmental change via volcanic outgassing of  $\text{CO}_2$  or  $\text{SO}_2$  or possibly by indirectly triggering the release of methane hydrates from the sea floor (Pálffy *et al.* 2001; Hesselbo *et al.* 2002). Although recent work by Verati *et al.* (2007) reveals intrusive magmatism commenced about 201 Ma ago, peak activity is restricted to between 199 and 197.5 Ma, and currently the temporal feasibility of CAMP as the main trigger for end-Triassic events is controversial. For example, Marzoli *et al.* (2004) and Knight *et al.* (2004) believe the beginning of CAMP pre-dates the Triassic-Jurassic palynological turnover event in the terrestrial realm, whereas Whiteside *et al.* (2007) suggest it post-dates the turnover.

Bolide impact has also been suggested as a possible cause for the end-Triassic event based principally on a modest iridium anomaly and a fern spore spike in eastern Canada (Olsen *et al.* 1987, 2002 *a, b*; Fowell and Olsen 1993; Fowell *et al.* 1994). Shocked quartz was reported from T-J boundary sections in Austria and Italy (Badjukov *et al.* 1987; Bice *et al.* 1992), but these reports have been discounted (Hallam and Wignall 1997). At this stage, an impact cannot be excluded although no impact crater has been found that conclusively coincides with the end-

Triassic event (Pálffy 2004; Hesselbo *et al.* 2007). Furthermore, a low rate of origination in the Rhaetian as well as the dependency of extinction intensity on the habitat of taxa make an impact scenario less likely (Kiessling *et al.* 2007).

As discussed by Hesselbo *et al.* (2007), one of the biggest problems in resolving the causes and events surrounding the end-Triassic mass extinction is lack of sufficiently high temporal resolution. Many of the published  $^{40}\text{Ar}/^{39}\text{Ar}$  and U-Pb dates may be too young due to an uncertainty in the decay constant of  $^{40}\text{K}$  and slight Pb loss in multi-grain U-Pb analyses. Recent advances mean these problems may be overcome and will lead to greater confidence in comparing the timing of different events in the future.

#### 1.2.4.3 Triassic-Jurassic boundary definition

Attempts to select a global stratotype section and point (GSSP) to define the basal Jurassic have been ongoing for over 20 years. Due to low sea level across the T-J boundary interval there are relatively few continuous sections worldwide (Hallam and Wignall 1997; Hesselbo *et al.* 2007). This issue is further complicated by the low diversity and low abundance of faunas, especially in the basal Jurassic. Six GSSP candidates from five areas are currently under consideration by the Jurassic Subcommittee, and a report is in preparation which will provide details of each proposal. A very brief outline of each candidate is included here.

- 1) St. Audrie's Bay, England (e.g. Warrington *et al.* 1994; Hesselbo *et al.* 2004; and references therein)

The boundary level would probably be at the lowest occurrence of *Psiloceras planorbis*. This level has historic precedence because it has been used to define the base of the Hettangian Stage in the United Kingdom for many years (e.g. Cope *et al.* 1980). The section provides a carbon isotope curve that shows a marked negative anomaly across the boundary interval and also provides magnetostratigraphy (Hesselbo *et al.* 2002; Hounslow *et al.* 2004). Unfortunately, a stratigraphic gap of about 10 m exists between the highest

Triassic bivalve and lowest *P. planorbis* (e.g., Warrington *et al.* 1994; Hounslow *et al.* 2004), although a Triassic conodont closes this gap to about 6 m. The section also includes a major facies change over the T-J boundary interval and lacks Triassic type ammonoids. This proposal would place the T-J boundary above the incoming of the first *Psiloceras* in St. Audrie's Bay (e.g. Bloos and Page 2000) and other areas (e.g., Lucas *et al.* in press; Hillebrandt *et al.* in press; and references therein).

2) Larne section, Waterloo Bay, Northern Ireland (Simms and Jeram 2006, in press)

The boundary level would be at the lowest occurrence of *Psiloceras planorbis*. The Larne section can be readily correlated with the St. Audrie's Bay section. Although the latter section is much better studied, the Larne section is an expanded section and has better ammonite preservation, diversity and abundance. It also has the potential for a useful carbon isotope curve and provides cyclostratigraphy and sequence stratigraphy. However, no Triassic type ammonites are present, and the Triassic fossil record is generally poor. At present, it lacks detailed data on the bivalve fauna and the presence of useful magnetostratigraphy.

3) Karwendel syncline, Austria (Hillebrandt *et al.* 2006, in press)

The boundary would be placed at the incoming of the first psiloceratid ammonite, *Psiloceras cf. spelae*. This section contains well preserved latest Triassic and earliest Hettangian type ammonites, other macrofossils and diverse microfossils. A palynological marker species permits correlation with coeval terrestrial sections. A carbon isotope curve is available showing a negative anomaly below the incoming of Jurassic type ammonites (Hillebrandt in press; Ruhl *et al.* in prep). The section may be remagnetized.

4) Ferguson Hill, Nevada – negative carbon isotope excursion (McRoberts *et al.* in press)

The boundary would be placed at the first negative peak in the carbon isotope excursion that spans the T-J boundary interval (Guex *et al.* 2003, 2004, 2007; Ward *et al.* 2007;

McRoberts *et al.* in press). This proposal has the advantage of widespread correlation between marine and terrestrial sections which also contain carbon curves with a marked negative excursion across the T-J boundary (e.g. Hesselbo *et al.* 2002, 2006; McRoberts 2004; Guex *et al.* 2004; Galli *et al.* 2005). The excursion would have to be correlated with a biostratigraphic datum (Remane *et al.* 1996; McRoberts 2004; Lucas *et al.* 2005). Both bivalves and ammonites are present in the section and could be used although they occur 1.6 and 2.5 m above the negative peak.

- 5) Ferguson Hill, Nevada – lowest occurrence of *Psiloceras tilmanni* Lange (Taylor *et al.* 1983; Guex *et al.* 1997, 2006; Lucas *et al.* 2005, 2007, in press; and references therein)

The boundary would be placed at the incoming of ammonites of the *Psiloceras tilmanni* group (first occurrence of *P. spelae*). This section has moderately abundant Triassic and Jurassic type ammonites across the T-J boundary interval although a stratigraphic gap of about 7 m exists between the highest Triassic and lowest Jurassic ammonite. Several microfossil groups including conodonts and radiolarians have been collected from the T-J boundary interval (Orchard *et al.* 2007). As discussed above in proposal 4, this section also provides a useful carbon isotope curve. In this proposal, the negative excursion would fall in the latest Triassic.

- 6) Kunga Island, QCI (Carter and Tipper 1999; Longridge *et al.* 2007, in press; and references therein)

The boundary would be placed at the dramatic turnover of radiolarian fauna that constrains the boundary to 0.8 m (Carter 1994, 1998; Carter *et al.* 1998; Longridge *et al.* 2007). This section has provided a date to constrain the T-J boundary (Pálffy *et al.* 2000a, b) and can be correlated with a useful carbon isotope curve from a section at Kennecott Point (Fig. 1.1) that shows a negative peak just below the radiolarian turnover. The Kunga Island section contains Jurassic ammonites from the Minutum to Polymorphum zones

(Fig. 1.2), which permit correlation with other areas. However, the section is difficult to access, lacks Triassic ammonites and lacks definitive ammonites from the Spelae Zone (Fig. 1.2). Thus it may be more suitable as a parastratotype section to assist with characterizing the boundary rather than as the holostratotype which defines it.

### **1.2.5 Paleobiogeography**

#### **1.2.5.1 Hispanic Corridor**

The western Tethys was linked to the eastern Pacific Ocean during Jurassic time via the Hispanic Corridor (Smith 1983; Fig. 1.3). The precise time of the initial opening of this seaway is still uncertain and has been the subject of much debate. Although sedimentological or geophysical evidence supporting this connection suggests an age no older than the late Middle Jurassic (Smith and Tipper 1986; Smith *et al.* 1990; Aberhan 2001; Rueda-Gaxiola 2006), paleontological data suggest a significantly earlier marine connection across rifting continental crust (e.g., Damborenea and Manceñido 1979; Hillebrandt 1981*b*, 2002; Smith and Tipper 1986; Sandy and Stanley 1993; Damborenea 2000; Aberhan 2001; Smith *et al.* 2001; Moyne *et al.* 2004).

#### **1.2.5.2 Terranes**

Western North America is a tectonically complex area that is made up of many 'suspect terranes' (e.g., Coney *et al.* 1980; Monger and Nokleberg 1996). The terranes were transported by subduction of the Pacific Plate beneath the North American Plate and then accreted to the stable craton of North America. The term suspect refers to the terranes uncertain paleogeographic affinities. By the end of the Early Jurassic, the terranes were approximately in their current latitudinal position with respect to the craton (Aberhan 1998; Smith 2006). However, faunal evidence suggests many of the terranes underwent significant northward displacement during the Early Jurassic (Taylor *et al.* 1984; Smith and Tipper 1986; Aberhan and Muster 1997; Aberhan 1998, 1999; Smith *et al.* 2001; Smith 2006). Faunal evidence also

suggests significant longitudinal displacement since Permian time (Belasky 1994), although by the Early Jurassic the terranes were positioned within the eastern Pacific (Taylor *et al.* 1984; Aberhan 1998; Smith 2006).

Hettangian ammonites are found in four different terranes that make up BC (Fig. 1.1). Holberg Inlet and the QCI are part of Wrangellia; Iskut River, Telegraph Creek and Babine Lake are part of Stikinia; Quesnel Lake and Salmo are part of Quesnellia; and Mt. Waddington and Taseko Lakes are part of the Cadwallader terrane (Fig. 1.1).

## **1.2.6 Paleobiology**

### **1.2.6.1 Sexual dimorphism**

Sexual dimorphism is recognized within a species by the presence of two different adult morphologies. Expected differences between the two groups include characteristics like bimodal size distribution, variocostation (when ribbing style on the outer whorls differs markedly from that on the inner), differences in the number of whorls and the presence of lappets or long rostra on the peristome (e.g. Callomon 1963). The larger form is the 'macroconch' and is believed to have been the female. The smaller form is the 'microconch' and is believed to have been the male (Callomon 1955, 1963; Davis *et al.* 1996). In order to be identified as dimorphs, the two groups must have the same stratigraphic range, there must be no mature intermediate forms, they should have identical early ontogenies, the ratio between dimorphs should be consistent across the stratigraphic and geographic range of the taxon and they should have identical phylogenies (Makowski 1963; Callomon 1963; Davis *et al.* 1996 and references therein).

In 1963, Callomon stated that the lowest point in the Jurassic where dimorphism became clearly recognizable was the late Toarcian, although it was probably present before that. Although dimorphism remains relatively poorly documented in the Hettangian, more recent work has led to the identification of dimorphism in numerous Hettangian groups (e.g., Rakús 1975, 1993a; Donovan *et al.* 1981; Guex 1981, 1995).



#### 1.2.6.2 Hydrostatic implications of asymmetries of the ammonite phragmocone

In most ammonites the siphuncle runs ventrally down the centre of the shell; however, in many Hettangian taxa, the siphuncle is displaced to one side (e.g., Guex 1995; Hillebrandt 2000a). This character is accompanied by an asymmetric septal suture line where the ventral lobe is shifted to one side of the whorl. The elements of the suture line are expanded on the non-siphuncle side, suggesting that septae may have had a greater surface area on this side. In contrast, on the siphuncle side, the elements of the suture line are simplified and compressed suggesting that septae may have had a reduced surface area.

It is possible that the displacement of the tissue and blood filled siphuncle may have affected the position of the shell's centre of mass. If the septal faces were expanded on the non-siphuncle side, this may have offset the mass of the displaced siphuncle and acted as a counterbalance mechanism that allowed the ammonite to remain upright in the water column. This hypothesis is tested in this thesis.

### **1.3 Summary of Objectives**

- 1) To provide a complete and detailed taxonomic analysis of the Hettangian ammonites from the two primary areas on the terranes of BC; the QCI and Taseko Lakes.
- 2) To provide a complete and detailed taxonomic analysis of the *Badouxia* fauna from Taseko Lakes including the earliest Sinemurian forms.
- 3) To use measured sections from the QCI and Taseko Lakes to delimit the stratigraphic ranges of each taxa.
- 4) To provide detailed information about the T-J boundary sections in the QCI.
- 5) To propose the Kunga Island section as a type section for the basal Jurassic.

- 6) To update the Hettangian and lowest Sinemurian portion of the North American Zonation of Taylor *et al.* (2001) based on the ammonite faunas from the QCI and Taseko Lakes.
- 7) To improve correlations between the terranes of BC and other areas of North America, South America, New Zealand, western and eastern Tethys, and northwest Europe during the Hettangian.
- 8) To consider whether the Hispanic Corridor was an effective influence on paleobiogeography during the Hettangian.
- 9) To use paleobiogeography to test the postulated positions of the Peninsular, Wrangellia and Cadwallader terranes during Hettangian time.
- 10) To more thoroughly document and improve understanding of sexual dimorphism in Hettangian ammonites.
- 11) To examine the hydrostatic implications of the asymmetric position of the siphuncle in *B. columbiae*.

## **1.4 Methods**

### **1.4.1 Literature review**

An extensive literature review was carried out to summarize the state of affairs in Hettangian and earliest Sinemurian ammonite systematics, Early Jurassic biogeography in the eastern Pacific and relevant aspects of ammonite paleobiology.

### **1.4.2 Field work**

Extensive fossil collections were made in Taseko Lakes during the summers of 2001, 2002 and 2003. Previous collections made by officers of the Geological Survey of Canada (GSC)

provided a large amount of supplementary material. In the field, sections were measured using the Brunton compass and tape technique. True stratigraphic thickness was calculated using Microsoft Excel.

Small Hettangian collections were made in the QCI during the summer of 2005; however, the majority of the fossil material was collected by officers of the GSC (primarily H. W. Tipper) as well as by previous graduate students of the University of British Columbia (UBC) (primarily G. Jakobs and J. Pálffy). Stratigraphic sections were measured by H. W. Tipper and E. S. Carter using the pogo stick method.

Preliminary collections from Holberg Inlet made by J. Pálffy were supplemented in the summer of 2004. Although identifying middle and upper Hettangian strata was possible, poor exposure made measuring a section impractical.

Collections from the Quesnel Lake area, made by officers of the GSC, are currently misplaced. An attempt was made to find the locality in the summer of 2004; however, instructions on its location were incomplete and despite an extended search, it could not be found.

#### **1.4.3 Collections from other areas in the BC terranes**

Other areas in the BC terranes with minor occurrences of Hettangian ammonites were not revisited, although in some cases this information was included in the body of the thesis. The data of Jakobs and Pálffy (1994) from Iskut River and the data of Frebold (1964*b*) from Telegraph Creek were included in the relevant synonymy lists and discussions in the body of the thesis. Due to journal restrictions on unpublished work, the data of Nadaraju (1993) from Iskut River was not considered. Due to the poor preservation, the Holberg Inlet faunas were not considered in the body of the thesis. Similarly, due to poor preservation and uncertain age allocation, the collections from the Salmo area were not included. The presence of Hettangian

taxa from Quesnel River could not be verified and it was not included. The single specimen collections from Babine Lake and Mount Waddington were not considered.

#### **1.4.4 Laboratory work**

Fossils were prepared for systematic study using rock saws, pneumatic drills and sandblasters. Where necessary, casts and molds were constructed. To facilitate data entry, the qualitative and quantitative measurements conform to the AMMON database developed at UBC (Smith 1986; Liang and Smith 1997). Taxonomic open nomenclature follows Bengtson (1988).

### **1.5 Presentation**

The body of this dissertation is made up of seven chapters (Chapters 2-8). The chapters are roughly ordered to follow geological time beginning with the T-J boundary and earliest Hettangian faunas and finishing with studies of late Hettangian and earliest Sinemurian faunas. Each chapter is a self-contained research article; chapters 2 and 5 are published, chapters 3, 6 and 7 are accepted for publication and chapters 4 and 8 are to be submitted for publication in various science journals and reports. This approach rather than a standard thesis format is useful to rapidly communicate results to the scientific community but it does result in some repetition. Although an effort was made to minimize redundancy, it was often unavoidable in the introduction to each paper and, to a lesser extent, in the discussion sections.

Chapter 2 is a study of the lower Hettangian sections in the QCI and includes the proposal of a section from Kunga Island as a parastratotype to assist with characterization and recognition of the T-J boundary. A detailed taxonomic study of the early Hettangian ammonite faunas from the QCI is included here.

Chapter 3 is a comprehensive study of the T-J boundary section at Kunga Island. The section is proposed as a potential GSSP for the basal Hettangian if radiolarians are designated as the primary marker fossil or as a parastratotype section if radiolarians are not chosen.

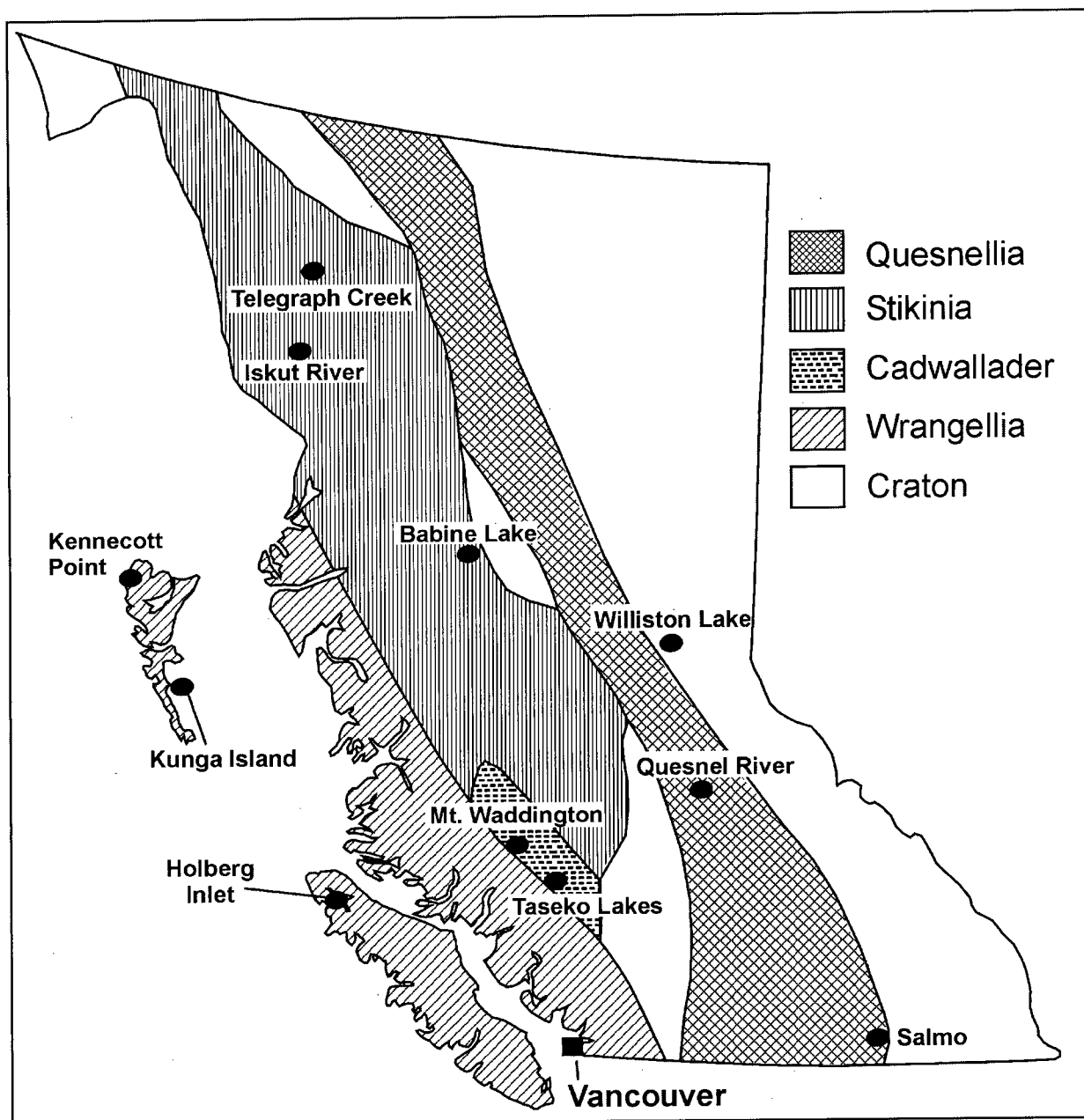
Chapter 4 consists of a comprehensive taxonomic study of the middle and late Hettangian faunas from the QCI. Based on these data, changes are made to the middle and upper Hettangian portion of the North American Zonation of Taylor *et al.* (2001). The data is also used to suggest correlations with other areas of North America, South America, New Zealand, western and eastern Tethys, and northwest Europe as well as to constrain the position of the Wrangellia terrane during the Hettangian.

Chapter 5 includes a taxonomic study of the *Badouxia* fauna from the late Hettangian and early Sinemurian in Taseko Lakes. Based on this data, changes are made to the upper Hettangian and lower Sinemurian portion of the North American Zonation of Taylor *et al.* (2001). Sexual dimorphism is noted in several species of *Badouxia* and discussed.

Chapter 6 consists of a taxonomic study of the late Hettangian *Sunrisites* fauna from Taseko Lakes. Paleobiogeographic issues are considered including a possible opening of the Hispanic Corridor as well as implications for the position of several terranes in the Hettangian. Sexual dimorphism is noted and discussed within the faunas.

Chapter 7 is a comprehensive taxonomic study of the late Hettangian fauna from Taseko Lakes [excluding the *Badouxia* and *Sunrisites* faunas and also the *Angulaticeras* fauna which was studied by Smith and Tipper (2000)]. Based on the data, changes are made to the upper Hettangian portion of the North American Zonation of Taylor *et al.* (2001) and correlations are suggested with other areas of North America, South America, New Zealand, western and eastern Tethys, and northwest Europe during the Hettangian.

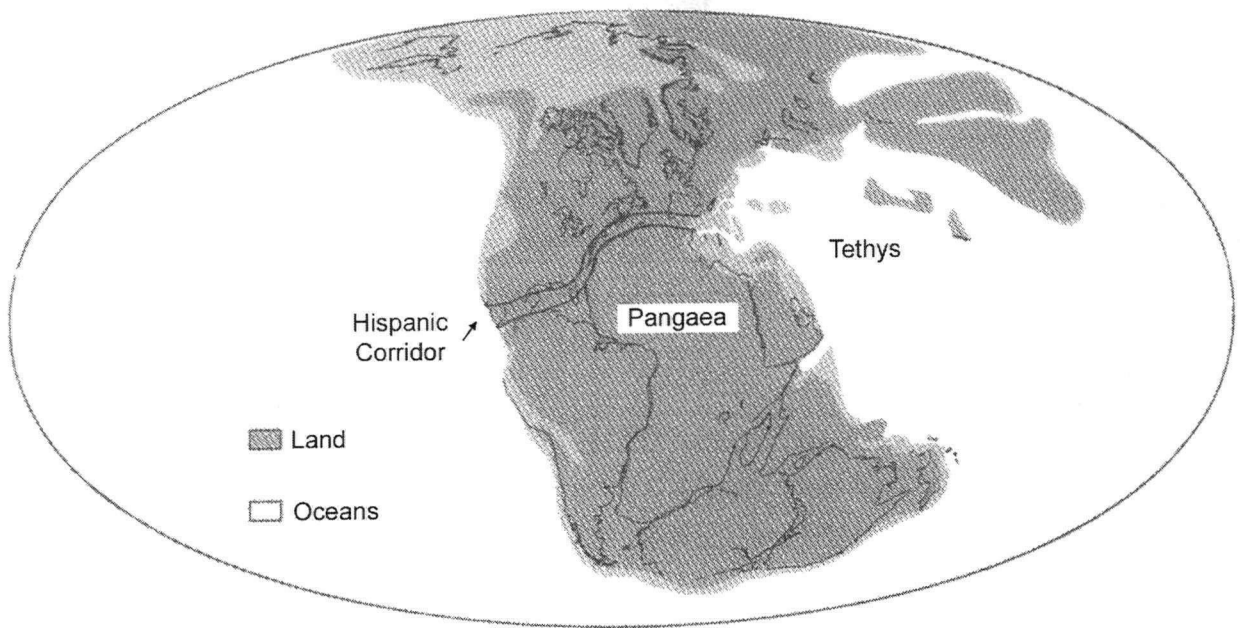
Chapter 8 is a computer based study of the hydrostatic effects of asymmetries within the phragmocone of the earliest Sinemurian ammonite, *B. columbiae*.



**Figure 1.1.** Map showing approximate locations of Hettangian ammonite occurrences in British Columbia (excluding Vancouver which is indicated only to assist with orientation); approximate positions of relevant terranes are also indicated. Terrane locations modified from Taylor *et al.* (1984) and Aberhan (1999).

AGE	NORTH AMERICA (Taylor <i>et al.</i> 2001)		NORTHWEST EUROPE (Donovan <i>in</i> Dean <i>et al.</i> 1961; Page 2003)	WESTERN TETHYS (Wöhner 1886; Page 2003)
LOWER SINEMURIAN	Canadensis Zone	Columbiae Subzone	Bucklandi Zone	
UPPER HETTANGIAN		Rursicostatum Subzone	Angulata Zone	Marmoreum Zone
		Oregonensis Zone		
		Morganense Zone		
MIDDLE HETTANGIAN	Sunrisense Zone	Liasicus Zone	Megastoma Zone	
	Pleuroacanthitoides Zone			
	Coronoides Zone			
	Occidentalis Zone			
	Mulleri Zone			
LOWER HETTANGIAN	Polymorphum Zone	Planorbis Zone	Calliphyllum Zone	
	Pacificum Zone			
	Minutum Zone			
	Spelae Zone			

**Figure 1.2.** Zonation for western Cordillera of North America as proposed by Taylor *et al.* (2001). Correlations with zones from northwest Europe and western Tethys are also shown. Only approximate correlations are implied.



**Figure 1.3.** Map showing the location of the Hispanic Corridor. Modified from Cecca (2002).



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## 2 EARLY HETTANGIAN AMMONITES AND RADIOLARIANS FROM THE QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA AND THEIR BEARING ON THE DEFINITION OF THE TRIASSIC-JURASSIC BOUNDARY<sup>1</sup>

### 2.1. Introduction

The extinction that marks the boundary between the Triassic and Jurassic is one of the so-called 'big five' that punctuate the Phanerozoic (Raup and Sepkoski 1982). The magnitude of the turnover is measured largely by comparing faunas from intervals on either side of the event but details at the actual boundary remain sketchy. This is because of the exceptionally low eustatic sea level at the time, which caused widespread unconformity and limited deposition on the continental shelves (Hallam 1990, 1997; Hallam and Wignall 2000). Sea level rose steadily in the Early Jurassic but during the Hettangian, the process had barely begun and for this time interval the rock record is meagre. Consequently, any stratigraphic section that spans the Triassic-Jurassic boundary (T-J boundary) is extremely important because of its potential contributions to understanding the timing and causes of the extinction as well as the dynamics of recovery. Such sequences occur in the Sandilands Formation exposed at Kennecott Point and Kunga Island in the Queen Charlotte archipelago of British Columbia (Fig. 2.1). This formation represents a relatively deep-water sequence which shallowed only slightly across the boundary. Faunas dominated by molluscs and radiolarians have been collected from these sections (Tipper and Carter 1990; Carter 1993; Tipper and Guex 1994; Tipper *et al.* 1994; Carter *et al.* 1998) and calibrated with geochronologic (Pálffy *et al.* 2000) and geochemical data (Ward *et al.* 2001, 2004).

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This chapter provides critical taxonomic information on the ammonite and radiolarian faunas from the basal Hettangian beds in the Queen Charlotte Islands (QCI). Because ammonoids almost became extinct at the T-J boundary, they are usually neither abundant nor diverse in the lowest Hettangian, which seriously undermines their noted qualities as index fossils. Furthermore, ammonoid preservation at this level is poor in North America, making confident identification difficult. On the other hand, radiolarians are better known across this critical interval. Since modern studies of Mesozoic radiolarians began in the 1970s, faunas have been dated by associated ammonoids, conodonts and/or other fossil groups. Many new species have been described and incorporated into increasingly more refined local and regional zonal schemes. Successful testing of these zonations now allows radiolarians to stand alone as primary indicators for dating rock.

At this point, there is no ideal candidate Global Stratotype Section and Point (GSSP) for defining the base of the Jurassic. The recent ICS announcement that all Phanerozoic boundary stratotypes must be defined by 2008 (cited in Warrington 2003) has lent urgency to the resolution of this problem. In the past, sections from Kunga Island, QCI (Carter and Tipper 1999; Haggart *et al.* 2001) and New York Canyon, Nevada (Taylor *et al.* 1983; Guex *et al.* 1997) have been proposed independently as potential GSSPs for the basal Hettangian. The stratigraphic level of the T-J boundary in the QCI is constrained by radiolarians (Carter and Hori 2005); however, the ammonoid fauna from these sections permits close correlation with the early Hettangian ammonite sequences of New York Canyon. Additional correlation between the two areas is possible using a negative anomaly in the carbon isotope curve which spans the boundary in both areas (Ward *et al.* 2001, 2004; Guex *et al.* 2004). Given our improved understanding of the correlation between the T-J boundary sections of the United States and Canada, as described in this paper, we argue that the North American sections should be used collectively to define and characterize the T-J boundary. A joint approach will allow the

radiolarian sequences and geochronologic records from the QCI (Carter 1993; Carter *et al.* 1998; Pálffy *et al.* 2000; Ward *et al.* 2001, 2004) to be combined with the geochemical and geophysical records as well as the precisely documented ammonite and bivalve sequences in Nevada (Guex 1980, 1982, 1995; Taylor *et al.* 2000; Guex *et al.* 1998, 2002, 2004).

In summary, the purpose of this paper is to 1) describe the Hettangian ammonites and radiolarians from the QCI and document their stratigraphic distribution in the context of recognizing the T-J boundary, and 2) assess the potential role of the QCI succession in formally defining the T-J boundary.

## 2.2 Geological Setting

Well-exposed, continuous T-J boundary beds occur at two localities in the QCI: Kennecott Point (section I) and Kunga Island (section III) (Fig. 2.1). A second section at Kennecott Point (section II) contains basal Hettangian but lacks Rhaetian faunas. All three sections are part of the Sandilands Formation (Kunga Group) that is several hundred metres thick and ranges in age from early Rhaetian to mostly the latest Sinemurian although its upper contact is diachronous and locally the upper beds are earliest Pliensbachian (Tipper and Carter 1990; Tipper *et al.* 1991, 1994; Smith and Tipper 1996). Sections I and II are composed of siltstone to medium-grained sandstone alternating with organic-rich, laminated to massive dark-grey to black shale. Section III consists of siliceous siltstone with minor, fine to medium grained sandstone interbeds. Thin tuff beds are present in both areas but are more common at Kennecott Point. Limestone beds, lenses and concretions are abundant in all three sections but less frequent and coarser/less calcareous in beds adjacent to the T-J boundary (Cameron and Tipper 1985; Tipper and Carter 1990; Desrochers and Orchard 1991; Carter 1993; Tipper and Guex 1994; Tipper *et al.* 1994; Carter *et al.* 1998; Haggart *et al.* 2001, 2002). Section I is cut by numerous small-scale offsets but otherwise, the QCI sections display minimal structural disruption. Beds in the two

Kennecott Point sections dip at shallow angles of 15-25° while in the Kunga Island section, beds are near vertical (Carter 1993; Tipper *et al.* 1994; Haggart *et al.* 2001; Ward *et al.* 2004).

According to Cameron and Tipper (1985), the Sandilands Formation was deposited in a relatively deep back-arc basin remote from the source of fine volcanic detritus and is the result of distal turbidites and lesser air-fall tuffs (Pálffy *et al.* 1990; Tipper and Guex 1994). More recent work suggests that the Queen Charlotte localities represent an outer shelf to upper slope setting (Haggart *et al.* 2001, 2002).

### 2.3 Biostratigraphy

The relevant ammonite and radiolarian zones currently in use for North America are shown in Figure 2.2. For the ammonites, these include the upper Rhaetian Crickmayi Zone (Tozer 1979) and the lower Hettangian Spelae, Minutus, Pacificum and Polymorphum zones (Taylor *et al.*, 2001). In the case of the radiolarians, these include the upper Rhaetian *Globolaxtorum tozeri* Zone and the lower Hettangian *Canoptum merum* Zone (Carter 1993; Carter *et al.* 1998). Correlation of the *Globolaxtorum tozeri* Zone with the Crickmayi Zone of Tozer (1979) is based on the co-occurrence of radiolarians characteristic of this zone with *Choristoceras nobile* Mojsisovics and *C. rhaeticum* Gümbel at Kennecott Point (Carter 1993). Correlation of the *Canoptum merum* Zone with the lower Hettangian was based on correlation with the *Psiloceras* Assemblage i.e. the range of the ammonite genus *Psiloceras* (Carter *et al.* 1998). This broad ammonite assemblage has since been divided into the four lower Hettangian zones mentioned above. Coeval ammonite zones and subzones in South America and Northwest Europe (Dean *et al.* 1961; Hillebrandt 2000; Bloos and Page 2000; Page 2003) are also indicated in Figure 2.2.

Except for ammonites of the Spelae Zone, an otherwise complete sequence of Upper Triassic (Carnian) through Lower Jurassic (Toarcian) ammonites occurs in the QCI, although specimens are rare around the T-J boundary (Tipper and Carter 1990; Carter 1993; Tipper and Guex 1994;

Tipper *et al.* 1994; Pálffy *et al.* 1994; Smith and Tipper 1996; Jakobs 1997) and it has taken several years of sampling to accumulate the ammonite faunas discussed here (Fig. 2.3). The ammonites are moderately to severely secondarily compressed and poorly preserved. The oldest Hettangian ammonites in all three sections are found above the first Hettangian radiolarians from the *Canoptum merum* Zone.

A complete succession of Rhaetian to Sinemurian radiolarians, including a detailed succession across the T-J boundary, is recorded in several hundred closely spaced collections from Kennecott Point and Kunga Island, QCI (Fig. 2.4). All radiolarians from the QCI are from limestone beds, lenses and concretions. Preservation is directly related to the texture of the limestone (fine grained micrites are usually best) and is generally good to excellent. The first few metres of Jurassic strata at Kennecott Point are barren of all fossils except radiolarians. Macrofossils are very rare in the lowest Jurassic strata at Kunga Island.

The stratigraphic position of lower Hettangian ammonite and upper Rhaetian and lower Hettangian radiolarian collections in sections I-III is shown in Figure 2.5; further information is found in the Appendix A. Faunas are illustrated in Plates 2.1-2.2.

### **2.3.1 Kennecott Point - Section I**

Upper Rhaetian ammonites from this section are from the Crickmayi Zone and include at least two different *Choristoceras* species, namely, *C. nobile* and *C. rhaeticum* (Tipper and Carter 1990; Carter 1993; Tipper *et al.* 1994; Tozer 1994; Carter *et al.* 1998; Ward *et al.* 2001). The highest Triassic *Choristoceras* in this section is found ~4 m below the base of the *Canoptum merum* radiolarian Zone (Ward *et al.* 2004) (Fig. 2.5). The lowest Hettangian portion of this section contains four ammonite collections (Fig. 2.3) whose positions are indicated in Figure 2.5. Sample A1 is the lowest collection and occurs 5.8 m above the first Hettangian radiolarians and 25.5 m above the base of the section. A1, A2 (at 26.7 m) and A4 (38 m) all contain ammonites from the group *Psiloceras tilmanni* Lange. Sample A3 at 27.7 m, contains a

form that is referred with uncertainty to *Nevadaphyllites*. In other areas of North America, ammonites from the group *Psiloceras tilmanni* range through the Spelae to Polymorphum zones (Taylor *et al.* 2001) while in South America this group is limited to the Tilmanni Zone (Hillebrandt 2000). Thus, the ammonite fauna from this section can only be constrained to the lower Hettangian rather than a specific North American ammonite zone.

Radiolarians from Section I (Fig. 2.4) are distributed at 13 horizons (Fig. 2.5). Specimens are rare but generally well preserved. The lowest sample (R1) occurs 14.4 m above the base of the section; radiolarians are assigned to the upper Rhaetian *Globolaxtorum tozeri* Zone. The lowest Jurassic samples, R2 and R3, occur at 19.7 m and 20.0 m respectively, and both contain a low diversity primitive fauna comprised of 'indeterminate spherical spumellarians', *Spumellaria* indet. X, *Udalia* spp. and rare *Tipperella kennecottensis* n. sp. and *Canoptum merum* Pessagno and Whalen. Sample R4 at 20.5 m, contains the above taxa plus the first *Archaeocenosphaera laseekensis* Pessagno and Yang, *Amuria impensa* Whalen and Carter, *Paronaella ravenensis* Whalen and Carter, *Udalia primaeva* Whalen and Carter, Gen. et sp. indet A sensu Whalen and Carter 1998, *Spumellaria* indet. B sensu Carter 1994, and three small, short-lived Rhaetian holdovers (*Icrioma* sp. A sensu Carter 1993, ? *Laxtorum perfectum* Carter and *Plafkerium* sp.). Samples R6-R11 are slightly more diverse: *Tozerium nascens* Whalen and Carter and *Charlottea* spp. first appear in R6; *Droltus hecatensis* Pessagno and Whalen and *Thurstonia* spp. in R7; *Praehexasaturnalis tettraradiatus* Kozur and Mostler in R8; *Pantanellium tanuense* Pessagno and Blome and *Relanus reefensis* Pessagno and Whalen in R10, and *Bipedis elizabethae* Whalen and Carter and *Parahsuum* spp. in R13. All Hettangian radiolarians belong to the lower Hettangian *Canoptum merum* Zone.

Section I has been documented in several previous publications (Tipper and Carter 1990; Ward *et al.* 2001, 2004) as section KPD (Tipper *et al.* 1994; Carter *et al.* 1998), whereas Tipper

and Guex (1994) included it as the larger part of a composite section that includes sections I and II herein.

### 2.3.2 Kennecott Point - Section II

The lower part of this section is barren and although it may potentially contain the T-J boundary, no Triassic fossils have been collected. The positions of the five early Hettangian ammonite collections (Fig. 2.3) are indicated in Figure 2.5. A1 may be the lowest level and contains an association of *Choristoceras* aff. *minutus* Guex and *Neophyllites* (?) sp. The exact location of A1 is somewhat uncertain due to multiple years of collecting. Samples A2 and A3 occur at 15.9 m and 16.8 m respectively, and both contain *Nevadaphyllites* (?) sp. Collection A4 at 18.2 m contains *Odoghertyceras* cf. *deweeveri* Guex, Taylor, Rakús, and Bucher while collection A5 at 18.9 m contains *Psiloceras* cf. *marcouxi* Guex, Taylor, Rakús and Bucher, *Psiloceras* ex. gr. *tilmanni* and *Neophyllites* (?) sp. Most of the ammonites from localities A1 to A5 are limited to the Minutus Zone (Taylor *et al.* 2001).

The positions of three radiolarian samples from Section II are shown in Figure 2.5. Sample R1, from a single limestone concretion, contains an abundant fauna of latest Rhaetian and earliest Hettangian radiolarians. This is probably the most unusual and exceptionally well-preserved radiolarian sample ever collected in the QCI. Preservation is uniform indicating the sample is not reworked and, considering the thickness of Kennecott Point strata, it is highly unlikely the sample is condensed. Over 1200 specimens have been examined and counted and many have been photographed for future study. Approximately 90% of the fauna is Hettangian, the remainder are short-lived Rhaetian holdovers (see Figs 2.4, 2.6). This sample was collected immediately above a thick clastic barren interval at the base of the section. R1 is approximately equivalent lithologically to the lowest Hettangian collections in section I and was probably positioned very close to the T-J boundary. Some Rhaetian specimens display complexities beyond typical morphotypes e.g. *Globolaxtorum tozeri*, and correlate well with faunas from the



topmost Rhaetian beds in section III at Kunga Island, and section 2 (SKUE) of Carter *et al.* (1998), also at Kunga Island. Many Triassic and Jurassic specimens are unusually small in size. Samples R2 and R3 each contain a sparse fauna that is clearly lower Hettangian with no Rhaetian survivors. This may be due to the overall paucity of individuals, but it is impossible to say. All radiolarians from section II belong to the lower Hettangian *Canoptum merum* Zone.

Lithologic correlation between sections I and II is problematic because the strata are homogeneous and slight disruptions are common. However, distinctive large concretionary masses at levels R8 in Section I and R2 in section II can be used as a lithologic marker bed to link the two sections (Fig. 2.5).

### 2.3.3 Kunga Island - Section III

The entire succession at Kunga Island has a cumulative thickness of ~145 m, and includes strata of Rhaetian to middle or late Hettangian age. The lower Hettangian portion of the section, illustrated in section III (Fig. 2.5), contains seven basal Hettangian ammonite collections (Fig. 2.3). The lowest collection (A1) is 1.9 m above the first Hettangian radiolarians (R2) and 6.45 m above the base of the section. It contains an indeterminate psiloceratid. Collection A2 at 13.2 m contains *Psiloceras* cf. *planocostatum* Hillebrandt and *Choristoceras* aff. *minutus*. A3 at 15.55 m also contains *C.* aff. *minutus*. Collection A4 occurs at 15.85 m and contains *Transipsiloceras* cf. *transiens* Guex. Collections A5 and A7 at 17.2 m and 19.35 m respectively both contain *Psiloceras* ex. gr. *tilmanni*. *Psiloceras* cf. *polymorphum* Guex is found in collections A6 (18.75 m) and A7. *Choristoceras minutus* is restricted to the Minutus Zone in North America whereas *P. planocostatum* is found in the Planocostatum Subzone in South America (which equates with the North American Pacificum Zone). *Transipsiloceras transiens* and *Psiloceras polymorphum* are both limited to the Polymorphum Zone in North America.

The complete succession has yielded over 70 radiolarian collections that document the faunal transition from the uppermost Triassic to lowermost Jurassic (Carter 1993; Carter *et al.* 1998;

Haggart *et al.* 2002). Section III (Fig. 2.5) illustrates the lower Hettangian part of the sequence showing the position of radiolarian collections at 8 different horizons: R1 is uppermost Rhaetian, R2-R8 are lower Hettangian; the distribution of species is shown in Figure 2.4. Sample R1 at 3.75 m contains over 70 species belonging to the upper Rhaetian *Globolaxtorum tozeri* Zone. A partial listing shows that most disappear at the end of the Triassic, with only a few surviving into the basal Hettangian. Samples R2 and R3, slightly higher at 4.55 and 4.8 m respectively, contain fair to moderately preserved post-extinction faunas very different from R1. These are believed to represent the transition into the Jurassic with sample R2 marking the base of the Jurassic on radiolarians. R2 equates to 81.55 m in the entire section (Carter and Hori 2005). Samples R2 and R3 contain 'indeterminate spherical spumellarians', *Tipperella kennecottensis* n. sp., *Udalia* spp., *Spumellaria* indet. X, and a few short-lived Rhaetian holdovers including *Livarella* spp. and *Pseudohagiastrum monstrosus* Pessagno; the latter is found elsewhere only in R1 of Section II. Sample R4 at 7.25 m contains a lower Hettangian fauna with extremely rare Rhaetian holdovers. Samples R5-R7 at 7.45, 7.74 and 10.15 m respectively, contain abundant well-preserved earliest Hettangian radiolarians with no Rhaetian holdovers. Between 10.15 and 16.45 m, strata are completely devoid of limestones and sampling was not possible. However sample R8 at 16.45 m contains a sparse early Hettangian fauna of the *Canoptum merum* Zone.

The complete succession which includes section III of this paper has been documented previously as SKUD (Carter 1993; Tipper *et al.* 1994; Carter *et al.* 1998; Ward *et al.* 2001).

#### **2.3.4 T-J boundary radiolarian faunas**

The most complete radiolarian succession across the T-J boundary is recognized in the QCI (Carter and Hori 2005) and supports postulation by Hallam and Wignall (1997) that the best evidence for catastrophic change at the end of the Triassic may come from microfossils. The

radiolarian turnover combined with continuous deposition and lack of facies changes over this interval marks the most distinct potential boundary level currently recognized worldwide.

Until recently radiolarians have played little part in the extinction/recovery scenario surrounding the T-J boundary mainly because the end-Triassic was interpreted as a time of widespread sea level fall (e.g. Hallam and Wignall 1997), and few deeper water faunas of this age were known. Rhaetian and/or Hettangian radiolarian faunas are now reported in the Northern Calcareous Alps (Kozur and Mostler 1981, 1990), Italy (Bertinelli *et al.* 2004), Hungary (Kozur 1993; Pálffy *et al.* 2007), Montenegro (Gorican 1994), southern Turkey (Tekin 1999, 2002a, 2002b), Oman and Peru (see Carter 1993), Japan (Yao *et al.* 1980, 1982; Hori 1992; Sugiyama 1997 etc.), Philippines (Yeh and Cheng 1996, 1998), northeast China (Yang and Mizutani 1991), New Zealand (Spörli and Aita 1988; Spörli *et al.* 1989) and Baja California (Whalen *et al.* 2003). In most cases the oldest Jurassic assemblages are middle to upper Hettangian; confirmed lower Hettangian faunas are known only in the QCI, Japan, and Hungary. The following three subsections discuss the characteristics and trends in the radiolarian genera and species surrounding the T-J boundary.

#### 2.3.4.1 Rhaetian radiolarian faunas and the end-Triassic extinction

Over 160 species are present in the diverse Rhaetian faunas of the QCI (Carter 1993). Approximately half disappeared in the upper part of the *Proparvicingula moniliformis* Zone (lower Rhaetian), but over 70 species are still present at the base of the *Globolaxtorum tozeri* Zone and most range into topmost beds of the Rhaetian. Increasingly complex new species arose throughout the latter zone indicating that speciation remained active almost until the end of the Triassic. Then quite suddenly, over the space of a few metres, five families, at least 25 genera (Fig. 2.6a), and nearly all Rhaetian species disappeared. Similar faunal changes recorded in the QCI and Japan strongly suggest that the radiolarian crisis at the end of the Triassic was global rather than local in extent (Carter and Hori 2005).

Groups of taxa most severely affected by the extinction are architecturally complex forms with highly sophisticated morphologies e.g., *Eptingium*, *Nabolella* Petrushevskaya 1981 (= *Squinabolella* Kozur and Mostler 1979), *Tetraporobrachia*, and short-ranging genera that continued to evolve almost to their apparent demise such as *Risella*, *Kungalaria* and *Globolaxtorum*. Survivors commonly include morphologically conservative genera such as *Canoptum*, *Pantanellium*, *Paronaella*, and others making their first 'primitive' appearance in the Rhaetian e.g., *Crucella*, *Bipedis*, *Canutus?* and some droltid/parahsuuid-like forms.

A distinctive characteristic of many Upper Triassic radiolarians is the possession of strongly twisted or spiraling triradiate spines. This is displayed strongly amongst spumellarian and entactiniid species but even the apical horn of some nassellarians is twisted. De Wever *et al.* (2001, p. 413) suggested this morphological character may be related to environmental factors, viral contamination or horizontal gene transfer. Twisted spines occur periodically in younger taxa but the character is never displayed with such overall intensity as in the Upper Triassic. It is important to emphasize that all forms with twisted spines disappeared at the T-J boundary.

Guex (1993, 2001) has suggested that conditions of ecological stress may contribute to simplification and/or reduced size in protists such as foraminifera, silicoflagellates and radiolarians. Sharply reduced size is observed amongst individuals in uppermost Rhaetian and lowermost Hettangian faunas and multicyrtid nassellarians frequently have fewer chambers as well. This phenomenon may support the ideas of O'Dogherty and Guex (2002) that spumellarians are more extinction-resistant than nassellarians and are thus more likely to dominate post-extinction faunas. This possibility is strongly expressed in the spumellarian-dominated Hettangian fauna.

#### 2.3.4.2 The lower Hettangian radiolarian fauna

The low diversity earliest Jurassic survival fauna is comprised mainly of primitive indeterminate spumellarians and entactiniids, a few species of both new and surviving genera,

and rare Rhaetian holdovers. The fact that the latter are so rare, tiny and morphologically varied suggests that they are temporary survivors that persisted for a very short time, then disappeared. Their occurrence, although minor, may be important in determining that while the extinction of radiolarians at the end of the Triassic was rapid, it was not instantaneous.

Survival faunas have generally been described as producing low diversity, simple forms (Erwin 2001). Erwin (1998) has also noted that early survival assemblages are often dominated by highly abundant geographically and environmentally widespread species and can also include blooms of opportunistic taxa that thrive only in difficult environmental conditions. Earliest Hettangian radiolarian faunas of the QCI are predominantly simple forms with spongy or irregularly latticed meshwork and long and rod-like rather than triradiate and/or twisted spines. Most spherical spumellarians and entactiniids lack definable organized structure, are extremely variable morphologically, and occur with floods of *Archaeocenosphaera laseekensis* a spherical form with simple hexagonal poreframes and no spines. *Pantanellium tanuense*, a probable opportunist, is abundant in all but the oldest samples; the rod-like spines of earliest morphotypes become triradiate by the middle Hettangian (see Plate 2.2, figs 16-17). The abundance of these two species suggests that oceanic productivity may have been restored sufficiently in the lowest Hettangian to allow vast numbers of these simple forms to proliferate. Nassellarians such as *Canoptum merum*, *Droetus hecatensis*, *Bipedis elizabethae* and indeterminate *Parahsuum* are rare and very small. Diversity remains low through the lower Hettangian and rarely is there more than one species per genus. Short-lived Rhaetian holdovers are rare (usually only one or two specimens per sample) and always small.

Radiolarians gradually become more diverse through the Hettangian and Sinemurian. There are no extinctions until near the end of the Hettangian, and then relatively few (Carter *et al.* 1998). Following the survival phase, recovery begins in the lower or middle Hettangian when existing genera begin to diversify, a few new genera appear (Fig. 2.6d) and triradiate spines

become more common. Over time the number of 'indeterminate spherical spumellarians' (possibly short-lived endemics) reduces as the fauna rebuilds.

#### 2.3.4.3 Surviving radiolarian genera

Over twenty genera that arose in the Carnian, Norian and Rhaetian survived the T-J boundary (Fig. 2.6b) and at least nine genera first appear in the lower Hettangian (Fig. 2.6c). Most surviving genera are present in the Hettangian but a few do not reappear until the Pliensbachian or higher. These tend to be genera whose species occur sporadically, hence their absence in the Hettangian may not be that unusual. It is unknown where these forms may have migrated to in intervening times but as Hettangian faunas elsewhere are better studied some answers may be provided.

Remarks on genera surviving the T-J boundary apply mainly to occurrences in the QCI and are based on detailed studies of Hettangian to lower Bajocian faunas (Carter *et al.* 1988, 1998; Carter and Jakobs 1991; Carter 2000; Gorican *et al.* 2003, in press). Younger Jurassic strata are missing and their fauna cannot be assessed, but slightly differing ranges for survivors elsewhere may be expected.

Surviving genera are classified into the following groups:

Genera barely surviving the extinction, e.g., *Fontinella*, *Deflandrecyrtium*, *Livarella* and *Proparvicingula*. Probably not true survivors because they are rare, very small in size, and all disappear completely by the middle Hettangian. They are referred to herein as 'Rhaetian holdovers', see Figure 2.6b.

Genera that survived the extinction, are present in the Hettangian, but disappeared before the end of the Lower Jurassic. These include *Amuria*, *Haeckelicyrtium*, *Laxtorum*, *Parentactinia* and *Tipperella*. The latter is abundant in the early Hettangian fauna but gradually disappears as the fauna rebuilds; *Parentactinia* (one species only) disappears at the end of the Hettangian; *Amuria* and *Laxtorum* are common in the Hettangian and Sinemurian but disappear soon

afterwards (two species of *Laxtorum* are known from the Aalenian - Bajocian in Japan, but in both species the genus originally was queried, and remains so); *Haeckelicyrtium* is rare in the Hettangian and Sinemurian, fairly common in the Pliensbachian, but unknown thereafter.

Genera that survived the extinction and undergo major radiation in the Jurassic and Cretaceous, e.g. *Canoptum*, *Crucella*, *Orbiculiformella*, *Pantanellium* and *Paronaella*. *Canoptum* disappears at the end of the Aalenian but all others range into the Cretaceous. *Archaeocenosphaera* and *Pseudoeucyrtis* could also be included in this group but their occurrence is sporadic and both disappear before the end of the Jurassic.

Genera that survived the extinction, are absent in the Hettangian, but reappear later in the Jurassic, e.g. *Bistarkum*, *Citriduma*, *Gorgansium* and *Cornutella*. A few species of *Bistarkum*, *Citriduma* and *Gorgansium* reappear in the Pliensbachian/Toarcian but apparently none range beyond the Middle Jurassic; *Cornutella* ranges to the Recent.

Saturnalids. This fragile entactiniid family (taxonomy of De Wever *et al.* 2001) is discussed separately because it was perhaps the least affected by events at the end of the Triassic.

*Mesosaturnalis*, *Paleosaturnalis*, *Praehexasaturnalis*, *Pseudacanthocircus*, and *Pseudoheliodiscus* all survived the extinction and a few species even crossed the boundary e.g., *Pseudacanthocircis troegeri* Kozur and Mostler and *Mesosaturnalis acuminatus* Carter (Carter 1993). Saturnalids are identified mainly by their outer ring as in all but the most exceptionally preserved specimens, the central sphere is usually missing. Why saturnalids are such strong survivors is a puzzling question.

## 2.4 Discussion

At the present time there are four potential stratotype sections being considered by the Subcommission on Jurassic Stratigraphy with, as previously mentioned, a decision expected by 2008 (cited in Warrington 2003). These candidate sections and relevant references are: 1) St

Audrie's Bay, Somerset, England (Hodges 1994; Warrington *et al.* 1994; Bloos and Page 2000; Hesselbo *et al.* 2002, 2004; Hounslow *et al.* 2004), 2) New York Canyon, Gabbs Valley Range, Nevada (Guex 1982, 1995; Taylor *et al.* 1983; Guex *et al.* 1997, 1998, 2002, 2003, 2004; Taylor and Guex 2002; Lucas *et al.* 2005), 3) Chilingote, Utcubamba Valley, Peru (Tilman 1917; Hillebrandt 1987, 1988, 1994, 1997, 2000), and 4) Kunga Island, Queen Charlotte Islands, British Columbia (Carter 1993; Tipper *et al.* 1994; Carter *et al.* 1998; Carter and Tipper 1999; Ward *et al.* 2001; Haggart *et al.* 2001, 2002; Haggart 2002). It is not the intention of this paper to pre-empt the Jurassic Subcommittee by assessing the relative strengths and weaknesses of these candidates; therefore, the sections from St. Audrie's Bay and Chilingote are not considered further herein. However, given new data, we compare the Canadian and United States sections and suggest an improved, unified North American approach to the boundary definition. This approach would reduce from four to three the number of primary candidate sections currently before the Subcommittee.

#### **2.4.1 Strengths and weaknesses of North American T-J boundary sections**

##### **2.4.1.1 New York Canyon, Ferguson Hill, Nevada**

The New York Canyon (NYC) exposure in Nevada has been proposed as a potential GSSP for the T-J boundary based not only on the ammonite and bivalve sequences but also the geochemical and geophysical stratigraphic record (Taylor *et al.* 1983, 2000; Guex *et al.* 1997, 2003, 2004). The candidate stratigraphic section is in the Muller Canyon Member of the Gabbs Formation exposed at Ferguson Hill in the Gabbs Valley Range. Lucas *et al.* (2005) recently proposed that the boundary be placed at the incoming of *Psiloceras tilmanni*. This occurs ~20 cm below bed N9 (as defined in Guex *et al.* 2004 as first indisputable Jurassic ammonites). This section is a strong contender for GSSP for the base of the Jurassic because it is the only candidate in the world to have a reasonably continuous stratigraphic succession yielding ammonites that span the T-J transition (Guex 1982, 1995; Taylor *et al.* 1983; Guex *et al.* 1997,



1998, 2002; Taylor and Guex 2002; Lucas *et al.* 2005). Although we consider Nevada as the prime North American candidate for the T-J GSSP, it has four shortcomings:

- 1) The lowest ammonite zone (Spelae Zone) that is believed to be Jurassic does not presently have correlatives elsewhere. While this enhances the potential importance of the NYC section for defining the boundary, it creates difficulties when trying to recognize the boundary and basal Jurassic strata elsewhere in the world.
- 2) The stratigraphic interval separating the highest Triassic and earliest Jurassic ammonites is relatively large at ~7.3 m (Guex *et al.* 2004, fig. 1).
- 3) Although its macrofossil sequence is of suitable quality for a GSSP, it has no significant microfauna.
- 4) There was no volcanic activity in Nevada during the T-J interval and consequently, there are no tuff beds interbedded with fossiliferous marine strata that can be used for calibrating biochronologic and geochronologic time scales.

The T-J boundary sections in the QCI have strengths that overcome several of the shortcomings of the Nevada section.

#### 2.4.1.2 Kunga Island (Section III), British Columbia

Carter and Tipper (1999) first proposed Section III at Kunga Island as a candidate GSSP for the basal Jurassic. The main strengths of this section are:

- 1) The radiolarian record constrains the boundary to within 0.8 m. The prospect of using radiolarians to mark the T-J boundary is supported by the cross-Pacific correlation of the T-J boundary interval radiolarians between the QCI and Japan (Carter and Hori 2005).
- 2) The rare Rhaetian holdovers found in the three lowest Jurassic radiolarian collections from this locality suggest probable assignment of the basal Hettangian beds to the Spelae Zone.

- 3) *Psiloceras* cf. *planocostatum* and *Choristoceras* aff. *minutus* can be used to correlate the lower part of this section with the Minutus and Pacificum zones in Nevada while *Transipsiloceras* cf. *transiens* and *Psiloceras* cf. *polymorphum* permit correlation of the upper portion of the section with the Polymorphum Zone.
- 4) The Kunga Island section has provided a U-Pb date for the T-J boundary of  $199.6 \pm 0.3$  Ma from 3.6 m below the boundary (Pálffy *et al.* 2000), and there is considerable potential to obtain more geochronologic data from the upper Rhaetian and lower Hettangian.
- 5) The outcrop is high on the shoreline and protected from wave action. Permanent markers were installed by the Geological Survey of Canada (J. Haggart, pers. comm., 2000). These markers begin at the latest Triassic radiometrically dated tuff bed (0.0 m) and range well into the Hettangian.
- 6) Kunga Island is part of Gwaii Haanas National Park Reserve. Although this means a permit is necessary prior to collecting, it also provides protection and conservation of the site.

#### 2.4.1.3 Kennecott Point (Sections I and II), British Columbia

The principal strengths of these sections are:

- 1) Sampling of successive beds in section I has produced a carbon isotope curve which records a distinct and prolonged negative excursion spanning the T-J boundary (Ward *et al.* 2001, 2004).
- 2) Section I includes both Triassic ammonites from the Crickmayi Zone and Jurassic ammonites which correlate broadly with the early Hettangian.
- 3) The highest Triassic ammonite and lowest Jurassic radiolarian collections in section I constrain the boundary within a 4.0 m interval.

- 4) In section I, radiolarian fauna R4 contains Rhaetian holdovers that suggests that the lower portion of this section could correlate with the Spelae ammonite Zone.
- 5) Section II contains a diverse early Hettangian ammonite fauna including *Choristoceras* aff. *minutus*, *Odoghertyceras* cf. *deweveri*, *Neophyllites* (?) sp. and *Psiloceras* cf. *marcouxi* which correlate the top of this section with the Minutus Zone. The mixed Triassic-Jurassic fauna in the lowest radiolarian collection (R1) suggests that the base of this section may fall within the Spelae ammonite Zone. The ammonite and radiolarian data from sections I and II can be correlated and calibrated because of similarities between the lowest Hettangian radiolarian faunas and the presence of a lithological marker horizon between levels R2 in section II and R8 in section I.

However, the QCI sections also have some drawbacks. The sections are somewhat difficult to access: Kennecott Point can be reached only by helicopter or possibly float plane while Kunga Island is accessible by small boat. The nearest airport is in Sandspit which is ~55 km from the Kunga Island site and ~115 km from Kennecott Point (although it is possible to drive the first 63 km to Juskatla). Although the radiolarian fauna suggests that strata from the Spelae Zone may be represented, conclusive ammonites from this zone have not been found. Finally, the early Hettangian ammonite fauna is sparse and poorly preserved.

#### **2.4.2 Joint North American Proposal**

We propose that the Gabbs Valley Range section in Nevada be considered as holostratotype for the T-J boundary GSSP and that section III at Kunga Island be designated a parastratotype. Establishing parastratotypes is recommended by the International Stratigraphic Guide in instances where critical features are not evident in the holostratotype (Salvador 1994). We consider the radiolarian biostratigraphy and the availability of radiogenic isotope dates in the Kunga Island section as critical features. This joint approach further negates the weaknesses of the Nevada section because the radiolarian fauna at Kunga Island constrains the T-J boundary

within a narrower stratigraphic interval. Direct correlations are possible between the Kunga Island section and the section at Ferguson Hill using common ammonite taxa. Several of the earliest Hettangian ammonites from Kunga Island correlate closely with forms from Nevada. *Choristoceras* aff. *minutus* indicates the Minutus Zone while occurrences of *Psiloceras* cf. *polymorphum* and *Transipsiloceras* cf. *transiens* correlate with the Polymorphum Zone. The psiloceratid and *Psiloceras* ex. gr. *tilmanni* also have clear early Hettangian affinities with related forms ranging from the Spelae to Polymorphum zones in Nevada (Guex 1995). Additionally, indirect correlations between the two sections are possible using data from Kennecott Point. Ammonites from section II including *Choristoceras* aff. *minutus*, *Odoghertyceras* cf. *deweeveri*, *Neophyllites* (?) sp. and *Psiloceras* cf. *marcouxi* correlate the top of this section with the Minutus Zone in Nevada. Further correlation between the two areas is documented in Guex *et al.* (2004) using negative carbon isotope anomalies which span the T-J boundary in Nevada (Guex *et al.* 2003) and at section I at Kennecott Point (Ward *et al.* 2001, 2004).

## 2.5 Conclusions

### 2.5.1 Ammonites

The ammonite fauna in the QCI lacks diversity and is poorly preserved. Nevertheless, this material is very important as it permits the QCI sections to be accurately correlated with sections in other areas. Particularly close correlations are possible with the early Hettangian section at Ferguson Hill in Nevada.

Ammonite faunas from the base of section I at Kennecott Point include *Choristoceras nobile* and *C. rhaeticum* and permit correlation of this portion of the section with the Crickmayi Zone. Broad correlations with the early Hettangian are possible for the upper portion of this section based on *Psiloceras* ex. gr. *tilmanni* and *Nevadaphyllites*. Section II at Kennecott Point contains

*P. cf. marcouxii*, *Neophyllites* (?) sp., *Odogertyceras cf. deweveri*, *Choristoceras aff. minutus*, *Nevadaphyllites* (?) sp., and *Psiloceras ex gr. tilmanni*. Most of these forms are restricted to the Minutus Zone in Nevada and permit correlation of the upper part of this section with the Minutus Zone. The lowest Hettangian portion of Section III at Kunga Island contains an indeterminate psiloceratid, *P. cf. planocostatum* and *C. aff. minutus* while the upper portion contains *P. ex. gr. tilmanni*, *Transipsiloceras cf. transiens* and *P. cf. polymorphum*. These faunas provide evidence for correlation with the Minutus and Pacificum zones and Polymorphum Zone respectively.

### 2.5.2 Radiolarians

The radiolarian fauna that crosses the T-J boundary in the QCI is the most diverse and precisely documented fauna known worldwide. Five families, at least 25 genera, and nearly all Rhaetian species disappeared at the end of the Triassic. These included morphologically complex genera such as *Eptingium*, *Nabolella* (= *Squinabolella* Kozur and Mostler), *Paratriassostrum* and *Tetraporobrachia* together with some short-ranging genera that originated in the Rhaetian e.g. *Globolaxtorum*, *Kungalaria*, *Risella* and *Praecitriduma*. A few Rhaetian holdovers such as *Deflandrecyrtium*, *Fontinella*, *Livarella* and *Proparvicingula* are known in basal Hettangian assemblages but they are rare, small in size, and all disappear by the middle Hettangian.

Earliest Hettangian survival faunas are comprised mainly of small primitive spumellarians and entactiniids with spongy or irregularly latticed meshwork and long rod-like spines. At least nine genera arise in the lower Hettangian (only one species per genus). These forms occur with floods of *Archaeocenosphaera laseekensis* and the opportunist *Pantanellium tanuense*. Nassellarians are rare in these assemblages. Genera that survive the T-J boundary are mainly conservative forms such as *Canoptum*, *Crucella*, *Orbiculiformella*, *Pantanellium* and *Paronaella*. These gradually diversify in the Hettangian but their greatest radiation occurs later

in the Jurassic and Cretaceous. Saturniid genera survived the boundary relatively unscathed. Other genera survived the extinction but disappeared in the Hettangian or Sinemurian e.g. *Amuria*, *Laxtorum*, *Parentactinia* and *Tipperella*, while others such as *Bistarkum* and *Cornutella* are absent in the Hettangian and Sinemurian and do re-occur in the Pliensbachian/Toarcian or later.

True recovery following the end-Triassic extinction does not begin until the middle-upper Hettangian when new genera arise and assemblages become more diverse.

### **2.5.3 Joint North American GSSP proposal**

A joint proposal with the Nevada section as holotype and section III at Kunga Island as parastratotype significantly strengthens the North American proposal for GSSP for the basal Hettangian. The two areas largely negate the weaknesses of one another with respect to their potential to define and characterize the T-J boundary. The QCI succession tightly constrains the boundary and provides geochronology and microfossils, whereas the Nevada succession provides a nearly complete ammonoid succession and is easier to access. The two sequences can be correlated using early Hettangian ammonite faunas. Correlations within the QCI (sections I and III) allows the use of carbon isotope data to further enhance correlation between the QCI and Nevada.

## **2.6 Palaeontology**

### **2.6.1 Ammonites**

The earliest Hettangian ammonite material from the QCI is poorly preserved. Despite this limitation, we feel the systematic study of the QCI fauna is of significant value due to the critical importance of the ammonites in the earliest Hettangian. The relative ages of relevant zones and subzones are shown in Figure 2.2. Abbreviations and measurements follow Smith (1986) and include maximum shell diameter (Dmax), shell diameter at which measurements

were made (D), umbilical diameter (UD), whorl height (WH) and umbilical diameter as a ratio of shell diameter (U). Due to the poor preservational state of the material, all measurements are approximate and to the nearest millimetre. Specimens are deposited in the type collection of the Geological Survey of Canada (GSC) in Ottawa.

**Superfamily CHORISTOCERATOIDEA Hyatt 1900**

**Family CHORISTOCERATIDAE Hyatt 1900**

**Genus CHORISTOCERAS Hauer 1865**

TYPE SPECIES: *Choristoceras marshi* Hauer 1865

***Choristoceras* aff. *minutus* Guex 1995**

Plate 2.1, figures 4-5.

aff. 1982 *Choristoceras crickmayi* Tozer; Guex, pl. 1, figs 9-10.

aff. 1995 *Choristoceras minutus* Guex, p. 11, pl. 1, figs 4-6.

MATERIAL AND MEASUREMENTS: Three flattened specimens. GSC 127462, Dmax- 17 mm, D- 17 mm, UD- 7 mm, U- 0.41, WH- 7 mm.

DESCRIPTION: Midvolute form that is beginning to detach at the adoral end of the outer whorl. Relatively sharp ribs are rectiradiate to weakly rursiradiate and gently sigmoidal on the flanks. The suture line is not preserved.

REMARKS: The QCI material is similar in volution and ribbing style to *C. minutus* Guex but differs in attaining larger size before uncoiling (Plate 2.1, fig. 4). This material also resembles *C. crickmayi* Tozer but has somewhat wider-spaced ribs at similar shell diameters. The specimen illustrated in Plate 2.1, figure 5 is fairly similar in rib shape to *C. shoshonensis* Taylor and Guex

(2002). The two forms differ in that the Queen Charlotte form is more slowly expanding and has ribs that are less consistently rursiradiate on the lower flank.

Measurements are not possible on two of the specimens due to deformation and incomplete preservation. Due to multiple years of collecting the same section, the exact location of the specimen illustrated in Plate 2.1, figure 5 is somewhat uncertain (Fig. 2.5). This specimen is discussed in Tipper and Guex (1994) and Guex *et al.* (2004) under the name *Choristoceras* aff. *crickmayi*.

OCCURRENCE: Based on the presence of earliest Hettangian radiolarians as well as co-occurring *Neophyllites* (?) sp., this material is from the early Hettangian in the QCI. *Choristoceras minutus* occurs in the Minutus Zone in Nevada (Taylor *et al.* 2001).

### **Superfamily PHYLLOCERATOIDEA Zittel 1884**

#### **Family JURAPHYLLITIDAE Arkell 1950**

#### **Genus NEVADAPHYLLITES Guex 1980**

TYPE SPECIES: *Nevadaphyllites compressus* Guex 1980

#### ***Nevadaphyllites* (?) sp.**

MATERIAL AND MEASUREMENTS: Six specimens. Dmax- 40 – 95 mm, UD- 11 – 27 mm, U- 0.23 - 0.31, WH- 18 – 41 mm.

DESCRIPTION: This form is strongly involute and preserved relief suggests it was strongly compressed with slightly subparallel flanks that tapered toward the venter. The umbilical wall is moderately high and sloping and the umbilical shoulder is distinct but rounded. The flanks and venter are smooth. The suture line is not preserved.



REMARKS: Due to the very poor preservation of the material this form is not figured. The possible generic assignment is based on volution and whorl cross-section. The inner whorls resemble *N. compressus* Guex but differ in lacking ventral undulations and constrictions at similar shell diameters. Further, it is much larger than a mature *N. compressus*. The QCI material is more evolute than *N. glaberrimus* (Neumayr) and *N. psilomorphus* (Neumayr).

This form has been documented in several previous publications under various names summarized as follows: *Nevadaphyllites* or *Paradasyceras* (Tipper and Carter 1990); *Nevadaphyllites* sp. (Tipper *et al.* 1994); *Nevadaphyllites*? (Tipper and Guex 1994) and; *Paradasyceras* aff. *uermoesense* (C-156966, C-156967); *Psiloceras* sp. (C-156340) (Carter *et al.* 1998) and; *Nevadaphyllites compressus* (Ward *et al.* 2001).

OCCURRENCE: In South America, *Nevadaphyllites* is limited to the lowest Hettangian Tilmanni Subzone (Hillebrandt 2000). However, the genus ranges from early to late Hettangian in North America (Taylor *et al.* 2001) and therefore is not very useful as an age diagnostic fossil. Based on co-occurring faunas this form is from the early Hettangian in the QCI.

### **Superfamily PSILOCERATOIDEA Hyatt 1867**

### **Family PSILOCERATIDAE Hyatt 1867**

### **Indeterminate psiloceratid**

Plate 2.1, figure 1

MATERIAL: One internal mould.

DESCRIPTION: This form is moderately evolute. The flanks are smooth. The suture line is not preserved.

REMARKS: Poor preservation prohibits identification beyond the family level. However, this form is comparable to evolute forms of *Psiloceras* ex gr. *tilmanni* and is also similar in volution to some species of *Neophyllites*. Measurements are not possible due to incomplete preservation.

OCCURRENCE: Based on the presence of earliest Hettangian radiolarians this specimen is of early Hettangian age in the QCI.

### **Genus PSILOCERAS Hyatt 1867**

TYPE SPECIES: *Ammonites planorbis* Sowerby 1824

*Psiloceras* ex gr. *tilmanni* Lange 1925

Plate 2.1, figure 2

MATERIAL AND MEASUREMENTS: Seven specimens. GSC 127459, Dmax- 34 mm, D- 34 mm, UD- 15 mm, U- 0.44, WH- 11 mm; GSC 127458, D- 38 mm, UD- 19 mm, U- 0.50, WH- 10 mm.

DESCRIPTION: This form is moderately evolute. Preserved relief suggests the whorls were compressed with an oval cross-section by 30 mm shell diameter. At this size, the umbilical wall is upright with a distinct but rounded umbilical shoulder. By 35 mm shell diameter, the umbilical wall slopes gently into the flanks and the umbilical shoulder is indistinct. The inner whorls are preserved in only one specimen (GSC 127457) which bears very weak, slightly prorsiradiate flank ribs. Beyond about 20 mm shell diameter the flanks in all specimens except one are smooth. Slightly more than the last half whorl of GSC 127459 is better preserved bearing fairly closely spaced rectiradiate to weakly rursiradiate growth striae on the flanks. The suture line is not preserved.

REMARKS: Due to poor preservation, measurements were taken on only two specimens from the QCI although all seven specimens are relatively evolute for the group. The style of ornament on GSC 127459 is very similar to a specimen of *P. tilmanni* figured by Hillebrandt (2000, pl. 12, fig. 3).

This form belongs to the group *Psiloceras tilmanni/pacificum*. At present there is discussion as to whether this form represents one or two species. Guex (1995) believes there are two species because *P. pacificum* Guex is consistently more evolute than *P. tilmanni* and *P. tilmanni* is older than *P. pacificum* (Guex *et al.* 1998). Hillebrandt (1994, 1997, 2000) feels that variation within *P. tilmanni* encompasses *P. pacificum* and considers the latter to be a junior synonym. Given the poor preservation of our material and the small sample size, we are unable to contribute to the resolution of this problem.

Material from this group has been documented in several previous publications under various names summarized as follows: *Psiloceras* aff. *primocostatum* (Tipper and Guex 1994; Tipper *et al.* 1994; Carter *et al.* 1998, C-177351); *Psiloceras* sp. (C-177353, C-156968) (Carter *et al.* 1998); *Psiloceras*? (C-159351) (Carter *et al.* 1998) and; *Psiloceras pacificum* (Ward *et al.* 2001). The various other *Psiloceras* recorded in Carter *et al.* (1998) (C-156971, C-159354, section SKUE) are now recognized as belonging to other genera from the middle Hettangian.

OCCURRENCE: In the QCI, this form is of early Hettangian age. In South America, this group is limited to the lowest Hettangian Tilmanni Zone (Hillebrandt 2000) whereas in North America, this group ranges across the lower Hettangian Spelae to Polymorphum zones (Taylor *et al.* 2001).

***Psiloceras* cf. *planocostatum* Hillebrandt 2000**

Plate 2.1, figure 9

cf. 1994 *Psiloceras* cf. *primocostatum* Hillebrandt, pl. 1, fig. 14.

cf. 2000 *Psiloceras planocostatum* Hillebrandt, p. 160, pl. 8, figs 1-9, text-figs 34a-b.

2004 *Psiloceras* cf. *planocostatum* Hillebrandt; Hall and Pitaru, pl. 1, fig. 1.

MATERIAL AND MEASUREMENTS: One internal mould. GSC 127461, Dmax- 23 mm, D- 20 mm, UD- 8 mm, U- 0.40, WH- 7 mm.

DESCRIPTION: This form is midvolute and preserved relief suggests the outer whorl had a moderately broad, oval cross-section. The umbilical wall is gently sloping and the umbilical shoulder is indistinct. The innermost whorls are not preserved. Beyond a shell diameter of 8 mm, relatively fine, flat ribs are weakly rursiradiate low to midflank before fading on the upper flank. Some ribs are slightly bent back at midflank. At a shell diameter of approximately 20 mm the ribs fade and the flank becomes smooth. The suture line is not preserved.

REMARKS: Although poor preservation prohibits a confident identification, this material appears most similar to *P. planocostatum* Hillebrandt. The QCI specimen differs from *P. primocostatum* Hillebrandt and *P. polymorphum* Guex in possessing flatter, less coarse ribs. It differs from *P. minillaensis* Hillebrandt and *P. rectocostatum* Hillebrandt in being more involute and having weaker, flatter ribs.

OCCURRENCE: In the QCI, this form is of early Hettangian age. In South America, *P. planocostatum* is found in the Planocostatum Subzone of the Tilmanni Zone (Hillebrandt 2000). *Psiloceras* cf. *planocostatum* has also been recognized from the early Hettangian at Williston Lake, British Columbia (Hall and Pitaru 2004).

***Psiloceras* cf. *marcouxi* Guex, Taylor, Rakús, Bucher 1998**

Plate 2.1, figure 6

cf. 1995 *Psiloceras* (?) sp. A. Guex, p. 17, pl. 1, figs 1-2, pl. 2, fig. 22.

cf. 1998 *Psiloceras marcouxi* Guex, Taylor, Rakús, Bucher, p. 78.

MATERIAL AND MEASUREMENTS: One flattened specimen. GSC 127460, D- 47 mm, UD- 19 mm, U- 0.40, WH- 17 mm.

DESCRIPTION: This form is moderately involute. The umbilical shoulder appears distinct but rounded. The innermost whorls are not preserved. Between shell diameters of approximately 15 and 30 mm, evenly spaced, moderately strong ribs are rectiradiate to weakly prorsiradiate on the lower and midflank. On the upper flank, ribs project forward and fade. Toward the end of this interval, ribs weaken and beyond shell diameters of 35 mm the flanks are virtually smooth. The suture line is not preserved.

REMARKS: This specimen closely resembles a specimen of *P. marcouxii* from Nevada (Guex 1995, pl. 1, fig. 1) although it differs from the other figured material for the species (Guex 1995, pl. 1, fig. 2; pl. 2, fig. 22) in lacking ribs on the flanks beyond shell diameters of 35 mm. The Queen Charlotte specimen is similar in whorl proportion to the most involute forms of *P. polymorphum* Guex but differs from this form as well as the more involute *P. rectocostatum* Hillebrandt in having ribs which are rectiradiate to weakly prorsiradiate rather than weakly rursiradiate at similar shell diameters. It is more involute than *P. planocostatum* Hillebrandt, *P. minillaensis* Hillebrandt and *P. primocostatum* Hillebrandt and possesses coarser, wider spaced ribs to larger shell diameter than *P. pressum* Hillebrandt.

This specimen is discussed in Carter *et al.* (1998) under the name *Psiloceras* cf. *polymorphum* (C-156970).

OCCURRENCE: In the QCI, this form is from the lowest Hettangian. *Psiloceras marcouxii* also occurs in the Minutus Zone in Nevada (Taylor *et al.* 2001).

***Psiloceras* cf. *polymorphum* Guex 1980**

Plate 2.1, figure 10

cf. 1980 *Psiloceras polymorphum* Guex, p. 136, pl. 1, fig. 8.

cf. 1995 *Psiloceras polymorphum* Guex, p. 20, pl. 6, figs 6-7, 15-19, pl. 7, figs 1-23, pl. 8, figs 1-12, pl. 9, figs 1-15, text-figs 11-12.

MATERIAL AND MEASUREMENTS: Three specimens. GSC 127454, Dmax- 16 mm, D- 16 mm, UD- 7 mm, U- 0.44, WH-6 mm; GSC 127453, D-122 mm, UD-67 mm, U- 0.55, WH-29 mm.

DESCRIPTION: This form is midvolute for the genus. On the inner whorls, rursiradiate ribs coarsen upflank, attaining greatest strength on the upper flank. Beyond 15 mm shell diameter ribs fade and by 20 mm the flanks are smooth. The suture line is not preserved.

REMARKS: Although poor preservation prohibits confident identification of this form at the species level, it is very similar to some specimens of *P. polymorphum*. Although the Taseko form attains a larger shell diameter (Dmax = 122 mm) than the Nevada material [Dmax = 88 mm (Guex 1995, pl. 9, figs 14-15)], the Nevada material is often incomplete and may have attained significantly larger shell size.

*Psiloceras polymorphum* from Nevada encompasses a wide spectrum of ribbing styles ranging from specimens where ornament fades at small shell diameters (Guex 1995; pl. 7, figs 5-6, 9-10, pl. 8, figs 9-10, pl. 9, figs 10-11) to those that remain strongly costate at much larger shell diameters (Guex 1995, pl. 6, figs 18-19, pl. 7, figs 22-23). The Queen Charlotte material is comparable to the specimens of *P. polymorphum* which smooth out early in development. End-members of *P. polymorphum* with this morphology are very similar to *P. primocostatum* Hillebrandt and the two species are probably closely related.

The Queen Charlotte material is more involute than *P. minillaensis* Hillebrandt and has much coarser ribs on the inner whorls than *P. pressum* Hillebrandt and *P. planocostatum* Hillebrandt.

OCCURRENCE: In the QCI, this form is from the lower Hettangian. *Psiloceras polymorphum* occurs in the Polymorphum Zone in Nevada (Taylor *et al.* 2001).

### Genus NEOPHYLLITES Lange 1941

TYPE SPECIES: *Neophyllites antecedens* (Lange 1931)

#### *Neophyllites* (?) sp.

Plate 2.1, figure 7

1982 *Psiloceras* sp. indet. Guex, pl. 1, fig. 8; non pl. 1, fig. 7.

1995 *Psiloceras* sp. indet. Guex, pl. 1, fig. 3.

2002 *Neophyllites* sp. A Guex, Bartolini, Taylor, p. 249, text-figs 2A, 3; non text-fig. 2B.

MATERIAL AND MEASUREMENTS: Two specimens. GSC 127456, Dmax- 30 mm, D- 28 mm, UD- 13 mm, U- 0.46, WH- 9 mm; GSC 127455, Dmax- 22 mm, D- 20 mm, UD- 10 mm, U- 0.50, WH- 6 mm.

DESCRIPTION: This form is evolute with a moderately high, slightly sloping umbilical wall and a distinct umbilical shoulder especially at larger diameters. The innermost whorls are not preserved. Beyond 10 mm, smooth, subparallel flanks taper gently toward the venter.

REMARKS: GSC 127456 is virtually morphologically identical to the specimen from New York Canyon that Guex originally attributed to *Psiloceras* sp. indet. (Guex 1982, 1995) and subsequently attributed to *Neophyllites* sp. A (Guex *et al.* 2002). Furthermore, the biometric measurements of the Queen Charlotte Islands material are very similar to the Nevada specimen. Guex *et al.* (2002) classified the Nevada specimen as *Neophyllites* based on morphological and biometric analysis. Although most species of *Neophyllites* have a steep umbilical wall and spiral rills on the shell, the genus is only confidently separated from *Psiloceras* using sutural

characteristics (Bloos 1999, 2004; Bloos and Page 2000). The suture line cannot be distinguished on either the QCI material or the specimen from Nevada (Guex *et al.* 2002). Furthermore, recent work by Guex *et al.* (2004) states that the assignment of the Nevada form to *Neophyllites* is now considered doubtful. For these reasons, the specimens from North America are referred with uncertainty to *Neophyllites*.

*Neophyllites* (?) sp. differs from the second specimen from Nevada attributed to *Neophyllites* sp. A (Guex 1982, pl. 1, fig. 7; Guex *et al.* 2002, text-fig. 2B) in that it is smooth rather than weakly ribbed on the body chamber. The Queen Charlotte material differs from *Rhacophyllites* in being more evolute and differs from most *Psiloceras* in having less inflated flanks and a steeper umbilical wall.

OCCURRENCE: This form is from the lowest Hettangian in the QCI. As discussed by Guex *et al.* (2002, 2004), *Neophyllites* (?) from Nevada is older than the first abundant *Psiloceras* belonging to the *P. pacificum* group and thus, these levels correlate with the NW European *Neophyllites* beds. *Neophyllites* in England and Germany are among the oldest representatives of the psiloceratids and comprise a level that is older in part than *P. psilonotum* (Bloos 1999; Bloos and Page 2000). In the Alps, *Neophyllites* may indicate an earlier level than the rest of the Calliphyllum Zone and, if this is correct, *Neophyllites* is the earliest Jurassic ammonite known in the Alps (Bloos 2004). *Neophyllites* is also possibly recognized from the earliest Hettangian in southern Tibet (Yin and Enay 2000).

### **Genus TRANSIPSILOCERAS Guex 1980**

TYPE SPECIES: *Transipsiloceras transiens* Guex 1980

### ***Transipsiloceras cf. transiens* Guex 1980**

Plate 2.1, figure 3



cf. 1980 *Transipsiloceras transiens* Guex, p. 138, pl. 2, fig. 3.

cf. 1995 *Transipsiloceras transiens* Guex, p. 24, pl. 1, fig. 7, pl. 5, figs 3-4, text-fig. 13.

MATERIAL AND MEASUREMENTS: One specimen. GSC 127450 , Dmax- 68 mm, D- 68 mm, UD-33 mm, U- 0.48, WH-18 mm.

DESCRIPTION: Moderately evolute form. Preserved relief suggests that the whorl cross-section was rounded on the inner whorls to high sub-oval on the outer whorls. Faint impressions of rursiradiate ribs are visible on the innermost whorls. Beyond 12 mm shell diameter, flanks bear weak undulations. The suture line is not preserved.

REMARKS: Although poor preservation does not permit a definitive identification at the species level, this form is very similar to a specimen of *T. transiens* figured by Guex (1995, pl. 1, fig. 7).

OCCURRENCE: In the QCI, this form is of early Hettangian age. *Transipsiloceras transiens* is found in the Polymorphum Zone in Nevada (Taylor *et al.* 2001).

### Family INCERTAE SEDIS

#### Genus ODOGHERTYCERAS Guex, Taylor, Rakús, Bucher 1998

TYPE SPECIES: *Odoghertyceras deweveri* Guex, Taylor, Rakús, Bucher 1998

#### *Odoghertyceras cf. deweveri* Guex, Taylor, Rakús, Bucher 1998

Plate 2.1, figure 8

cf. 1994 *Choristoceras* sp. Hillebrandt, pl. 1, figs 20a-b.

cf. 1998 *Odoghertyceras deweveri* Guex, Taylor, Rakús, Bucher, p. 80, pl. 1, figs 1-2, 4.

MATERIAL: One specimen.

DESCRIPTION: This form is midvolute and preserved relief suggests the whorl cross-section was fairly broad. Ribs on the flanks are cursiradiate and weakly sigmoidal. On the inner whorls, ribs thicken into distinct tubercles on the upper flank. On the outer whorls, thickening of the ribs is apparent on the ventro-lateral shoulder. Megastriae are visible on the adapical side of the thickened area and project strongly forward onto the venter. The suture line is not preserved.

REMARKS: Although poor preservation prohibits a confident identification, this material is similar in volution and ribbing style to *O. deweveri*. Some specimens of *Odoghertyceras* look very similar to the innermost whorls of weathered *Psiloceras*. Measurements are not possible due to incomplete preservation.

OCCURRENCE: In the QCI, this form is of early Hettangian age. *Odoghertyceras deweveri* is found in the Minutus Zone in Nevada and from an approximately similar level in South America (Hillebrändt 1994; Guex *et al.* 1998).

### **2.6.2 Radiolarians (E.S. Carter)**

All illustrated specimens are deposited with the Geological Survey of Canada (Cordilleran Division), Vancouver, Canada.

## **Phylum PROTOZOA**

## **Class ACTINOPODA**

## **Subclass RADIOLARIA Müller 1858**

## **Order POLYCYSTINA Ehrenberg 1838, emend. Riedel 1967**

## **Genus *Archaeocenosphaera* Pessagno and Yang in Pessagno *et al.* 1989**

TYPE SPECIES: *Archaeocenosphaera ruesti* Pessagno and Yang 1989, p. 203.

## ***Archaeocenosphaera laseekensis* Pessagno and Yang 1989**

Plate 2.2, figure 15

*Archaeocenosphaera laseekensis* Pessagno and Yang in Pessagno *et al.* 1989, p. 203; pl. 2, figs 18, 21-22, 25; Carter 1994, pl. 1, fig. 6; Carter *et al.* 1998, p. 57, pl. 11, figs 1, 5, 9, 21; Carter and Hori 2005, pl. 1A, fig. 5.

*Cenosphaera laseekensis* (Pessagno and Yang) – Gawlick *et al.* 2001, fig. 2.1.

OCCURRENCE: Lower Jurassic; Hettangian - lower Sinemurian. QCI, Canada; Inuyama, Japan; Northern Calcareous Alps, Austria.

**Genus *Canoptum* Pessagno 1979 in Pessagno *et al.* 1979**

TYPE SPECIES: *Canoptum poissoni* Pessagno 1979 in Pessagno *et al.* 1979.

***Canoptum merum* Pessagno and Whalen 1982**

Plate 2.2, figure 18

*Canoptum merum* Pessagno and Whalen 1982, p. 124; pl. 1, fig. 1, 15-16, 20; pl. 12, fig. 11. Carter 1994, p. 1, fig. 5. Carter *et al.* 1998, p. 64, pl. 16, fig. 3. Tekin 2002*b*, p. 189, pl. 4, fig. 8.

OCCURRENCE: Lower Jurassic; Hettangian. QCI, Canada; southern Turkey.

**Genus *Canutus* Pessagno and Whalen 1982**

TYPE SPECIES: *Canutus tipperi* Pessagno and Whalen 1982, p. 129.

***Canutus? beehivensis* Carter 1993**

Plate 2.2, figure 8

*Canutus?* sp. 1, Carter 1990, pl. 2, fig. 9.

*Canutus? beehivensis* Carter 1993, p. 107, pl. 20, figs 1-5, 18.

OCCURRENCE: Upper Triassic; Rhaetian. QCI, Canada; Baja California Sur.

**Genus *Deflandrecyrtium* Kozur and Mostler 1979**

TYPE SPECIES: *Deflandrecyrtium popofskyi* Kozur and Mostler 1979, p. 96.

***Deflandrecyrtium nobense* Carter 1993**

Plate 2.2, figure 10

*Deflandrecyrtium nobense* Carter 1993, p. 94, pl. 14, figs 13-15.

OCCURRENCE: Upper Triassic; Rhaetian. QCI, Canada; Baja California Sur.

**Genus *Droltus* Pessagno and Whalen 1982**

TYPE SPECIES: *Droltus lyellensis* Pessagno and Whalen 1982, p. 122.

***Droltus hecatensis* Pessagno and Whalen 1982**

Plate 2.2, figure 20

*Droltus hecatensis* Pessagno and Whalen 1982, p. 121, pl. 1, figs 12-13, 18, 22; pl. 4, figs 1-2, 6, 10; pl. 12, figs 18-19. Hattori 1989, pl. 12, fig. F. Carter 1994, pl. 1, fig. 14. Pujana 1996, p. 138, fig. 9. pl. 1, figs 6, 16-17. Carter *et al.* 1998, p. 63, pl. 15, fig. 14. Tekin 2002b, p. 186, pl. 3, fig. 9.

*Droltus* sp. - Sashida 1988, p. 24, pl. 3, figs 7, 16-17.

OCCURRENCE: Lower Jurassic; Hettangian - lower Pliensbachian. QCI, Canada; west central Argentina; central Japan; southern Turkey.

**Genus *Globolaxtorum* Carter 1993**

TYPE SPECIES: *Globolaxtorum tozeri* Carter 1993, p. 111.

***Globolaxtorum tozeri* Carter 1993**

Plate 2.2, figure 1

*Syringocapsa* sp. B, Yoshida 1986, p. 17; pl. 6, figs 13-14.

*Podocapsa?* sp. 1, Carter 1990, pl. 2, fig. 5.

*Katroma* sp. A, Yeh 1992, p. 68; pl. 5, fig. 12.

*Globolaxtorum tozeri* Carter 1993, p. 111; pl. 19, figs 14-16, 18-19. Bragin 1997, p. 28.

Tipper *et al.* 1998, pl. 4.1, fig. 24. Carter and Guex 1999, p. 192; pl. 2, figs 14-15. Carter and Hori 2005, pl. 1A, fig. 7; pl. 1B, fig. 7.

*Globolaxtorum* sp. C - Tekin 1999, p. 179; pl. 44, fig. 5.

OCCURRENCE: Upper Triassic; upper Rhaetian. QCI, Canada; Inuyama, Japan; Uson Island, Philippines; Far East Russia; Hungary; Oman; southern Turkey; Baja California Sur.

**Genus *Icrioma* De Wever 1979 in DeWever *et al.* 1979**

TYPE SPECIES: *Icrioma tetrancistrum* De Wever 1979, p. 86.

***Icrioma* sp. A sensu Carter 1993**

Plate 2.2, figure 2

*Icrioma?* sp. A - Carter 1993, p. 47, pl. 3, figs 3, 5, 8, 12, 15.

*Icrioma* sp. A – Yeh and Cheng 1996, p. 6, pl. 2, figs 10, 13.

OCCURRENCE: Upper Triassic; Rhaetian. QCI, Canada; Baja California Sur; Philippines.

**Genus *Kungalaria* Dumitrica and Carter 1999**

TYPE SPECIES: *Kungalaria newcombi* Dumitrica and Carter 1999, p. 421.

***Kungalaria newcombi* Dumitrica and Carter 1999**

Plate 2.2, figure 4

Entactiniid gen. and sp. indet. – Carter 1993, p. 40, pl. 13, figs 16, 19.

*Kungalaria newcombi* Dumitrica and Carter 1999, p. 431, pl. 1, figs 1-4; pl. 2, figs 2-6.

OCCURRENCE: Upper Triassic; Rhaetian. QCI, Canada; Baja California Sur.

**Genus *Pantanellium* Pessagno 1977**

TYPE SPECIES: *Pantanellium riedeli* Pessagno 1977, p. 78.

***Pantanellium tanuense* Pessagno and Blome 1980**

Plate 2.2, figures 16-17

*Pantanellium tanuense* Pessagno and Blome 1980, p. 259; pl. 4, figs 3-4, 24; Tipper *et al.*

1991, pl. 8, fig. 5; Carter 1994, pl. 1, fig. 10; Carter *et al.* 1998, p. 49; pl. 1, figs 4, 11,

26; Gorican 1994, pl. 1, figs 14-18; Hori *et al.* 2004, fig. 6-12; Carter and Hori 2005, pl.

1A, fig. 1; pl. 1B, fig. 1.

*Pantanellium* sp. aff. *tanuense* Pessagno and Blome - Spörli and Aita 1988, pl. 4, fig. 2.

Spörli *et al.* 1989, fig. 5, no. 6.

*Ellipsoxiphus tanuensis* (Pessagno and Blome) – Kozur 1993, text-fig. 3i.

OCCURRENCE: Lower Jurassic; Hettangian - lower Sinemurian. QCI, Canada; Japan; New Zealand; Hungary; Montenegro.

**Genus *Paronaella* Pessagno 1971, emend. Baumgartner 1980**

TYPE SPECIES: *Paronaella solanoensis* Pessagno 1971, pp. 48-49.

***Paronaella ravenensis* Whalen and Carter 1998**

Plate 2.2, figure 9

*Paronaella* sp. Carter 1994, pl. 1, fig. 17.

*Paronaella ravenensis* Whalen and Carter in Carter *et al.* 1998, p. 51, pl. 13, figs 1-2, 6, 9, 12, 16. Yeh and Cheng 1998, p. 15, pl. 1, figs 11, 42.

OCCURRENCE: Lower Jurassic; Hettangian - lower Sinemurian. QCI, Canada; Philippines.

**Genus *Pseudohagiastrum* Pessagno 1979 in Pessagno *et al.* 1979**

TYPE SPECIES: *Pseudohagiastrum monstuosum* Pessagno in Pessagno *et al.* 1979, p. 165.

***Pseudohagiastrum monstuosum* Pessagno group**

Plate 2.2, figure 6

*Pseudohagiastrum monstuosum* Pessagno in Pessagno *et al.* 1979, p. 165, pl. 6, figs 1-2.

*Pseudohagiastrum* sp. cf. *P. monstuosum* Pessagno - Carter 1993, p. 88, pl. 12, fig. 4.

REMARKS: The arms of this species are quite variable in length and width. A fifth arm has been observed in some uppermost Rhaetian specimens.

OCCURRENCE: Upper Triassic; upper Norian - Rhaetian. Baja California Sur; QCI, Canada.

**Genus *Risella* Carter 1993**

TYPE SPECIES: *Risella tledoensis* Carter 1993, p. 75.

***Risella tledoensis* Carter 1993**

Plate 2.2, figure 3

Gen. nov. C sp. – Carter 1990, pl. 2, fig. 1.

*Hagiastrum* (?) sp. - Bragin 1991, pl. 7, fig. 2.

*Risella tledoensis* Carter 1993, p. 75, pl. 9, figs 10-11, 13. Yeh and Cheng 1996, p. 8, pl. 4, figs 2, 6. Sugiyama 1997, p. 130. Carter and Guex 1999, p. 75, pl. 9, figs 10-11, 13. Tekin 1999, p. 102, pl. 14, figs 3-4.

OCCURRENCE: Late Triassic; Rhaetian. QCI, Canada; Baja California Sur; central Japan; Philippines; southern Turkey; Russian Far East.

**Genus *Tipperella* Carter 2007 in Longridge *et al.* 2007**

TYPE SPECIES: *Tipperella kennecottensis* Carter 2007 in Longridge *et al.* 2007, p. 163

DERIVATION OF NAME: Genus named for Dr. H.W. Tipper (Geological Survey of Canada) who passed away during the completion of the research project that resulted in this paper. The name honours his lifetime contribution to our understanding of the Jurassic geology and palaeontology of British Columbia.



DIAGNOSIS: Simple subspherical test with four spines in tetrahedral position.

DESCRIPTION: Simple test subspherical to subtetrahedral in shape with four spines in tetrahedral position. Cortical shell wall thick and variable; composed either of small polygonal pore frames or spongy meshwork; interior cavity filled with spongy meshwork. Spines variable in size and shape; spines robust to fine and delicate; triradiate and twisted, to circular in axial section and straight.

REMARKS: The shell of this primitive genus changes very little from Rhaetian to Hettangian, however a significant difference is observed in the spines. Spines are triradiate and strongly twisted through most of the Rhaetian (see *Spumellaria* gen. and sp. indet D, Carter 1993, p. 92; pl. 13, figs 9-10), but towards the end of the stage they begin to untwist. In contrast by the basal Hettangian, the spines are straight and circular in cross section (Plate 2.2, figs 7, 11).

OCCURRENCE: Triassic; Rhaetian to Lower Jurassic; Hettangian; QCI, Canada; Baja California Sur, Mexico; central Japan; southern Turkey.

***Tipperella kennecottensis* Carter 2007 in Longridge *et al.* 2007**

Plate 2.2, figures 7, 11

*Spongotrochus* sp. - Carter 1994, pl. 1, fig. 7.

*Tozerium nascens* Whalen and Carter - Tekin 2002b, p. 189; pl. 4, fig. 1.

*Spongotrochus?* sp. sensu Carter 1994 - Carter and Hori 2005, pl. 1A, fig. 4; pl. 1B, fig. 4.

DERIVATION OF NAME: Named for the type locality at Kennecott Point, QCI.

HOLOTYPE: GSC 111698

PARATYPE: GSC 11170

DIAGNOSIS: Test small and simple with four slim rod-like spines.

DESCRIPTION: Test usually small, subtetrahedral in shape. Cortical wall thick, composed of small polygonal pore frames or spongy meshwork. Spines variable in length; slim and tapering, circular in axial section. See Table 2.1 for measurements.

REMARKS: This primitive species with its small variable test and slim, rod-like spines is highly abundant immediately above the Triassic-Jurassic boundary and is an excellent indicator for the base of the Jurassic.

OCCURRENCE AND RANGE: Upper Triassic; uppermost Rhaetian - Lower Jurassic; Hettangian; Sandilands Formation, QCI, Canada; Inuyama, Japan; Turkey.

### **Genus *Tozerium* Whalen and Carter 1998**

TYPE SPECIES: *Tozerium nascens* Whalen and Carter 1998, p. 43.

### ***Tozerium nascens* Whalen and Carter 1998**

Plate 2.2, figure 12

*Tozerium nascens* Whalen and Carter in Carter *et al.* 1998, p. 44, pl. 1, figs 1, 7-8, 13-14, 23-24.

non *Tozerium nascens* Whalen and Carter – Tekin 2002*b*, p. 189, pl. 4, fig. 1.

OCCURRENCE: Lower Jurassic; Hettangian – lower Sinemurian. QCI, Canada.

### **Genus *Udalia* Whalen and Carter 1998**

TYPE SPECIES: *Udalia dennisoni* Whalen and Carter 1998, p. 59.

### ***Udalia primaeva* Whalen and Carter 1998**

Plate 2.2, figure 19

Gen. and sp. indet. I. Carter 1994, pl. 1, fig. 18.

*Udalia primaeva* Whalen and Carter in Carter *et al.* 1998, p. 60, pl. 6, figs 8, 12, 15-16, 20,  
23. Tekin 2002b, p. 186, pl. 3, figs 4-5.

OCCURRENCE: Lower Jurassic; Hettangian – lower Sinemurian. QCI, Canada; Hungary;  
southern Turkey.

#### INCERTAE SEDIS

#### **Spumellarian indet. A sensu Whalen and Carter 1998**

Plate 2.2, figure 5

Spumellarian indet. A, Whalen and Carter in Carter *et al.* 1998, p. 61; pl. 11, figs 10-11, 15.

Carter and Hori 2005, pl. 1A, fig. 3; pl. 1B, fig. 3.

OCCURRENCE: Lower Jurassic; Hettangian. QCI, Canada; Inuyama, Japan.

#### ***Spumellaria* indet. B sensu Carter 1994**

Plate 2.2, figure 13

*Spumellaria* indet. B, Carter 1994, pl. 1, fig. 3.

REMARKS: Primitive spherical nodose form with irregular, variably-sized poreframes.

Provenance uncertain.

OCCURRENCE: Lower Jurassic; basal Hettangian. QCI, Canada.

#### ***Spumellaria* indet. X**

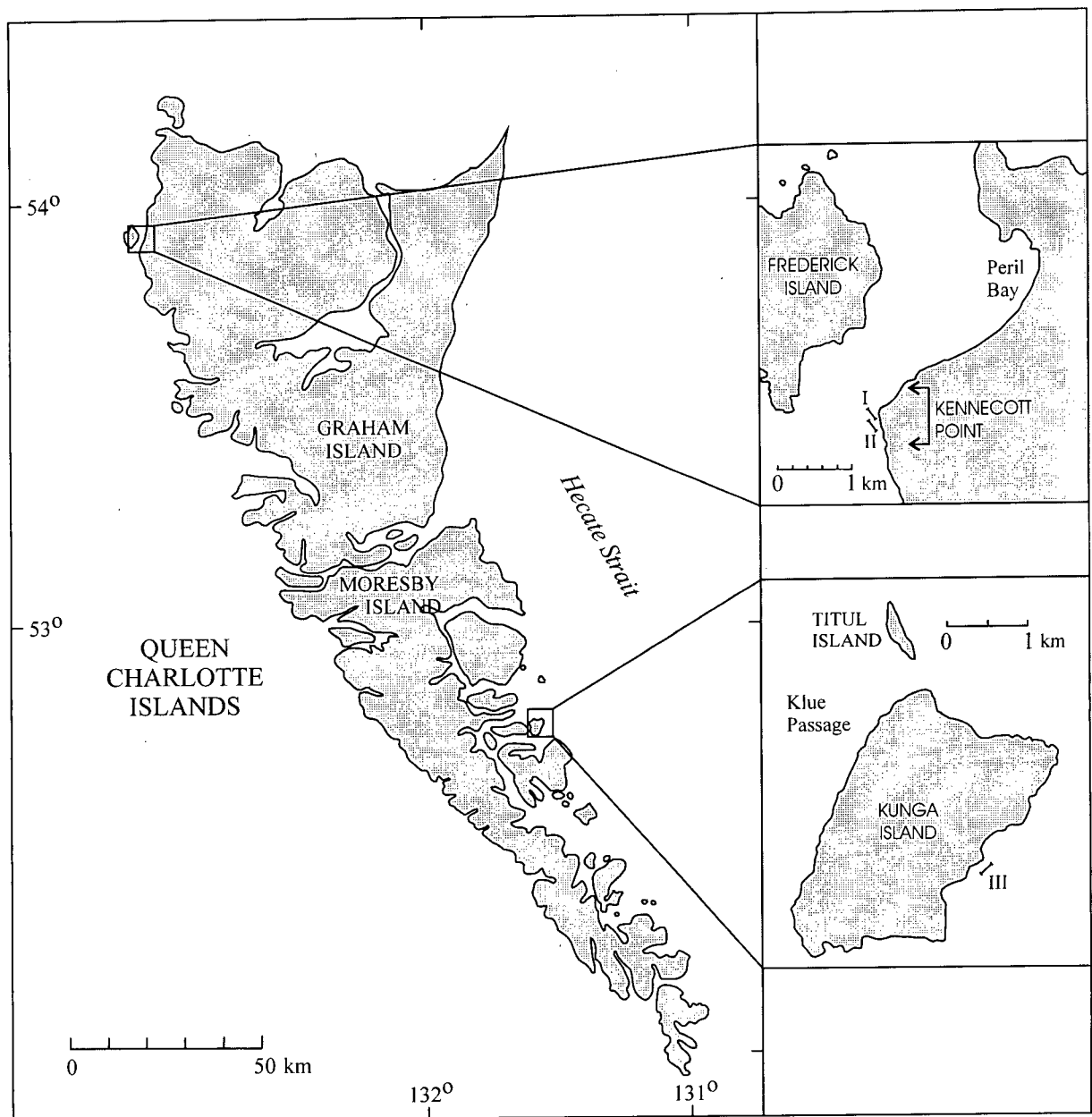
Plate 2.2, figure 14

REMARKS: This primitive spongy elliptical species appears to be a short-ranging survival taxon found only in the basal Hettangian. It is unknown whether it later evolves into a form with multiple spines (as seen in the mid to late Hettangian) or simply dies out.

OCCURRENCE: Upper Triassic; uppermost Rhaetian - Lower Jurassic; lower Hettangian. QCI, Canada.

	Holotype	Max.	Min.	Mean
Maximum diameter of test	132	197	131	142
Length of longest spine	111	178	75	134

**Table 2.1.** Measurements ( $\mu\text{m}$ ) of *Tipperella kennecottensis* sp. nov. based on 14 specimens.



**Figure 2.1.** Localities of sections and isolated outcrops bearing latest Triassic and early Hettangian ammonite and radiolarian faunas in the Queen Charlotte Islands.

AGE	NORTH AMERICAN ZONES <sup>1,2</sup>	QUEEN CHARLOTTE ISLAND FAUNA			SOUTH AMERICAN ZONES AND SUBZONES <sup>5</sup>	NORTHWEST EUROPEAN ZONES <sup>6</sup>	
		Ammonites	Radiolarians <sup>3,4</sup>				
HETTANGIAN	Polymorphum	●	<i>Canoptum merum</i> Zone	●	Rectocostatum	Planorbis	
					Primocostatum		
	Pacificum	●		●	Tilmanni		Planocostatum SZ
	Minutus	●		●	Tilmanni SZ		
	Spelae	?		?			
RHAETIAN	Crickmayi	●	<i>Globolaxtorum tozeri</i> Zone	●	Marshi		

**Figure 2.2.** Rhaetian and lower Hettangian ammonite and radiolarian zones and subzones with zonal levels represented by faunas in the Queen Charlotte Islands marked by solid circles.

<sup>1</sup>Tozer (1979); <sup>2</sup>Taylor *et al.* (2001); <sup>3</sup>Carter (1993); <sup>4</sup>Carter *et al.* (1998); <sup>5</sup>Hillebrandt (2000); <sup>6</sup>Dean *et al.* (1961).

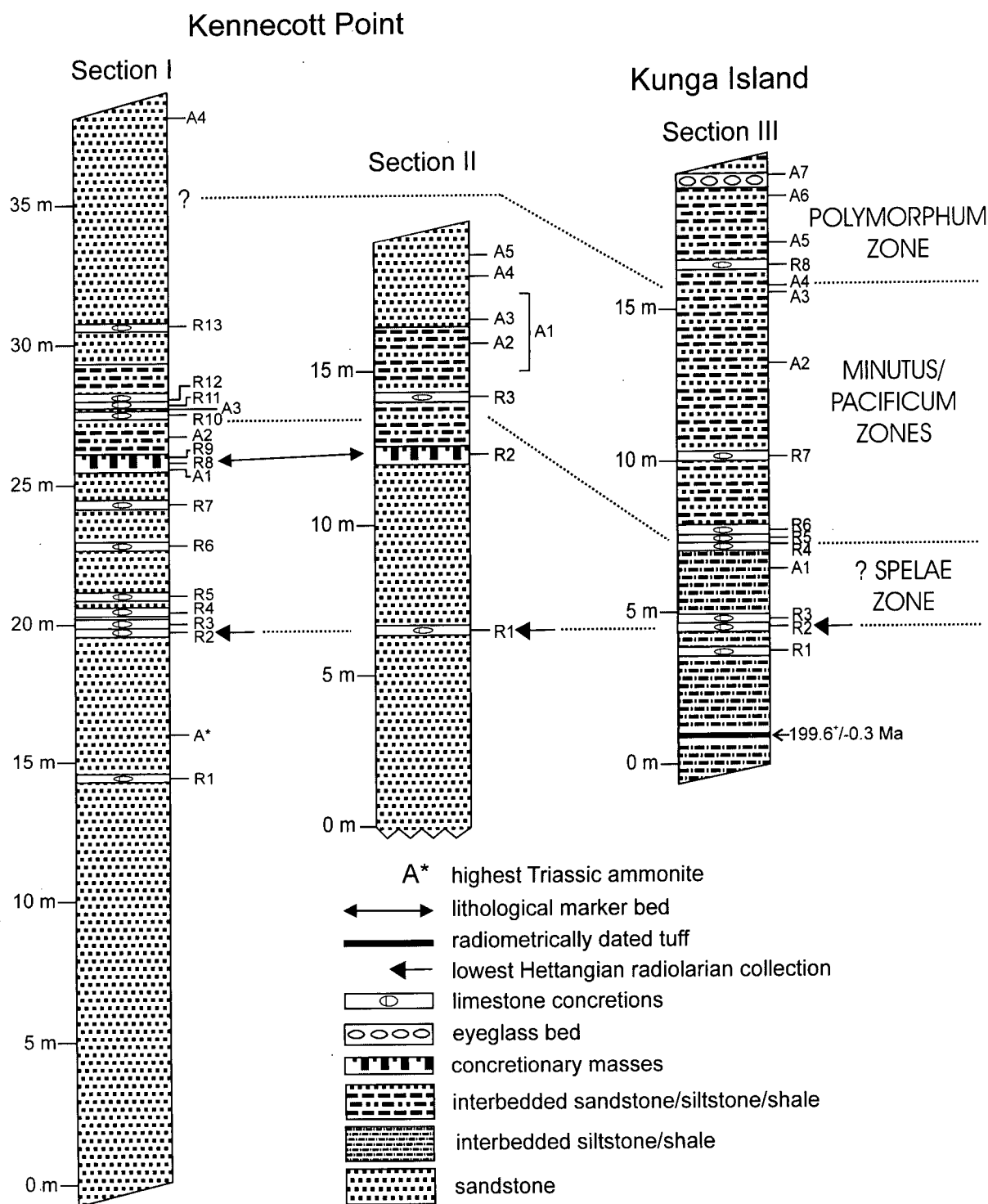
	Kennecott Point										Kunga Island						
Measured section	I				II					III							
Localities	A1	A2	A3	A4	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5	A6	A7	
<i>Choristoceras</i> aff. <i>minutus</i>					X						X	X					
<i>Odoghertyceras</i> cf. <i>deweveri</i>								X									
<i>Neophyllites</i> (?) sp.					X				X								
<i>Psiloceratid</i> indet.										X							
<i>Psiloceras</i> ex. gr. <i>tilmanni</i>	X	X		X					X					X		X	
<i>Psiloceras</i> cf. <i>marcouxi</i>									X								
<i>Psiloceras</i> cf. <i>planocostatum</i>											X						
<i>Psiloceras</i> cf. <i>polymorphum</i>															X	X	
<i>Nevadaphyllites</i> (?) sp.			X			X	X										
<i>Transipsiloceras</i> cf. <i>transiens</i>													X				

**Figure 2.3.** Early Hettangian ammonites from sections I, II and III in the Queen Charlotte Islands.



	Kennecott Point													Kunga Island										
Measured section	I													II			III							
Radiolarian localities (R)	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	R 13	R 1	R 2	R 3	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8
<i>Cantalum gratum</i>														R			A							
<i>Cantalum tianense</i>														R										
<i>Canoptum</i> cf. <i>unicum</i> sensu Carter	R																A							
<i>Canutus?</i> <i>beehivensis</i>	?													R			A							
<i>Crucella?</i> sp. A sensu Carter														C			A							
<i>Deflandrecyrtium nobense</i>														R			A							
<i>Globolaxtorum tozeri</i>														R			A							
<i>Pantanellium newkluense</i>														R			A							
<i>Risella tledensis</i>														R			A							
<i>Squinabolella</i> sp. C sensu Carter														C			A							
<i>Globolaxtorum</i> sp. A sensu Carter																	C	R						
<i>Loupanus thompsoni</i>	R																A							
<i>Livarella valida</i>																	C	R						
<i>Eptingium oneismos</i>														R			A		R					
<i>Kungalaria newcombi</i>														C			A		R					
<i>Livarella</i> spp.																	A	R	C					
<i>Paratriassostrum</i> spp.																	A	A	A					
<i>Eucyrtid</i> gen. et sp. indet.	R																A	R	R					
<i>Pseudohagiastrum monstrosus</i>														C			A	R	C					
<i>Deflandrecyrtium</i> spp.														R			C			R				
<i>Mesosaturnalis acuminatus</i>																	A			C				
<i>Atalanta epaphrodita</i>														R	>				R					>
<i>Icrioma</i> sp. A sensu Carter	<			R										C			C							
<i>Laxtorum perfectum</i>	<			?										R			C							
<i>Laxtorum</i> spp.	C													R			A							
<i>Plafkerium</i> spp.	<			R													C							
Spumellarian indet. X	R	R	R	C		C	R							R	R	R	C	R		C	R	R		
Indet. spherical spumellarians	R	C	C	C	A	A	A	A	A	A	A	A	A	A	R	R		A	A	A	C	A	C	C
<i>Udalia</i> spp.		R	R	C		C	C	C	C	C	C		C	A		>		C	C	A	C	A	C	R
<i>Tipperella kennecottensis</i>	?	?	R	C		A	A	A	A	A		C	A	A		>	C	C	C	A	C	A	A	C
<i>Canoptum merum</i>		?	R	R		R	R	R	R				R	C		>			?		C			>
<i>Udalia primaeva</i>				R		C	R			C	R		C	C	C	>		?	R	A	C	A	C	R
<i>Amuria impensa</i>				R		R	R	R	R	C			C	A	R	>						C	R	R
<i>Archaeocenospaera laseekensis</i>				C		A	C	C	C	A			A	A		C				A	C	A	A	>
<i>Paronaella ravensis</i>				R									C	C		>				C	C	A		R
Gen. et sp. indet. A (W & C 1998)				R			R							A		>		?		C	C	C	C	>
Spumellaria indet. B (Carter 1994)				C		C				R				A						C	R	C	R	C
<i>Charlottea</i> spp.						R	C			R			C					?	R	C	C	R		>
<i>Tozerium nascens</i>						R	C			C	R		C	?		>		?		A	C	C	A	R
<i>Droetus hecatensis</i>							C			C	C		C						R	C	?	A		R
<i>Thurstonia</i> spp.							R	R						>	R		>			C	R	C	C	>
<i>Praehexasaturnalis tetradialatus</i>								R						>						C		R		>
<i>Relanus reefensis</i>					?					R	C		C						?	R	R	R		>
<i>Pantanellium tanuense</i>										C	C	C	C							A	C	A	C	R
<i>Bipedis elizabethae</i>														R						R		R		>
<i>Parahsum</i> spp.													C							C	C	C		R

**Figure 2.4.** Latest Rhaetian and early Hettangian radiolarians from Sections I, II and III in the Queen Charlotte Islands. Abundance is relative to each individual sample based on preservation: A = very abundant; A = abundant; C = common; R = rare; ? = questionable occurrence (usually based on inadequate preservation); < indicates range extends lower; > indicates range extends higher.



**Figure 2.5.** Measured sections showing upper Rhaetian and lower Hettangian radiolarian and ammonoid fossil localities in the Queen Charlotte Islands; A = ammonites; R = radiolarians.

Age Group	Rhaetian	Hettangian	
		lower	middle - upper
a	▲ Ayrtonius		
	▲ Betraccium		
	▲ Bipedis (Triassic type)		
	▲ Cantalum		
	▲ Entactinosphaera		
	▲ Eptingium		
	▲ Ferresium		
	▲ Icrioma		
	▲ Kahlerospaera		
	▲ Naboella (=Squinabolella K and M)		
	▲ Paratriassostrum		
	▲ Pentactinocarpus		
	▲ Pentaspongodiscus		
	▲ Plafkerium		
	▲ Pseudohagiastrum		
	▲ Tetraporobrachia		
	▲ Triassocrucella		
	▲ Veghicyclia		
	Kungalania		
	Loupanus	?	
b	Praecitriduma		
	Spum. gen. et sp. B (Carter 1993)		
	Spum. gen. et sp. E (Carter 1993)		
	Risella		
	Globolaxtorum		
	▲ Deflandrecyrtium	-----	
	▲ Livarella	-----	
	▲ Fontinella	-----	
	Proparvicingula	-----	
	Tipperella n. gen.	-----	
	▲ Parentactinia	-----	
	▲ Pseudacanthocircus	-----	
	Amuria	-----	
	Archaeocenosphaera	-----	
	▲ Canoptum	-----	
	Citriduma*	-----	
	Crucella	-----	
	▲ Gorgansium*	-----	
	▲ Haeckelicyrtium	-----	
	▲ Laxtorum**	-----	
	▲ Orbiculiformella	-----	
c	Palaeosaturnalis	-----	
	▲ Pantanellium	-----	
	Paronaella	-----	
	Praehexasaturnalis	-----	
	▲ Pseudoheliodiscus	-----	
	Pseudoeucyrtis	-----	
	Mesosaturnalis	-----	
	Bistarkum*	-----	
	Cornutella*	-----	
	Spum. B (Carter 1994)	-----	
d	Atalanta	-----	
	Bipedis (Jurassic type)	-----	
	Charlottea	-----	
	Droilus	-----	
	Parahsuum	-----	
	Relanus	-----	
	Thurstonia	-----	
	Tozerium	-----	
	Udalia	-----	
			Danubea
			Empirea
			Nitrader
			Protokatroma
			Anaticaputula
			Beatricea
			Liassosaturnalis
			Saitoum
			Trexus

**Figure 2.6.** Range chart showing the occurrence of Rhaetian – Hettangian genera in the Queen Charlotte Islands. Groups illustrated include: a – genera disappearing at the T-J boundary; b – genera surviving the T-J boundary; c – genera first appearing at base of Hettangian; d – genera first appearing in middle-upper Hettangian. Other symbols: ▲ range extends below Rhaetian; ► range extends above Hettangian; dotted line indicates missing in this interval; dashed line indicates rare, sporadic occurrence; \* genus occurs in Rhaetian but does not appear again until Pliensbachian or higher; \*\* all *Laxtorum* with tubes disappeared end of Rhaetian.

**Plate 2.1.** Hettangian ammonites from the Sandilands Formation, Queen Charlotte Islands; all figures are natural size.

Figure 1, *Psiloceratid* indet. GSC 127451 from A1, section III, Kunga Island.

Figure 2, *Psiloceras* ex. gr. *tilmanni* Lange. GSC 127459 from A4, section I, Kennecott Point.

Figure 3, *Transipsiloceras* cf. *transiens* Guex. GSC 127450 from A4, section III, Kunga Island.

Figure 4, *Choristoceras* aff. *minutus* Guex. GSC 127452 from A3, section III, Kunga Island.

Figure 5, *Choristoceras* aff. *minutus* Guex. GSC 127462 from A1, section II, Kennecott Point.

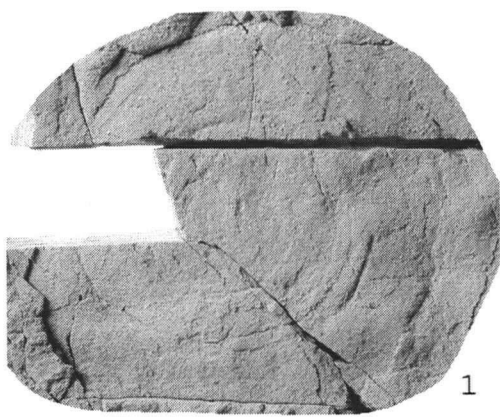
Figure 6, *Psiloceras* cf. *marcouxi* Guex, Taylor, Rakús, Bucher. GSC 127460 from A5, section II, Kennecott Point.

Figure 7, *Neophyllites* (?) sp. GSC 127456 from A1, section II, Kennecott Point.

Figure 8, *Odoghertyceras* cf. *deweeveri* Guex, Taylor, Rakús, Bucher. GSC 127449 from A4, section II, Kennecott Point.

Figure 9, *Psiloceras* cf. *planocostatum* Hillebrandt. GSC 127461 from A2, section III, Kunga Island.

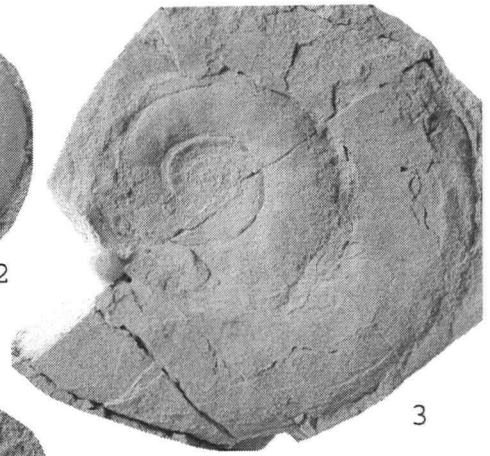
Figure 10, *Psiloceras* cf. *polymorphum* Guex. GSC 127453 from A6, section III, Kunga Island.



1



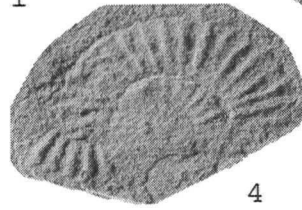
2



3



6



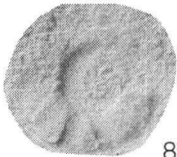
4



5



7



8



9



10

**Plate 2.2.** Scanning electron micrographs of Hettangian radiolarians from the Sandilands Formation, Queen Charlotte Islands. Figures 1-4, 6, 8 and 10 are short-lived Rhaetian holdovers from sample R1 of section II. Figures 5, 7, 9, 11, 13-15, 18, 20 are earliest Hettangian; figures 12, 16 and 19 are late lower Hettangian; figure 17 is middle Hettangian.

Figure 1, *Globolaxtorum tozeri* Carter. GSC 111699 from R1, section II, Kennecott Point; scale bar = 150µm.

Figure 2, *Icrioma* sp. A sensu Carter 1993. GSC 111700 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 3, *Risella tledoensis* Carter. GSC 111701 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 4, *Kungalaria newcombi* Dumitrica and Carter. GSC 111702 from R1, section II, Kennecott Point; scale bar = 150µm.

Figure 5, Gen. et sp. indet. A sensu Whalen and Carter 1998. GSC 111697 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 6, *Pseudohagiastrum monstuosum* Pessagno group. GSC 111703 from R1, section II, Kennecott Point; scale bar = 150µm.

Figure 7, *Tipperella kennecottensis* sp. nov. GSC 111698 (holotype) from R1, section II, Kennecott Point. Cortical shell composed of fine polygonal pore frames (compare with Plate II, 11); scale bar = 100µm.

Figure 8, *Canutus? beehivensis* Carter. GSC 111704 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 9, *Paronaella ravenensis* Whalen and Carter. GSC 111705 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 10, *Deflandrecyrtium nobense* Carter. GSC 111706 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 11, *Tipperella kennecottensis* sp. nov. GSC 111707 (paratype, showing spongy wall structure) from R1, section II, Kennecott Point; scale bar = 150µm.

Figure 12, *Tozerium nascens* Whalen and Carter. GSC 99424 from 89-CNA-SKUE-6, Kunga Island; scale bar = 100µm.

Figure 13, *Spumellaria* indet. B sensu Carter 1994. GSC 99423 from R4, section III, Kunga Island; scale bar = 100µm.

Figure 14, *Spumellaria* indet. X. GSC 111708 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 15, *Archaeocenosphaera laseekensis* Pessagno and Yang. GSC 99426 from R4, section III, Kunga Island; scale bar = 100µm.

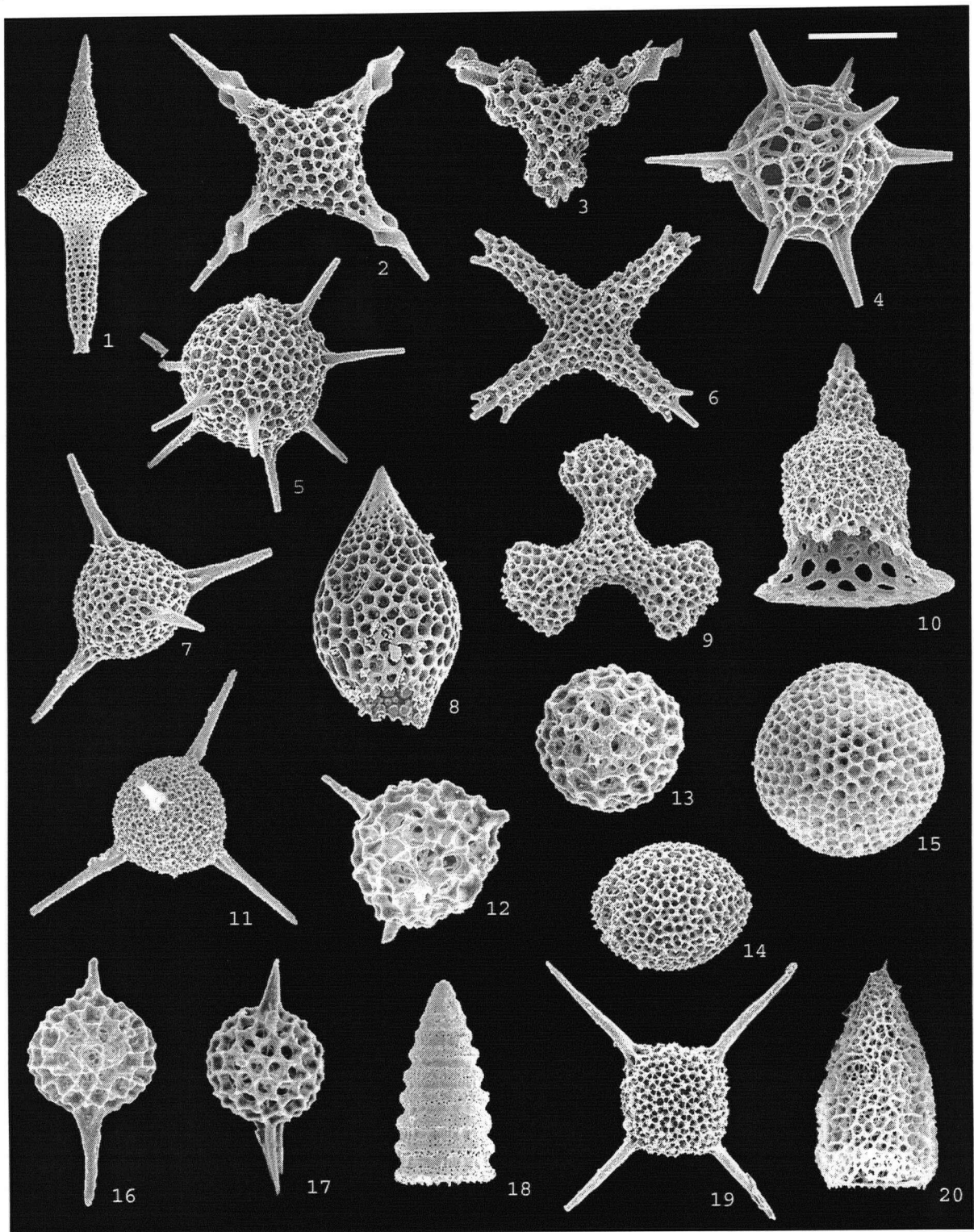
Figure 16, *Pantanellium tanuense* Pessagno and Blome. GSC 111709 from 89-CNA-SKUE-6, Kunga Island. Note narrow rod-like spines; scale bar = 110µm.

Figure 17, *Pantanellium tanuense* Pessagno and Blome. GSC 107689 from sample QC-543, Kunga Island. Note change to triradiate spines in younger specimens; scale bar = 108µm.

Figure 18, *Canoptum merum* Pessagno and Whalen. GSC 111710 from R1, section II, Kennecott Point; scale bar = 100µm.

Figure 19, *Udalia primaeva* Whalen and Carter. GSC 107742 from 89-CNA-SKUE-6, Kunga Island; scale bar = 100µm.

Figure 20, *Droltus hecatensis* Pessagno and Whalen. GSC 99434 from GSC loc. C-173357 (89-SKUD-339), Kunga Island; scale bar = 100µm.





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# 3 THE TRIASSIC-JURASSIC TRANSITION AT KUNGA ISLAND, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA<sup>1</sup>

## 3.1 Introduction

Several stratigraphic sections in the Queen Charlotte Islands of British Columbia, Canada contain exceptionally well preserved radiolarian faunas that cross the Triassic-Jurassic boundary (T-J boundary). In particular, a section at Kunga Island shows a dramatic turnover of radiolarians that could be used to define and constrain the T-J boundary to within one metre, a precision that is greater than any other fossil group. The Kunga section was originally proposed as a GSSP candidate for the basal Jurassic by Carter and Tipper (1999) and again by Haggart *et al.* (2002). These proposals are updated here. We propose that if radiolarian sequences are selected as the primary standard (*sensu* Callomon 1984) for defining the T-J boundary, then the section at Kunga Island should be selected as GSSP.

If radiolarian sequences are not selected as the primary standard then we propose that they should be considered as a secondary standard and that the Kunga Island section be designated as a parastratotype in order to better characterize the Triassic-Jurassic transition. In some circles parastratotypes are also known as auxiliary reference sections. In addition to radiolarians, the Kunga Island sequence permits the calibration of time scales based on ammonites, radiometric ages and, indirectly, with the carbon isotope curve. The aim of designating any stratotype is, of course, to provide the international community with the widest spectrum of stratigraphic information that helps both to define the boundary and to characterize it as thoroughly as possible. This maximizes the potential for regional and global correlation. No single section is

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<sup>1</sup> A version of this chapter has been accepted for publication. Longridge, L.M., Carter, E.S., Haggart, J.W. and Smith, P.L. in press. The Triassic-Jurassic transition at Kunga Island, Queen Charlotte Islands, British Columbia. *International Subcommission on Jurassic Stratigraphy Newsletter*.

perfect in this regard and, consequently, the International Stratigraphic Guide of the IUGS Commission on Stratigraphy (Salvador 1994) has recognized the benefit of designating a parastratotype. The holostatotype is the GSSP and, of course, always has precedence in defining the boundary. The parastratotype provides critical information not present in the holostatotype. The designation of parastratotypes is a well established procedure and there are several examples in stratigraphic studies of the Jurassic. These include the definition of the Bajocian where the Murtinheira section at Cabo Mondego, Portugal, is the GSSP and the Bearreraig Bay section on the Isle of Skye, Scotland, is designated an auxiliary stratotype (Pavia and Enay 1997) and the establishment of the Lower Jurassic ammonite zonation of North America (Smith *et al.* 1988; Jakobs *et al.* 1994; Taylor *et al.* 2001; Longridge *et al.* 2006a).

Below, we summarize the details of the Kunga Island section as currently understood.

### **3.2 Location and Access**

The proposed section is located in the supratidal region on the southeast shore of Kunga Island (NTS 103 B/13, Zone 9; 52°45.573', 131°33.638') (Fig. 3.1, section 1; Fig. 3.2). Kunga Island is a small island on the southeastern edge of the Queen Charlotte Islands (QCI), British Columbia (Fig. 3.1). Kunga Island is part of Gwaii Haanas National Park Reserve. Although a permit is required for collecting, this restriction provides protection and conservation of the site (Haggart in press). Access to Kunga Island involves flying into Sandspit, on Moresby Island, QCI, approximately 55 km from the Kunga Island site. The section is then accessed by vehicle over about 60 km of logging road and then by boat.

### **3.3 Paleogeographical Context**

Kunga Island is part of the Wrangellia terrane which is considered to be allochthonous to North America. During Triassic/Jurassic time, Wrangellia was more southerly and further outboard of its current position relative to the craton but it was eventually accreted to North

America at some time during the Middle Jurassic (van der Heyden 1992; Thompson *et al.* 1991; Haggart *et al.* 1995), Cretaceous (Monger 1998), or Paleogene (Ward *et al.* 1997). The constraints on its location at the end of the Triassic and beginning of the Jurassic are reasonably well documented. Permian coral, brachiopod, and fusulinid faunas (Monger 1984; Belasky 1994; Belasky *et al.* 2002), Sinemurian and Pliensbachian bivalve faunas (Aberhan 1999 and references therein), and Pliensbachian ammonite faunas (Smith and Tipper 1986; Smith *et al.* 2001; Smith 2006) tie the terrane to the Northern Hemisphere and the eastern Pacific. The distribution of the ammonites *Sunrisites* and *Badouxia* are additional evidence that Wrangellia was located in the eastern Pacific during the Hettangian (Taylor *et al.* 1984; Smith 2006; Longridge *et al.* in press).

### **3.4 Tectonic History and Structural Setting**

The Kunga Island section was deposited in the Mesozoic Hecate basin (Haggart 1993). The basin was affected by southwest directed folding and contractional faulting in the Middle Jurassic, block faulting in the Late Jurassic, northeast-directed folding in the Late Cretaceous and extensional block faulting and reverse faulting in the Paleogene (Thompson *et al.* 1991). Despite this regional deformation, the section at Kunga Island is, for the most part, structurally intact.

### **3.5 Lithostratigraphy and Depositional Paleoenvironment**

The Kunga Island section is part of the Sandilands Formation of the Kunga Group. The Sandilands Formation is several hundred metres thick and ranges in age from early Rhaetian to mostly the latest Sinemurian, although its upper contact is diachronous and locally ranges in age from earliest Pliensbachian (Tipper and Carter 1990; Tipper *et al.* 1991, 1994; Smith and Tipper 1996). The Rhaetian and very basal Hettangian part of the Formation at Kunga Island are remarkably consistent, well-indurated silicified siltstone with minor, fine- to medium-grained

sandstone, and thin tuff interbeds (Fig. 3.3). Common micrite concretions frequently yield abundant radiolarians and conodonts. Despite intensive search, no macrofossils have been found in the Rhaetian part of the Kunga Island sequence, which was probably deposited in deep water. Above this stratigraphic level, the section becomes much more clastic-dominated and limestone disappears (Fig. 3.3). About 15 m higher, limestone concretions reappear and yield middle Hettangian radiolarians (Carter *et al.* 1998). Beds in the section are near vertical but otherwise the section displays minimal structural disruption (Carter 1993; Carter *et al.* 1998). Permanent markers identifying beds in the section were installed by the Geological Survey of Canada. These markers begin at the latest Triassic radiometrically dated tuff bed (0.0 m) and range well into the Hettangian (T-J boundary is at 3.6 m).

Cameron and Tipper (1985) suggested that much of the Sandilands Formation was deposited in a relatively deep back-arc basin somewhat distant from a source of fine volcanic detritus which is present in distal turbidites and less common air-fall tuffs (Pálffy *et al.* 1990; Tipper and Guex 1994). However, the precise paleogeographic setting of the Late Triassic-Early Jurassic strata of the Wrangellia terrane is poorly constrained at present and more recent work suggests that the Rhaetian/Hettangian parts of the Sandilands Formation were deposited in an outer shelf to upper slope setting (Haggart *et al.* 2001, 2002). The lack of significant turbidites within the Kunga Island section supports the interpretation of deposition in a shallower water environment. Importantly, the presence of abundant radiolarians suggests direct access to the open ocean.

### 3.6 Paleontology

The QCI contain two localities with uninterrupted succession of Rhaetian to Hettangian strata: Kennecott Point and Kunga Island (Fig. 3.1). The radiolarians are abundant and well preserved at both localities and clearly represent the most important faunal successions of Rhaetian-Hettangian radiolarians known today. The Rhaetian part of the sequence is dated by

closely associated conodonts at both localities (Tipper and Carter 1990; Orchard 1991; Carter 1993; Tipper *et al.* 1994) and rare ammonoids at Kennecott Point (Tipper and Carter 1990; Tipper *et al.* 1994; Ward *et al.* 2004), while lower Hettangian ammonites date the succession at both localities (Tipper and Guex 1994; Tipper *et al.* 1994; Carter *et al.* 1998; Longridge *et al.* 2007). Radiolarians are the most abundant group throughout the Rhaetian and provide the most complete and continuous record of faunal change across the T-J boundary. Many closely spaced collections at each locality document the dynamics of faunal change and closely constrain the position of the T-J boundary. The dramatic turnover of radiolarian species (Carter 1994, 1998; Carter *et al.* 1998) is characterized by a significant extinction of Rhaetian taxa that are replaced by a low diversity Hettangian fauna composed of very simple forms.

Since the 1970s, Mesozoic radiolarians have been dated by associated ammonoids, conodonts and/or other fossil groups, and vast numbers of radiolarian species have been described. Many were integrated into local and regional zonal schemes that have been increasingly refined over the years. However, subsequent testing over wider areas using the Unitary Associations (UA) method (Guex 1991) has now reached a level of accuracy that allows radiolarians to stand alone as primary indicators for dating rock. This capability is particularly important in areas where radiolarians are the only fossils available for age dating (e.g. chert sequences in oceanic terranes) or where the completeness of the faunal succession is such that the accuracy achieved by radiolarians is superior to that of other fossil groups.

Very few radiolarians of Rhaetian and Hettangian age were known prior to Geological Survey of Canada sponsored discoveries at Kennecott Point and the southeast side of Kunga Island (1986-1990). Preliminary results clearly indicated that a well-preserved succession of Rhaetian and Hettangian radiolarians was present at both localities (Carter *et al.* 1989; Carter 1990; Tipper and Carter 1990). Further collecting at Kunga Island in 1997-98 and 2000 increased the sampling density across this critical interval and provided more precise data on the



range of key taxa. In 1993, Carter described the Rhaetian faunas and established two radiolarian zones: the *Proparvicingula moniliformis* Zone and the overlying *Globolaxtorum tozeri* Zone using the Unitary Associations method of Guex (1977, 1991). This work was based on the documentation of over 140 short-ranging Rhaetian species, most of which were new (Carter 1993). A number of species have been described since that time (Yeh and Cheng 1996; Sugiyama 1997; Dumitrica and Carter 1999; Tekin 1999, 2002a; Carter and Hori 2005; Longridge *et al.* 2007), others have been recognized informally, and the range of still others originating in the Carnian and Norian, has been extended to the Rhaetian.

### 3.6.1 Biostratigraphy – radiolarians, conodonts, ammonites

On the southeast side of Kunga Island there is a continuous sequence from the Rhaetian (Carter 1993, fig. 9) to the middle Hettangian (Carter *et al.* 1998). Over 130 m of Rhaetian strata are present in two sections [sections 3 and 5 of Carter (1993); Fig. 3.1, section 1]. These strata overly up to 100 m of partly-disrupted, dark grey, calcite-veined argillaceous strata with rare *Monotis* in the 30-50 m interval. Above the section proposed herein (Fig. 3.3), ~45 m of strata contains middle Hettangian ammonites. The two Rhaetian sections have been correlated using radiolarians. Despite intensive search, no macrofossils have been found in Rhaetian beds at Kunga Island, but conodonts are common and radiolarians abundant.

The Triassic-Jurassic transitional interval as discussed herein includes radiolarians from the *Globolaxtorum tozeri* Zone (upper Rhaetian) and the *Canoptum merum* Zone (lower Hettangian) (Fig. 3.4), upper Rhaetian conodonts (Carter 1993; Fig. 3.5) and ammonites that are possibly from the Spelae Zone and definitely from the Minutum to Polymorphum zones (lower Hettangian) (Longridge *et al.* 2007; Figs 3.3, 3.6).

In total, radiolarians occur in 16 discrete horizons collected over a stratigraphic interval of 37.45 metres, the majority of which are concentrated in about 10 m of strata spanning the boundary (Fig. 3.3). Diagnostic T-J boundary radiolarians are shown on Plate 1. Rhaetian

radiolarian collections begin 56 m above the base of the formation and are present up to 80.75 m, an interval of 24.75 metres. Five conodont horizons occur in the top 20.8 m of upper Triassic strata with the highest conodont occurrence at 79.1 m (Fig. 3.3). Prior to collecting in 2000, the first typical Hettangian radiolarians were believed to begin at 84.5 m (Carter 1998; Carter *et al.* 1998). However since the finding of transitional faunas (mostly Jurassic) at 81.55 m and 81.8 m in 2000, this level has been lowered to 81.55 m (Carter and Hori 2005). This level is <1.0 m above the final occurrence of Rhaetian radiolarians, 2.45 m above the last conodonts and 3.6 m above a tuff layer within the Triassic-Jurassic transition yielding a U-Pb zircon age of  $199.6 \pm 0.3$  Ma (Pálffy *et al.* 2000). Seven ammonite horizons occur within 14.8 m of early Hettangian strata with the first ammonite at 83.45 m, 1.9 m above the first Jurassic radiolarians (Fig. 3.3). Further information is found in Appendix B.

#### 3.6.1.1 Radiolarian biology and extinction

Basal Hettangian radiolarian faunas of the *Canoptum merum* Zone can be recognized by the common occurrence of *Tipperella kennecottensis* together with other simple spherical forms with rod-like spines, the incoming of *Canoptum merum*, *Droltus hecatensis*, *Tozerium nascens*, *Udalia primaeva*, and a little higher by the first appearance of the distinctive species *Pantanellium tanuense* (Plate 3.1). A complete discussion of the lower Hettangian faunas is found in Longridge *et al.* (2007).

Radiolarian faunas from the upper Rhaetian *Globolaxtorum tozeri* zone, up to the extinction event at the end of the Triassic are rich and diverse, composed largely of genera originating in the late Carnian and Norian, and some in the Rhaetian. They differ from radiolarians of the underlying *Betraccium deweveri* Zone (upper Norian *Monotis* equivalent) by lacking the widely distributed nominal taxon, and many species of *Ferresium* and *Laxtorum* described by Blome (1984). Spumellarians outnumber nassellarians by a ratio of about 2:1. Radiation began early in the Rhaetian at Kunga Island and continued to topmost beds (Carter 1993), a phenomenon that

contrasts sharply with the diminishing diversity of other faunas at this time. The radiolarian fauna includes over 170 short-ranging species: 154 species were described or informally designated by Carter (1993), a few others have been recognized subsequently (Dumitrica and Carter 1999; Carter and Hori 2005), and many others are still undescribed. Some are widely distributed e.g., *Globolaxtorum tozeri*, and have proven to be extremely useful for age dating (Yeh and Cheng 1996; Sugiyama 1997; Tekin 1999; Amodeo 1999; Bertinelli *et al.* 2004; Yeh and Yang 2006; Orchard *et al.* 2007, in press). The most abundant and characteristic genera of the *G. tozeri* zone are *Betraccium* Pessagno and Blome (but not *B. deweveri*), *Canutus* Pessagno and Whalen, *Citriduma* De Wever, *Deflandrecyrtium* Kozur and Mostler, *Fontinella* Carter, *Globolaxtorum* Carter, *Kungalaria* Dumitrica and Carter, *Laxtorum* Blome, *Livarella* Kozur and Mostler, *Loupanus* Carter, *Nabolella* Petrushevskaya, *Plafkerium* Pessagno and *Serilla* (= *Risella*) Carter (Carter in press).

Twisted spines are characteristic of many Upper Triassic species, to the degree that poorly preserved samples can even be dated approximately by the presence of strongly twisted spines. This distinctive feature is prevalent amongst both spumellarians and nassellarians of Rhaetian age and is particularly useful when differentiating late Rhaetian (with twisted spines) and early Hettangian faunas (with straight, rod-like spines).

Carter (1990) distinguished several broad taxonomic groups amongst the Rhaetian fauna: (1) conservative forms such as canoptids and pantanellids; (2) architecturally complex forms such as the hat-shaped nassellarians *Deflandrecyrtium*, *Haekelicyrtium*, *Nabolella* and *Citriduma*; (3) rapidly-radiating forms of the *Laxtorum*-*Globolaxtorum* lineage and the *Ferresium*-*Risella* lineage (Carter and Guex 1999); and (4) ancestral Jurassic forms such as *Crucella*, *Bistarkum*, *Bipedis*, *Canutus*, *Droltus* etc. Continuing studies indicate these assemblages are still valid, and suggest that each of these groups tends to react in a similar way approaching the T-J boundary

i.e., most architecturally complex and rapidly-evolving forms disappear at the end of the Triassic, while the conservative and ancestral Jurassic forms survive.

Radiolarians underwent major faunal change at the end of the Triassic: five families disappeared including the Hexaporobracchiidae, Hindeosphaeridae, Nabollellidae, Pentactinocarpidae (De Wever *et al.* 2001, p. 389) and the Deflandrecyrtiidae. Many Triassic genera became extinct or nearly so (Longridge *et al.* 2007, p. 152) but the most noticeable effect was upon species. Ninety-five species are recorded in the *Globolaxtorum tozeri* Zone alone (Fig. 3.4). A few range upward from the *Betraccium deweveri* Zone or below, over 60 species arose in the *Proparvicingula moniliformis* Zone, and 12 species originated within the *G. tozeri* Zone. With the exception of over 20 species that disappeared in lower beds of the *G. tozeri* Zone, the remainder range into the highest beds of the Triassic, and a very few pass into the basal Hettangian [see discussion of 'short-ranging Rhaetian holdovers' in Longridge *et al.* (2007, p. 153)]. The abrupt disappearance of over 55 species takes place above the 80.75 m level and is followed <1 m above by the appearance of a low diversity transitional fauna comprised of a few Rhaetian species, most notably *Livarella*, many peculiar transitional forms, and a few Hettangian genera. Less than three metres above, at 84.25 m an abundant basal Hettangian fauna is present that is characteristic of the *Canoptum merum* Zone.

#### 3.6.1.2 Worldwide correlation using radiolarians

A similar radiolarian fauna has been recognized in Japan (Hori 1992) and faunal correlation across the T-J boundary on a global scale has been established (Carter and Hori 2005). Other faunas of Rhaetian and/or Hettangian/Sinemurian age are recognized in Austria (Gawlik *et al.* 2001), Baja California (Whalen *et al.* 1998), Italy (Bertinelli *et al.* 2004), Nevada (Orchard *et al.* 2007), New Zealand (Spörli and Aita 1988; Hori *et al.* 1996), Peru (Carter 1993; Suzuki *et al.* 2002), Turkey (Tekin 1999, 2002a, b), the Philippines (Yeh 1992; Yeh and Cheng 1996, 1998) and Far East Asia, including Russia (Bragin 1991), China (Yang and Mizutani 1991; Yeh and

Yang 2006) and Japan (e.g., Yao *et al.* 1980; Kishida and Hisada 1985; Igo and Nishimura 1984; Sato *et al.* 1986; Sugiyama 1997; etc.). Studies are ongoing in several of these localities and although the precise boundary interval is missing in all but Japan thus far, published data fully support observations on faunal extinction and recovery around the T-J boundary.

### **3.7 Radioisotopic Dating**

The Kunga Island section has provided a U-Pb date for the T-J boundary of  $199.6 \pm 0.3$  Ma from 3.6 m below the boundary (Pálffy *et al.* 2000), and work is underway to refine its accuracy and precision. A slight increase in age is expected (Pálffy and Mundil 2006). There is also considerable potential to obtain more geochronologic data from the upper Rhaetian and lower to middle Hettangian.

### **3.8 Magnetostratigraphy and Carbon Isotope Stratigraphy**

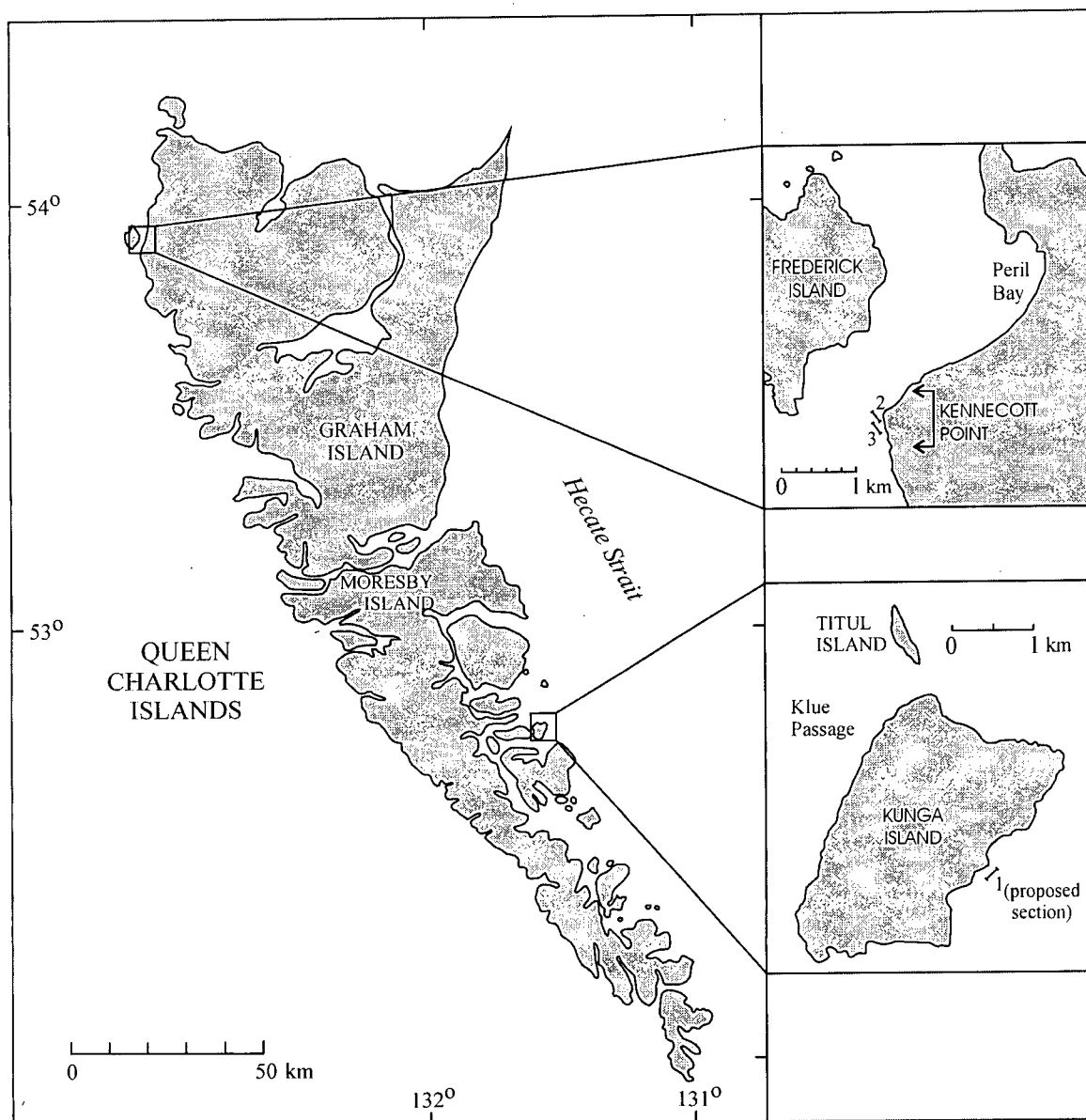
Magnetostratigraphy was attempted on the Kunga Island section but the samples were remagnetized (Carter and Galbrun 1990; Galbrun pers. comm. to Carter 1990). The section has been affected by low grade metamorphism and has a conodont alteration index of 4.5-5.0 (Orchard and Forster 1991). The diagenetic alteration of the section means it is not possible to obtain a useful carbon curve (Ward *et al.* 2001). However, a section at Kennecott Point in the northwest QCI (Fig. 3.1, section 2) is much less metamorphosed (Orchard and Forster 1991; Haggart *et al.* 2001, 2002) and has produced a carbon isotope curve showing a distinct and prolonged negative excursion of  $\sim 2$  per mil spanning the T-J boundary (Fig. 3.7; Ward *et al.* 2001, 2004; Williford *et al.* 2007). This section is readily correlated with the Kunga Island section using radiolarian and ammonite faunas common to both sections.

### 3.9 The Base of the Jurassic System at Kunga Island

If the T-J boundary is defined using radiolarians as the primary standard, the Kunga Island section is an excellent candidate GSSP for the base of the Jurassic System. The radiolarian fauna that crosses the T-J boundary in the QCI is the most diverse and well documented of this age in the world. The close correlation of the T-J boundary radiolarian faunas with those in the Inuyama area of Japan demonstrates the global distribution of the radiolarians and their utility as index fossils. Radiolarian preservation is excellent and the rapid stratigraphic turnover, continuous deposition and lack of facies changes make the Kunga Island section an exceptional GSSP candidate. The section has already provided a date to constrain the T-J boundary and has significant potential for further refining the geochronologic time scale for the Late Triassic and Hettangian. The ammonoid fauna from the section permits approximate correlation with early Hettangian ammonite sequences elsewhere (Longridge *et al.* 2007). Although ammonites conclusively restricted to the Spelae Zone have not been found, *Psiloceras* cf. *planocostatum* and *Choristoceras* aff. *minutum* can be used to correlate the lower part of the Hettangian portion of the section with the Minutum and Pacificum zones. *Transipsiloceras* cf. *transiens* and *Psiloceras* cf. *polymorphum* permit correlation of the upper portion of the section with the Polymorphum Zone. Correlations are also possible using Triassic and Jurassic ammonite faunas from sections at Kennecott Point (Fig. 3.1, sections 2 and 3; Longridge *et al.* 2007, sections I and II) where there is a well documented carbon isotope curve showing a negative anomaly that can be used for global correlation (Fig. 3.7; Ward *et al.* 2001, 2004; Williford *et al.* 2007).

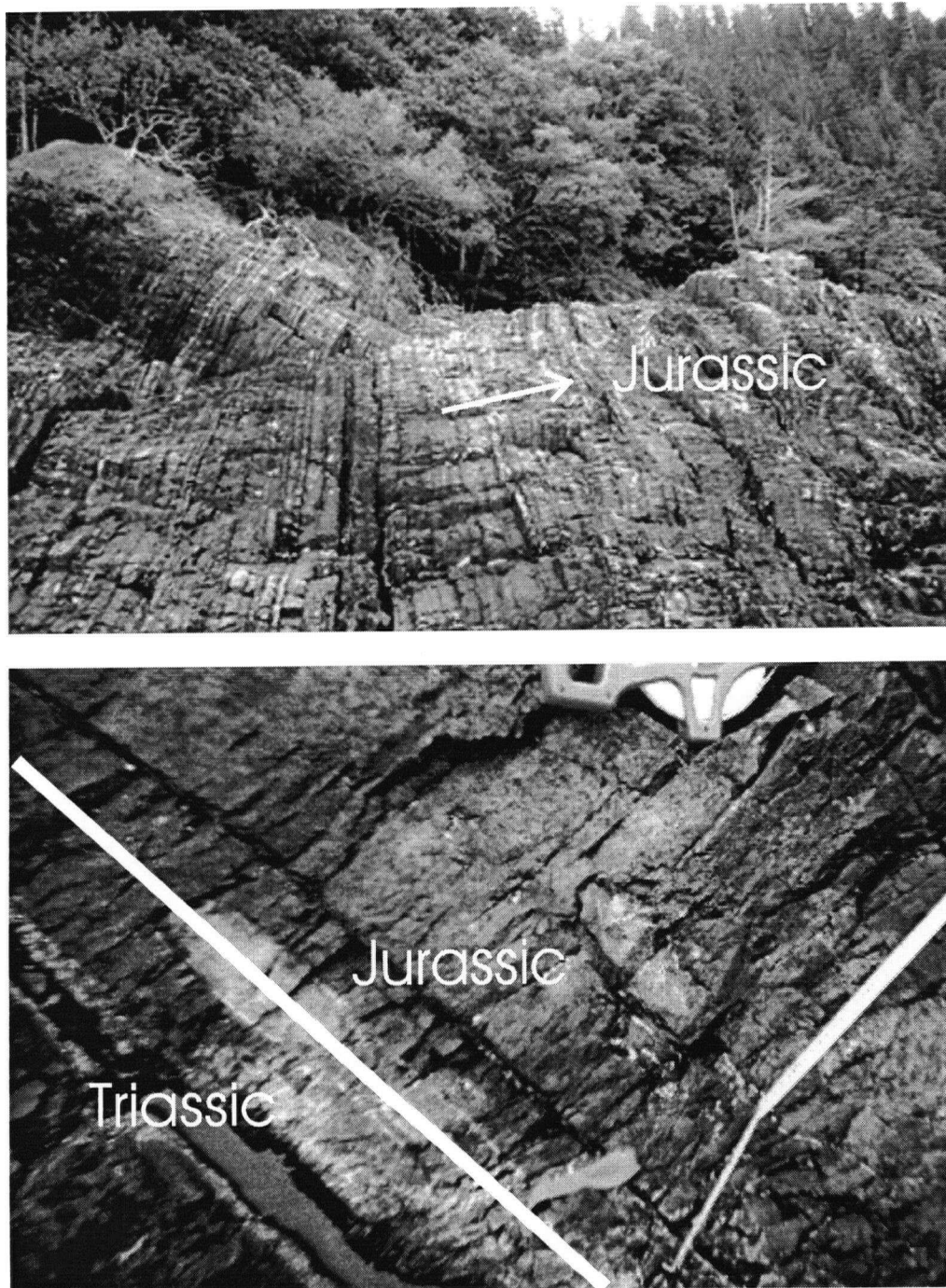
The exceptional quality and relatively sharp transition of the radiolarian fauna across the T-J boundary as well as the potential for radiometric dating in the Late Triassic and throughout the early and middle Hettangian make the Kunga Island section unique. Thus, we feel that if radiolarians are not used to define the T-J boundary, the Kunga Island section should be

designated as a parastratotype section. This will further characterize the interval and increase its correlation potential, improving the probability of it being recognized elsewhere. The ammonite faunas from the Kunga Island section as well as the negative carbon curve excursion at Kennecott Point permit correlation with several other T-J boundary GSSP candidates. For example, we have previously published information proposing that the North American Jurassic stratotype proposals be combined such that the Ferguson Hill section in Nevada is the GSSP (Taylor *et al.* 1983; Guex *et al.* 1997, 2006; Lucas *et al.* 2007, in press) and the Kunga Island section is a parastratotype (Longridge *et al.* 2006b, 2007; Lucas *et al.* 2007, in press). The current level of the T-J boundary in the Kunga Island section as indicated in Figure 3.3 is based exclusively on the radiolarian faunas. If the Kunga Island section is designated as a parastratotype rather than a GSSP, the level of the boundary would have to be adjusted to align it with whatever primary standard is used in the GSSP.

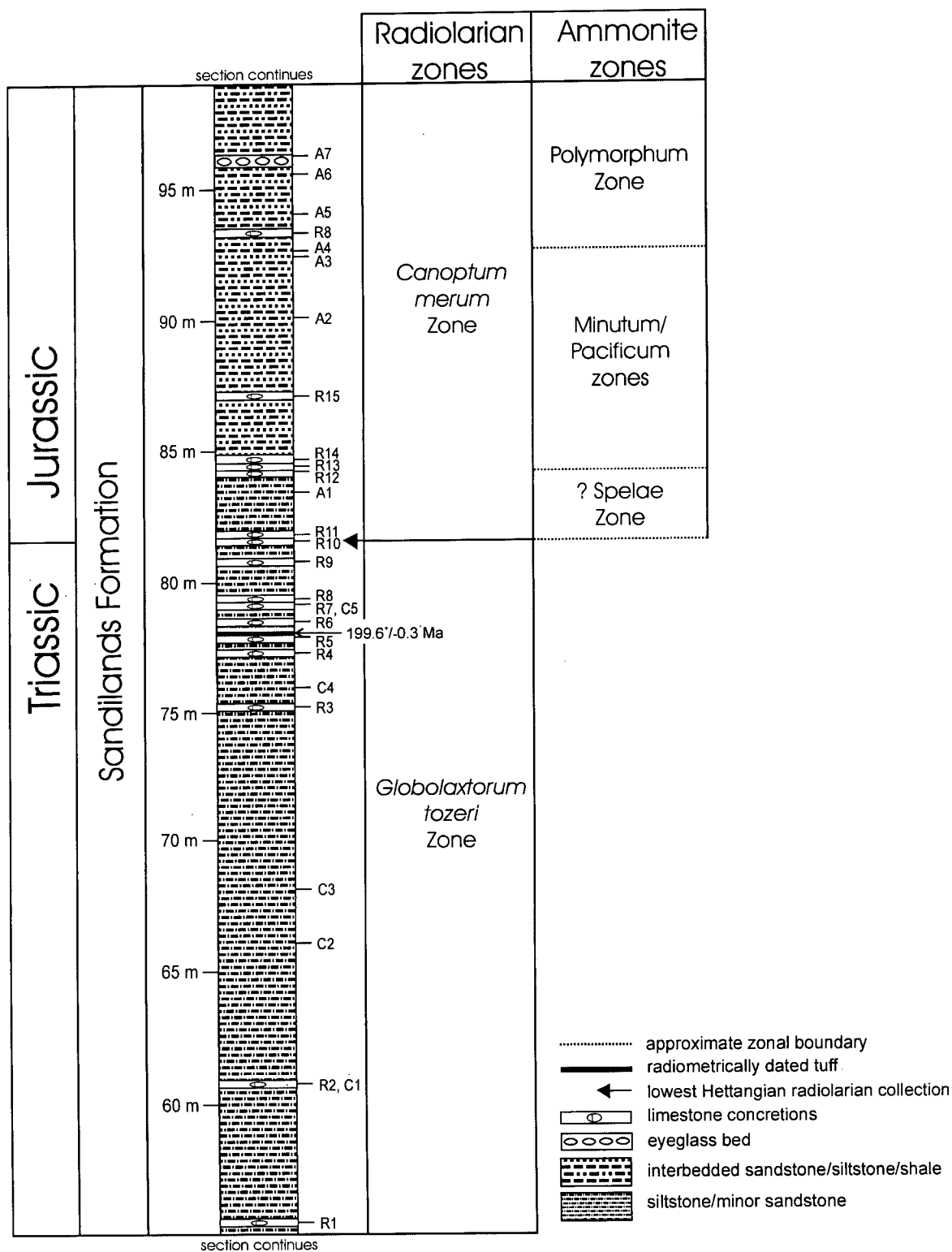


**Figure 3.1.** Localities of sections bearing latest Triassic and early Hettangian ammonite and radiolarian faunas in the Queen Charlotte Islands.





**Figure 3.2.** Proposed stratotype section on Kunga Island. View to NE. Adopted from Smith (1998, p. 188, fig. 4.32), photo E. Carter. The inserted arrow indicates the boundary level but not exactly the stratotype point.



**Figure 3.3.** Proposed Kunga Island section showing upper Rhaetian and lower Hettangian radiolarian, upper Rhaetian conodont and lower Hettangian ammonite localities; R = radiolarians, C = conodonts, A = ammonites. (Modified after Haggart *et al.* 2002 and Longridge *et al.* 2007).

Radiolarian species	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	R 13	R 14	R 15	R 16
<i>Betraccium inornatum</i> Blome	X															
<i>Betraccium</i> sp. C sensu Carter 1993	X															
<i>Canoptum</i> sp. A sensu Carter 1993	X															
<i>Plafkerium fidicularium</i> Carter	X															
<i>Plafkerium</i> sp. A sensu Carter 1993	X															
<i>Praecitriduma apexensis</i> Carter	X															
<i>Nabolella</i> aff. <i>desrochersi</i> (Carter)	X															
<i>Entactinosphaera?</i> <i>amphilapes</i> Carter	X	X														
<i>Nabolella causia</i> (Carter)	X	X														
<i>Nabolella</i> aff. <i>causia</i> (Carter)	X	X														
<i>Nabolella desrochersi</i> (Carter)	X	X														
<i>Betraccium</i> aff. <i>inornatum</i> Blome	X	X														
<i>Ferresium</i> sp. C sensu Carter 1993	X	X														
<i>Plafkerium</i> sp. B sensu Carter 1993	<	X														
<i>Citriduma</i> sp. C sensu Carter 1993	X	X	X													
<i>Triassocrucella</i> aff. <i>triassicum</i> Kozur & Mostler	<			X												
<i>Globolaxtorum cristatum</i> Carter	X	X				X										
<i>Amuria</i> sp. A sensu (Carter 1993)	<	X					X									
<i>Haekelicyrtium karcharos</i> Carter	<	X					X									
<i>Citriduma asteroides</i> Carter	X	X	X		X			X								
<i>Plafkerium keloense</i> Carter	X	X				X	X	X								
<i>Spumellaria</i> gen. et sp. indet. C sensu Carter 1993	<								X							
<i>Veghicyclia austriaca</i> Kozur & Mostler	X	X					X		X							
<i>Amuria</i> sp. B sensu (Carter 1993)	X	X					X	X	X							
<i>Betraccium kennecottense</i> Carter	X	X			X	X	X	X	X							
<i>Betraccium nodulum</i> Carter	X	X			X	X	X	X	X							
<i>Betraccium</i> sp. E sensu Carter 1993	X	X	X		X		X	X	X							
<i>Bipedis acrostylus</i> Bragin	<	X					X		X							
<i>Bistarkum cylindratum</i> Carter	X	X	X	X	X	X	X	X	X							
<i>Canoptum</i> aff. <i>dixonii</i> Pessagno & Whalen	X	X				X	X	X	X							
<i>Canoptum triassicum</i> Yao	X	X		X		X	X	X	X							
<i>Canoptum</i> aff. <i>unicum</i> Pessagno & Whalen	<		X	X		X	X	X	X							
<i>Canoptum</i> sp. B sensu Carter 1993	X	X			X	X	X	X	X							
<i>Cantalum gratum</i> Carter	X	X	X		X		X	X	X							
<i>Cantalum</i> sp. A sensu Carter 1993	<						X	X	X							
<i>Canutus?</i> <i>beehivensis</i> Carter	X	X	X			X	X	X	X							
<i>Crucella?</i> sp. A sensu Carter 1993	X	X	X		X	X	X	X	X							
<i>Deflandrecyrtium nobense</i> Carter	X	X		X	X	X	X	X	X							
<i>Deflandrecyrtium ithacanthum</i> (Sugiyama)	<						X	X	X							
<i>Entactinosphaera?</i> aff. <i>simoni</i> Kozur & Mostler	X	X				X	X	X	X							
<i>Entactinosphaera?</i> <i>spinulata</i> Carter	<	X	X		X		X	X	X							
Eucyrtid gen. et sp. indet sensu Carter 1993	<	X	X	X	X		X	X	X							
<i>Ferresium teekwoonense</i> Carter	X	X	X			X	X	X	X							
<i>Fontinella clara</i> Carter	X	X			X		X	X	X							
<i>Fontinella louisensis</i> Carter	X	X							X							
<i>Globolaxtorum tozeri</i> Carter	X	X	X	X	X	X	X	X	X							
<i>Haliomma swellensis</i> Carter	X	X				X	X	X	X							
<i>Icrioma?</i> sp. A sensu Carter 1993	X	X	X			X	X	X	X							

Radiolarian species	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	R 13	R 14	R 15	R 16
<i>Pseudoheliodiscus</i> aff. <i>sandspitensis</i> (Blome)	<				X		X	X	X							
<i>Laxtorum capitaneum</i> Carter	X	X	X			X	X	X	X							
<i>Laxtorum perfectum</i> Carter	X	X		X		X	X	X	X							
<i>Laxtorum porterheadense</i> Carter	X	X	X			X	X	X	X							
<i>Liassosaturnalis</i> aff. <i>parvis</i> Kozur & Mostler	X	X					X	X	X							
<i>Livarella densiporata</i> Kozur & Mostler	X	X		X			X		X							
<i>Loupanus thompsoni</i> Carter	X	X	X		X	X	X	X	X							
<i>Orbiculiformella multibrachiata</i> (Carter)	X	X			X	X	X	X	X							
<i>Pantanellium newkluense</i> Carter	X		X		X		X	X	X							
<i>Paronaella beatricia</i> Carter	<		X	X	X	X	X	X	X							
<i>Paratriassostrum crassum</i> Carter	X	X			X		X	X	X							
<i>Paratriassostrum omegaense</i> Carter	<	X	X	X	X	X	X	X	X							
<i>Paratriassostrum</i> sp. A sensu Carter 1993	X	X	X		X	X	X	X	X							
<i>Paratriassostrum</i> sp. B sensu Carter 1993	<		X	X	X	X	X	X	X							
<i>Pentactinocarpus</i> cf. <i>sevaticus</i> Kozur & Mostler	<	X				X	X	X	X							
<i>Octostella dihexacanthus</i> (Carter)	X	X				X	X	X	X							
<i>Plafkerium gadoense</i> Carter	X	X	X			X	X	X	X							
<i>Praecitriduma canthofistula</i> Carter	<							X	X							
<i>Pseudacanthocircus trogeri</i> Kozur & Mostler	X	X	X	X	X	X	X	X	X							
<i>Serilla conchusum</i> (Carter)	X	X				X	X	X	X							
<i>Serilla ellisensis</i> (Carter)	X	X				X	X	X	X							
<i>Serilla stalkungiensis</i> (Carter)	X	X				X		X	X							
<i>Serilla tangilensis</i> (Carter)	X	X				X			X							
<i>Serilla tledoensis</i> (Carter)	X	X				X	X	X	X							
<i>Serilla</i> sp. A sensu (Carter 1993)	X	X				X	X	X	X							
<i>Nabolella</i> sp. C sensu (Carter 1993)	X	X		X					X							
<i>Spumellaria</i> gen. et sp. indet. E sensu Carter 1993	<	X				X	X	X	X							
<i>Spumellaria</i> gen. et sp. indet. D sensu Carter 1993	X	X	X		X	X	X	X	X							
<i>Livarella valida</i> Yoshida	<			X			X	X	X	X						
<i>Livarella</i> spp.	X	X	X	X	X	X	X	X	X	X	X					
<i>Eptingium onesimos</i> Carter	<	X	X		X	X	X	X	X		X					
<i>Kungalaria newcombi</i> Dumitrica & Carter	X	X				X	X	X	X		X					
<i>Paratriassostrum</i> spp.	X	X	X	X	X	X	X	X	X	X	X					
<i>Pseudohagiastrum</i> spp.	X	X	X	X	X	X	X	X	X	X	X					
<i>Deflandrecyrtium</i> sp. B sensu Carter 1993	<						X		X			X				
<i>Fontinella habros</i> Carter	X	X	X		X		X	X	X			X				
<i>Fontinella inflata</i> Carter	X	X				X	X	X	X			X				
<i>Pseudoheliodiscus</i> sp. B sensu (Carter 1993)	<						X		X			X				
<i>Spumellaria</i> gen. et sp. indet. B sensu Carter 1993	X	X		X	X	X	X	X	X			X				
<i>Mesosaturnalis acuminatus</i> Carter				X	X	X	X	X	X			X				
<i>Pseudohagiastrum giganteum</i> Carter & Hori					X		X	X	X							
<i>Serilla</i> sp. B sensu (Carter & Guex 1999)						X	X	X	X							
<i>Globolaxtorum</i> sp. A sensu Carter 1993							X	X	X	X						
<i>Stauracanthocircus transitus</i> Kozur & Mostler							X		X			X				>
<i>Spumellaria</i> indet X (Carter in Longridge et al. 2007)							X	X	X	X		X	X	X		>
<i>Tipperella kennecottensis</i> Carter									X	X	X	X	X	X	X	X
Indet. spherical forms										X	X	X	X	X	X	X
<i>Udalia primaeva</i> Whalen & Carter										?	X	X	X	X	X	X

Radiolarian species	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	R 13	R 14	R 15	R 16
<i>Udalia</i> spp.										X	X	X	X	X	X	X
<i>Tozerium nascens</i> Whalen & Carter										?		X	X	X	X	X
Gen. et sp. indet. A sensu Whalen & Carter 1998										?		X	X	X	X	X
<i>Charlottea</i> spp.											?	X	X	X	X	>
<i>Droltus hecatensis</i> Pessagno & Whalen											X	X	?	X		X
<i>Thurstonia</i> spp.												?	X	X	X	X
<i>Atalanta epaphrodita</i> Cordey & Carter												X				>
<i>Archaeocenosphaera laseekensis</i> Pessagno & Yang												X	X	X	X	>
<i>Bipedis elizabethae</i> Whalen & Carter												X		X		>
<i>Laxtorum</i> sp. B sensu Whalen & Carter 1998												X		X		>
<i>Pantanellium tanuense</i> Pessagno & Blome												X	X	X	X	X
<i>Parahsuum</i> spp.												X	X	X		X
<i>Paronaella ravenensis</i> Whalen & Carter												X	X	X		X
<i>Præhexasaturnalis tetra radiatus</i> Kozur & Mostler												X		X		>
<i>Relanus reefensis</i> Pessagno & Whalen												X	X	X	X	X
<i>Spumellaria</i> indet B sensu Carter 1994												X	X	X	X	X
<i>Canoptum merum</i> Pessagno & Whalen												?		X		>
<i>Amuria impensa</i> Whalen & Carter														X	X	>

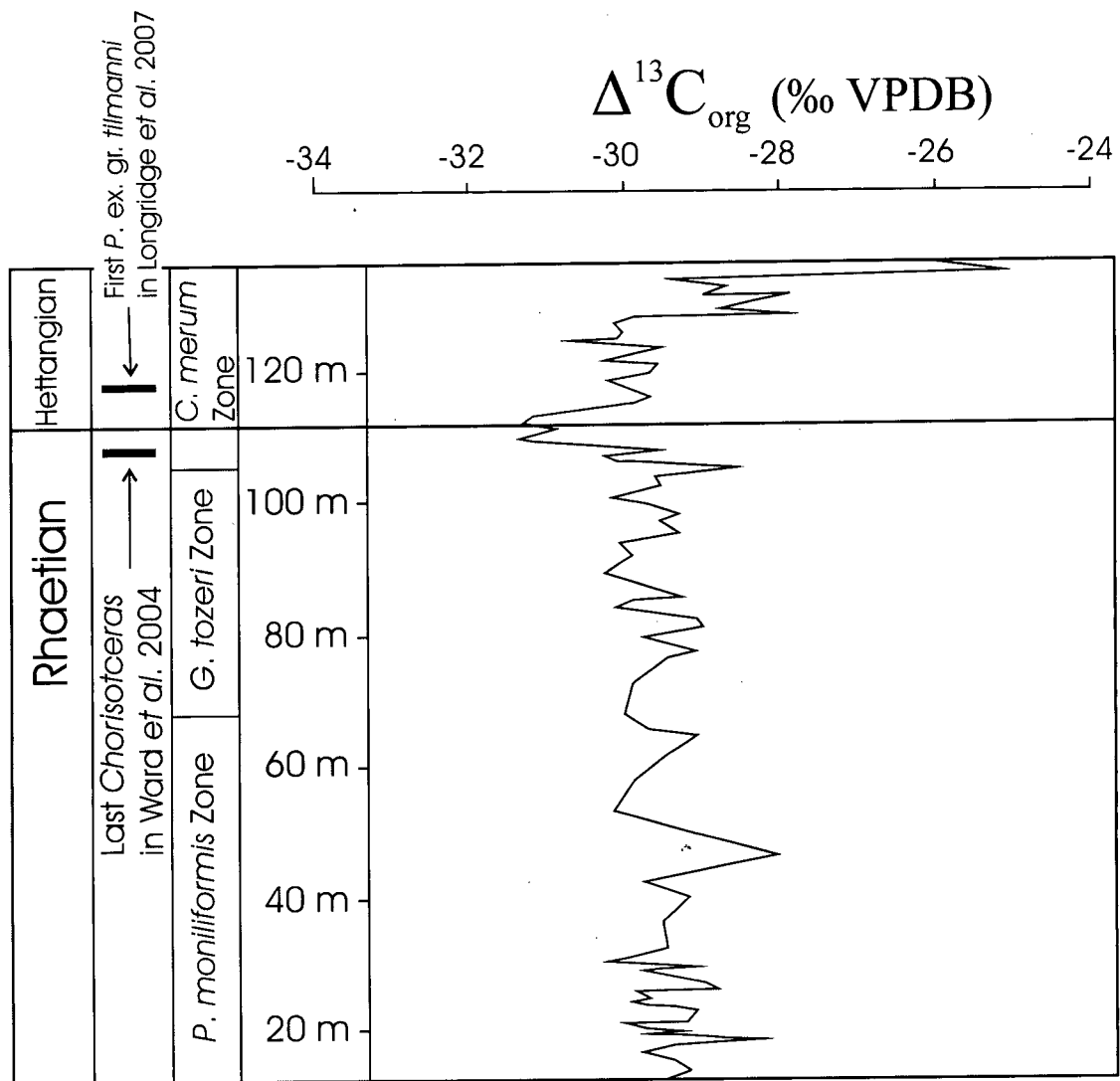
**Figure 3.4.** Latest Rhaetian and early Hettangian radiolarians from the proposed section at Kunga Island, Queen Charlotte Islands; < indicates range extends lower, > indicates range extends higher.

Conodont species	C1	C2	C3	C4	C5
Undifferentiated <i>Epigondolella</i>	X				
<i>Epigondolella</i> sp.		X			
Ramiform elements		X		X	X
<i>Epigondolella</i> ex. gr. <i>bidentata</i>			X		
<i>Parvigondolella</i> sp.			X		
<i>Neogondolella</i> sp.					X

**Figure 3.5.** Latest Rhaetian conodonts from the proposed section at Kunga Island, Queen Charlotte Islands.

Ammonite species	A 1	A 2	A 3	A 4	A 5	A 6	A 7
<i>Choristoceras</i> aff. <i>minutum</i>		X	X				
<i>Odoghertyceras</i> cf. <i>deweveri</i>							
<i>Neophyllites</i> (?) sp.							
Psiloceratid indet.	X						
<i>Psiloceras</i> ex. gr. <i>tilmanni</i>					X		X
<i>Psiloceras</i> cf. <i>marcouxi</i>							
<i>Psiloceras</i> cf. <i>planocostatum</i>		X					
<i>Psiloceras</i> cf. <i>polymorphum</i>						X	X
<i>Nevadaphyllites</i> (?) sp.							
<i>Transipsiloceras</i> cf. <i>transiens</i>				X			

**Figure 3.6.** Early Hettangian ammonites from the proposed section at Kunga Island, Queen Charlotte Islands.



**Figure 3.7.**  $\delta^{13}\text{C}_{\text{org}}$  record for Rhaetian to Lower Hettangian strata at Kennecott Point, Queen Charlotte Islands, British Columbia. Modified from Williford *et al.* (2007).



**Plate 3.1.** Scanning electron micrographs of diagnostic Triassic-Jurassic boundary Radiolaria from the Sandilands Formation, Queen Charlotte Islands. Figures 1-11 are upper Rhaetian; length of scale bar at top of page = number of micrometers ( $\mu\text{m}$ ) cited for each illustration. Figures 12-20 are lower Hettangian; length of scale bar at base of plate = 100  $\mu\text{m}$  for all specimens illustrated.

Figure 1. *Globolaxtorum tozeri* Carter. GSC 85927 from GSC loc. C-140489, Kennecott Point; scale bar = 100 $\mu\text{m}$ .

Figure 2. *Risella* sp. D sensu Carter and Guex 1999. GSC 107645 from R-1, GSC loc. C-173287, Kunga Island; scale bar = 100 $\mu\text{m}$ .

Figure 3. *Mesosaturnalis acuminatus* Carter. GSC 101908 from R-1, GSC loc. C-173287, Kunga Island; scale bar = 158 $\mu\text{m}$ .

Figure 4. *Bipedis acrostylus* Bragin. GSC 85921 from GSC loc. C-127798, Louise Island; scale bar = 81 $\mu\text{m}$ .

Figure 5. *Betraccium kennecottense* Carter. GSC 85911 from GSC loc. C-164674, Kennecott Point; scale bar = 80 $\mu\text{m}$ .

Figure 6. *Livarella densiporata* Kozur and Mostler. GSC 85912 from GSC loc. C-164674, Kennecott Point; scale bar = 100 $\mu\text{m}$ .

Figure 7. *Nbolella causia* (Carter). GSC 85929 from GSC loc. C-164674, Kunga Island; scale bar = 100 $\mu\text{m}$ .

Figure 8. *Citriduma asteroides* Carter. GSC 85930 from GSC loc. C-164674, Kunga Island; scale bar = 100 $\mu\text{m}$ .

Figure 9. *Canoptum triassicum* Yao. GSC 102083 from GSC loc. C-164693/13, Kunga Island; scale bar = 100 $\mu\text{m}$ .

Figure 10. *Laxtorum capitaneum* Carter. GSC 107648 from R-8, GSC loc. C-173280, Kunga Island; scale bar = 100 $\mu\text{m}$ .

Figure 11. *Canoptum* sp. aff. *C. unicum* Pessagno and Whalen. GSC 85933 from GSC loc. C-140489, Kennecott Point; scale bar = 100 $\mu\text{m}$ .

Figure 12. *Canoptum merum* Pessagno and Whalen. GSC 99425 from GSC loc. C-140496, Kennecott Point.

Figure 13. *Spumellaria* indet. B sensu Carter 1994. GSC 99423 from R2, GSC loc. C-173357, Kunga Island.

Figure 14. *Tozerium nascens* Whalen and Carter. GSC 99424 from GSC loc. C-173332, Kunga Island.

Figure 15. *Archaeocenosphaera laseekensis* Pessagno and Yang. GSC 99426 from R2, GSC loc. C-173357, Kunga Island.

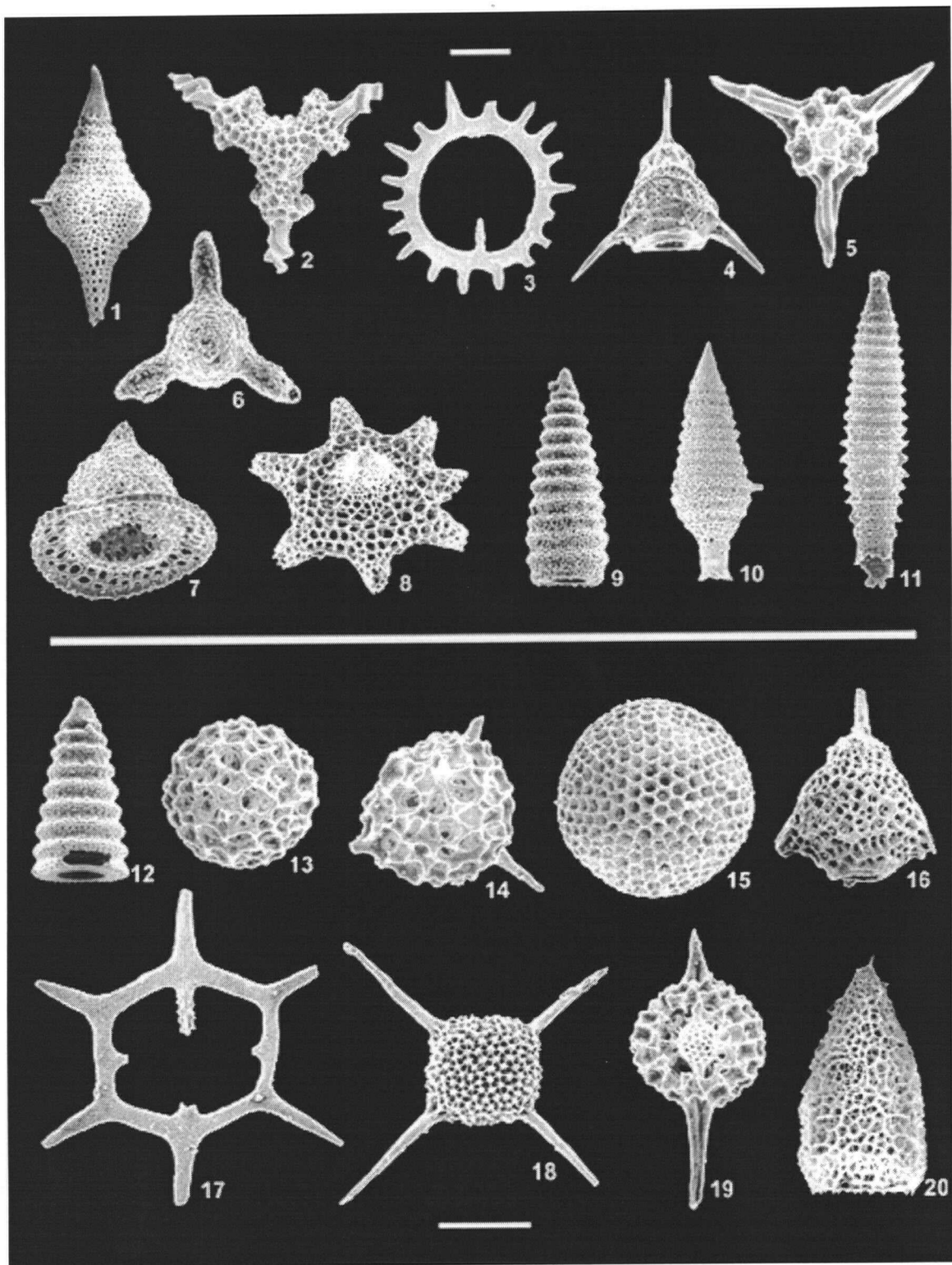
Figure 16. *Bipedis elizabethae* Whalen and Carter. GSC 99433 from GSC loc. C-173332, Kunga Island.

Figure 17. *Praehexasaturnalis tetraradiatus* Kozur and Mostler. GSC 99439 from GSC loc. C-173332, Kunga Island.

Figure 18. *Udalia primaeva* Whalen and Carter. GSC 107742 from GSC loc. C-173332, Kunga Island.

Figure 19. *Pantanellium tanuense* Pessagno and Blome. GSC 129052 from R4, GSC loc. 173285, Kunga Island.

Figure 20. *Droltus hecatensis* Pessagno and Whalen. GSC 99434 from R2, GSC loc. C-173357, Kunga Island.



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### **Update on proposed definition of T-J boundary discussed in Chapters 2 and 3 (September 2007)**

Since Chapter 2 was completed in 2006 and Chapter 3 was completed in May, 2007, a new GSSP proposal has been put forward for the basal Hettangian (McRoberts *et al.* 2007). In this candidate, the T-J boundary is placed at the peak of the first negative carbon isotope excursion in the Ferguson Hill section in Nevada. I feel that this is the optimal solution for the definition of the T-J boundary. This isotopic event is a short-lived and widely correlatable event that is associated with two potential biostratigraphic markers, the incoming of the bivalve *Agerchlamys boellingi* and the incoming of ammonites of the *Psiloceras tilmanni* group (1.6 m and 2.6 m above the event respectfully)(McRoberts *et al.* 2007 and references therein).

A mixed interval of Triassic-Jurassic type faunas follows the first peak in the carbon isotope curve in the QCI and Nevada (e.g., Longridge *et al.* 2007a; Williford *et al.* 2007; McRoberts *et al.* 2007; Guex 1995) and also possibly in China (Yin *et al.* 2006, 2007). *Choristoceras* is a well recognized Triassic ammonite genus that also occurs with basal Hettangian type ammonite faunas in the QCI, Nevada and China (e.g., Guex 1995; Longridge 2007a; Yin *et al.* 2007) whereas Triassic radiolarian faunas persist with basal Hettangian type

radiolarian faunas in the QCI and Peru (Longridge *et al.* 2007a; Hillebrandt *et al.* 2007).

Defining the T-J boundary at the negative peak in the carbon isotope curve places these mixed radiolarian and ammonite faunas in the basal Jurassic and permits them to be useful as characterizing taxa to assist with recognizing the basal Hettangian elsewhere.

In addition to the GSSP in Nevada, I feel the Kunga Island section should be designated a parastratotype section for the basal Hettangian to assist with characterizing the T-J interval (as proposed in Longridge *et al.* 2007a, b). This section has provided geochronometry from the uppermost Triassic (Pálffy *et al.* 2000; Pálffy and Mundil 2006). Furthermore, the striking radiolarian turnover would be of great value as an additional biostratigraphic marker across the T-J boundary interval. Radiolarians are characteristic of a somewhat more offshore facies than is typical for the mollusks. They stand in marked contrast to the ammonites in that they are abundant, diverse, and well preserved across the T-J interval and recover quickly following the extinction event. Close correlations between the Ferguson Hill section and the QCI are possible using the negative excursion in the carbon curve from Kennecott Point (Williford *et al.* 2007; Longridge *et al.* 2007a, b; and references therein). Approximate correlations are also possible using the early Hettangian ammonites found at both localities (e.g., Guex 1980, 1995; Guex *et al.* 1998, 2002; Longridge *et al.* 2007a).

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# 4 MIDDLE AND LATE HETTANGIAN (EARLY JURASSIC) AMMONITES FROM THE QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA, CANADA<sup>1</sup>

## 4.1 Introduction

The Queen Charlotte Islands (QCI) (Fig. 4.1) contain the most complete record of Hettangian ammonite faunas in Canada. Preliminary lists of the main taxa present were given by Tipper and Carter (1990), Tipper and Guex (1994), Tipper *et al.* (1994) and Carter *et al.* (1998). More detailed taxonomic studies were completed by Longridge *et al.* (2007) on the early Hettangian faunas and by Pálffy (1991) on the uppermost Hettangian faunas of the Rursicostatum Zone [Fig. 4.2; Rursicostatum Subzone of Taylor *et al.* (2001); Longridge *et al.* (2006)]. The latter study was part of Pálffy's unpublished Master's thesis and only a biostratigraphic summary is in print (Pálffy *et al.* 1994). This study is the first detailed account of the middle and late Hettangian faunas from the QCI.

In general, North American Early Jurassic ammonites are of Tethyan affinity or endemic to the eastern Pacific, and for this reason a separate zonation for the Hettangian and Sinemurian of the Western Cordillera of North America has been established by Taylor *et al.* (2001). However, little Canadian information was included when the zonation was established. Since then, Longridge *et al.* (2006) made significant changes to the upper Hettangian and lower Sinemurian zones based on a detailed study of the *Badouxia* fauna from Taseko Lakes (Fig. 4.2). Further updating of the zonation was done by Longridge *et al.* (in press *a*) based on additional taxonomic studies of the latest Hettangian faunas from Taseko Lakes (Longridge *et al.* in press

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<sup>1</sup> A version of this chapter will be submitted for publication. Longridge, L.M., Pálffy, J., Smith, P.L. and Tipper, H.W. Middle and late Hettangian (Early Jurassic) ammonites from the Queen Charlotte Islands, British Columbia, Canada. *Revue de Paléobiologie*.

*a, b*). Details of the diverse ammonite fauna described here will further increase the precision of the North American Zonation for the middle and upper Hettangian (Fig. 4.2).

In the QCI, sections often contain volcanic tuffs interbedded with fossiliferous rock, providing the opportunity to calibrate radiometric dates with the ammonite succession at the zonal level. A tuff bed from the latest Triassic at Kunga Island has already provided a U-Pb date of  $199.6 \pm 0.3$  Ma (Pálffy *et al.* 2000) which is currently used to approximate the age of the base of the Jurassic (e.g. Gradstein *et al.* 2004). Work is underway by Pálffy and others to date several middle Hettangian tuffs taken from some of the sections discussed below. Consequently, a detailed knowledge of the ammonite successions from the QCI has added importance in order to improve the correlation potential of these dates with sections in other areas.

Finally, the QCI fauna can improve Hettangian correlations within North America as well as between North America and the rest of the world. Ammonite endemism and provincialism are widespread in the Hettangian making correlation difficult. The QCI fauna helps to address these problems because it contains many taxa with affinities to other areas. This paper highlights correlations between the middle and late Hettangian fauna in the QCI and contemporaneous faunas in other areas of North America, South America, New Zealand, western and eastern Tethys, and northwest Europe.

## 4.2 Geological Setting

The QCI are located on the western margin of the Canadian Cordillera (Fig. 4.1). The fauna described herein is found within the Sandilands Formation of the Kunga Group. The Sandilands Formation, established by Cameron and Tipper (1985) [black limestone member of the Kunga Formation of Sutherland Brown (1968)], is several hundred meters thick and ranges in age from early Rhaetian to mostly the latest Sinemurian, although its upper contact is diachronous and locally the unit is as young as earliest Pliensbachian (Tipper and Carter 1990; Tipper *et al.* 1991,

1994; Smith and Tipper 1996). It is typically composed of thinly bedded dark shale and dark grey or blue siltstone. Fine to medium grained sandstone, tuffaceous beds and limestone beds, lenses and concretions are common. Cameron and Tipper (1985) suggested that much of the Sandilands Formation was deposited in a relatively deep back-arc basin somewhat distant from a source of fine volcanic detritus which is present in distal turbidites and less common air-fall tuffs (Pálffy *et al.* 1990; Tipper and Guex 1994). However, the precise paleogeographic setting of the Late Triassic-Early Jurassic strata of the Wrangellia terrane is poorly constrained at present and more recent work suggests that the Rhaetian/Hettangian parts of the Sandilands Formation were deposited in an outer shelf to upper slope setting (Haggart *et al.* 2001, 2002). *In situ* ammonite specimens from the Mulleri to Rursicostatum zones were collected from the nine sections described below.

#### **4.2.1 Stratigraphic sections**

Stratigraphic sections exist in two principal areas (Fig. 4.1):

Kennecott Point includes sections A to G, yielding middle and late Hettangian ammonites. All sections are exposed at low tide on a wave-cut platform. Section A and the lower portion of section B contain material from the Mulleri and Occidentalis zones. The upper portion of section B contains material from the Coronoides to Sunrisensis zones whereas section C contains material from the Sunrisensis Zone. Section D contains material from the Sunrisensis and Morganense zones and section G contains material from the Sunrisensis and Mineralense zones. Finally, sections E and F contain material from the Mineralense and Rursicostatum zones. Figures 4.3-4.7 show details of the stratigraphy and collection localities for each section. The lower portion of section KPB described by Carter *et al.* (1998) is a composite section including sections A, B, D and E. The lower portion of section D of Pálffy *et al.* (1994) is equivalent to section E of the current paper. The lower part of section F and all of section G of Pálffy *et al.* (1994) are equivalent to our sections F and G respectively.



Sections H and I are exposed in the supratidal region on the southern side of Kunga Island where beds are steeply dipping to nearly vertical. Both sections contain material from the Mulleri and Occidentalis to Coronoides zones. Figure 4.7 shows details of the stratigraphy and collection localities for each section. Section H begins near the top of section III of Longridge *et al.* (2007) (ammonite level A7 of section III is equivalent to H\* in section H) and is equivalent to the upper portion of section SKUD described by Tipper *et al.* (1994) and Carter *et al.* (1998). Section I is equivalent to the upper portion of section SKUE (Tipper *et al.* 1994; Carter *et al.* 1998). Another section on the north side of Kunga Island contains very poorly preserved late Hettangian material (lower portion of KUD in Carter *et al.* 1998). Collections from this section are not included herein as the poor preservation does not permit identification.

Figure 4.8 shows approximate correlations between sections A-I. Appendix C contains detailed data for sections A-I, including a brief geographical description of each site, latitude and longitude as well as Geological Survey of Canada (GSC) numbers for each location.

### 4.3 Systematic Paleontology

Although a few beds yield some better preserved, three-dimensional material, the common mode of preservation of ammonites in the Sandilands Formation is flattened internal moulds resulting in significant information loss, especially for ventral features and whorl section. The extensive use of open nomenclature is therefore inevitable. Figure 4.9 shows the ranges of ammonite taxa found within the Mulleri/Occidentalis to Mineralense/Rursicostatum zones in the QCI.

Abbreviations and measurements follow Smith (1986) and include shell diameter (D), umbilical diameter (UD), whorl width (WW), whorl height (WH), umbilical diameter as a ratio of shell diameter (U), ratio of the whorl width to the whorl height (WWWH) and primary ribs per half whorl (PRHW). Graphical plots of several of these parameters are shown below and

include all measurable specimens of each species collected. A record of the exact measurements of each specimen is located in Appendix D. All measured and figured specimens are deposited in the type collection of the Geological Survey of Canada in Ottawa.

**Suborder PHYLLOCERATINA Arkell, 1950**

**Superfamily PHYLLOCERATOIDEA Zittel, 1884**

**Family PHYLLOCERATIDAE Zittel, 1884**

**Genus PHYLLOCERAS Suess, 1865**

TYPE SPECIES: *Ammonites heterophyllus* Sowerby, 1820

***Phylloceras* cf. *asperaense* Hillebrandt, 2000b**

Plate 4.1, figures 2-3, 10-11; Figure 4.10A

cf. 2000b *Phylloceras asperaense* Hillebrandt, p. 140, pl. 1, figs 4-7; text-fig. 27c-e.

in press a *Phylloceras* cf. *asperaense* Hillebrandt; Longridge *et al.*, pl. 1, figs 26-27; text-figs 9B, 10B.

MATERIAL AND MEASUREMENTS: Two well preserved, three-dimensional measured specimens (GSC 129066-129067) and one incomplete specimen. Measurements of volution are presented in Figure 4.11A.

DESCRIPTION: Compressed form, evolute for genus. Whorl cross-section high oval. Umbilical wall one short arch. Flanks weakly convex with greatest width midflank. Venter broad and smooth. Flanks smooth aside from weak, prorsiradiate growth lines. Septal suture line with triphyllic first and second lateral saddles and spatular folioles (Fig. 4.10A).

REMARKS: *Phylloceras* cf. *asperaense* from the QCI is very similar to the South American material in volution and whorl shape. In addition, the suture line of the two forms is nearly identical at similar whorl height.

OCCURRENCE: Sections A and B, Mulleri/Occidentalis zones.

**Family JURAPHYLLITIDAE Arkell, 1950**

**Genus PARADASYCERAS Spath, 1923a**

TYPE SPECIES: *Phylloceras uermoesense* Herbich, 1878

Neotype figured by Rakús 1993a, p. 948, pl. 4, fig. 1.

***Paradasyceras carteri* sp. nov.**

Plate 4.1, figures 4-5, 15, 20, 25-26; Figure 4.10D

DERIVATION OF NAME: Named for Elizabeth Carter for her extensive contribution to our understanding of Triassic and Jurassic radiolarian faunas in the QCI.

MATERIAL AND MEASUREMENTS: Eleven measured specimens (GSC 129070-129080) and many incomplete or distorted specimens or fragments (GSC 129068-129069, 129102).

Preservation varies from moderate to very good with many three-dimensional specimens.

Measurements of volution are presented in Figure 4.11A.

HOLOTYPE: GSC 129068 (Pl. 4.1, fig. 20) from the Mulleri and Occidentalis zones, Kennecott Point, section A, level 04, QCI.

PARATYPES: GSC 129069-129080, 129102 from the Mulleri and Occidentalis zones, Kennecott Point sections A and B, QCI.

DIAGNOSIS: Involute form. Whorl cross-section elliptical. Flanks parallel. Prorsiradiate growth lines on inner whorls. Body chamber with strong, concave to prorsiradiate flank ribs that continue across venter in forward-directed chevron.

DESCRIPTION: Compressed form, involute for genus. On inner whorls, umbilical wall upright, umbilical shoulder distinct but rounded. Whorl cross-section elliptical. Flanks parallel to weakly trapezoidal flanks. Widest point of whorl upper flank. Venter broad and rounded. Flanks smooth except straight to weakly sigmoid prorsiradiate growth lines visible on best-preserved material. Body chamber whorl cross-section compressed. Strong rectiradiate to prorsiradiate flank ribs weakest on lower flank, strongest on upper flank. Strong ribs continue across venter forming forward-directed chevron. Suture line not preserved.

REMARKS: *Paradasyceras carteri* has significantly more involute inner whorls than other species of *Paradasyceras* and lacks the sharp umbilical angle that helps characterize the type species. It is referred to *Paradasyceras* principally because of similarities in body chamber ornament to *P. bonifacii* (Wähner, 1898) and *P. bonifaciformis* Guex, 1995 and also resembles established species of the genus in whorl cross-section.

The inner whorls of *P. carteri* resemble some species of *Phylloceras* at similar shell diameters but differ in having parallel flanks and a more upright umbilical wall. The inner whorls of *P. carteri* are difficult to distinguish from poorly preserved *Fergusonites striatus* that lack ornament. The former usually have flatter flanks, lack constrictions and are more involute by 30 mm shell diameter.

OCCURRENCE: Sections A and B, Mulleri/Occidentalis zones.

### **Genus FERGUSONITES Guex, 1980**

TYPE SPECIES: *Fergusonites striatus* Guex, 1980

***Fergusonites striatus* Guex, 1980**

Plate 4.1, figures 6-8, 21; Figure 4.10C

1980 *Fergusonites striatus* Guex, p. 132, pl. 1, fig. 1.

1995 *Fergusonites striatus* Guex, p. 15, pl. 2, figs 1-6.

cf. 2000a *Fergusonites* cf. *striatus* Guex; Hillebrandt, p. 140, pl. 1, figs 2-3; text-fig. 27a-b.

**MATERIAL AND MEASUREMENTS:** Twelve measured (GSC 129081-129092) and eight incomplete specimens and fragments. Preservation varies from moderate to very good with many three-dimensional specimens. Measurements of volution are presented in Figure 4.11A.

**DESCRIPTION:** Moderately involute. Compressed with suboval whorl cross-section. Umbilical wall and shoulder rounded. Flanks weakly convex with widest point of whorl mid to upper flank. Venter broad and rounded. Fine, regularly spaced ribs prorsiradiate on flanks becoming rectiradiate on upper flank and across venter. Ribs weakest on lower flank, strongest on upper flank and across venter. Ribs regular in strength except in two specimens (Pl. 4.1, figs 6-8; GSC 129091) where rib strength varies somewhat. Ribs visible on internal mould but usually stronger on shell. Three specimens bear constrictions at adoral end (Pl. 4.1, figs 6-8, D = 30.5 mm; GSC 129084 and 129092, D = c. 25 mm). Constrictions hook back on umbilical shoulder then follow trajectory of ribbing. Suture line not available.

**REMARKS:** As discussed by Hillebrandt (2000a), confident assignment of the South American examples at the species level is precluded because the constriction that marks the aperture of *F. striatus* cannot be verified.

**OCCURRENCE:** Sections A and B, Mulleri/Occidentalis zones.

**Genus NEVADAPHYLLITES Guex, 1980**

TYPE SPECIES: *Nevadaphyllites compressus* Guex, 1980

***Nevadaphyllites psilomorphus* (Neumayr, 1879)**

Plate 4.1, figures 17-18, 27; Figure 4.10B

1879 *Phylloceras psilomorphum* Neumayr, p. 21, pl. 2, fig. 4.

1952 *Phylloceras psilomorphum* Neumayr; Lange, p. 82, pl. 1, fig. 1; text-fig. 1.

1995 *Phylloceras psilomorphum* Neumayr; Guex, p. 16, pl. 21, figs 5-6, 11-12.

? 1995 *Phylloceras* sp.; Dommergues *et al.*, p. 169, pl. 1, fig. 3.

1999 *Phylloceras psilomorphum* Neumayr; Böhm *et al.*, p. 185, pl. 24, fig. 4; text-fig. 36.

? 2004 *Phylloceras psilomorphum* Neumayr; Stevens, p. 14, pl. 2, fig. 1.

cf. 2007 *Nevadaphyllites cf. psilomorphus* (Neumayr); Yin *et al.*, p. 11, pl. 1, figs 31-32; table 2.

in press *a Nevadaphyllites psilomorphus* (Neumayr); Longridge *et al.*, pl. 1, figs 1-2, 5-6.

MATERIAL AND MEASUREMENTS: Six measured specimens (GSC 129093-129098) and many flattened specimens or fragments. Preservation varies from moderate to very good with several three-dimensional specimens. Measurements of volution are presented in Figure 4.11B.

DESCRIPTION: Midvolute and compressed for genus. Umbilical wall one short arch. Widest point of whorl near umbilicus, flanks relatively subparallel, sloping gently toward narrow but rounded venter. Best preserved specimen shows weak, prorsiradiate, sigmoid striae on flanks (Pl. 4.1, figs 17-18). Septal suture not preserved.

REMARKS: *Nevadaphyllites psilomorphus* from the QCI has very similar volution to the specimens figured by Neumayr (1879) and Lange (1952). Rakús (1993a) differentiates *N.*

*glaberrimus* (Neumayr) from *N. psilomorphus* principally based on a difference in the shape of the umbilical wall. He claims that the former species has an umbilical wall that is one short arch whereas the latter species has an umbilical wall that is straighter with a more distinct umbilical shoulder (as illustrated in Lange 1952, text-fig. 1.1). The QCI material has a short, convex umbilical wall. Nevertheless, we have placed the QCI material in *N. psilomorphus* because we feel the lectotype of the species (Neumayr 1879, pl. 2, fig. 4) also has a convex umbilical wall.

*Nevadaphyllites psilomorphus* from the QCI is slightly more evolute than the Taseko Lakes material (Longridge *et al.* in press *a*) and the more depressed material from Salzburg (Böhm *et al.* 1999) and Nevada (Guex 1995). Due to poor preservation, the specimens of Dommergues *et al.* (1995) and Stevens (2004) are attributed with uncertainty to *N. psilomorphus*. The QCI form is significantly more compressed than the more evolute *Phylloceras asperaense* Hillebrandt and the more involute *P. chilense* Hillebrandt.

OCCURRENCE: Section A and B, Mulleri/Occidentalis zones; section B, Coronoides to Sunrisensis zones.

### ***Nevadaphyllites aff. compressus* Guex, 1980**

Plate 4.1, figures 12-14

v? 1967 Ammonite gen. et sp. indet. 3., Frebold, p. 29, pl. 5, fig. 8.

aff. 1980 *Nevadaphyllites compressus* Guex, p. 135, pl. 1, fig. 7.

aff. 1995 *Nevadaphyllites compressus* Guex, p. 12, pl. 2, figs 7-12; text-fig. 8.

aff. 2000a *Nevadaphyllites compressus* Guex; Hillebrandt, p. 139, pl. 1, fig. 1.

in press *a* *Nevadaphyllites aff. compressus* Guex; Longridge *et al.*, pl. 1, figs 28-29.

MATERIAL AND MEASUREMENTS: One measured specimen (GSC 129099) and one fragment (GSC 129100). Measurement of volution is presented in Figure 4.11B.

DESCRIPTION: Compressed and midvolute for genus. Umbilical wall upright with rounded umbilical shoulder. Flanks subparallel tapering slightly toward relatively narrow but rounded venter. Upper flank and venter with weak undulations in well preserved areas of body chamber. At adoral end of specimen, a sigmoid constriction occurs on internal mould that has its greatest inflection midflank and projects forward across venter. Constriction absent on external shell.

REMARKS: *Nevadaphyllites* aff. *compressus* is most similar to *N. compressus* Guex but differs in having a lower, gently arched umbilical wall. It differs from *N. aff. compressus* from Taseko Lakes in bearing ventral undulations on the body chamber (Longridge *et al.* in press a). Due to poor preservation, it is not possible to identify this form with confidence. *Nevadaphyllites* aff. *compressus* may represent a new species but our limited, poorly preserved material does not warrant a new species designation at this time.

*Nevadaphyllites* aff. *compressus* has similar volution to *Nevadaphyllites* (?) sp. from the lower Hettangian beds in the QCI (Longridge *et al.* 2007). Poor preservation hinders confident comparison; however, the early Hettangian form can attain much larger shell diameters.

OCCURRENCE: Section A, Mulleri/Occidentalis zones.

***Nevadaphyllites* sp.**

Plate 4.1, figure 16

MATERIAL AND MEASUREMENTS: One flattened, measured specimen (GSC 129101).

Preservation poor. Measurement of volution is presented in Figure 4.11B.

DESCRIPTION: Midvolute form for genus. Flanks with fine striae strongest on upper flank.

Adoral end of specimen with sigmoid constriction.



REMARKS: The volution of *Nevadaphyllites* sp. is similar to *N. psilomorphus*. It differs in having striae on the flanks, a constriction at the adoral end of the specimen and in reaching maturity at much smaller shell diameters.

OCCURRENCE: Section A, Mulleri/Occidentalis zones.

**Genus TOGATICERAS Rakús, 1993a**

TYPE SPECIES: *Phylloceras togatum* (Neumayr, 1879).

***Togaticeras togatum* (Neumayr, 1879)**

Plate 4.1, figures 1, 9, 23-24

1879 *Phylloceras togatum* Neumayr, p. 21, pl. 1, figs 16-17.

1993a *Togaticeras togatum* (Neumayr); Rakús, p. 946, pl. 3, figs 6-7 (specimens of Neumayr refigured); text-fig. 15.

cf. 1995 *Togaticeras* cf. *togatum* (Neumayr); Guex, p. 15, pl. 2, fig. 21.

1999 *Togaticeras togatum* (Neumayr); Rakús, p. 331, pl. 1, figs 2-5; text-fig. 2.

2000 *Togaticeras togatum* (Neumayr); Kment, p. 190, pl. 1, fig. 8.

in press a *Togaticeras togatum* (Neumayr); Longridge *et al.*, pl. 1, figs 21-22.

MATERIAL AND MEASUREMENTS: Eleven measured specimens (GSC 129104-129114) and many poorly preserved or incomplete specimens and fragments (GSC 129103). All three-dimensional specimens have a shell diameter under 20 mm; larger specimens flattened.

Measurements of volution are presented in Figure 4.11B.

DESCRIPTION: Compressed, midvolute to involute form. Suboval whorl cross-section.

Umbilical wall one short arch. Umbilical shoulder distinct but rounded. Flanks weakly convex.

Venter broad and rounded. Flanks and venter smooth aside from distinct, strongly prorsiradiate constrictions present on internal mould. Constrictions sigmoid on flanks projecting forward across venter. Six to seven constrictions per whorl at shell diameters of 20 mm. At shell diameters *c.* 30 mm up to 11 constrictions on outer whorl. A partial suture line is preserved on one specimen (GSC 129108). The second lateral saddle is diphyllic and moderately strongly incised.

REMARKS: *Togaticeras togatum* from the QCI includes specimens that are more strongly involute than previously recognized (Pl. 4.1, fig. 1). It is possible that these forms are a new species; however, as there is no difference in the stratigraphic range of the more evolute and involute specimens, we feel this difference is most likely due to variation within *T. togatum*. The portion of suture line preserved on GSC 129108 is very similar to the equivalent part of the suture of the lectotype figured by Rakús (1993*a*, text-fig. 15).

OCCURRENCE: Sections A and B, Mulleri/Occidentalis zones; sections B and H, Coronoides Zone; section B, Pleuroacanthites and Sunrisensis zones.

**Suborder PSILOCERATINA Houša, 1965**

**Superfamily LYTOCERATOIDEA Neumayr, 1875**

**Family PLEUROACANTHITIDAE Hyatt, 1900**

**Genus INDETERMINATE**

**Genus indeterminate sp. nov.**

Plate 4.2, figure 8

MATERIAL: One somewhat distorted and flattened, moderately preserved specimen (GSC 129115).

DESCRIPTION: Evolute form for genus ( $UD/D = c. 48\%$ ). No constrictions visible. Flank ribs rursiradiate, projecting forward on upper flank. Inner whorls with weakly swollen regularly spaced ribs. Some ribs show weak tubercles. Beyond shell diameter of *c.* 20 mm, ribs more crowded and irregular in spacing and strength. Ribs lack ventrolateral nodes although small ventrolateral swellings visible on some ribs. Ribs continue onto venter.

REMARKS: Genus indet. sp. nov. shares many similarities in ornament to the Pleuroacanthitidae and may be an intermediate form between the *Pleuroacanthites* with its rursiradiate and swollen ribs on the inner whorls and *Ectocentrites* with its finer, tuberculate ribs.

It differs from species of *Tayloricites* Guex in lacking constrictions and ventrolateral nodes on the inner whorls. It is similar in volution and ribbing density to *E. dommerguesi* Meister, Khuc, Huyen and Doyle, but differs in having much weaker ribbing that is rursiradiate rather than prorsiradiate. Genus indet. sp. nov. is similar in ribbing density and strength to *E. italicus* Meneghini but is more evolute, lacks constrictions and has ribs that are rursiradiate rather than weakly prorsiradiate.

OCCURRENCE: Section I, Mulleri/Occidentalis zones.

### **Genus ECTOCENTRITES Canavari, 1888**

TYPE SPECIES: *Ammonites petersi* Hauer, 1856

*Ectocentrites pacificus* sp. nov.

Plate 4.2, figures 9, 11, 15

DERIVATION OF NAME: Named for the location in the eastern Pacific.

MATERIAL AND MEASUREMENTS: Nine measured specimens (GSC 129117, 129119-129126) and many incomplete specimens and fragments (GSC 129116, 129118). All material flattened. Measurements of volution and ribbing density are presented in Figure 4.11C-D.

HOLOTYPE: GSC 129117 (Pl. 4.2, fig. 9) from the Sunrisensis Zone, Kennecott Point, section D, level 01, QCI.

PARATYPES: GSC 129116, 129118, 129119-129126 from the Coronoides to Sunrisensis zones, Kennecott Point, section B-D, QCI.

DIAGNOSIS: Involute form. No constrictions. Sigmoid flank ribs project forward on upper flank. Ribs bear ventrolateral tubercles. Ribs irregularly spaced. Ribs on outer whorls may continue strongly across venter.

DESCRIPTION: Involute form for genus. No constrictions. Sigmoid flank ribs rursiradiate to weakly prorsiradiate, projecting forward on upper flank. Ribs begin on lower flank, coarsen upflank and bear ventrolateral tubercles. Ribs on innermost whorls somewhat variable in strength. Ribs on intermediate and outer whorls irregularly spaced. Preservation limited but ribs on intermediate whorls may weaken on venter while on outer whorls ribs continue strongly across venter (Pl. 4.2, fig. 15).

REMARKS: *Ectocentriles pacificus* differs from the majority of the type material of *E. petersi* (Hauer) in lacking constrictions on the inner whorls and is more involute at equivalent shell diameters. Meister *et al.* (2000, p. 85) discuss differences between *E. cf. petersi* from South American and *E. petersi*. These include the early appearance of ribs on the inner whorls and the presence of a ventral depression caused by weak ribbing between ventrolateral tubercles. As far as preservation permits analysis, these differences are also present in *E. pacificus* from the QCI.

*Ectocentriles pacificus* is very similar in volution and ornament to *E. cf. petersi* from South America (Hillebrandt 1981, pl. 1, fig. 6; 2000d, pl. 12, fig. 9). Hillebrandt (2000d, p. 86) mentions that the depth of rib interspaces on the innermost whorls are different on the South American specimen and this gives the impression of constrictions. Although some discrepancy in rib interspace depth is also visible in some of the QCI specimens, the specimens do not have constrictions. The poor quality of preservation in the QCI material as well as the limited quantity of South American material means it is not possible to be certain if this is a significant difference.

OCCURRENCE: Section B, Coronoides to Sunrisensis zones; sections C and D, Sunrisensis Zone.

### **Genus PLEUROACANTHITES Canavari, 1888**

TYPE SPECIES: *Ammonites biformis* Sowerby, 1831

#### ***Pleuroacanthites cf. biformis* (Sowerby, 1831)**

Plate 4.2, figures 7, 14, 17

cf. 1882 *Lytoceras* (?) *biforme* (Sowerby); Canavari, p. 156, pl. 17, figs 8-11.

cf. 1888 *Pleuracanthites biformis* (Sowerby); Canavari, p. 121, pl. 3, figs 8-12, 18.

cf. 1894 *Pleuracanthites biformis* (Sowerby); Wähner, p. 34, pl. 3, fig. 2, pl. 4, figs 1-3, pl. 5, figs 1-7, pl. 9, figs 3-4.

cf. 1995 *Pleuroacanthites biformis* (Sowerby); Guex, p. 42, pl. 23, figs 5-6; text-fig. 17.

aff. 1995 *Pleuroacanthites* aff. *biformis* (Sowerby); Guex, p. 42, pl. 24, figs 13-14.

cf. 1999 *Psilophyllites* sp. Yin *et al.*, fig. 3.8.

aff. 2007 *Pleuroacanthites* aff. *biformis* (Sowerby); Yin *et al.*, p. 11, text-fig. 5E-G, 6; table

4.

MATERIAL AND MEASUREMENTS: One measured specimen (GSC 129137), two measured external moulds (GSC 129138-129139) and ten incomplete specimens and fragments (GSC 129136, 129141). Material is partially to completely flattened. Measurements of volution are presented in Figure 4.11E.

DESCRIPTION: Inner whorls moderately evolute to moderately involute. Midvolute at larger shell diameters. Cross-section in better preserved fragment has convex flanks with flattened ventral area that projects into a slight median protuberance at midline. Parabolic ribs strongly rursiradiate on lower and middle flanks, projecting sharply forward on ventrolateral shoulder. Rib strength and spacing variable in some specimens, more regular in others. Ribs weakest on lower flanks developing greater strength upflank where they can be very strong. Ribs often asymmetric with steep adapical and gentler adoral slopes. Weaker ribs continue toward midline of venter. On largest specimen (Pl. 4.2, fig. 17) ribs on last whorl weaken on upper flank. Suture line not preserved.

REMARKS: Similar to *P. biformis* from the Austrian Alps and Italy, *P. cf. biformis* from the QCI varies considerably in volution on the inner whorls.

OCCURRENCE: Section A, Mulleri/Occidentalis zones; section B, Coronoides to Pleuroacanthitoides zones.

***Pleuroacanthites charlottensis* sp. nov.**

Plate 4.2, figures 1, 5

DERIVATION OF NAME: Named for the Queen Charlotte Islands where the type material was collected.

MATERIAL AND MEASUREMENTS: Five measured specimens (GSC 129143-129147) and two incomplete specimens (GSC 129142). Smaller material partially three-dimensional; larger material flattened. Measurements of volution are presented in Figure 4.11E.

HOLOTYPE: GSC 129142 (Pl. 4.2, fig. 5) from the Coronoides Zone, Kennecott Point, section B, level 10, QCI.

PARATYPES: GSC 129143-129147 from the Mulleri/Occidentalis to Coronoides, Kennecott Point, sections A and B, QCI.

DIAGNOSIS: Evolute for genus. Whorl cross-section compressed. Inner whorls with rursiradiate parabolic ribs with steep adapical and gentler adoral slopes. Intermediate whorls with weak rectiradiate ribs. Outer whorl smooth.

DESCRIPTION: Evolute on inner whorls; midvolute on outer whorls. Whorl cross-section compressed by 25 mm shell diameter. Inner whorls with asymmetric, moderate to strongly rursiradiate parabolic ribs with steep adapical and gentler adoral slopes. Rib strength variable, often having greatest strength at top of flanks. Beyond shell diameters of 20-25 mm, very weak rectiradiate ribs are more closely spaced. Occasional strong, rursiradiate ribs still present on flanks (Pl. 4.2, fig. 5). Outer whorl of largest specimen smooth (Pl. 4.2, fig. 5). Suture line not preserved.

REMARKS: *Pleuroacanthites charlottensis* is most similar to *P. biformis evolutus* Lange (1952, pl. 11, fig. 4). However, the QCI form is more evolute at similar shell diameters and also lacks a keel. Unfortunately, it is not possible to compare the two forms at larger size as the alpine form of Lange (1952, p. 93) is a microconch. The ornament is too regular in spacing and orientation in the specimens figured by Wöhner (1894, pl. 5, figs 3, 8) that Lange also attributes to his new subspecies. Additionally, figure 3 is too depressed. Volution and cross-section of the

inner and intermediate whorls of *P. charlottensis* are similar to *P. polycyclus* Wähner. The QCI form differs in having more crowded, irregularly orientated ornament on the inner whorls and in being considerably more involute at large shell diameters. *Pleuroacanthites charlottensis* is more evolute and compressed on the inner whorls than *P. polycycloides* Wähner.

OCCURRENCE: Section A, Mulleri/Occidentalis zones; section B, Coronoides Zone.

***Pleuroacanthites* sp.**

Plate 4.2, figure 13

MATERIAL AND MEASUREMENTS: One partially flattened specimen (GSC 129148).

Measurement of volution is presented in Figure 4.11E.

DESCRIPTION: Midvolute for genus. Inner whorls not preserved. On inner half of outer whorl, evenly spaced, swollen ribs resemble nodes on flanks. On outer half of outer whorl, broad, weakly prorsiradiate to concave ribs on flanks. Growth lines that follow trajectory of ribs visible between some ribs. Suture line not available.

REMARKS: The poor preservation of this specimen does not permit confident identification. However, this specimen probably represents a new species because it differs from all other currently recognized *Pleuroacanthites* in ribbing style.

OCCURRENCE: Section B, Mulleri/Occidentalis zones.

**Genus EOLYTOCERAS Frebold, 1967**

TYPE SPECIES: *Eolytoceras tasekoi* Frebold, 1967

***Eolytoceras* cf. *praecursor* Guex**



MATERIAL AND MEASUREMENTS: Nine measured specimens (GSC 129127-129129, 129130-129135) and many incomplete specimens (GSC 129140). Some uncompressed material. Measurements of volution are presented in Figure 4.11C.

DESCRIPTION: Inner whorls evolute for genus. Depressed on inner whorls (Pl. 4.2, figs 2-3) becoming weakly compressed at medium shell diameters. Nucleus nodose. After this, moderately to strongly swollen ribs irregular in spacing and strength, often beginning midflank with greatest strength on upper flank. Beyond shell diameters of 25-30 mm, prorsiradiate to concave ribbing weak and closely spaced. Some specimens maintain this flank ribbing to end of preserved shell. Others become smooth. In some specimens, periodic undulations occur on flanks (Pl. 4.2, fig. 4). At shell diameters of *c.* 50 mm, specimens diverge into two groups. One group evolute to end of preserved shell. Other group becomes more involute. Last 1/3 whorl of GSC 129127 (Pl. 4.2, fig. 4) not chambered. Suture line too incomplete to illustrate. Saddles with spatular folioles, umbilical lobes retracted.

REMARKS: Some specimens of *Eolytoceras cf. praecursor* are very similar to *E. praecursor* from Nevada (e.g. Pl. 4.2, fig. 4). However, this species is represented only by the holotype and it is currently not possible to ascertain the variability of the species. Some of the QCI specimens become more involute at larger shell diameters and have swollen ribs that continue to larger shell diameters than the holotype. Therefore the QCI material is placed with uncertainty to *E. praecursor*.

It is possible that *E. cf. praecursor* is a sexually dimorphic species. The inner whorls are very similar yet differences in volution beyond shell diameters of *c.* 50 mm make it possible to divide the material into two groups. One group is consistently evolute (Pl. 4.2, figs 4, 6) whereas the other is involute (Pl. 4.2, fig. 16). One specimen may be a microconch as approximately last one

third of the outer whorl is body chamber (Pl. 4.2, fig. 4). Unfortunately, the suture lines are mostly obscured and are not preserved in the rest of the larger material, so it is not possible to see approximation. Due to poor preservation, other signs of maturity such as the presence of a rostrum and egression cannot be confirmed. Potential microconch or macroconch status is indicated in plate caption where possible.

As discussed by Guex (1995) for the Nevada specimen, the juvenile whorls of *Eolytoceras* cf. *praecursor* resemble *Pleuroacanthites mulleri*. Some of this material closely resembles the holotype of *T. transiens* Guex (1980, pl. 2, fig. 3; 1995, pl. 5, fig. 3-4) from the early Hettangian but differs in being consistently more evolute on the inner and intermediate whorls (e.g. Pl. 4.2, fig. 4).

OCCURRENCE: Section B, Coronoides to Pleuroacanthitoides zones; Section H, Coronoides Zone.

***Eolytoceras* cf. *tasekoi* Frebold, 1967**

Plate 4.1, figures 19, 22

cf. 1967 *Eolytoceras tasekoi* Frebold, p. 14, pl. 8, figs 1-2.

cf. 1970 *Eolytoceras tasekoi* Frebold; Wiedmann, p. 1007, pl. 7, fig. 4; text-figs 9C, 30D, 31 (Holotype refigured).

1999 *Eolytoceras* cf. *tasekoi* Frebold; Pálffy *et al.*, p. 1543, fig. H.

cf. 2000 *Eolytoceras tasekoi* Frebold; Taylor, pl. 1, figs 1-10.

2000 *Eolytoceras* cf. *tasekoi* Frebold; Kment, p. 195, pl. 2, fig. 2.

aff. 2002a *Eolytoceras* aff. *tasekoi* Frebold; Meister *et al.*, p. 445, figs 3, 7.

? 2004 *Eolytoceras* cf. *tasekoi* Frebold; Stevens, p. 17, pl. 1, figs 1-5 only (*non* figs 7-8).

cf. in press a *Eolytoceras tasekoi* Frebold; Longridge *et al.*, pl. 1, figs 20, 23.

MATERIAL AND MEASUREMENTS: Six measured specimens (GSC 107365, 107367, 129150-129153) and many incomplete specimens (GSC 129149). All except one specimen flattened. Measurements of volution are presented in Figure 4.11C-D.

DESCRIPTION: Moderately evolute. Whorl cross-section ellipsoid, compressed, flanks slightly convex. Some specimens with weak prorsiradiate ribbing on inner whorls. Some specimens with occasional faint ribs on intermediate whorls. Rare specimens with occasional weak, slightly prorsiradiate constrictions.

The New Zealand material (Stevens 2004) is very poorly preserved and cannot be identified with confidence even at the generic level.

OCCURRENCE: Section D, Morganense Zone; section G, Mineralense Zone; sections E and F, Mineralense and Rursicostatum zones. Also occurs in the Columbiae Zone in the QCI.

***Eolytoceras* aff. *constrictum* Longridge, Smith, Tipper**

Plate 4.3, figures 1, 9

aff. in press *a Eolytoceras constrictum* Longridge *et al.*, pl. 1, figs 3-4, 24-25; text-figs 9N, 10D.

MATERIAL AND MEASUREMENTS: Two measured specimens (GSC 107373-107374).

Material partially compressed. Measurements of volution are presented in Figure 4.11C.

DESCRIPTION: Evolute form. Flanks convex. Innermost whorls smooth. Adorally, slightly convex flares develop from an early stage (6-7 flares/half whorl at  $D > 25$  mm). At later growth stages, ventrolateral nodes develop on flares. Flares may be accompanied by a flanking constriction. Some specimens with fine growth lines.

REMARKS: *Eolytoceras* aff. *constrictum* is very similar on the inner whorls to *E. constrictum* from Taseko Lakes although it attains much larger shell diameters. Additionally, in the Taseko

Lakes material the flares are always preceded by a constriction (Longridge *et al.* in press *a*). It is unclear whether these represent species level differences or simply variations within a single species.

*Eolytoceras* aff. *constrictum* differs from other species of *Eolytoceras* in having prominent flares. It is similar to several specimens of *Analytoceras articulatum* (Sowerby) figured by Wöhner (1894, pl. 54, fig. 3; pl. 58, figs 1-3) in having flares and nodes on the outer whorls but differs in lacking articulated inner whorls.

OCCURRENCE: Sections E and F, Mineralense/Rursicostatum zones. Also occurs in the Columbiae Zone in the QCI.

### **Superfamily PSILOCERATOIDEA Hyatt, 1867**

### **Family PSILOCERATIDAE Hyatt, 1867**

### **Genus EUPHYLLITES Wöhner, 1898**

TYPE SPECIES: *Aegoceras struckmanni* Neumayr, 1879

### ***Euphyllites occidentalis* Guex, 1980**

Plate 4.3, figures 2-4, 10-11; Figure 4.10G

1980 *Euphyllites occidentalis* Guex, p. 132, pl. 1, fig. 9.

1995 *Euphyllites occidentalis* Guex, p. 30, pl. 21, figs 1-2, pl. 22, figs 1-4, 7-12.

MATERIAL AND MEASUREMENTS: Eight measured specimens (GSC 129154-129161) and several incomplete specimens or fragments. Most specimens three-dimensional; preservation moderate to good. Measurements of volution are presented in Figure 4.11E.

DESCRIPTION: Evolute form. Nucleus nodose. Inner whorls depressed with weak, prorsiradiate flank ribs to c. 20 mm shell diameter (Pl. 4.3, fig. 2). At shell diameters over 20 mm, whorls become compressed (Pl. 4.3, figs 3-4) with weakly convex flanks and a broad, smooth venter. Beyond shell diameters of 20 mm, flanks vary from smooth to bearing irregular ribs of variable strength and orientation (Pl. 4.3, figs 10-11). Two specimens shows faint, straight to weakly concave growth lines on the flanks that project forward on venter (GSC 129159). Septal suture line not preserved.

REMARKS: As discussed by Guex (1995), it is not possible to see the ornament on the type material of *E. occidentalis* at shell diameters of less than 15 mm. The material from the QCI confirms that this species does not bear constrictions on the innermost whorls. Differences between *E. occidentalis* and other species of *Euphyllites* are given in Guex (1995).

OCCURRENCE: Sections A and B, Mulleri/Occidentalis zones.

### **Genus CALOCERAS Hyatt, 1871**

TYPE SPECIES: *Ammonites torus* D'Orbigny, 1844

#### ***Caloceras* aff. *bloomfieldense* Donovan, 1956**

Plate 4.4, figure 1

aff. 1952 *Psiloceras* (*Caloceras*) *multicostatum* Donovan, p. 638, pl. 22, fig. 4; text-figs 2-3.

aff. 1986 *Caloceras bloomfieldense* Donovan; Hodges, p. 241, fig. 3.2-3.3.

MATERIAL AND MEASUREMENTS: One flattened measured specimen (GSC 129162).

Measurements of volution and ribbing density are presented in Figure 4.12A-B.

DESCRIPTION: Evolute form. Straight, sharp, crowded flank ribs weakly to moderately rursiradiate. Ribs fade on upper flank.

REMARKS: *Caloceras* aff. *bloomfieldense* differs from *C. bloomfieldense* in having a slightly lower number of ribs on the innermost whorls and a higher number of ribs on the intermediate whorls. It also has flank ribs that are rursiradiate throughout ontogeny. *Caloceras bloomfieldense* was originally described by Donovan (1952) under the name *C. multicostatum*. The QCI form is similar to some specimens of *C. pirondi* (Reynès) (e.g. Guerin-Franiette 1990, pl. 2, fig. 3) but differs in having flank ribs that are rursiradiate rather than rectiradiate to prorsiradiate.

OCCURRENCE: Section B, Coronoides Zone.

### **Genus DISCAMPHICERAS Spath, 1923a**

TYPE SPECIES: *Aegoceras kammerkareense* Gümbel, 1861

As discussed in Donovan (1958), the first written description of the holotype of *A.*

*kammerkareense* was given by Gümbel (1861) whereas a suture line of the specimen was first figured in Wähner (1884, pl. 25, fig. 2).

### ***Discamphiceras silberlingi* Guex, 1980**

Plate 4.4, figures 6, 10

1980 *Discamphiceras silberlingi* Guex, p. 132, pl. 2, fig. 2.

cf. 1981 *Discamphiceras* cf. *D. toxophorum* Wähner; Imlay, p. 29, pl.1, figs 3, 8-10.

? 1981 *Discamphiceras* cf. *D. toxophorum* Wähner; Imlay, p. 29, pl.1, fig. 4.

1995 *Discamphiceras silberlingi* Guex, p. 28, pl. 6, figs 4-5, 8-9; pl. 11, figs 1-2, 5-6, 9-12; pl. 12, figs 4, 7-8; pl. 14, figs 1-2, 7-14; pl. 15, figs 5-6; text-fig. 15.

cf. 1999 *Discamphiceras* cf. *silberlingi* Guex; Pálffy *et al.*, fig. 4A, 4D.

? 1999 *Discamphiceras* aff. *reissi* (Tilmann); Pálffy *et al.*, fig. 4C.

non 2000 *Discamphiceras* cf. *silberlingi* Guex; Yin and Enay, pl. 2, figs 5-7.

cf. 2000 *Discamphiceras* cf. *silberlingi* Guex; Hall *et al.*, p. 1375, fig. 3.

in press a *Discamphiceras* *silberlingi* Guex; Longridge *et al.*, pl. 2, figs 17-18, 20.

**MATERIAL AND MEASUREMENTS:** Twenty-four measured specimens (GSC 129163-129180, 130669-130674) and many incomplete specimens and fragments. Material reasonably well preserved; some three-dimensional specimens. Measurements of volution and ribbing density are presented in Figure 4.12C, E.

**DESCRIPTION:** Strongly compressed, moderately evolute to moderately involute form with subelliptical whorl cross-section. Inner whorls with low yet upright umbilical wall. Umbilical shoulder rounded. Nearly flat flanks taper gently toward broad venter. Specimens where nucleus well preserved ornamented with nodes to shell diameters of 3.5 to 5 mm. Beyond this, ribs rectiradiate to weakly prorsiradiate. By shell diameters of 15 mm, gently flexuous, prorsiradiate ribs vary considerably in strength. Narrow ribs begin on lowest flank, widening and having greatest strength midflank before fading on upper flank. In well-preserved material, ribs project forward, sometimes dividing into two ribs, before crossing venter in a forward-directed chevron. Suture line not preserved.

**REMARKS:** Some of the material from Alaska (Pálffy *et al.* 1999) is marked with a question mark in the synonymy list due to poor preservation which hampers certainty of identification. The material identified by Yin and Enay (2000) as *D.* cf. *silberlingi* was recently re-classified as *D. pleuronotum* (Yin *et al.* 2007). Some New Zealand specimens figured as *Waehneroceras otapiriense* Stevens (2004, pl. 2, figs 4-9, 11-13) are very similar in volution and ribbing style to

*D. silberlingi*; however, this species differs in being much less compressed (Stevens 2004, text-fig. 13).

*Discamphiceras silberlingi* is closely related to the South American forms *D. reissi* (Tilmann) and *D. cf. calcimontanum* (Wähner) of Hillebrandt (2000c).

OCCURRENCE: Sections A and H, Mulleri/Occidentalis zones; section B, Mulleri/Occidentalis to Sunrisensis zones; section C, Sunrisensis Zone.

***Discamphiceras aff. pleuronotum* (Canavari, 1882)**

Plate 4.4, figures 2, 5

aff. 1882 *Aegoceras pleuronotum* Canavari, p. 169, pl. 19 figs 2, 4-5, non 3.

aff. 1884 *Aegoceras pleuronotum* Canavari; Wähner, p. 110, pl. 25, fig. 3.

aff. 1888 *Psiloceras pleuronotum* Canavari, p. 149, pl. 5, figs 2, 4-5.

? 1960 *Psiloceras (Discamphites) reissi* (Tilmann); Cecioni, p. 12, pl. 1, fig. B1-B2.

cf. 1987 *Psiloceras cf. reissi* (Tilmann); Hillebrandt, pl. 1, figs 1-5.

aff. 1999 *Kammerkarites haploptychus* (Wähner); Yin *et al.*, fig. 3.10-3.12.

aff. 1999 *Discamphiceras* sp.; Yin *et al.*, fig. 3.14.

cf. 2000c *Discamphiceras cf. pleuronotum* (Canavari); Hillebrandt, p. 7, pl. 2, figs 5-12;  
text-fig. 1h-n.

aff. 2007 *Discamphiceras pleuronotum* (Canavari); Yin *et al.*, p. 20, pl. 3, figs 5-6, 8-11, pl. 4, figs 1-5, 10-11, 15; text-fig. 13A-D; table 4.

MATERIAL AND MEASUREMENTS: Three measured specimens (GSC 130677-130679), one measured external cast (GSC 130680), two incomplete specimens and two external casts (GSC 130676). Preservation is moderate Measurements of volution and ribbing density are presented in Figure 4.12D-E.



DESCRIPTION: Compressed form, evolute for genus. Nucleus nodose. Slightly sloping umbilical wall that becomes higher with increasing shell diameter. Umbilical shoulder gently rounded. Rectiradiate to weakly prorsiradiate ribs begin on umbilical wall or lowest flank having greatest strength midflank before fading on upper flank. One specimen with better preserved venter shows weak ribs dividing into two on uppermost flank and projecting forward across venter. Suture line not preserved.

REMARKS: Although incomplete preservation of whorl cross-section and lack of a suture line hinders confident comparison, the QCI form is very similar to some specimens of *Discamphiceras cf. pleuronotum* of Hillebrandt (2000c, pl. 2, figs 6, 9, 12). The eastern Pacific form closely resembles *D. pleuronotum* (Canavari) in volution, whorl cross-section and rib number but differs in having flank ribs that are rectiradiate to weakly prorsiradiate rather than weakly rursiradiate. Furthermore, as discussed by Hillebrandt (2000c, p. 8), *D. pleuronotum* has a much more strongly incised suture line with deeper lateral and umbilical lobes (Canavari 1882, pl. 19, fig. 2c) than *D. cf. pleuronotum* from South America.

OCCURRENCE: Section A, Mulleri/Occidentalis zones; section B, Coronoides Zone.

***Discamphiceras cf. submesogenos* Guex, 1995**

Plate 4.4, figure 8

cf. 1995 *Discamphiceras submesogenos* Guex, p. 29, pl. 11, figs 3-4, 7-8, pl. 13, figs 5-12, pl. 14, figs 3-4.

MATERIAL AND MEASUREMENTS: Fourteen measured (GSC 130681-130694) and many incomplete specimens. All material flattened. Measurements of volution are presented in Figure 4.12D.

DESCRIPTION: Involute for genus. Nucleus nodose. Following this, weak, prorsiradiate growth lines project forward on lower flank, rectiradiate on upper flank (GSC 130690, not figured). Intermittent weak ribs that follow trajectory of growth lines present in some specimens. On two specimens, ribs project forward onto venter in a forwardly directed chevron (Pl. 4.4, fig. 8). Suture line not preserved.

REMARKS: Although the QCI material can be slightly more involute and two specimens bear ventral ribbing that is more pronounced than the type material of *D. submesogenos*, it is very similar in other respects. *Discamphiceras* cf. *submesogenos* is most similar to *D. mesogenos* (Wähner) but differs in being more involute and in having intermittent ribbing on the flanks and venter.

OCCURRENCE: Section B, Pleuroacanthitoides to Sunrisensis zones.

***Discamphiceras* aff. *antiquum* Guex, 1980**

Plate 4.4, figures 4, 7

aff. 1980 *Discamphiceras antiquum*, Guex, p. 131, pl. 1, fig. 4.

cf. 1985 *Psiloceras reissi* Tilmann; Prinz, p. 170, pl. 2, fig. 2.

cf. 1985 *Psiloceras* cf. *peruvianum* (Lange); Prinz, p. 171, pl. 2, fig. 3.

cf. 1994 *Discamphiceras* cf. *reissi* (Tilmann); Hillebrandt, pl. 1, fig. 12.

cf. 1995 *Discamphiceras* aff. *reissi* (Tilmann); Guex, p. 26, pl. 2, figs 13-19.

aff. 1995 *Discamphiceras antiquum*, Guex, p. 27, pl. 12, figs 1-3, 5-6, pl. 15, figs 3-4, 7-12;  
text-fig. 14.

cf. 2000a *Discamphiceras* cf. *antiquum* Guex; Hillebrandt, pl. 14, figs 14-20.

cf. 2000c *Discamphiceras* cf. *antiquum* Guex; Hillebrandt, p. 4, pl. 1, figs 1-12; text-fig. 1b-  
c.

**MATERIAL AND MEASUREMENTS:** Three measured specimens (GSC 130696-130698), seven incomplete specimens (GSC 130695) and three external casts. All material at least partially flattened. Measurements of volution are presented in Figure 4.12D.

**DESCRIPTION:** Involute for genus. Preserved relief in two specimens suggests whorl cross-section strongly compressed. Nucleus nodose. Following this, weak, prorsiradiate ribs sigmoidal on flanks. Ribs project forward on lower flank and backward on upper flank. Preservation of outer whorls poor, but specimens appear to smooth out somewhat on flanks. Suture line not preserved.

**REMARKS:** *Discamphiceras* aff. *antiquum* from the QCI is very similar to *D. cf. antiquum* from South America (Hillebrandt 2000a, c) and *Discamphiceras* aff. *reissi* from Nevada (Guex 1995) in volution and ornament. Incomplete preservation of whorl cross-section and lack of a suture line hinders confident assignment.

*Discamphiceras* aff. *antiquum* from the QCI predominantly differs from the more evolute *D. antiquum* from Nevada (Guex 1980, 1995) in possessing more distinct ribs on the flanks, especially at small shell diameters.

**OCCURRENCE:** Section A, Mulleri/Occidentalis zones; section B, Mulleri/Occidentalis to Coronoides zones.

### **Genus ALSATITES Haug, 1894**

**TYPE SPECIES:** *Ammonites liasicus* D'Orbigny, 1844; by subsequent designation of Haug, 1894.

**REMARKS:** Guex (1987, 1995) places *Laqueoceras* in synonymy with *Alsatites* while Hillebrandt (2000d) maintains *Laqueoceras* as a separate genus based on the absence of a keel. The former approach is adopted here.

***Alsatites cf. liasicus* (d'Orbigny, 1844)**

Plate 4.7, figure 7

- cf. 1844 *Ammonites liasicus* d'Orbigny, p. 199, pl. 48.
- cf. 1879 *Ammonites liasicus* d'Orbigny; Reynès, pl. VI, figs 9-12.
- cf. 1879. *Aegoceras laqueolus* Schloenbach; Wright, p. 315, pl. XV, fig. 1-2, 10-12, pl. 16, figs 1-2.
- cf. 1941 *Porarietites (Alsatites) laqueolus* (Schloenbach); Lange, p. 163, pl. 20, figs 1-3, 5.
- cf. 1961 *Alsatites liasicus* (D'Orbigny); Dean *et al.*, pl. 63, fig. 3.
- cf. 1976 *Alsatites liasicus* (D'Orbigny); Schlegelmilch, p. 40, pl. 10, fig. 4.
- cf. 1990 *Alsatites liasicus* (D'Orbigny); Guerin-Franiatte, p. 58, pl. 5, fig. 1, pl. 6, figs 1-2, pl. 7, fig. 1.
- non. 1993b *Alsatites liasicus* (D'Orbigny); Rakús, p. 28, pl. 1, figs 3-4, 7, pl. 7, figs 1, 3-5, pl. 8, fig. 7; text-figs 21-26.
- cf. 1994 *Alsatites* sp., Hillebrandt, pl. 1, fig. 1a-b.
- 2000d *Alsatites cf. liasicus* (D'Orbigny); Hillebrandt, p. 75, pl. 6, fig. 2a-b.
- cf. 2004 *Alsatites liasicus* (D'Orbigny); Hall and Pitaru, p. 4, pl. 1, fig. 5.

MATERIAL AND MEASUREMENTS: Three measured specimens (GSC 130699, 130701), one measured external cast (GSC 130700) and two incomplete specimens. Material partially flattened. Measurements of volution and rib density are presented in Figure 4.12A-B.

DESCRIPTION: Evolute form. Nodose nucleus. Beyond this, moderately strong flank ribs weakly rursiradiate to rectiradiate. Weakened ribs project forward on uppermost flank onto venter. One specimen has ribs that bend forward midflank becoming prorsiradiate. Venter poorly preserved. However, one fragment is smooth at whorl height of 4 mm while in another

specimen, a keel is suggested at a whorl height of 6 mm (Pl. 4.7, fig. 7). Suture line and cross-section not available.

REMARKS: The similarity of *A. liasicus* to *Gyrophioceras morganense* was discussed by Taylor (1998, p. 491) when he erected the new species and again by Hillebrandt (2000d, p. 76) with specific reference to the South American specimen of *A. cf. liasicus*. The QCI material is especially similar to the paratype of *G. morganense* (Taylor, 1998, fig. 21.11-21.12) but differs from the slightly more involute species in having less strongly rursiradiate ribs at the base of the flanks.

As discussed by Rakús (1993b), the material from the West Carpathians has much sparser flank ribbing than other *A. liasicus*.

OCCURRENCE: Section B, Coronoides Zone.

***Alsatites cf. proaries* (Neumayr, 1879)**

Plate 4.7, figures 8, 10

cf. 1879 *Arietites proaries* Neumayr, p. 37, pl. 7, figs 1-2.

cf. 1882 *Aegoceras helicoideum* (Menghini); Canavari, p. 38, pl. 5, fig. 7.

cf. 1882 *Aegoceras tortuosum* Canavari, p. 39, pl. 5, fig. 8.

cf. 1886 *Arietites proaries* Neumayr; Wähner, p. 217, pl. 28, figs 1-2, pl. 29, figs 1-4, pl. 30, figs 5-11.

cf. 1888 *Arietites proaries* Neumayr; Canavari, p. 161, pl. 5, figs 7-8.

cf. 1963 *Arietites (Alsatites) proaries* Neumayr; Blind, p. 100, pl. 3, fig. 6.

MATERIAL AND MEASUREMENTS: Eight measured (GSC 130703-130710) and many incomplete specimens (GSC 156959). All material flattened. Measurements of volution and rib density are presented in Figure 4.12A-B.

DESCRIPTION: Evolute form. Ribs on innermost whorls weakly rursiradiate to rectiradiate. At shell diameters greater than 10 mm, ribs regularly spaced, more or less concave and crowded. Beyond shell diameters of 40-60 mm, concave ribbing becomes less crowded and can be irregular in spacing and strength (Pl. 4.7, fig. 8). At large shell diameters ribbing strongly concave (Pl. 4.7, fig. 10). Suture line and cross-section not available.

REMARKS: *Alsatites* cf. *proaries* is very similar in volution and ribbing style to *A. proaries* although the QCI form can also have ribs that are less crowded and more irregularly spaced at larger shell diameters (Pl. 4.7, fig. 8). *Alsatites* cf. *proaries* is somewhat similar in ribbing style to *Laqueoceras* cf. *sublaqueus* (Wöhner) from South America (Hillebrandt 2000d, pl. 3, figs 8-9) but is more evolute at large shell diameters and has ribs that are more consistently concave on the flanks. *Alsatites* cf. *proaries* is similar in volution and ribbing style to *Paracaloceras haueri* (Gümbel) but lacks evidence of a keel. *Alsatites* ex. gr. *proaries* of Guex (1995) is much more involute than the QCI material. *Alsatites* cf. *proaries* is similar to the paratype of *Gyrophioceras morganense* (Taylor, 1998, fig. 21.11-21.12) and some specimens of *A. liasicus*. It differs in being more involute and in having denser ribbing on the inner whorls.

OCCURRENCE: Section B, Pleuroacanthitoides to Sunrisensis zones; section C, Sunrisensis Zone; section C, probably Morganense Zone.

***Alsatites* ex. gr. *proaries* (Neumayr, 1879)**

Plate 4.7, figures 5-6

ex gr. 1879 *Arietites proaries* Neumayr, p. 37, pl. 7, figs 1-2.

ex gr. 1882 *Aegoceras helicoideum* (Menghini); Canavari, p. 38, pl. 5, fig. 7.

ex gr. 1882 *Aegoceras tortuosum* Canavari, p. 39, pl. 5, fig. 8.

ex gr. 1886 *Arietites proaries* Neumayr; Wöhner, p. 217, pl. 28, figs 1-2, pl. 29, figs 1-4, pl. 30, figs 5-11.

ex gr. 1888 *Arietites proaries* Neumayr; Canavari, p. 161, pl. 5, figs 7-8.

ex gr. 1963 *Arietites (Alsatites) proaries* Neumayr; Blind, p. 100, pl. 3, fig. 6.

1995 *Alsatites* ex. gr. *proaries* (Neumayr); Guex, p. 48, pl. 26, figs 3-4, 7, pl. 28, figs 1-2, 5-6, pl. 29, figs. 1-6, pl. 30, figs. 3-4; text-fig. 20.

**MATERIAL AND MEASUREMENTS:** Six measured specimens (GSC 130712-130717) and several incomplete specimens and fragments (GSC 130711). All material partially or completely flattened. Measurements of volution and rib density are presented in Figure 4.12A-B.

**DESCRIPTION:** Midvolute form for genus. Ribbing on inner whorls variable in strength and spacing. Specimens divide into two groups beyond shell diameters of 30 mm. In one group, fine, crowded flank ribs are prorsiradiate to weakly concave (Pl. 4.7, fig. 5). In other group, concave flank ribs remain stronger and more widely spaced (Pl. 4.7, fig. 6). Suture line and cross-section not available although preserved relief suggests venter was smooth to maximum preserved shell diameter ( $D = c. 48$  mm).

**REMARKS:** *Alsatites* ex gr. *proaries* from the QCI is moderately to strongly more involute and has stronger ribs on the inner whorls than most *A. proaries*. *Alsatites* ex gr. *proaries* from the QCI has similar morphological variability as *A. ex. gr. proaries* in Nevada (Guex 1995).

**OCCURRENCE:** Section B, Coronoides to Pleuroacanthitoides zones; section H, Coronoides Zone.

### **Genus MULLERITES Guex, 1980**

**TYPE SPECIES:** *Mullerites pleuroacanthitoides* Guex, 1980

**REMARKS:** *Mullerites* may be a synonym of *Alsatites* as *M. pleuroacanthitoides* shares many characteristics with species of *Alsatites*.

***Mullerites cf. pleuroacanthitoides* Guex, 1980**

Plate 4.3, figures 6, 8

cf. 1980 *Mullerites* gen. n. *pleuroacanthitoides* sp. n. Guex, p. 135, pl. 4, fig. 2.

cf. 1995 *Mullerites pleuroacanthitoides* Guex, p. 46, pl. 25, figs 1-2, pl. 28, figs 3-4, 7-11, pl. 30, figs 1-2, 13-14; text-fig. 19.

1999 *Mullerites cf. pleuroacanthitoides* Guex; Pálffy *et al.*, fig. 4N-O.

MATERIAL AND MEASUREMENTS: Seven measured (GSC 130718-130724) and one incomplete specimen. Material partially to completely flattened. Measurements of volution and rib number are presented in Figure 4.12A-B.

DESCRIPTION: Evolute form. Preserved relief suggests cross-section of inner whorls subrounded. Nucleus nodose. Flank ribs more or less irregular in spacing and strength. Ribbing on inner whorls weakly concave to straight. Ribbing on outer whorls concave. Ribs bend forward and continue onto venter.

REMARKS: *Mullerites cf. pleuroacanthitoides* may be slightly more evolute on the inner whorls than *M. pleuroacanthitoides* from Nevada. Some specimens of the QCI form resemble *A. nigromontanus* (Gümbel). They differ on the inner whorls in having ribs that are less strongly rursiradiate and on the outer whorls in being more evolute and in having ribs that are less crowded.

OCCURRENCE: Section B, *Pleuroacanthitoides* to *Sunrisensis* zones; section C, *Sunrisensis* Zone.

**Genus SUNRISITES Guex, 1980**



TYPE SPECIES: *Sunrisites sunrisensis* Guex, 1980.

***Sunrisites cf. chilensis* Hillebrandt, 2000c**

Plate 4.6, figures 10, 14-16

cf. 2000c *Sunrisites chilensis* Hillebrandt, p. 38, pl. 10, fig. 1, pl. 11, figs 1-4, pl. 12, figs 1-2; text-fig. 5.

MATERIAL AND MEASUREMENTS: Eight measured specimens (GSC 130727-130734) and many incomplete specimens and fragments (GSC 130725-130726). Preservation varies from moderate to poor with one partial three-dimensional specimen. Measurements of volution and number of ribs are presented in Figure 4.13A-B.

DESCRIPTION: Evolute on inner whorls, moderately involute on outer whorls. Preserved relief suggests cross-section of intermediate whorls rounded; cross-section of outer whorls high oval with rounded venter. Widest point of whorl low midflank. Umbilical wall upright, umbilical shoulder rounded. In some specimens ribbing on innermost whorls irregularly spaced. In others ribs regularly spaced from nucleus. Beyond shell diameters of *c.* 15 mm, strong, rectiradiate to weakly concave flank ribs regularly spaced in all specimens. At shell diameters of *c.* 75 mm, ribbing becomes weakly prorsiradiate and irregular in spacing and strength. In one specimen, ribs bifurcate on upper flank projecting forward onto venter as weak, forwardly inclined striae. One specimen showing complex, strongly retracted umbilical lobes (Pl. 4.6, fig. 16). At large shell diameters nodes bullae are present on the lower flank (Pl. 4.6, fig. 15).

REMARKS: Volution and ribbing on the inner whorls of *S. cf. chilensis* are very similar to *S. hadroptychus* (Wöhner). The QCI form differs in having ribs that are irregular and much weaker at large shell diameters. Some *S. cf. chilensis* resemble *Alsatites nigromontanus* of Guex (1995) on the inner whorls but differ in lacking ribs on the umbilical wall and in having ribs that are

less concave at similar shell diameters. *Sunrisites* cf. *chilensis* is more involute than *S. brimblecombei* at large shell diameters and differs from *S. chilcotinensis* in having a lower number of ribs that are never nodal on the inner whorls.

OCCURRENCE: Section B, C, and G, Sunrisensis Zone; section D, Sunrisensis and Morganense zones.

*Sunrisites* cf. *senililevis* Longridge, Smith, Pálffy, Tipper

Plate 4.6, figure 11

cf. in press *b Sunrisites senililevis* Longridge *et al.*, figs 7.1-7.2, 7.7-7.8, 8.3

MATERIAL AND MEASUREMENTS: One poorly preserved external mould (GSC 107385). Measurements of volution and ribbing density are presented in Figure 4.13A-B.

DESCRIPTION: Moderately involute for genus. Rectiradiate ribs blunt, coarse, and widely spaced (8-9 ribs per half whorl) with high rounded profile. Ribs show greatest height midflank.

REMARKS: The inner and intermediate whorls of this species differ from all other *Sunrisites* species in having much coarser and more widely spaced ribs.

OCCURRENCE: Section F, Mineralense/Rursicostatum zones.

### **Genus BADOUXIA Guex and Taylor, 1976**

TYPE SPECIES: *Psiloceras canadense* Frebold, 1951

#### ***Badouxia canadensis* (Frebold, 1951)**

Plate 4.4, figures 3, 9

1951 *Psiloceras canadense* Frebold, p. 3, pl. 1, figs 2, 4 (holotype refigured here)-5.

- 1967 *Psiloceras occidentale* Frebold, p. 19, pl. 1, figs 4-5, text-fig. 4.
- 1967 *Eolytoceras* sp. indet. 2. Frebold, p. 16, pl. 6, fig. 2.
- 1987 *Badouxia* cf. *canadensis* (Frebold); Quinzio Sinn, pl. 1, fig. 11.
- 1994 *Badouxia canadensis* (Frebold); Pálffy *et al.*, pl. 1, fig. 3.
- 1994 *Badouxia canadensis* (Frebold); Hillebrandt pl. 1, fig. 4.
- 1998 *Badouxia oregonensis* Taylor, p. 494, fig. 23 (11-14).
- ? 1999 *Badouxia?* sp.; Pálffy *et al.*, fig. 5F.
- ? 1999 *Badouxia canadensis* (Frebold); Pálffy *et al.*, fig. 5I.
- 2000 *Badouxia canadensis* (Frebold); Taylor pl. 2, figs 10-15.
- 2000b *Badouxia* cf. *canadensis* (Frebold); Hillebrandt pl. 2, fig. 5.
- 2000c *Badouxia canadensis* (Frebold); Hillebrandt p. 46, pl. 14, figs 4, 7, 11, pl. 15, fig. 10.
- ? 2000c *Badouxia canadensis* (Frebold); Hillebrandt p. 46, pl. 14, figs 6, 8, pl. 15, figs 11, 17, pl. 16, figs 2, 3, 5-6.
- 2006 *Badouxia canadensis* (Frebold); Longridge *et al.*, p. 802, pl. 1; text-figs 10A-C, 11A-B.

**MATERIAL AND MEASUREMENTS:** Three flattened measured specimens (GSC 107392-107393, 107397) and one incomplete specimen (GSC 107399). Some specimens with preserved relief. Measurements of volution and ribbing density are presented in Figure 4.13A-B.

**DESCRIPTION:** Moderately evolute to moderately involute form. Whorl cross-section rounded to ellipsoid. On inner whorls, simple flank ribs of moderate strength vary in density and orientation from weakly to strongly prorsiradiate. Ribs arise at flank base, show greatest height mid-flank before fading on upper flank. At large shell diameters ( $D > 6$  cm), flanks become smooth.

REMARKS: In 1991, Pálffy completed a study of the *Badouxia* fauna from the QCI as part of his unpublished Master's thesis. Since this time, several detailed taxonomic studies of *Badouxia* assemblages from other areas of North America have occurred. A study by Longridge *et al.* (2006) resulted in the elimination of two previously recognized species, *Badouxia occidentalis* (Frebold) and *B. oregonensis* Taylor, which were placed in synonymy with *B. canadensis* (Frebold). These taxonomic changes are reflected herein.

OCCURRENCE: Section G, Mineralense Zone; sections E and F, Mineralense/Rursicostatum zones. Also occurs in the Columbiae Zone in the QCI.

### Genus **PSEUDAETOMOCERAS** Spath, 1923*b*

TYPE SPECIES: *Arietites abnormilobatus* Wähner, 1886

#### *Pseudaetomoceras* cf. *castagnolai* (Cocchi in Canavari, 1882)

Plate 4.3, figures 5, 7

cf. 1882 *Arietites* (*Oxynoticeras*) *Castagnolai* Cocchi; Canavari, p. 141, pl. 20, figs 18-19.

cf. 1886 *Arietites Castagnolai* Cocchi; Wähner, p. 58, pl. 21, fig. 2; pl. 23, figs 2-3.

cf. 1888 *Arietites Castagnolai* Cocchi; Canavari, p. 136, pl. 6, figs 18-19; text-fig. 6b.

cf. 1995 *Pseudaetomoceras castagnolai* (Cocchi); Guex, p. 52, pl. 27, fig. 25.

cf. 2000 *Pseudaetomoceras castagnolai* (Cocchi); Kment, p. 206, pl. 3, fig. 2.

2000 *Pseudaetomoceras* cf. *castagnolai* (Cocchi); Kment, p. 206, pl. 3, fig. 3.

in press *a Pseudaetomoceras* cf. *castagnolai* (Cocchi); Longridge *et al.*, pl. 3, figs 22-23;  
text-fig. 9G.

MATERIAL: Twelve flattened specimens and fragments (GSC 130735-130736).

DESCRIPTION: Involute form for genus. Crowded flank ribs strongly concave on flanks. Keel suggested by *c.* 18 mm shell diameter. Suture line and cross-section not available.

REMARKS: Measurements were not taken on the QCI material due to inconsistent preservation of the keel that would produce inaccurate measurements of shell diameter.

OCCURRENCE: Section B, Pleuroacanthitoides to Sunrisensis zones; section C, Sunrisensis Zone; section D, Sunrisensis to Morganense zones.

***Pseudaetomoceras cf. doetzkirchneri* (Gümbel, 1861)**

Plate 4.2, figures 10, 12

cf. 1879 *Arietites Doetzkirchneri* (Gümbel); Neumayr, p. 40, pl. 5, fig. 1.

cf. 1879 *Ammonites Doetzkirchneri* Gümbel; Reynès, pl. 33, figs 7-8.

cf. 1886 *Arietites Doetzkirchneri* (Gümbel); Wähner, p. 56, pl. 22, figs 1-2.

cf. 1995 *Pseudaetomoceras doetzkirchneri* (Gümbel); Guex, p. 52, pl. 27, figs 7-8, 15-16, 23-24.

? 2004 *Pseudaetomoceras doetzkirchneri* (Gümbel); Hall and Pitaru, p. 4, pl. 2, fig. 2.

MATERIAL AND MEASUREMENTS: Three measured specimens (GSC 130738-130740) and two external moulds (GSC 130737). All material flattened. Measurements of volution and number of ribs are presented in Figure 4.13A-B.

DESCRIPTION: Moderately evolute for genus. Moderately crowded flank ribs concave on flanks. No definitive keel by shell diameters of *c.* 27 mm. Suture line and cross-section not available.

REMARKS: *Pseudaetomoceras cf. doetzkirchneri* may have a slightly lower number of ribs on the inner whorls than *P. doetzkirchneri*. The specimen of Hall and Pitaru (2004, pl. 2, fig. 2) is

marked with a question mark in the synonym list as it has sigmoid flank ribs. This character is not as apparent in other *P. doetzkirchneri*.

OCCURRENCE: Sections B and C, Sunrisensis Zone.

Family SCHLOTHEIMIIDAE Spath, 1923*b*

**Genus STORTHOCERAS Lange, 1941**

TYPE SPECIES: *Aegoceras extracostatum* Wöhner, 1882

These species are assigned to the genus *Storthoceras* based on the small shell diameter and lack of interruption of ribs on the venter of the internal whorls.

***Storthoceras* aff. *garfieldense* (Taylor, 1998)**

Plate 4.8, figures 20, 25

aff. 1998 *Saxoceras garfieldense* (Taylor), p. 479, figs 13.6-13.7, 13.10-13.13, 14.3-14.4.

MATERIAL AND MEASUREMENTS: Fourteen measured specimens (GSC 130741-130754) and many incomplete specimens and fragments. All material flattened except one specimen with partial, poorly preserved venter. Measurements of volution and ribbing density are presented in Figure 4.13C-D.

DESCRIPTION: Involute form for genus. Fine, moderately crowded sigmoid ribs on flanks. Ribs project forward on uppermost flank onto venter. On largest specimen (Pl. 4.8, fig. 25), some ribs concave on flanks of outer whorl. Preservation poor but ribbing fades somewhat on venter. Suture line and whorl cross-section not preserved.

REMARKS: *Storthoceras* aff. *garfieldense* is most similar in ribbing number and style to the holotype of *S. garfieldense* (Taylor 1998, fig. 14.3-14.4) although it may be slightly more involute than *S. garfieldense* at small shell diameters and is somewhat more evolute at large shell diameters. *Storthoceras* aff. *garfieldense* is similar to the slightly more evolute *Schlotheimia* (?) sp. A of Hillebrandt (2000c, pl. 8, figs 26-29). The small shell diameter of the South American material precludes confident comparison with the QCI form. *Aegoceras* n. f. indeterminate of Wöhner (1884, pl. 23, fig. 5) is similar to the QCI form in volution and rib trajectory but has a higher number of ribs at comparable shell diameters. The flank rib trajectory resembles that of *Storthoceras* cf. *circacostatum* (Wöhner) but the South American form is more involute. Flank ribs on *S. aff. garfieldense* are more sigmoid than in alpine *Storthoceras circacostatum*.

OCCURRENCE: Section B, Coronoides to Sunrisensis zones; sections H and I, Coronoides Zone.

***Storthoceras* cf. *australe* Hillebrandt, 2000c**

Plate 4.8, figures 14, 19

- cf. 1965 *Schlotheimia angulata* (Schlotheim); Thiele, p. 39, pl. 4, figs 9-11.
- cf. 1968 *Schlotheimia* (*Schlotheimia*) sp. ex. gr. *S. angulata* (Schlotheim); Cecioni and Westermann, p. 68, pl. 7, figs 3-4.
- cf. 1980 *Schlotheimia* cf. *angulata* (Schlotheim); Escobar, p. 66, pl. 4, figs 1-4.
- cf. 1988 *Schlotheimia* cf. *angulata* (Schlotheim); Riccardi *et al.*, pl. 1, figs 10-11.
- cf. 1990 *Storthoceras* cf. *haploptychum* (Wöhner); Hillebrandt, pl. 3, fig. 13.
- cf. 1990 *Storthoceras* sp.; Hillebrandt, pl. 3, figs 16-18, 21-22.
- cf. 1991 *Schlotheimia* cf. *angulata* (Schlotheim); Riccardi *et al.*, fig. 4.10-4.11.
- cf. 2000c *Storthoceras australe* Hillebrandt, p. 23, pl. 6, fig. 12-24, text-fig. 3e-h.

MATERIAL AND MEASUREMENTS: Eight measured specimens (GSC 130755-130762) and many incomplete specimens and fragments. All material flattened. Measurements of volution and ribbing density are presented in Figure 4.13C-D.

DESCRIPTION: Evolute form for genus. Moderately crowded rursiradiate ribs. Most ribs straight to weakly concave on flanks. Occasional flank ribs weakly sigmoid. Ribs project strongly forward on upper flank. Whorl cross-section and suture line not preserved.

REMARKS: *Storthoceras* cf. *australe* is very similar to *S. australe* from South America in volution as well as rib number and orientation. *Storthoceras* cf. *australe* differs from the more involute *S. aff. garfieldense* from the QCI in having much less common sigmoid flank ribs. The QCI form is more involute than *Schlotheimia phobetica* Lange.

OCCURRENCE: Section B, Pleuroacanthitoides to Sunrisensis zones.

***Storthoceras* sp.**

Plate 4.8, figures 9-10

MATERIAL: One partially preserved whorl fragment (GSC 130764).

DESCRIPTION: Evolute form for genus. Whorl cross-section high suboval. Irregularly spaced flank ribs concave to sigmoid. Ribs project strongly forward on upper flank. Much weakened ribs continue across venter in forward-directed chevron. Suture line not preserved.

REMARKS: This fragment is assigned to *Storthoceras* based on the sigmoidal ribs that are clearly projected forward on the venter. More complete material is required in order for this form to be identified at the species level.

This fragment is more evolute and less densely ribbed than *Storthoceras* aff. *garfieldense* from the QCI and is much more evolute than the type material of *S. garfieldense* from Nevada.



It is less densely ribbed and has ribs that are more consistently sigmoid than *S. australe* from South America, *S. cf. australe* from the QCI and *K. frigga* (Wähner). This fragment resembles *C. harpoptychum* (Holland) and *Curviceras cf. harpoptychum* of Hillebrandt (2000c) but differs in having ribs that are more strongly sigmoid, project more strongly forward on the venter and are more irregularly spaced.

OCCURRENCE: Section B, Coronoides Zone.

### **Genus CURVICERAS Blind, 1963**

TYPE SPECIES: *Ammonites subangularis* Oppel, 1862

#### ***Curviceras haidae* sp. nov.**

Plate 4.8, figures 12-13

DERIVATION OF NAME: Named after the Haida Native Indian tribe that is indigenous to the QCI (Haida Gwaii).

MATERIAL AND MEASUREMENTS: One measured three-dimensional specimen (GSC 130763). Measurements of volution and ribbing density are presented in Figure 4.13C-D.

HOLOTYPE: GSC 130763 (Pl. 4.8, figs 12-13) from the Coronoides Zone, Kennecott Point, section B, level 12, QCI.

DIAGNOSIS: Moderately evolute form. Whorl cross-section high suboval. On inner whorls, flank ribs rectiradiate to weakly concave. Ribs on outer whorl more distantly spaced and weakly concave. Ribs continue uninterrupted across venter.

DESCRIPTION: Moderately evolute form. Whorl cross-section high suboval. Umbilical wall on outer whorl upright, umbilical shoulder rounded. On inner whorls, crowded flank ribs

rectiradiate to weakly concave. Ribs on outer whorl more distantly spaced and weakly concave. Ribs begin on lowest flank, increasing in strength upflank. Rib style on venter of inner whorls unknown. On outer whorl, ribs project forward on uppermost flank and continue uninterrupted across venter in a forward-directed chevron. Ribs with greatest height midventer. Septal suture line is not preserved.

REMARKS: *Curvicerias haidae* is unusual in having very strong ribbing across the venter which is similar in strength to *W. insolitum* of Guérin-Franiatte (1990) and *C. hircinum* (Quenstedt). However, *C. haidae* is more evolute and has weaker, more closely spaced ribs than the former and has concave rather than sigmoid ribs like the latter. The lateral morphology of the *C. haidae* is similar to *Saxoceras* aff. *extracostatum* (Wähner) (*Aegoceras* n.f. indet, cf. *extracostatum* in Wähner 1882, pl. 16, fig. 1) but it differs in having much stronger ribs crossing the venter. *Curvicerias haidae* differs from the slightly more involute *S.* aff. *portlocki* in having more dense ribbing on the inner whorls and in having ribbing that continues uninterrupted across the venter. The QCI form is more evolute than *Saxoceras?* ex gr. *portlocki* of Pálffy et al. (1999, fig. 4I) and has finer more closely spaced ribs than the inner whorls of *Kammerkarites* cf. *frigga* (Pálffy et al. 1999, fig. 4E). *Curvicerias haidae* somewhat resembles the alpine species *S. curviornatum* (Wähner) and *S. circacostatum* (Wähner) but differs in being more evolute, and in having ribs that are much stronger across the venter. In addition, the ribs in *S. curviornatum* are sigmoid rather than concave.

OCCURRENCE: Section B, Coronoides Zone.

### **Genus SAXOCERAS Lange, 1924**

TYPE SPECIES: *Saxoceras costatum* Lange, 1924.

***Saxoceras* aff. *portlocki* (Wright, 1881)**

Plate 4.8, figures 2-5, 11, 15

aff. 1881 *Aegoceras Portlocki* Wright, p. 372, pl. 48, figs 4-5.

aff. 1952 *Schlotheimia (Waehneroceras) portlocki* (Wright); Donovan, p. 646, pl. 12, fig. 5.

aff. 1961 *Schlotheimia (Waehneroceras) portlocki* (Wright); Dean *et al.*, pl. 63, fig. 4.

aff. 1965 *Waehneroceras (Waehneroceras) portlocki* (Wright); Elmi and Mouterde, p. 224,  
pl. 6, figs 2, 5.

? 1981 *Waehneroceras* cf. *W. portlocki* (Wright); Imlay, p. 30, pl. 2, figs 7, 10-15.

aff. 1986 *Waehneroceras portlocki* (Wright); Guerin-Franiatte and Muller, p. 418, pl. 3, fig.  
3.

aff. 1990 *Waehneroceras portlocki* (Wright); Guerin-Franiatte, p. 89, pl. 10, fig. 14, pl. 11,  
fig. 3.

? 1995 *Saxoceras extracostatum* (Wöhner); Guex, p. 36, pl. 16, figs 3-4, 8-9.

1999 *Saxoceras?* sp.; Pálffy *et al.*, fig. 4G, J.

? 2004 *Waehneroceras subangulare* (Oppel); Hall and Pitaru, p.4, pl. 1, fig. 4.

aff. 2004 *Waehneroceras* cf. *portlocki* (Wright); Hall and Pitaru, p.4, pl. 1, fig. 7.

MATERIAL AND MEASUREMENTS: Seven measured specimens (GSC 130766-130772) and many distorted specimens and fragments (GSC 130765). Some specimens with partial three-dimensional preservation. Measurements of volution and ribbing density are presented in Figure 4.13C-D.

DESCRIPTION: Midvolute form. Whorl cross-section high suboval with widest point of whorl low flank if ribs not considered (Pl. 4.8, figs 4-5). Flank ribs on inner whorls crowded, sharp and usually concave. Beyond shell diameters of 30 mm, more coarse flank ribs can be concave, straight or sigmoid and rectiradiate to weakly prorsiradiate. Spacing between ribs variable with

ribs more or less crowded. Ribs have greatest strength on uppermost flank where they project forward onto venter. Most ribs sharply interrupted on venter forming a smooth band down the midline. In some specimens, occasional ribs weaken but continue across venter in forward-directed chevron. Septal suture line is not preserved.

REMARKS: *Saxoceras* aff. *portlocki* differs from *S. portlocki* on the inner whorls in having flank ribs that are more commonly concave rather than sigmoid and weakly prorsiradiate on the flanks. It includes specimens with ribs that are less strongly projected forward on the uppermost flank and other specimens with more widely spaced ribbing on the flanks at larger shell diameters. *Saxoceras* aff. *portlocki* is probably a new species but it cannot be established until better preserved large material is found.

As discussed at length by Guex (1995, p. 35), *S. portlocki* and *S. extracostatum* may belong to the same biospecies. They differ only with respect to the ventral ornament of the internal whorls. *Saxoceras portlocki* has ribs that are consistently interrupted on the venter whereas in *S. extracostatum* has ribs that continue across the venter. The ventral ornament of the QCI form is intermediate between these two 'species'. Although most ribs are interrupted on the venter, occasional ribs weaken but continue across the venter.

*Saxoceras* aff. *portlocki* differs *W. subangulare* (Oppel) in being more consistently involute and in having ribs that are much less commonly sigmoid on the flanks at similar shell diameters. Ribs also continue less commonly across the venter. The QCI form resembles a specimen described under *Schlotheimia angulata* in Hall and Pitaru (2004, pl. 2, fig. 4). It differs in being more involute and in having ribs that are much less commonly prorsiradiate on the inner whorls. As discussed above, the distance between the flank ribs of *S. aff. portlocki* is variable. The division of the specimens into different species based on this difference would be arbitrary as there is a continuum of variation within the material. The specimens with wider spaced ribs are similar on the outer whorl to *S. schroederi* Lange (e.g. Pl. 4.8, fig. 15).

Several occurrences in other areas of North American are tentatively included in the synonymy list because they differ somewhat from the QCI form. A specimen figured by Hall and Pitaru (2004, pl. 1, fig. 4) has ribs that are more commonly sigmoid on the flanks and are not interrupted on the venter (Hall and Pitaru 2004, p. 4). The fragments figured by Guex (1995, pl. 16, figs 3-4, 8-9) differ in being more depressed and in having flank ribs that are less strongly concave. Imlay (Imlay 1981, p. 30) describes the venter in his Alaska material as smooth along its midline but does not mention the occurrence of occasional ribs continuing across the venter. Unfortunately, no ventral view is figured.

OCCURRENCE: Sections B and I, Coronoides Zone.

### **Genus KAMMERKARITES Spath, 1924**

TYPE SPECIES: *Aegoceras diploptychum* Wöhner, 1882

#### ***Kammerkarites* sp. nov.**

Plate 4.5, figure 1

MATERIAL AND MEASUREMENTS: Two flattened specimens (GSC 130773-130774).

Measurements of volution and ribbing density are presented in Figure 4.14A-B.

DESCRIPTION: Evolute form. Straight flank ribs rectiradiate to rursiradiate on inner whorls. Beyond shell diameters of 20 mm, flank ribs slightly concave to weakly prorsiradiate. Ribs project slightly forward mid to upper flank. Ribs remain strong across entire flank. Suture line not preserved.

REMARKS: The QCI form is probably a new species but it cannot be formally established until better preserved material is collected. The flattened state of the current specimens means it is not possible to define whorl cross-section or ventral features. Furthermore, a suture line is lacking.

*Kammerkarites* sp. nov. is similar in volution and rib number to a specimen of *Curviceras* cf. *engonium* (Lange) of Hillebrandt (2000c, pl. 6, fig. 9). Poor preservation and the small size of the South American specimen hamper very close comparison. The smaller material of *C.* cf. *engonium* figured by Hillebrandt (2000c, pl. 6, figs 4-8) is more involute than the QCI form and has a lower number of flank ribs. The rib orientation of the more involute *K. bayoensis* Hillebrandt is similar to the QCI form but it differs having much stronger flank ribs. *Kammerkarites* sp. nov. is similar to *K. paltar* (Wöhner) but is more evolute at large shell diameters and has strong ribs that are more consistent on the uppermost flanks. The inner whorls of *Kammerkarites* sp. nov. resemble *K. beneckeii* (Guerin-Franjatte) but the QCI form is more evolute on the outer whorls and has ribs that are much stronger on the upper flank.

OCCURRENCE: Section A, Mulleri/Occidentalis zones.

***Kammerkarites* aff. *chinchillaensis* Hillebrandt, 2000c**

Plate 4.5, figures 2, 5

aff. 2000c *Kammerkarites chinchillaensis* Hillebrandt, p. 15, pl. 5, figs 4-14; text-fig. 2h-m.

MATERIAL AND MEASUREMENTS: One measured (GSC 130776) and one incomplete specimen (GSC 130775). Both specimens flattened and poorly preserved. Measurement of volution is presented in Figure 4.14A.

DESCRIPTION: One involute (Pl. 4.5, fig. 2) and one midvolute specimen (Pl. 4.5, fig. 5).

Innermost whorls with strong, rectiradiate ribs that have greatest strength on upper flank. By

shell diameters of *c.* 25 mm, ribs weaken. Very faint prorsiradiate ribs occur on outer whorl.

Suture line and whorl cross-section not preserved.

REMARKS: Although the volution of the two specimens of *K. aff. chinchillaensis* differs, the style of ornament is very similar. Due to small sample size, a clear understanding of the variation in the volution of this form is not possible. Thus, the two specimens are not separated here.

Ribbing style of the QCI form is very similar to *K. chinchillaensis* from South America. However, GSC 130776 (Pl. 4.5, fig. 2) is considerably more involute than *K. chinchillaensis* and the QCI form may represent a new species.

OCCURRENCE: Sections A and B, Mulleri/Occidentalis zones.

***Kammerkarites cf. frigga* (Wähner, 1884)**

Plate 4.8, figures 6-8

cf. 1884 *Aegoceras frigga* Wähner, p. 106, pl. 23, figs 1-3.

cf. 1952 *Storthoceras frigga* (Wähner); Lange, p. 127, pl. 16, figs 6, 9; text-fig. 61.

cf. 1993b *Kammerkarites frigga* (Wähner); Rakús, p. 22, pl. 2, figs 2-4, pl. 3, figs 2-5; text-figs 13-15.

? 1994 *Storthoceras* sp.; Hillebrandt, pl. 1, figs 5, 8.

cf. 1995 *Kammerkarites frigga* (Wähner); Guex, p. 32, pl. 17, figs 5-14.

cf. 1999 *Kammerkarites frigga* (Wähner); Rakús, p. 340, pl. 4, figs 1, 3-5; text-fig. 11.

1999 *Kammerkarites cf. frigga* (Wähner); Pálffy *et al.*, fig. 4 B, E-F, H.

cf. 2000 *Choristoceras aff. marshi* (Hauer); Yin and Enay, p. 607, figs 3.1-3.2.

? 2000c *Storthoceras cf. frigga* (Wähner); Hillebrandt, pl. 6, figs 28-31.

? 2004 *Kammerkarites frigga* (Wähner); Stevens, p. 33, pl. 4, figs 14-15, pl. 5, figs 1-14.

cf. 2007 *Kammerkarites frigga* (Wähner); Yin *et al.*, p. 24, pl. 4, figs 6-9, 12-14; table 4.

MATERIAL AND MEASUREMENTS: Thirteen measured specimens (GSC 130777-130789) and several distorted specimens and fragments. All material flattened except one three-dimensional specimen. Measurements of volution and ribbing density are presented in Figure 4.14A-B.

DESCRIPTION: Evolute form, compressed on inner whorls. Nucleus nodose. Flank ribs prorsiradiate projecting strongly forward on uppermost flank. On three-dimensional specimen (Pl. 4.8, figs 7-8,  $D_{max} = c. 18 \text{ mm}$ ), ribs cross venter in a chevron of slightly greater than  $90^\circ$ .

REMARKS: Guex (1981, 1995) proposed *K. frigga* as the microconch and *K. haploptychus* (Wöhner) as the macroconch of a sexually dimorphic pair. The morphological variation seen within these two species in the QCI as well as their similar stratigraphic range supports this idea.

The material of Hillebrandt (1994, 2000c) and Stevens (2004) is marked with a question mark in the synonymy list. The QCI form of *K. cf. frigga* is similar to two specimens of *Storthoceras cf. frigga* of Hillebrandt (1994, pl. 1, fig. 5; 2000c, pl. 6, figs 28-29). It has a much lower number of ribs than the remaining specimens Hillebrandt attributed to *S. cf. frigga* (1994, pl. 1, fig. 8; 2000c, pl. 6, figs 30-31). The small shell diameter of the South American material precludes confident comparison with the QCI form. The majority of Stevens material is not well preserved; however, the ribs often appear too prorsiradiate on the flanks and the bend forward on the ventrolateral shoulder is less marked than in most *K. frigga*. As Stevens (2004, p. 33) mentions, the New Zealand form may also be more involute.

OCCURRENCE: Section A, Mulleri/Occidentalis zones; section B, Mulleri/Occidentalis to Coronoides zones.

***Kammerkarites cf. haploptychus* (Wöhner, 1882)**

Plate 4.5, figures 3, 6-7



- cf. 1882 *Aegoceras haploptychum* Wähner, p. 76, pl. 17, figs 1-5.
- cf. 1952 *Storthoceras haploptychum* (Wähner); Lange, p. 132, pl. 17, figs 1-3.
- cf. 1963 *Psiloceras (Storthoceras) haploptychum* (Wähner); Blind, p. 56, pl. 1, fig. 7.
- cf. 1995 *Kammerkarites haploptychus* (Wähner); Guex, p. 32, pl. 15, figs 1-2, pl. 17, figs 3-4, pl. 18, figs 3-8, pl. 19, figs 1-2, 5-7.

**MATERIAL AND MEASUREMENTS:** Three measured specimens (GSC 130790-130792) and many incomplete specimens and fragments. This form can get very large (Dmax = c. 270 mm). Material is moderately preserved; all material is flattened. Measurements of volution are presented in Figure 4.14A.

**DESCRIPTION:** Midvolute form for genus. Flank ribs weakly rursiradiate on innermost whorls. On intermediate whorls ribs vary from weakly rursiradiate to weakly prorsiradiate low to midflank projecting forward on upper flank. Ribs have greatest strength low to midflank fading on upper flank. Beyond c. 125 mm shell diameter, flank ribs more widely spaced and concave to weakly prorsiradiate (Pl. 4.5, fig. 3).

**REMARKS:** The North American *K. haploptychus* may include slightly more evolute forms than the alpine variety of *K. haploptychus*. One specimen of *K. haploptychus* from the QCI (Pl. 4.5, fig. 6) and one specimen of Guex (1995, pl. 19, figs 5-6) are very similar to *Storthoceras (Megastomoceras) schmidtii* (Lange) (Lange 1941, pl. 3, fig. 10).

**OCCURRENCE:** Sections A, H and I, Mulleri/Occidentalis zones; section B, Mulleri/Occidentalis to Coronoides zones.

***Kammerkarites cf. rectiradiatus* Guex, 1995**

Plate 4.4, figure 11

- cf. 1995 *Kammerkarites rectiradiatus* Guex, p. 33, pl. 18, figs 1-2.

MATERIAL AND MEASUREMENTS: One flattened measured specimen (GSC 130675).

Measurements of volution and ribbing density are presented in Figure 4.14A-B.

DESCRIPTION: Involute form for genus. Strong prorsiradiate ribs with greatest strength mid to upper on inner whorls. Beyond *c.* 25 mm shell diameter, strong ribs rectiradiate with greatest strength midflank. Uppermost flank smooth.

REMARKS: Hillebrandt (2000c, p. 8) commented on the similarity of *K. rectiradiatus* and *Discamphiceras pleuronotum*. However, the large size and lack of suture line on the former form do not permit a thorough comparison. Unfortunately, the poorly preserved QCI specimen is also large and lacks a suture line.

*Kammerkarites cf. rectiradiatus* is similar to some specimens of *D. silberlingi*. The former form probably differs in having ribs that are weaker on the upper flank although more and better-preserved material is required to fully assess the differences between the two forms. *Kammerkarites cf. rectiradiatus* has ribs that continue much less frequently onto the venter than the more evolute *K. diploptychoides* Guex.

OCCURRENCE: Section B, Coronoides Zone.

***Kammerkarites aff. megastoma* (Gümbel, 1861)**

Plate 4.5, figure 4

aff. 1882 *Aegoceras megastoma* Gümbel; Wähner, p. 78, pl. 18, figs 1-6.

aff. 1963 *Psiloceras (Discamphiceras) megastoma* (Gümbel); Blind, p. 53, pl. 2, fig. 2.

aff. 1976 *Psiloceras (Discamphiceras) megastoma* (Gümbel); Schlegelmilch, p. 34, pl. 5, fig.

9.

aff. 1990 *Waehneroceras (Kammerkarites) megastoma* (Gümbel); Guérin-Franjatte, p. 95, pl.

12, fig. 4.

aff. 1993b *Kammerkarites megastoma* (Gümbel); Rakús, p. 21, pl. 4, fig. 1; text-fig. 12.

ex. gr. 1999 *Kammerkarites* ex gr. *megastoma* (Gümbel); Pálffy *et al.*, fig. 4R.

non. 2004 *Kammerkarites megastoma* (Gümbel); Stevens, p. 31, pl. 6, figs 1-2; text-fig. 18.

MATERIAL AND MEASUREMENTS: One flattened measured specimen (GSC 130794).

Measurements of volution and ribbing density are presented in Figure 4.14A-B.

DESCRIPTION: Midvolute form for genus. Flank ribs on innermost whorls closely spaced and weakly rursiradiate. Ribbing style between shell diameters of 40 – 65 mm obscured. Beyond this, flank ribs evenly spaced and rectiradiate. Ribs begin on lowest flank, have greatest strength midflank and fade on upper flank. Ribs on last part of outer whorl weaker.

REMARKS: The ribbing style of *K. aff. megastoma* is similar to *K. megastoma* but the two forms differ in several respects. The inner whorls of *K. aff. megastoma* are poorly preserved but suggest it is somewhat more involute at small shell diameters. In addition, it is slightly more evolute at large shell diameters and has a higher number of ribs on the outer whorls. It is not possible to recognize the cross-section or ventral features on the QCI specimen as it is flattened. Also, the single sample does not permit an understanding of the variability within the species. More and better material is required before a new species can be established.

Stevens (2004, p. 32) points out several differences between the New Zealand *K. megastoma* and other specimens of the genus. We consider the ribbing too prorsiradiate to be *K. megastoma* and the specimens are much too involute.

The ribbing style and number of the QCI form are similar to *K. beneckeii* (Guerin-Franiatte) on the outer whorls. However, the French form is much more evolute on the inner whorls.

OCCURRENCE: Section B, Mulleri/Occidentalis zones.

Plate 4.8, figure 1

cf. 1980 *Kammerkarites praecoronoides* Guex, p. 134, pl. 1, fig. 5.

cf. 1995 *Kammerkarites praecoronoides* Guex, p. 34, pl. 10, figs 1-20.

MATERIAL AND MEASUREMENTS: One flattened slightly distorted specimen (GSC 130793).

DESCRIPTION: Midvolute specimen. Nodose nucleus. Irregularly spaced, rectiradiate flank ribs. Ribs have greatest strength on upper flank projecting weakly forward on uppermost flank.

REMARKS: This specimen falls within the variation in rib number and volution of *K. praecoronoides*.

OCCURRENCE: Section A, Mulleri/Occidentalis zones.

**Genus FRANZICERAS Buckman, 1923**

TYPE SPECIES: *Franziceras ruidum* Buckman, 1923

***Franziceras cf. coronoides* (Guex, 1980)**

Plate 4.6, figures 1-2, 4-6, 12-13

cf. 1980 *Alsatitoides coronoides* Guex, p. 130, pl. 1, fig. 2.

cf. 1995 *Franziceras coronoides* (Guex), p. 37, pl. 20, figs 1-10, pl. 27, figs 17-18, 26-27.

MATERIAL AND MEASUREMENTS: Eight measured (GSC 130795, 130796-130803) and many incomplete specimens (GSC 130702, 130796). In part good preservation; some small three-dimensional specimens, large specimens partially to completely flattened. Measurements of volution and ribbing density are presented in Figure 4.14C-D

DESCRIPTION: Midvolute form. Nucleus nodose. Cross-section of inner whorls suboval if ribs not considered; weakly trapezoidal if ribs considered (Pl. 4.6, figs 5-6). Inner whorls with rectiradiate to weakly prorsiradiate flank ribs with ventrolateral nodes. Weakened ribs project forward on venter. In adult stage, preserved relief suggests whorl cross-section weakly trapezoidal if ribs not considered; strongly trapezoidal if ribs considered. Ribs powerful and strongly rursiradiate. Ventrolateral nodes persist in some specimens (Pl. 4.6, fig. 2). Keel variable. In one specimen, keel visible beyond shell diameter of 8 mm. In other specimen, slight median protrusion but no defined keel at whorl height of 10 mm. Weakened ribs project forward on venter (Pl. 4.6, fig. 1). In well preserved fragment, ribs bifurcate into two or three coarse folds that project forward across venter (Pl. 4.6, fig. 6). Suture line not available.

REMARKS: *Franziceras* cf. *coronoides* may have a slightly lower number of ribs on the inner whorls than the type material of *F. coronoides*. Similar to what we see in the Nevada material, the QCI form shows considerable variation in volution. The specimen from Nevada (Guex 1995, pl. 20, figs 3-4) is similar to the more evolute forms from the QCI (Pl. 4.6, fig. 4) whereas the specimens from Nevada (Guex 1995, pl. 20, figs 1-2, 5-6) are similar to the more involute forms in the QCI (Pl. 4.6, fig. 2). However, in the QCI material, the more evolute variety of the species occurs slightly lower in section (section B, locality 12) than the more involute variety (section B, localities 18-21). More collections are required to ascertain whether this difference in stratigraphic level is due to collection failure or a true difference at the species level. As mentioned above, the inner whorls of *F. cf. coronoides* are virtually identical to those of *F. coronoides*, *K. praecoronoides* and *Franziceras kennecottense* sp. nov. from the QCI. It differs from the later two species at larger shell diameters in having ribs that are much stronger and much more rursiradiate. In addition, the ventrolateral nodes persist to larger shell diameters in *F. coronoides* than in *K. praecoronoides* (>30 mm).

The more evolute specimens of the QCI form which lack a distinct keel are very similar to *F. graylockense* Taylor. They differ in having ventrolateral nodes as well as in having ribs that are consistently more strongly rursiradiate at similar shell diameters. Ribs of the adult stage are much more rursiradiate than in *F. ruidum* Buckman. The inner and intermediate whorls of *F. cf. coronoides* are similar to *F. sebanum* (Pickler) but the QCI form differs at large shell diameters as the ribs are stronger, less crowded and more strongly rursiradiate. The QCI form is much more involute than *F. aff. ruidum* from Nevada.

OCCURRENCE: Section B, Coronoides to Sunrisensis zones.

***Franziceras kennecottense* sp. nov.**

Plate 4.6, figures 3, 7-9; Figure 4.11F

DERIVATION OF NAME: Named for Kennecott Point on Graham Island, QCI where the type material originates.

MATERIAL AND MEASUREMENTS: Seventeen measured (GSC 130805-130818, 131665-131667) and many incomplete specimens (GSC 130804). Material moderately preserved; some three-dimensional specimens. Measurements of volution and ribbing density are presented in Text-figure 14C-D.

HOLOTYPE: GSC 130806 (Pl. 4.6, fig. 3) from the Coronoides Zone, Kennecott Point, section B, level 14, QCI.

PARATYPES: GSC 130805, 130807-130818, 131665-131667 from the Coronoides to Sunrisensis zones, Kennecott Point, section B, QCI; Kunga Island, section H.

DIAGNOSIS: Midvolute form. Whorl cross-section probably weakly trapezoidal. Moderately strong, gently sigmoid ribs weakly rursiradiate to weakly prorsiradiate. Ventrolateral nodes present. Ribs weaken on venter. Ribs can bifurcate. Some with low keel.

DESCRIPTION: Midvolute form. Preserved relief suggests whorl cross-section weakly trapezoidal, tapering toward dorsum beyond 25 mm shell diameter. Innermost whorls nodose. Beyond this, moderately strong, gently sigmoid ribs weakly rursiradiate to weakly prorsiradiate on flanks. At top of flanks, ribs have ventrolateral nodes beyond which they bend sharply forward and weaken on venter. In best preserved specimen, ribs bifurcate into two or three coarse folds that project forward across venter (Pl. 4.6, figs 7-8). Some specimens with low keel beyond shell diameters of 12 mm. Suture line not preserved.

REMARKS: As discussed by Guex (1995, p. 34), the juvenile stage of *F. coronoides* Guex and *Kammerkarites praecoronoides* Guex from Nevada (Guex 1995, p. 34) are nearly identical. In addition, the inner whorls of *F. kennecottense* and *F. cf. coronoides* from the QCI are virtually indistinguishable from these two species. *Franziceras kennecottense* differs from *K.*

*praecoronoides* at larger shell diameters as the ventrolateral nodes and keel persist and the flank ribs are much less sigmoid. It differs from *F. coronoides* in being more evolute and in having much weaker flank ribs that are much less rursiradiate at large shell diameters. The inner and intermediate whorls of *F. kennecottense* are similar to *F. sebanum* but the QCI form differs at large shell diameters as the ribs are less crowded and more rectiradiate. The QCI form has flank ribs that are much weaker than *F. ruidum*.

OCCURRENCE: Section B, Coronoides to Sunrisensis zones; section H, Coronoides Zone.

### Genus SCHLOTHEIMIA Bayle, 1878

TYPE SPECIES: *Ammonites angulatus* Schlotheim, 1820; lectotype in Lange, 1951, p. 31, pl. 1, fig. 2.

*Schlotheimia* sp.

**MATERIAL AND MEASUREMENTS:** Five measured specimens (GSC 131668-131672) and nine incomplete specimens and fragments. Some partially preserved three-dimensional material; maximum shell diameter of *c.* 30 mm. Measurements of volution and ribbing density are presented in Figure 4.15A-B.

**DESCRIPTION:** Evolute form for genus. Whorl cross-section high suboval. On one specimen where nucleus visible, three strong ribs occur (Pl. 4.8, fig. 16). Beyond shell diameters of 3 mm, narrow, sharp ribbing is concave to weakly prorsiradiate on flanks. Ribs have greatest strength on uppermost flank, projecting strongly forward onto venter. Ribs form a chevron on venter with an angle of *c.* 90°. Ribbing is abruptly interrupted on midline of venter producing a smooth channel. Suture line is not preserved.

**REMARKS:** *Schlotheimia* sp. differs from *S. angulata* in being slightly more evolute and in having flank ribs that can be more strongly concave at similar shell diameters. The QCI form is similar to *S. phobetica* Lange in volution and in having some ribs that are weakly prorsiradiate. However, it differs in having a lower number of ribs per whorl, in having some ribs that are concave on the flanks and in having ribs that are completely interrupted on the venter. It is slightly more evolute than a similar specimen from the alpine Megastoma Zone (*Aegoceras angulatum* Schloth. var. ind. of Wähner 1886, pl. 20, fig. 6). Larger material is needed before this form can be identified at the species level.

**OCCURRENCE:** Section B, Coronoides Zone.

### **Genus ANGULATICERAS Quenstedt, 1883**

**TYPE SPECIES:** *Ammonites lacunatus* J. Buckman, 1844; designated by Lange, 1924.



REMARKS: The generic assignments of the species *dumitricai* and *cachinensis* are uncertain as they share several of the characteristics of Bloos (1988a) which are commonly used to separate the genera *Angulaticeras* and *Schlotheimia*. This problem is discussed by Hillebrandt (2000c, p. 31). He suggests that the two American species may represent a branch of limited development within the Schlotheimiidae. Given the poor preservation of our material, we are unable to contribute to the resolution of this problem.

***Angulaticeras* (?) cf. *dumitricai* Guex, 1995**

Plate 4.8, figures 21, 23-24

cf. 1995 *Angulaticeras dumitricai* Guex, p. 40, pl. 31, figs 1-2, 5-6, 11-14, 17-20, 23-26, pl. 32, figs 2-3.

MATERIAL AND MEASUREMENTS: Five flattened measured specimens (GSC 131674-131678) and one measured external mould with preserved relief (GSC 131673). Measurements of volution and ribbing density are presented in Figure 4.15A-B. In cases where the flank ribs bifurcate, both ribs are included.

DESCRIPTION: Midvolute form for genus. Whorl cross-section high suboval. Umbilical wall upright, umbilical shoulder distinct but rounded. On inner whorls weakly sigmoidal to straight ribs crowded and rectiradiate to weakly prorsiradiate. Ribs narrowest on lower flanks thickening upflank with greatest width on ventral shoulder. Ribs project slightly forward on uppermost flank. On some specimens, occasional ribs bifurcate low flank. At large shell diameter (DMAX > c. 55 mm), widest point of whorl upper flank. Ribs weakly sigmoid and rectiradiate to weakly rursiradiate. Suture line not preserved.

REMARKS: *Angulaticeras* (?) cf. *dumitricai* is very close to the type material of the species in volution, rib number and morphology. *Angulaticeras* (?) *dumitricai* differs from the more involute *A.* (?) *cachinensis* (Hillebrandt) in having ribs that bifurcate much less commonly.

OCCURRENCE: Sections B and C, Sunrisensis Zone.

***Angulaticeras* (?) cf. *cachinensis* (Hillebrandt, 2000c)**

Plate 4.8, figure 22

? 1988 *Schlotheimia* cf. *polyptycha* Lange; Riccardi *et al.*, pl. 1, fig. 9.

? 1994 *Schlotheimia* cf. *marmorea* (Oppel); Hillebrandt, p. 302, pl. 1, fig. 9.

1994 *Sulciferites marmoreus* (Oppel); Pálffy *et al.* pl. 1, fig. 1.

cf. 2000c *Schlotheimia cachinensis* (Hillebrandt), p. 28, pl. 7, figs 1-14, cf. 15; text-fig. 4a-d.

MATERIAL: One flattened incomplete specimen.

DESCRIPTION: Involute form. Sharp, strong, gently prorsiradiate flank ribs almost straight or slightly curved forward. Bifurcation of ribs occurs near umbilical shoulder, intercalating ribs also present.

REMARKS: *Angulaticeras* (?) cf. *dumitricai* is very close to the type material of the species in volution, rib number and morphology. It may have ribs that are slightly stronger on the lowest flanks at small shell diameters. *Angulaticeras* (?) *cachinensis* has ribs that bifurcate much more commonly than *A. trapezoidale* and the more evolute *A.* (?) *dumitricai*.

OCCURRENCE: Sections E and F, Mineralense/Rursicostatum zones. Also occurs in the Columbiae Zone in the QCI.

***Angulaticeras* cf. *ventricosum* (Sowerby, 1831)**

Plate 4.8, figure 18

- cf. 1856 *Ammonites moreanus* d'Orbigny, Hauer [part], p. 51, pl. 15, figs. 3, 4 (*non* figs. 1, 2).
- cf. 1882 *Aegoceras ventricosum*, Canavari, p. 43, pl. 4, figs 10-11.
- cf. 1888 *Schlotheimia ventricosa* (Sowerby); Canavari, p. 136, pl. 4, figs 10-11.
- cf. 1886 *Aegoceras ventricosum*, Wähner [part], p. 186, pl. 23, figs. 4--7, 9, 12 (*non* figs. 8, 10, 11).
- non. 1963 *Angulaticeras ventricosum*, Blind, p. 81, pl. 1, fig. 17 [= *Schlotheimia* sp. indet., Bloos, 1979, p. 147, pl. 1, fig. 9)].
- cf. 1976 *Sulciferites ventricosus*, Schlegelmilch, p. 37, pl. 7, fig. 6.
- cf. 1979 *Angulaticeras ventricosum*, Bloos, p. 145, pl. 1, figs. 1--8.
- 1981 *Angulaticeras* cf. *ventricosum*, Hillebrandt, p. 504, pl. 2, fig. 2.
- 1985 *Angulaticeras* cf. *ventricosum*, Prinz, p. 173, pl. 2, fig. 9.
- cf. 1987 *Angulaticeras ventricosum*, Quinzio Sinn, pl. 3, fig. 6.
- 1987 *Angulaticeras* cf. *ventricosum*, Quinzio Sinn, pl. 3, fig. 5.
- cf. 1990 *Charmasseiceras ventricosum* (Sowerby); Guerin-Franiette, p. 142, pl. 25, fig. 3.
- cf. 1993 *Sulciferites ventricosus* (Sowerby); Rakús and Lobitzer, p. 927, pl. 2, fig. 5; text-fig. 17.
- 2000b *Angulaticeras* cf. *ventricosum* (Sowerby); Hillebrandt, pl. 2, figs 7-8.
- ? 2004 *Angulaticeras* cf. *ventricosum* (Sowerby); Stevens, p. 39, pl. 7, figs 16-17, pl. 8, figs 1-4.

MATERIAL AND MEASUREMENTS: One poorly preserved flattened measured specimen (GSC 107376). Primary ribs = 10; secondary ribs = 18. Measurement of volution is presented in Figure 4.15A.

DESCRIPTION: Involute form of small size. Umbilical shoulder rounded. Sharp, crowded flank ribs slightly sigmoid and gently prorsiradiate. Bifurcation and intercalation of ribs common but without consistent pattern. Bifurcation at various points from umbilical shoulder to lower flank.

REMARKS: Bloos (1979) treated this species in detail. The species displays a certain amount of variability in ribbing (shape and density). The QCI specimen occupies the straighter, coarser end of the spectrum. It is distinguished from *A. trapezoidale* (Sowerby) by its narrower umbilicus and finer sigmoid ribbing (Smith and Tipper 2000).

The New Zealand material (Stevens, 2004) is very coarsely ribbed for *A. ventricosum*.

OCCURRENCE: Section C, Mineralense Zone. Also occurs in the Columbiae Zone in the QCI.

### **Superfamily ARIETITOIDEA Hyatt, 1875**

#### **Family ARIETITIDAE Hyatt, 1875**

Generic assignment of late Hettangian species of the Family Arietitidae are often controversial (e.g. Donovan and Forsey 1973; Donovan *et al.* 1981; Corna 1987; Bloos 1994, 1996; Taylor 1998; Meister *et al.* 2002b). Sutural characteristics, whorl cross-section and ventral features are often critical yet they are missing in the QCI material. This often makes certain identification difficult at the species level and generic assignments tenuous.

#### **Genus GYROPHIOCERAS Spath, 1924**

TYPE SPECIES: *Arietites praespiratissimus* Wöhner, 1887.

REMARKS: The taxonomic position of *Gyrophioceras* is controversial. The most recent approaches have been to consider *Gyrophioceras* as a subgenus of *Vermiceras* (Bloos 1994, 1996; Kment 2000) or *Paracaloceras* (Taylor 1998, Stevens 2004). Taylor and Guex (2002)

have recognized *Gyrophioceras* as a separate genus. We follow the latter approach here based principally on the shape of the suture line that is more similar to *Vermiceras* in some species of *Gyrophioceras* and more similar to *Paracaloceras* in others.

***Gyrophioceras* cf. *morganense* (Taylor, 1998)**

Plate 4.7, figure 11

cf. 1998 *Paracaloceras* (*Gyrophioceras*) *morganense* Taylor, p. 490, fig. 21.7-21.8, 21.11-21.12, 22.

cf. 2002 *Gyrophioceras morganense* Taylor; Taylor and Guex, pl. 2, figs 1-2, 4.

MATERIAL: One fragment (GSC 131680).

DESCRIPTION: Involute form for genus. Crowded flank ribs weakly concave. Ribs strongest on lower and middle flank projecting forward on upper flank. No keel visible.

REMARKS: *Gyrophioceras* cf. *morganense* may be slightly more involute than other *G. morganense*. It is particularly similar to the paratype of Taylor (1998, fig. 21.11-21.12). The QCI form resembles a specimen of *Alsatites sublaqueus* (Wähner 1886, pl. 30, fig. 4) but differs in being more involute. It is similar to *Laqueoceras* cf. *sublaqueus* of Hillebrandt (2000a) but differs in being more evolute on the inner whorls and in having ribs that are more regular in spacing and strength.

OCCURRENCE: Section D, Morganense Zone.

***Gyrophioceras* aff. *praespiratissimum* (Wähner, 1887)**

Plate 4.7, figure 3

aff. 1887 *Arietites praespiratissimus* n. f. Wähner, p. 139, pl. 36, figs 1-3.

aff. 1963 *Arietites* (*Alsatites*) *praespiratissimus* Wähner; Blind, p. 101, pl. 4, fig. 2.

aff. 1994 *Vermiceras* (*Gyrophioceras*) *praespiratissimum* (Wähner); Bloos, p. 10, pl. 3, figs 5-10, text-figs 6, 8.

cf. 2004 *Gyrophioceras praespiratissimum* (Wähner); Bertinelli *et al.*, p. 91, fig. 5.

MATERIAL: One measured (GSC 131679) and one distorted specimen. Both specimens flattened. Measurement of volution is presented in Figure 4.15A.

DESCRIPTION: Evolute form for genus. Nucleus nodose. Weakly rursiradiate flank ribs straight to slightly concave. Ribs uniform in spacing and strength. Moderately strong keel present beyond shell diameters of 27 mm.

REMARKS: *Gyrophioceras* aff. *praespiratissimum* is similar in volution and rib number to *G. praespiratissimum* (Wähner) but differs in having ribs that are more uniformly weakly rursiradiate. It differs from *A. liasicus* in having flank ribs that are less concave and has a stronger keel than *A. liasicus* and *G. morganense*. *Gyrophioceras* aff. *praespiratissimum* is more involute and has more strongly rursiradiate flank ribs than *G. supraspiratum* (Wähner).

OCCURRENCE: Section C, Sunrisensis Zone.

***Gyrophioceras* cf. *supraspiratum* (Wähner, 1888)**

Plate 4.7, figure 2

cf. 1888 *Arietites supraspiratus* n. f. Wähner, p. 298, pl. 20, figs 6-9.

cf. 1888 *Arietites supraspiratus* Wähner; Canavari, p. 177, pl. 6, fig. 2.

? 1984 *Vermiceras* (*Vermiceras*) *supraspiratum* (Wähner); Braga *et al.*, p. 273, pl. 1, fig. 7.

cf. 1985 *Vermiceras supraspiratus* (Wähner); Venturi, fig. 1c-c2; text-fig. 6.

cf. 2004 *Gyrophioceras supraspiratum* (Wähner); Bertinelli *et al.*, p. 91, fig. 5.

MATERIAL AND MEASUREMENTS: One partially compressed measured specimen (GSC 107400). Measurements of volution and ribbing density are presented in Figure 4.15A-B.

DESCRIPTION: Strongly evolute form ( $UD/D = c. 70\%$ ). Flanks appear convex. Moderately densely ribbed with rib frequency increasing steadily. Rectiradiate flank ribs slightly concave adorally. Venter with low keel by shell diameter of  $c. 30$  mm.

REMARKS: *Gyrophioceras* cf. *supraspiratum* is similar in volution and ribbing style to *Paracaloceras* (?) sp. A of Hillebrandt (2000d, pl. 11, figs 1-2). Unfortunately, a closer comparison is impossible as preservation in the QCI material is poor and the South American material is incomplete and is principally of much larger shell diameter. The QCI form is somewhat similar to *G. morganense* and *Paracaloceras perspiratum* (Wähner) but differs in having more dense ribbing. It differs from *Alsatites proaries* in having more concave ribs and differs from evolute species of *Metophioceras* (e.g. *M. janus* Spath, *M. caesar* (Reynès), *M. longidomus* (Quenstedt)) in having flattened flanks and as far as preservation permits us to observe, lack of a tricarinate-bisulcate venter. The QCI form differs from *Vermiceras scylla* (Reynès) in bearing showing traces of a more prominent keel at similar shell diameters and in having straighter ribs.

OCCURRENCE: Sections E and F, Mineralense/Rursicostatum zones. Also occurs in the Columbiae Zone in the QCI.

### Genus PARACALOCERAS Spath, 1923b

TYPE SPECIES: *Ammonites coregonensis* Sowerby, 1831.

The holotype of Sowerby is lost and that figured by Canavari, 1882, pl. 24, fig. 15 (and 1888, pl. 5, fig. 15) was designated as a neotype by Donovan and Forsey (1973, p. 7).

***Paracaloceras cf. rursicostatum* Frebold, 1967**

Plate 4.7, figure 1

- cf. 1951 *Arietites* sp. indet. Frebold, p. 3, pl. 3, fig. 2.
- cf. 1967 *Paracaloceras rursicostatum* Frebold, p. 26, pl. 7, figs 1-2; pl. 9, fig. 1.
- cf. 1981 *Paracaloceras rursicostatum* Frebold; Imlay, p. 33, pl. 6, figs 1-11.
- ? 1988 *Vermiceras* (*Paracaloceras*) cf. *rursicostatum* Frebold; Riccardi *et al.*, pl. 2, fig. 6.
- ? 1991 *Vermiceras* (*Paracaloceras*) cf. *rursicostatum* Frebold; Riccardi *et al.*, fig. 4.22.
- cf. 1995 *Paracaloceras rursicostatum* Frebold; Guex, p. 54, pl. 32, fig. 1.
- cf. 1999 *Paracaloceras* cf. *rursicostatum* Frebold; Pálffy *et al.*, fig. 5C.
- cf. 2000 *Metophioceras rursicostatum* (Frebold); Taylor, pl. 4, figs 1-2, 9.
- cf. 2002 *Metophioceras* aff. *rursicostatum* (Frebold); Taylor and Guex, pl. 2, fig. 8.
- cf. in press *a Paracaloceras rursicostatum* Frebold; Longridge *et al.*, pl. 2, figs 19, 21-22;  
text-figs 9U, 10I.

MATERIAL AND MEASUREMENTS: Two measured specimens (GSC 107402, 107413) and several other incompletely preserved specimens. Measurements of volution and ribbing density are presented in Figure 4.15A-B.

DESCRIPTION: Evolute form. Flanks slightly convex. Dense, rectiradiate to rursiradiate, slightly concave flank ribs. When preservation allows, venter with prominent keel possibly flanked by sulci.

REMARKS: End members of *P. rursicostatum* look very different; however, a detailed study on very well preserved material from Taseko Lakes has revealed that division of the species based on differences in volution, whorl cross-section or rib orientation, density or strength would be arbitrary (Longridge *et al.*, in press *a*).



Due to lack of information on ventral characteristics, it is difficult to identify the QCI material with certainty. It probably has a stronger keel than *P. grunowi* (Hauer) and differs from *Epammonites cordieri* (Canavari) in having weaker flank ribs, particularly on the lowermost and uppermost flanks. It differs from *P. multicostatum* Frebold in being slightly less densely ribbed on the innermost whorls and in having flank ribs that are much less commonly prorsiradiate.

OCCURRENCE: Section E, Mineralense/Rursicostatum zones. Also occurs in the Columbiae Zone in the QCI.

***Paracaloceras* (?) sp.**

Plate 4.7, figures 4, 9

MATERIAL AND MEASUREMENTS: Two measured specimens (GSC 131681-131682).

Measurements of volution and ribbing density are presented in Figure 4.15A-B.

DESCRIPTION: Evolute form. Nucleus probably nodose (Pl. 4.7, fig. 9). Strongly rursiradiate flank ribs moderately spaced. Venter with keel by 25 mm shell diameter.

REMARKS: *Paracaloceras* (?) sp. has a lower number of flank ribs than *P. rursicostatum* beyond shell diameters of 30 mm and has flank ribs that are more strongly rursiradiate at very small shell diameters. The strongly rursiradiate character of the ribs is similar to *Schreinbachites retroversicostatus* (Canavari) although the QCI form lacks irregularities in rib spacing and strength, the keel is stronger at similar whorl heights and as far as preservation permits observation, the QCI form has a nodose nucleus.

OCCURRENCE: Section C, Sunrisensis Zone.

## 4.4 North American Middle and Upper Hettangian Ammonite Zones

Ammonite taxa from the QCI indicate the presence of all zones currently recognized in the middle and upper Hettangian portion of the North American Zonation (Taylor *et al.* 2001; Longridge *et al.* 2006). However, the position of the boundary between the Mulleri and Occidentalis zones is uncertain. In the North American Zonation, *D. antiquum*, *K. frigga* and *K. haploptychus* are restricted to the Mulleri Zone whereas *E. occidentalis* is restricted to the Occidentalis Zone and *D. silberlingi* does not appear until the Occidentalis Zone. In the QCI these two groups of taxa share some or all of the same range (Figure 4.9). For this reason the Mulleri and Occidentalis zones are currently maintained as one stratigraphic unit in the QCI. Similarly, the boundary between the Mineralense and Rursicostatum zones is also uncertain. Several of the key taxa that are used to characterize these zones in the North American Zonation have not yet been found in the QCI [e.g. *P. mineralense* Taylor, *A. posttaurinum*, *D. ornatum* Taylor, *Paradiscamphiceras athabascanense* Taylor in the Mineralense Zone; *Paracaloceras retroversicostatum* (Canavari), *Pseudaetomoceras shoshonense* Taylor, *Schlotheimia* ex. gr. *stenorhyncha* (Lange) in the Rursicostatum Zone (Taylor *et al.* 2001)]. In addition, several species of the genus *Badouxia* are important in identifying the Mineralense and Rursicostatum zones. A new study of the *Badouxia* fauna is necessary to update which species of the genus occur in the QCI. Many of these forms (or species closely related to them) permit correlations with other areas as indicated below. Zones discussed in the text are shown in Figure 4.2.

## 4.5 Correlation with Other Areas

### 4.5.1 North America

#### 4.5.1.1 Canada.

In Canada, Hettangian ammonite collections are principally restricted to British Columbia with the exception of *Discamphiceras* cf. *silberlingi* that occurs in subsurface strata in

northwestern Alberta. The exact level of this collection is uncertain but it is broadly placed in the middle to upper Hettangian (Hall *et al.* 2000). At Williston Lake in British Columbia, *Nevadaphyllites psilomorphus* is found in lower Hettangian strata while *N. compressus* is found in the Polymorphum Zone. *Nevadaphyllites cf. compressus* is also recognized in the middle Hettangian where it occurs with *Togaticeras togatum*, *Alsatites liasicus*, *Saxoceras cf. portlocki* and *Kammerkarites frigga* (Hall and Pitaru 2004). *Badouxia canadensis* (Frebold) [including *B. oregonensis* Taylor which was placed in synonymy with *B. canadensis* by Longridge *et al.* (2006)] and possibly *Pseudaetomoceras doetzkirchneri* occur in beds that correlate with the Mineralense and Rursicostatum zones (Hall and Pitaru 2004). In the Iskut River map area, *Paracaloceras cf. rursicostatum* occurs in what is probably either the Rursicostatum or Columbiae Zone (Jakobs and Pálffy 1994). In the Taseko Lakes area, *Phylloceras cf. asperaense* and *T. togatum* are limited to the Mineralense Zone whereas *N. psilomorphus*, *N. aff. compressus*, *Eolytoceras tasekoi* and *E. constrictum* are limited to the Rursicostatum Zone (Frebold 1967; Longridge *et al.* in press a). *Discamphiceras silberlingi*, *P. rursicostatum*, *Sunrisites senililevis* and *B. canadensis* occur in the Mineralense and Rursicostatum zones while a single specimen of *Pseudaetomoceras cf. castagnolai* was collected from talus but is probably also from one of these two zones (Frebold 1951, 1967; Longridge *et al.* 2006, in press a, b).

These taxa permit correlation with the QCI succession. *Nevadaphyllites compressus*, *N. psilomorphus* and the possible occurrence of *P. doetzkirchneri* allow broad correlations between Williston Lake and the QCI in the Hettangian whereas *N. cf. compressus*, *A. liasicus*, *T. togatum*, *S. cf. portlocki* and *K. frigga* permit tighter correlation with the middle Hettangian. *Badouxia canadensis* permits correlations between the Mineralense and Rursicostatum zones in Taseko Lakes, Williston Lake and the QCI although in the latter area, the species ranges into the Columbiae Zone. Direct correlations are possible between Taseko Lakes and the QCI in the Mineralense and Rursicostatum zones using *S. senililevis*, *E. constrictum* and *P. rursicostatum*

whereas more broad correlations are possible between the two areas using *E. cf. tasekoi* whose range extends into the Morganense Zone and *D. silberlingi* that occurs in the middle Hettangian in the QCI. Finally, *P. cf. rursicostatum* in the Iskut River area permits broad correlation with the Mineralense through Columbiae zones in the QCI.

#### 4.5.1.2 Alaska.

In Alaska, the best stratigraphic section with Hettangian faunas is in Puale Bay where *Kammerkarites cf. frigga*, *K. ex. gr. megastoma*, *D. cf. silberlingi*, *Mullerites cf. pleuroacanthitoides* and *Saxoceras aff. portlocki* occur in strata that are broadly equivalent to the Mulleri to Pleuroacanthitoides zones whereas *E. cf. tasekoi*, *P. cf. rursicostatum* and possibly *B. canadensis* occur in strata that are probably equivalent to the Rursicostatum Zone although the Mineralense Zone cannot be excluded (Imlay 1981; Pálffy *et al.* 1999; Longridge *et al.* 2006). Outside of Puale Bay, Alaskan faunas are generally less well constrained stratigraphically because collections often come from isolated localities and often consist of single species (Imlay 1981). *Saxoceras aff. portlocki* possibly occurs at Alinchak Bay and Wide Bay in middle to upper Hettangian beds. *Paracaloceras cf. rursicostatum* occurs in the late Hettangian (probably Rursicostatum Zone) in the Kenai Peninsula and the Healy quadrangle.

*Kammerkarites cf. frigga*, *K. ex. gr. megastoma*, *D. cf. silberlingi*, *M. cf. pleuroacanthitoides* and *S. aff. portlocki* provide broad correlations between the middle Hettangian in Alaska and the QCI. *Eolytoceras cf. tasekoi*, *P. cf. rursicostatum* and possibly *B. canadensis* provide correlation between the Mineralense and Rursicostatum zones in both areas although the first species is also found in the Morganense Zone while the latter two range into the Columbiae Zone in the QCI.

#### 4.5.1.3 Oregon, Nevada and Mexico.

Oregon and Nevada in the United States have many taxa that permit correlation with the QCI ammonite succession whereas taxa from the Sonora region in Mexico permit much more limited

correlation. In Oregon, *N. compressus* is found in the Morganense and Mineralense zones (Taylor 1998; Taylor *et al.* 2001; Taylor and Guex 2002). *Gyrophioceras morganense*, *G. aff. supraspiratum* and *D. silberlingi* occur in the Morganense Zone whereas *B. canadensis* occurs in the Mineralense Zone (Taylor 1998; Taylor and Guex 2002). Finally, *P. aff. rursicostatum* occurs in the Columbiae to Trigonatum zones (Taylor 1998; Taylor and Guex 2002). In Nevada, *N. compressus* occurs in the Pacificum and Polymorphum zones (Guex 1980, 1995; Taylor *et al.* 2001). *Togaticeras cf. togatum* was collected *ex situ* but is probably from lower Hettangian strata whereas *Fergusonites striatus* ranges throughout the middle Hettangian (Guex 1980, 1995; Taylor *et al.* 2001). *Discamphiceras antiquum*, *K. frigga*, *K. rectiradiatus* and *K. haploptychus* occur in the Mulleri Zone, *Euphyllites occidentalis* is limited to the Occidentalis Zone and *K. praecoronoides*, *Franziceras coronoides* and possible *S. portlocki* occur in the Coronoides Zone (Guex 1980, 1995; Taylor 1998). *Pleuroacanthites biformis* is found in the Mulleri through Pleuroacanthitoides zones whereas *D. silberlingi* ranges from the Occidentalis to Pleuroacanthitoides zones (Guex 1980, 1995). *Mullerites pleuroacanthitoides*, *Eolytoceras praecursor*, *N. psilomorphus* and *Storhoceras garfieldense* are limited to the Pleuroacanthitoides Zone (Guex 1980, 1995; Taylor 1998; Taylor *et al.* 2001). *Discamphiceras submesogenos* and *A. ex. gr. proaries* occur in the Pleuroacanthitoides and Sunrisense zones (Guex 1995; Taylor *et al.* 2001). *Pseudaetomoceras doetzkirchneri* occurs in the Pleuroacanthitoides through Mineralense zones, *Angulaticeras dumitricai* occurs in the Sunrisense through Mineralense zones and *P. castagnolai* is limited to the Sunrisense Zone (Guex 1995; Taylor 1998). *Eolytoceras tasekoi* is recognized from the Rursicostatum Zone whereas *P. rursicostatum* and *B. canadensis* are found in the Mineralense through Columbiae zones (Guex 1995; Taylor 2000). Finally, a float specimen of *Angulaticeras cf. ventricosum* may have come from the Trigonatum Zone (Taylor 1998; Taylor *et al.* 2001). In Mexico, *B. canadensis* permits correlation of what are probably the Rursicostatum and Columbiae zones

and possibly the Trigonatum Zone (González-León *et al.* 1996; Taylor *et al.* 2001; Taylor and Guex 2002) with the Mineralense to Columbiae zones in the QCI.

The middle and late Hettangian phylloceratids from the QCI permit broad correlations with the Hettangian in Oregon and Nevada. In Nevada, several ammonite taxa permit direct correlation with the QCI faunas. Direct correlations in the Mulleri and Occidentalis zones are possible using *E. occidentalis*, *D. antiquum*, *D. haploptychus* and *K. frigga*. The possible occurrence of *S. aff. portlocki* suggests a direct correlation with the Coronoides Zone whereas *P. biformis* permits direct correlation of the Mulleri and Occidentalis through Pleuroacanthitoides zones. *Discamphiceras cf. submesogenos* permits direct correlation of the Pleuroacanthitoides and Sunrisensis zones. Finally, *B. canadensis* and *P. rursicostatum* permit direct correlation of the Mineralense through Columbiae zones in both areas. In several cases, the ranges of the taxa from Nevada differ somewhat although they are still useful for correlation. Broad correlations are possible between in the middle Hettangian using *A. ex. gr. proaries*, *S. garfieldense* and *M. pleuroacanthitoides*, *K. rectiradiatus*, *K. praecoronoides*, *F. coronoides* and *D. silberlingi*. *Eolytoceras praecursor* is limited to the Pleuroacanthitoides Zone whereas in the QCI it occurs in the Coronoides through Pleuroacanthitoides zones. *Pseudaetomoceras castlagnolai* occurs only in the Sunrisense Zone whereas in the QCI it extends from the Pleuroacanthitoides through Morganense zones. In the QCI, *A. (?) dimitricai* and *P. doetzkirchneri* and are limited to the Sunrisensis Zone whereas in Nevada they range from the middle middle to late Hettangian. In Oregon, *G. morganense* permits direct correlation with the Morganense Zone. It is possible to make broad correlations between the late Hettangian and early Sinemurian in the QCI and Nevada and Oregon using *B. canadensis*, *G. supraspiratum* and *P. rursicostatum* in Oregon and *E. tasekoi* and *A. cf. ventricosum* in Nevada.

## 4.5.2 South Pacific

### 4.5.2.1 South America.

South America has numerous taxa in common with the middle and late Hettangian faunas from the QCI. *Nevadaphyllites compressus* occurs in the Tilmanni Subzone and *Phylloceras asperaense* occurs in the Reissi through Peruvianus zones (Hillebrandt 2000a) whereas *F. cf. striatus* and *Kammerkarites aff. chinchillaensis* permit correlation with the Bayoensis Zone (Hillebrandt 2000a, c). *Discamphiceras aff. antiquum* and *D. aff. pleuronotum* (Hillebrandt 2000a, c) occur in the Reissi Zone. *Storthoceras australe* definitely occurs and *K. frigga* may occur in the Australe Horizon (Hillebrandt 2000c). *Alsatites cf. liasicus*, *Sunrisites chilensis* and *Angulaticeras (?) cf. cachinensis* occur in the Peruvianus Zone (Hillebrandt 2000c, d). *Badouxia canadensis* occurs throughout the Canadensis Zone (Geyer 1979; Quinzio 1987; Hillebrandt 1990, 1994, 2000b, c). Finally, *A. cf. ventricosum* is found in the *Coroniceras aff. conybeari* horizon (Hillebrandt 2000b).

*Alsatites cf. liasicus* and *A. cf. ventricosum* occur in slightly younger strata in South America than in the QCI whereas *A. (?) cachinensis* occurs in slightly older strata. *Fergusonites cf. striatus* and *K. chinchillaensis* can be used to correlate the Bayoensis Zone with the Mulleri and Occidentalis zones in the QCI. *Discamphiceras aff. antiquum*, *D. aff. pleuronotum* and the possible occurrence of *K. frigga* permit broad correlations between the Reissi Zone in South America with the Mulleri and Occidentalis through the Coronoides zones in the QCI whereas *S. australe* suggests a slightly younger association of the Australe Horizon with the Pleuroacanthitoides and Sunrisensis zones. *Sunrisites chilensis* permits correlation of the South American Peruvianus Zone with the Sunrisensis and Morganense zones. *Badouxia canadensis* permits correlation of the Canadensis Zone in South America with the Mineralense through Columbiae zones in the QCI.

#### 4.5.2.2 New Zealand.

Based on the work of Stevens (2004), approximate correlations are possible between the QCI ammonite successions and those of New Zealand although often the identifications of New Zealand material are questionable. Possible *K. frigga* occurs in what is probably the early middle Hettangian in New Zealand and permits correlation with the Mulleri and Occidentalis through Coronoides zones in the QCI. In New Zealand, possible *N. psilomorphus* occurs in what are probably middle to lower upper Hettangian strata equivalent to the North American Mulleri to Morganense zones and permits broad correlations with the middle Hettangian in the QCI. Possible *E. tasekoi* may occur in the late Hettangian of New Zealand permitting broad correlation with the late Hettangian in the QCI. Finally, possible *A. ventricosum* may have come from the Rotiforme Subzone in New Zealand permitting broad correlation between the latest Hettangian and early Sinemurian successions in the QCI and the earliest Sinemurian in New Zealand.

### **4.5.3 Europe**

#### 4.5.3.1 Western Tethys (circum-Mediterranean).

Many of the middle and late Hettangian QCI taxa also occur in the Tethyan circum-Mediterranean area. These correlations have added importance as Mediterranean faunas are now quite well correlated with successions in northwest Europe, permitting indirect correlations with the primary standard succession (e.g. Bloos 1983; Guérin-Franniate 1990; Mouterde and Corna 1997; Page 2003). In Austria, *N. psilomorphus* is found throughout the Hettangian (Neumayr 1879; Lange 1952; Dommergues *et al.* 1995; Böhm *et al.* 1999; Kment 2000) whereas in Hungary, *N. cf. psilomorphus* is found from talus that is very likely to be from the lower to middle Hettangian (Pálffy *et al.* 2001). *Togaticeras togatum* is found in lower and middle Hettangian strata in Austria (Rakús 1993a, 1999; Kment 2000). The Hettangian phylloceratids from the QCI permit broad correlations with the Hettangian of the circum-Mediterranean.



*Pleuroacanthitoides biformis* is found in the Megastoma Zone in Austria and probably the late Hettangian in Italy (Canavari 1888; Wähner 1894; Venturi 1985). *Pseudaetomoceras castagnolai* occurs in the Marmoreum Zone in Austria and probably the late Hettangian in Italy (Canavari 1882; Wähner 1886; Canavari 1888; Venturi 1985; Kment 2000). *Eolytoceras* cf. *tasekoi* occurs in the Marmoreum Zone in Austria (Kment 2000) and can be used to indicate the presence of upper Hettangian strata. *Discamphiceras pleuronotum* and *A. proaries* occur in the Megastoma Zone in Austria and probably the upper Hettangian in Italy (Wähner 1884, 1886; Canavari 1888; Lange 1952; Venturi 1985). *Pseudaetomoceras doetzkirchneri*, *K. haploptychus*, *K. frigga* and *K. megastoma* occur in the Megastoma Zone in Austria (Wähner 1882, 1884, 1886; Lange 1952; Blind 1963; Rakús 1999). *Gyrophioceras praespiratissimum* occurs in the Megastoma and Marmoreum zones in Austria and the late Hettangian in Italy (Wähner 1887; Bertinelli *et al.* 2004). *Gyrophioceras supraspiratum* occurs in the Megastoma and Marmoreum Zones in Austria probably occurs in the late Hettangian in Italy and possibly occurs in the late Hettangian in Spain (Wähner 1888; Braga *et al.* 1984; Canavari 1888; Venturi 1985; Bertinelli *et al.* 2004). *Kammerkarites megastoma* also occurs in the Liasicus Zone in the West Carpathians (Rakús 1993b). *Angulaticeras ventricosum* is predominantly from the Rotiforme Zone in Austria although it is also known from a late Hettangian-Early Sinemurian assemblage in Austria and Italy (Canavari 1888, Venturi 1985; Wähner 1886; Rakús and Lobitzer 1993).

#### 4.5.3.2 Eastern Tethys.

Broad correlations are possible between the middle and upper Hettangian ammonite successions in the QCI and the Hettangian and earliest Sinemurian in the eastern Tethys. *Nevadaphyllites* cf. *psilomorphus* is found in the Calliphyllum Zone in Tibet (Yin *et al.* 2007) and permits broad correlation with middle Hettangian strata in the QCI. *Pleuroacanthites* aff. *biformis*, *D. pleuronotum* and *K. frigga* occur in the Pleuronotum Zone in Tibet (Yin *et al.* 2007) and permit correlations with the Mulleri through *Pleuroacanthitoides* zones in the QCI. Finally,

*E. aff. tasekoi* occurs in lower Sinemurian strata that are probably equivalent to the Conybeari or Rotiforme subzones in Vietnam (Meister *et al.* 2002a) and permit broad correlations between the earliest Sinemurina in Vietnam and the late Hettangian in the QCI.

#### 4.5.3.3 Northwest Europe.

Several taxa from the middle and late Hettangian in the QCI permit direct correlations with the northwest European successions. These successions (e.g. Dean *et al.* 1961; Mouterde and Corna 1997; Page 2003) are considered the primary standard for Early Jurassic biochronology (Callomon 1984). Thus, these correlations have added importance. *Kammerkarites haploptychus* is recognized from the Laqueus Subzone in England (Donovan 1952) and permits correlation with the Mulleri and Occidentalis to Coronoides Zones in the QCI. *Caloceras bloomfieldense* occurs in the Liasicus Zone in England and possibly the Portlocki Subzone and definitely the Laqueus Subzone in Wales (Donovan, 1952; Dean *et al.* 1961; Hodges 1986), *S. portlocki* occurs in the Portlocki Subzone in France and the Liassic Zone in England (Donovan 1952; Dean *et al.* 1961; Elmi and Mouterde 1965; Guerin-Franiatte 1990) and *A. liasicus* occurs in the Laqueus Subzone in France and England and in the middle Hettangian in Germany (Lange 1941; Donovan 1952; Elmi and Mouterde 1965; Schlegelmilch 1976; Guerin-Franiatte 1990). These taxa permit direct correlation of the Coronoides Zone in the QCI with the middle Hettangian successions in Europe. In addition *K. megastoma* occurs in strata from the Planorbis Zone in Germany, the Laqueus Subzone in England and the middle and late Hettangian in France (Donovan, 1952; Schlegelmilch 1976; Guerin-Franiatte 1990) and *A. ventricosum* is recognized in the early Sinemurian in Germany and the Rotiforme Subzone in France (Schlegelmilch 1976; Bloos 1979; Guerin-Franiatte 1990). These taxa allow broad correlations between the middle and late Hettangian ammonite successions in the QCI and the Hettangian and early Sinemurian in Europe.

## 4.6 Paleobiogeography

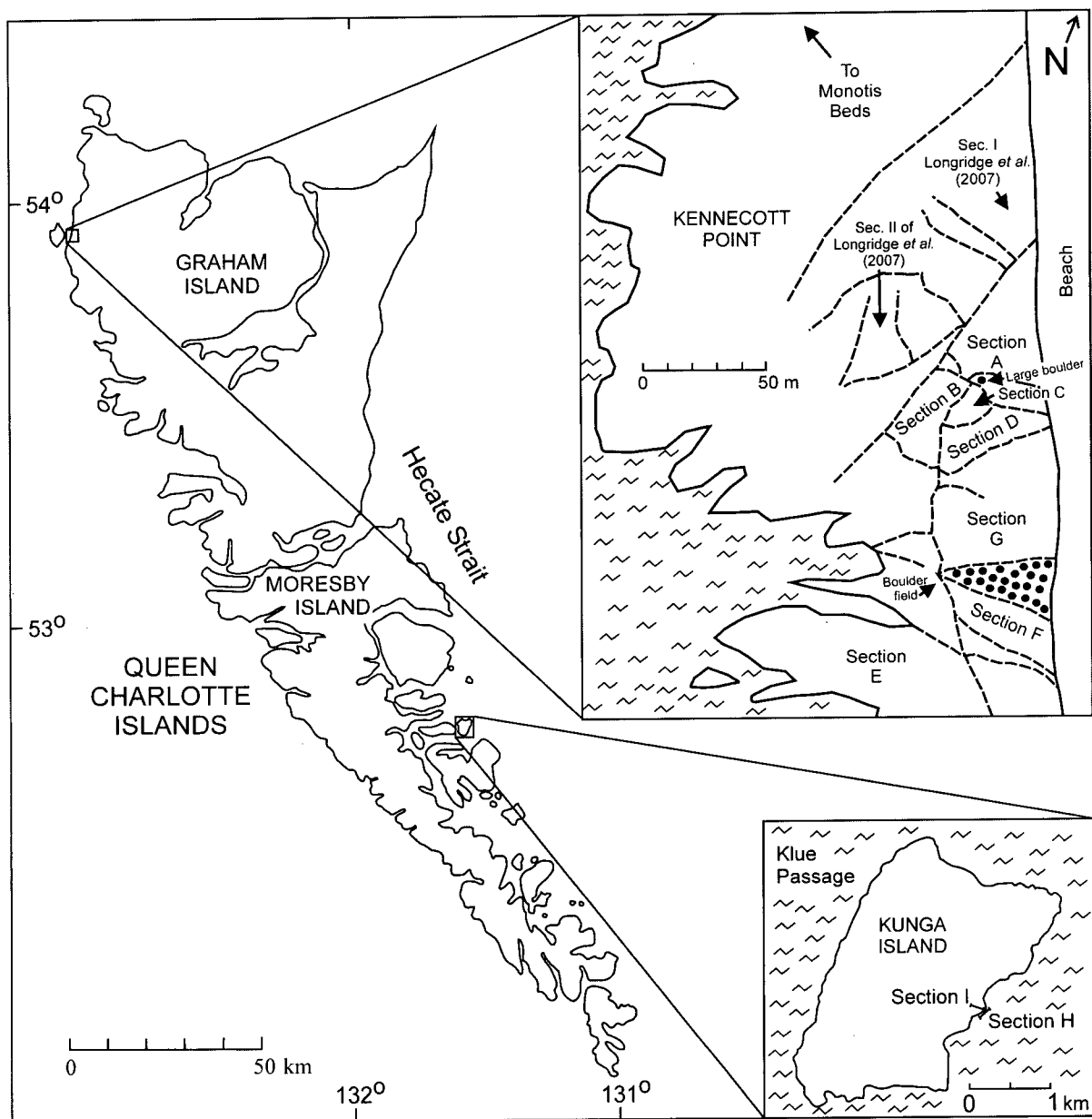
The rich Hettangian ammonite fauna from the QCI is principally of east Pacific and Tethyan affinities although some important taxa with Boreal affinity are also present. The QCI are part of the displaced terrane, Wrangellia (Jones *et al.* 1977). Based on faunal evidence, Wrangellia is believed to have been in the eastern Pacific and the northern Hemisphere during Permian through Early Jurassic time (e.g., Monger 1984; Taylor *et al.* 1984; Smith and Tipper 1986; Belasky 1994; Aberhan 1999; Smith *et al.* 2001; Belasky *et al.* 2002; Smith 2006; Longridge *et al.* in press *b*). The Hettangian ammonites in the QCI support this claim. They have strong affinity with contemporaneous endemic faunas from other areas of North America, particularly Nevada. Correlations with South America are also strong and suggest open communication throughout the eastern Pacific during Hettangian time.

Based on ammonite and bivalve distribution patterns, it has been proposed that Wrangellia was displaced northward between several hundred to over 1000 km since Sinemurian and Pliensbachian times (e.g., Taylor *et al.* 1984; Aberhan 1999; Smith 2006). Today, the QCI are at a similar latitude to the autochthonous Fernie Basin which contains the Williston Lake Hettangian ammonite fauna (Hall and Pitaru 2004). However, the diversity is far greater in the QCI fauna than the Williston Lake fauna where the succession lacks *Paradasyceras*, *Fergusonites*, *Ectocentrites*, *Eolytoceras*, *Pleuroacanthites*, *Euphyllites*, *Caloceras*, *Mullerites*, *Angulaticeras* and *Franziceras* (Hall and Pitaru 2004). The succession in the QCI is more similar to the Nevada fauna in composition as well as diversity. Nevada was also part of autochthonous North America during the Hettangian. A diversity gradient is commonly recognized from north to south on the craton with increasing diversity toward the equator (Smith and Tipper 1986; Smith 1999 and references therein). The difference in diversity between the Williston Lake faunas and the QCI and Nevada faunas as well as the strong similarities between

the QCI and Nevada faunas support the hypothesis of a significant northward displacement of Wrangellia relative to the craton since Early Jurassic time.

#### 4.7 Conclusions

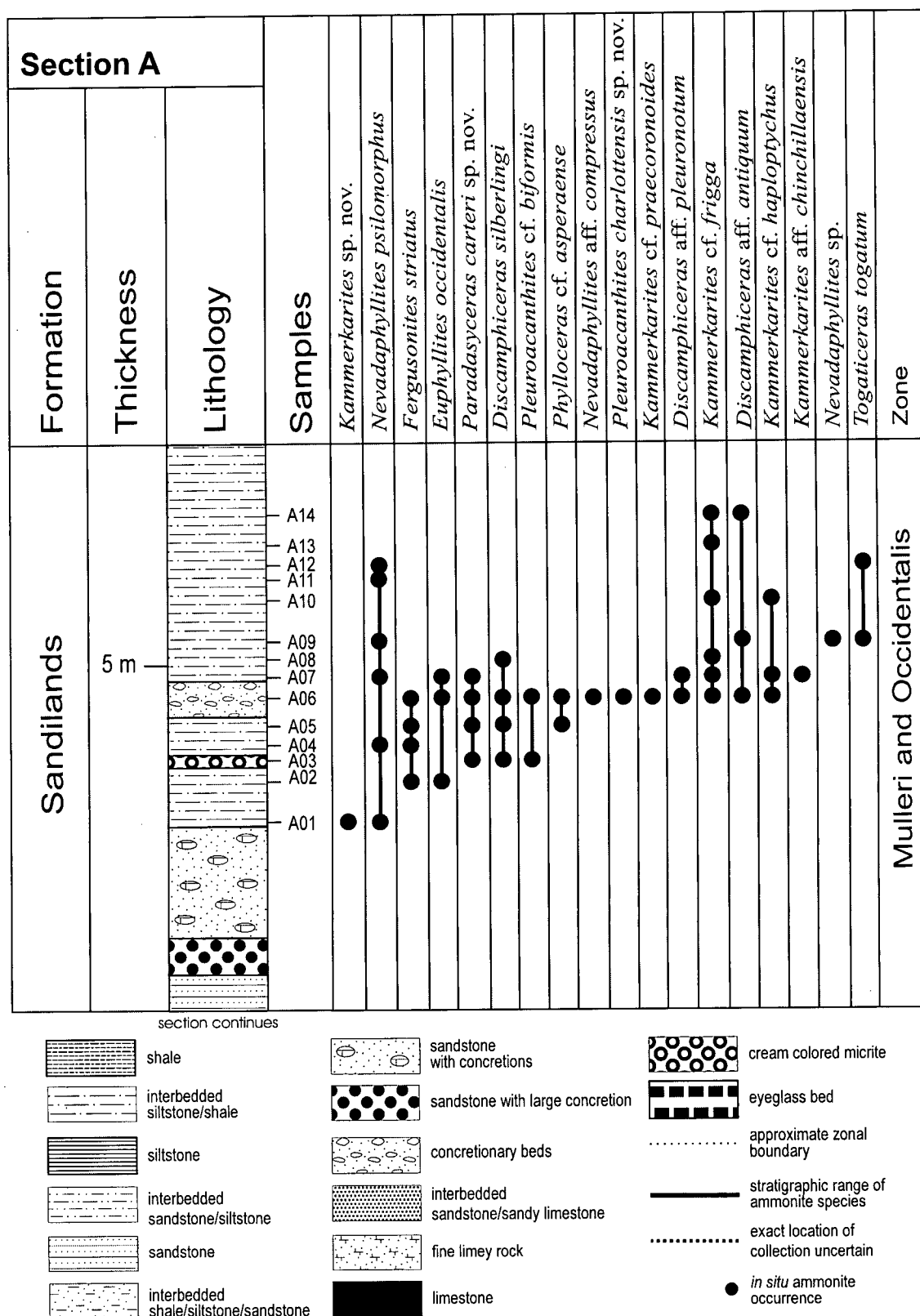
The QCI contain the most diverse middle and late Hettangian ammonite fauna in Canada. In total, fifty-three taxa from the Mulleri and Occidentalis through Mineralense and Rursicostatum zones are present including five new species, *Paradasyceras carteri*, *Franziceras kennecottense*, *Pleuroacanthites charlottensis*, *Ectocentrites pacificus* and *Curviceras haidae*. This study greatly expands our knowledge of the fauna and ranges of North American ammonites during the Hettangian and significantly improves the accuracy of the North American regional ammonite zonation. In addition, it permits correlations with other areas of North America, South America, New Zealand, western and eastern Tethys, and northwest Europe in the Hettangian and early Sinemurian. The QCI fauna supports the location of Wrangellia in the northern Hemisphere and the eastern Pacific during the Hettangian and suggests the terrane has been displaced significantly northward since the Hettangian.



**Figure 4.1.** Localities of sections and isolated outcrops bearing middle and late Hettangian ammonites in the Queen Charlotte Islands.

AGE	NORTH AMERICA (Taylor <i>et al.</i> 2001; Longridge <i>et al.</i> 2006)	SOUTH AMERICA (Hillebrandt 2000b, d)		NORTHWEST EUROPE (Donovan <i>in</i> Dean <i>et al.</i> 1961; Bloos 1988b; Page 2003)		WESTERN TETHYS (Wahner 1886; Page 2003)	EASTERN TETHYS (Yin <i>et al.</i> 2007)
LOWER SINEMURIAN	Trigonatum Zone	Horizon with <i>Coroniceras</i> ( <i>Metophioceras</i> ) aff. <i>gracile</i>		Bucklandi Zone	Rotiforme Subzone	rotiforme	
	Columbiae Zone	Horizon with <i>Coroniceras</i> ( <i>Metophioceras</i> ) aff. <i>conybeari</i>			Conybeari Subzone		
UPPER HETTANGIAN	Rursicostatum Zone	Arcuatum Horizon		Angulata Zone	Depressa Subzone	Marmoreum Zone	
	Mineralense Zone	Canadensis Zone	Varaense Subzone		Complanata Subzone		
			Cuevitensis Subzone				
	Morganense Zone				Extranodosa Subzone		
MIDDLE HETTANGIAN	Sunrisensis Zone	Peruvianus Zone		Liasicus Zone	Laqueus Subzone	Megastoma Zone	Pleuronotum Zone
	Pleuroacanthitoides Zone	Reissi Zone	Australe Horizon				
	Coronoides Zone		Reissi Horizon				
	Occidentalis Zone						
	Mulleri Zone	Bayoensis Zone					
LOWER HETTANGIAN	Polymorphum Zone	Rectocostatum Zone		Planorbis Zone	Johnstoni Subzone	Calliphyllum Zone	Calliphyllum Zone
	Pacificum Zone	Primocostatum Zone			Planorbis Subzone		
	Minutum Zone	Tilmanni Zone					
	Spelae Zone						

**Figure 4.2.** Zonation for Hettangian and lower Sinemurian showing correlation of North American zones with South America, northwest Europe, western Tethys (circum-Mediterranean), eastern Tethys and New Zealand. Only approximate correlations are implied.



**Figure 4.3.** Lithostratigraphy and fossil localities of Section A at Kennecott Point, Queen Charlotte Islands.

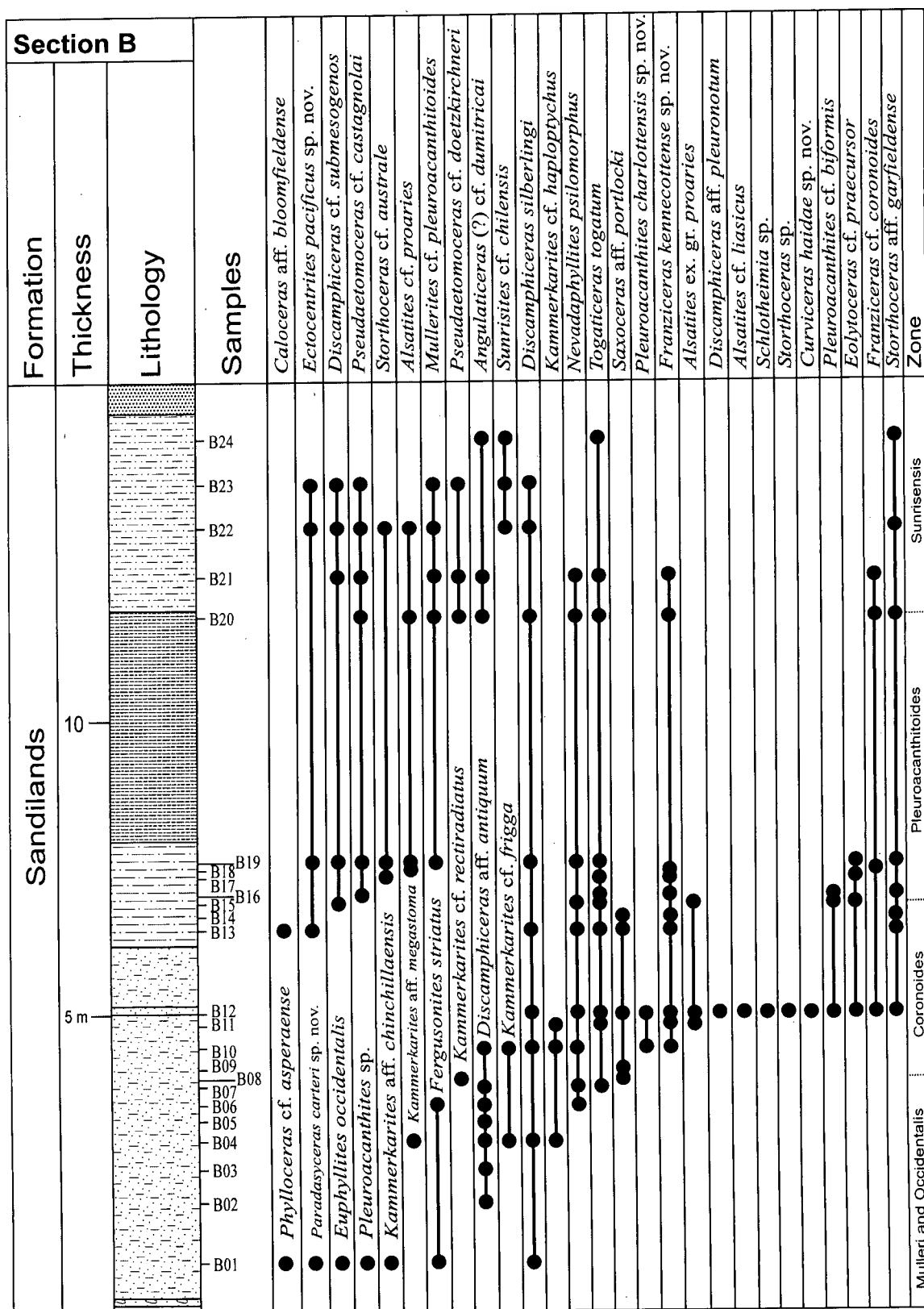
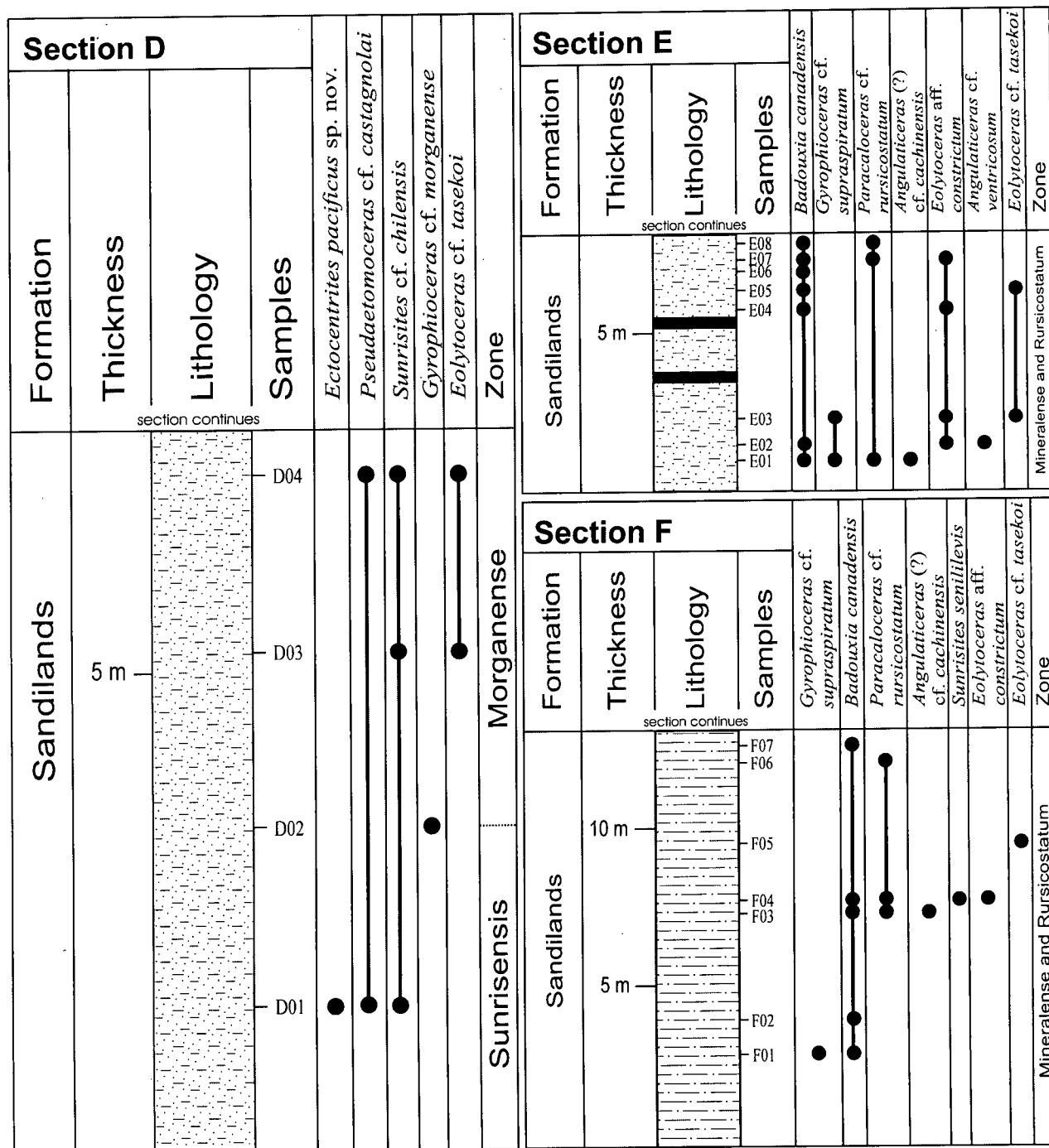


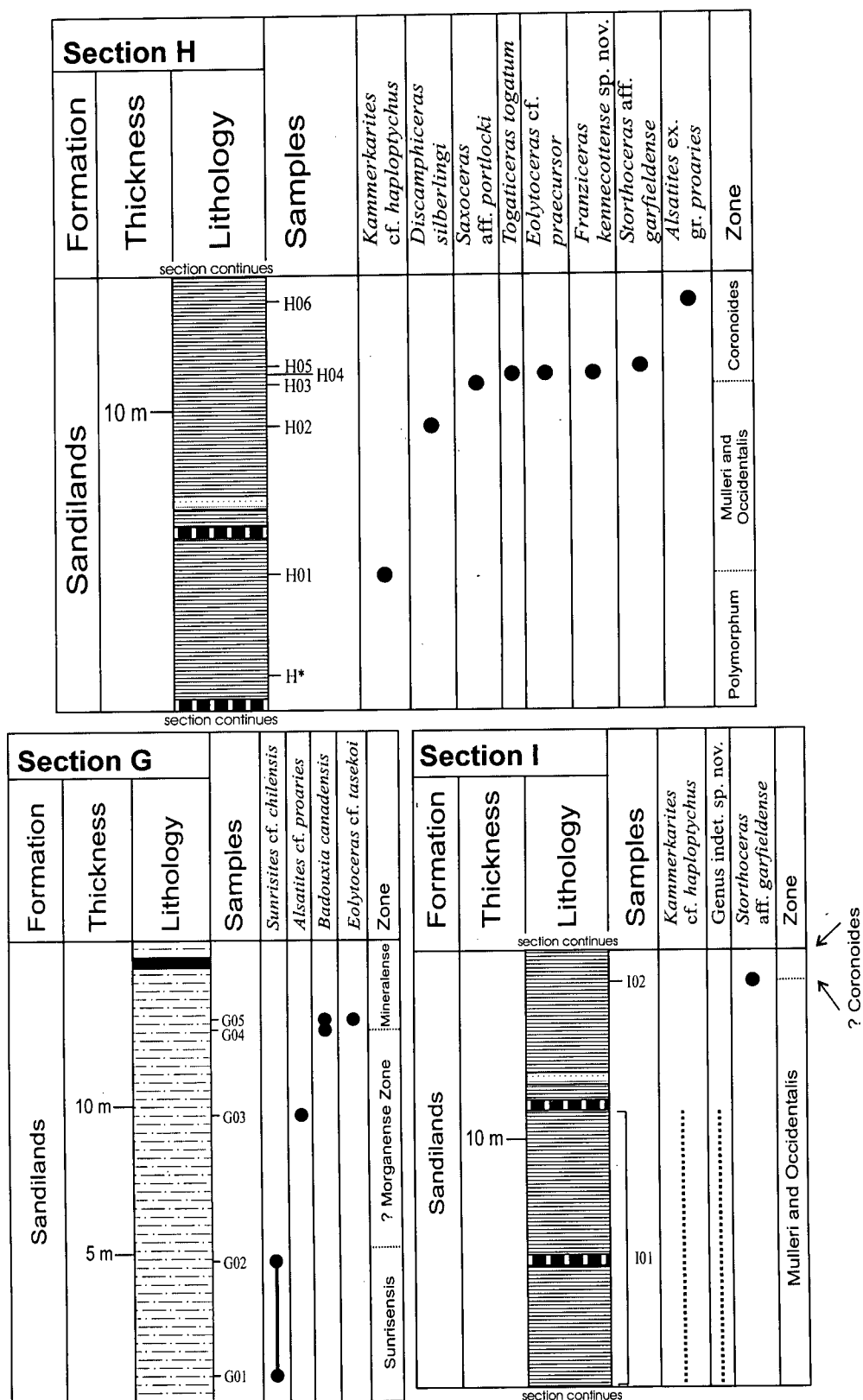
Figure 4.4. Lithostratigraphy and fossil localities of Section B at Kennecott Point, Queen Charlotte Islands; for key, see Figure 4.3.



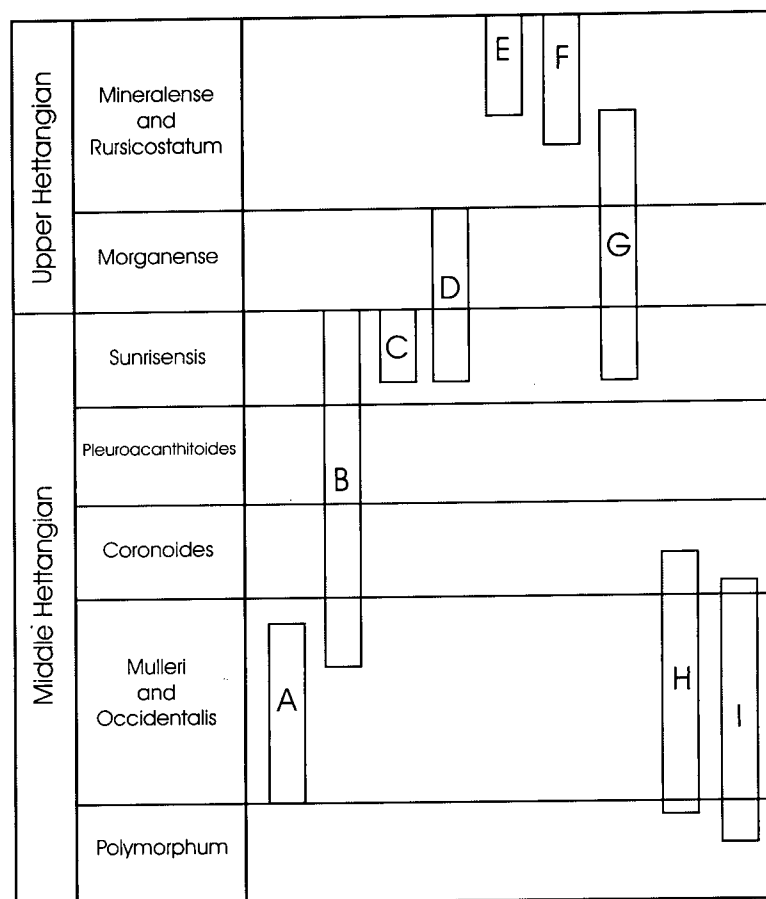




**Figure 4.6.** Lithostratigraphy and fossil localities of Sections D-F at Kennecott Point, Queen Charlotte Islands; for key, see Figure 4.3.



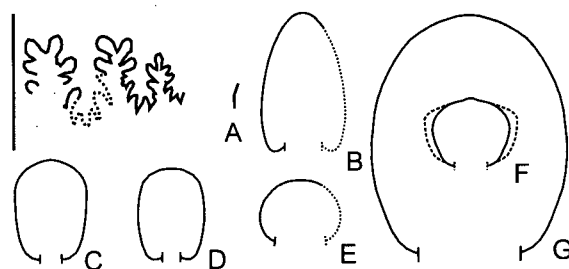
**Figure 4.7.** Lithostratigraphy and fossil localities of Sections G-I. Section G at Kennecott Point, Sections H-I at Kunga Island, Queen Charlotte Islands; for key, see Figure 4.3.



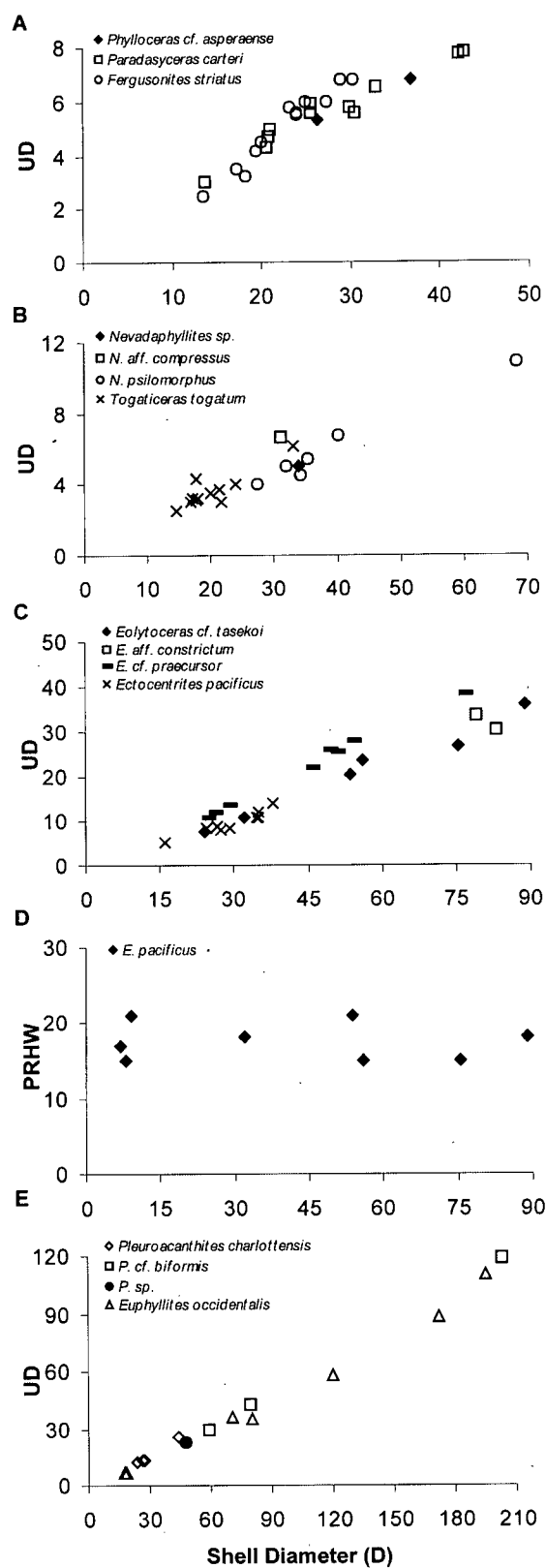
**Figure 4.8.** Approximate correlation of stratigraphic sections from the Queen Charlotte Islands.

Fauna	Mulleri/Occidentalis zones	Coronoides Zone	Pleuroacanthitoides Zone	Sunrisensis Zone	Morganense Zone	Mineralense/Rursicostatum zones
<b>Kammerkarites</b> sp. nov.						
<i>Fergusonites striatus</i>						
<b>Kammerkarites</b> aff. <i>megastoma</i>						
<i>Euphyllites occidentalis</i>						
<b>Paradasyceras</b> <i>carteri</i> sp. nov.						
<b>Kammerkarites</b> aff. <i>chinchillaensis</i>						
<b>Pleuroacanthites</b> sp.						
<b>Phylloceras</b> cf. <i>asperaense</i>						
<b>Nevadaphyllites</b> aff. <i>compressus</i>						
<b>Kammerkarites</b> cf. <i>praeconoides</i>						
Genus indet. sp. nov.						
<b>Nevadaphyllites</b> sp.						
<b>Discamphiceras</b> aff. <i>pleuronotum</i>						
<b>Discamphiceras</b> aff. <i>antiquum</i>						
<b>Kammerkarites</b> cf. <i>haploptychus</i>						
<b>Kammerkarites</b> cf. <i>frigga</i>						
<b>Pleuroacanthites</b> <i>charlottensis</i> sp. nov.						
<b>Pleuroacanthites</b> cf. <i>biformis</i>						
<b>Nevadaphyllites</b> <i>psilomorphus</i>						
<b>Discamphiceras</b> <i>silberlingi</i>						
<b>Togaticeras</b> <i>togatum</i>						
<b>Kammerkarites</b> cf. <i>rectiradiatus</i>						
<b>Saxoceras</b> aff. <i>portlocki</i>						
<b>Alsatites</b> cf. <i>liasicus</i>						
<b>Curvicerias</b> <i>haidae</i> sp. nov.						
<b>Storhoceras</b> sp.						
<b>Schlotheimia</b> sp.						
<b>Caloceras</b> aff. <i>bloomfieldense</i>						
<i>Alsatites</i> ex. gr. <i>proaries</i>						
<i>Eolytoceras</i> cf. <i>praecursor</i>						
<b>Franziceras</b> <i>kennecottense</i> sp. nov.						
<i>Franziceras</i> cf. <i>coronoides</i>						
<b>Storhoceras</b> aff. <i>garfieldense</i>						
<b>Ectocentrites</b> <i>pacificus</i> sp. nov.						
<i>Discamphiceras</i> cf. <i>submesogenos</i>						
<i>Mullerites</i> cf. <i>pleuroacanthitoides</i>						
<b>Storhoceras</b> cf. <i>australe</i>						
<b>Alsatites</b> cf. <i>proaries</i>						
<i>Pseudatetomoceras</i> cf. <i>castagnolai</i>						
<i>Pseudatetomoceras</i> cf. <i>doetzkirchneri</i>						
<i>Angulaticeras</i> (?) cf. <i>dumitricai</i>						
<b>Gyrophiceras</b> aff. <i>praespiratissimum</i>						
<b>Paracaloceras</b> (?) sp.						
<b>Sunrisites</b> cf. <i>chilensis</i>						
<i>Gyrophiceras</i> cf. <i>morganense</i>						
<i>Eolytoceras</i> cf. <i>tasekoi</i>						
<i>Badouxia</i> <i>canadensis</i>						
<b>Gyrophiceras</b> cf. <i>supraspiratum</i>						
<b>Eolytoceras</b> aff. <i>constrictum</i>						
<b>Paracaloceras</b> cf. <i>rursicostatum</i>						
<b>Angulaticeras</b> cf. <i>ventricosum</i>						
<b>Angulaticeras</b> (?) cf. <i>cachinensis</i>						
<i>Sunrisites</i> cf. <i>senililevis</i>						

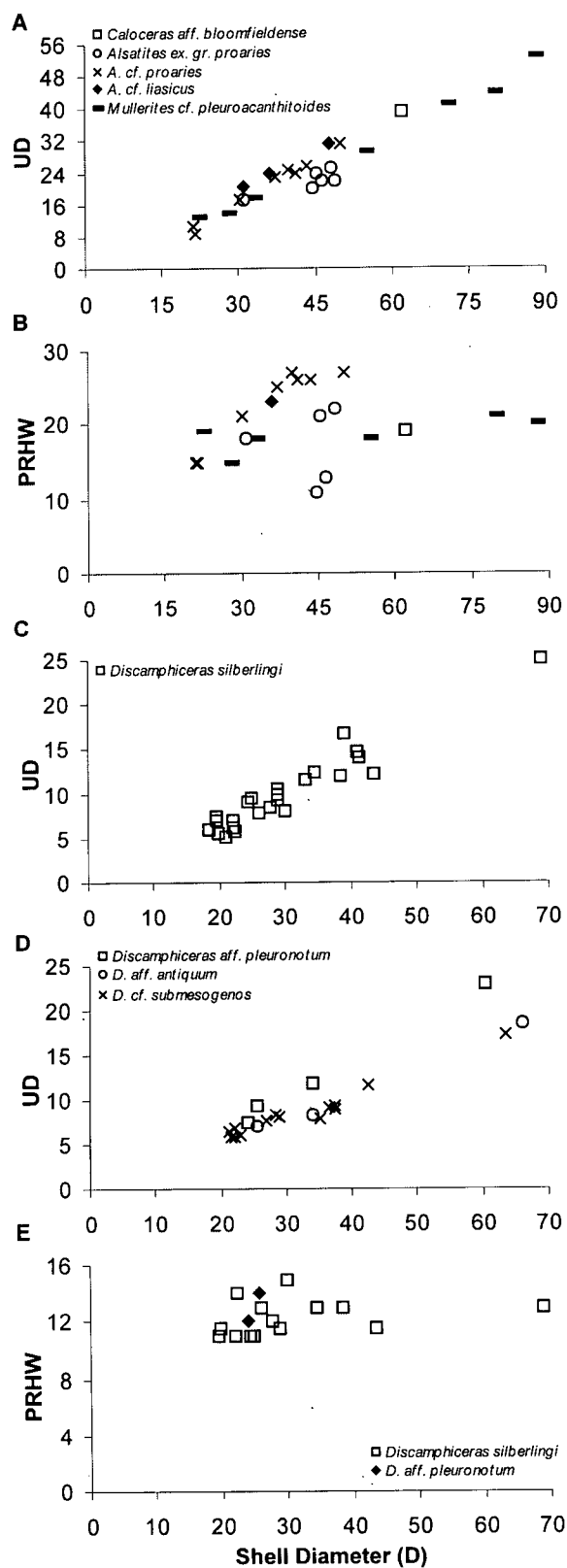
**Figure 4.9.** Ranges of ammonites from the Mulleri/Occidentalis zones to the Mineralense/Rursicostatum zones in the Queen Charlotte Islands. Taxa indicated in bold are new records for the Coronoides through Morganense zones of the North American Zonation. In the Mulleri/Occientalis as well as Mineralense/Rursicostatum zones, taxa are also indicated in bold if they are not previously recognized from either zone. In cases where the zonal range is not entirely new but is extended from what was previously recognized, the new portion of the range is indicated with a thicker line.



**Figure 4.10.** Trace of septal suture and whorl shape cross-sections for middle and late Hettangian ammonites from the Queen Charlotte Islands. Figures are  $\times 1$  unless otherwise indicated. A, *Phylloceras* cf. *asparaense* Hillebrandt, GSC 129066, WH = 11.3 mm;  $\times 2$ . B, *Nevadaphyllites psilomorphus* (Neumayr), GSC 129093. C, *Fergusonites striatus* Guex, GSC 129082. D, *Paradasyceras carteri* sp. nov., GSC 129102. E, *Eolytoceras* cf. *praecursor* Guex, GSC 129140. F, *Franziceras kennecottense* sp. nov., GSC 130804. G, *Euphyllites occidentalis* Guex, GSC 129155.

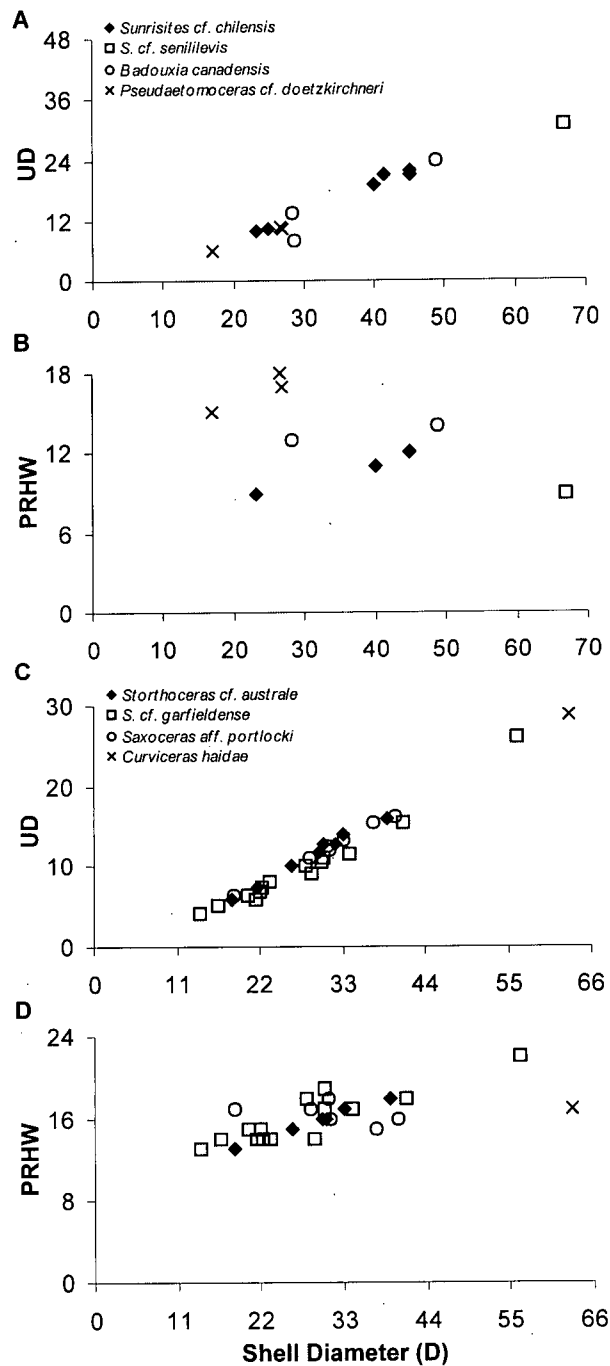


**Figure 4.11.** Plots of measurements of Phylloceratina and Psiloceratina from the Queen Charlotte Islands. A-C, E, umbilical diameter (UD) versus shell diameter (D). D, primary ribs per half whorl (PRHW) versus shell diameter (D).

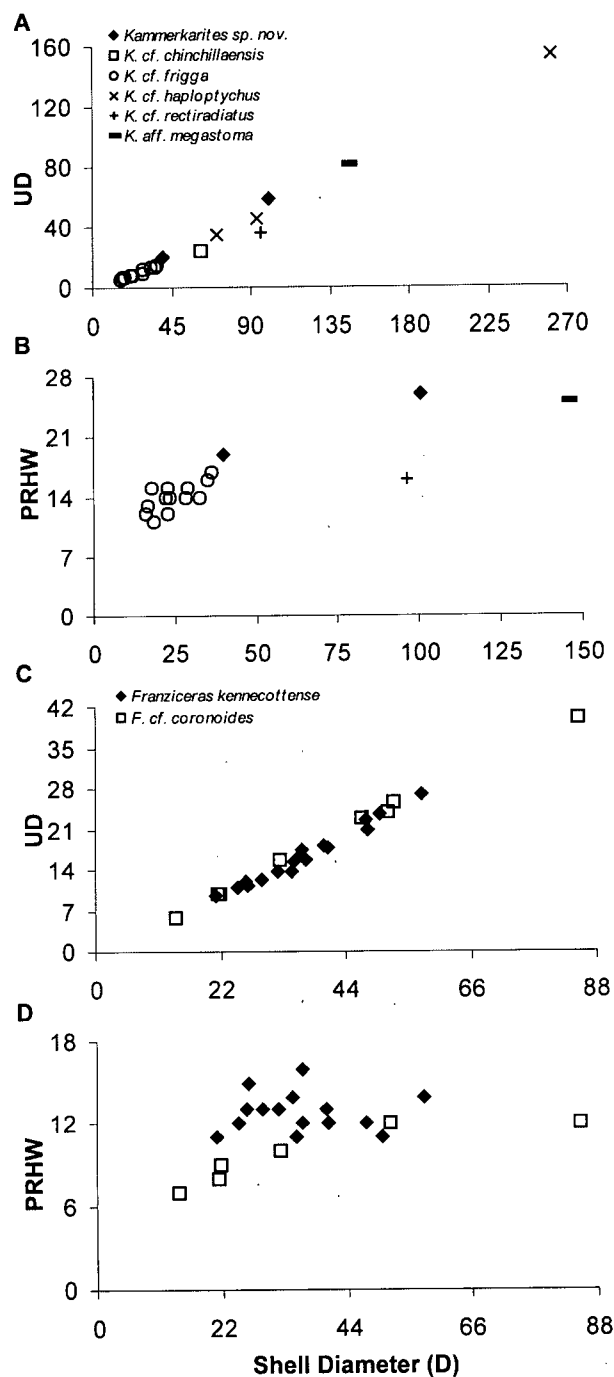


**Figure 4.12.** Plots of measurements of Psiloceratina from the Queen Charlotte Islands. A, C-D, umbilical diameter (UD) versus shell diameter (D). B, E, primary ribs per half whorl (PRHW) versus shell diameter (D).

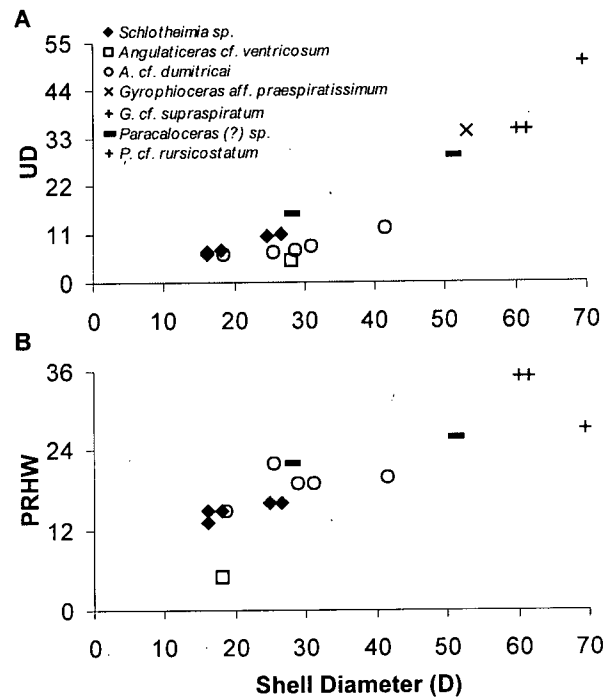




**Figure 4.13.** Plots of measurements of Psiloceratina from the Queen Charlotte Islands. A, C, umbilical diameter (UD) versus shell diameter (D). B, D, primary ribs per half whorl (PRHW) versus shell diameter (D).



**Figure 4.14.** Plots of measurements of Psiloceratina from the Queen Charlotte Islands. A, C, umbilical diameter (UD) versus shell diameter (D). B, D, primary ribs per half whorl (PRHW) versus shell diameter (D).



**Figure 4.15.** Plots of measurements of Psiloceratina from the Queen Charlotte Islands. A, umbilical diameter (UD) versus shell diameter (D). B, primary ribs per half whorl (PRHW) versus shell diameter (D).

**Plate 4.1.** All specimens from the Sandilands Formation. All figures are  $\times 0.85$ .

Figure 1, *Togaticeras togatum* (Neumayr), GSC 129103; hypotype; Pleuroacanthitoides Zone; GSC loc. no. C-156960, Sec. B, loc. 17.

Figures 2-3, *Phylloceras* cf. *asperaense* Hillebrandt, GSC 129066; Mullerites and Occidentalis zones; GSC loc. no. C-156302, Sec. A, loc. 04.

Figures 4-5, *Paradasyceras carteri* sp. nov., GSC 129070, paratype; Mulleri and Occidentalis zones; GSC loc. no. C-156998, Sec. A, loc. 02.

Figures 6-8, *Fergusonites striatus* Guex, GSC 129082, hypotype; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 9, *Togaticeras togatum* (Neumayr), GSC 129104; hypotype; Pleuroacanthitoides Zone; GSC loc. no. 156308, Sec. B, loc. 16.

Figures 10-11, *Phylloceras* cf. *asperaense* Hillebrandt, GSC 129067; Mullerites and Occidentalis zones; GSC loc. no. C-156985, Sec. B, loc. 01.

Figure 12, *Nevadaphyllites* aff. *compressus* Guex, GSC 129100; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figures 13-14, *Nevadaphyllites* aff. *compressus* Guex, GSC 129099; Mulleri and Occidentalis zones; GSC loc. no. C-156301, Sec. A, loc. 05.

Figure 15, *Paradasyceras carteri* sp. nov., GSC 129071, paratype; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 16, *Nevadaphyllites* sp., GSC 129101; Mullerites and Occidentalis zones; GSC loc. no. C-156908, Sec. A, loc. 08.

Figures 17-18, *Nevadaphyllites psilomorphus* (Neumayr), GSC 129093; hypotype; Coronoides Zone; GSC loc. no. C-156915, Sec. B, loc. 12.

Figure 19, *Eolytoceras* cf. *tasekoi* Frebold, GSC 129149; Morganense Zone; GSC loc. no. C-156328, Sec. D, loc. 04.

Figure 20, *Paradasyceras carteri* sp. nov., GSC 129068, holotype; Mulleri and Occidentalis zones; GSC loc. no. C-156302, Sec. A, loc. 04.

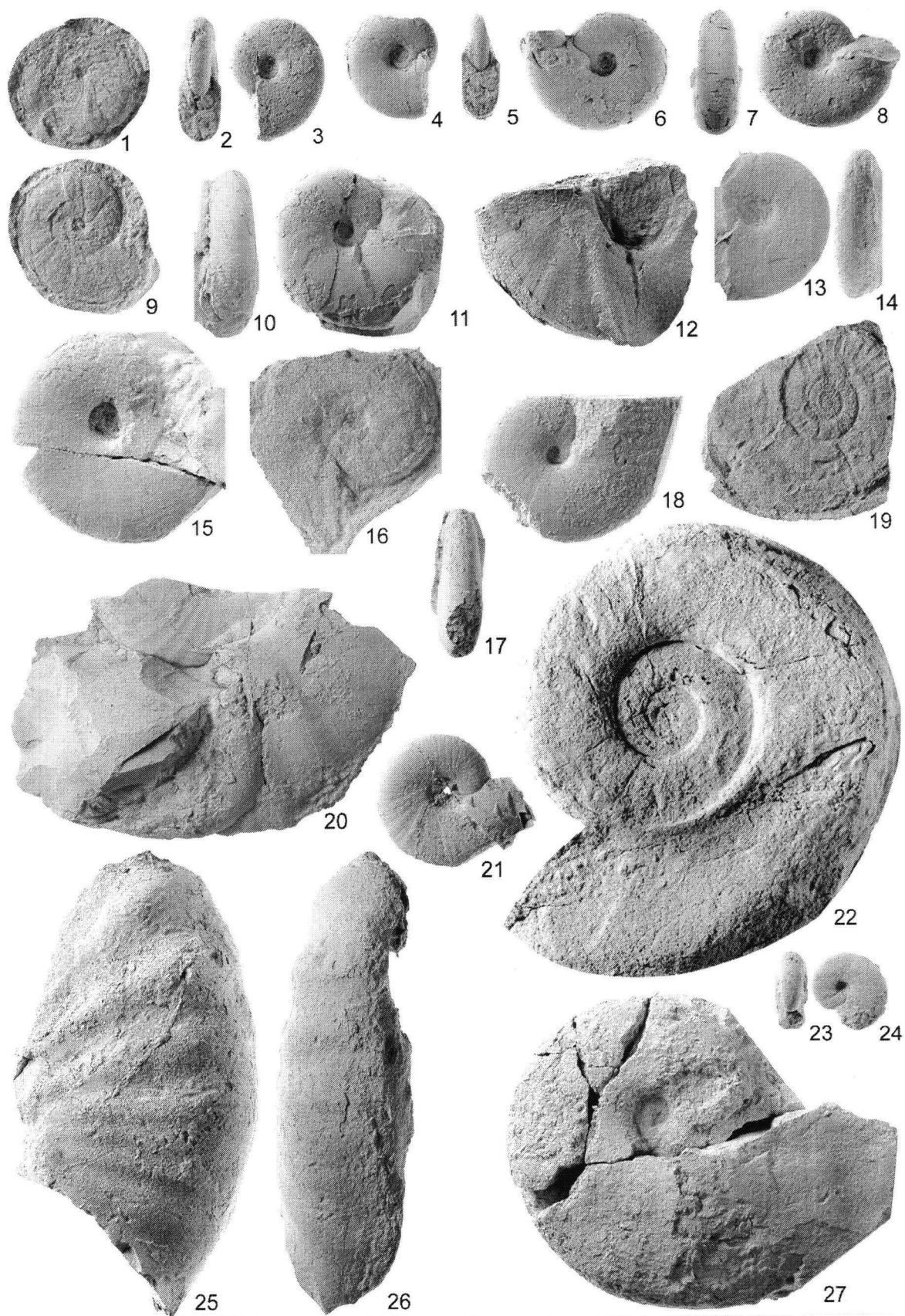
Figure 21, *Fergusonites striatus* Guex, GSC 129081, hypotype; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 22, *Eolytoceras* cf. *tasekoi* Frebold, GSC 107365; Mineralense and Rursicostatum zones, GSC loc. no. C-159289, Sec. E, loc. 03.

Figures 23-24, *Togaticeras togatum* (Neumayr), GSC 129105, hypotype; Coronoides Zone; GSC loc. no. 156915, Sec. B, loc. 12.

Figures 25-26, *Paradasyceras carteri* sp. nov., GSC 129069, paratype; Mulleri and Occidentalis zones; GSC loc. no. C- 156906, Sec. A, loc. 05.

Figure 27, *Nevadaphyllites psilomorphus* (Neumayr), GSC 129094, hypotype; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.



**Plate 4.2.** All specimens from the Sandilands Formation. Except for 17 all figures are  $\times 0.75$ . Where possible, possible microconch [m] and macroconch [M] forms are noted.

Figure 1, *Pleuroacanthites charlottensis* sp. nov., GSC 129143, paratype; Mulleri and Occidentalis zones; GSC loc. no. C-156344, Sec. A, loc. 05.

Figures 2-3, *Eolytoceras* cf. *praecursor* Guex, GSC 129140; Coronoides Zone; GSC loc. no. C-156915, Sec. B, loc. 12.

Figure 4, *Eolytoceras* cf. *praecursor* Guex, [m], GSC 129127; Coronoides Zone; GSC loc. no. C-156915, Sec. B, loc. 12; arrow marks position of last septal suture.

Figure 5, *Pleuroacanthites charlottensis* sp. nov., GSC 129142, holotype; Coronoides Zone; GSC loc. no. 156995, Sec. B, loc. 10.

Figure 6, *Eolytoceras* cf. *praecursor* Guex, [m], GSC 129128; Pleuroacanthitoides Zone; GSC loc. no. C-156305, Sec. B, loc. 19.

Figure 7, *Pleuroacanthites* cf. *biformis* (Sowerby), GSC 129141; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 8. Genus indet. sp. nov., GSC 129115; Mulleri and Occidentalis zones, GSC loc. no. C-159363, Sec. I, loc. 01.

Figure 9, *Ectocentriles pacificus* sp. nov., GSC 129117, holotype; Sunrisensis Zone; GSC loc. no. C-156324, Sec. D, loc. 01.

Figure 10, *Pseudaetomoceras* cf. *doetzkirchneri* (Gümbel), GSC 130738; Sunrisensis Zone; GSC loc. no. C-156927, Sec. B, loc. 23.

Figure 11, *Ectocentriles pacificus* sp. nov., GSC 129118, paratype; Sunrisensis Zone; GSC loc. no. C-156925, Sec. B, loc. 22.

Figure 12, *Pseudaetomoceras* cf. *doetzkirchneri* (Gümbel), GSC 130737; Sunrisensis Zone; GSC loc. no. C-157623, Sec. B, loc. 20.

Figure 13. *Pleuroacanthites* sp., GSC 129148; Mulleri and Occidentalis zones, GSC loc. no. C-156985, Sec. B, loc. 01.

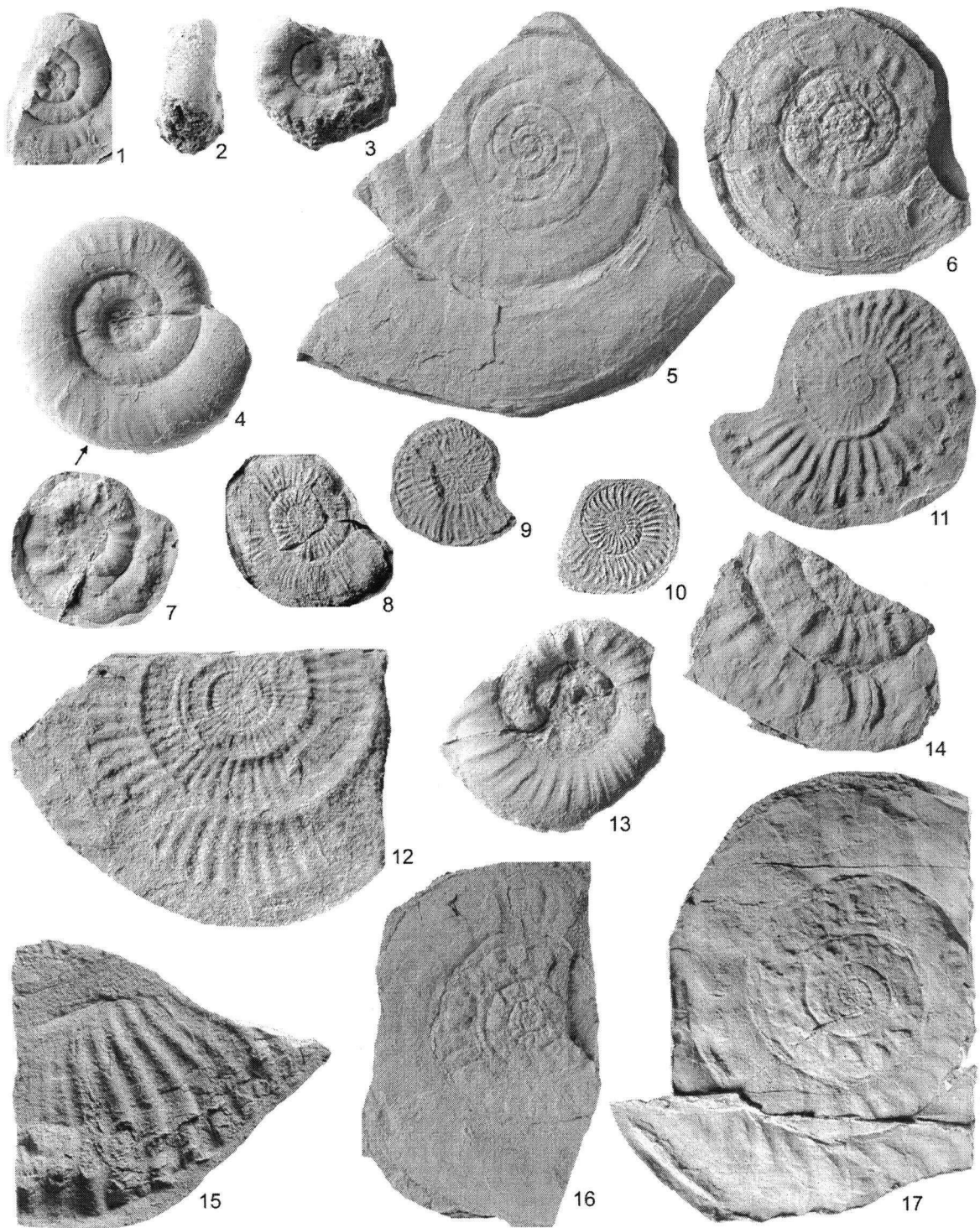
Figure 14, *Pleuroacanthites* cf. *biformis* (Sowerby), GSC 129136, Sec. B, loc. uncertain.

Figure 15, *Ectocentriles pacificus* sp. nov., GSC 129116, paratype; Sunrisensis Zone; GSC loc. no. C-156318, Sec. C, loc. 04.

Figure 16, *Eolytoceras* cf. *praecursor* Guex, [M], GSC 129129; Pleuroacanthitoides Zone; GSC loc. no. C-156309, Sec. B, loc. 15.

Figure 17, *Pleuroacanthites* cf. *biformis* (Sowerby), GSC 129137; Pleuroacanthitoides Zone; GSC loc. no. C-156308, Sec. B, loc. 16; latex cast of external mould,  $\times 0.375$ .





**Plate 4.3.** All specimens from the Sandilands Formation. Except for 5 and 11 all figures are  $\times 0.85$ .

Figure 1, *Eolytoceras* aff. *constrictum* Longridge *et al.*, GSC 107374; Mineralense and Rursicostatum zones; GSC loc. no. C-175211, Sec. E, loc. 07; latex cast of external mould.

Figure 2, *Euphyllites occidentalis* Guex, GSC 129157, hypotype; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figures 3-4, *Euphyllites occidentalis* Guex, GSC 129155, hypotype; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 5, *Pseudaetomoceras* cf. *castagnolai* (Canavari), GSC 130735; Pleuroacanthitoides Zone; GSC loc. no. C-156305, Sec. B, loc. 19;  $\times 0.425$ .

Figure 6, *Mullerites* cf. *pleuroacanthitoides* Guex, GSC 130719; Sunrisensis Zone; GSC loc. no. C-156313, Sec. B, loc. 22.

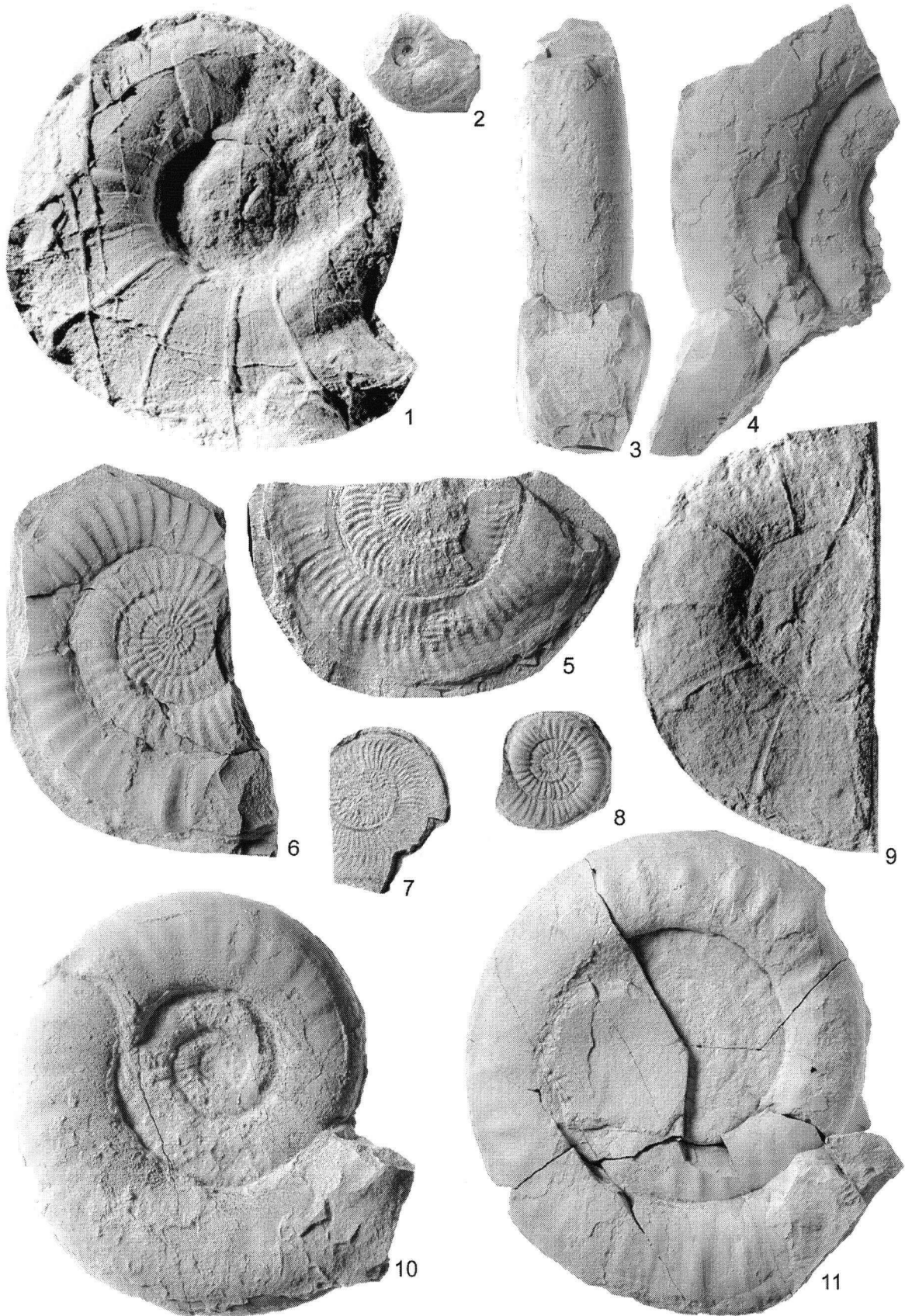
Figure 7, *Pseudaetomoceras* cf. *castagnolai* (Canavari), GSC 130736; Sunrisensis Zone; GSC loc. no. C-156316, Sec. C, loc. 06.

Figure 8, *Mullerites* cf. *pleuroacanthitoides* Guex, GSC 130718; Pleuroacanthitoides Zone; GSC loc. no. C-156305, Sec. B, loc. 19.

Figure 9, *Eolytoceras* aff. *constrictum* Longridge *et al.*, GSC 107373; Mineralense and Rursicostatum zones; GSC loc. no. C-159290, Sec. E, loc. 02.

Figure 10, *Euphyllites occidentalis* Guex, GSC 1129154, hypotype; Mulleri and Occidentalis zones, GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 11, *Euphyllites occidentalis* Guex, GSC 129156, hypotype; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05;  $\times 0.425$ .



**Plate 4.4.** All specimens from the Sandilands Formation. Except for 3 all figures are  $\times 0.85$ .

Figure 1, *Caloceras* aff. *bloomfieldense* Donovan, GSC 129162; Coronoides Zone; GSC loc. no. C-157633, Sec. B, loc. 13.

Figure 2, *Discamphiceras* aff. *pleuronotum* (Canavari), GSC 130677; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 3, *Badouxia canadensis* (Frebold), GSC 107399, hypotype; Mineralense and Rursicostatum zones; GSC loc. no. C-156406, Sec. F, loc. 04; latex cast of external mould,  $\times 0.425$ .

Figure 4, *Discamphiceras* aff. *antiquum* Guex, GSC 130695; Mulleri and Occidentalis zones; GSC loc. no. C-156986, Sec. B, loc. 02.

Figure 5, *Discamphiceras* aff. *pleuronotum* (Canavari), GSC 130676; Mulleri and Occidentalis zones; GSC loc. no. C-156906, Sec. A, loc. 05.

Figure 6, *Discamphiceras silberlingi* Guex, GSC 129163; Coronoides Zone; hypotype; GSC loc. no. C-156303, Sec. B, loc. 12.

Figure 7, *Discamphiceras* aff. *antiquum* Guex, GSC 130696; Mulleri and Occidentalis zones; GSC loc. no. C-156908, Sec. A, loc. 08.

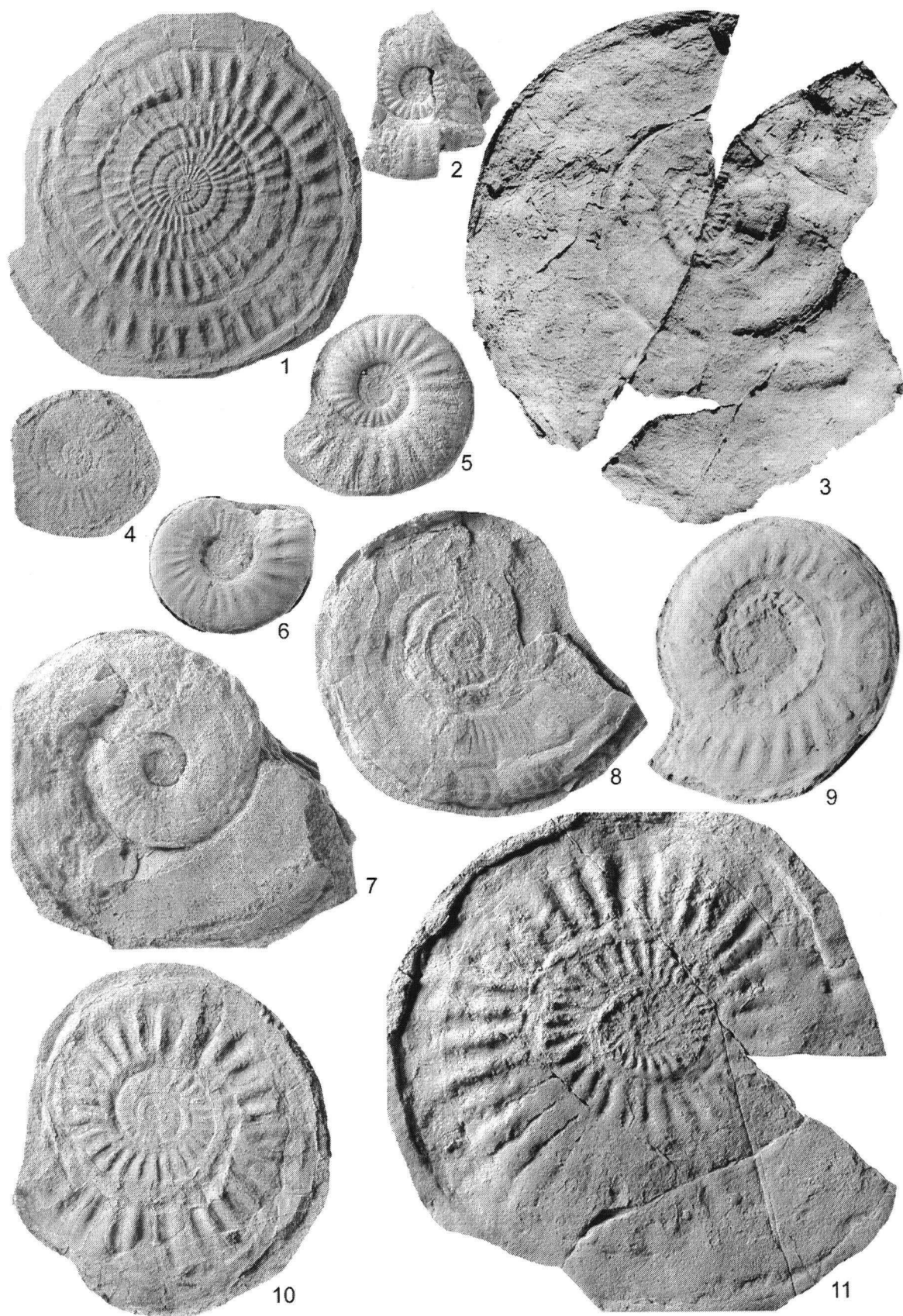
Figure 8, *Discamphiceras* cf. *submesogenos* Guex, GSC 130681; Pleuroacanthitoides Zone; GSC loc. no. C-156305, Sec. B, loc. 19.

Figure 9, *Badouxia canadensis* (Frebold), GSC 107392, hypotype; Mineralense and Rursicostatum zones; GSC loc. no. C-156420, Sec. F, loc. 01.

Figure 10, *Discamphiceras silberlingi* Guex, GSC 129164; Pleuroacanthitoides Zone; hypotype; GSC loc. no. C-156305, Sec. B, loc. 19.

Figure 11, *Kammerkarites* cf. *rectiradiatus* Guex, GSC 130675; Coronoides Zone; GSC loc. no. C-156993, Sec. B, loc. 08.





**Plate 4.5.** All specimens from the Sandilands Formation. Except for 3 and 4 all figures are  $\times 0.85$ .

Figure 1, *Kammerkarites* sp. nov., GSC 130773; Mullerites and Occidentalis zones; GSC loc. no. C-157640, Sec. A, loc. 01.

Figure 2, *Kammerkarites* aff. *chinchillaensis* Hillebrandt, GSC 130776; Mullerites and Occidentalis zones; GSC loc. no. C-156304, Sec. A, loc. 06.

Figure 3, *Kammerkarites* cf. *haploptychus* (Wähner), GSC 130790; Mullerites and Occidentalis zones; GSC loc. no. C-156988, Sec. A, loc. 02;  $\times 0.34$ .

Figure 4, *Kammerkarites* aff. *megastoma* (Gümbel), GSC 130794; Mullerites and Occidentalis zones; hypotype; GSC loc. no. C-157636, Sec. B, loc. 04;  $\times 0.51$ .

Figure 5, *Kammerkarites* aff. *chinchillaensis* Hillebrandt, GSC 130775; Mullerites and Occidentalis zones; GSC loc. no. C-156339, Sec. B, loc. 01.

Figure 6, *Kammerkarites* cf. *haploptychus* (Wähner), GSC 130792; Coronoides Zone; GSC loc. no. C-156332, Sec. B, loc. 10.

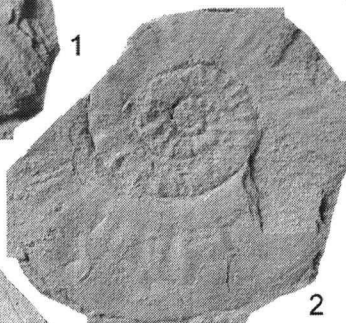
Figure 7, *Kammerkarites* cf. *haploptychus* (Wähner), GSC 130791; Mullerites and Occidentalis zones; GSC loc. no. C-156988, Sec. B, loc. 04; latex cast of external mould.



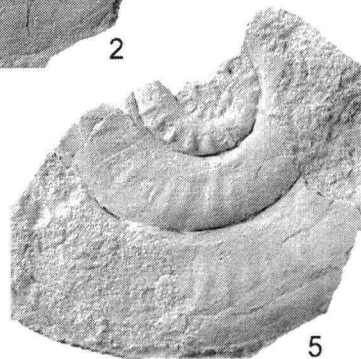
1



3



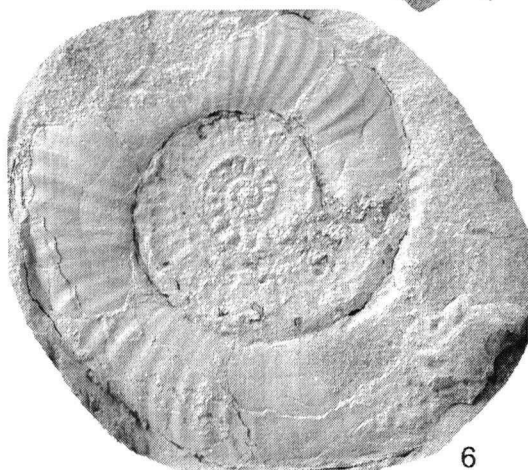
2



5



4



6



7

**Plate 4.6.** All specimens from the Sandilands Formation. All figures are  $\times 0.85$ .

Figure 1, *Franziceras* cf. *coronoides* (Guex), GSC 130702; Sunrisensis Zone; GSC loc. no. C-156312, Sec. B, loc. 21.

Figure 2, *Franziceras* cf. *coronoides* (Guex), GSC 130795; Sunrisensis Zone; hypotype; GSC loc. no. C-156924, Sec. B, loc. 21.

Figure 3, *Franziceras kennecottense* sp. nov., GSC 130806, holotype; Coronoides Zone; GSC loc. no. C-156310, Sec. B, loc. 14.

Figure 4, *Franziceras* cf. *coronoides* (Guex), GSC 130797; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figures 5-6, *Franziceras* cf. *coronoides* (Guex), GSC 130796; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figures 7-8, *Franziceras kennecottense* sp. nov., GSC 130804, paratype; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figure 9, *Franziceras kennecottense* sp. nov., GSC 130805, paratype; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figure 10, *Sunrisites* cf. *chilensis* Hillebrandt, GSC 130727; Sunrisensis Zone; GSC loc. no. C-156317, Sec. C, loc. 05.

Figure 11, *Sunrisites* cf. *senililevis* Longridge *et al.*, GSC 107385; Mineralense and Rursicostatum zones; GSC loc. no. C-156406, Sec. F, loc. 04; latex cast of external mould.

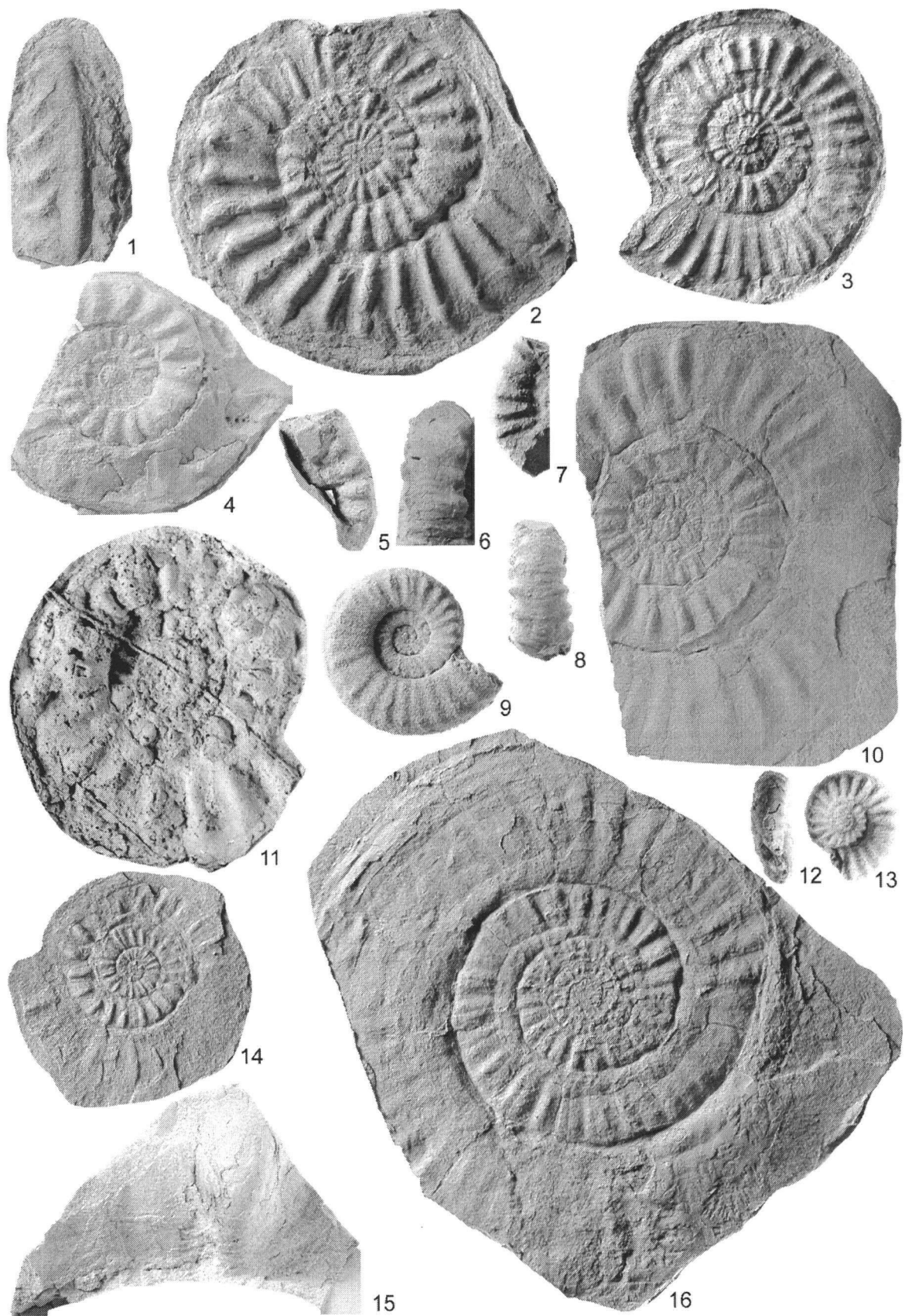
Figures 12-13, *Franziceras* cf. *coronoides* (Guex), GSC 130802; Coronoides Zone; GSC loc. no. C-156915, Sec. B, loc. 12.

Figure 14, *Sunrisites* cf. *chilensis* Hillebrandt, GSC 130728; Sunrisensis Zone; GSC loc. no. C-156317, Sec. C, loc. 05.

Figure 15, *Sunrisites* cf. *chilensis* Hillebrandt, GSC 130725; Sunrisensis Zone; GSC loc. no. C-156317, Sec. C, loc. 05.

Figure 16, *Sunrisites* cf. *chilensis* Hillebrandt, GSC 130726; Sunrisensis Zone; GSC loc. no. C-157637, Sec. B, loc. 24.





**Plate 4.7.** All specimens from the Sandilands Formation. Except for 10 all figures are  $\times 0.85$ .

Figure 1, *Paracaloceras* cf. *rursicostatum* Frebold, GSC108505; lowermost Columbiae Zone; GSC loc. no. C-159284, Sec. E, 0.5 m above level 08.

Figure 2, *Gyrophioceras* cf. *supraspiratum* (Wähner), GSC 107400; Mineralense and Rursicostatum zones; GSC loc. no. C-159251, Sec. E, loc. 01.

Figure 3, *Gyrophioceras* aff. *praespiratissimum* (Wähner), GSC 131679; Sunrisensis Zone; GSC loc. no. C-156317, Sec. C, loc. 05.

Figure 4, *Paracaloceras* (?) sp., GSC 131681; Sunrisensis Zone; GSC loc. no. C-156317, Sec. C, loc. 05.

Figure 5, *Alsatites* ex. gr. *proaries* (Neumayr), GSC 130712; Coronoides Zone; GSC loc. no. C-156915, Sec. B, loc. 12.

Figure 6, *Alsatites* ex. gr. *proaries* (Neumayr), GSC 130711; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

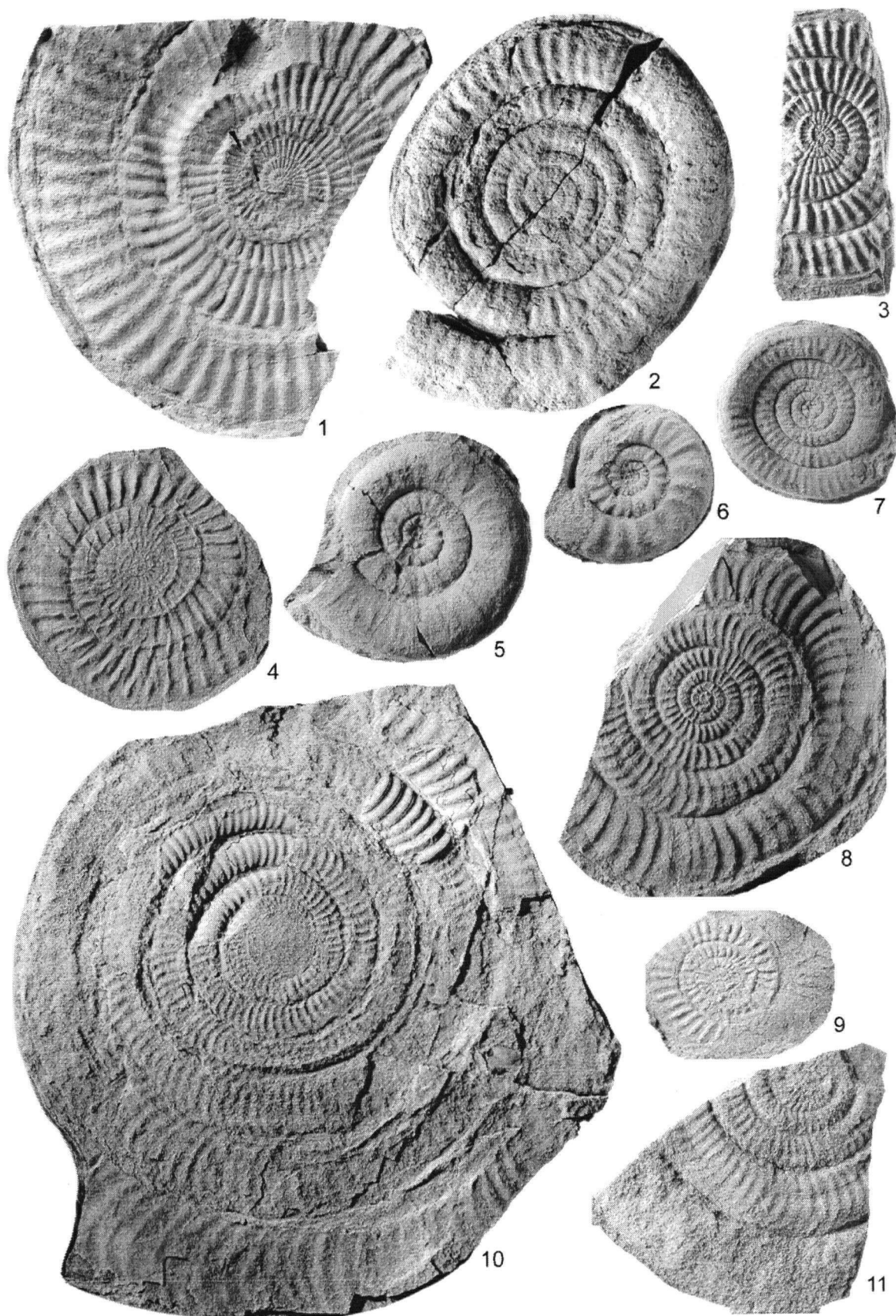
Figure 7, *Alsatites* cf. *liasicus* (d'Orbigny), GSC 130699; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figure 8, *Alsatites* cf. *proaries* (Neumayr), GSC 130703; Pleuroacanthitoides Zone; GSC loc. no. C-156305, Sec. B, loc. 19.

Figure 9, *Paracaloceras* (?) sp., GSC 131682; Sunrisensis Zone; GSC loc. no. C-156317, Sec. C, loc. 05.

Figure 10, *Alsatites* cf. *proaries* (Neumayr), GSC 156959; Morganense Zone?; GSC loc. no. C-175203, Sec. G, loc. 03; some shell material preserved,  $\times 0.595$ .

Figure 11, *Gyrophioceras* cf. *morganense* (Taylor), GSC 131680; Morganense Zone; GSC loc. no. C-156326, Sec. D, loc. 02.



**Plate 4.8.** All specimens from the Sandilands Formation. All figures are  $\times 0.85$ .

Figure 1, *Kammerkarites* cf. *praecoronoides* Guex, GSC 130793; Mullerites and Occidentalis zones; GSC loc. no. C-156344, Sec. A, loc. 05.

Figures 2-3, *Saxoceras* aff. *portlocki* (Wright), GSC 130767; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figures 4-5, *Saxoceras* aff. *portlocki* (Wright), GSC 130768; Coronoides Zone; GSC loc. no. C-156915, Sec. B, loc. 12.

Figure 6, *Kammerkarites* cf. *frigga* (Wöhner), GSC 130777; Mulleri and Occidentalis zones; GSC loc. no. C-156988, Sec. B, loc. 04.

Figures 7-8, *Kammerkarites* cf. *frigga* (Wöhner), GSC 130778; Mulleri and Occidentalis zones; GSC loc. no. C-156301, Sec. A, loc. 05.

Figures 9-10, *Storhoceras* sp., GSC 130764; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figure 11, *Saxoceras* aff. *portlocki* (Wright), GSC 130765; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figures 12-13, *Curviceras haidae* sp. nov., GSC 130763, holotype; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figure 14, *Storhoceras* cf. *australe* Hillebrandt, GSC 130756; Sunrisensis Zone; GSC loc. no. C-156313, Sec. B, loc. 22.

Figure 15, *Saxoceras* aff. *portlocki* (Wright), GSC 130766; Coronoides Zone; GSC loc. no. C-156913, Sec. B, loc. 10.

Figures 16-17, *Schlotheimia* sp., GSC 131668; Coronoides Zone; GSC loc. no. C-156303, Sec. B, loc. 12.

Figure 18, *Angulaticeras* cf. *ventricosum* (Sowerby), GSC 107376; Mineralense and Rursicostatum zones; GSC loc. no. C-159290, Sec. E, loc. 02.

Figure 19, *Storhoceras* cf. *australe* Hillebrandt, GSC 130755; Sunrisensis Zone; GSC loc. no. C-156313, Sec. B, loc. 22.

Figure 20, *Storhoceras* aff. *garfieldense* (Taylor), GSC 130741; Pleuroacanthitoides Zone; GSC loc. no. C-156305, Sec. B, loc. 19.

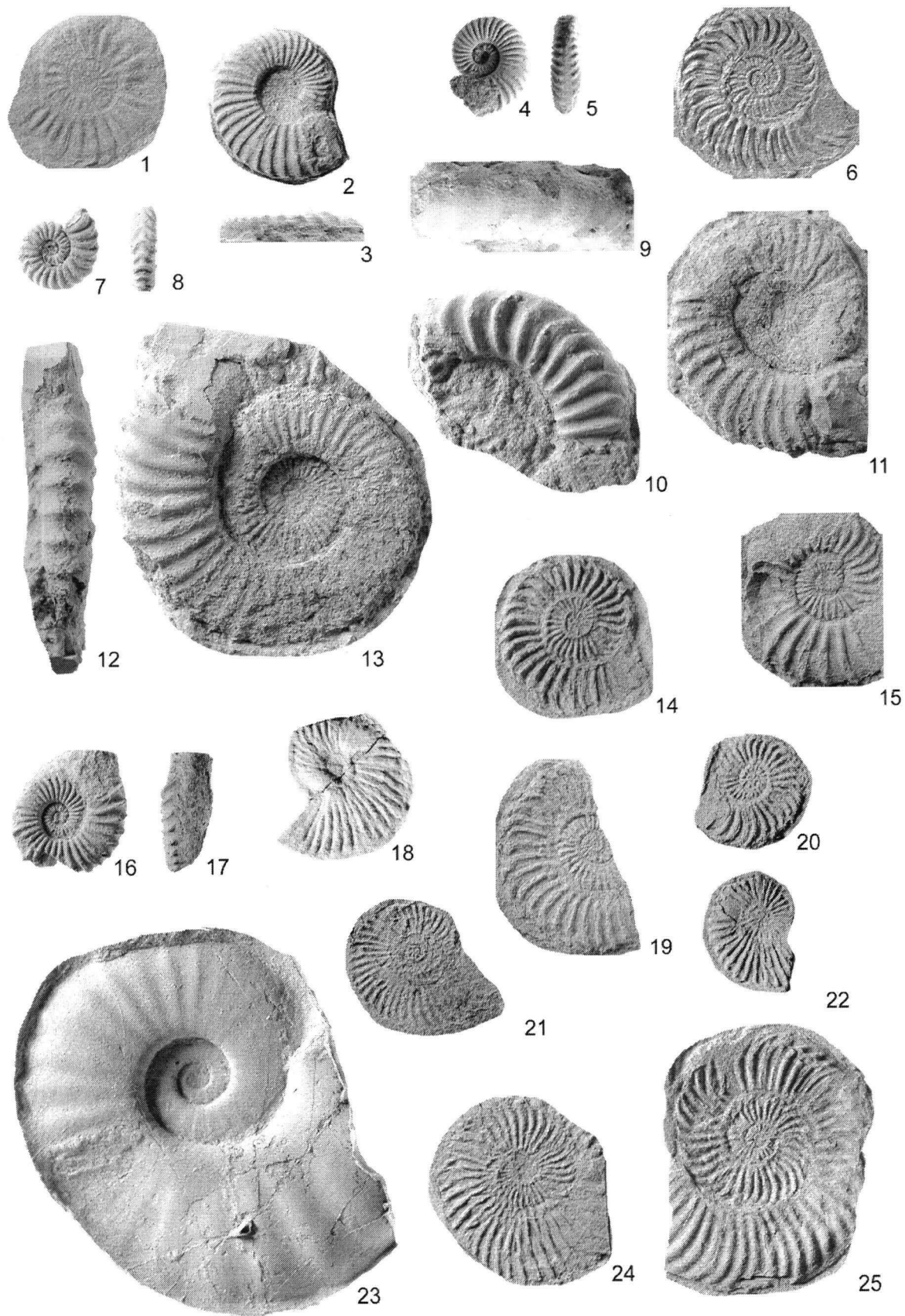
Figure 21, *Angulaticeras* (?) cf. *dumitricai* Guex, GSC 131675; Sunrisensis Zone; GSC loc. no. C-156322, Sec. C, loc. 01.

Figure 22, *Angulaticeras* (?) cf. *cachinensis* (Hillebrandt), GSC 107379; lowermost Columbiae Zone; GSC loc. no. C-159282, Sec. E, 1.3 m above level 08.

Figure 23, *Angulaticeras* (?) cf. *dumitricai* Guex, GSC 131673; middle or late Hettangian, exact locality uncertain; latex cast of external mould.

Figure 24, *Angulaticeras* (?) cf. *dumitricai* Guex, GSC 131674; Sunrisensis Zone; GSC loc. no. C-156317, Sec. C, loc. 05.

Figure 25, *Storthoceras* aff. *garfieldense* (Taylor), GSC 130742; Sunrisensis Zone; GSC loc. no. C-156313, Sec. B, loc. 22.





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## 5 THE EARLY JURASSIC AMMONITE *BADOUXIA* FROM BRITISH COLUMBIA, CANADA<sup>1</sup>

### 5.1 Introduction

Taseko Lakes in British Columbia has yielded the most prolific, well-preserved and diverse collection of *Badouxia* currently known. Frebold (1951) did early work on the faunas of the area and established the first record of what was to become *Badouxia* when he erected the species *Psiloceras canadense* from the late Hettangian. After further work on additional material, Frebold (1967) identified two more species from the area, *Psiloceras occidentale* and *Psiloceras columbiae*. Guex and Taylor (1976) formally erected the genus *Badouxia*, recognizing *B. canadensis* (Frebold) from Taseko Lakes as the type species and including *B. columbiae* (Frebold) as another species. Since then, *Badouxia* has been recognized from many other areas. Most species are endemic to the eastern Pacific with occurrences in British Columbia, Nevada, Oregon, Alaska, Mexico, Peru, Argentina and Chile (Frebold 1964; Imlay 1981; Hillebrandt 1981, 1990, 1994, 2000*a, b*; Prinz 1985; Quinzio Sinn 1987; Riccardi *et al.* 1988, 1991; Jakobs and Pálffy 1994; Pálffy *et al.* 1994, 1999; Guex 1995; Taylor 1998, 2000; Taylor *et al.* 2001; Taylor and Guex 2002; Hall and Pitaru 2004). There is also a record of *Badouxia* from the Austrian Alps (Rakús 1993) and unsubstantiated reports of *Psiloceras* (*Franziceras*) *canadense* (now *B. canadensis*) from Siberia in the Russian Federation (Polubotko and Repin 1967; Repin 1984) and *Badouxia?* from Vietnam (Elmi 1993).

Frebold (1967) proposed the first North American ammonite zone, the Canadense Zone (now Canadensis Zone), in an attempt to deal with a principally endemic assemblage now recognized to span the Hettangian/Sinemurian boundary in North America (Bloos 1983; Pálffy *et al.* 1994;

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<sup>1</sup> A version of this chapter has been published. Longridge, L.M., Smith, P.L. and Tipper, H.W. 2006. The Early Jurassic ammonite *Badouxia* from British Columbia, Canada. *Palaeontology*, **49**, 795-816.

Taylor 1998, 2000; Smith and Tipper 2000; Taylor *et al.* 2001). *Badouxia* is a fundamental part of this assemblage and was used for both definition and subdivision of this interval. Taylor *et al.* (2001) established a formal zonation for the Hettangian/Sinemurian of the Western Cordillera of North America in which they divided the Canadensis Zone into two subzones; the Rursicostatum Subzone of Hettangian age and the Columbiae Subzone of Sinemurian age (Fig. 5.1). The first occurrence of *B. canadensis* marked the base of the Rursicostatum Subzone while the incoming of *B. columbiae* marked the base of the Columbiae Subzone. In addition, *B. mexicana* Taylor, Guex and Rakús and *B. occidentalis* characterized the Canadensis Zone. *B. oregonensis* was the name-bearer for the subjacent Oregonensis Zone with *B. striata* Guex also occurring within this zone.

Despite the importance of *Badouxia* to the North American Zonation, current delineation of species within the genus is poor. Previous work on *B. canadensis* suggested individual species could display remarkable variability in characteristics traditionally used to divide ammonite genera. Early work on South American material identified important differences in volution within *B. canadensis* (Hillebrandt 1981; Riccardi *et al.* 1991). Detailed work completed more recently by Hillebrandt (2000*b*), indicated that whorl proportion in the species varied in a continuous fashion with volution in end-members differing significantly. In addition, important differences in ribbing style and density have been documented for the species (Riccardi *et al.* 1991; Hillebrandt 2000*b*). However, in the past, a number of *Badouxia* species were erected based on differences in volution as well as ribbing strength, density, duration and orientation within small collections (Frebold 1967; Guex 1995; Taylor 1998; Taylor *et al.* 2001). As demonstrated by variation within material attributed to *B. canadensis* in South America, the accurate identification and description of species requires a comprehensive study of large collections.

Evidence of sexual dimorphism is present within three different *Badouxia* species from Taseko Lakes. Dimorphism has been documented previously in other Hettangian genera (Callomon 1981; Guex 1981, 1995) but has never been recognized in *Badouxia* before.

Although much of the late Hettangian/early Sinemurian fauna in North America is endemic, taxa such as the Schlotheimiidae permit correlation with the Tethyan sequences of the circum-Mediterranean area (Smith and Tipper 2000). Correlation between the Tethyan successions and those of north-west Europe are now quite well documented (Bloos 1983; Guérin-Franiatte 1990; Mouterde and Corna 1997; Page 2003). These similar faunas permit calibration between North America, the Tethyan realm and north-west Europe. Such correlations are important because volcanic rocks in North America permit geochronologic calibration of the successions (Pálffy *et al.* 1999, 2000).

For these reasons, it is necessary to re-examine the *Badouxia* fauna from Taseko Lakes. The study is assisted by extensive new collections in addition to an improved understanding of the geology of the area resulting from recent mapping (Schiarizza *et al.* 1997; Smith *et al.* 1998; Umhoefer and Tipper 1998).

## 5.2 Revisions to the North American Zonation

This study of the *Badouxia* fauna from the type area requires major taxonomic changes to the genus, as presented below in the systematics section. In addition, it has revised the range of the type species, *B. canadensis*. Consequently we propose the following revisions to the current zonation for the Western Cordillera of North America.

The Oregonensis Zone is re-named the Mineralense Zone (Fig. 5.1) because the name-bearer for the Oregonensis Zone, *B. oregonensis*, is a synonym of *B. canadensis*. The Canadensis Zone is eliminated and the Rursicostatum and Columbiae subzones of Taylor *et al.* (2001) are raised to the level of full zones (Fig. 5.1). Traditionally, the base of the Canadensis Zone has been

recognized by the incoming of the first *B. canadensis*. However, this study establishes that *B. canadensis* begins at the base of the earlier Mineralense Zone. There are several possible solutions to this problem. The Canadensis Zone could be retained across the Hettangian/Sinemurian boundary but this has two drawbacks. Firstly, the Canadensis Zone would no longer be correlated by the first appearance of *B. canadensis* which would make older literature confusing. Secondly, the Canadensis Zone would continue to span a stage boundary which is less than ideal. A second option is to redefine the span of the Canadensis Zone to include the Oregonensis Zone and Rursicostatum Subzone rather than the Rursicostatum and Columbiae subzones of Taylor *et al.* (2001). However, restricting the Canadensis Zone to the Hettangian would create great confusion with respect to the older literature. Further, the redefinition of some of the original type material of *B. canadensis* increases the possibility of misunderstanding the Canadensis Zone. For these reasons, the Canadensis Zone is here abandoned.

In addition to the characterizing taxa listed below for each zone, further Taseko Lakes taxa that distinguish these zones will be described in a subsequent paper. The affected zones are correlated with the standard zones of north-west Europe (Dean *et al.* 1961; Bloos 1979, 1983, 1984; Page 1992, 1995, 2003; Mouterde and Corna 1997; Bloos and Page 2000, 2002), the alpine zones of the Mediterranean (Wöhner 1882-1898; Blind 1963; Bloos 1983, 1988b; Page 2003) and the South American zones of Hillebrandt (1987, 1988, 2000c) (Fig. 5.1).

### 5.2.1 Mineralense Zone

Index, *Paracaloceras* (*Gyrophioceras*) *mineralense* Taylor. Stratotype, as discussed by Taylor *et al.* (2001), the type section is at Morgan Mountain in Oregon. The base of the zone is c. 45 m above the bottom of the section figured by Taylor (1998, Fig. 5.2) and is recognized by the incoming of *Discamphiceras ornatum* Taylor. Other characterizing taxa reported in Taylor *et al.* (2001) include the stratigraphically restricted occurrences of *Paracaloceras* (*G.*)

*mineralense* Taylor, and *Paradiscamphiceras athabascanense* Taylor. This zone is further characterized by the first appearance of *Badouxia canadensis* (Frebold) as understood herein, *Metophioceras rursicostatum* (Frebold), *Angulaticeras* cf. *trapezoidale* (Sowerby) and *Angulaticeras marmoreum* (Oppel), and by the last appearance of *Nevadaphyllites compressus* Guex. In addition to the type locality, from north to south in North America, the zone occurs in the following geographic areas: (1) the Queen Charlotte Islands (Tipper and Guex 1994, part of Doetzkirchneri beds); (2) Williston Lake (Hall and Pitaru 2004); (3) Taseko Lakes (Smith and Tipper 2000; this study); (4) Morgan Mountain in Oregon (Taylor and Guex 2002); and (5) Pamlico and New York Canyon in Nevada (Taylor 1998). We designate section C and the lower portions of sections A and D in Taseko Lakes as auxiliary reference sections for the zone.

### 5.2.2 Rursicostatum Zone

Index, *Metophioceras rursicostatum* (Frebold). Stratotype, as recorded by Taylor *et al.* (2001) the type section is in First Canyon, Shoshone Mountains, Nevada. The base of the zone is *c.* 1 m above the bottom of the section of Taylor (2000, Fig. 5.2) and consists of the upper 2 m of limestone beds within the Ferguson Hill Member (localities 6815 through 6817). The base of the zone is recognized herein by the incoming of *Badouxia castlensis* sp. nov. The zone is characterized by the first appearance of *Badouxia forticostata* sp. nov. and, as recorded in Taylor *et al.* (2001), the stratigraphically restricted occurrences of *Badouxia mexicana* Taylor, Guex and Rakús, *Paracaloceras retroversicostatum* (Canavari), *Pseudaetomoceras shoshonense* Taylor and *Schlotheimia* ex. gr. *stenorhyncha* (Lange). *Metophioceras rursicostatum* (Frebold) is found in the zone and *Eolytoceras tasekoi* Frebold, *Eolytoceras guexi* Taylor, *Angulaticeras* cf. *trapezoidale* (Sowerby) and *Angulaticeras marmoreum* (Oppel) make their last appearance. In addition to the type locality, from north to south in North America, the zone occurs in the following geographic areas: (1) Alaska (Imlay 1981; Pálffy *et al.* 1999); (2) Telegraph Creek (Frebold 1964); (3) Iskut River (Jakobs and Pálffy 1994); (4) the Queen Charlotte Islands (Pálffy

*et al.* 1994; Tipper and Guex 1994); (5) Williston Lake (Hall and Pitaru 2004); (6) Taseko Lakes (Frebold 1951, 1967; Smith and Tipper 2000; this study); (7) Oregon (Taylor 1988); and (8) Sonora in Mexico (Taylor *et al.* 2001). We designate section B and the upper portion of sections A and D in Taseko Lakes as auxiliary reference sections for the zone.

### 5.2.3 Columbiae Zone

Index, *Badouxia columbiae* (Frebold). Stratotype, as discussed by Taylor *et al.* (2001), the type section occurs in First Canyon, Shoshone Mountains, Nevada. The base of the zone is c. 2.4 m above the bottom of the section of Taylor (2000, Fig. 5.2) and consists of the lower 2.7 m of grey bioclastic limestone beds within the Ferguson Hill Member (localities 65 through 24). The base of this zone is correlated by the incoming of *Badouxia columbiae* (Frebold). As discussed by Taylor *et al.* (2001), the zone is characterized by the restricted occurrences of *Angulaticeras pulchrum* (Guérin-Franiatte), *Angulaticeras westermanni* Smith and Tipper, *Pseudotropites ultraliasicus* of Taylor *et al.* (2001), *Paracaloceras* cf. *grunowi* (Hauer), *Hyerifalchia* n. sp. and *Paracaloceras concavum* Taylor. In addition, *Badouxia forticostata* sp. nov., *Metophioceras rursicostatum* (Frebold) and *Nevadaphyllites microumbilicatus* Taylor make their last appearance in this zone and *Epammonites* aff. *rotarium* (Buckman) first appears in this zone. Besides the type locality, from north to south in North America, the zone occurs in the following geographic areas: (1) Puale Bay in Alaska (Pálffy *et al.* 1999); (2) the Queen Charlotte Islands (Pálffy *et al.* 1994); (3) Taseko Lakes (Frebold 1967; Smith and Tipper 2000; this study); and (4) Williams Reservoir in Oregon (Taylor and Guex 2002). We designate sections F, G and the upper portion of section E from Taseko Lakes as auxiliary reference sections for the zone.

### 5.3 Geological Setting

The study area falls within the Taseko Lakes map area (Energy, Mines and Resources Canada, map sheets 92-O/2, O/3) on the eastern margin of the southern Coast Mountains (Fig. 5.2). The *Badouxia* fauna described herein is found within the Castle Pass Member of the Last Creek Formation which disconformably overlies the Triassic Tyaughton Formation and is interpreted as a transgressive sequence of nearshore to inner shelf deposits (Umhoefer and Tipper 1998). The unit is extensively faulted and folded although generally unmetamorphosed. The Castle Pass Member is dominated by interbeds of volcanic-pebble conglomerate and coarse to medium-grained sandstone. *In situ* *Badouxia* specimens from the Mineralense, Rursicostatum and Columbiae zones were collected from the 7 sections and 12 isolated localities described below.

#### 5.3.1 Stratigraphic sections

Stratigraphic sections exist in two principal areas (Fig. 5.2):

1. The Castle Pass area includes four sections. Section C and the lower portion of sections A and D contain material from the Mineralense Zone whereas section B and the upper portion of sections A and D contain material from the Rursicostatum Zone. All four sections yield ammonites of late Hettangian age. The tops of all four sections are faulted. Figures 5.3-5.6 show details of the stratigraphy and collection localities for each section.
2. Three sections of uppermost Hettangian and lowermost Sinemurian age are exposed in the headwaters of Last Creek. Section E begins at the top of the Rursicostatum Zone continuing into the Columbiae Zone. Sections F and G probably span the majority of the Columbiae Zone but are fault bounded at both the lower and upper limits. Figures 5.7-5.9 show details of the stratigraphy and collection localities for each section.



### **5.3.2 Isolated localities**

Collections from localities 1-4, 6 and 12 are from the Rusicostatum Zone. Localities 5 and 7-11 contain fauna equivalent to the Columbiae Zone. Figure 5.2 shows the location of each isolated locality.

Detailed data for sections A-G and localities 1-12 is recorded in Appendix E. This information includes a brief geographical description of each site including latitude and longitude where possible as well as GSC numbers for each location.

### **5.4 Systematic Paleontology**

Abbreviations and measurements follow Smith (1986) and include shell diameter (D), umbilical diameter (UD), whorl width (WW), whorl height (WH), umbilical diameter as a ratio of shell diameter (U), ratio of the whorl width to the whorl height (WWWH) and primary ribs per half whorl (PRHW). Graphical plots of several of these parameters are shown below and include all measurable specimens of each species collected from Taseko Lakes. A record of the exact measurements of each specimen is recorded in Appendix F.

All measured and figured specimens are deposited in the type collection of the Geological Survey of Canada (GSC) in Ottawa.

**Superfamily PSILOCERATOIDEA Hyatt, 1867**

**Family PSILOCERATIDAE Hyatt, 1867**

**Subfamily SUNRISITINAE Hillebrandt, 2000*b***

**Genus BADOUXIA Guex and Taylor, 1976**

TYPE SPECIES: *Psiloceras canadense* Frebold, 1951, from the Canadensis Zone (*sensu* Frebold) of Taseko Lakes, Canada; designated by Guex and Taylor (1976).

DIAGNOSIS: Moderately involute to moderately evolute shell with compressed oval to subtriangular whorl section. Flank ribs on inner and intermediate whorls vary in strength, density and duration differing in orientation from weakly to strongly prorsiradiate. Outer whorls generally smooth but may show bullae at very large shell diameters. Venter varies from smooth to strongly-ribbed. Suture line simple and asymmetric with ventral lobe offset from median line.

***Badouxia canadensis* (Frebold, 1951)**

Plate 5.1, figures 1-18; Figures 5.10A-C, 5.11A-B

1951 *Psiloceras canadense* Frebold, p. 3, pl. 1, figs 2, 4 (holotype refigured here)-5.

1967 *Psiloceras occidentale* Frebold, p. 19, pl. 1, figs 4-5, text-fig. 4.

1967 *Eolytoceras* sp. indet. 2. Frebold, p. 16, pl. 6, Fig. 5.

1976 *Badouxia* gen. n., Guex and Taylor, p. 525.

1987 *Badouxia* cf. *canadensis* (Frebold); Quinzio Sinn, pl. 1, fig. 11.

1994 *Badouxia canadensis* (Frebold); Pálffy *et al.*, pl. 1, fig. 3.

1994 *Badouxia canadensis* (Frebold); Hillebrandt pl. 1, fig. 4.

1998 *Badouxia oregonensis* Taylor, p. 494, Fig. 53 (11-14).

? 1999 *Badouxia?* sp.; Pálffy *et al.*, fig. 5F.

? 1999 *Badouxia canadensis* (Frebold); Pálffy *et al.*, fig. 5I.

2000 *Badouxia canadensis* (Frebold); Taylor pl. 2, figs 10-15.

2000a *Badouxia* cf. *canadensis* (Frebold); Hillebrandt pl. 2, fig. 5.

2000b *Badouxia canadensis* (Frebold); Hillebrandt p. 46, pl. 14, figs 4, 7, 11; pl. 15, fig.

? 2000b. *Badouxia canadensis* (Frebold); Hillebrandt p. 46, pl. 14, figs 6, 8; pl. 15, figs 11, 17; pl. 16, figs 2-3, 5-6.

**MATERIAL AND MEASUREMENTS:** Material studied includes 211 measured specimens, c. 100 incomplete specimens and many fragments. Measurements of volution, whorl shape and ribbing density are presented in Figure 5.12.

**DESCRIPTION:** Compressed, moderately involute to moderately evolute form with volution varying between 30 and 48 per cent at 60 mm. The following is a description of the ontogenetic changes that characterize this species.

Inner whorls subrounded. Beyond 10 mm whorl shape varies with volution. In evolute forms, whorls subrounded to oval with widest point at mid-flank and low, gently sloping umbilical wall. In more involute forms, whorls subelliptical with widest point low on flank. Umbilical wall increases in height with growth, becoming undercut in some, with distinct but rounded umbilical shoulder. Evolute forms have low, gently sloping umbilical wall. Blunt, simple ribs of moderate strength vary in density and orientation from weakly to strongly prorsiradiate. Occasionally specimens have nodes on nucleus. Ribs arise at flank base, show greatest height mid-flank before fading on upper flank. Flanks taper gently to smooth, rounded venter. Faint, adorally projecting growth lines visible on venter in some. Evolute specimens ribbed to maturity, smoothing out in some at end of body-chamber. Ribs weaken for about half a whorl on more involute specimens, varying from closely to more distantly spaced before disappearing at diameters between 30 and 80 mm. Septal suture asymmetric and simple with first lateral lobe longer than ventral lobe which is offset from median line (Fig. 5.11A-B).

On outer whorls at diameters greater than 80 mm, whorl shape varies from high sub-elliptical to subtriangular with rounded, smooth venter. Umbilical wall moderately high and weakly

undercut. Umbilical shoulder distinct but rounded. Virtually smooth although occasional ribs may occur (GSC 127013).

Five specimens show distinct signs of maturity (GSC 127020, 127021 figured here) including approximation of the last three septal sutures (GSC 127020 and 127181 only), uncoiling of the umbilical seam, effacement of ribbing on the body-chamber and possession of rostrum. They range in total shell diameter from 53 to 62 mm. Much larger, incomplete material is common throughout the Rursicostatum Zone with the largest measurable specimen reaching 180 mm in shell diameter (GSC 127257).

REMARKS: *Badouxia canadensis* is similar to *B. forticostata* but differs in having significantly weaker ribs. More evolute forms of *B. canadensis* resemble certain species of *Sunrisites* but differ in having weaker, prorsiradiate ribs. *Badouxia occidentalis* (placed here in synonymy with *B. canadensis*) was established based on differences in ribbing duration and shell volution that are now recognized to be end-members of a continuum of variation within *B. canadensis* (Fig. 5.12B). *Badouxia oregonensis* (placed here in synonymy with *B. canadensis*) was erected based on differences in ribbing density and orientation which are now considered to fall within the variation of *B. canadensis* (Fig. 5.12B, E).

Close examination of the *Badouxia* fauna from Taseko Lakes supports the division of *B. canadensis* into two species, *B. canadensis* and *B. forticostata* discussed below. Material currently classified as *B. canadensis* from other areas of North America appears to agree well with this distinction, whereas parallels with the illustrated material from South America are less clear-cut. Strong ribs are present on some of the South American material, but the difference between ribbing strength within the material appears more continuous. In addition, the ribbing on some of the South American material appears coarser than on the North American material. For this reason, some of the South American material is marked with a question mark in the synonymy lists for *B. canadensis* and *B. forticostata*.

There are two forms that are transitional between *B. canadensis* and later species of *Badouxia*. The first, *B. canadensis* transient A, is intermediate between *B. canadensis* and *B. forticostata* although it is considered here to be closer to the former. It is illustrated in Plate 5.3, figures 7-8, 11-12 and Figure 5.11C. It is also illustrated in Frebold (1967), plate 1, figures 1-2 and text-figure 3. In total, seven measured specimens and three fragments are available for study. Measurements of volution, whorl shape and ribbing density are presented in Figure 5.13. This transient differs from *B. canadensis* in having stronger ribbing on the lower flank that is asymmetric with steep adapical and gentler adoral slopes. Furthermore, ribbing continues to larger shell diameters on more involute forms. This transient differs from *B. forticostata* in having significantly weaker ribbing. One specimen (total shell diameter 89 mm) (GSC 19947) shows signs of maturity including approximation of the last two septal sutures, uncoiling of the umbilical seam and possession of a rostrum. The largest specimen (GSC 127036) is entirely septate at a total diameter of *c.* 115 mm. The second transitional form, *B. canadensis* transient B, is intermediate between *B. canadensis* and *B. columbiae* although it is considered here to be nearer to the former. It is illustrated in Plate 5.2, figures 1, 4-5 and Figure 5.10D. Three measured specimens are available for study. Measurements of volution, whorl shape and ribbing density are presented in Figure 5.14. This transient differs from *B. canadensis* in having ribbing that continues weakly onto the ventro-lateral shoulder where it projects forward before fading on most specimens. At a large shell diameter (>65 mm) in one specimen, ribs occasionally continue across the venter. This transient differs from *B. columbiae* in having significantly weaker ribbing on the ventro-lateral shoulder that very rarely crosses the venter. This transient is similar to *B. castlensis* but differs in having more distantly spaced ribs which are more pronounced mid-flank and project less consistently onto the venter. One specimen (total diameter 64 mm) (GSC 127028) shows signs of maturity including approximation of the last three septal sutures, uncoiling of the umbilical seam and possession of a rostrum.

OCCURRENCE: *Badouxia canadensis* is restricted to the Mineralense and Rursicostatum Zones from the upper Hettangian exposed on sections A-E and localities 1-3 and 6. *Badouxia canadensis* transients A and B are restricted to the uppermost Hettangian portion of the Rursicostatum Zone. *Badouxia canadensis* transient A was collected from sections A and E and at locality 2. *Badouxia canadensis* transient B was collected from section E and localities 8 and 12.

***Badouxia castlensis* sp. nov.**

Plate 5.2, figures 6-8, 14-15; Figures 5.10E, 5.11D

? 2000b *Badouxia canadensis* Frebold; Hillebrandt, p. 46, pl. 15, fig. 12.

2001 *Badouxia mexicana* Taylor, Guex and Rakús, p. 398, pl. 1, figs 1-2 [*non* figs 3-6 (= *B. mexicana*)].

DERIVATION OF NAME: Named after Castle Pass near where the holotype was collected.

MATERIAL AND MEASUREMENTS: Material studied includes 18 measured specimens, 4 incomplete specimens and 2 whorl fragments. Measurements of volution, whorl shape and ribbing density are presented in Figure 5.15.

HOLOTYPE: GSC 127034 (Pl. 5.2, figs 14-15) from the Rursicostatum Zone, Castle Pass section B06, Taseko Lakes.

PARATYPES: GSC 127030 (Pl. 5.2, figs 6-7), 127032 (Pl. 5.2, fig. 8), 127056-127059, 127080-127091.

DIAGNOSIS: Compressed, moderately evolute form. Ribs prorsiradiate, closely spaced and straight to slightly convex with greatest height at mid-flank. Most ribs hook forward and fade in the ventro-lateral area. Venter smooth.

DESCRIPTION: An evolute, compressed form. Whorl shape subrounded with low umbilical wall and square but gently rounded umbilical shoulder on inner whorls. Intermediate and outer whorls oval to subelliptical. Umbilical wall varies from gently sloping into the flank to low but upright with square umbilical shoulder. Widest point of whorl mid-flank, venter broad and rounded. Nucleus bears simple ribs or nodes. Following this, ribs arise at flank base, strongly prorsiradiate, closely spaced and straight to slightly convex with greatest height occurring mid-flank. Ribs hook forward and fade in ventro-lateral area on most, so venter is smooth. Largest specimen has occasional ribs that bend forward, crossing the venter in a weak chevron (GSC 127034). Ribbing strength varies from weak to moderate with tendency to increase in strength stratigraphically up-section. Septal suture simple and shows the ventral lobe offset from the median line (Fig. 5.11D).

REMARKS: *Badouxia castlensis* sp. nov. most closely resembles *B. mexicana* but is more consistently evolute and slowly expanding than the majority of the type material for *B. mexicana* (Fig. 5.15) with the exception of plate 1, figures 1-2 of Taylor *et al.* (2001). This species resembles *B. canadensis* but differs in having a higher average number of ribs per whorl as well as ribs which bend forward sharply before fading on the ventro-lateral shoulder, rather than having ribs which fade at the top of the flank. This species vaguely resembles *B. columbiae* but differs in having weaker ribs that very rarely cross the venter.

OCCURRENCE: This species is restricted to the Rursicostatum Zone exposed on sections A-B and D-E and at locality 6.

***Badouxia forticostata* sp. nov.**

Plate 5.2, figures 9-13, 16-17; Plate 5.3, figures 1-6, 9-10; Figures 5.10F-H, 5.11E-F

1951 *Psiloceras canadense* Frebold, p. 3, pl. 1, figs 1, 6, pl. 2, fig. 1, pl. 3, fig. 1.

1964 *Psiloceras canadense* Frebold, p. 6, pl. 1, figs 1-5.

- 1967 *Psiloceras canadense* Frebold, p. 18, pl. 1, fig. 1.
- 1981 *Badouxia canadensis* (Frebold); Imlay, p. 31, pl. 2, figs 18-28.
- 1981 *Caloceras canadense* (Frebold); Hillebrandt, p. 7, pl. 1, fig. 5.
- 1985 *Psiloceras canadense* Frebold; Prinz, p. 188, pl. 2, fig. 4.
- 1988 *Badouxia canadensis* (Frebold); Riccardi *et al.*, pl. 2, figs 3-4.
- 1990 *Badouxia* cf. *canadensis* (Frebold); Hillebrandt, pl. 3, fig. 6.
- 1991 *Badouxia canadensis* (Frebold); Riccardi *et al.* fig. 4 (17-18) (refigured from Riccardi *et al.*, 1988).
- ? 1993 *Badouxia* cf. *columbiae* (Frebold); Rakús, p. 926, pl. 1, fig. 4, text-fig. 15.
- ? 1994 *Badouxia canadensis* (Frebold); Jakobs and Pálffy, pl. 1, fig. 3.
- 2000 *Badouxia canadensis* (Frebold); Taylor pl. 2, figs 7-9, 16-19.
- 2000a *Badouxia* cf. *canadensis* (Frebold); Hillebrandt, pl. 2, fig. 6.
- 2000b *Badouxia canadensis* (Frebold); Hillebrandt, p. 46, pl. 14, figs 1, 2, 5; pl. 15, figs 1, 4-7, 15-16; pl. 16, figs 1, 4, 9, 11-13; text-fig. 8e.
- ? 2000b *Badouxia canadensis* (Frebold); Hillebrandt, p. 46, pl. 14, figs 3, 6, 9-10, 12; pl. 15, figs 2-3, 8-9, 14; pl. 16, figs 7-8, 10.
- ? 2000b. *Badouxia* cf. *canadensis* (Frebold); Hillebrandt p. 53, pl. 16, figs 14-15.

DERIVATION OF NAME: Named for the strong morphology of the ribs.

MATERIAL AND METHODS: Material studied includes 38 measured specimens, 12 incomplete specimens and many fragments. Measurements of volution, whorl shape and ribbing density are presented in Figure 5.16.

HOLOTYPE: GSC 127043 (Pl. 5.3, figs 1-2) from the Rursicostatum Zone, isolated locality 3 on Tyaughton Creek, Taseko Lakes.



PARATYPES: GSC 127035 (Pl. 5.2, figs 16-17), 127037 (Pl. 5.3, fig. 4), 127038 (Pl. 5.3, fig. 3), 127040 (Pl. 5.2, figs 9-10), 127041 (Pl. 5.3, fig. 5), 127042 (Pl. 5.2, figs 12-13), 127044 (Pl. 5.3, fig. 9), 127046 (Pl. 5.2, fig. 11), 127047 (Pl. 5.3, fig. 6), 127048 (Pl. 5.3, fig. 10), 127039, 127045, 127049, 127285-127308.

DIAGNOSIS: Compressed, moderately involute to moderately evolute form with strong, coarse to sharp, weakly to strongly prorsiradiate ribs that bend forward and fade in the ventro-lateral area. The venter is smooth and rounded showing faint secondary ribs which divide and project forward across the venter in some specimens.

DESCRIPTION: Compressed shell with variable volution ranging from moderately involute to moderately evolute. Umbilical diameter ranges from 33 to 47 per cent at 65 mm.

Inner whorls subrounded with gently sloping umbilical wall. Whorl shape suboval between *c.* 10 and 40 mm diameter with low, gently sloping to upright umbilical wall and gently rounded umbilical shoulder. Widest point of whorl mid-flank. Beyond 40 mm, whorl shape depends on volution. Evolute specimens have similar whorl shape to juvenile whorls. As specimens become increasingly involute, whorl shape changes to subelliptical. Widest point of whorl lowest flank with subparallel flanks sloping gently toward the venter. Umbilical wall increases in height with increasing expansion rate and slightly undercut on more involute specimens. Nucleus of some with nodes. Ribs strongest lower to mid-flank, coarse to sharply crested, straight to slightly convex and weakly to strongly prorsiradiate. On more involute specimens, at diameters greater than 50 mm, weak rursiradiate ribs may be visible on umbilical shoulder before being distinctly hooked forward on the lowest flank. On low and mid-flank, these ribs asymmetric with steep adapical and gentler adoral slopes. Ribs on all are strongest on lower flank and weaken on upper flank where they swing forward and fade. Venter in some completely smooth, whereas in others the primary rib divides into two on the upper flank continuing across the venter in a faintly visible forwardly inclined parabola (GSC 127037). Similarly shaped, additional weak secondary

ribs may be visible on venter (GSC 127049). Some evolute specimens remain strongly ribbed until maturity where they smooth out at end of body-chamber. In specimen GSC 127038, ribs are still visible on the lower flank at a WH of 48 mm. On more involute forms, ribs fade with increasing diameter, remaining visible only on lower flank by approximately 60 mm (GSC 127035). Suture simple with ventral lobe offset from the median line (Fig. 5.11E-F).

Only the holotype (GSC 127043) is mature, showing smoothing out of ornament toward end of body-chamber, uncoiling of umbilical seam and a distinct constriction directly preceding rostrum. The largest specimen (GSC 127038) is septate and remains ribbed to mid-flank at WH 48 mm.

REMARKS: This species resembles *B. canadensis* but differs in having much stronger ribs. This species is similar to both *B. mexicana* and *B. castlensis* but has much stronger ribs which are less dense on average and vary in strength with position along the flank. This species is somewhat similar to *B. columbiae* but has much stronger ribs visible low to mid-flank which project more weakly on the ventral-shoulder and are rarely visible on the venter.

OCCURRENCE: *Badouxia forticostata* is restricted to the top of sections A and B and the lower portion of sections E, F and G and is also found at localities 2-6, 8-10 and 12. It is restricted to the top of the Rursicostatum Zone and the base of the Columbiae Zone.

***Badouxia columbiae* (Frebold, 1967)**

Plate 5.4, figures 1-12; Figures 5.10I-J, 5.11G

1951 *Schlotheimia* (*Scamnoceras*) cf. *acuticosta* Frebold, p. 6, pl. 4, fig. 1.

1951 *Schlotheimia* (?) sp. indet. Frebold, p. 7, pl. 4, figs 2-4.

1967 *Psiloceras* (*Curviceras*) *columbiae* Frebold, p. 20, pl. 1, fig. 10; pl. 2, figs 1-5 (fig. 4 refigured here); pl. 3 Fig. 5, text-figure 5.

? 1981 *Badouxia columbiae* (Frebold); Imlay, p. 31, pl. 2, figs 22-23.

? 1999 *Badouxia?* sp.; Pálffy *et al.*, fig. 5E.

1999 *Badouxia columbiae* (Frebold); Pálffy *et al.*, fig. 5G.

2000 *Badouxia columbiae* (Frebold); Taylor, pl. 2, figs 1-6.

? 2000 *Badouxia cf. occidentalis* (Frebold); Taylor, pl. 2, figs 20-21.

2002 *Badouxia columbiae* (Frebold); Taylor and Guex, pl. 2, figs 6-7.

MATERIAL AND MEASUREMENTS: Material studied includes 82 measured specimens, c. 20 incomplete specimens and many fragments. Measurements of volution, whorl shape and ribbing density are presented in Figure 5.17.

DESCRIPTION: Compressed, involute to moderately evolute species with volution ranging from 25 to 47 per cent at 56 mm diameter. The following is a description of the ontogenetic changes that characterize this species.

Inner whorls subrounded. Beyond 10 mm whorl shape varies from subelliptical with parallel flanks and broad to subtriangular venter with sub-parallel flanks tapering gently into sub-acute venter. Umbilical wall in evolute to midvolute specimens slopes gently into flank in some; in others umbilical wall more distinct with marked but rounded umbilical shoulder. In most strongly involute specimens umbilical wall high and strongly undercut. Ribs differ from sharp to blunt on inner whorls, beginning on lowest flank and varying in style between gently prorsiradiate with a hook forward at the ventral shoulder to bending forward progressively up flank giving rib gently curved appearance. The former have greatest strength on upper flank whereas the latter are fairly uniform in strength with slight increase mid-flank. Occasional specimens have nodes on nucleus. Strength of ribbing in ventral area variable, sometimes changing at different diameters within single specimen. Ribs range from strong and clearly defined crossing venter in forwardly inclined chevron to those that bend forward on ventral

shoulder and then fade completely, leaving smooth venter. Faint adorally projecting secondary ribs visible on venter in some. More evolute specimens remain strongly ribbed until end of body-chamber where ribs may fade (GSC 127053, 127055). On more involute material, ribs spread out on some (GSC 19925) whereas others show no change in spacing between ribs which fade on all with increasing diameter. Specimens become smooth between 45 and 75 mm diameter; on some, last few ribs only visible to mid-flank (GSC 127051).

Specimens become progressively more involute with increasing shell diameter, thus umbilical diameter to shell diameter ratio (U) is *c.* 22 per cent by 200 mm (GSC 127050). Outer whorls virtually smooth, although occasional prorsiradiate ribs may be apparent to mid-flank on some. One very large fragment with a whorl height of 190 mm shows prorsiradiate bullae beginning at the top of lower flank continuing to ventral shoulder (GSC 127056). Ventral lobe of suture offset from median line and shorter than first lateral lobe (Fig. 5.11G).

Two specimens (GSC 127053, 127055) show signs of maturity including approximation of last two septal sutures (GSC 127055 only), modification of ribbing at end of the aperture (GSC 127053 only), uncoiling of umbilical seam and possession of rostrum. These remain ribbed throughout ontogeny and have shell diameter of 43 and *c.* 62 mm. Much larger, incomplete material common throughout Columbae Zone. The largest (GSC 127056) has a whorl height on body-chamber of approximately 190 mm with smooth penultimate whorls followed by marked bullae on body-chamber.

REMARKS: This species most closely resembles both *B. mexicana* and *B. castlensis* but differs in having stronger ribs which are more clearly defined on the ventral shoulder. It vaguely resembles *B. forticostata* but differs in having weaker ribs on the flanks that commonly persist more definitely across the venter.

OCCURRENCE: This species is found high in stratigraphic section E and throughout sections F and G as well as at localities 7-9 and 11. It is restricted to the Columbae Zone.

## 5.5 Summary and Conclusions

This taxonomic study has altered the definition and ranges of several *Badouxia* species that are of principal importance to the zonation for the Western Cordillera of North America (Taylor *et al.* 2001). Due to these changes, necessary alterations to the existing zonation include the elimination of the Canadensis Zone and the elevation of its formerly erected Rursicostatum and Columbiae subzones to the level of full zones. The previously defined Oregonensis Zone is renamed the Mineralense Zone.

Figure 5.18 illustrates the stratigraphic ranges of *Badouxia* species from Taseko Lakes. There are four species and two transitional forms. Aside from *B. castlensis* which is consistently evolute, most species of *Badouxia* show a significant range of continuously variable morphology with respect to whorl proportion, umbilical shoulder height, and ribbing density, duration, and direction. Certain trends are evident within different species including a higher umbilical wall in more involute specimens and the persistence of ribbing later in ontogeny in more evolute material. However, each of these parameters shows continuous variation between end-members found at the same stratigraphic horizon and a division of the material into different species based on these differences would be arbitrary. The only consistent characteristics useful in identifying species of *Badouxia* are differences in strength and cross-sectional profile of the ribbing on the flanks, and the presence or absence of ribs on the venter. Small sample size has led to oversplitting of the genus in the past as end-members of a continuum were identified as separate species. On this basis, *B. occidentalis* Frebold, 1967 and *B. oregonensis* Taylor, 1998 are placed in synonymy with *B. canadensis*. Two transitional forms were found in the uppermost Hettangian Rursicostatum Zone. *Badouxia canadensis* transient A is intermediate between *B. canadensis* and *B. forticostata*. *Badouxia canadensis* transient B is intermediate between *B. canadensis* and *B. columbiae*. These transitional forms provide

interesting information on the history of the evolution of the genus including establishing a partial phylogeny for *Badouxia* species.

Several different species of *Badouxia* from Taseko Lakes show signs of sexual dimorphism. As discussed by Callomon (1963, 1981), sexual dimorphism is considered established if two distinct, contemporaneous groups of shells are virtually identical on the inner whorls and are phylogenetically linked, showing the simultaneous appearance of new characters in both branches. Division of material into two groups is based primarily on a bimodal shell size distribution and differences in ribbing style. As discussed in the systematics section, collections of *B. canadensis*, *B. canadensis* transient A, *B. forticostata* and *B. columbiae* contain one or more small, mature specimens ranging in size from 43 to 89 mm. In addition, contemporaneous collections for each species also contain much larger though incomplete material, which is often septate to much greater size. *Badouxia columbiae* shows the most extreme size difference including a small, mature specimen of 43 mm diameter and a fragment with a body-chamber whorl height of 190 mm. In addition to differences in size, the small specimens of each species remain strongly ribbed until maturity smoothing out in some cases at the adoral end of the body-chamber. The larger specimens are smooth on the outer whorls except the unusually large specimen of *B. columbiae* that is smooth on the penultimate whorls and bears bullae on the body-chamber. The inner whorls of specimens from both small and large groups fall within the variation attributed to each species. Further, the differences in ribbing style that define different species of *Badouxia* become apparent in both small and large groups over the same stratigraphic interval suggesting they are phylogenetically linked. Bimodal size distribution and differences in ornament as well as simultaneous changes in ribbing style within both small and large groups of each species strongly suggest that *Badouxia* was sexually dimorphic. The small, ribbed specimens represent the microconchs and the large, smooth forms correspond to the macroconchs for each species.

The stratigraphic distribution of *Badouxia* species permits the recognition of five distinct intervals in Taseko Lakes. The co-occurring *Angulaticeras* fauna from the area firmly tie intervals 1-3 to the Hettangian. The age of the base of interval 4 is uncertain. The contemporaneous *Angulaticeras* fauna suggests the middle and upper portions of interval 4 and the whole of interval 5 are Sinemurian (Smith and Tipper 2000) (Fig. 5.18). The intervals are recognized as follows:

Interval 1 contains only *B. canadensis* and is restricted to the Mineralense Zone. At the top of the zone, *Angulaticeras* cf. *trapezoidale* appears (Smith and Tipper 2000). Although *A. trapezoidale* is reported as high as the Bucklandi Zone in France (Guérin-Franiatte 1990) it is characteristic of the upper Hettangian Angulata Zone in Europe (Bloos 1979, 1983).

Interval 2 yields an association of *B. canadensis* and *B. castlensis* and is limited to the lower portion of the Rursicostatum Zone. In addition to the last occurrence of *A. cf. trapezoidale* this interval also contains the first occurrence of *A. marmoreum* (Smith and Tipper 2000) which is restricted to the Hettangian in Europe. It is characteristic of the upper Hettangian Marmoreum Zone in the Alps and Depressa Subzone in north-west Europe (Bloos 1988a; Bloos and Page 2000).

Interval 3 contains *B. canadensis*, *B. castlensis*, *B. forticostata*, *B. canadensis* transient A and *B. canadensis* transient B and is restricted to the upper portion of the Rursicostatum Zone. The last occurrence of *A. marmoreum* is at the top of this level, again supporting a Hettangian age.

Interval 4 yields *B. columbiae* and *B. forticostata* and is limited to the lower portion of the Columbiae Zone. As mentioned by Taylor (2000) there is little foundation for correlation of the lowest *B. columbiae* beds. In the Angulata Zone in north-west Europe, faunas are almost exclusively composed of *Schlotheimia*. However, this genus is rare in the eastern Pacific and thus, it is difficult to distinguish Hettangian from Sinemurian faunas (Bloos and Page 2000, 2002). Many of the eastern Pacific Hettangian ammonite genera are lacking in the Northwest

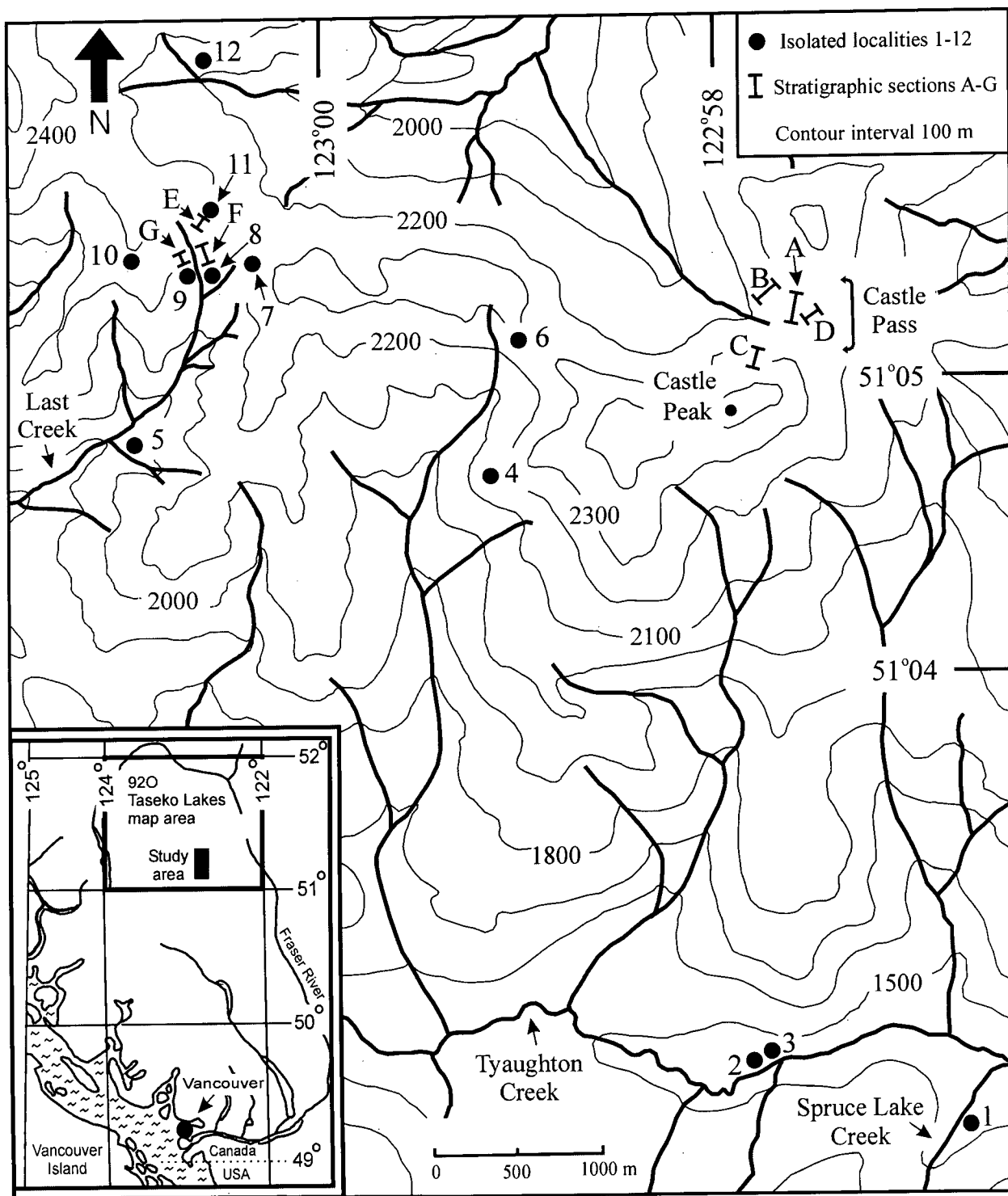
European Province. Correlation of faunas between the eastern Pacific and the Tethyan regions is often better. Unfortunately, the earliest Sinemurian portion of the Conybeari Subzone is missing in the northeastern Alps (Bloos 1988b; Bloos and Page 2000, 2002). A Sinemurian age for the base of the Columbiae Zone was first suggested by Taylor (1990, 1998) and formally established by Taylor *et al.* (2001). This claim will only be confirmed by the correlation of additional material collected at the boundary. At this point, the age of the base of the Columbiae Zone remains uncertain. *Angulaticeras westermanni* first occurs in the middle portion of this interval and, although it is currently only recognized in Taseko Lakes, its compressed morphology suggests an affinity with the Sinemurian '*charmassei*' group (Smith and Tipper 2000). On this basis, the middle and upper portions of interval 4 are considered to be Sinemurian.

Interval 5 contains only *B. columbiae* and is restricted to the upper Columbiae Zone. In Taseko Lakes, this interval yields *A. westermanni* and the first occurrence of *A. pulchrum* and is definitely of Sinemurian age (Smith and Tipper 2000). *A. pulchrum* is characteristic of the Rotiforme Subzone of the Bucklandi Zone in Europe (Guérin-Franiatte 1990) and conclusively demonstrates a Sinemurian age. Further, in the Shoshone Mountains in Nevada, *Paracaloceras* cf. *grunowi* (Hauer) (Taylor 1990, 2000) and *Epammonites* aff. *rotarium* (Buckmann) (Taylor 2000) occur in the upper part of the *B. columbiae* beds clearly indicating a Sinemurian age.

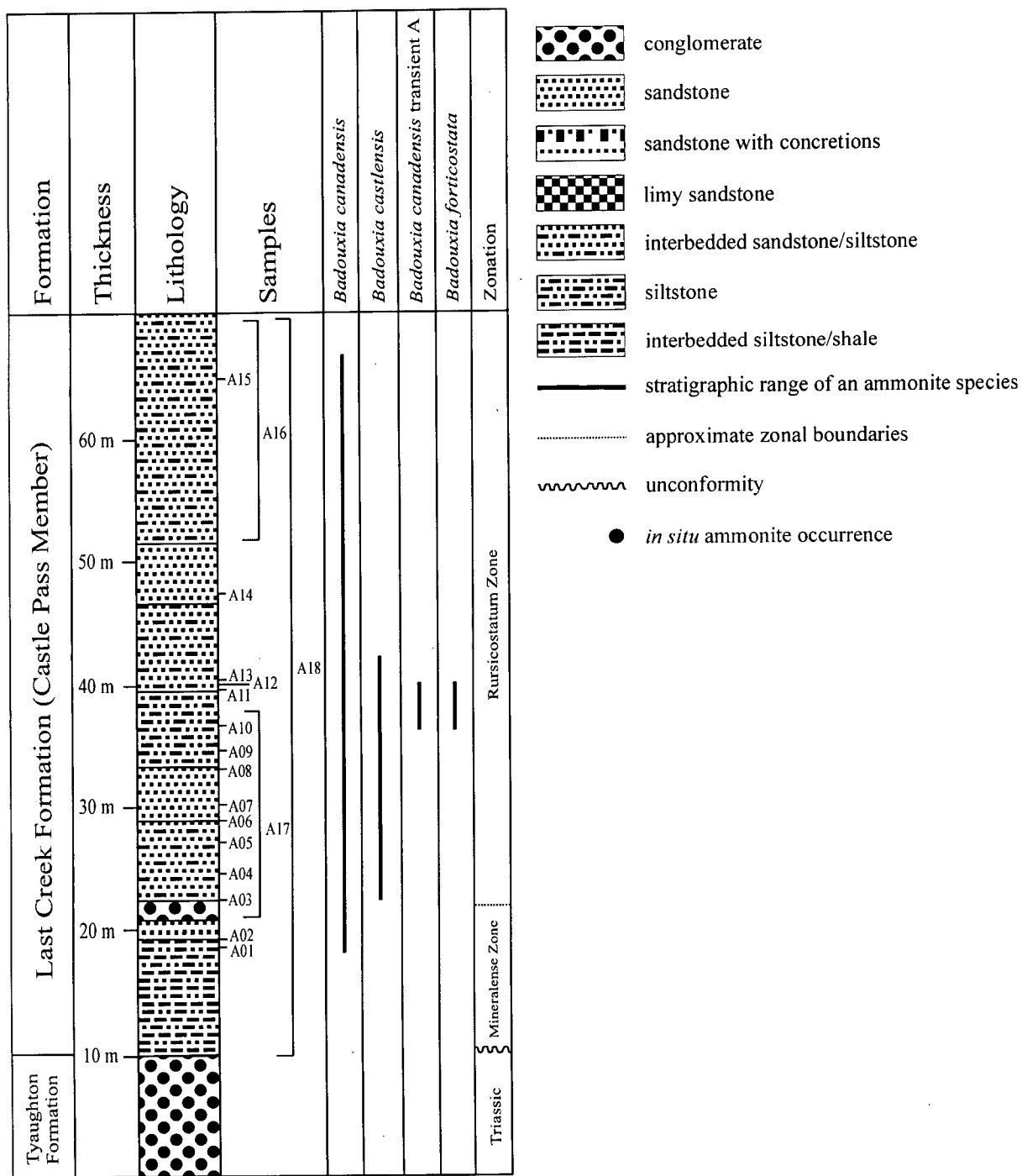


AGE	NORTH AMERICA			SOUTH AMERICA	NORTHWEST EUROPE		ALPS
	Previous Zonation		Revised Zonation				
Sinemurian	Canadensis Zone	Columbiae Subzone	Columbiae Zone		Bucklandi Zone	Conybeari Subzone	
Hettangian				Arcuatum Horizon		Depressa Subzone	Marmoreum Zone
		Rursicostatum Subzone	Rursicostatum Zone	Canadensis Zone	Angulata Zone	Complanata Subzone	
		Oregonensis Zone	Mineralense Zone				

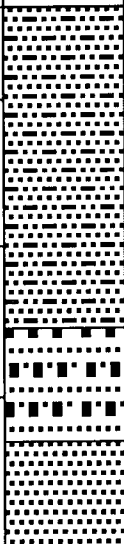



**Figure 5.1.** Revised Zonation for Hettangian/Sinemurian boundary in North America showing correlation of North American zones with South America, the Alps and north-west Europe.



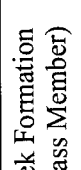



**Figure 5.2.** Localities of sections and isolated outcrops bearing *Badouxia* in Taseko Lakes.



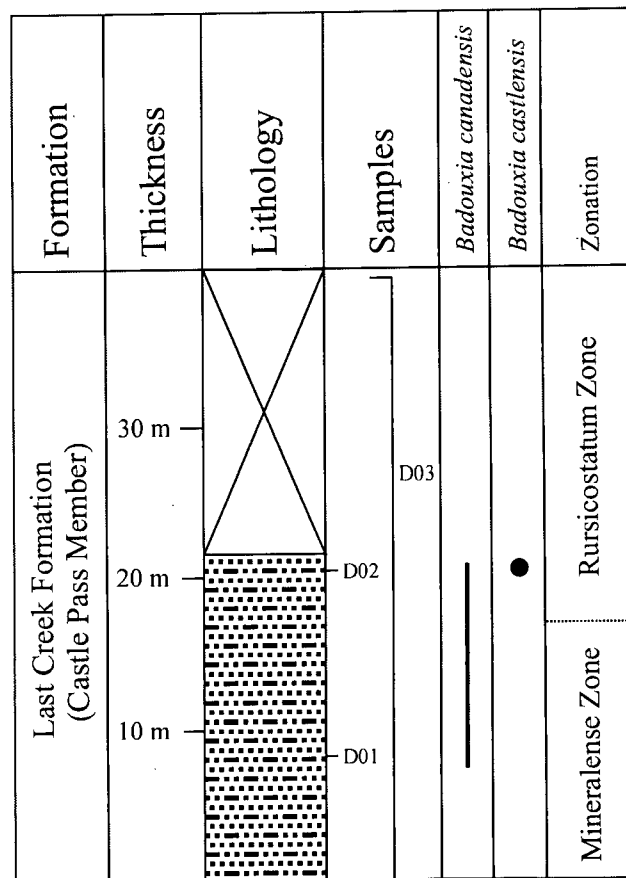
**Figure 5.3.** Lithostratigraphy and fossil localities of Section A at Castle Pass, Taseko Lakes; for key, see Figure 5.3.

Formation	Thickness	Lithology	Samples	<i>Badouxia canadensis</i>	<i>Badouxia castlensis</i>	<i>Badouxia forticostata</i>	Zonation	
Last Creek Formation (Castle Pass Member)	30 m		B07				Rursicostatum Zone	
			B06					
	20 m		B05					
			B04					
			B03					
	10 m		B02					
			B01					
			B08					

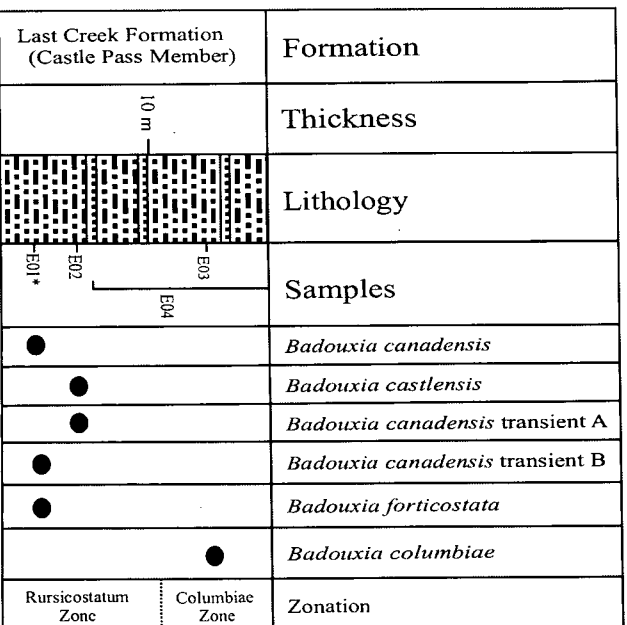
**Figure 5.4.** Lithostratigraphy and fossil localities of Section B at Castle Pass, Taseko Lakes; for key, see Figure 5.3.

Last Creek Formation (Castle Pass Member)	Formation
Tyughton Formation	Thickness
	Lithology
	Samples
	<i>Badouxia canadensis</i>
	<i>Paracaloceras (Gyrophioceras)</i> cf. <i>mineralense</i>
	Zonation

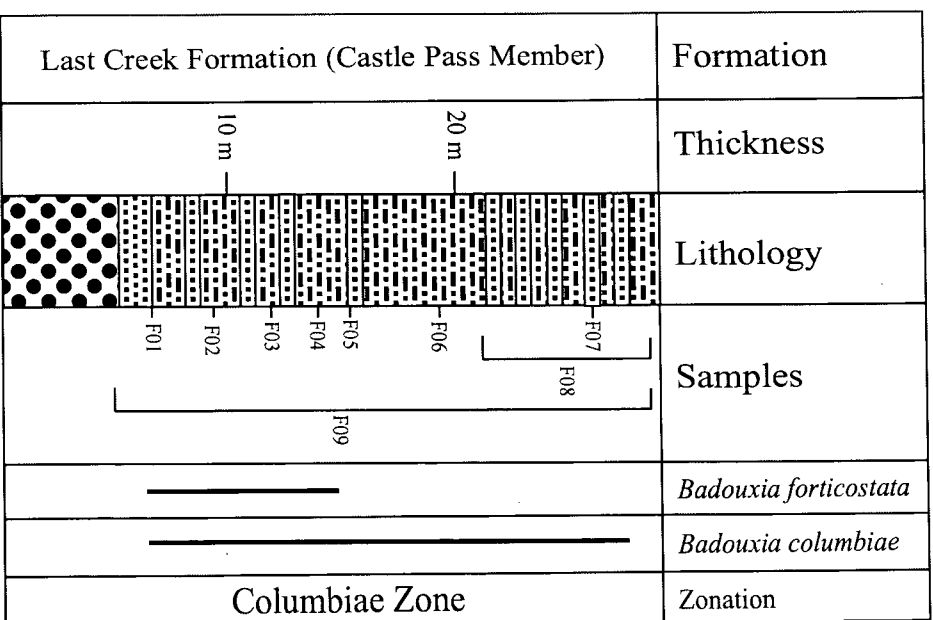
**Figure 5.5.** Lithostratigraphy and fossil localities of Section C at Castle Pass, Taseko Lakes; for key, see Figure 5.3.



**Figure 5.6.** Lithostratigraphy and fossil localities of Section D at Castle Pass, Taseko Lakes; for key, see Figure 5.3.

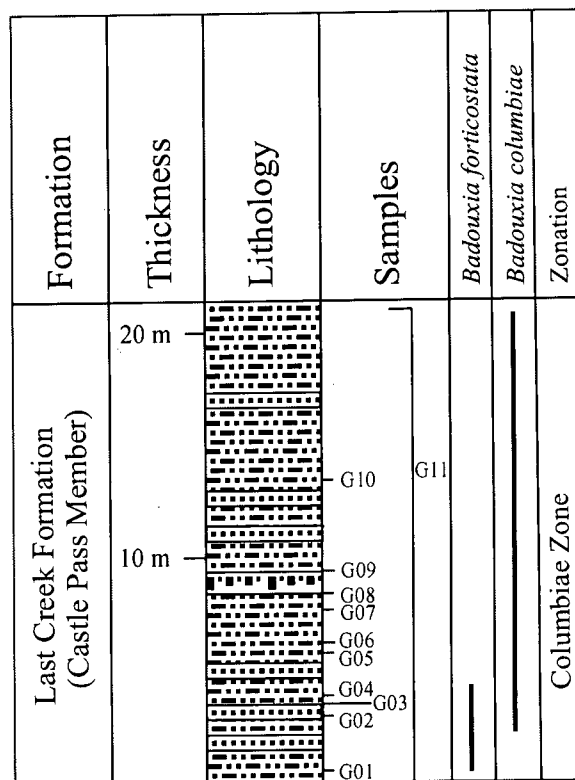


**Figure 5.7.** Lithostratigraphy and fossil localities of Section E at the top of Last Creek, Taseko Lakes. \*This collection was probably *in situ* although it may be talus; for key, see Figure 5.3.

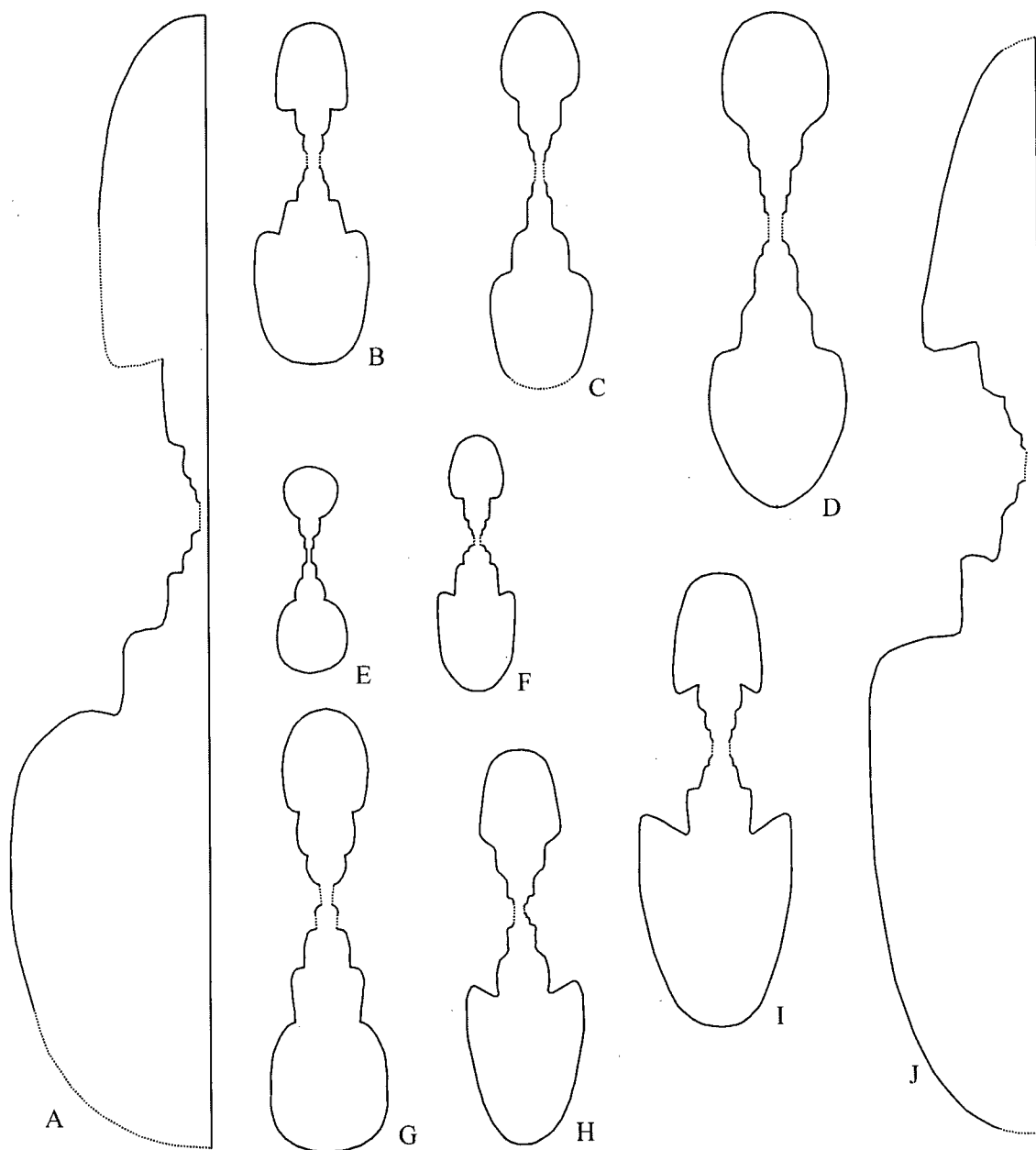


**Figure 5.8.** Lithostratigraphy and fossil localities of Section F at the top of Last Creek, Taseko Lakes; for key, see Figure 5.3.

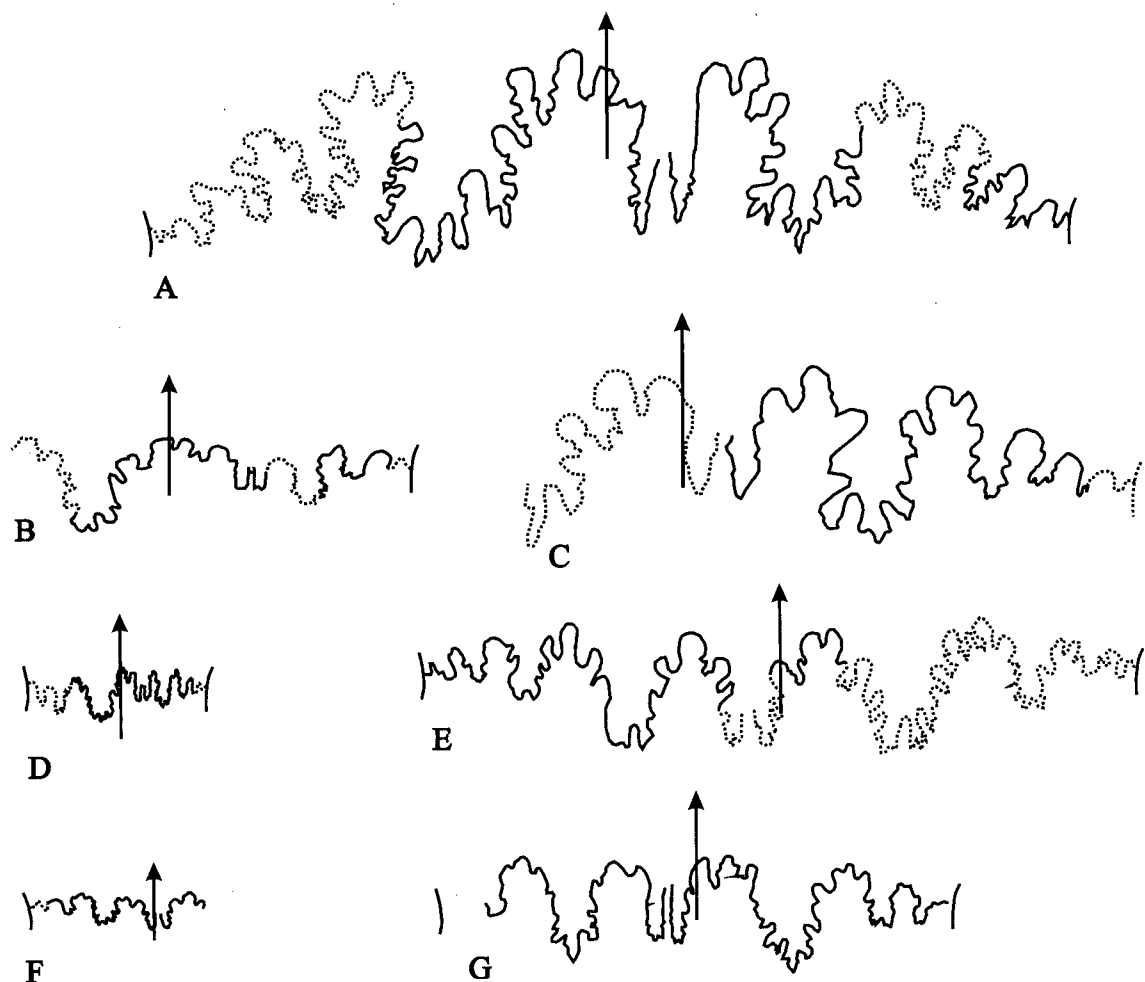




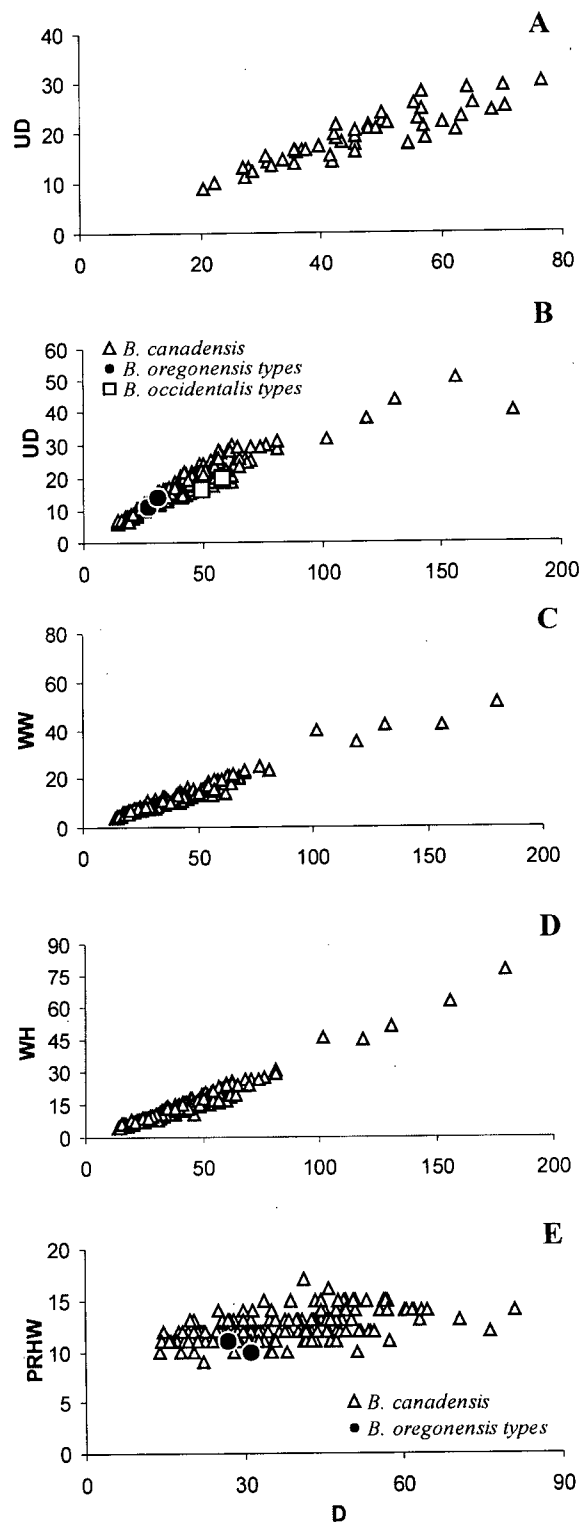
**Figure 5.9.** Lithostratigraphy and fossil localities of Section G at the top of Last Creek, Taseko Lakes; for key, see Figure 5.3.



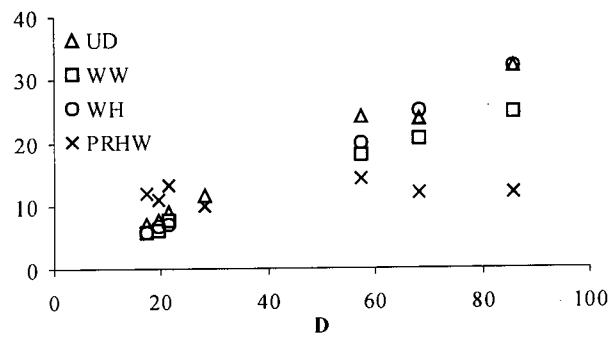
**Figure 5.10.** Whorl shape cross-sections for species of *Badouxia*. All figures  $\times 0.9$ . A-C, *Badouxia canadensis* (Frebold, 1951). A, GSC 127024. B, GSC 127027. C, GSC 127022. D, *Badouxia canadensis* transient B, GSC 127031. E, *Badouxia castlensis* sp. nov., GSC 127030. F-H, *Badouxia forticostata* sp. nov. F, GSC 127047. G, GSC 127043. H, GSC 127035. I-J, *Badouxia columbiae* (Frebold, 1967). I, GSC 127319. J, GSC 127050.



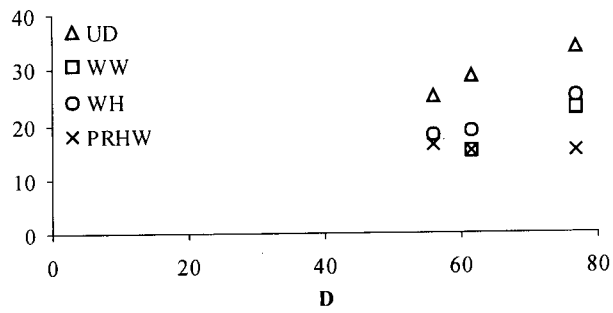
**Figure 5.11.** Traces of septal suture for species of *Badouxia* at whorl heights indicated. All sutures are  $\times 2$ . A-B, *Badouxia canadensis* (Frebold, 1951). A, GSC 127027, WH = 21 mm. B, GSC 127181, WH = 11.9 mm. C, *Badouxia canadensis* transient A, GSC 19947, WH = 17.8 mm. D, *Badouxia castlensis* sp. nov., GSC 127032, WH = 6.9 mm. E-F, *Badouxia forticostata* sp. nov. E, GSC 127043, WH = 16 mm. F, GSC 127042, WH = 5.9 mm. G, *Badouxia columbiae* (Frebold, 1967), GSC 127052, WH = 11.6 mm.



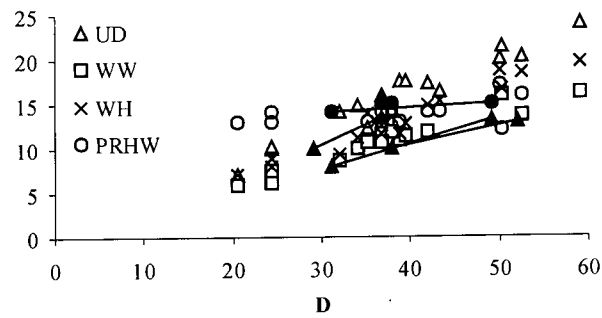
**Figure 5.12.** Plots of measurements of *Badouxia canadensis* from Taseko Lakes. A, umbilical diameter (UD) versus shell diameter (D) of specimens up to 80 mm diameter and exclusively from section D bed 02. B, umbilical diameter versus shell diameter of all measurable material. *Badouxia oregonensis* types from Oregon (Taylor 1998) and *Badouxia occidentalis* types of Frebold (1967) are also included. C, whorl width (WW) versus shell diameter of all measurable material. D, whorl height (WH) versus shell diameter of all measurable material. E, primary ribs per half whorl (PRHW) versus shell diameter of all measurable material. *Badouxia oregonensis* types from Oregon (Taylor 1998) are also indicated.



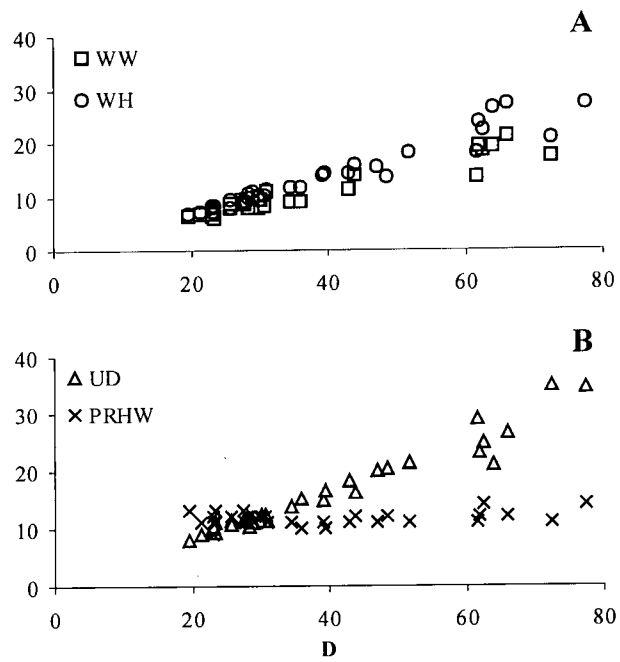
**Figure 5.13.** Plot of measurements of *Badouxia canadensis* transient A including umbilical diameter (UD), whorl width (WW), whorl height (WH) and primary ribs per half whorl (PRHW) versus shell diameter (D).



**Figure 5.14.** Plot of measurements of *Badouxia canadensis* transient B including umbilical diameter (UD), whorl width (WW), whorl height (WH) and primary ribs per half whorl (PRHW) versus shell diameter (D).

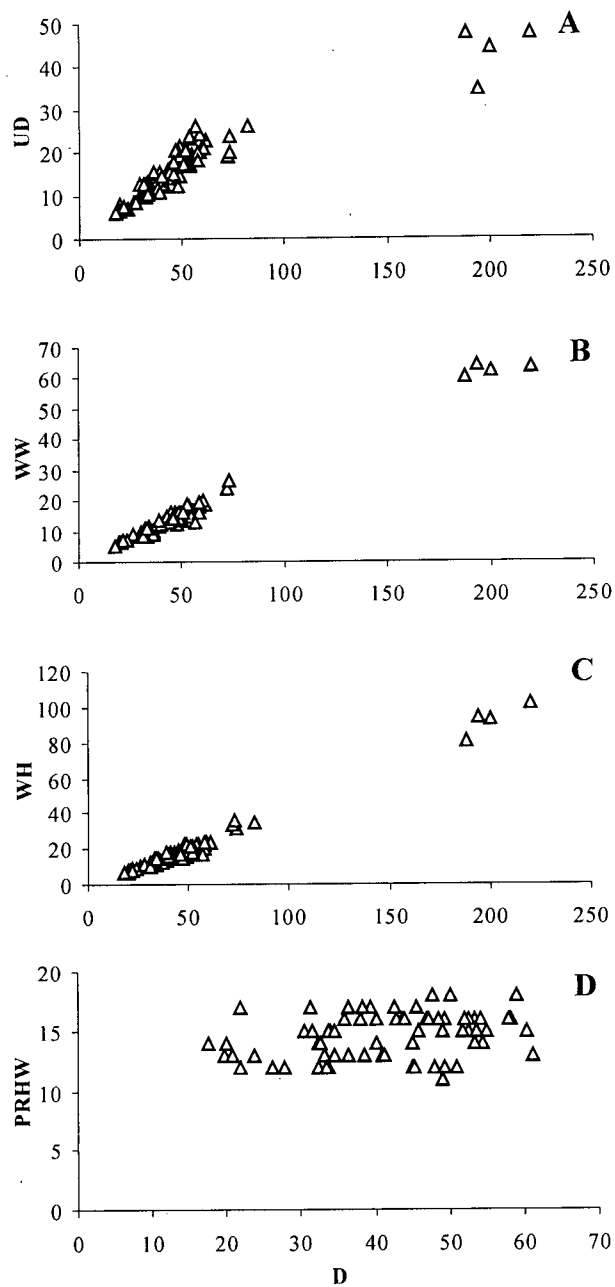


**Figure 5.15.** Plot of measurements of *Badouxia castlensis* sp. nov. including umbilical diameter (UD), whorl width (WW), whorl height (WH) and primary ribs per half whorl (PRHW) versus shell diameter (D). Measurements for the type material of *Badouxia mexicana* Taylor, Guex and Rakús are indicated by the solid symbols. Multiple measurements from a single specimen are joined by lines.

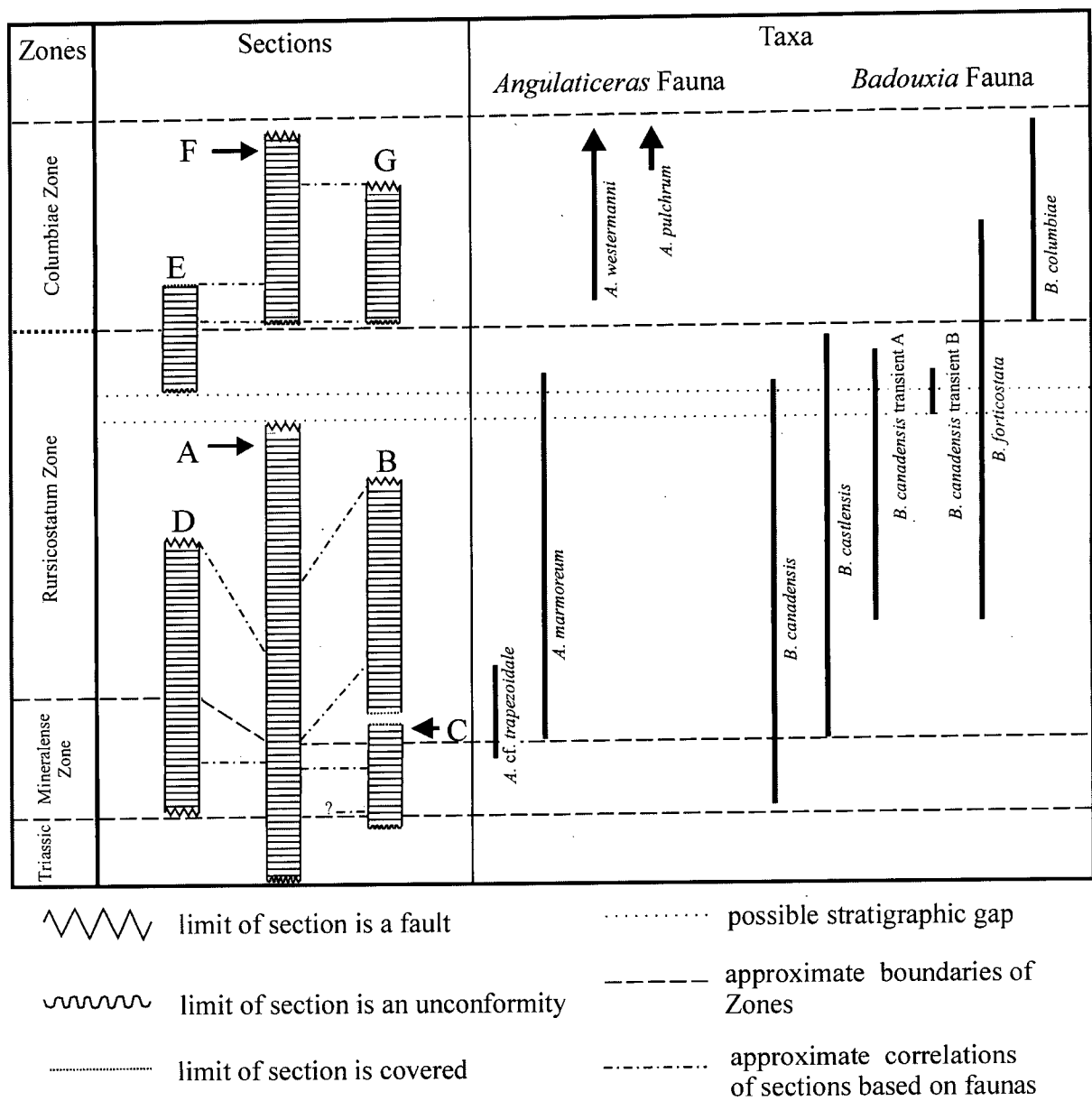


**Figure 5.16.** Plots of measurements of *Badouxia forticostata* sp. nov. from Taseko Lakes. A, whorl width (WW) and whorl height (WH) versus shell diameter (D). B, umbilical diameter (UD) and primary ribs per half whorl (PRHW) versus shell diameter.





**Figure 5.17.** Plots of measurements of *Badouxia columbiae* from Taseko Lakes. A, umbilical diameter (UD) versus shell diameter (D). B, whorl width (WW) versus shell diameter. C, whorl height (WH) versus shell diameter. D, primary ribs per half whorl (PRHW) versus shell diameter (D).



**Figure 5.18.** Approximate correlation of stratigraphic sections from Taseko Lakes showing the ranges of *Angulaticeras* and *Badouxia* species.

**Plate 5.1.** Figures 1-18. *Badouxia canadensis* (Frebold). All specimens from the Rursicostatum Zone, Last Creek Formation. Except for 1 and 6 all figures are  $\times 0.9$ . Arrow marks last visible septal suture. Where possible, microconch [m] and macroconch [M] forms are noted.

Figure 1, [M], GSC 127013, hypotype; GSC loc. no. C-143327, Sec. D, loc. 02;  $\times 0.675$ .

Figures 2-3, GSC 127014, hypotype; GSC loc. no. C-118700, Sec. B, loc. 07.

Figures 4-5, GSC 127019, hypotype; GSC loc. no. 62362, Sec. A, loc. 05.

Figure 6, [M], GSC 127024, hypotype; GSC loc. no. C-175396, Sec. B, loc. 08;  $\times 0.45$ .

Figures 7-8, GSC 11206, holotype (refigured from Frebold 1951); GSC loc. no. 56394, isolated loc. 3.

Figure 9, GSC 127026, hypotype; GSC loc. no. C-143304, Sec. B, loc. 03.

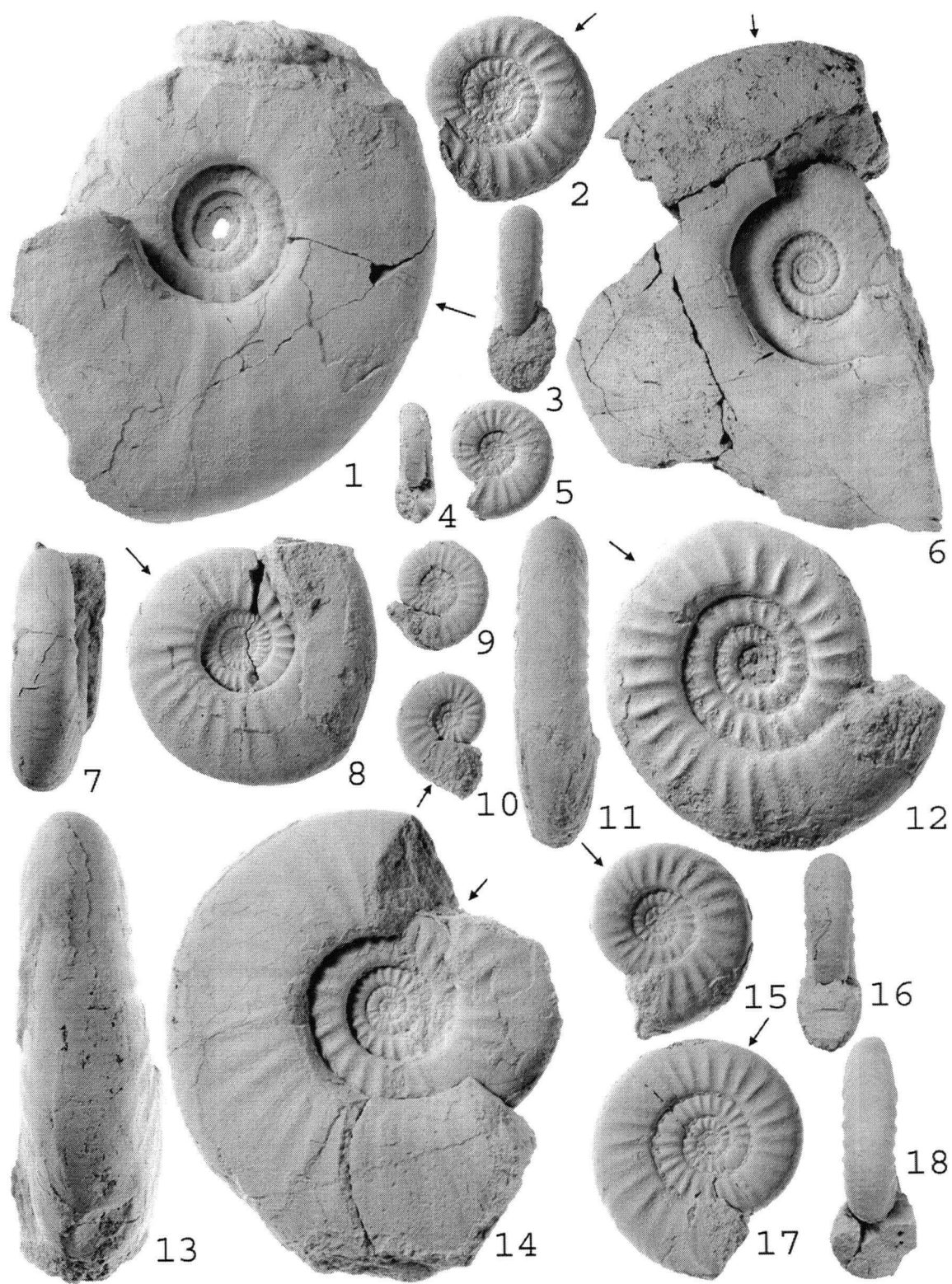
Figure 10, GSC 127023, hypotype; GSC loc. no. C-143322, Sec. D, loc. 03.

Figures 11-12, [m], GSC 127021, hypotype; GSC loc. no. C-177635, Sec. A, loc. 04.

Figures 13-14, GSC 127018, hypotype; GSC loc. no. C-175372, Sec. D, loc. 02.

Figures 15-16, GSC 127015, hypotype; GSC loc. no. C-208958, Sec. B, loc. 04.

Figures 17-18, [m], GSC 127020, hypotype; GSC loc. no. C-208958, Sec. B, loc. 04.



**Plate 5.2.** All specimens from the Last Creek Formation. All figures are  $\times 0.9$ . Arrow marks last visible septal suture. Where possible, microconch [m] and macroconch [M] forms are noted.

Figure 1, *Badouxia canadensis* transient B, [m], GSC 127028, hypotype; Rursicostatum Zone; GSC loc. no. C-175379, isolated loc. 8.

Figures 2-3, *Badouxia forticostata* sp. nov., GSC 127035, paratype; Columbiae Zone; GSC loc. no. C-175389, Sec. G, loc. 03.

Figures 4-5, *Badouxia canadensis* transient B, GSC 127031, hypotype; Rursicostatum Zone; GSC loc. no. C-208963, Sec. E, loc. 01.

Figures 6-7, *Badouxia castlensis* sp. nov., GSC 127030, paratype; Rursicostatum Zone; GSC loc. no. 62448, isolated loc. 6.

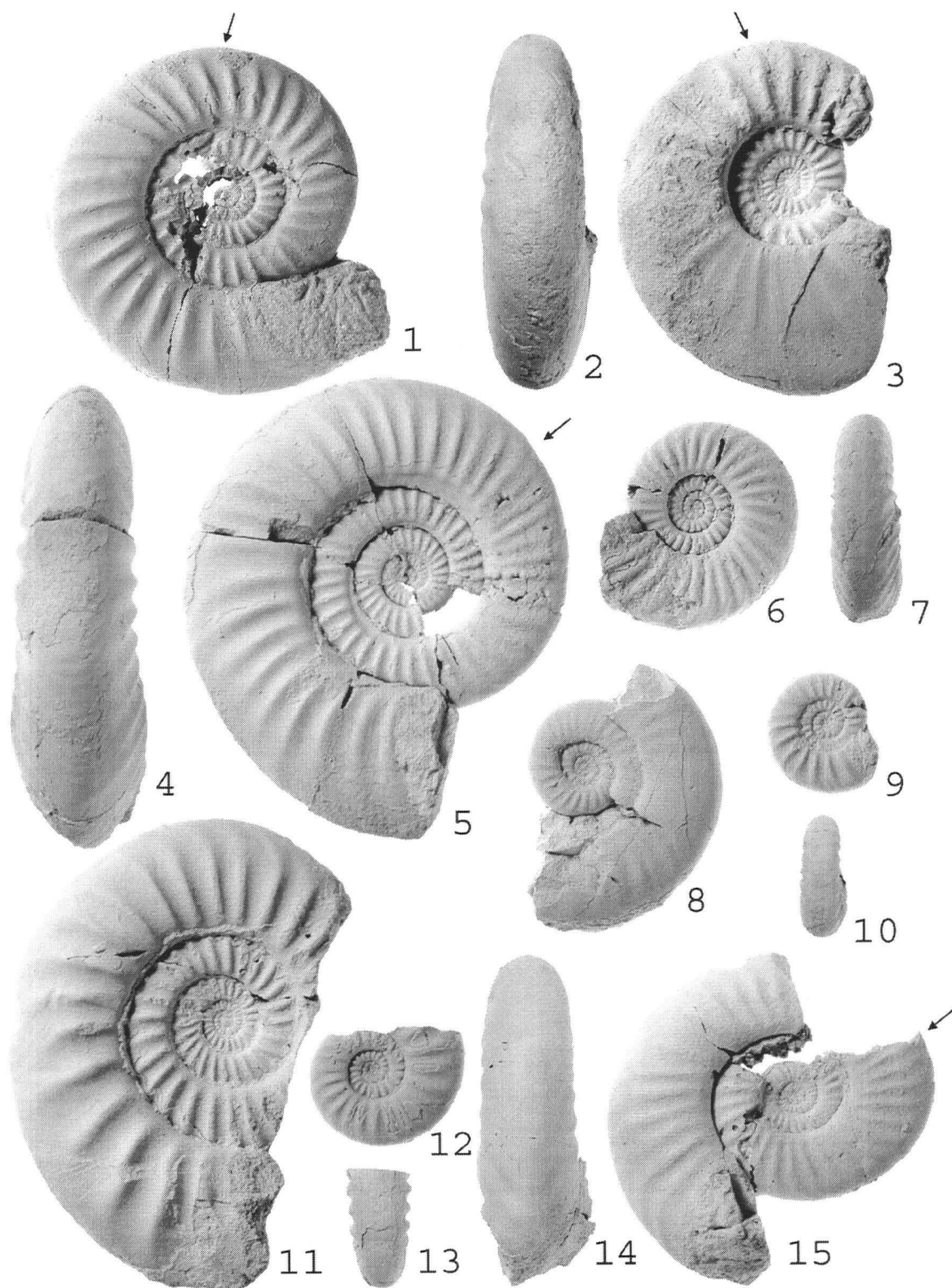
Figure 8, *Badouxia castlensis* sp. nov., GSC 127032, paratype; Rursicostatum Zone; GSC loc. no. C-143327, Sec. D, loc. 02.

Figures 9-10, *Badouxia forticostata* sp. nov., GSC 127040, paratype; Rursicostatum Zone; GSC loc. no. 10093, isolated loc. 3.

Figure 11, *Badouxia forticostata* sp. nov., GSC 127046, paratype; Rursicostatum Zone; GSC loc. no. C-208962, isolated loc. 12.

Figures 12-13, *Badouxia forticostata* sp. nov., GSC 127042, paratype; Columbiae Zone; GSC loc. no. 62487, isolated loc. 9.

Figures 14-15, *Badouxia castlensis* sp. nov., GSC 127034, holotype; Rursicostatum Zone; GSC loc. no. C-118699, Sec. B, loc. 06.



**Plate 5.3.** All specimens from the Last Creek Formation. Except for 7-8, all figures are  $\times 0.9$ . Arrow marks last visible septal suture. Where possible, microconch [m] and macroconch [M] forms are noted.

Figures 1-2, *Badouxia forticostata* sp. nov., [m], GSC 127043, holotype; Rursicostatum Zone; GSC loc. no. 56394, isolated loc. 3.

Figure 3, *Badouxia forticostata* sp. nov., [M], GSC 127038, paratype; Columbiae Zone; GSC loc. no. C-208973, isolated loc. 8.

Figure 4, *Badouxia forticostata* sp. nov., GSC 127037, paratype; Rursicostatum Zone; GSC loc. no. C-208954, talus from top of Last Creek.

Figure 5, *Badouxia forticostata* sp. nov., GSC 127041, paratype; Rursicostatum Zone; GSC loc. no. C-208962, isolated loc. 12.

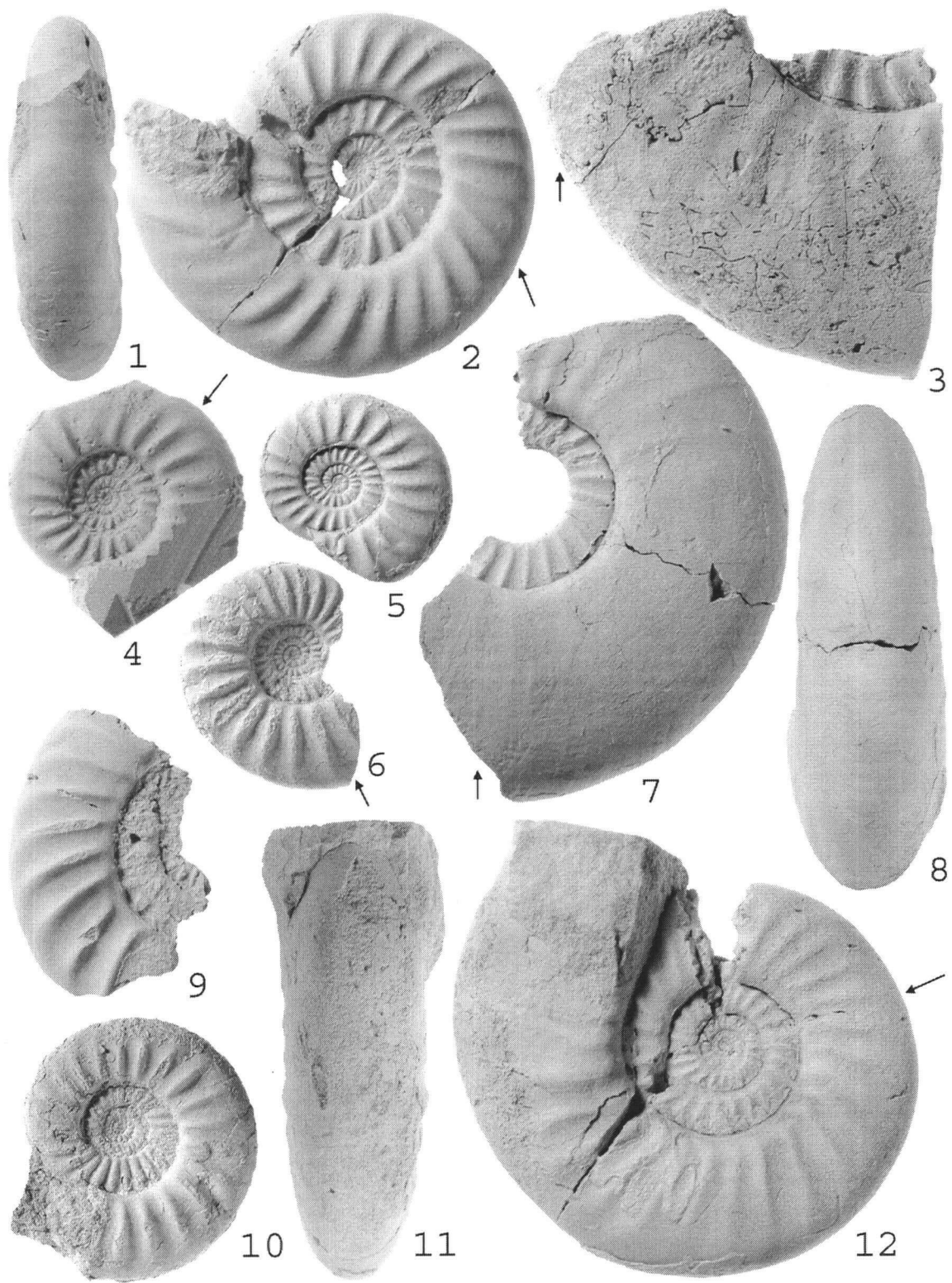
Figure 6, *Badouxia forticostata* sp. nov., GSC 127047, paratype; Columbiae Zone; GSC loc. no. 62409, Sec. F, loc 03.

Figures 7-8, *Badouxia canadensis* transient A, [M], GSC 127036, hypotype; Rursicostatum Zone; GSC loc. no. 62504, isolated loc. 2;  $\times 0.54$ .

Figure 9, *Badouxia forticostata* sp. nov., GSC 127044, paratype; Columbiae Zone; GSC loc. no. 62409, Sec. F, loc. 03.

Figure 10, *Badouxia forticostata* sp. nov., GSC 127048, paratype; Rursicostatum Zone; GSC loc. no. C-118700, Sec. B, loc 07.

Figures 11-12, *Badouxia canadensis* transient A, [m], GSC 19947, hypotype (refigured from Frebold, 1967); Rursicostatum Zone; GSC loc. no. 62504, isolated loc. 2.





**Plate 5.4.** All specimens from the Columbiæ Zone, Last Creek Formation. Except for 1-2 and 11 all figures are  $\times 0.9$ . Arrow marks last visible septal suture. Where possible, microconch [m] and macroconch [M] forms are noted.

Figures 1-2, *Badouxia columbiæ* (Frebold), [M], GSC 127050, hypotype; GSC loc. no. C-208956, Sec. E, loc. 04;  $\times 0.45$ .

Figure 3, *Badouxia columbiæ* (Frebold), GSC 127054, hypotype; GSC loc. no. 94223, Sec. F, loc. 09.

Figures 4-5, *Badouxia columbiæ* (Frebold), GSC 19925, holotype (refigured from Frebold 1967), GSC loc. no. 62494, isolated loc. 9.

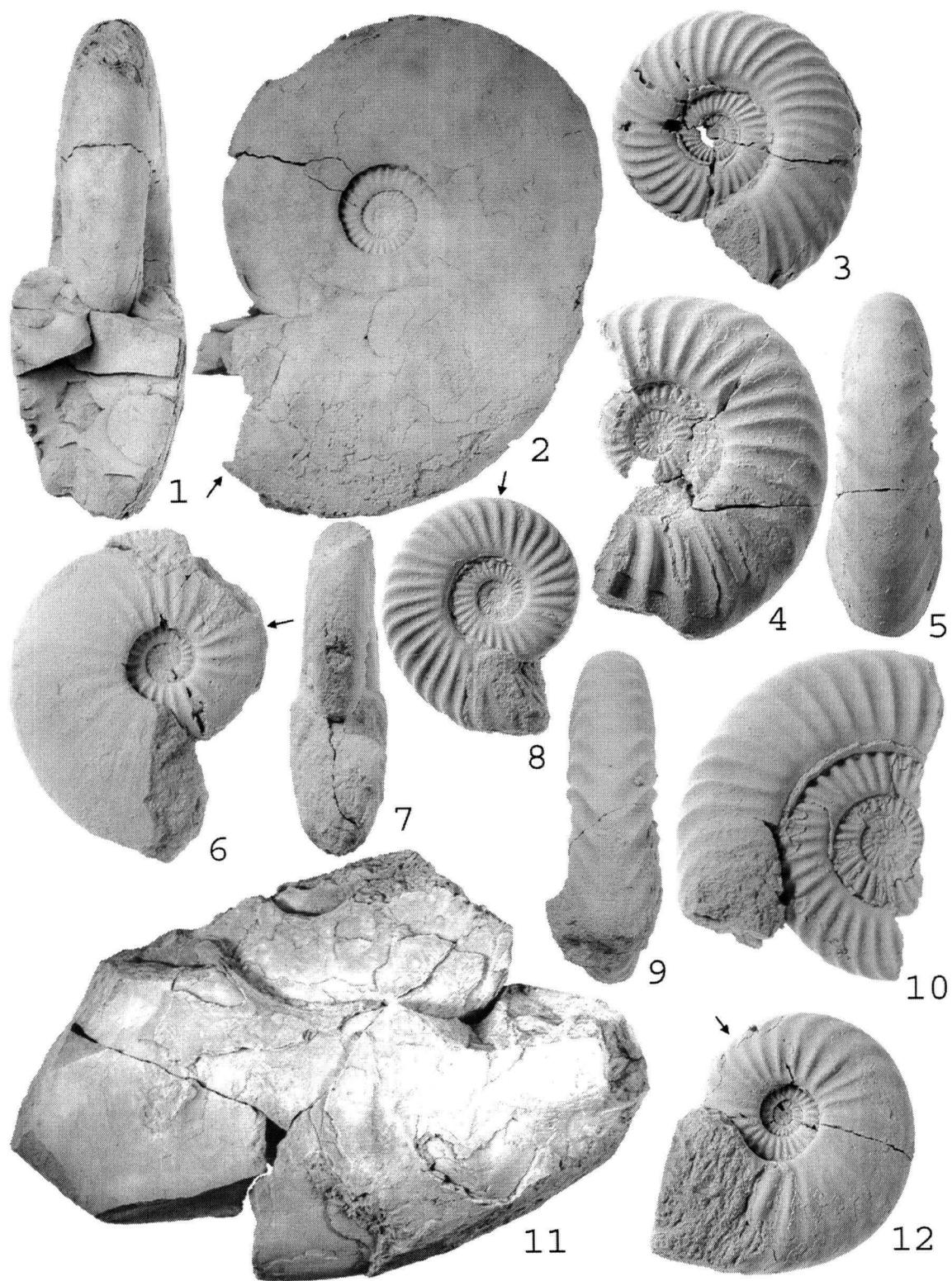
Figures 6-7, *Badouxia columbiæ* (Frebold), GSC 127051, hypotype; GSC loc. no. 94231, Sec. G, loc. 05.

Figure 8, *Badouxia columbiæ* (Frebold), [m], GSC 127055, hypotype; GSC loc. no. C-208976, Sec. F, loc. 06.

Figures 9-10, *Badouxia columbiæ* (Frebold), [m], GSC 127053, hypotype; GSC loc. no. C-208956, isolated loc. 11.

Figure 11, *Badouxia columbiæ* (Frebold), [M], GSC 127056, hypotype; GSC loc. no. 11189, stream talus from top of Last Creek;  $\times 0.225$ .

Figure 12, *Badouxia columbiæ* (Frebold), GSC 127052, hypotype; GSC loc. no. 62478, isolated loc. 7.



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## 6 THREE NEW SPECIES OF THE HETTANGIAN (EARLY JURASSIC) AMMONITE *SUNRISITES* FROM BRITISH COLUMBIA, CANADA<sup>1</sup>

### 6.1 Introduction

Taseko Lakes in British Columbia yields the best-preserved and most diverse North American collections of *Sunrisites* discovered to date, but this is the first systematic study of the fauna. The genus was erected by Guex (1980) based on material from Nevada, with *S. sunrisensis* Guex, 1980 designated as the type species. Since then, *Sunrisites* has been found to occur widely in middle and upper Hettangian strata on the American craton (e.g., Guex 1995; Hillebrandt 2000a; Hall and Pitaru 2004) as well as on several North American allochthonous terranes (e.g., Pálffy *et al.* 1994, 1999; González-León *et al.* 1996; Taylor 1998). The only occurrences of the genus outside the eastern Pacific are of *S. hadroptychus* (Wähner 1886) and *S. aff. hadroptychus* (*Aegoceras hadroptychum* in Wähner 1886 and *Caloceras hadroptychum* and *C. aff. hadroptychum* in Kment 2000) in the Austrian Alps and Ardèche, France (*Franziceras hadroptychum* in Elmi and Mouterde 1965; Mouterde and Elmi 1993) as well as *S. sunrisensis* and *Sunrisites* sp. indet. from the Mt. Camicia area in Italy (Bertinelli *et al.* 2004).

The current ammonite zonation for North America (Taylor *et al.* 2001) interprets *Sunrisites* as limited to the Sunrisensis through Mineralense zones (the latter formerly the Oregonensis Zone of Taylor *et al.* 2001; Longridge *et al.* 2006) (Fig. 6.1). However, Pálffy (1991) and Pálffy *et al.* (1994) have demonstrated that in the Queen Charlotte Islands *Sunrisites* ranges as high as the Rursicostatum Zone (formerly the Rursicostatum Subzone, Canadensis Zone of Taylor *et al.* 2001; Longridge *et al.* 2006). Although the upper limit of the stratigraphic range of *Sunrisites* in

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North America needs clarification, species of the genus have considerable potential as guide fossils for correlation in the Western Cordillera.

This paper provides a systematic description of the *Sunrisites* fauna from Taseko Lakes, which includes the introduction of three new species. The genus is of interest from a paleobiogeographic, biochronological, and paleobiological perspective and it is for these reasons that a study of the Taseko Lakes fauna was undertaken.

## 6.2 Geological Setting

The Taseko Lakes map area (Energy, Mines and Resources Canada, map sheet 92O/2) lies on the eastern margin of the southern Coast Mountains (Fig. 6.2). Recent mapping has significantly improved understanding of the geology of the area (Schiarizza *et al.* 1997; Smith *et al.* 1998; Umhoefer and Tipper 1998). The *Sunrisites* fauna described herein was collected from the Castle Pass Member of the Last Creek Formation. This unit is made up of volcanic pebble conglomerate, coarse to medium-grained sandstone, and interbedded siltstone and shale. The Formation is interpreted as a transgressive sequence of nearshore to inner shelf deposits which disconformably overlie the Triassic Tyaughton Formation (Umhoefer and Tipper 1998). The Castle Pass Member is extensively faulted and folded although generally unmetamorphosed. *Sunrisites* specimens from the Mineralense and Rursicostatum zones were collected in situ from the four sections and two isolated localities described below.

### 6.2.1 Stratigraphic sections

In the Castle Pass area four sections were measured which yield ammonites of late Hettangian age (Fig. 6.2). Section C and the lower portion of sections A and D contain material from the Mineralense Zone whereas section B and the upper portion of sections A and D contain material from the Rursicostatum Zone. The tops of all four sections are faulted. Figure 6.3 shows details of the stratigraphy and collection levels for each section.

### 6.2.2 Isolated localities

Isolated localities 1 and 2 are from the top of the Mineralense Zone or the base of the Rursicostatum Zone (Fig. 6.2).

Detailed data for sections A-D and localities 1-2 are contained in Appendix G. This information includes a brief geographical description of each site, including latitude and longitude as well as Geological Survey of Canada (GSC) locality numbers.

### 6.3 Systematic Paleontology

Measurements for all measurable specimens of each species collected from Taseko Lakes are given in Table 6.1. Abbreviations and measurements follow Smith (1986) and include shell diameter (D), umbilical diameter (UD), whorl width (WW), whorl height (WH), umbilical diameter as a ratio of shell diameter (U), ratio of the whorl width to the whorl height (WWWH), and primary ribs per half whorl (PRHW).

All specimens are deposited in the type collection of the Geological Survey of Canada (GSC) in Ottawa.

#### **Family PSILOCERATIDAE Hyatt, 1867**

#### **Subfamily SUNRISITINAE Hillebrandt, 2000a**

#### **Genus SUNRISITES Guex, 1980**

TYPE SPECIES: *Sunrisites sunrisensis* Guex, 1980.

DIAGNOSIS: Moderately evolute to moderately involute, weakly compressed to depressed forms which can attain large shell diameters. Strong ribs on flanks of inner whorls fade at large shell diameters. Faint, forwardly inclined striae cross venter on inner and intermediate whorls. Suture line often asymmetric with ventral lobe offset from median line.

DISCUSSION: According to Guex (1995, p. 50), it is difficult to distinguish *S. sunrisensis* from *Badouxia canadensis* at shell diameters of less than 30 mm (Frebold 1951). Guex claims that the two species can be distinguished at shell diameters larger than 30 mm due to the development of a narrower umbilicus in *B. canadensis*. More recent work on *Badouxia* faunas (Hillebrandt 2000a; Longridge *et al.* 2006) has revealed that *B. canadensis* varies widely in evolution, encompassing the range of variation found within species of *Sunrisites* (including *S. sunrisensis*). Nevertheless, *B. canadensis* can be consistently separated from species of *Sunrisites* by weaker ribbing that is prorsiradiate rather than rursiradiate to rectiradiate on the intermediate whorls.

The *Sunrisites* material from Taseko Lakes indicates a much broader range of variability in the genus than was previously recognized. Usually species of *Sunrisites* are midvolute to evolute throughout ontogeny but the Taseko Lakes material contains species which become significantly more involute at large shell diameters. Although the evidence is not conclusive, all three species of *Sunrisites* from Taseko Lakes display signs of sexual dimorphism. Dimorphism has been documented previously in other Hettangian genera (e.g., Callomon 1981; Guex 1981, 1995; Longridge *et al.* 2006) but has not been previously recognized in *Sunrisites*. Dimorphism is established if two distinct, contemporaneous groups of shells are virtually identical on the inner whorls and are phylogenetically linked, showing the concurrent appearance of new characters in both groups. Material is divided into two groups based primarily on bimodal shell size distribution and differences in ribbing style (Callomon 1963, 1981; Davis *et al.* 1996). *Sunrisites* is thought to be the ancestor of the ammonite *Badouxia*, which shows strong evidence of dimorphism in three species from Taseko Lakes (Longridge *et al.* 2006), including clear bimodal size distribution and differences in ornament. These *Badouxia* species also exhibit the simultaneous appearance of new characters in both groups. Similar signs are evident in the three species of *Sunrisites* from Taseko Lakes. Although specimens are incomplete and maturity

cannot be firmly established, contemporaneous collections of *S. brimblecombei* n. sp. and *S. chilcotinensis* n. sp. contain specimens which are very similar on the innermost whorls but diverge into two groups based on differences in shell diameter and ribbing style. The first group attains very large shell diameters (up to 22 cm) and is variocostate, becoming smooth early in ontogeny. In the second group, the overall preserved shell diameter is much smaller (typically 6 cm) and ribbing is isocostate, continuing to a larger shell diameter than in the first group. These differences in ornament and signs of bimodal size distribution suggest that *S. brimblecombei* and *S. chilcotinensis* were sexually dimorphic. The small, ribbed specimens represent the microconchs and the large, smooth forms correspond to the macroconchs for each species. Although there are fewer specimens of *S. senililevis* n. sp., the holotype may be a macroconch because it is very large and becomes smooth on the outer whorl.

***Sunrisites brimblecombei* sp. nov.**

Plates 6.1.1-6.1.4, 6.1.7-6.1.9, 6.2.3-6.2.4, 6.2.9-6.2.10; Figures 6.6A-6.6C, 6.6E-6.6G  
partim 1951 *Psiloceras canadense* Frebold, p. 3, pl. 1, fig. 3a-b; 1967, p. 18, pl. 1, fig. 3a-c.  
cf. 1981 *Psiloceras* (*Franziceras*) cf. *P. (F.) ruidum* Buckman. Imlay, p. 29, pl. 1, figs 12-  
14, 18-24.  
cf. 1999 *Sunrisites?* sp. Pálffy *et al.*, fig. 5a, b.

DERIVATION OF NAME: Named after Cory Brimblecombe of the Vancouver Paleontological Society, who collected and subsequently donated the holotype to the GSC.

MATERIAL AND MEASUREMENTS: Material studied includes 22 measured specimens, 10 incomplete specimens and many fragments. Measurements of volution, whorl shape, and ribbing density are presented in Table 6.1.

HOLOTYPE: GSC 127383 (Plate 6.2.9-6.2.10); macroconch from the Rursicostatum Zone, section B01, Taseko Lakes.

PARATYPES: GSC 127384–127404. Locality information for each paratype is indicated in Table 6.1. All specimens are from the Castle Pass Member of the Last Creek Formation in Taseko Lakes, British Columbia, from the upper Hettangian Mineralense and Rursicostatum zones.

DIAGNOSIS: Weakly compressed to weakly depressed form which attains shell diameters in excess of 22 cm. Evolute at small shell diameters, becoming moderately involute at larger diameters. Rursiradiate to rectiradiate ribs vary in strength on inner whorls, weak and irregular on outer whorls. Septal suture line asymmetric.

DESCRIPTION: Weakly compressed to weakly depressed form ( $WWWH = 0.9\text{--}1.15$  at 5 cm shell diameter). Inner whorls relatively evolute for genus (Plate 6.1.9, 6.2.3). Between shell diameters of 40 to 60 mm, shell volution varies from moderately evolute to moderately involute ( $U = 40\%\text{--}49\%$ ). Beyond shell diameters of 70 mm, form is consistently involute for genus. The following describes the ontogenetic changes characterizing this species.

On inner and intermediate whorls ( $D < 5$  cm), whorl shape varies according to compression. In more depressed forms, whorl cross section wide suboval with moderately high, upright umbilical wall and rounded yet distinct umbilical shoulder; venter broad and rounded. In more compressed forms, whorl cross section high suboval with more sloping umbilical wall and rounded umbilical shoulder. Venter somewhat narrower and slightly tectiform. Beyond 60 mm, all specimens compressed, having subrectangular cross section with high, upright to slightly undercut umbilical wall. Whorl widest low to midflank, tapers gently toward broad, rounded venter. Outermost whorl of largest specimen (Plate 6.1.1- 6.1.2;  $WH = 86$  mm) (Fig. 6.6B-6.6C) weakly depressed and subrounded, curving gently from widest point of whorl on lower flank to broad, rounded venter.

Nodes on nucleus to shell diameters of approximately 4 mm. Beyond this, straight to slightly concave ribs vary somewhat in strength and orientation from weakly rursiradiate to rectiradiate. Ribs arise at flank base, show greatest height midflank before fading on upper flank. On inner whorls of three specimens, ribs project gently forward onto venter before they fade (GSC 127386, 127401; not figured). Faint, adorally projecting striae visible on venter in some specimens (GSC 127388, 127401; not figured). While some specimens remain ribbed to shell diameters of 60 mm (Plate 6.1.3-6.1.4), in others ribs weaken and become irregular in strength and spacing beyond shell diameters of 45 mm (Plate 6.1.7, GSC 127400). Irregular and weakened ribs initially rursiradiate on lower flank becoming prorsiradiate on the mid and upper flank. Some of these ribs project forward and continue across venter. On largest specimen (Plate 6.1.1-6.1.2), final portion of outer whorl (WH = 86 mm) nearly smooth. At small size, septal suture line simple and asymmetric with first lateral lobe longer than ventral lobe which is offset from median line (Fig. 6.6A). Suture line at larger shell sizes not visible.

As considered above in the discussion of *Sunrisites*, specimens limited to smaller shell diameters that bear ribs to the end of the preserved shell may be microconchs (Plate 6.1.3-6.1.4, 6.1.8-6.1.9, 6.2.3-6.2.4) whereas specimens that are smooth and attain significantly larger shell diameters may be macroconchs (Plate 6.1.1-6.1.2, 6.1.7, 6.1.9, 6.2.10). One specimen (Plate 6.1.9) shows uncoiling of the umbilical seam at the end of the outer whorl, suggesting it may be mature. Unfortunately both the inner part of the outer whorl and the aperture are missing, so it is not possible to establish an accurate body chamber length.

REMARKS: With respect to variation in rib orientation and number, the inner whorls of *S. brimblecombei* are similar to *S. peruvianus* and *S. sunrisensis*. *Sunrisites brimblecombei* also shows similar volution to *S. sunrisensis* and the otherwise more evolute *S. peruvianus* at small shell diameters. However, the Taseko Lakes material encompasses the variation in whorl cross section which differentiates *S. sunrisensis* and *S. peruvianus*. In addition, it has a higher

stratigraphic position, becomes more involute at comparably large shell diameters, and attains an overall larger shell diameter than both of these forms. *Sunrisites brimblecombei* is somewhat similar to *S. chilensis* but differs in lacking swollen ribs at small shell diameters. Furthermore, it has ribs that are consistently rursiradial to rectiradial to larger shell diameters and is significantly more involute beyond shell diameters of 70 mm. *Sunrisites brimblecombei* differs from *S. hadroptychus* in having ribs that are less consistently concave on the inner whorls and rursiradial to rectiradial rather than prorsiradial on the intermediate whorls. Additionally, it is more involute and has weaker ribbing that is irregular in spacing and strength at shell diameters beyond 70 mm. GSC 127395 (Plate 6.2.3-6.2.4) is somewhat similar to certain species of *Franziceras* Buckman, 1923 but differs in having a narrower whorl cross section as well as ribs which are strongest midflank and fade sharply, dividing into two or three very faint striae which project forward over the venter rather than having flank ribs which continue onto the venter.

OCCURRENCE: *S. brimblecombei* was found in sections A–D at Castle Pass as well as at isolated localities 1 and 2. It is from the Mineralense and Rursicostatum zones. In addition to occurrences in British Columbia, the species is also known from upper Hettangian strata in Alaska (Imlay 1981; Pálffy *et al.* 1999).

***Sunrisites chilcotinensis* sp. nov.**

Plates 6.1.5-6.1.6, 6.1.10-6.1.12, 6.2.5-6.2.6, 6.2.11; Figure 6.6H-6.6J

cf. 1981 *Psiloceras* (*Franziceras*) sp. indet. Imlay, p. 29, pl. 1, figs. 11, 15-16.

? 1981 *Psiloceras* (*Franziceras*) sp. indet. Imlay, p. 29, pl. 1, fig. 17.

DERIVATION OF NAME: Named after the Chilcotin Ranges where the studied *Sunrisites*-bearing localities occur.

**MATERIAL AND MEASUREMENTS:** Material includes 9 measured specimens, 2 incomplete specimens and 10 fragments. Measurements of volution, whorl shape, and ribbing density are presented in Table 6.1.

**HOLOTYPE:** GSC 127406 (Plate 6.2.5); microconch from Rursicostatum Zone, section B01, Taseko Lakes.

**PARATYPES:** GSC 127405, 127407–127413. Locality information for each specimen is indicated in Table 6.1. All specimens are from the Castle Pass Member of the Last Creek Formation in Taseko Lakes, British Columbia, from the upper Hettangian Mineralense and Rursicostatum zones.

**DIAGNOSIS:** Moderately involute form which attains large diameter ( $D > 150$  mm). Inner whorls depressed, outer whorls compressed. Moderately coarse, weakly rursiradiate to rectiradiate ribbing strongest on mid to upper flank of inner and intermediate whorls. Some ribs swollen into nodes. Outer whorls and venter smooth.

**DESCRIPTION:** Evolute and moderately depressed on inner whorls ( $WWWH = 1.30$  at shell diameters of 30 mm). Umbilical wall fairly high with indistinct umbilical shoulder. Widest point of whorl at midflank. Venter broad and rounded. Shell expansion rate somewhat variable.

Beyond shell diameters of about 40 mm, whorl cross section becomes compressed and high suboval. Umbilical wall upright and umbilical shoulder distinct but rounded. Widest point of whorl remains at midflank. Venter narrow but rounded. Strong, rectiradiate to weakly prorsiradiate ribs begin on lowest flank, reach maximum height at mid to upper flank and fade rapidly at ventrolateral shoulder. Some ribs that reach maximum height on upper flank thickened and resemble nodes. In some specimens (Plate 6.1.10–6.1.12, 6.2.6, 6.2.11), at shell diameters between 42 and 55 mm, weaker, slightly sigmoidal ribs limited to lower two thirds of flank. GSC 127405 (Plate 6.1.10–6.1.12) preserved to large shell diameter where beyond approximately 55 mm, flanks become completely smooth except for very faint lirae on areas



where shell material preserved. On better-preserved specimens, weak, forwardly inclined striae cross venter on inner and intermediate whorls. Holotype (Plate 6.2.5) maintains strong ribs on lower two thirds of flank until maximum preserved shell diameter (c. 67 mm). On outer flank, ribs subdivided into two or three finer ribs that continue across venter. Last three flank ribs on this specimen slightly concave. No complete septal suture line available. However, small portion of septal suture visible on GSC 127405 (macroconch) where ventral lobe slightly offset from plane of bilateral symmetry. At small shell diameters, first lateral lobe visible on some specimens is somewhat deeper than ventral lobe. At larger shell diameters, other paratypes (macroconchs) show somewhat phylloid and fairly heavily serrated first lateral saddle. Also show simple secondary serrations.

As considered above in the discussion of *Sunrisites*, specimens limited to smaller shell diameters that bear ribs to the end of the preserved shell may be microconchs (holotype, Plate 6.2.5) whereas smooth forms that attained large shell diameter may be macroconchs (Plate 6.1.10-6.1.12). Plate 6.1.12 shows uncoiling of the umbilical seam at the end of the outer whorl, suggesting the specimen may be mature. Unfortunately incomplete preservation means it is not possible to establish an accurate body chamber length.

REMARKS: This species is attributed to *Sunrisites* based on the evolute, depressed form of the inner whorls as well as the strong, weakly rursiradiate to rectiradiate ribs on the inner whorls and the forwardly inclined striae present on the venter. *Sunrisites chilcotinensis* is most similar to two specimens of *S. chilensis* (Hillebrandt 2000a, pl. 11, fig. 4, pl. 12, fig. 1). It differs from this species in having wider spaced ribs on the inner whorls and, at larger shell diameters, becomes more involute and compressed with flanks that become smooth. *Sunrisites chilcotinensis* differs from *S. senililevis* n. sp. in having ribs that are less coarse on the inner whorls as well as a much more compressed whorl cross section on the intermediate and outer whorls. It differs on the inner whorls from *S. brimblecombei* n. sp. and the rectiradiate ribbed *S.*

*hadroptychus* in having much thicker ribs. The outer whorls differ from both species in being more compressed and virtually smooth. It has much stronger ribs on the inner whorls than *S. sunrisensis* and *S. peruvianus* and attains much larger shell diameters.

OCCURRENCE: *S. chilcotinensis* is found in sections A and B at Castle Pass and at locality 2 where it is restricted to the Mineralense and Rursicostatum zones. This form is also recognized from Alaska and is of Hettangian to early Sinemurian age (Imlay 1981).

***Sunrisites senililevis* sp. nov.**

Plate 6.2.1-6.2.2, 6.2.7-6.2.8; Figure 6.6D

1991 *Sunrisites* (?) *senililevis* n. sp. Pálfy, p. 95, pl. 5, figs. 5, 9.

DERIVATION OF NAME: *Senililevis* is Latin for “old smooth” and refers to the smooth outer whorl of the holotype. This species was originally proposed by Pálfy (1991, p. 95, pl. 5, figs 5, 9) in his unpublished master’s thesis.

MATERIAL AND MEASUREMENTS: Material studied includes 1 measured specimen, 1 incomplete specimen and 2 fragments. Measurements of volution, whorl shape, and ribbing density are presented in Table 6.1.

HOLOTYPE: GSC 127414 (Plate 6.2.1–6.2.2); macroconch from the Rursicostatum Zone, section D02, Taseko Lakes.

PARATYPE: GSC 127415, section D, talus. Specimen is from the Castle Pass Member of the Last Creek Formation in Taseko Lakes, British Columbia, from the upper Hettangian Mineralense and Rursicostatum zones.

DIAGNOSIS: Moderately involute form which attains large diameter ( $D > 163$  mm). Inner whorls moderately depressed, outer whorls equidistant. Very coarse, widely spaced, weakly

rursiradiate to rectiradiate ribs on inner and intermediate whorls. Virtually smooth flanks on outer whorl. Venter smooth.

DESCRIPTION: Moderately involute for genus. Inner whorls weakly depressed ( $WWWH = 0.88$  at 25 mm shell diameter). Intermediate and outer whorls same high as wide ( $WWWH = 1.02$  at 163 mm shell diameter) with an ellipsoid whorl cross section showing greatest whorl width on the lower part of the flank. Umbilical wall moderately high and rounded on inner and intermediate whorls and umbilical shoulder indistinct. On outer whorl, umbilical wall high and slightly undercut with distinct but rounded umbilical shoulder. Rursiradiate to weakly rectiradiate ribs blunt, coarse, and widely spaced (eight ribs per half whorl) with high rounded profile. Ribs begin on lowest flank and show greatest height at mid to upper flank. Ribs on inner whorls end abruptly at ventro-lateral shoulder while at larger shell diameters ribs fade on uppermost flank before disappearing. GSC 127415 (Plate 6.2.7-6.2.8) shows faint growth striae that bend weakly forward across venter ( $WH = c. 7$  mm). On holotype, GSC 127414 (Plate 6.2.1-6.2.2), venter only visible on intermediate and outer whorls and appears smooth. Flank ribs weaken by an umbilical diameter of  $c. 40$  mm and by 50 mm umbilical diameter shell smooth. Septal suture line of entirely septate holotype too incomplete to be illustrated. Several short segments of different suture lines visible at  $WH = c. 22-25$  mm. First lateral saddle fairly heavily serrated and shows simple secondary serrations. Umbilical lobes weakly retracted.

As mentioned above in the discussion of *Sunrisites*, it is possible that the holotype of *S. senililevis* is a macroconch based on its large shell diameter and smooth outer whorl (Plate 6.2.1-6.2.2).

REMARKS: The inner and intermediate whorls of this species differ from all other *Sunrisites* species in having much coarser and more widely spaced ribs. Nevertheless, this form is attributed to *Sunrisites* as it shares many characteristics recognized in other species of the genus, including depressed inner whorls, weakly rursiradiate to rectiradiate ribbing that is strongest

midflank, and the presence of growth lines on the venter of the inner whorls. In addition to the difference in ribbing style on the inner and intermediate whorls, this form differs from *S. chilensis*, *S. hadroptychus*, and *S. chilcotinensis* n. sp. in being more involute and depressed and it attains a much larger size than *S. peruvianus* and the more evolute *S. sunrisensis*.

OCCURRENCE: *Sunrisites senililevis* is restricted to the Mineralense and Rursicostatum zones exposed on sections C and D at Castle Pass. This form is also found in the Rursicostatum Zone in the Queen Charlotte Islands (Pálffy 1991; Pálffy *et al.* 1994).

## 6.4 Discussion

Early Jurassic ammonite faunas in western North America had strong Tethyan affinities as well as a high degree of endemism (Guex 1980, 1995; Taylor *et al.* 1984; Smith *et al.* 1988; Jakobs *et al.* 1994; Pálffy *et al.* 1994). For these reasons, a separate zonation for the Hettangian and Sinemurian of the Western Cordillera of North America was erected by Taylor *et al.* (2001) with some subsequent modifications based on an intensive study of the *Badouxia* fauna from Taseko Lakes (Longridge *et al.* 2006). As *Badouxia* species are the most important taxa for subdividing the late Hettangian in North America, their ranges in Taseko Lakes are included in Figure 6.4. Currently, *Sunrisites* is limited to the Megastoma Zone and possibly lower Marmoreum Zone in Austria (Wähner 1886; Kment 2000), the Liasicus Zone in France (Elmi and Mouterde 1965; Mouterde and Corna 1997), the early late Hettangian in Italy (Bertinelli *et al.* 2004), the Peruvianus Zone in South America (Hillebrandt 2000a), the middle Hettangian in Williston Lake (Hall and Pitaru 2004), and the Sunrisensis to Mineralense zones in the remainder of North America (Taylor *et al.* 2001; Longridge *et al.* 2006) (Fig. 6.1). The ranges of *Sunrisites* species from Taseko Lakes (Fig. 6.4) support the findings of Pálffy (1991) and Pálffy *et al.* (1994) in the Queen Charlotte Islands indicating an extension of the generic range to include the uppermost Hettangian Rursicostatum Zone (Fig. 6.1).

At the species level, the genus is well represented in South America and includes *S. chilensis* Hillebrandt (2000a), *S. peruvianus* (Lange, 1941), *S. sunrisensis*, and *S. cf. sunrisensis* (Hillebrandt 1981a, 1987, 1988, 1990, 1994, 2000a, b; Chong and Hillebrandt 1985; Riccardi *et al.* 1991; Prinz and Hillebrandt 1994). The South American occurrences are restricted to the upper middle to lower upper Hettangian Peruvianus Zone (Fig. 6.1) (Hillebrandt 2000a). North American occurrences consist of two different groups of *Sunrisites* species. The first includes *S. sunrisensis* and *S. aff. hadroptychus* from Nevada (Guex 1995), *S. aff. sunrisensis* from Oregon (Taylor 1998), and *S. sunrisensis* from Williston Lake, British Columbia (Hall and Pitaru 2004) and Sonora, Mexico (González-León *et al.* 1996, 2000). These species are restricted to the upper middle to upper Hettangian Sunrisensis to Mineralense zones (Fig. 6.1). The second group consists of the three new species of *Sunrisites* discussed herein including *Sunrisites?* sp. from Alaska (Pálffy *et al.* 1999) and *Sunrisites* sp. (Tipper and Guex 1994; Carter *et al.* 1998) and *Sunrisites* n. sp. (Pálffy 1991; Pálffy *et al.* 1994) from the Queen Charlotte Islands. This second group is limited to the upper Hettangian Mineralense and uppermost Hettangian Rursicostatum zones and consequently, is younger than the assemblage of *Sunrisites* species from South America and younger in part than the first group of *Sunrisites* species from North America.

*Sunrisites* has some interesting potential paleobiogeographical implications. The Hispanic Corridor linked the western Tethys with the eastern Pacific Ocean during Jurassic time (Smith 1983). Although there is no direct sedimentological or geophysical evidence for this connection before the late Middle Jurassic (Smith and Tipper 1986; Smith and Westermann 1990; Aberhan 2001; Cecca 2002), paleontological data suggest that a shallow marine connection existed across rifting continental crust significantly earlier (e.g., Damborenea and Manceñido 1979; Hillebrandt 1981b, 2002; Smith and Tipper 1986; Sandy and Stanley 1993; Damborenea 2000; Aberhan 2001; Smith *et al.* 2001; Moyne *et al.* 2004). The formation of such a connection would, of course, also be a function of eustatic sea level rise. The precise time of the initial

opening of this seaway is still uncertain and has been the subject of much debate. Based on brachiopod and coral faunas, Sandy and Stanley (1993) proposed the corridor may have opened as early as the Norian. Some bivalve faunal data suggests the Hispanic Corridor did not open until the Pliensbachian (Damborenea and Manceñido 1979; Aberhan 2001), whereas other bivalve groups suggest a possible Hettangian opening for the seaway (Damborenea 2000 and references therein; Sha 2001). Guérin-Franiatte (1990) proposed a probable Hettangian opening of the Hispanic Corridor based on ammonite evidence. The distribution of *Sunrisites* was first cited by Mousterde and Elmi (1993) as possible evidence for an opening of a seaway between the western Tethys and the eastern Pacific in the middle Hettangian. As discussed above, *Sunrisites* is recorded in Austria, France and Italy as well as throughout the eastern Pacific. The genus is not known from the eastern Tethys Ocean as might be expected if this were the portal of migration between western Tethys and the eastern Pacific oceans. However, at the present time, possible instances of fossiliferous middle and upper Hettangian rocks in the southern and eastern Tethys are limited to small collections from Viet Nam, Timor, New Caledonia, and New Zealand (e.g. Krumbeck 1923; Spath 1923; Avias 1953; Meister *et al.* 2002; Stevens 2004). Before we can obtain a clear picture of the dispersal route of the genus, we need a better understanding of the ammonite distribution in the southern and eastern Tethys in order to eliminate the possibility that *Sunrisites* migrated eastward across the Pacific or via the South Pacific (Newton 1988; Elmi 1993; Dommergues 1994).

*Sunrisites* is found in several areas which formed part of the North American craton during Hettangian time including Nevada, Williston Lake in eastern British Columbia, and northern Alaska (Fig. 6.5). The genus also occurs on a few of the tectonostratigraphic terranes which make up a large portion of western North America (Coney *et al.* 1980; Taylor *et al.* 1984; Tipper 1984; Smith and Tipper 1986; Monger and Nokleberg 1996; Smith *et al.* 2001; Smith 1999, 2006; and references therein). These include the Antimonio terrane in northwestern

Mexico (González-León *et al.* 1996, 2000, 2005), the Izee terrane in Oregon (Silberling *et al.* 1984; Taylor 1998; Taylor and Guex 2002), the Wrangellia terrane in the Queen Charlotte Islands (Smith and Tipper 1986; Pálffy 1991; Pálffy *et al.* 1994; Tipper and Guex 1994), the Peninsular terrane in southern Alaska (Wang *et al.* 1988; Nokleberg *et al.* 1994, 2001; Pálffy *et al.* 1999; and references therein), and the Cadwallader terrane in Taseko Lakes (Schiarizza *et al.* 1997; Umhoefer and Tipper 1998) (Fig. 6.5). During the Early Jurassic, the location of these terranes was somewhat uncertain. The Antimonio terrane is interpreted as representing a fore-arc basin adjacent to southern California during the Hettangian. Later in the Jurassic, this terrane probably shifted to its current location by left-lateral movement along the Mojave-Sonora megashear (González-León *et al.* 2005 and references therein). The Izee terrane was probably close to the North American continent in the Early Jurassic, forming part of a larger composite of terranes that accreted to cratonic North America in the mid-Cretaceous (Avé Lallemant 1995). Proximity to the craton of the Antimonio and Izee terranes is suggested by the presence of *S. sunrisensis* on the craton in Nevada (Guex 1995; Taylor 1998) and Williston Lake (Hall and Pitaru 2004) while *S. aff. sunrisensis* is found on the Izee terrane (Taylor 1998) and *S. sunrisensis* is found on the Antimonio terrane (González-León *et al.* 1996). The location of Wrangellia is reasonably well known because Permian coral, brachiopod, and fusulinid faunas (Monger 1984; Belasky 1994; Belasky *et al.* 2002), Sinemurian and Pliensbachian bivalve faunas (Aberhan 1999 and references therein), as well as Pliensbachian ammonite faunas (Smith and Tipper 1986; Smith *et al.* 2001; Smith 2006) tie the terrane to the Northern Hemisphere and the eastern Pacific during these intervals. Additionally, the distribution of the ammonite *Badouxia* is evidence that Wrangellia was located in the eastern Pacific during the Hettangian (Taylor *et al.* 1984; Smith 2006). According to Nokleberg *et al.* (1994), the Wrangellia and Peninsular terranes represent different stratigraphic levels within the Wrangellia superterrane and consequently, they probably share a similar history in terms of their pre-accretion location

in the Early Jurassic. The distribution of *Badouxia* and *Sunrisites* on both terranes further supports a link between the two terranes by the late Hettangian. In addition, both genera are found on the Cadwallader terrane (Frebold 1951, 1967; Longridge *et al.* 2006), also providing evidence that it was located in the eastern Pacific during the late Hettangian. Unfortunately, the early late Hettangian fossil record from the Cadwallader, Wrangellia, and Peninsular terranes as well as cratonal Alaska is either incomplete or the faunas are not well enough studied to make meaningful comparisons with the more southern localities. However, for the latest Hettangian, records on the three more northerly terranes are better known. Specimens now assigned to *S. brimblecombei* are found on both the Cadwallader and Peninsular terranes (Frebold 1951; Imlay 1981; Pálffy *et al.* 1999) while those now recognized as *S. senililevis* are common to the Cadwallader and Wrangellia terranes (Pálffy 1991) (Fig. 6.5). Furthermore, specimens here identified as *S. chilcotinensis* and *S. brimblecombei* are found on the Cadwallader terrane and the North American craton in northern Alaska (Imlay 1981) (Fig. 6.5). These linkages suggest that the Wrangellia, Peninsular, and Cadwallader terranes were in the Northern Hemisphere during the late Hettangian. However, the restricted occurrences of *S. brimblecombei*, *S. chilcotinensis* and *S. senililevis* to the Cadwallader, Wrangellia and Peninsular terranes as well as the craton in northern Alaska (Fig. 6.5) are unlikely to be due simply to differences in the age of available outcrops. Fossiliferous localities of uppermost Hettangian age exist in Nevada and Williston Lake (Taylor 1998, 2000; Hall and Pitaru 2004) that do not yield these three species. This may be evidence for some longitudinal separation between the craton and the Cadwallader, Wrangellia and Peninsular terranes during the latest Hettangian.

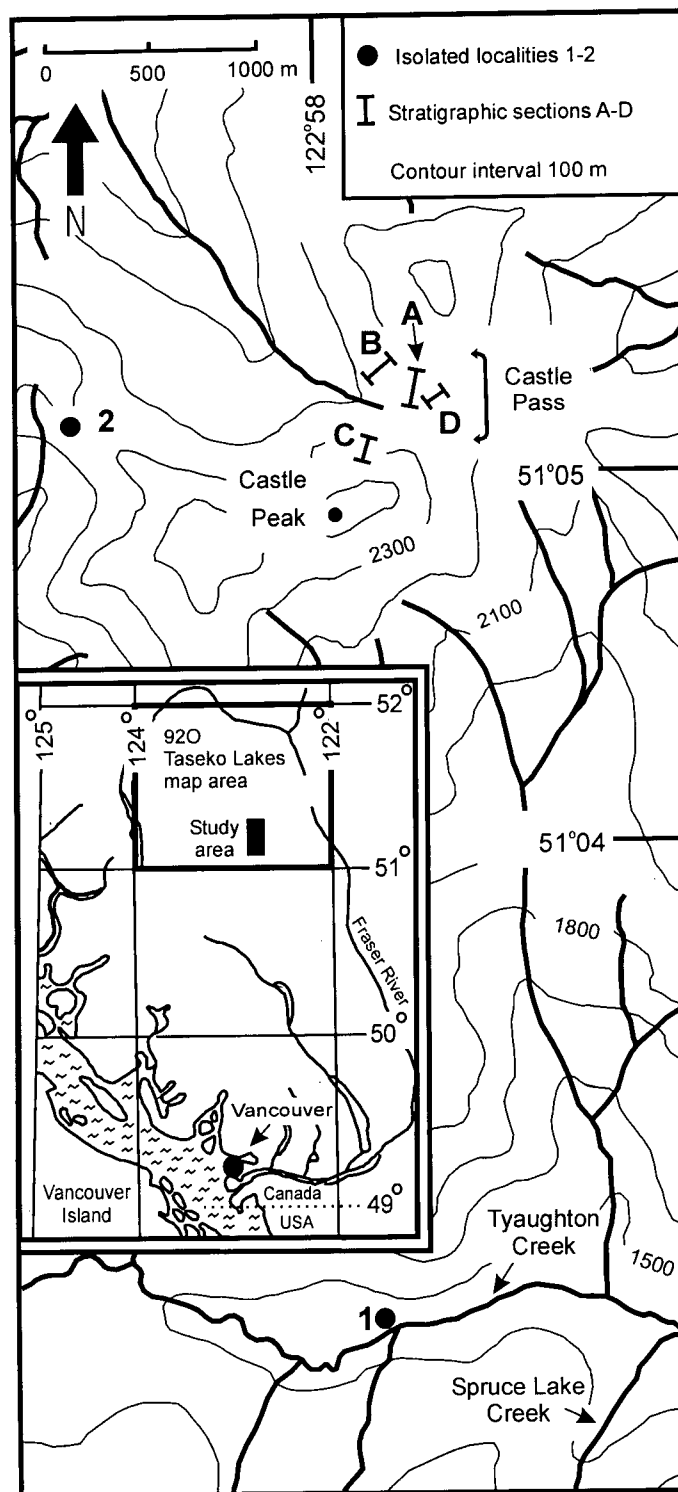


Taxon	GSC #	Map loc.	DMAX	D	UD	U	WW	WH	WWWH	PRHW
<b><i>S. brimblecombei</i></b>	<b>127383</b>	<b>B01</b>	<b>85.1</b>	<b>85.1</b>	<b>34.0</b>	<b>0.40</b>	<b>29.0</b>	<b>31.0</b>	<b>0.94</b>	<b>—</b>
<i>S. brimblecombei</i>	127384	D02	ca. 60	ca. 59	ca. 27	0.46	ca. 19	ca. 19	1.00	12
<i>S. brimblecombei</i>	127385	B02	—	ca. 41	ca. 19	0.46	13.2	12.8	1.03	11
<i>S. brimblecombei</i>	127386	A09	—	21.6	10.2	0.47	7.7	6.7	1.15	9
<i>S. brimblecombei</i>	127387	D02	—	22.6	10.4	0.46	7.1	7.3	0.97	12
<i>S. brimblecombei</i>	127388	D02	38.8	38.8	17.4	0.45	13.3	12.3	1.08	11
<i>S. brimblecombei</i>	127389	A05	47.8	47.8	20.0	0.42	15.8	15.8	1.00	9
<i>S. brimblecombei</i>	127390	D02	40.0	40.0	16.8	0.42	13.8	13.6	1.01	11
<i>S. brimblecombei</i>	127391	D02	—	36.7	17.0	0.46	12.3	11.8	1.04	11
<i>S. brimblecombei</i>	127392	A04	31.5	30.2	13.8	0.46	10.3	9.5	1.08	9
<i>S. brimblecombei</i>	127393	D01	—	19.8	8.3	0.42	7.1	6.2	1.15	11
<i>S. brimblecombei</i>	127394	D03	—	28.9	13.2	0.46	10.1	9.1	1.11	10
<i>S. brimblecombei</i>	127395	D02	49.1	46.5	22.9	0.49	15.8	13.8	1.14	9
<i>S. brimblecombei</i>	127396	I1	—	17.0	8.5	0.50	6.0	5.0	1.20	8
<i>S. brimblecombei</i>	127397	A11	—	21.5	10.7	0.50	6.7	6.0	1.12	9
<i>S. brimblecombei</i>	127398	A11	29.3	25.1	11.8	0.47	9.1	7.7	1.18	10
<i>S. brimblecombei</i>	127399	D02	—	30.7	13.9	0.45	10.5	10.1	1.04	12
<i>S. brimblecombei</i>	127400	B02	107.3	107.0	42.2	0.39	31.5	36.2	0.87	12
<i>S. brimblecombei</i>	127401	B01	—	ca. 21	10.7	0.50	7.3	6.1	1.20	9
<i>S. brimblecombei</i>	127402	D02	—	ca. 227	87.6	0.39	ca. 95	86.0	1.10	—
<i>S. brimblecombei</i>	127403	A12	19.3	19.3	8.3	0.43	7.6	5.8	1.31	9
<i>S. brimblecombei</i>	127404	A06	—	47.9	22.3	0.47	17.3	14.2	1.22	—
<b><i>S. chilcotinensis</i></b>	<b>127406</b>	<b>B01</b>	<b>—</b>	<b>ca. 67</b>	<b>31.3</b>	<b>0.47</b>	<b>—</b>	<b>ca. 21</b>	<b>—</b>	<b>10</b>
<i>S. chilcotinensis</i>	127405	A13	ca. 92	ca. 92	39.5	0.43	26.4	29.4	0.90	—
<i>S. chilcotinensis</i>	127407	A03	21.9	21.5	10.2	0.47	7.4	6.2	1.19	9
<i>S. chilcotinensis</i>	127408	A02	29.8	29.8	14.1	0.47	10.5	9.3	1.13	8
<i>S. chilcotinensis</i>	127409	A09	23.4	22.9	11.2	0.49	8.2	6.6	1.24	10
<i>S. chilcotinensis</i>	127410	A04	31.7	29.7	14.0	0.47	12.2	9.0	1.36	8
<i>S. chilcotinensis</i>	127411	B03	50.6	50.0	25.4	0.51	15.2	13.3	1.14	10
<i>S. chilcotinensis</i>	127412	A06	—	29.2	15.3	0.52	10.4	8.0	1.30	10
<i>S. chilcotinensis</i>	127413	A03	—	ca. 53	ca. 26	0.49	16.6	16.1	1.03	10
<b><i>S. senillilevis</i></b>	<b>127414</b>	<b>D02</b>	<b>ca. 163</b>	<b>ca. 163</b>	<b>62.0</b>	<b>0.38</b>	<b>ca. 64</b>	<b>62.5</b>	<b>1.02</b>	<b>—</b>

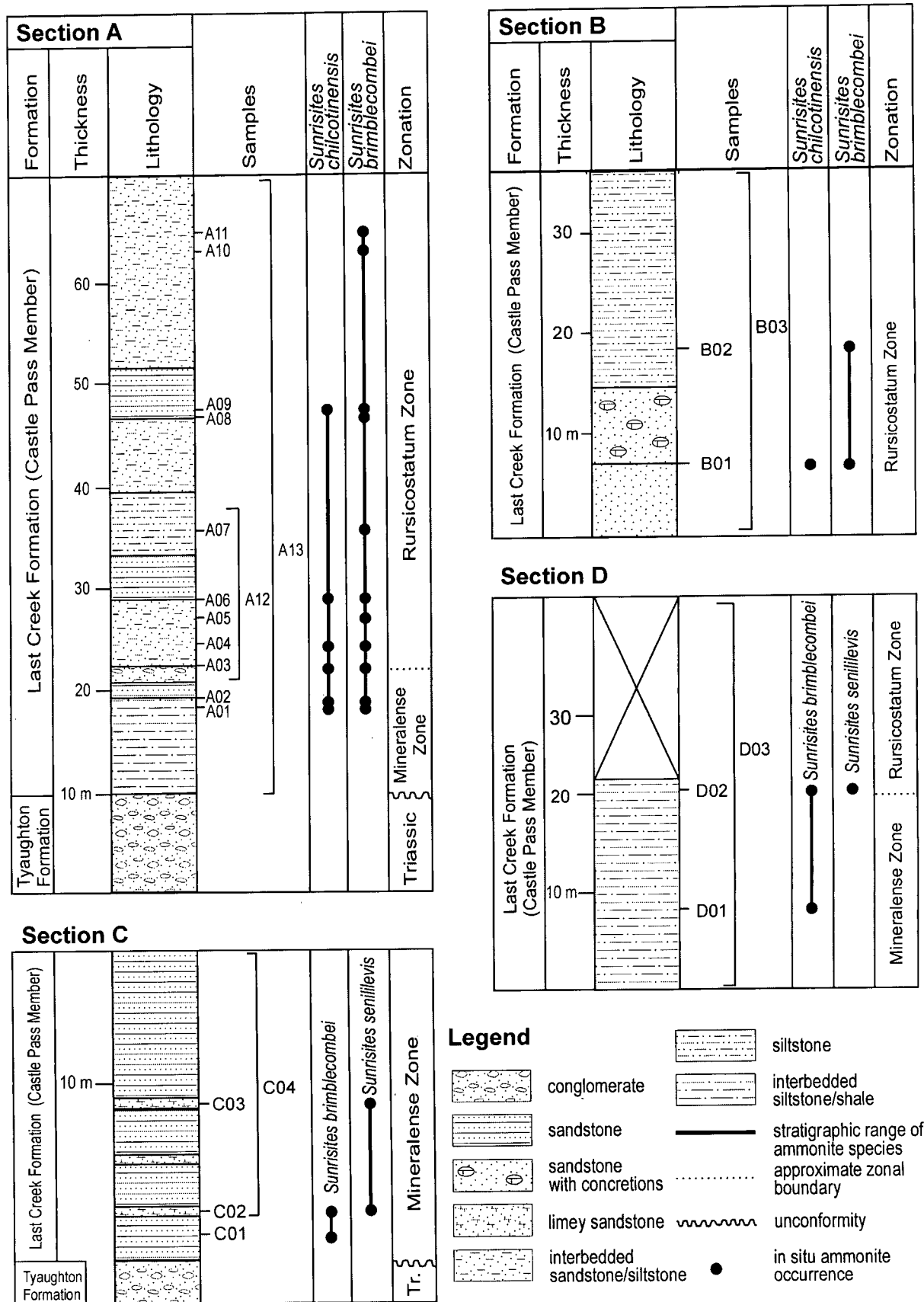
**Table 6.1.** Locality information and measurements for *Sunrisites* species from Taseko Lakes. Locality information is indicated by section letter and locality number or isolated locality number. A = section A, B = section B, D = section D, I = isolated locality. Measurements include maximum shell diameter (DMAX), shell diameter (D), umbilical diameter at shell diameter D (UD), umbilical diameter/shell diameter (U), whorl width at shell diameter D (WW), whorl height at shell diameter D (WH), whorl width/whorl height (WWWH), and primary ribs per half whorl at shell diameter D (PRHW). Holotypes of each species are indicated in bold.

AGE	NORTH AMERICAN ZONES (Taylor <i>et al.</i> 2001; Longridge <i>et al.</i> 2006)	SOUTH AMERICAN ZONES (Hillebrandt 2000a)	NORTHWEST EUROPEAN ZONES (Donovan <i>in</i> Dean <i>et al.</i> 1961)	ALPINE ZONES (Wähner 1882-1898; Page 2003)
LATE HETTANGIAN	Rursicostatum Zone	Arcuaturn Horizon	Angulata Zone	Marmoreum Zone
	Mineralense Zone	Canadensis Zone		
	Morganense Zone	Peruvianus Zone		Megastoma Zone
MIDDLE HETTANGIAN	Sunrisensis Zone		Liasicus Zone	

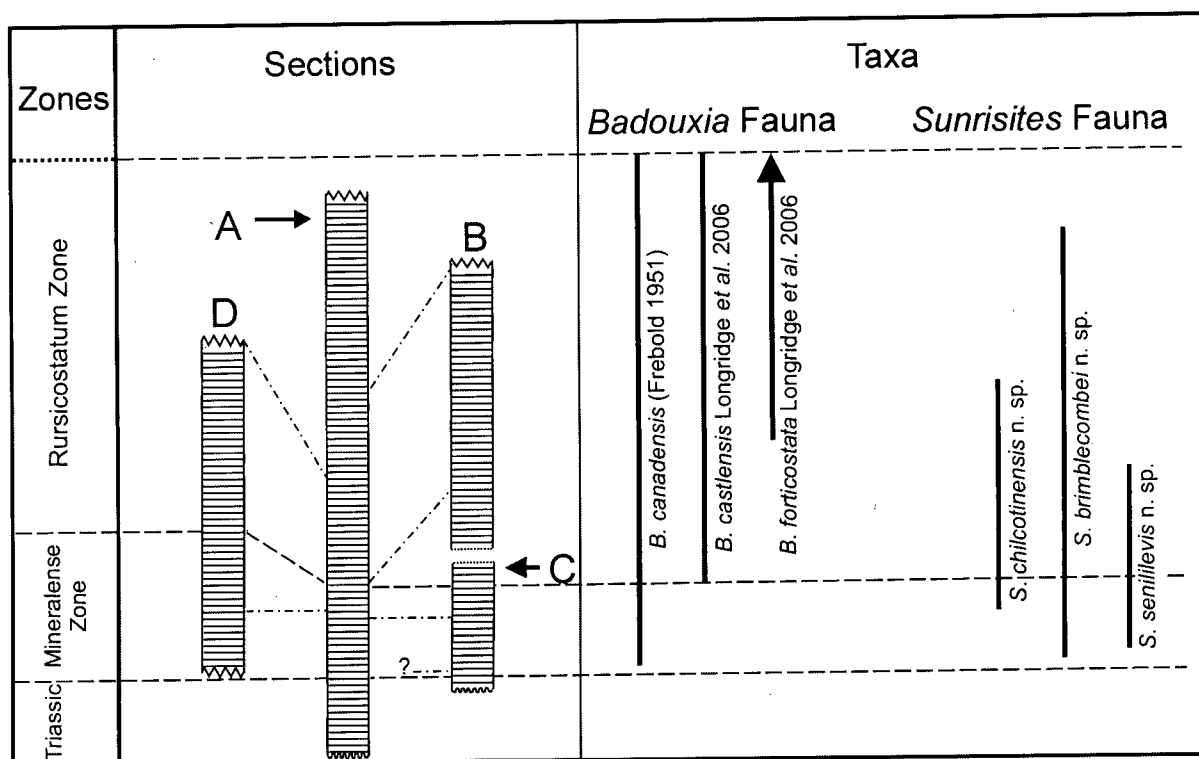
**Figure 6.1.** Standard zonation for the Hettangian, showing correlation of North American zones with South America, the Alps, and northwest Europe.



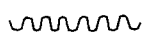
**Figure 6.2.** Localities of sections and isolated outcrops yielding *Sunrisites* Guex, 1980 in Taseko Lakes.



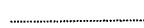
**Figure 6.3.** Lithostratigraphy and fossil localities of sections A-D at Castle Pass, Taseko Lakes.



limit of section is a fault



limit of section is an unconformity



limit of section is covered

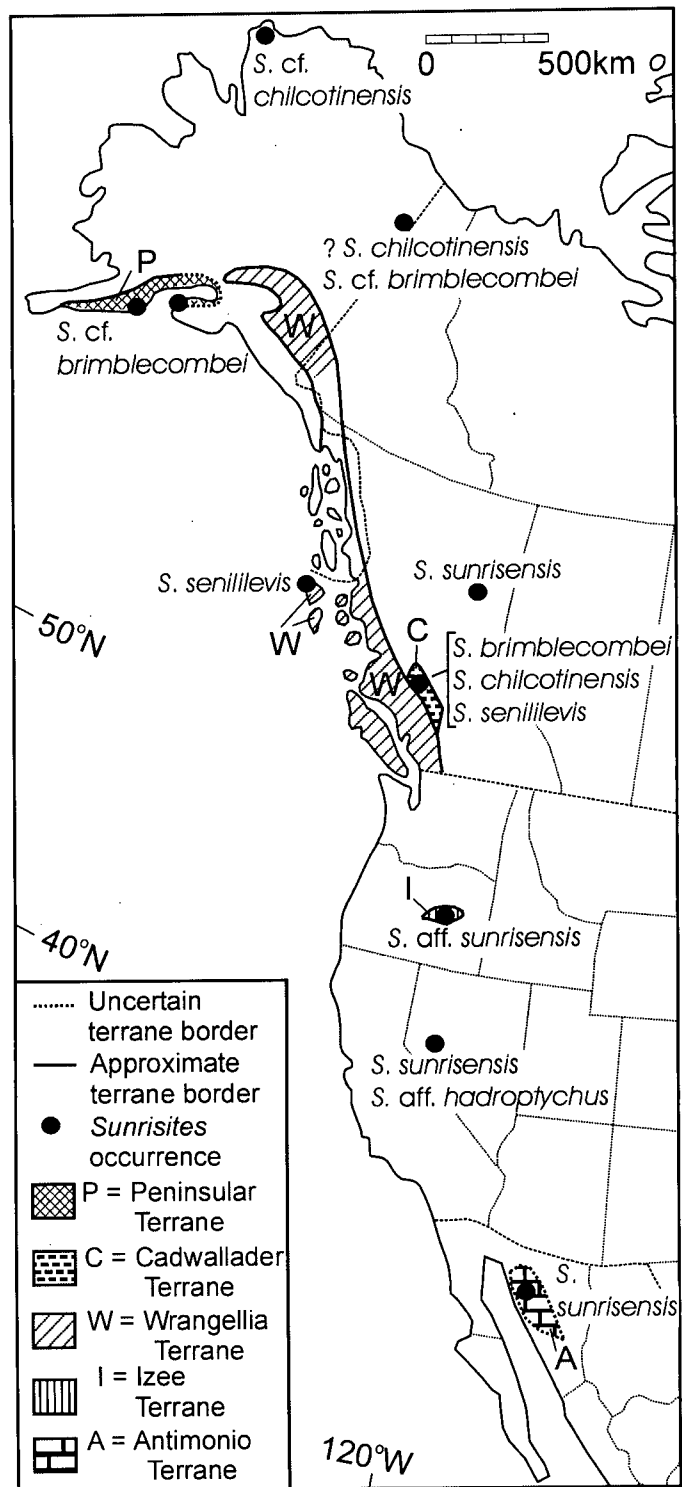


approximate boundaries of zones

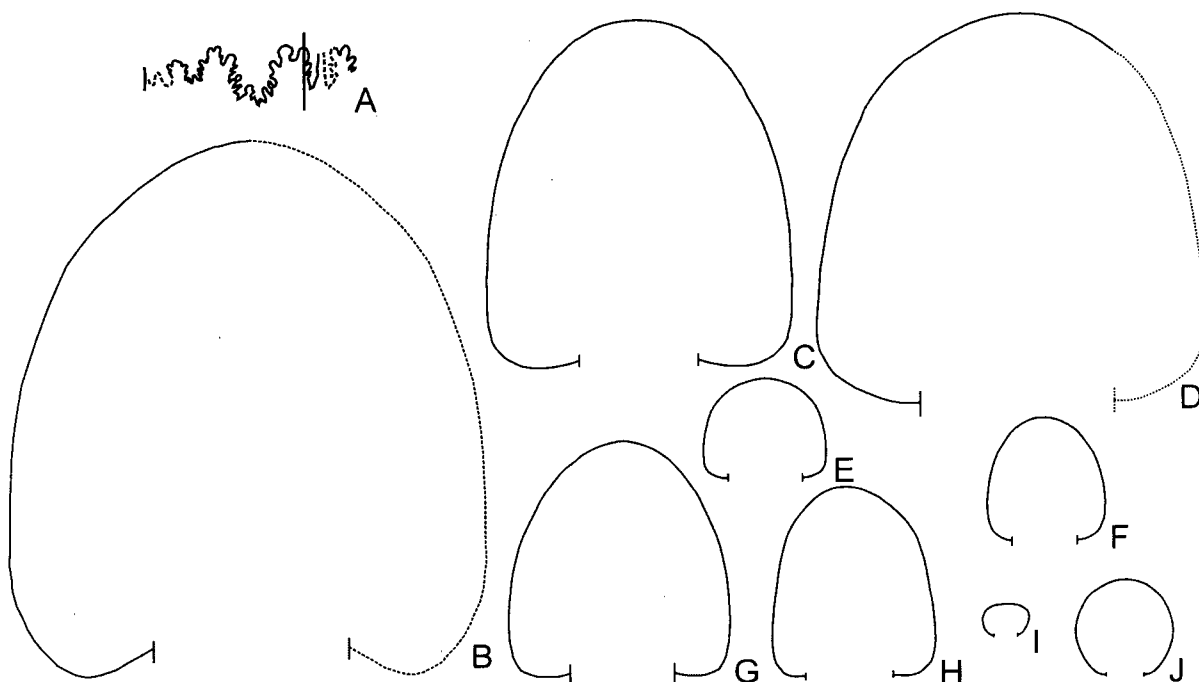


approximate correlations of sections based on faunas

**Figure 6.4.** Approximate correlation of stratigraphic sections from Taseko Lakes showing the ranges of *Badouxia* Guex and Taylor, 1976 and *Sunrisites* species.



**Figure 6.5.** Map of western North America showing terranes that were allochthonous to the craton during the Hettangian (modified from Taylor *et al.* 1984; Aberhan 1999).



**Figure 6.6.** Traces of septal suture and whorl shape cross-sections for species of *Sunrisites* from Taseko Lakes, British Columbia. Where possible, potential microconch [m] and macroconch [M] forms are noted. All figures  $\times 0.9$  unless otherwise indicated.

Figure A, *Sunrisites brimblecombei* sp. nov., GSC 127388, WH = 7.4 mm, paratype; GSC loc. no. 143327, Sec. D, loc. 02,  $\times 1.8$ .

Figures B-C, *Sunrisites brimblecombei* sp. nov., [M], GSC 127402 (Plate 6.1.1-6.2.2), paratype; GSC loc. no. 143327, Sec. D, loc. 02.

Figure D, *Sunrisites senililevis* sp. nov., [M], GSC 127414 (Plate 6.2.1-6.2.2), holotype; GSC loc. no. Sec. D, loc. 02.

Figure E, *Sunrisites brimblecombei* sp. nov., [m], GSC 127404 (Plate 6.1.8-6.1.9), paratype; GSC loc. no. 208993, Sec. A, loc. 06.

Figure F, *Sunrisites brimblecombei* sp. nov., [m], GSC 127384 (Plate 6.1.3-6.1.4), paratype; GSC loc. no. 175372, Sec. D, loc. 02.

Figure G, *Sunrisites brimblecombei* sp. nov., [M], GSC 127400, paratype; GSC loc. no. 208958, Sec. B, loc. 02.

Figure H, *Sunrisites chilcotinensis* sp. nov., [M], GSC 127405 (Plate 6.1.10-6.1.12), paratype; GSC loc. no. 143295, Sec. A, talus.

Figures I-J, *Sunrisites chilcotinensis* sp. nov., GSC 127413 (Plate 6.2.6, 6.2.11), paratype; GSC loc. no. 143319, Sec. A, loc. 03.

**Plate 6.1.** *Sunrisites* from Taseko Lakes, British Columbia. All specimens from the Rursicostatum Zone, Last Creek Formation. Except for 1-2 and 12 all figures are  $\times 0.9$ . Arrow marks last preserved septal suture. Where possible, probable microconch [m] and macroconch [M] status are noted.

Figures 1-2, *Sunrisites brimblecombei* sp. nov., [M], GSC 127402, paratype, GSC loc. no. C-143327, Sec. D, loc. 02,  $\times 0.36$ .

Figures 3-4, *Sunrisites brimblecombei* sp. nov., [m], GSC 127384, paratype, GSC loc. no. C-175372, Sec. D, loc. 02.

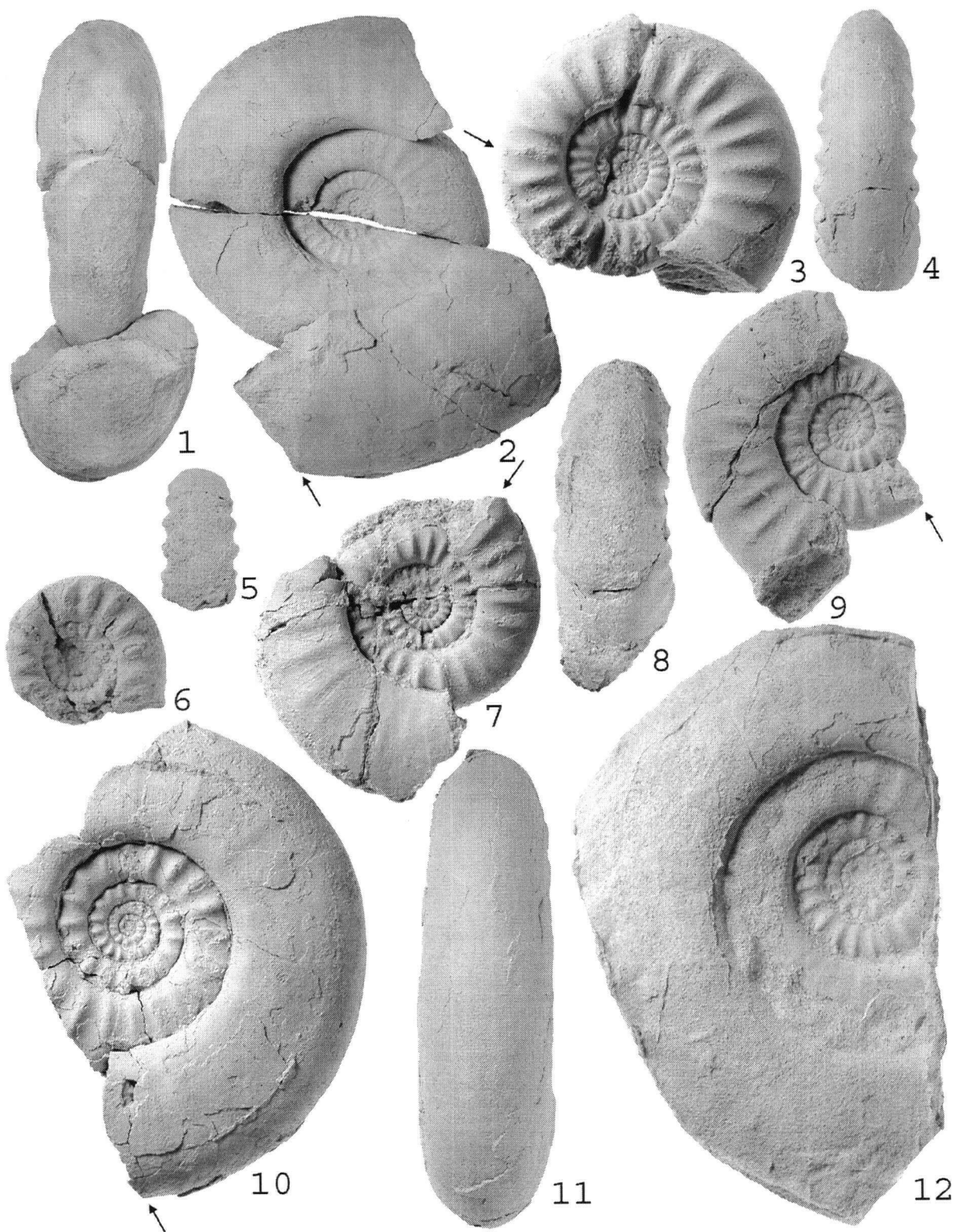
Figures 5-6, *Sunrisites chilcotinensis* sp. nov., GSC 127410, paratype; GSC loc. no. 177633, Sec. B, loc. 01.

Figure 7, [M], *Sunrisites brimblecombei* sp. nov., GSC 127385, paratype, GSC loc. no. C-208958, Sec. B, loc. 02.

Figures 8-9, *Sunrisites brimblecombei* sp. nov., [m], GSC 127404, paratype, GSC loc. no. C-208993, Sec. A, loc. 06.

Figures 10-12, *Sunrisites chilcotinensis* sp. nov., [M], GSC 127405, paratype, GSC loc. no. C-143295, Sec. A, talus. 10-11, preserved inner whorls, 12, latex peel of entire specimen,  $\times 0.72$ .





**Plate 6.2.** *Sunrisites* from Taseko Lakes, British Columbia. All specimens from the Rursicostatum Zone, Last Creek Formation. All figures are  $\times 0.9$ . Arrow marks last preserved septal suture. Where possible, potential microconch [m] and macroconch [M] forms are noted.

Figures 1-2, *Sunrisites senililevis* sp. nov., [M], GSC 127414, holotype, GSC loc. no. C-143327, Sec. D, loc. 02;

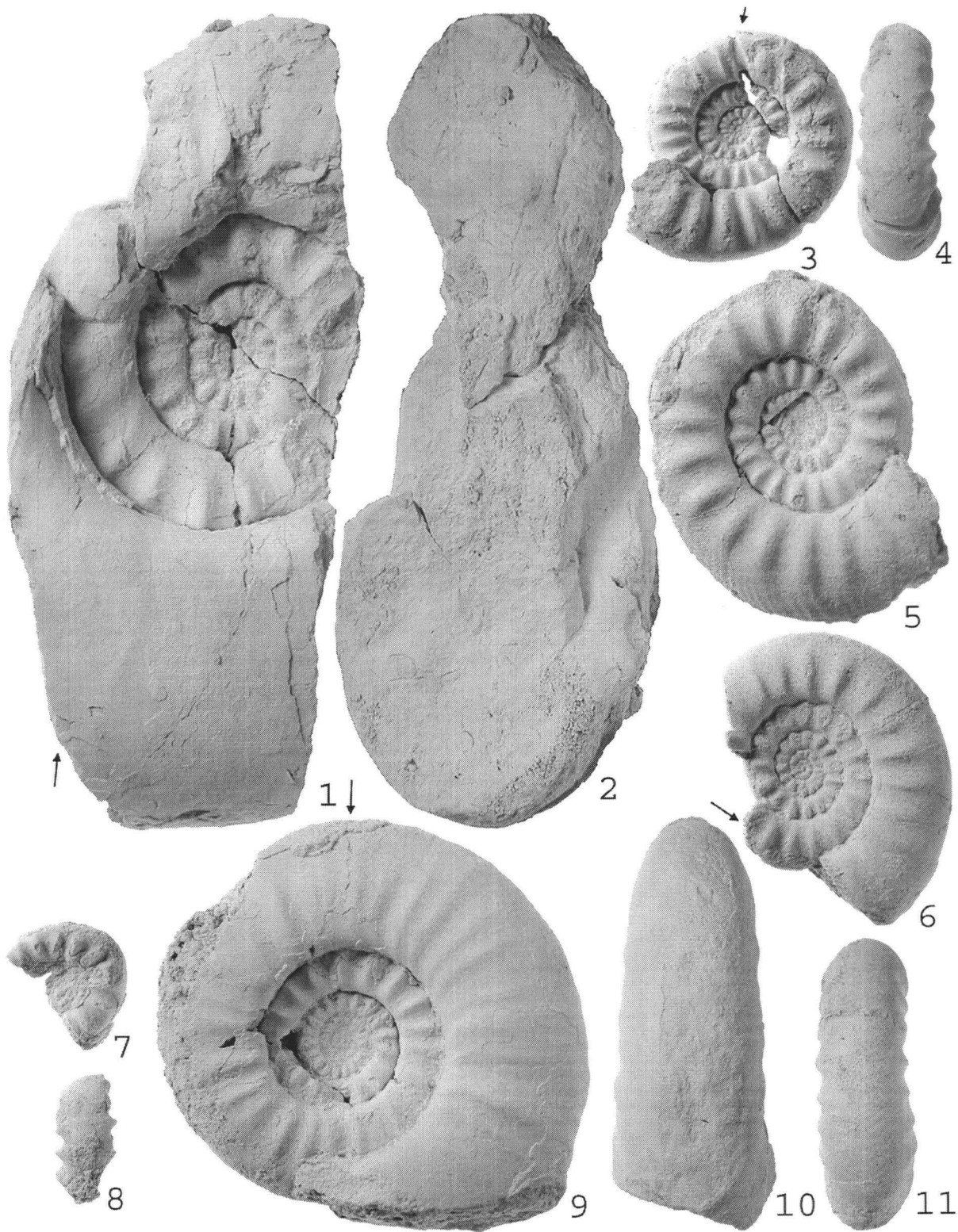
Figures 3-4, *Sunrisites brimblecombei* sp. nov., [m], GSC 127395, paratype, GSC loc. no. C-175372, Sec. D, loc. 02;

Figure 5, *Sunrisites chilcotinensis* sp. nov., [m], GSC 127406, holotype, GSC loc. no. 117233, Sec. B, loc. 01;

Figures 6, 11, *Sunrisites chilcotinensis* sp. nov., GSC 127413, paratype, GSC loc. no. 143319, Sec. A, loc. 03.

Figures 7-8, *Sunrisites senililevis* sp. nov., GSC 127415, paratype, GSC loc. no. C-143322, Sec. D, talus.

Figures 9-10, *Sunrisites brimblecombei* sp. nov., [M], GSC 127383, holotype, GSC loc. no. C-117233, Sec. B, loc. 01.



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# 7 LATE HETTANGIAN (EARLY JURASSIC) AMMONITES FROM TASEKO LAKES, BRITISH COLUMBIA, CANADA<sup>1</sup>

## 7.1 Introduction

Taseko Lakes (Fig. 7.1) has yielded the best preserved and most diverse collection of late Hettangian ammonites yet discovered in British Columbia (BC). Early studies of the fauna were undertaken by Frebold (1951, 1967). At that time, eastern Pacific ammonite faunas were poorly understood and species were frequently grouped into established northwest European taxa. Since then, knowledge of eastern Pacific Hettangian ammonite faunas has improved considerably. Detailed systematic studies have been completed on faunas from localities in other areas of BC, Alberta, Alaska, Oregon, Nevada, Mexico and South America (e.g., Imlay 1981; Guex 1980, 1995; Hillebrandt 1981, 1988, 1990, 1994, 2000*a-d*; Smith and Tipper 1986; Riccardi *et al.* 1991; Pálffy *et al.* 1994; Jakobs and Pálffy 1994; Taylor 1998; Pálffy *et al.* 1999; Taylor and Guex 2002; Hall *et al.* 2000; Hall and Pitaru 2004). These studies demonstrate that Early Jurassic eastern Pacific ammonites had strong Tethyan affinities as well as a high degree of endemism (Guex 1980, 1995; Taylor *et al.* 1984; Smith *et al.* 1988; Jakobs *et al.* 1994; Pálffy *et al.* 1994). Frebold's early studies were also hampered because they were based on small collections which limited understanding of the diversity of the fauna and variation within populations. However, recent mapping has greatly improved our understanding of the geology of Taseko Lakes (Schiarizza *et al.* 1997; Smith *et al.* 1998; Umhoefer and Tipper 1998) and encouraged further collecting that has dramatically increased the size of the sample.

A study of the ammonite fauna from Taseko Lakes is of interest for two principal reasons. Firstly, the data are important for increasing the precision of the late Hettangian portion of the

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<sup>1</sup> A version of this chapter has been accepted for publication. Longridge, L.M., Smith, P.L. and Tipper, H.W. in press. Late Hettangian (Early Jurassic) ammonites from Taseko Lakes, British Columbia, Canada. *Palaeontology*.

North American Zonation (Fig. 7.2). Due to the principally Tethyan or endemic nature of Early Jurassic ammonites in the eastern Pacific, a separate zonation for the Hettangian and Sinemurian of the Western Cordillera of North America has been established by Taylor *et al.* (2001). Except for information available from the early studies by Frebold (1951, 1967), the only Taseko Lakes taxa included in the North American Zonation of Taylor *et al.* (2001) were species of *Angulaticeras* studied by Smith and Tipper (2000). Since then, Longridge *et al.* (2006) made significant changes to the zonation of the late Hettangian and early Sinemurian based on a detailed study of the *Badouxia* fauna from Taseko Lakes (Fig. 7.2). An additional taxonomic study was recently completed on the late Hettangian ammonite *Sunrisites* (Longridge *et al.* in press) and this information has not yet been included within the zonation. The systematics of the remaining ammonite fauna from Taseko Lakes are presented here. A comprehensive study of this material is important because the exceptional quality and diversity of the fauna provide important data for updating the North American Zonation, making it more comprehensive and more widely applicable, especially in Canada.

Secondly, the Taseko Lakes fauna can improve Hettangian correlations within North America as well as between North America and the rest of the world. Northwest European ammonite successions (e.g., Dean *et al.* 1961; Mouterde and Corna 1997; Page 2003) are considered the primary standard for Early Jurassic biochronology (Callomon 1984). However, in northwest Europe, the turnover from schlotheimiid dominated faunas in the late Hettangian to arietitid dominated faunas in the early Sinemurian is sharp (e.g., Dean *et al.* 1961; Bloos 1994; Bloos and Page 2002). In other areas, by contrast, these faunas are not so mutually exclusive and the transition is much more gradual. This makes correlations between northwest Europe and other areas difficult (e.g., Bloos 1994; Bloos and Page 2000, 2002). Correlations are further impeded by endemism and provincialism. The Taseko Lakes fauna addresses these problems because it contains many taxa that are common throughout the eastern Pacific as well as several

cosmopolitan taxa that make intercontinental correlation possible. Correlation between North America and other areas is of particular significance in that the interbedded volcanic and fossiliferous marine rocks in North America permit the calibration of geochronological and biochronological time scales (Pálffy *et al.* 1999, 2000). This paper highlights correlations between the late Hettangian fauna in Taseko Lakes and contemporaneous faunas in other areas of North America, South America, New Zealand, western and eastern Tethys, and northwest Europe.

## **7.2 Geological Setting**

The study area lies within the Taseko Lakes map area (Energy, Mines and Resources Canada, map sheets 92-O/2, O/3) on the eastern margin of the southern Coast Mountains (Fig. 7.1). The fauna described herein is found within the Castle Pass Member of the Last Creek Formation which disconformably overlies the Triassic Tyaughton Formation and is interpreted as a transgressive sequence of nearshore to inner shelf deposits (Umhoefer and Tipper 1998). The unit is extensively faulted and folded although generally unmetamorphosed. The Castle Pass Member is dominated by interbeds of volcanic-pebble conglomerate and coarse to medium-grained sandstone. *In situ* ammonite specimens from the upper Hettangian Mineralense and Rursicostatum zones (Fig. 7.2) were collected from the four sections and four isolated localities described below.

### **7.2.1 Stratigraphic sections**

The Castle Pass area includes four sections, A to D, yielding late Hettangian ammonites. Section C and the lower portion of sections A and D contain material from the Mineralense Zone whereas section B and the upper portion of sections A and D contain material from the Rursicostatum Zone. The tops of all four sections are faulted. Figure 7.1 shows the location of

the sections and Figures 7.3-7.6 show details of the stratigraphy and collection localities for each section. Figure 7.7 shows approximate correlations between sections A-D.

### **7.2.2 Isolated localities**

Collections from isolated localities 1 and 4 are from the Rursicostatum Zone whereas locality 3 is from the Mineralense Zone. The exact zonal level of the talus specimen collected at locality 2 is uncertain although it is probably from the Mineralense or Rursicostatum Zone. Figure 7.1 shows the location of each isolated locality.

Detailed data for sections A-D and localities 1-4 are deposited in the Appendix H. This information includes a brief geographical description of each site including latitude and longitude as well as Geological Survey of Canada (GSC) numbers for each location.

## **7.3 Systematic Paleontology**

The Taseko Lakes material is generally very well preserved. Ammonites are usually uncompressed and frequently display septal suture lines. Figure 7.8 shows the ranges of ammonite forms found within the Mineralense and Rursicostatum zones in Taseko Lakes. Abbreviations and measurements follow Smith (1986) and include shell diameter (D), umbilical diameter (UD), whorl width (WW), whorl height (WH), umbilical diameter as a ratio of shell diameter (U), ratio of the whorl width to the whorl height (WWWH) and primary ribs per half whorl (PRHW). Graphical plots of several of these parameters are shown below and include all measurable specimens of each species collected. A record of the exact measurements of each specimen is deposited in the Appendix I. All measured and figured specimens are deposited in the type collection of the GSC in Ottawa.

**Suborder PHYLLOCERATINA Arkell, 1950**

**Superfamily PHYLLOCERATOIDEA Zittel, 1884**

**Family PHYLLOCERATIDAE Zittel, 1884**

**Genus PHYLLOCERAS Suess, 1865**

TYPE SPECIES: *Ammonites heterophyllus* Sowerby, 1820

***Phylloceras cf. asperaense* Hillebrandt, 2000b**

Plate 7.1, figures 26-27; Figures 7.9B- 7.10B

cf. 2000b *Phylloceras asperaense* Hillebrandt, p. 140, pl. 1, figs 4-7; text-fig. 27c-e.

MATERIAL AND MEASUREMENTS: One specimen, GSC 127416. Measurements of volution and whorl shape are presented in Figure 7.11A-B.

DESCRIPTION: Compressed form, evolute for genus. Whorl cross-section high oval. Umbilical wall high and upright. Umbilical shoulder rounded. Flanks weakly convex with largest width at midflank. Flanks smooth. Venter smooth and broad. Portions of suture line visible including first lateral lobe and first and second lateral saddle (Fig. 7.10B). Saddles triphyllic becoming progressively narrower with increasing whorl height.

REMARKS: Although the small size of the specimen hinders a confident identification, it most closely resembles *P. asperaense* in volution and whorl shape. In addition, the suture line of the two forms is nearly identical at similar whorl height.

OCCURRENCE: Section D, Mineralense Zone.

**Family JURAPHYLLITIDAE Arkell, 1950**

**Genus NEVADAPHYLLITES Guex, 1980**



TYPE SPECIES: *Nevadaphyllites compressus* Guex, 1980

***Nevadaphyllites psilomorphus* (Neumayr, 1879)**

Plate 7.1, figures 1-2, 5-6; Figures 7.9A-7.10A

1879 *Phylloceras psilomorphum* Neumayr, p. 21, pl. 2, fig. 4.

1952 *Phylloceras psilomorphum* Neumayr; Lange, p. 82, pl. 1, fig. 1; text-fig. 1.

1995 *Phylloceras psilomorphum* Neumayr; Guex, p. 16, pl. 21, figs 5-6, 11-12.

? 1995 *Phylloceras* sp.; Dommergues *et al.*, p. 169, pl. 1, fig. 3.

1999 *Phylloceras psilomorphum* Neumayr; Böhm *et al.*, p. 185, pl. 24, fig. 4; text-fig.

36.

? 2004 *Phylloceras psilomorphum* Neumayr; Stevens, p. 14, pl. 2, fig. 1.

cf. 2007 *Nevadaphyllites* cf. *psilomorphus* (Neumayr); Yin *et al.*, pl. 1, figs 31-32.

MATERIAL AND MEASUREMENTS: Three specimens (GSC 127417 – 127419).

Measurements of volution and whorl shape are presented in Figure 7.11A-B.

DESCRIPTION: Involute and compressed. Umbilical wall rounded, umbilical shoulder gently rounded. GSC 127417 (Pl. 7.1, figs 1-2) and GSC 127419 have widest point of whorl near the umbilicus, flanks relatively flat and subparallel, sloping gently toward narrow but rounded venter. GSC 127418 (Pl. 7.1, figs 5-6) has weakly convex flanks and broader venter. Two smallest specimens show very weak, prorsiradiate, sigmoid striae on flanks. Surface of largest specimen poorly preserved; however, no ornamentation visible. First and second lateral saddles diphyllic with spatular folioles (Fig. 7.10A).

REMARKS: When Guex (1980) established *Nevadaphyllites* he attributed *Phylloceras psilomorphus* Neumayr to the genus. However, the generic assignment of the species

*psilomorphus* has been controversial. Rakús (1993, p. 947), Guex (1995, p. 13), Taylor (1998, p. 476), Kment, (2000, p. 190); Pálffy *et al.* (2001, p. 1048) and Yin *et al.* (2007) attributed the species to *Nevadaphyllites* while Guex (1995, p. 16), Böhm *et al.* (1999), Hillebrandt (2000b, p. 140), Taylor *et al.* (2001, p. 391) and Stevens (2004) attributed the species to *Phylloceras*. According to Guex (1980), *Nevadaphyllites* was defined in part by the presence of a strong peristomal constriction on the internal mould and ventral undulations on the shell of the adult body chamber. More recent work has shown that the constriction is absent in several mature specimens of *N. microumbilicatus* from Oregon (Taylor 1998) and Taseko Lakes (this paper) as well as in incomplete large specimens from the Northern Calcareous Alps (Rakús and Lobitzer 1993). Further, several forms of *Nevadaphyllites* including *N. glaberrimus* (Neumayr) lack ventral undulations on the body chamber. Thus, these characteristics cannot be used for reliably differentiating the two genera. *Phylloceras* is traditionally seen as a form with a gently rounded umbilical shoulder, weakly convex flanks and a rounded venter. *Nevadaphyllites* is more compressed, has a more defined umbilical shoulder and flatter subparallel flanks which taper toward a relatively narrow venter. The lack of agreement as to the generic rank of *psilomorphus* probably results from the variability evident in some of these characteristics. The lectotype of *N. psilomorphus* from Fonsjoch (Neumayr 1879, pl. 2, fig. 4), for example, has a gently rounded umbilical shoulder and subparallel flanks that taper toward a narrow venter while the cross-section of the same species also collected at Fonsjoch (Lange 1952, pl. 11, fig. 1, text-fig. 1.1) has a more distinct umbilical shoulder and weakly convex flanks. In addition, several other collections of *psilomorphus* that are often the same age and come from the same locality vary considerably in whorl proportion and breadth of the venter (Guex 1995; Böhm *et al.* 1999; this study). We attribute *psilomorphus* to *Nevadaphyllites* based principally on its compressed shell shape.

The Taseko Lakes material is very similar to the lectotype for the species (Neumayr 1879, pl. 2, fig. 4). *Nevadaphyllites psilomorphus* from Nevada (Guex 1995) may be slightly more evolute than the Taseko Lakes material and the *N. psilomorphus* from Salzburg (Böhm *et al.* 1999) is consistently more depressed. Due to poor preservation, the specimens of Dommergues *et al.* (1995) and Stevens (2004) are attributed with uncertainty to *N. psilomorphus*. This species also resembles *P. chilense* Hillebrandt but differs in having a narrower whorl cross-section.

OCCURRENCE: Section C, talus from Mineralense Zone; Sections A and B, Rursicostatum Zone.

***Nevadaphyllites aff. compressus* Guex, 1980**

Plate 7.1, figures 28-29; Figure 7.9C

? 1967 Ammonite gen. et sp. indet. 3., Frebold, p. 29, pl. 5, fig. 8.

aff. 1980 *Nevadaphyllites compressus* Guex, p. 135, pl. 1, fig. 7.

aff. 1995 *Nevadaphyllites compressus* Guex, p. 12, pl. 2, figs 7-12; text-fig. 8.

aff. 2000b *Nevadaphyllites compressus* Guex; Hillebrandt, p. 139, pl. 1, fig. 1.

MATERIAL AND MEASUREMENTS: One specimen (GSC 127420). Measurement of evolution is presented in Figure 7.11A.

DESCRIPTION: Evolute for genus. Innermost whorls depressed and subrounded. By 25 mm shell diameter, whorl cross-section strongly compressed. Umbilical wall and shoulder arch gently into subparallel flanks that taper slightly toward relatively narrow but rounded venter. Flanks virtually smooth although very faint sigmoidal striae visible in areas where shell well preserved. Venter smooth. At adoral end of specimen, a sigmoidal constriction occurs on internal mould that has its greatest inflection midflank and projects forward across venter. Constriction absent on shell. Suture line not visible.

REMARKS: *Nevadaphyllites* aff. *compressus* is most similar to *N. compressus* but differs in having no ventral undulations on the living chamber as well as a less convex umbilical wall and less defined umbilical shoulder. A specimen figured by Frebold (1967, pl. 5, fig. 8) from the Columbiae Zone is somewhat larger than *N. aff. compressus* and lacks a constriction but is otherwise very similar. Due to poor preservation, it is not possible to identify this form with confidence. *Nevadaphyllites* aff. *compressus* may represent a new species but our single specimen and its preservation does not warrant a new species designation at this time.

*Nevadaphyllites* aff. *compressus* is similar to *N. glaberrimus* in having no pronounced umbilical shoulder and no ventral undulations on the living chamber but differs in being significantly more evolute as well as possessing flexuous striae on the flanks. It differs from *N. aff. glaberrimus* of Rakús (1993) in lacking radiate plications on the phragmocone and body wall. *Nevadaphyllites* aff. *compressus* differs from *N. psilomorphus* in being more compressed, having a distinct constriction at the end of the body chamber, possessing flexuous striae in areas of the shell that are well preserved and having flanks that converge less strongly toward the venter. It is very similar to the illustrated cross-section of *Nevadaphyllites* sp. from the Northern Calcareous Alps (Rakús and Lobitzer 1993, text-fig. 10). The figured specimen of this material (Rakús and Lobitzer 1993, pl. 2, fig. 9) is very similar to the Taseko Lakes specimen but differs in having a much larger shell diameter and lacking the apertural constriction.

OCCURRENCE: Section B, Rursicostatum Zone.

***Nevadaphyllites microumbilicatus* Taylor, 1998**

Plate 7.1, figures 13-16; Figure 7.9D

1998 *Nevadaphyllites microumbilicatus* Taylor, p. 475, fig. 9.1-9.2, 9.5-9.6.

2004 *Nevadaphyllites pounamuus* Stevens, p. 15, pl. 2, fig. 2.

MATERIAL AND MEASUREMENTS: One measured specimen (GSC 127421) and two fragments (GSC 127422). Measurement of volution is presented in Figure 7.11A.

DESCRIPTION: Involute and strongly compressed. Moderately high umbilical wall, slightly undercut on inner whorls, becoming upright on body chamber. Umbilical shoulder distinct but rounded. Flanks subparallel, tapering slightly toward narrow, rounded venter. Flanks and venter smooth to shell diameters of approximately 30 mm. At larger shell diameters, weak striations occur that are strongly prorsiradiate on lower flank and rectiradiate on mid to upper flank. On ventro-lateral shoulder, ornament strengthens considerably into folds which project forward across venter. Suture line not well preserved; however, first and second lateral saddles diphyllid with spatular folioles. On mature specimen (GSC, 127421, Pl. 7.1, figs 15-16), slightly more than half of outer whorl is body chamber. Aperture is only preserved low to midflank. In addition to ventral ornament commonly present on the mature body chamber of juraphyllitids, significant uncoiling of umbilical seam precedes aperture.

REMARKS: The ventral folds on our entire specimen (Pl. 7.1, figs 15-16) are relatively coarse and similar to those figured on the paratype from Oregon (Taylor 1998, figs 9.5-9.6) whereas the ventral folds on the fragment (GSC 127422, Pl. 7.1, figs 13-14) are much finer and more similar to the holotype (Taylor 1998, figs 9.1-9.2).

*Nevadaphyllites microumbilicatus* shares many similarities with some species of *Partschiceras*.

Stevens (2004) erected a new species of *Nevadaphyllites* from New Zealand, *N. pounamuus*, which is here placed in synonymy with *N. microumbilicatus*. The new species designation was based principally on the strength of the chevrons on the venter. However, the strength of the chevrons on the New Zealand material is very similar to that seen on the paratype shown by Taylor (1998, figs 9.5-9.6) and similarly fall within the variability in strength seen within *N. microumbilicatus* from Taseko Lakes.

OCCURRENCE: Sections A and B, Rursicostatum Zone.

**Genus FERGUSONITES Guex, 1980**

TYPE SPECIES: *Fergusonites striatus* Guex, 1980

***Fergusonites hendersonae* sp. nov.**

Plate 7.1, figures 9-10, 32; Figure 7.9M

DERIVATION OF NAME: Named after Heidi Henderson of the Vancouver Paleontological Society who collected and subsequently donated many Hettangian specimens from Taseko Lakes to the GSC collections.

MATERIAL AND MEASUREMENTS: Two measured specimens. Measurements of volution and whorl shape are presented in Figure 7.11A-B.

HOLOTYPE: GSC 127423 (Pl. 7.1, figs 9-10; Figure 7.9M) from the Rursicostatum Zone, Castle Pass section A, level 06, Taseko Lakes.

PARATYPE: GSC 127424 (Pl. 7.1, fig. 32) from the Rursicostatum Zone, Castle Pass section A, level 07, Taseko Lakes.

DIAGNOSIS: Moderately involute form with undercut umbilical wall and sub-oval cross-section. Weak, sigmoidal ribbing on body chamber increases in strength up-flank projecting forward across venter. Bears weak, slightly sigmoid constrictions on ventral half of whorls.

DESCRIPTION: Moderately involute. Compressed with suboval whorl cross-section. Umbilical wall relatively high and weakly undercut. Umbilical shoulder rounded. Flanks gently convex with widest point of whorl low on midflank. Venter broad and rounded. Whorl surface smooth except on body chamber where flanks show evenly spaced, prorsiradiate, weakly sigmoid ribs

that are barely perceptible on lower flank, increasing in strength towards venter. Ribs strongest on top of upper flank and across venter where they project forward. On preserved half of outer whorl of paratype (Pl. 7.1, fig. 32), two weak constrictions visible. On outer whorl of holotype (Pl. 7.1, figs 9-10), ventral half of internal mould bears four weak, slightly sigmoid constrictions that strengthen across venter and follow trajectory of ribs. Constrictions also visible on shell. No flares present on either internal mould or shell. Suture line incompletely preserved. Saddles diphyllic with first lateral saddle broader and lower than second lateral saddle.

REMARKS: This material is placed in *Fergusonites* because of the oval whorl cross-section and the presence of weak, slightly sigmoid ribs mid to upper flank that continue across the venter. This species differs from *F. neumayri* (Rakús) in being more involute, having weak constrictions on the ventral portion of the flank and having a slightly undercut rather than a gently sloping umbilical wall. It differs from *F. striatus* in having several shallow constrictions on the ventral half of the flank and ribs that begin later in ontogeny and project forward across the venter.

This material resembles some species of *Calliphyloceras* in having weak, slightly sigmoid constrictions that begin midflank and strengthen as they cross the venter. It differs in being more evolute than most species of the genus, lacking lirae and having constrictions that are visible on the shell.

OCCURRENCE: Section A, Rursicostatum Zone.

### **Genus TOGATICERAS Rakús, 1993**

TYPE SPECIES: *Phylloceras togatum* (Neumayr, 1879).

*Togaticeras togatum* (Neumayr, 1879)

Plate 7.1, figures 21-22; Figures 7.9E, 7.10C

1879 *Phylloceras togatum* Neumayr, p. 21, pl. 1, figs 16-17.

1993 *Togaticeras togatum* (Neumayr); Rakús, p. 946, pl. 3, figs 6-7 (specimens of Neumayr refigured); text-fig. 15

cf. 1995 *Togaticeras* cf. *togatum* (Neumayr); Guex, p. 15, pl. 2, fig. 21.

1999 *Togaticeras togatum* (Neumayr); Rakús, p. 331, pl. 1, figs 2-5; text-fig. 2.

2000 *Togaticeras togatum* (Neumayr); Kment, p. 190, pl. 1, fig. 8.

MATERIAL AND MEASUREMENTS: One specimen (GSC 127425). Measurements of volution and whorl shape are presented in Figure 7.11A-B.

DESCRIPTION: Compressed, moderately evolute form. Suboval whorl cross-section. Umbilical wall weakly undercut. Umbilical shoulder distinct but rounded. Flanks weakly convex. Venter broad and rounded. Flanks and venter smooth aside from distinct, strongly prorsiradiate constrictions present on internal mould. Constrictions slightly sigmoid on flanks and project forward across venter. Outer whorl bears 9 constrictions ( $D = 32.6$  mm). Suture line similar to those figured by Rakús (1993, text-fig. 15; 1999, text-fig. 2). First lateral saddle shorter and wider than second lateral saddle. Saddles diphyllic with spatular folioles (Fig. 7.10C).

REMARKS: As discussed by Rakús (1993), this species differs from *T. stella* (Sowerby) in having a larger number of constrictions and a rounded umbilical wall and edge. It is more involute and has more convex flanks than *T. goisernense* Rakús.

OCCURRENCE: Section A, Mineralense Zone.

***Togaticeras* aff. *goisernense* Rakús, 1999**

Plate 7.1, figures 11-12

aff. 1999 *Togaticeras goisernense* Rakús, p. 331, pl. 1, fig. 1; text-fig. 3.



MATERIAL AND MEASUREMENTS: One moderately preserved specimen that may be slightly secondarily compressed (GSC 127426). Measurement of volution is presented in Figure 7.11A.

DESCRIPTION: Strongly compressed form. Evolute for genus. Whorl shape subrectangular with subparallel flanks which taper weakly toward venter. Umbilical wall low and rounded. Umbilical shoulder square and distinct. Outer whorl bears two strongly prorsiradiate constrictions on internal mould. Constrictions weakly sigmoid on flanks and project forward across venter. Adoral constriction much stronger where a swelling is preserved at the ventro-lateral shoulder on adapical side. Beyond this constriction, fine sigmoid lirae present on flanks and project forward over venter. Suture line not preserved.

REMARKS: *Togaticeras* aff. *goisernense* differs from *T. goisernense* from Austria in having constrictions which project forward across the venter and in having ventro-lateral swellings on the adapical side of the last constriction. This form is likely a new species; however, the state of preservation, quantity and size of the material does not warrant the establishment of a new species at this time. *Togaticeras* aff. *goisernense* differs from *T. stella* in being more evolute and having constrictions that are prorsiradiate as well as having flatter flanks and a lower umbilical wall. It differs from *T. togatum* in being significantly more evolute and having flatter, subparallel flanks and a smaller number of constrictions per whorl.

OCCURRENCE: Section A, Mineralense Zone.

**Suborder PSILOCERATINA Houša, 1965**

**Superfamily LYTOCERATOIDEA Neumayr, 1875**

**Family PLEUROACANTHITIDAE Hyatt, 1900**

## Genus EOLYTOCERAS Frebold, 1967

TYPE SPECIES: *Eolytoceras tasekoi* Frebold, 1967

REMARKS: Stevens (2004) mentioned that *E. chongi* Hillebrandt may be a junior synonym of *E. tasekoi*. We feel that *E. tasekoi*, *E. chongi* and *E. guexi* Taylor are very closely related forms. The shell diameter at which constrictions begin, in addition to the strength of the constrictions within single specimens of *Eolytoceras* is quite variable within these three species. However, as it is unclear at this time whether these represent specific variation or simply variability within a single species the three established species are maintained here.

### *Eolytoceras tasekoi* Frebold, 1967

Plate 7.1, figures 20, 23

1967 *Eolytoceras tasekoi* Frebold, p. 14, pl. 8, figs 1-2.

1970 *Eolytoceras tasekoi* Frebold; Wiedmann, p. 1007, pl. 7, fig. 4; text-figs 9C, 30D, 31 (Holotype refigured).

1977 *Psiloceras* cf. *P. erugatum* (Phillips); Frebold and Poulton, pl. 1, fig. 9.

1999 *Eolytoceras* cf. *tasekoi* Frebold; Pálffy *et al.*, p. 1543, fig. H.

2000 *Eolytoceras tasekoi* Frebold; Taylor, pl. 1, figs 1-10.

cf. 2000 *Eolytoceras* cf. *tasekoi* Frebold; Kment, p. 195, pl. 2, fig. 2.

aff. 2002a *Eolytoceras* aff. *tasekoi* Frebold; Meister *et al.*, p. 445, figs 3, 7.

? 2004 *Eolytoceras* cf. *tasekoi* Frebold; Stevens, p. 17, pl. 1, figs 1-5 only (*non* figs 7-8).

MATERIAL AND MEASUREMENTS: Nine measured specimens (GSC 20059, holotype of Frebold, 1967; GSC 20060, paratype of Frebold, 1967; GSC 127428-127435) and two

incomplete specimens. Measurements of volution and whorl shape are presented in Figure 7.11C-D.

DESCRIPTION: Moderately evolute. Whorl shape depressed and subrounded on innermost whorls becoming compressed and subrectangular to oval with increasing size. Umbilical wall upright on inner whorls with distinct but rounded umbilical shoulder. In some specimens, umbilical wall gently slopes into flank and umbilical shoulder becomes indistinct later in ontogeny. Flanks weakly to moderately convex with widest point of whorl low to mid-flank. Venter relatively smooth and rounded. Nucleus smooth in some specimens while in others distinct nodular ribs occur that are most developed on upper flank. Beyond approximately 8 mm, all specimens virtually smooth except for distinct prorsiradiate growth lines recognizable in well-preserved material. Growth lines begin on umbilical wall or low on flank, incline forward up flank with greatest strength on ventral shoulder, then project forward across venter. GSC 20059 (holotype), 20060 (paratype), 127427 (Pl. 7.1, fig. 20), 127428 (Pl. 7.1, fig. 23) and 127435 (not figured) show very weak constrictions. GSC 127428 bears small, distinct ventro-lateral nodes similar to material discussed in Taylor (2000). Largest specimen (GSC 127427) relatively poorly preserved but exhibits weak, irregularly spaced prorsiradiate ribs on outer whorl. Suture line can be weakly asymmetric with ventral lobe slightly offset from median line. As discussed and figured by Frebold (1967, p. 14, text-fig. 2), ventral lobe shorter than first lateral lobe and both first and second lateral lobes tripartite; saddle endings phylloid.

REMARKS: The style and strength of ribbing in some specimens of *E. tasekoi* are similar to *E. artemesia* Taylor from which it differs by being more involute. *Eolytoceras tasekoi* differs from *E. chongi*, *E. guexi* and *E. constrictum* n. sp. in bearing only very weak constrictions and lacking flares. It is more involute than *E. praecursor* Guex.

A form which Meister *et al.* (2002a) assigned to *E. aff. tasekoi* occurs in the Bucklandi Zone in Vietnam and Stevens (2004) identified *E. cf. tasekoi* in the late Hettangian in New Zealand. However, poor preservation of these forms precludes confident assignment at the species level. OCCURRENCE: Sections A, B and D and isolated localities 1 and 4, Rursicostatum Zone.

***Eolytoceras chongi* Hillebrandt, 2000d**

Plate 7.1, figures 19, 30-31; Figures 7.9F, 7.10G

1967 *Eolytoceras* cf. *E. tasekoi* Frebold, p. 15, pl. 6, fig. 1a-c.

1967 *Eolytoceras* sp. indet. 1, Frebold, p. 15, pl. 8, figs 3-4.

1967 *Eolytoceras* sp. indet. 3, Frebold, p. 16, pl. 6, fig. 3.

2000a *Eolytoceras* sp. Hillebrandt, pl. 2, figs 2-3.

2000d *Eolytoceras chongi* Hillebrandt, p. 86, pl. 11, figs 3-4; pl. 12, figs 2-8; text-fig.

2a-c.

aff. 2002a *Eolytoceras* aff. *guexi* Taylor; Meister *et al.*, p. 449, pl. 1, figs 1, 5-6, 8-11, 13-14.

MATERIAL AND MEASUREMENTS: Eleven measured specimens (GSC 20063-20065, 127436, 127438-127444) and many fragments (GSC 127437, 127445-127446). Measurements of volution and whorl shape are presented in Figure 7.11C-D.

DESCRIPTION: Moderately evolute. Innermost whorls depressed and subrounded becoming compressed and subrectangular to suboval with increasing size. Umbilical wall upright on inner whorls with distinct but rounded umbilical shoulder. In most specimens, umbilical wall gently slopes into flanks and umbilical shoulder becomes indistinct later in ontogeny. Flanks weakly to moderately convex with widest point of whorl low to mid-flank. Venter reasonably smooth and rounded. Nucleus smooth in some specimens while others show distinct nodular ribs. Beyond

approximately 8 mm shell diameter, all specimens smooth aside from distinct prorsiradial growth lines recognizable in well-preserved material. Growth lines begin on umbilical wall or low on flank, incline forward up flank with greatest strength on ventral shoulder, then project forward across venter. In addition, weak constrictions and occasional weak ribs occur on inner whorls. Beyond approximately 35 mm shell diameter constrictions more distinct on some specimens. Constrictions often accompanied by weak flare on adoral side. Constrictions can be slightly convex and flare often strongest low to mid-flank. On some specimens, weak irregularly spaced ribs occur between constrictions. GSC 127446 (not figured) shows increasing strength of growth lines on ventro-lateral shoulder in addition to two weak ventro-lateral nodes following a constriction. In addition, GSC 20062 (Frebold 1967, pl. 6, fig. 3) shows swellings on ventro-lateral area following constrictions. The fragment GSC 127437 (Pl. 7.1, fig. 19), has more distinct ventro-lateral nodes on adapical side of two preserved constrictions. Ventral lobe slightly offset from median line and shorter than first lateral lobe. Both first and second lateral lobes tripartite (Fig. 7.10G). Two large specimens, GSC 20063 (Frebold 1967, pl. 6, fig. 1) and 127436 (Pl. 7.1, figs 30-31), show egression after last septal suture and are probably mature macroconchs.

REMARKS: Although the Taseko Lakes material differs from some of the type material of *E. chongi* in that it does not possess such strongly developed ribs low to mid-flank, it is very similar in ornament and whorl proportion to the holotype and paratype 890305/1/54. As discussed by Hillebrandt (2000b), *E. chongi* is probably closely related to *E. guexi*. The strength of the constrictions in *E. chongi* from Taseko Lakes vary between that shown for *E. chongi* and *E. guexi*. However, the well-preserved Taseko Lakes material consistently differs from *E. guexi* in that ventro-lateral nodes are lacking altogether in the majority of the material and are very weak in the remaining specimens.

The Taseko Lakes material is similar to *E. aff. guexi* that occurs in early Sinemurian strata equivalent to the Bucklandi Zone in Vietnam (Meister *et al.* 2002a). The Vietnamese specimens are similar to *E. chongi* in that they lack ventro-lateral nodes and this character separates them from *E. guexi*. However, poor preservation prohibits a confident assignment for this form at the species level.

OCCURRENCE: Sections A, B and D, Rursicostatum Zone.

***Eolytoceras aff. guexi* Taylor, 1998**

Plate 7.1, figures 7-8, 17-18; Figure 7.9O

aff. 1998 *Eolytoceras guexi* Taylor, p. 478, fig. 9.10-9.12, 9.14.

MATERIAL AND MEASUREMENTS: Five measured specimens (GSC 127447-127448, 128981-128983); four under 20 mm shell diameter, one *c.* 28 mm shell diameter. Measurements of volution and whorl shape are presented in Figure 7.11C-D.

DESCRIPTION: Moderately evolute. Whorl shape depressed and subrounded on innermost whorls becoming compressed and subrectangular to oval with increasing size. Umbilical wall upright with distinct but rounded umbilical shoulder. Flanks moderately convex with widest point of whorl mid-flank. Nucleus bears distinct nodular ribs that change to growth lines beyond a shell diameter of *c.* 7.5 mm. Growth lines begin on umbilical wall or low on flank and project in a rectiradial direction up flanks and across venter until 15 mm shell diameter where they become prorsiradial and incline forward across venter. In addition, distinct constrictions visible on internal mould of 3 specimens beginning at shell diameters of 7-10 mm. Constrictions on largest specimen broad and prorsiradial by 15 mm and have only a very weak ventral projection. No flares associated with constrictions. Suture line asymmetric with ventral lobe

offset from median line. Ventral lobe shorter than first lateral lobe. Both first and second lateral lobes tripartite; saddle endings phylloid.

REMARKS: The current collection of *E. aff. guexi* is small and limited to material of small shell diameter. This form is most similar to *E. guexi* and *E. chongi* in whorl cross-section, volution and ornament. It differs in having clear constrictions at a significantly smaller shell diameter as well as strong, sharp ribs on the inner whorls. The Taseko material is considered to have an affinity with *E. guexi* because, as discussed by Taylor (1998), this form develops constrictions at smaller shell diameters than the ventro-lateral nodes. However, further collecting is required before this material can be assigned with confidence at the species level. *Eolytoceras aff. guexi* differs from *E. constrictum* sp. nov. in developing constrictions at smaller shell diameters and lacking flares adoral to constrictions. This material is similar to the inner whorls of *Analytoceras* but differs in having fewer, less regularly spaced constrictions that usually begin at larger shell diameters.

OCCURRENCE: Section C, Mineralense Zone; talus section D.

***Eolytoceras constrictum* sp. nov.**

Plate 7.1, figures 3-4, 24-25; Figures 7.9N, 7.10D

DERIVATION OF NAME: Named for the strong constrictions that are present early in development.

MATERIAL AND MEASUREMENTS: Six measured specimens, 2 incomplete specimens and 9 fragments. Measurements of volution and whorl shape are presented in Figure 7.11C-D.

HOLOTYPE: GSC 128985 (Pl. 7.1, figs 24-25; Fig. 7.10D) from the Rursicostatum Zone, Castle Pass section A, level 15, Taseko Lakes.

PARATYPES: GSC 128984 (Pl. 7.1, figs 3-4; Fig. 7.9N), talus; 128986, level 07; 128987, level 15; 128988, level 05; 128989, level 04; all specimens from the Rursicostatum Zone, Castle Pass, section A, Taseko Lakes.

DIAGNOSIS: Moderately evolute form. Smooth until shell diameters of 15 to 20 mm after which distinct prorsiradiate constrictions are immediately followed adorally on internal mould by coarse flares that often show greatest strength low to mid-flank. Growth lines sometimes visible between constrictions. Venter smooth and rounded. Saddle endings on septal suture more or less phylloid.

DESCRIPTION: Moderately evolute. Small form. Innermost whorls subrounded and depressed beyond which shell weakly depressed to moderately compressed showing a round to oval whorl shape. Umbilical wall slightly sloping with rounded umbilical shoulder that varies from gently sloping to distinct. Flanks weakly to moderately convex with widest point of whorl low to mid-flank. Venter relatively smooth and rounded. Nucleus in three specimens smooth while two specimens show weak ribs on nucleus. One specimen displays distinct nodular ribs most developed on upper flank. Beyond shell diameters of *c.* 5 mm, all specimens virtually smooth aside from weak prorsiradiate growth lines recognizable in well-preserved material. Growth lines begin on umbilical wall or low on flank, incline forward up flank projecting forward across venter. Between *c.* 15 and 20 mm shell diameter, strong constrictions develop which are followed on adoral side by distinct, narrow prorsiradiate and slightly sigmoid flares. Flares continue for full length of flank often showing greatest strength low on flank. GSC 128989 (not figured), shows a single weak ventro-lateral swelling at top of a flare. Septal suture may be weakly asymmetric with ventral lobe offset from median line. Both first and second lateral lobes tripartite; saddle endings phylloid (Fig. 7.10D).

REMARKS: This species differs from *E. guexi* and *E. chongi* in having stronger constrictions at similar shell diameters that are preceded by strong flares low to mid-flank. Specimen TUB



900929/1/3 of Hillebrandt (2000*d*, pl. 12, fig. 8) is similar to this new species. This species differs from species of *Analytoceras* by lacking constrictions on the innermost whorls and lacking conspicuous parabolic nodes.

OCCURRENCE: Section A, Rursicostatum Zone.

**Superfamily PSILOCERATOIDEA Hyatt, 1867**

**Family PSILOCERATIDAE Hyatt, 1867**

**Subfamily DISCAMPHICERATINAE Guex and Rakús, 1991**

**Genus DISCAMPHICERAS Spath, 1923*a***

TYPE SPECIES: *Aegoceras kammerkarensense* Gümbel, 1861

***Discamphiceras silberlingi* Guex, 1980**

Plate 7.2, figures 17-18, 20

1980 *Discamphiceras silberlingi* Guex, p. 132, pl. 2, fig. 2.

cf. 1981 *Discamphiceras* cf. *D. toxophorum* Wähner; Imlay, p. 29, pl.1, figs 3, 8-10.

? 1981 *Discamphiceras* cf. *D. toxophorum* Wähner; Imlay, p. 29, pl.1, fig. 4.

1995 *Discamphiceras silberlingi* Guex, p. 28, pl. 6, figs 4-5, 8-9; pl. 11, figs 1-2, 5-6, 9-12; pl. 12, figs 4, 7-8; pl. 14, figs 1-2, 7-14; pl. 15, figs 5-6; text-fig. 15.

cf. 1999 *Discamphiceras* cf. *silberlingi* Guex; Pálffy *et al.*, fig. 4A, 4D.

? 1999 *Discamphiceras* aff. *reissi* (Tilman); Pálffy *et al.*, fig. 4C.

non 2000 *Discamphiceras* cf. *silberlingi* Guex; Yin and Enay, pl. 2, figs 5-7.

cf. 2000 *Discamphiceras* cf. *silberlingi* Guex; Hall *et al.*, p. 1375, fig. 3.

MATERIAL AND MEASUREMENTS: Nine measured specimens (GSC 128992-129001), four incomplete specimens and one external mould. Measurements of volution, whorl shape and ribbing density are presented in Figure 7.12.

DESCRIPTION: Strongly compressed, moderately evolute to moderately involute form with subelliptical whorl cross-section. Inner whorls with low yet upright umbilical wall gradually increasing in height with increasing shell diameter. Umbilical shoulder distinct but rounded. Nearly flat flanks taper gently toward broad venter. All specimens where nucleus visible ornamented with nodes to shell diameters of 3.5 to 5 mm. Beyond this, ribs rectiradiate to weakly prorsiradiate. By shell diameters of 15 mm, gently flexuous, prorsiradiate ribs vary considerably in strength. Ribs occasionally begin on umbilical wall but more commonly begin on lowest flank having greatest strength midflank before fading on upper flank. At this point, ribs project forward, sometimes dividing into two ribs, before crossing venter in a forward-directed chevron. Suture line incomplete; asymmetric with ventral lobe offset from median line. First lateral lobe deeper than ventral lobe at a whorl height of 7 mm. Suture relatively simple.

REMARKS: *Discamphiceras silberlingi* is closely related to the South American forms *D. reissi* (Tilman) and *D. cf. calcimontanum* (Wöhner) of Hillebrandt (2000c). It differs from *D. ornatum* Taylor in having an umbilical wall that is not undercut and having weaker ribs on the inner whorls. It differs from *D. calcimontanum* in being more evolute and having flank ribs that are prorsiradiate rather than predominantly rursiradiate.

*Discamphiceras silberlingi* is currently recognized only from the middle and upper Hettangian of North America (Guex 1980, 1995; Taylor 1998; Pálffy *et al.* 1999; Hall *et al.* 2000; Taylor *et al.* 2001). Some of the material from Alaska is marked with a question mark in the synonymy list due to poor preservation which hampers certainty of identification. The material identified by Yin and Enay (2000) as *D. cf. silberlingi* was recently re-classified as *D. pleuronotum* (Yin *et al.* 2007).

OCCURRENCE: Sections A and C, Mineralense Zone; sections A and D, lower Rursicostatum Zone.

***Discamphiceras aff. silberlingi* Guex, 1980**

Plate 7.2, figures 7-8, 14; Figure 7.9P

MATERIAL AND MEASUREMENTS: One measured specimen (GSC 128991) and one external cast (GSC 128990). Measurements of volution, whorl shape and ribbing density are presented in Figure 7.12.

DESCRIPTION: Moderately involute. Strongly compressed with subelliptical whorl cross-section. Umbilical wall moderately high becoming undercut at shell diameters of 10 to 12 mm. Nearly flat flanks taper from lower flank toward venter. Nucleus preserved in only one specimen where nodes evident to shell diameter of 5 mm. Weak, closely spaced, prorsiradiate ribs appear on lower flank, have greatest strength midflank, before fading on upper quarter of flank where they divide into two or three ribs that continue across venter in forward directed chevron. Flank ribs are straight to shell diameters of approximately 15 mm then become sigmoid. At larger shell diameters, ornament varies on flanks between sigmoid ribbing and lines of growth which follow trajectory of ribs. Only one simple lateral saddle visible at small shell diameter (WH = 5.5 mm).

REMARKS: The ornament and volution of this form are similar to some specimens of *D. silberlingi* and *D. reissi* but it differs in having a strongly undercut umbilical wall. This form is probably a new species but the small size and limited number of specimens preclude establishing a new species at this time. The ribbing on the inner whorls is weaker and more closely spaced than in specimens of *D. silberlingi* from Taseko Lakes. *Discamphiceras aff. silberlingi* is similar to *D. ornatum* in having a strongly undercut umbilical wall but differs in

having significantly weaker ribs on the inner whorls. In addition, the ornament on the Taseko Lakes material is more variable in strength on the outer whorl, consisting partly of ribs and partly of growth lines that share the trajectory of the ribs. It differs from *D. kammerkaroides* Guex in being slightly more evolute and having a strongly undercut umbilical wall.

OCCURRENCE: Section D, Mineralense Zone.

***Discamphiceras* sp. nov.**

Plate 7.2, figures 11-13; Figures 7.9Q, 7.10H

MATERIAL AND MEASUREMENTS: Eleven measured specimens (GSC 129002-129012), one measured external cast, one incomplete specimen and three fragments. Measurements of volution, whorl shape and ribbing density are presented in Figure 7.12.

DESCRIPTION: Moderately involute to midvolute form. Compressed with subelliptical whorl cross-section. Umbilical wall upright on inner whorls. Umbilical shoulder distinct but rounded. Widest point of whorl on lower flank beyond which flanks taper gently toward rounded venter. On outer whorls umbilical wall gently sloping with an indistinct umbilical shoulder. Nucleus has nodes to shell diameters of 3.5 to 5 mm. Beyond this, weak ribs are relatively straight and weakly prorsiradiate across flanks before projecting forward on upper quarter of flank. Ribs cross venter in forward directed chevron. By about 10 mm, ribs become sigmoid on flanks and in some specimens, ribs divide into two on upper flank before crossing venter. At shell diameters of 15 to 20 mm, ribs fade and are very weak on the flanks. At this size venter may be smooth or may bear numerous faint striae which project forward in a bow. At shell diameters greater than 40 mm, flanks are usually smooth although very faint striae may be visible in some areas. Cross-section not known at larger diameters as the internal mould of single larger specimen is missing. Relatively simple suture line only visible on small specimens (WH = 7

mm) where ventral lobe clearly offset from median line and shallower than first lateral lobe (Fig. 7.10H).

REMARKS: The Taseko Lakes form is probably a new species but it cannot be formally established until better preserved material is collected. At this time, all measurable specimens are under 40 mm shell diameter. The only larger specimen available for study is an incomplete external mould. *Discamphiceras* sp. nov. is similar to *D. antiquum* Guex in the morphology of the umbilical shoulder, flanks, and venter. In addition some *D. antiquum* share the characteristic weak flank ribbing on the inner whorls which divides into two or three faint, forward directed striae across the venter. However, *Discamphiceras* sp. nov. differs in lacking constrictions and including more evolute and more depressed forms in addition to occurring much higher stratigraphically. It is also similar to *D. cf. antiquum* of Hillebrandt (2000c) but can be more evolute, less compressed, generally has weaker ribbing and is found significantly higher stratigraphically. *Discamphiceras* sp. nov. differs from *D. submesogenos* Guex and *D. mesogenos* (Wöhner) by being more evolute and having weak ribs on the inner whorls. The inner whorls are very similar to the more weakly ribbed forms of *D. reissi*, *D. cf. calcimontanum* of Hillebrandt (2000c) and *D. silberingi* (Guex 1995, pl. 6, figs 8-9). It differs from these three forms in being very weakly ribbed at shell diameters ranging from 15 to 20 mm and becoming virtually smooth beyond shell diameters of 40 mm. Finally, *Discamphiceras* sp. nov. differs from *D. pleurolisum* (Wöhner) in being more involute and having ribs that are prorsiradiate rather than rursiradiate on the inner whorls.

OCCURRENCE: Sections A and C, Mineralense Zone; sections A and D, lower Rursicostatum Zone.

#### Subfamily ALSATITINAE Spath, 1924

## Genus ALSATITES Haug, 1894

TYPE SPECIES: *Ammonites liasicus* D'Orbigny, 1844; by subsequent designation of Haug, 1894.

REMARKS: Guex (1987, 1995) places *Laqueoceras* in synonymy with *Alsatites* while Hillebrandt (2000*d*) maintains *Laqueoceras* as a separate genus based on the absence of a keel. The former approach is adopted here.

### *Alsatites* aff. *bipartitus* (Hillebrandt, 2000*d*)

Plate 7.3, figures 8-9, 12; Figure 7.9K

aff. 2000*d* *Laqueoceras bipartitum* Hillebrandt, p. 66, pl. 1, figs 1-30; table 1; text-fig. 1a-l.

cf. 2000*d* *Laqueoceras* cf. *bipartitum* Hillebrandt, p. 66, pl. 1, fig. 31.

MATERIAL AND MEASUREMENTS: Six measured specimens (GSC 129013-129018).

Measurements of volution, whorl shape and ribbing density are presented in Figure 7.13.

DESCRIPTION: Depressed, evolute form which becomes moderately involute at larger shell diameters. On inner whorls, cross-section subrectangular, umbilical wall gently sloping becoming more upright on outer whorls. Umbilical shoulder gently rounded. Flanks weakly to moderately convex with widest point of whorl mid to upper flank. Moderately strong, nodular ribs on inner whorls. Beyond *c.* 3 mm, weak, irregularly spaced ribs begin on umbilical shoulder becoming stronger as they progress up flank. Greatest height of ribs is mid to upper flank. Ribs fade on ventro-lateral shoulder. Orientation of ribs varies across flanks. Some ribs are concave beginning in a strongly rursiradiate direction on umbilical wall before projecting across flanks. Ribs have an asymmetric cross-section with steeper slopes on adapical side of rib and more gradual slopes on adoral side. Other ribs within same specimen virtually straight and project in a

rectiradiate direction across flanks. These ribs have a nearly symmetrical cross-section. On lower flank, some ribs divide into two parallel ribs that project up flank divided by shallow cleft. At ventro-lateral shoulder, ribs divide into two weak ribs or growth lines that cross venter in forwardly directed chevron. Occasionally, additional growth lines visible between ribs on upper flank and across venter. At larger shell diameters ( $D = 30$  mm), ribs become more widely spaced. Suture line not available.

REMARKS: At small shell diameters *A. aff. bipartitus* is very similar to *A. bipartitus* from South America. At larger shell diameters, *A. aff. bipartitus* differs in being slightly more involute in addition to having ribs that are more widely spaced. This form is similar to a fragment of *A. cf. bipartitus* figured by Hillebrandt (2000d, pl. 1, fig. 31) although poor preservation of the South American specimen prohibits a confident identification.

*Alsatites aff. bipartitus* from Taseko Lakes is very similar to *Sunrisites sunrisense* Guex as well as *A. pamlicoensis* Taylor in cross-section and volution but differs in having irregularly spaced ribs that vary from rectiradiate to concave. In addition, the ribs often bifurcate on the flanks.

OCCURRENCE: Sections A and C, Mineralense Zone.

***Alsatites* sp.**

Plate 7.3, figures 6-7, 13-16, 21; Figures 7.9L, 7.10F

MATERIAL AND MEASUREMENTS: One measured specimen (GSC 129019) and three fragments (GSC 129020-129021, 129066). Measurements of volution, whorl shape and ribbing density are presented in Figure 7.13.

DESCRIPTION: Weakly depressed form, relatively involute for genus. Whorl cross-section sub-rounded with widest point of whorl mid-flank. Nucleus bears nodes to *c.* 5 mm shell

diameter after which ribs fade until *c.* 7 mm diameter. Following this, ribs are generally weakly rursiradiate. Occasional ribs bifurcate on lowest flank. In these instances, adapical rib rursiradiate and adoral rib weakly prorsiradiate up flank. Beyond 12 mm shell diameter, stronger ribs begin on umbilical wall or base of flank, are straight to slightly concave and rectiradiate to weakly prorsiradiate on flanks. On uppermost flank, ribs divide into two where they fade and cross venter in forward-directed chevrons (Pl. 7.3, figs 13, 16). Occasionally additional weak ribs present on venter between chevrons. Intermediate whorl (WH = 23 mm) has weaker, straight ribs while outer whorl bears weak, slightly prorsiradiate, concave flank ribs. Venter broad; one specimen with very slight median protuberance (Pl. 7.3, figs 13). Suture weakly asymmetric and external lobe slightly deeper than first lateral lobe. First and second lateral saddles have simple secondary lacerations (Fig. 7.10F). Only third umbilical lobe visible and weakly retracted. On GSC 129020 (Pl. 7.3, fig. 21), suture line partially visible in one area of the flank (WH = 24.5 mm) where third lateral saddle narrow at base and third lateral lobe slopes toward umbilicus.

REMARKS: The Taseko Lakes form has similarities to *Sunrisites*, *Alsatites* and *Kammerkarites*.

It is assigned here to *Alsatites* due to the convex, alsatitoid nature of some of the ribbing.

*Alsatites* sp. is most similar to *A. nigromontanus* (Gümbel) of Guex (1995) but differs in including specimens that are more evolute on the inner whorls as well specimens that have weakly prorsiradiate ribs on the lower flank of the inner whorls. *Alsatites* sp. also resembles some specimens of *L. (?) intermedianus* from South America (Hillebrandt 2000d, pl. 3, figs 1, 3-4) although the Taseko Lakes material includes more involute forms and includes specimens where occasional ribs divide into two on the lower flank. This form differs from *A. bipartitus* in having finer ribs that are more evenly spaced on the flanks. It is more involute and has less coarse ribs than *A. proaries* (Neumayr). *Alsatites* sp. is similar in rib thickness and volution to *Kammerkarites anisophylloides* (Lange) but differs in having ribs that are less concave and



more widely spaced at similar shell diameters. It has much finer flank ribs than *Sunrisites chilensis* Hillebrandt and *S. peruvianus* (Lange) at similar shell diameters and differs from *S. brimblecombei* Longridge, Smith, Pálffy and Tipper in having finer ribs that are weakly concave and occasionally divide into two on the lower flanks.

OCCURRENCE: Sections A and C, Mineralense to lower Rursicostatum zones.

### Genus **PSEUDAETOMOCERAS** Spath, 1923b

TYPE SPECIES: *Arietites abnormilobatus* Wähner, 1886

#### ***Pseudaetomoceras* cf. *castagnolai* (Cocchi in Canavari 1882)**

Plate 7.3, figures 22-23; Figure 7.9G

cf. 1882 *Arietites* (*Oxynoticeras*) *Castagnolai* Cocchi; Canavari, p. 141, pl. 20, figs 18-19.

cf. 1886 *Arietites Castagnolai* Cocchi; Wähner, p. 58, pl. 21, fig. 2; pl. 23, figs 2-3.

cf. 1888 *Arietites Castagnolai* Cocchi; Canavari, p. 136, pl. 6, figs 18-19; text-fig. 6b.

cf. 1995 *Pseudaetomoceras castagnolai* (Cocchi); Guex, p. 52, pl. 27, fig. 25.

cf. 2000 *Pseudaetomoceras castagnolai* (Cocchi); Kment, p. 206, pl. 3, fig. 2.

2000 *Pseudaetomoceras* cf. *castagnolai* (Cocchi); Kment, p. 206, pl. 3, fig. 3.

MATERIAL AND MEASUREMENTS: One measured specimen (GSC 129022). Measurement of volution is presented in Figure 7.13A.

DESCRIPTION: Compressed, moderately involute form. Inner whorls missing. Lanceolate cross-section on intermediate and outer whorls. Umbilical wall gently slopes into flanks.

Ribbing on intermediate whorl weakly to moderately concave on flanks. On outer whorl, ribs closely spaced and strongly concave on flanks continuing onto venter where they fade. Keel

visible beyond shell diameters of 20 mm. On outer whorl, keel high and narrow. In areas where shell material present, keel forms bead on crest. Suture line not visible.

REMARKS: Although it is difficult to identify this specimen with confidence because it is incomplete, it is very similar to *P. castagnolai*, particularly a specimen figured by Wöhner (1886, pl. 23, fig. 2). This form differs from the more evolute *P. victoriense* sp. nov. and the more involute *P. abnormilobatus* (Wöhner) in having significantly more concave ribbing on the flanks and higher rib densities at similar whorl heights. It differs from the more evolute *P. doetzkirchneri* (Gümbel) in having a keel at much smaller shell diameters and differs from *P. shoshonense* Taylor in having weaker, more densely spaced and more strongly concave ribs at similar shell diameters. *Pseudaetomoceras* cf. *castagnolai* differs from the more involute *P. arcuatum* Hillebrandt by having ribs that are more strongly concave and less prorsiradiate low to mid-flank.

OCCURRENCE: Talus collection at isolated locality 2, probably from Mineralense or Rursicostatum Zone.

***Pseudaetomoceras victoriense* sp. nov.**

Plate 7.3, figures 1-2, 5; Figures 7.9I, 7.10E

DERIVATION OF NAME: Named after Victoria, the capital city of British Columbia.

MATERIAL AND MEASUREMENTS: Three measured and four incomplete specimens.

Measurements of volution, whorl shape and ribbing density are presented in Figure 7.13.

HOLOTYPE: GSC 129023 (Pl. 7.3, figs 1-2; Figs 7.9I, 7.10E) from the Rursicostatum Zone, Castle Pass section A, level 13, Taseko Lakes.

PARATYPES: GSC 129024 (Pl. 7.3, fig. 5), 129025; both specimens from the Rursicostatum Zone, Castle Pass section A, level 04, Taseko Lakes.

DIAGNOSIS: Moderately evolute, strongly compressed. Whorl cross-section lanceolate. Ribs straight and weakly rursiradiate on inner and intermediate whorls becoming concave on outer whorls. Ventral keel present beyond 5 mm shell diameter. Septal suture complex.

DESCRIPTION: Moderately evolute. Depressed, suboval whorl cross-section on nucleus changing to strongly compressed, lanceolate cross-section beyond 5 mm shell diameter.

Umbilical wall on inner whorls varies from upright to indistinct. Beyond 20 mm shell diameter umbilical wall indistinct sloping gradually into flanks. Nucleus bears nodes to approximately 4 mm shell diameter beyond which ribs appear. On inner whorls ( $D < 35$  mm), straight, moderately strong ribs begin on umbilical wall, are weakly rursiradiate on flanks before projecting forward as they fade on venter. On intermediate whorls, ribs closely spaced and straight to weakly concave on flanks. On holotype (GSC 129023, Pl. 3, figs 1-2), ribs weakly concave on flanks projecting forward on ventral shoulder before fading on venter. Ribs become more widely spaced and weaker toward adoral end of last whorl. Beyond 5 mm shell diameter, a ventral keel is present that rapidly becomes high and narrow. In areas where shell material present, keel forms a bead on crest. Suture line moderately denticulate with especially deep external lobe and relatively shallow lateral lobes (Fig. 7.10E). Umbilical lobes strongly retracted. Holotype probably mature specimen. Final portion of phragmocone broken; however, at least last three visible sutures approximated. Final whorl unchambered.

REMARKS: *Pseudaetomoceras victoriense* most closely resembles *P. shoshonense* but it differs in having denser ribbing (29 versus 18 PRHW at a UD of 24 mm) that is weakly rursiradiate on the inner whorls. It is similar to *P. arcuatum* (Hillebrandt 2000d, pl. 5, fig. 1, pl. 7, fig. 2) but differs in having weakly rursiradiate ribs on the inner and intermediate whorls ( $D < 40$  mm) and having a less distinct umbilical wall. Additionally, *P. victoriense* differs from *P. arcuatum* in having a higher number of ribs on the intermediate and outer whorls and a suture with a deep external lobe and smaller lateral lobes. The trajectory of the ribbing on the inner whorls of *P.*

*victoriense* is similar to that of *P. abnormilobatus* although it can be stronger on the lower flank. In addition, *P. victoriense* differs in being more evolute and having costation on the outer whorl that is weaker on the ventro-lateral shoulder and concave on the flanks. The suture is generally similar in form but less denticulate at a whorl height of 21 mm (suture of *P. abnormilobatus*, Wähner 1886, pl. 23 fig. 5b). It differs from *P. castagnolai* and *P. doetzkirchneri* in having ribbing on the inner and intermediate whorls that is much straighter and weakly rursiradiate. Furthermore, *P. victoriense* is more involute than *P. doetzkirchneri* and has a ventral keel by a shell diameter of 6 mm. *Paracaloceras victoriense* resembles *Pseudaetomoceras* sp. of Bertinelli *et al.* (2004) but differs in being more slowly expanding and having ribs that are more closely spaced, straighter and more rectiradiate with increasing diameter.

OCCURRENCE: Sections A and C, Mineralense and Rursicostatum zones.

***Pseudaetomoceras* sp.**

Plate 7.3, figure 17; Figure 7.9H

MATERIAL AND MEASUREMENTS: One specimen (GSC 129026). Measurement of volution is presented in Figure 7.13A.

DESCRIPTION: Moderately involute, compressed specimen with lanceolate cross-section. Inner whorls missing. Umbilical wall on intermediate and outer whorls upright with a distinct but rounded umbilical shoulder. Ribbing only barely discernable on lower flanks increasing slightly in strength mid to upper flank. Ribs closely spaced, straight and rectiradiate. On outer whorl, ribs bend forward on ventro-lateral shoulder and fade on venter. Keel visible beyond 20 mm shell diameter.

REMARKS: The poor preservation of this specimen does not permit confident identification. However, this specimen probably represents a new species because it differs from all other currently recognized *Pseudaetomoceras* in having very weakly developed flank ribs.

OCCURRENCE: Talus from section C, Mineralense Zone.

### **Family SCHLOTHEIMIIDAE Spath, 1923b**

A comprehensive study of *Angulaticeras* species from Taseko Lakes was presented by Smith and Tipper (2000). *Angulaticeras marmoreum* (Quenstedt) and *A. cf. trapezoidale* (Sowerby) were both found to occur in the late Hettangian. For the sake of completeness, the ranges of these taxa are included in the range chart herein (Fig. 7.8). For systematic information on these species, refer to Smith and Tipper (2000). Based on new information on the ammonite faunas from the area (Longridge *et al.* 2006; this study), the stratigraphic level of the boundary between the Mineralense and Rursicostatum zones has been slightly altered. *Angulaticeras cf. trapezoidale* is now limited to the Mineralense Zone in Taseko Lakes whereas *A. marmoreum* occurs in the Rursicostatum Zone.

### **Genus SCHLOTHEIMIA Bayle, 1878**

TYPE SPECIES: *Ammonites angulatus* Schlotheim, 1820; lectotype in Lange, 1951, p. 31, pl. 1, fig. 2.

#### ***Schlotheimia cf. cuevitensis* Hillebrandt, 2000c**

Plate 7.3, figures 3-4, 10-11

? 1979 *Schlotheimia* sp. ex gr. *complanata* Koenen; Geyer, p. 206, text-fig. 5A.

cf. 1987 *Schlotheimia* (*Scamnoceras*) cf. *postangulata* Lange; Quinzio, pl. 2, figs 4-5.

- cf. 1987 *Schlotheimia* (*Scamnoceras*) cf. *polyptycha* Lange; Quinzio, pl. 2, fig. 6.
- cf. 1987 *Curviceras* sp. Quinzio, pl. 2, fig. 3
- cf. 1990 *Schlotheimia* cf. *montana* (Wähner); Hillebrandt, pl. 3, figs 7-8.
- cf. 1994 *Schlotheimia* cf. *montana* (Wähner); Hillebrandt, pl. 1, fig. 2-2b.
- cf. 2000c *Schlotheimia cuevitensis* Hillebrandt, p. 32, pl. 8, figs 1-25; text-fig. 4e-h.
- ? 2000 *Schlotheimia* ex gr. *stenorhyncha* Lange; Taylor, pl. 1, figs 13-15.

**MATERIAL AND MEASUREMENTS:** Two measured specimens (GSC 129027-129028) and five fragments. Measurements of volution, whorl shape and ribbing density are presented in Figure 7.13.

**DESCRIPTION:** Midvolute form ( $U = 31-36\%$  at 18 mm) with rounded, high-rectangular whorl cross-section. Umbilical wall distinct, umbilical shoulder rounded. Sharp, fine, undivided ribs begin on lower flank coarsening slightly upflank. Ribs straight to slightly concave and weakly prorsiradiate projecting slightly more forward on top of flanks. Ribs sharply interrupted on venter forming an angle of approximately  $130^\circ$ . Suture line not available.

**REMARKS:** Ribbing style as well as the variation in volution and rib density are very similar *S. cuevitensis*. At 19 mm shell diameter, one side of GSC 129027 (Pl. 7.3, figs 3-4) has a rib that bifurcates low on the upper flank. The point of division is marked by a shell expansion that resembles a node. Because this character is found on only one side of the shell, it is probably pathologic.

As indicated in the synonymy list, this form is also recognized with varying degrees of confidence in Chile, Argentina, Peru and Nevada and may range throughout the eastern Pacific. As noted by Hillebrandt (2000c), the flattened Peruvian specimen described by Geyer (1979) can only be referred to *S. cuevitensis* with reservation. The Nevada material is also attributed to *S. cf. cuevitensis* with reservation. Taylor (2000) describes ribbing that crosses the venter

without interruption at the adoral end of the last whorl, a characteristic not recognized in the South American material.

The Taseko Lakes form is similar to *S. montana* (Wöhner) and *S. (Scamnoceras) hypolepta* Lange. Hillebrandt (2000c) describes the difference between the South American form and the European and Mediterranean forms as a rectangular rather than trapezoidal whorl cross-section in *S. hypolepta* and ribs which project significantly more forward on the venter in *S. montana*. One further difference is that *S. montana* also has a somewhat trapezoidal whorl cross-section. The differences between the eastern Pacific form and *S. stenorhyncha* Lange are described in Taylor (1998) and include less flexuous ribbing and slightly less forwardly projected ribbing on the venter in the eastern Pacific form.

OCCURRENCE: Section C, Mineralense Zone.

### **Genus FRANZICERAS Buckman, 1923**

TYPE SPECIES: *Franziceras ruidum* Buckman, 1923

#### ***Franziceras* aff. *graylockense* Taylor, 1998**

Plate 7.3, figures 18-20; Figure 7.9J

aff. 1998 *Franziceras graylockense* Taylor, p. 479, figs 12, 13.3-13.5, 13.14-13.15.

aff. 2002 *Franziceras graylockense* Taylor; Taylor and Guex, pl. 2, figs 3, 12-13.

MATERIAL AND MEASUREMENTS: Four measured (GSC 129029-129032) and two damaged specimens; six fragments. Measurements of volution, whorl shape and ribbing density are presented in Figure 7.13.

DESCRIPTION: Moderately evolute for genus. Depressed, suboval whorl cross-section when ribs not considered. If ribs included, whorl cross-section trapezoidal, tapering toward dorsum. Umbilical wall sloping and umbilical shoulder indistinct. Nucleus has blunt nodes to shell diameters of *c.* 6 mm. Beyond this, weak ribs begin on umbilical wall or on lower flank strengthening toward venter. Ribs attain greatest height on upper flank where ventro-lateral swellings visible in some cases. Ribs on inner whorls weakly prorsiradiate. Beyond shell diameters of 18-22 mm, ribs rectiradiate to rursiradiate. Ribs weaken and project forward on venter then fade. In well-preserved specimens, weak ventral folds continue across venter. Venter smooth except in one specimen which shows very slight median elevation (GSC 129030, Pl. 7.3, figs 18-19). No complete suture line visible although it appears simple and somewhat asymmetric with ventral lobe offset from median line.

REMARKS: This is the youngest occurrence of *Franziceras* yet described worldwide. It has overall morphological similarity with *F. graylockense* and, as in some specimens of this species, the Taseko Lakes material lacks a keel. However, although the Taseko Lakes material is only slightly more evolute and depressed than the holotype of *F. graylockense*, it is significantly more evolute and depressed than the paratypes. Thus, it is difficult to demonstrate that *F. graylockense* and *F. aff. graylockense* simply represent variants, particularly as there is a difference in stratigraphic range. Our form differs from the more involute *F. ruidum* (Buckman) in being more depressed and in having ribs that are more strongly rursiradiate on the outer whorls, and from *F. coronoides* (Guex) in lacking a keel and lacking distinct ventro-lateral nodes on the inner whorls. It is more evolute than *F. sebanum* (Neumayr) and more depressed than *F. gonioptychum* (Wöhner) and also lacks a keel.

OCCURRENCE: Section C and isolated locality 3, Mineralense Zone.



**Family ARIETITIDAE Hyatt, 1875**

**Subfamily ARIETITINAE Hyatt, 1875**

Generic assignment of late Hettangian species of the Subfamily Arietitinae is often controversial (e.g., Donovan and Forsey 1973; Donovan *et al.* 1981; Corna 1987; Bloos 1994, 1996; Taylor 1998; Meister *et al.* 2002b). Where possible, groups described below are assigned to different genera based on similarities with other established groups, common sutural characteristics and whorl shape.

**Genus GYROPHIOCERAS Spath, 1924**

TYPE SPECIES: *Arietites praespiratissimus* Wöhner, 1887.

***Gyrophioceras cf. mineralense* (Taylor, 1998)**

Plate 7.2, figures 23-24; Figure 7.9Y

cf. 1998 *Paracaloceras* (*Gyrophioceras*) *mineralense* Taylor, p. 490, fig. 21.3-21.6.

MATERIAL: One fragment (GSC 129033).

DESCRIPTION: Very evolute, slightly compressed form with subquadrate whorl cross-section. Umbilical wall upright with gently rounded umbilical shoulder. Flanks weakly convex with widest point of whorl on upper flank. Moderately distinct ventral shoulder. Ribs moderately to strongly rursiradiate on umbilical wall. Ribs on flanks vary from concave to rectiradiate. Ribs generally strongest on upper flank although overall rib strength and rib spacing varies considerably. On ventro-lateral shoulder, ribs bend forward sharply where they weaken and project forward across venter. Well-developed keel marks middle of venter. Suture line not visible.

REMARKS: The Taseko Lakes specimen has very similar ribbing to the type material for *G. mineralense*. However, the type material is of considerably smaller shell diameter and is slightly more depressed with somewhat more rapidly enlarging whorls.

OCCURRENCE: Section C, Mineralense Zone.

### Genus PARACALOCERAS Spath, 1923b

TYPE SPECIES: *Ammonites coregonensis* Sowerby, 1831.

The holotype of Sowerby is lost and that figured by Canavari, 1882, pl. 24, fig. 15 (and 1888, pl. 5, fig. 15) was designated as a neotype by Donovan and Forsey (1973, p. 7).

### *Paracaloceras rursicostatum* Frebold, 1967

Plate 7.2, figures 19, 21-22; Figures 7.9U, 7.10I

1951 *Arietites* sp. indet. Frebold, p. 3, pl. 3, fig. 2.

1967 *Paracaloceras rursicostatum* Frebold, p. 26, pl. 7, figs 1-2; pl. 9, fig. 1.

? 1981 *Paracaloceras rursicostatum* Frebold; Imlay, p. 33, pl. 6, figs 1-11.

cf. 1988 *Vermiceras* (*Paracaloceras*) cf. *rursicostatum* Frebold; Riccardi *et al.*, pl. 2, fig. 6.

cf. 1991 *Vermiceras* (*Paracaloceras*) cf. *rursicostatum* Frebold; Riccardi *et al.*, fig. 4.22.

? 1995 *Paracaloceras rursicostatum* Frebold; Guex, p. 54, pl. 32, fig. 1.

cf. 1999 *Paracaloceras* cf. *rursicostatum* Frebold; Pálffy *et al.*, fig. 5C.

2000 *Metophioceras rursicostatum* (Frebold); Taylor, pl. 4, figs 1-2, 9.

? 2002 *Metophioceras* aff. *rursicostatum* (Frebold); Taylor and Guex, pl. 2, fig. 8.

MATERIAL AND MEASUREMENTS: Thirteen measured specimens including 3 measured external casts (GSC 56416, holotype of Frebold, 1967; GSC 129035-129046) and many fragments (GSC 129034, 129047). Measurements of volution, whorl shape and ribbing density are presented in Figure 7.14.

DESCRIPTION: Evolute form. Moderately depressed on inner whorls becoming progressively less depressed at larger shell diameters. Whorl cross-section of inner whorls subquadrate. By shell diameters of 5-13 cm, shell becomes weakly compressed with subrectangular whorl cross-section. Nucleus bears nodes which become ribs beyond shell diameters of 3-4 mm. Ribs moderately strong and convex on flanks projecting weakly forward onto venter before they fade. At small shell diameters ribs are rectiradiate. Beyond this, rib orientation is variable and in some specimens ribs become strongly rursiradiate at shell diameters beyond 13 mm (Frebold 1967, pl. 9, fig. 1). In others, ribs remain essentially rectiradiate to end of preserved specimen ( $D = c. 13$  cm; GSC 129035, Pl. 2, figs 21-22) At shell diameters of less than  $c. 18$  mm, venter smooth. Beyond this, a weak keel forms and between shell diameters of 25-30 mm weak lateral sulci develop. By shell diameters of 35 mm, venter strongly tricarinate-bisulcate. Septal suture line moderately indentate. Ventral lobe somewhat deeper than first lateral lobe. First lateral saddle slightly higher than second lateral saddle (Fig. 7.10I).

REMARKS: The generic assignment of this form has fluctuated between *Paracaloceras* (Frebold 1967; Imlay 1981; Guex 1995; Pálffy *et al.* 1999) and *Metophioceras* (Taylor 1990, 2000; Pálffy *et al.* 1994; Jakobs and Pálffy 1994; Taylor *et al.* 2001; Taylor and Guex 2002). Herein it is assigned to *Paracaloceras*, based on the overall similarity in shape of the suture line, the style of ornament on the innermost whorls and the close morphological relationship of *P. rursicostatum* to *P. coregonense* (Sowerby). Although the suture line of *P. rursicostatum* has a deeper indentation on the dorsal side of the first lateral saddle than is found in most species of *Paracaloceras*, this character is sometimes recognized in *P. coregonense* (e.g., Canavari 1888,

pl. 5, fig. 14d; Bloos 1996, fig. 6a) as well as in other species of *Paracaloceras* (e.g. Bloos 1996, fig. 7a). *Paracaloceras rursicostatum* has nodes on the innermost whorls before normal ribbing begins. As discussed by Bloos (1996, fig. 8), this character is useful to separate *Paracaloceras* and *Metophioceras* as species of the former genus bear tubercles on the innermost whorls while the innermost whorls of *Metophioceras* (included as subgenus of *Coroniceras* in Bloos 1994) species are smooth. Finally, *Paracaloceras rursicostatum* is from the same group as *P. coregonense*. The similarity of some Taseko Lakes arietitid material (including *P. rursicostatum*) and *P. coregonense* has already been documented by Frebold (1967, p. 23-24). As discussed in Frebold (1967, p. 26), there is a gradual transition within the *P. coregonense* figured by Wähner (1888) with rib orientation varying between rectiradiate and rursiradiate. This change in rib orientation is also seen in *P. rursicostatum*, and as with *P. coregonense*, the shell diameter at which the orientation of ribbing changes is highly variable. Frebold originally established the species *P. rursicostatum* because the holotype has much more strongly rursiradiate ribs than any example of *P. coregonense*. The following is a description of the additional differences currently recognized between *P. rursicostatum* from Taseko Lakes and *P. coregonense*. *Paracaloceras rursicostatum* has a narrower range of whorl cross-sections on the innermost whorls ( $D < 30$  mm). It is consistently similar to the more compressed forms of *P. coregonense*. *Paracaloceras rursicostatum* is slightly more depressed and evolute than *P. coregonense* at large shell diameters ( $D > 150$  mm). *Paracaloceras rursicostatum* is often less densely ribbed between umbilical diameters of 8 – 35 mm although the range of variation includes denser ribbed forms that overlap with *P. coregonense*. Beyond 80 mm shell diameter, *P. rursicostatum* is less densely ribbed (27-28 PRHW) than *P. coregonense* (31-37 PRHW). Finally, *P. rursicostatum* develops a keel at smaller shell diameters ( $D < 18$  mm). Based on these differences, *P. rursicostatum* is maintained as a separate species from *P. coregonense*. Although end members of *P. rursicostatum* look very different, division of the

current Taseko Lakes material on the basis of volution, whorl cross-section or rib orientation, density or strength would be arbitrary.

OCCURRENCE: Sections A, B, C and D, Mineralense and Rursicostatum zones. Also occurs in the Columbiae Zone in Taseko Lakes (Frebold 1967).

***Paracaloceras* aff. *varaense* Hillebrandt, 2000d**

Plate 7.4, figures 5-7, 10-14; Figures 7.9V-W, Z

aff. 1981 *Alsatites* cf. *platystoma* (Lange); Hillebrandt, p. 503, pl. 1, fig. 7a-b.

aff. 1987 *Alsatites* cf. *platystoma* (Lange); Quinzio, pl. 1, fig. 10a-b.

aff. 1988 *Vermiceras* cf. *gracile* (Spath); Riccardi *et al.*, pl. 2, figs 8-9.

aff. 1991 *Vermiceras* cf. *gracile* (Spath); Riccardi *et al.*, fig. 5.1-5.2.

aff. 2000d *Paracaloceras varaense* Hillebrandt, p. 79, pl. 4, fig. 5; pl. 5, figs 3-5; pl. 8, figs 1-6; pl. 9, figs 1-3; pl. 10, figs 1-4; pl. 12, fig. 1; text-fig. 1n-q.

MATERIAL: Whorl fragments of one large specimen (GSC 129049), one external cast and four fragments (GSC 129048, 129050-129051).

DESCRIPTION: Weakly to moderately depressed and moderately evolute. Broad to suboval cross-section with weakly to strongly convex flanks showing greatest width low to midflank. Whorl cross-section of GSC 129051 (Pl. 7.4, figs 6-7) appears subrectangular, tapering slightly towards umbilicus. However, this fragment is somewhat distorted and tapered shape of flanks may be due to secondary alteration. On inner and intermediate whorls, weak ribs gently convex on flanks. Strength and spacing of ribs somewhat variable. On outer whorls (WH= c. 40 mm) ribs vary significantly in strength, spacing and orientation on flanks before projecting forward on ventro-lateral shoulder. Some ribs weak, closely spaced and weakly rursiradiate while others much stronger, more widely spaced and more strongly rursiradiate. Stretched ribs project

strongly forward onto venter where they fade remaining weakly visible until edge of lateral sulci. At small whorl heights (WH = 40 mm) lateral sulci are shallow. At larger size, depth of lateral sulci varies considerably from barely perceptible (Pl. 7.4, figs 12-13, Fig. 7.9W) to moderately deep (Fig. 7.9Z). Central keel strong and broad. Only small portion of suture line visible on GSC 129049 (Pl. 7.4, fig. 11) (WH = 34 mm). It is highly indentate and has strongly retracted third lateral lobe.

REMARKS: This form has an affinity with *P. varaense* from South America but differs at large shell diameters in having ribs that can be much stronger in addition to including specimens with deeper lateral sulci. As discussed by Hillebrandt (2000d), one of the critical differences between *P. varaense* and several other species including *P. grunowi* (Hauer), *P. haueri* (Gümbel), *P. salinarium* (Hauer), and *P. perspiratum* (Wähner) (the latter three species are considered by Hillebrandt to belong to *Alpinoceras*) is found in the suture line. Although there are clear morphological differences between *P. varaense* (and *P. aff. varaense*) and these species, the lack of a complete suture line in addition to the incomplete preservation of the Taseko Lakes material prohibits confident identification at the species level.

As documented by Hillebrandt (2000d), *P. varaense* exhibits variability in cross-section, rib strength and rib interval. The irregular, dense and weak ribbing in *P. varaense* as well as the suture line suggest this form is intermediate between *Paracaloceras* and *Alpinoceras* (Hillebrandt 2000d; G. Bloos, pers. comm. 2005).

*Paracaloceras* aff. *varaense* is similar to *P. cf. grunowi* identified from Nevada (Taylor 1990) but differs in having ribs which are more irregular in strength and spacing. *Paracaloceras* aff. *varaense* differs from *P. subsalinarium* (Wähner) in having ribs that are almost rectiradial rather than rursiradial on the flanks as well as being less depressed and having more shallow ventral sulci at similar shell diameters. It differs from the more rapidly expanding *P. salinarium* in having ribs that are more concave on the inner whorls, fade more quickly on the venter and

are consistently weaker on the outer whorl. *Paracaloceras* aff. *varaense* differs from *P. grunowi* and *P. aff. grunowi* of Dommergues *et al.* (1995) in having ribs that are more widely and irregularly spaced in addition to developing a keel earlier in ontogeny. *Paracaloceras* aff. *varaense* differs from *P. haueri* in being somewhat more depressed and rapidly expanding and having ribs that are more rursiradiate on the inner whorls and much stronger on the flanks with much shallower ventral sulci at larger shell diameters. The inner whorls of the Taseko material are somewhat similar to *P. centauroides* (Savi and Meneghini) but differ in having ribs that are more irregular in spacing and strength. The outer whorls differ principally in being more depressed and lacking lateral keels. Finally, *P. aff. varaense* resembles '*Caloceras*' *ortoni* Hyatt but differs in having more rectiradiate ribbing on the flanks of the inner whorls as well as ribs that can be much more strongly developed and wider spaced on the outer whorls.

As noted by Guex (1995, p. 54), a morphologically close form to what is now recognized to be *P. varaense* was collected from the Mineralense Zone (previously Oregonensis Zone) in New York Canyon and identified as *P. aff. haueri*.

OCCURRENCE: Sections A and B, Rursicostatum Zone; talus section D.

### ***Paracaloceras* sp. A**

Plate 7.2, figures 1-2; Figures 7.9S, 7.10J

MATERIAL AND MEASUREMENTS: Four measured specimens (GSC 129053-129056).

Measurements of volution, whorl shape and ribbing density are presented in Figure 7.14.

DESCRIPTION: Weakly depressed, evolute and reasonably slowly expanding for genus.

Innermost whorls missing. Whorl cross-section on intermediate whorls rounded, outer whorls subquadrate. On intermediate whorls, ribs straight and rectiradiate to weakly prorsiradiate.

Between shell diameters of 35-70 mm, ribs become slightly convex and weakly rursiradiate.

Beyond this, moderately strong ribs somewhat irregular in strength, spacing and orientation. Ribs project forward onto venter where they quickly fade as they reach lateral keels. Venter bisulcate-tricarinate on all visible whorls. Central keel higher than lateral keels. Suture line moderately indentate. Ventral lobe longer than first lateral lobe. First lateral saddle slightly higher and broader than second lateral saddle (Fig. 7.10J).

REMARKS: *Paracaloceras* sp. A is probably a new species but there is not enough well preserved material to introduce a new species. This form differs from *P. rursicostatum* in being more slowly expanding in the outer whorls as well as in having ribs that are more widely spaced and somewhat irregular on the flanks.

OCCURRENCE: Sections A and D, Rursicostatum Zone.

### ***Paracaloceras* sp. B**

Plate 7.4, figures 3-4, 8-9; Figures 7.9X, 7.10K

MATERIAL: Three fragments (GSC 129057-129059).

DESCRIPTION: Moderately evolute and depressed. Whorl cross-section oval to weakly subtrigonal. Ribs weakly concave and widely spaced on flanks projecting forward onto venter. Ribs fade as they reach lateral keels. Ventral shoulder indistinct as flanks curve gently into venter. Venter bisulcate-tricarinate with central keel much higher than lateral keels. Sulci shallow. Suture line moderately indentate. Ventral lobe longer than first lateral lobe. First lateral saddle slightly higher and broader than second lateral saddle (Fig. 7.10K).

REMARKS: Due to incomplete preservation, an identification at the species level is not possible. *Paracaloceras* sp. B has weaker flank ribs and a narrower venter than the more evolute *Paracaloceras* sp. A. It differs from *Paracaloceras* (?) spp. from Taseko Lakes in having



weaker ribs than the more evolute GSC 129061 and having more widely spaced, concave ribs and a narrower venter than GSC 129060.

OCCURRENCE: Section B, Rursicostatum Zone.

***Paracaloceras* (?) spp.**

Plate 7.2, figures 5-6, 15-16

DESCRIPTION: Specimen GSC 129060 (Pl. 7.2, figs 5-6; Fig. 7.9R) weakly depressed and subquadrate. At adapical end flanks virtually parallel and ventro-lateral shoulder distinct. Toward adoral end, widest point of whorl on lowest flank beyond which flanks taper slightly toward a more gently rounded ventro-lateral shoulder. Ribs weak on lower flank increasing in strength as they proceed up flank. Some ribs weakly prorsiradiate on flanks and project strongly forward on ventro-lateral shoulder while others more strongly prorsiradiate on flanks with a correspondingly weaker change in orientation on ventro-lateral shoulder. Ribs fade as reach lateral keels. Venter tricarinate-bisulcate with strongly developed central keel and moderately deep lateral furrows. Suture line not preserved.

Specimen GSC 129061 (Pl. 7.2, figs 15-16) evolute and moderately depressed with subquadrate whorl cross-section. Strong ribs widely spaced with greatest strength varying between midflank and ventro-lateral shoulder. Ribs project forward on venter where they quickly fade. Venter strongly bisulcate-tricarinate. Suture line not preserved.

REMARKS: The generic assignment of these specimens is uncertain as the amount of material is very limited and the inner whorls and suture line are not preserved.

OCCURRENCE: Section B (GSC 129060) and D (GSC 129061), Rursicostatum Zone.

TYPE SPECIES: *Ammonites conybeari* Sowerby, 1816

***Metophioceras* (?) sp.**

Plate 7.4, figures 1-2; Figures 7.9T, 7.10L

MATERIAL AND MEASUREMENTS: One completely septate specimen (GSC 129062).

Measurements of volution, whorl shape and ribbing density are presented in Figure 7.14.

DESCRIPTION: Evolute form, compressed and rapidly expanding for genus. Innermost whorls not preserved. First preserved whorl weakly compressed ( $WWWH = .95$  at UD of 43 mm) becoming increasingly compressed with increasing shell diameter ( $WWWH = .82$  at UD of 106 mm). On innermost preserved whorl ribs reasonably sharp, gently concave and weakly rursiradiate (25 PRHW at UD = 38 mm). At adoral end of second preserved whorl, ribs become coarser and more strongly rursiradiate and concave. This rib orientation continues to end of specimen. Ribs slightly swollen in ventro-lateral area where they project strongly forward onto venter then fade as reach lateral keels. Ribs on innermost preserved whorl evenly placed on either side of specimen while ribs on outermost whorls can be offset. Venter deeply sulcate and strongly tricarinate with central keel higher than lateral keels. Suture line moderately heavily lacerated. Ventral lobe longer than first lateral lobe. First lateral saddle has very deep indentation on dorsal flank and is much lower and broader than second lateral saddle (Fig. 7.10L).

REMARKS: The generic assignment is based on the presence of rursiradiate ribbing and a central keel that is higher than the ventro-lateral carinae. However, the assignment to *Metophioceras* is considered uncertain for several reasons. Firstly, the inner whorls are missing so the nucleus cannot be assessed for whorl shape or the presence of tubercles before ribbing

begins. Secondly, some *Epammonites* share some similarities in suture line with *Metophioceras* (?) sp. (Wähner 1891, pl. 17, fig. 4, Guérin-Franiatte 1966, pl. 101). Finally, the variability within each arietitid ammonite genus is generally high and more than one specimen is required before a confident generic assignment is possible.

*Metophioceras* (?) sp. is probably a new species; however, more material is needed before this form can be properly documented. This form is superficially similar to the holotype of *P. rursicostatum* (Frebold 1967, pl. 7, fig. 1, pl. 9, fig. 1) but differs in being significantly more rapidly expanding and compressed on the intermediate whorls as well as in having ribs that are much stronger on the lower flank. Unfortunately, the suture line on the holotype of *P. rursicostatum* is not preserved. However, the suture line of another *P. rursicostatum* specimen from Taseko Lakes (Fig. 7.10L) is very different from the suture of *Metophioceras* (?) sp. In *P. rursicostatum* the first and second lateral saddles are approximately equal in width and the first lateral saddle is higher than the second lateral saddle.

OCCURRENCE: Section D, Rursicostatum Zone.

### **Genus SCHREINBACHITES Bloos, 1994**

TYPE SPECIES: *Arietites retroversicostatus* Canavari, 1882; lectotype of the type species (Canavari 1882, pl. 20, fig. 13) designated by Guérin-Franiatte, 1990, p. 162.

#### ***Schreinbachites* (?) aff. *laqueoides* (Hyatt, 1889)**

Plate 7.2, figures 3-4, 9-10

aff. 1934 *Arietites francojurensis* Kuhn, p. 44, pl. 1, fig. 8.

aff. 1976 *Paracaloceras laqueoides* (Hyatt); Schlegelmilch, p. 45, pl. 10, fig. 5.

aff. 1990 *Gyrophioceras inversum* Guérin-Franiatte, p. 163, pl. 30, fig. 4.

aff. 1994 *Schreinbachites laqueoides* (Hyatt); Bloos, p. 29, pl. 1, figs 1-12; pl. 2, figs 1-3; text-figs 23-30, 35-38.

2000 *Paracaloceras* aff. *laqueoides* (Hyatt); Taylor, pl. 3, figs 3-4.

MATERIAL AND MEASUREMENTS: Three measured specimens including one measured external cast (GSC 129063-129065). Measurements of volution, whorl shape and ribbing density are presented in Figure 7.14.

DESCRIPTION: Strongly evolute and depressed with subrectangular whorl cross-section. Nucleus smooth to 2-3 mm shell diameter. Subsequently, ribbing on flanks weakly rursiradial to weakly prorsiradial and somewhat irregular in strength and spacing (especially in GSC 129064, Pl. 7.2, figs 9-10) to approximately 15 mm. Beyond this, weak ribbing remains irregular and slightly concave, bending back on lower flank and slightly forward at top of upper flank. Majority of ribs terminate at top of flank although occasional ribs weaken and bend forward on venter terminating at ventral sulci. Throughout ontogeny, occasional rib pairs are stronger and show a broadening on ventral edge where they project abruptly forward toward following rib. Flattened venter bears a low keel flanked by weak sulci by a shell diameter of 6 mm. Although ventral area of aperture of GSC 129063 (Pl. 7.2, figs 3-4) is missing, it is likely a mature specimen based on distinct widening of aperture at end of specimen as well as weaker, more closely spaced ribbing on final half of last whorl. Suture line not available.

REMARKS: Due to lack of a suture line, this form is referred with uncertainty to *Schreinbachites*. It most closely resembles *S. laqueoides* Hyatt. A thorough review of *S. laqueoides* is given in Bloos (1994) who describes variation in rib direction and irregularity in ribbing which includes the occurrence of ribs that project sharply forward on the top of the flank. These characteristics are also found in the Taseko Lakes material. Furthermore, beyond shell diameters of 15 mm, volution and whorl cross-section of *S. (?)* aff. *laqueoides* fall within

the variation of *S. laqueoides*. Nevertheless, *S. (?) aff. laqueoides* likely represents a new species as it differs in being slightly more evolute at very small shell diameters, developing lateral sulci at smaller shell diameters and having somewhat weaker and more numerous ribs. As discussed by Bloos (1994), one method of recognizing maturity in *S. laqueoides* is the presence of condensed and reduced ribbing on the second half of the body chamber. This character is visible in GSC 129063 (Pl. 7.2, fig. 3) and may suggest maturity.

The Taseko material is significantly weaker ribbed than the larger form of *S. aff. laqueoides* recognized from Nevada (Taylor 2000, pl. 3, figs 3-4) and is significantly more evolute and compressed than *Schreinbachites (?)* sp. B and the coarser ribbed *Schreinbachites (?)* sp. A of Hillebrandt (2000d, pl. 10, figs 5-9). *Schreinbachites (?) aff. laqueoides* is superficially similar to *Gyrophioceras mineralense* of Taylor (1998) but differs in having a smooth nucleus and a keel which is significantly stronger on the inner whorls.

OCCURRENCE: Section B and isolated locality 4, Rursicostatum Zone.

## **7.4 North American Upper Hettangian Ammonite Zones**

Ranges of late Hettangian ammonite taxa from Taseko Lakes are given in Figure 7.8 where taxa indicated in bold are new records (this chapter; Longridge *et al.* in press) for the Mineralense and Rursicostatum zones of the North American Zonation. Many of these forms (or species closely related to them) permit correlations with other areas as indicated below (Fig. 7.15). Zones discussed in the text are shown in Figure 7.2.

## **7.5 Correlation with Other Areas**

### **7.5.1 North America**

#### 7.5.1.1 Canada.

In Canada, Hettangian ammonite collections are principally restricted to British Columbia with the exception of *Discamphiceras cf. silberlingi* that occurs in subsurface strata in

northwestern Alberta. The exact level of this collection is uncertain but it is broadly placed in the middle to late Hettangian (Hall *et al.* 2000). At Williston Lake in British Columbia, *Nevadaphyllites compressus* and *N. cf. microumbilicatus* are found in the Polymorphum Zone. The latter species ranges up into strata that are broadly equivalent to the middle Hettangian where it occurs with *Togaticeras togatum* (Hall and Pitaru 2004) whereas *Badouxia canadensis* (Frebold) [including *B. oregonensis* Taylor which was placed in synonymy with *B. canadensis* by Longridge *et al.* (2006)] occurs in beds that correlate with the Mineralense and Rursicostatum zones (Hall and Pitaru 2004). At the generic level in the Queen Charlotte Islands (QCI), *Fergusonites* indicates the Occidentalis and Coronoides zones whereas *Eolytoceras tasekoi* occurs throughout the late Hettangian as well as in the earliest Sinemurian (Pálffy *et al.* 1994; Tipper and Guex 1994). According to Pálffy *et al.* (1994), *Angulaticeras marmoreum* and *A. cf. trapezoidale* (*Sulciferites cf. trapezoidalis* in Pálffy *et al.* 1994) also occur in the QCI with the former occurring in the Columbiae Zone and the latter straddling the Rursicostatum and Columbiae zones (Smith and Tipper, 2000). Also in the QCI, *Sunrisites senililevis* Longridge, Smith, Pálffy and Tipper occurs in the Rursicostatum Zone [*Sunrisites* n. sp. of Pálffy *et al.* (1994)(Longridge *et al.* in press)], *Paracaloceras cf. rursicostatum* (*Metophioceras cf. rursicostatum* in Pálffy *et al.* 1994) occurs in the Rursicostatum through Columbiae zones and *B. canadensis* [includes *Badouxia* n. sp. of Pálffy *et al.* (1994) which was representing *B. oregonensis*] occurs in the Mineralense through Columbiae zones (Pálffy *et al.* 1994). In the Iskut River map area, *B. forticostata*, *A. cf. marmoreum* and *A. cf. trapezoidale* (*Sulciferites cf. marmoreus* and *S. cf. trapezoidalis* in Jakobs and Pálffy, 1994) are very likely from the Rursicostatum Zone although the Mineralense Zone cannot be excluded (Jakobs and Pálffy 1994; Longridge *et al.* 2006). *Paracaloceras cf. rursicostatum* (*Metophioceras cf. rursicostatum* in Jakobs and Pálffy, 1994) occurs in what is probably either the Rursicostatum or Columbiae Zone (Jakobs and Pálffy 1994). In the Telegraph Creek map area, the exact level of *B. forticostata*

Longridge, Smith and Tipper is uncertain as this species was not found in association with any other ammonites (Friebold 1964; Longridge *et al.* 2006). However, it is probably of late Hettangian or earliest Sinemurian age.

*Sunrisites senililevis* in the QCI permits direct correlation with the Rursicostatum Zone in Taseko Lakes. *Angulaticeras marmoreum* and *A. cf. trapezoidale* indicate the presence of the Mineralense and Rursicostatum zones in Iskut River although in the QCI these species currently range into the Columbiae Zone. However, the taxonomic identification of *A. marmoreum* in the QCI has been questioned by Smith and Tipper (2000) and may need revision. *Angulaticeras trapezoidale* ranges into the Bucklandi Zone in France (Guérin-Franiatte 1990; Smith and Tipper 2000) so it is not unexpected that the species may range into the early Sinemurian in Canada. *Badouxia canadensis* permits correlations between the Mineralense and Rursicostatum zones in Taseko Lakes, Williston Lake and Iskut River although in the QCI the species ranges into the Columbiae Zone. Several other taxa from Taseko Lakes are relatively longer ranging and thus, only provide the opportunity for broad age correlations between different areas of Canada. These include *D. silberlingi* which is found in middle to late Hettangian strata, *Eolytoceras tasekoi* which ranges from the Morganense through Columbiae zones and *P. rursicostatum* that ranges from the Mineralense through Columbiae zones.

#### 7.5.1.2 Alaska.

In Alaska, the best stratigraphic section with Hettangian faunas is in Puale Bay where *Discamphiceras cf. silberlingi* occurs in strata that are broadly equivalent to the Mulleri to Pleuroacanthitoides zones while *Eolytoceras cf. tasekoi*, *Paracaloceras cf. rursicostatum*, *Angulaticeras cf. trapezoidale*, *Sunrisites cf. brimblecombei*, *Badouxia forticostata* and possibly *B. canadensis* occur in strata that are probably equivalent to the Rursicostatum Zone although the Mineralense Zone cannot be excluded (Imlay 1981; Pálffy *et al.* 1999; Smith and Tipper 2000; Longridge *et al.* 2006, in press). Outside of Puale Bay, Alaskan faunas are generally less

well constrained in time because collections often come from isolated localities and often consist of single species (Imlay 1981). *Paracaloceras* cf. *rursicostatum* occurs in the late Hettangian (probably Rursicostatum Zone) in the Kenai Peninsula and the Healy quadrangle. *Badouxia forticostata* also occurs in the latter area and may also come from the Rursicostatum Zone (Imlay 1981; Longridge *et al.* 2006). *Angulaticeras* cf. *marmoreum* occurs in northern Alaska and although its exact age is uncertain, it may occur in strata equivalent to the Mineralense and Rursicostatum zones (Imlay 1981; Smith and Tipper 2000). *Sunrisites* cf. *brimblecombei* and *S.* cf. *chilcotinensis* Longridge, Smith, Pálffy and Tipper occur in what are probably upper Hettangian strata from the Coleen quadrangle in east-central Alaska. Further occurrences that are probably of similar age include *S.* cf. *brimblecombei* in the Seldovia area on the Kenai Peninsula and *S.* cf. *chilcotinensis* in the subsurface of northernmost Alaska (Imlay 1981; Longridge *et al.* in press).

*Eolytoceras* cf. *tasekoi*, *P.* cf. *rursicostatum*, *A.* cf. *trapezoidale*, *S.* cf. *brimblecombei*, *B.* *forticostata* and possibly *B. canadensis* provide direct correlations between the Mineralense and Rursicostatum zones in Taseko Lakes and Alaska. *Angulaticeras* cf. *marmoreum*, *S.* cf. *brimblecombei* and *S.* cf. *chilcotinensis* provide more general correlations with the late Hettangian.

#### 7.5.1.3 Oregon and Nevada.

Many important localities for late Hettangian ammonites occur in Oregon and Nevada in the United States (e.g., Guex 1980, 1995; Taylor 1990, 1998, 2000; Taylor and Guex 2002). In Nevada, *Nevadaphyllites compressus* occurs in the Pacificum and Polymorphum zones whereas *N. psilomorphus* occurs in the Pleuroacanthitoides Zone (Guex 1980, 1995; Taylor *et al.* 2001). In Oregon, *N. compressus* is found in the Morganense and Mineralense zones whereas *N. microumbilicatus* occurs in the Rursicostatum and Columbiae zones (Taylor 1998, 2000; Taylor *et al.* 2001; Taylor and Guex 2002). At the generic level, *Fergusonites* permits correlation with



the middle Hettangian in Nevada (Guex 1995; Taylor *et al.* 2001). *Eolytoceras tasekoi*, *Badouxia forticostata* and possibly *Schlotheimia cuevitensis* are recognized from the Rursicostatum Zone in Nevada while *E. guexi* occurs in the Morganense Zone in Oregon and the Rursicostatum Zone in Nevada (Taylor 1998, 2000; Longridge *et al.* 2006). *Discamphiceras silberlingi* ranges from the Occidentalis to Pleuroacanthitoides zones in Nevada, and this species as well as *Franziceras graylockense* are also found in the Morganense Zone in Oregon (Guex 1980, 1995; Taylor 1998; Taylor and Guex 2002). *Pseudaetomoceras castagnolai* is identified in the Sunrisense Zone in Nevada (Guex 1995). In Oregon and Nevada, *Gyrophioceras mineralense* occurs in the Mineralense Zone (Taylor 1998) while *Schreinbachites* aff. *laqueoides* occurs in the Mineralense Zone in Nevada (Taylor 2000; Taylor *et al.* 2001). *Paracaloceras rursicostatum* occurs in the Mineralense to Columbiae zones in Nevada whereas *P.* aff. *rursicostatum* occurs in the Columbiae to Trigonatum zones in Oregon (Guex 1995; Taylor 1998, 2000; Taylor and Guex 2002). *Badouxia canadensis* is found in the Mineralense through Columbiae zones in Nevada and in the Mineralense Zone in Oregon (Taylor 1998, 2000).

The late Hettangian phylloceratids from Taseko Lakes permit broad correlations with the Hettangian and earliest Sinemurian in Oregon and Nevada. Ammonite taxa that permit direct correlation of the Mineralense and Rursicostatum zones in Taseko Lakes with Nevada and Oregon include *G. mineralense*, *Schreinbachites* aff. *laqueoides*, *Eolytoceras tasekoi*, *B. forticostata* and possibly *Schlotheimia* cf. *cuevitensis*. Several other taxa from Taseko Lakes are relatively longer ranging and thus, only provide the opportunity for broad age correlations. These include *D. silberlingi* which ranges from the Occidentalis through the Morganense zones, *E. guexi* which ranges through the Morganense through Rursicostatum zones and *Paracaloceras rursicostatum* that ranges from the Mineralense through Columbiae zones. Finally, there are a couple of additional taxa which occur at somewhat different zonal levels in the USA. These

include *Pseudaetomoceras castagnolai* from the Sunrisensis Zone and *F. graylockense* from the Morganense Zone. Unfortunately, only one specimen of *P. cf. castagnolai* has been found from talus in Taseko Lakes so it is of limited value for correlation purposes. The *Franziceras* from Taseko Lakes has an affinity with *F. graylockense* but is not the same species so it is reasonable that their ranges would differ.

#### 7.5.1.4 Mexico.

In the Sonora region of northern Mexico, *Badouxia canadensis* occurs in what are probably the Rursicostatum and Columbiae zones and may range as high as the Trigonatum Zone (González-León *et al.* 1996; Taylor *et al.* 2001) whereas *B. castlensis* Longridge, Smith and Tipper is found in the Trigonatum Zone (Taylor *et al.* 2001; Longridge *et al.* 2006). The latter species was only recently defined and the exact extent of its range is uncertain at this point although these taxa indicate broad correlations between late Hettangian faunas in Taseko Lakes and similar to slightly younger aged faunas in Mexico.

### **7.5.2 South Pacific**

#### 7.5.2.1 South America.

South America also has many late Hettangian taxa in common with Taseko Lakes. *Nevadaphyllites compressus* occurs in the Tilmanni Subzone and *Phylloceras asperaense* occurs in the Reissi through Peruvianus zones (Hillebrandt 2000b) whereas at the generic level, *Fergusonites* permits correlation with the Bayoensis Zone (Hillebrandt 2000b, d). *Alsatites bipartitus* is restricted to the Peruvianus Zone although *A. cf. bipartitus* may range into the Canadensis Zone in Argentina (Hillebrandt 2000d). *Schlotheimia cuevitensis* is found in the Cuevitensis Subzone while *Paracaloceras varaense*, *Angulaticeras marmoreum*, *A. trapezoidale* and possibly *Badouxia castlensis* occur in the Varaense Subzone of the Canadensis Zone (Hillebrandt 1981, 2000c, d; Quinzio 1987; Riccardi *et al.* 1988, 1991; Longridge *et al.* 2006). *Eolytoceras chongi* and *B. canadensis* occur throughout the Canadensis Zone (Geyer 1979;

Quinzio 1987; Hillebrandt 1990, 1994, 2000c, d). *Badouxia forticostata* occurs in the Varaense Subzone and possibly ranges through the entire Canadensis Zone and Arcuatum horizon (Hillebrandt 2000 c, d; Longridge *et al.* 2006).

The late Hettangian phylloceratids from Taseko Lakes permit broad correlations with the Hettangian of South America. *E. chongi*, *S. cuevitensis*, *P. varaense*, *A. marmoreum*, *A. trapezoidale*, *B. canadensis* and possibly *B. castlensis* correlate the Canadensis Zone in South America with the Mineralense and Rursicostatum zones in Taseko Lakes. *Alsatites bipartitus* occurs in slightly older strata in South America than *A. aff. bipartitus* from Taseko Lakes. However, *A. cf. bipartitus* from Argentina (Hillebrandt 2000d, pl. 1, fig. 29) resembles the Taseko Lakes form and may be from similar age strata.

#### 7.5.2.2 New Zealand.

Approximate correlations are possible between the Taseko Lakes ammonite successions and those of New Zealand. *Nevadaphyllites psilomorphus* occurs in what are probably middle to lower upper Hettangian strata equivalent to the North American Mulleri to Morganense zones whereas *N. microumbilicatus* occurs in strata that may equate to the Rursicostatum and Columbiae zones (Stevens 2004). These phylloceratid faunas permit broad correlations between the late Hettangian successions in Taseko Lakes and the Hettangian and earliest Sinemurian in New Zealand. Furthermore, *Eolytoceras tasekoi* may occur in the late Hettangian of New Zealand as does *Angulaticeras marmoreum*, although its exact stratigraphic level is uncertain.

### **7.5.3 Europe**

#### 7.5.3.1 Western Tethys (circum-Mediterranean).

Taxa occurring in both North America and the Tethyan circum-Mediterranean area permit indirect correlations with the primary standard of northwest Europe because correlation between Tethys and northwest Europe is now quite well documented (e.g., Bloos 1983; Guérin-Franniate 1990; Mouterde and Corna 1997; Page 2003). Late Hettangian faunas from Taseko Lakes

contain several taxa that are useful in this regard. In Austria, *Nevadaphyllites psilomorphus* is found throughout the Hettangian (Neumayr 1879; Lange 1952; Dommergues *et al.* 1995; Böhm *et al.* 1999; Kment 2000) whereas *Togaticeras togatum* is found in lower and middle Hettangian strata (Rakús 1993, 1999; Kment 2000). *Togaticeras goisernense* is also found in strata that are broadly equivalent to the lower to middle Hettangian (Rakús 1999). *Nevadaphyllites* cf. *psilomorphus* is found from talus that is very likely to be from the lower to middle Hettangian in Hungary (Pálffy *et al.* 2001). The late Hettangian phylloceratids from Taseko Lakes permit broad correlations with the Hettangian of the circum-Mediterranean. *Angulaticeras marmoreum* occurs in the Marmoreum Zone in Austria and Spain while *A. trapezoidale* occurs in the Marmoreum Zone in Austria and the upper Hettangian in Italy (Wähner 1886; Canavari 1888; Blind 1963; Braga *et al.* 1984; Venturi 1985; Böhm *et al.* 1999; Smith and Tipper 2000). These occurrences were used by Smith and Tipper (2000) to correlate the Mineralense and Rursicostatum zones with the Marmoreum Zone. Extending the range of *A. marmoreum* as discussed above suggests correlation of the entire Rursicostatum Zone with the Marmoreum Zone, a correlation supported by the occurrence of *Badouxia forticostata* in the Rursicostatum and Columbiae zones in Taseko Lakes and its probable occurrence in the Marmoreum Zone in Austria (Rakús and Lobitzer 1993; Longridge *et al.* 2006). As further supporting evidence, *Pseudaetomoceras* cf. *castagnolai* occurs in talus from the Mineralense or Rursicostatum zones in Taseko Lakes whereas *P. castagnolai* occurs in the upper Hettangian in Italy and the Marmoreum Zone in Austria (Canavari 1882; Wähner 1886; Canavari 1888; Venturi 1985; Kment 2000). *Eolytoceras* cf. *tasekoi* occurs in the Marmoreum Zone in Austria (Kment 2000) and can be used to indicate the presence of upper Hettangian strata.

#### 7.5.3.2 Eastern Tethys.

Broad correlations are possible between the late Hettangian Taseko Lakes ammonite successions and the Hettangian and earliest Sinemurian in the eastern Tethys. *Nevadaphyllites*

cf. *psilomorphus* is found in the Calliphyllum Zone in Tibet (Yin *et al.* 2007) and taxa closely related to *E. tasekoi* and *E. chongi* occur in lower Sinemurian strata that are probably equivalent to the Conybeari or Rotiforme subzones in Vietnam (Meister *et al.* 2002a).

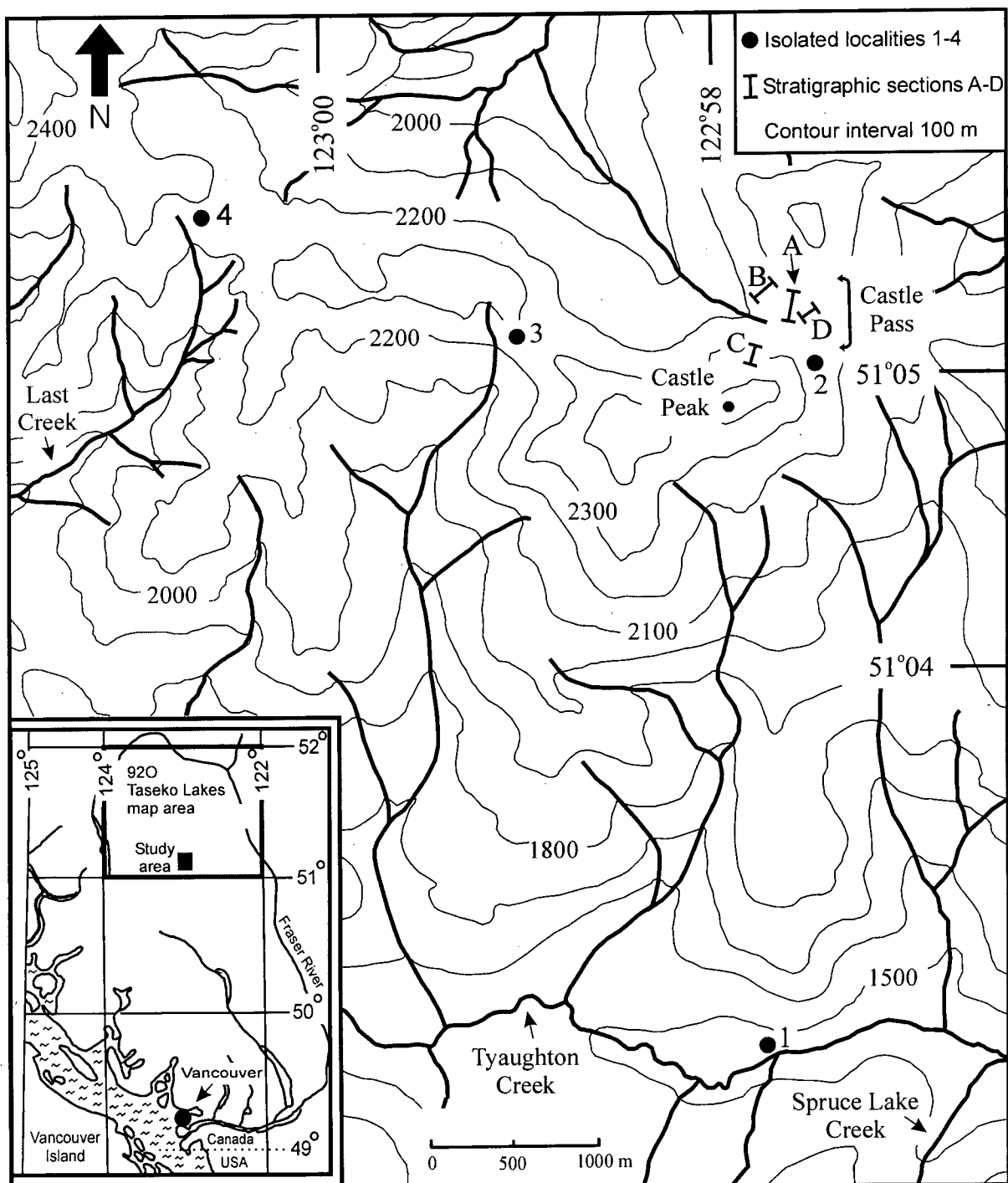
#### 7.5.3.3 Northwest Europe.

Correlation of the sequences from the eastern Pacific with those of the northwest Europe is difficult yet direct correlations with Europe are of great importance because the European succession is the primary worldwide standard. Several taxa from the Mineralense and Rursicostatum zones in Taseko Lakes are useful in this regard including *Angulaticeras marmoreum* which is restricted to the Depressa Subzone in southwest Germany and southwest England as well as *A. trapezoidale* that is found in the Angulata Zone in Europe, although there is a Bucklandi Zone occurrence in France (e.g., Blind 1963; Bloos 1979, 1983, 1988a; Guérin-Franiatte 1990; Smith and Tipper 2000; Page 2002). Smith and Tipper (2000) used the co-occurrence of *A. marmoreum* and *A. cf. trapezoidale* from Taseko Lakes to correlate the Mineralense and the base of the Rursicostatum zones with the northwest European Complanata Subzone. Similarly they correlated the remainder of the Rursicostatum Zone with the northwest European Depressa Subzone based on the range of *A. marmoreum* which at that time included most of the Rursicostatum Zone. Since then, additional collections have shown that *A. marmoreum* ranges to the top of the Rursicostatum Zone in Taseko Lakes. This extended range strengthens the claim that the upper portion of the Rursicostatum Zone correlates with the Depressa Subzone in northwest Europe. Another relevant taxa is *Schreinbachites* (?) aff. *laqueoides* which occurs in the middle of the Rursicostatum Zone in Taseko Lakes. *Schreinbachites* (?) *laqueoides* occurs in the Complanata Subzone in France and southern Germany (Bloos 1994). Therefore *S. (?) aff. laqueoides* provides a second link for the lower and middle portion of the Rursicostatum Zone with the Complanata Subzone.

## 7.6 Summary and Conclusions

The late Hettangian ammonite fauna from Taseko Lakes is diverse and relatively well-preserved. In total, thirty-five taxa from the Mineralense and Rursicostatum zones are present including three new species, *Fergusonites hendersonae*, *Eolytoceras constrictum* and *Pseudaetomoceras victoriense*. This material is very important as it greatly expands our understanding of the fauna and ranges of ammonites currently included in the North American regional ammonite zonation. Furthermore, this fauna permits the following correlations between different areas:

1. The Mineralense and Rursicostatum zones are present in Taseko Lakes and can be readily correlated with contemporaneous strata elsewhere in North America.
2. The Mineralense and Rursicostatum zones of North America are broadly equivalent to the Canadensis Zone and probably the Arcuatum horizon of the South American succession.
3. Broad correlations are possible with middle to late Hettangian and earliest Sinemurian taxa in New Zealand.
4. The Mineralense and Rursicostatum zones are broadly equivalent to the circum-Mediterranean Marmoreum Zone.
5. The Mineralense Zone and the lower to middle portion of the Rursicostatum Zone are probably equivalent to the Complanata Subzone whereas the upper portion of the Rursicostatum Zone may equate to the Depressa Subzone of the northwest European succession.

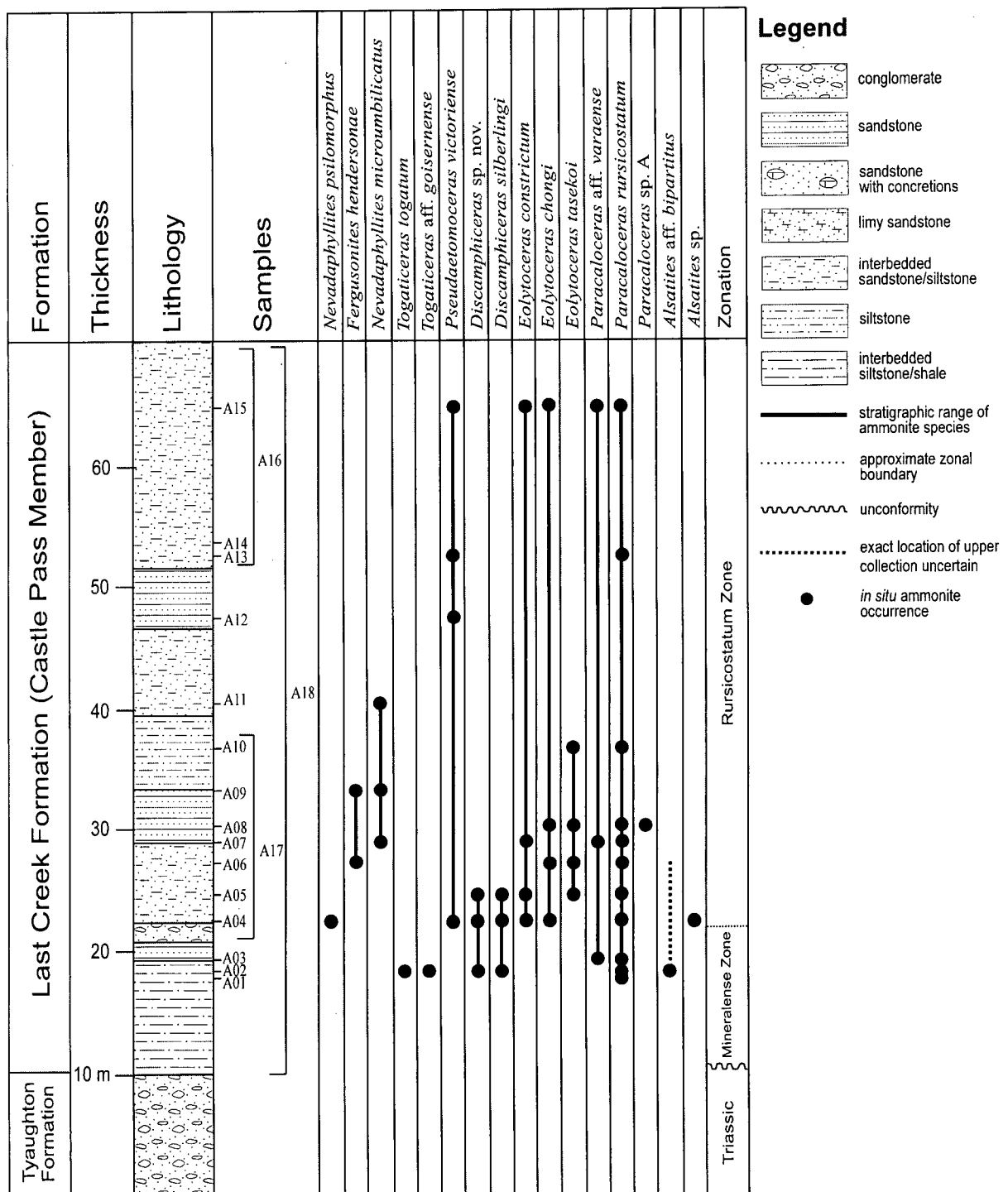


**Figure 7.1.** Localities of sections and isolated outcrops bearing late Hettangian ammonites in Taseko Lakes.

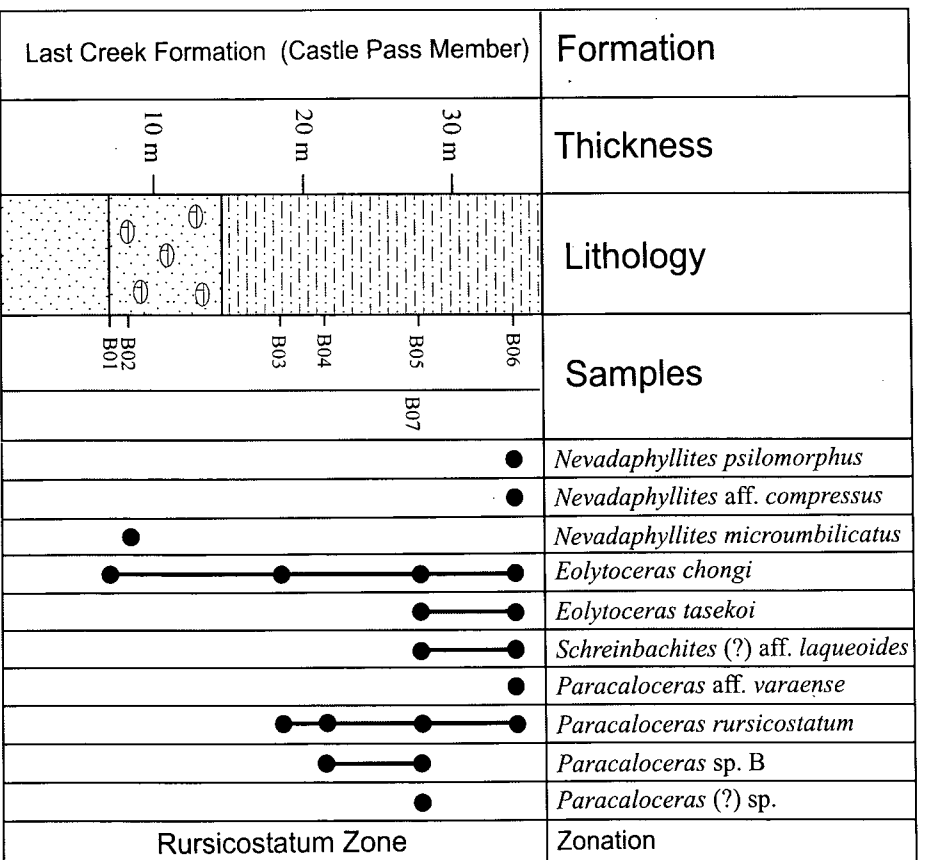
AGE	NORTH AMERICA (Taylor <i>et al.</i> 2001; Longridge <i>et al.</i> 2006)	SOUTH AMERICA (Hillebrandt 2000a, d)	NORTHWEST EUROPE (Donovan <i>in</i> Dean <i>et al.</i> 1961; Bloos 1988b; Page 2003)	WESTERN TETHYS (Wahner 1886; Page 2003)	EASTERN TETHYS (Yin <i>et al.</i> 2007)
EARLY SINEMURIAN	14 Trigonatum Zone	32 Horizon with <i>Coroniceras</i> ( <i>Metophioceras</i> ) aff. <i>gracile</i>	Bucklandi Zone	50 Rotiforme Subzone	65 rotiforme
	13 Columbiae Zone	31 Horizon with <i>Coroniceras</i> ( <i>Metophioceras</i> ) aff. <i>conybeari</i>		49 Conybeari Subzone	64
LATE HETTANGIAN	12 Rursicostatum Zone	Arcuaturn Horizon 30 Canadensis Zone Varaense Subzone 29	Angulata Zone	48 Depressa Subzone	63 Marmoreum Zone
	11 Mineralense Zone	Cuevitisensis Subzone 28		47 Complanata Subzone	
	10 Morganense Zone	27	Liasicus Zone	46 Extranodosa Subzone	62 Megastoma Zone
	9 Sunrisensis Zone	Peruvianus Zone		45 Laqueus Subzone	
MIDDLE HETTANGIAN	8 Pleuroacanthitoides Zone	26		44 Portlocki Subzone	
	7 Coronoides Zone	Reissi Zone			
	6 Occidentalis Zone				
	5 Mulleri Zone	Bayoensis Zone 25			
EARLY HETTANGIAN	4 Polymorphum Zone	Rectocostatum Zone 24	Planorbis Zone	43 Johnstoni Subzone	61 Calliphyllum Zone
	3 Pacificum Zone	Primocostatum Zone 23		42 Planorbis Subzone	
	2 Minutus Zone	Tilmanni Zone 22			72 Calliphyllum Zone
	1 Spelae Zone	21	41		71 Tibeticum Zone

**Figure 7.2.** Zonation for Hettangian showing correlation of North American zones with South America, northwest Europe, western Tethys (circum-Mediterranean), eastern Tethys and New Zealand. Only approximate correlations are implied. Units are numbered to facilitate correlation with Figure 7.15.

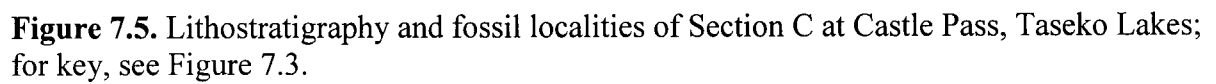




**Figure 7.3.** Lithostratigraphy and fossil localities of Section A at Castle Pass, Taseko Lakes.

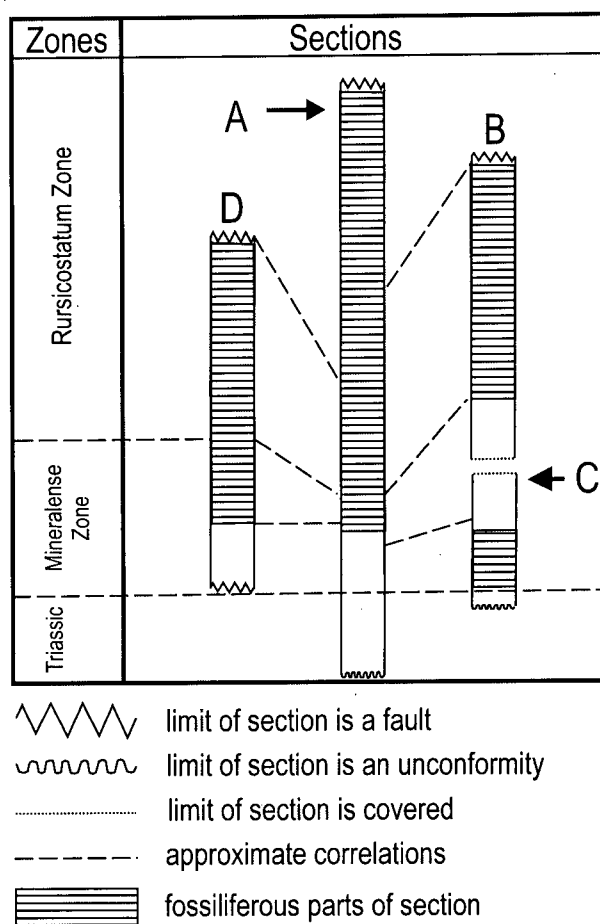


**Figure 7.4.** Lithostratigraphy and fossil localities of Section B at Castle Pass, Taseko Lakes; for key, see Figure 7.3.



Last Creek Formation (Castle Pass Member)		Formation
<div> <div>10 m</div> <div>20 m</div> <div>30 m</div> </div>		Thickness
		Lithology
<div> <div>D01</div> <div>D02</div> <div>D03</div> </div>		Samples
●		<i>Phylloceras</i> cf. <i>asperaense</i>
●		<i>Discamphiceras</i> sp. nov.
●		<i>Discamphiceras silberlingi</i>
●		<i>Discamphiceras</i> aff. <i>silberlingi</i>
		<i>Eolytoceras chongi</i>
		<i>Eolytoceras tasekoi</i>
		<i>Metophioceras</i> (?) sp.
		<i>Paracaloceras rursicostatum</i>
		<i>Paracaloceras</i> sp. A
		<i>Paracaloceras</i> (?) sp.
Mineralense Zone	Rursicostatum Zone	Zonation

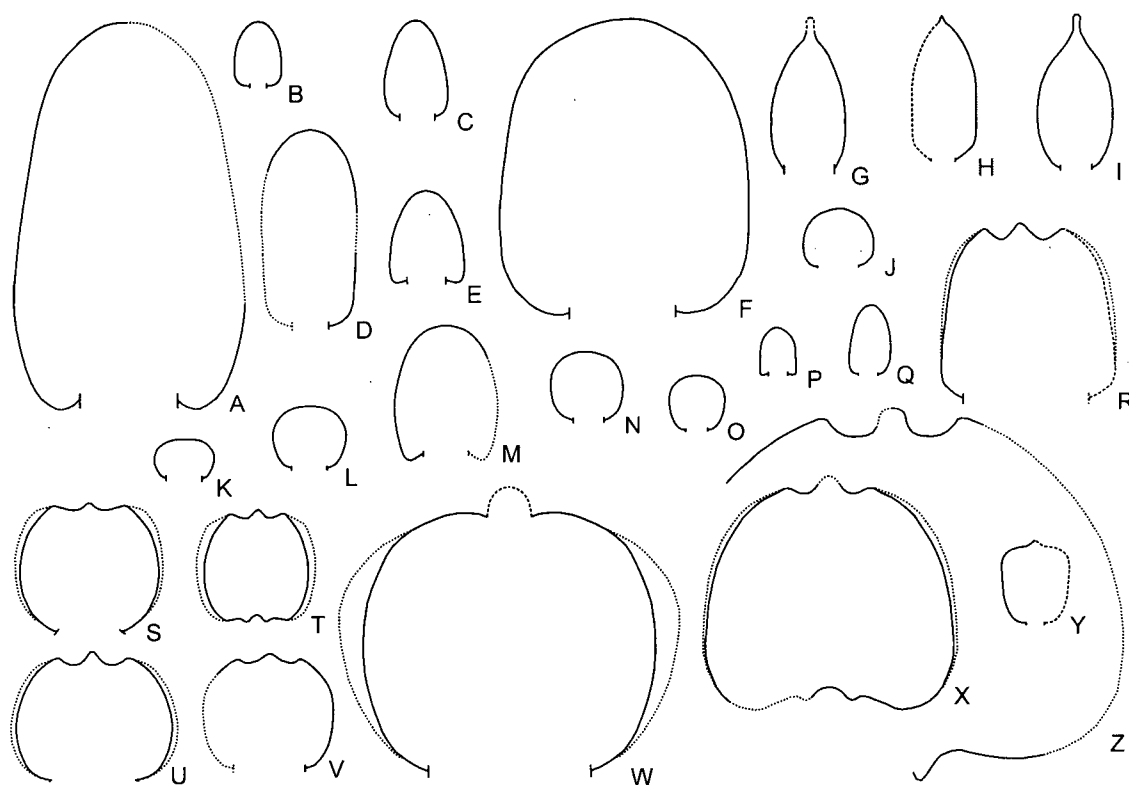
**Figure 7.6.** Lithostratigraphy and fossil localities of Section D at Castle Pass, Taseko Lakes; for key, see Figure 7.3.



**Figure 7.7.** Approximate correlation of stratigraphic sections from Taseko Lakes.

Fauna	Mineralense Zone	Rursicostatum Zone
<i>Phylloceras</i> cf. <i>asperaense</i> Hillebrandt	•	
<i>Nevadaphyllites psilomorphus</i> (Neumayr)		—
<i>Nevadaphyllites</i> aff. <i>compressus</i> Guex		•
<i>Nevadaphyllites microumbilicatus</i> Taylor		—
<i>Fergusonites hendersonae</i> sp. nov.		—
<i>Togaticeras togatum</i> (Neumayr)	•	
<i>Togaticeras</i> aff. <i>goisernense</i> Rakús	•	
<i>Eolytoceras tasekoi</i> Frebold		—
<i>Eolytoceras chongi</i> Hillebrandt		—
<i>Eolytoceras</i> aff. <i>guexi</i> Taylor	•	—
<i>Eolytoceras constrictum</i> sp. nov.		—
<i>Discamphiceras silberlingi</i> Guex	—	
<i>Discamphiceras</i> aff. <i>silberlingi</i> Guex	•	
<i>Discamphiceras</i> sp. nov.	—	
<i>Alsatites</i> aff. <i>bipartitus</i> (Hillebrandt)	—	.....
<i>Alsatites</i> sp.	—	
<i>Pseuduetomoceras victoriense</i> sp. nov.	—	—
<i>Schlotheimia</i> cf. <i>cuevitensis</i> Hillebrandt	•	
<i>Franziceras</i> aff. <i>graylockense</i> Taylor	—	
<i>Gyrophioceras</i> cf. <i>mineralense</i> (Taylor)	•	
<i>Paracaloceras rursicostatum</i> Frebold	—	→
<i>Paracaloceras</i> aff. <i>varaense</i> Hillebrandt	—	—
<i>Paracaloceras</i> sp. A		—
<i>Paracaloceras</i> sp. B		—
<i>Paracaloceras</i> (?) spp.		—
<i>Metophioceras</i> (?) sp.		•
<i>Schreinbachites</i> (?) aff. <i>laqueoides</i> (Hyatt)		—
<i>Sunrisites brimblecombei</i> Longridge et al.	—	—
<i>Sunrisites chilcotinensis</i> Longridge et al.	—	—
<i>Sunrisites senililevis</i> Longridge et al.	—	
<i>Angulaticeras</i> cf. <i>trapezoidale</i> (Sowerby)	•	
<i>Angulaticeras marmoreum</i> (Oppel)		—
<i>Badouxia canadensis</i> (Frebold)	—	—
<i>Badouxia castlensis</i> Longridge et al.		—
<i>Badouxia forticostata</i> Longridge et al.		→

**Figure 7.8.** Ranges of ammonites from the Mineralense and Rursicostatum zones in Taseko Lakes. Taxa indicated in bold are new records for the Mineralense and Rursicostatum zones of the North American Zonation.

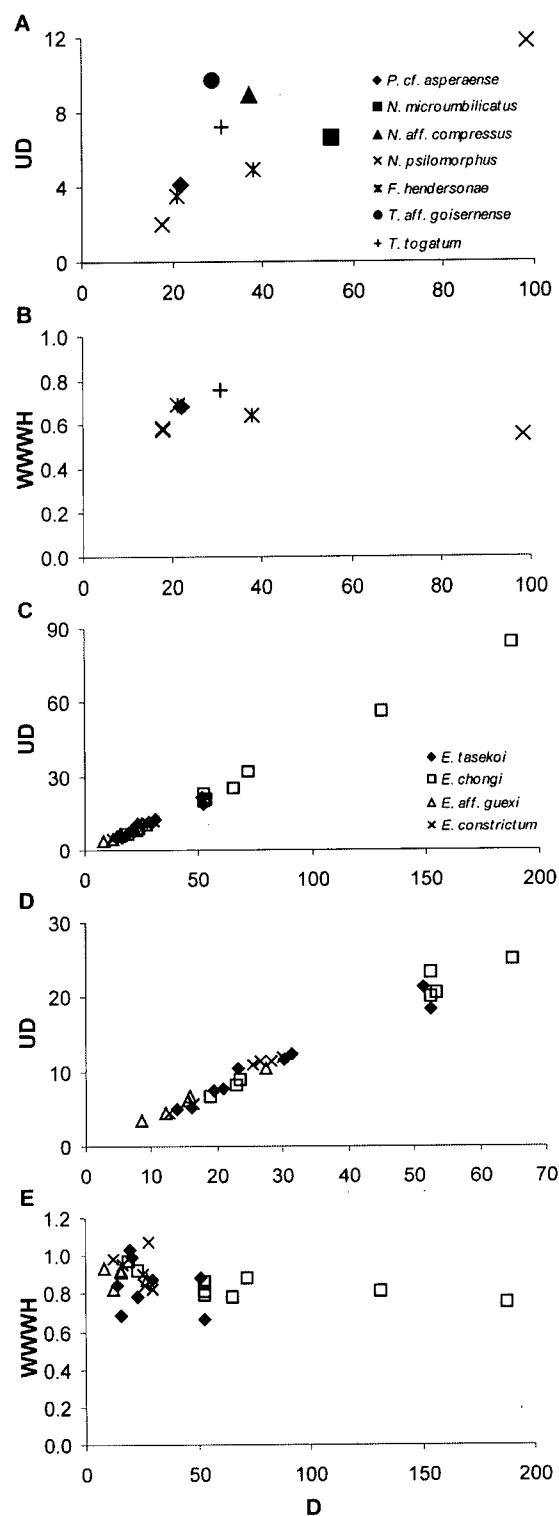


**Figure 7.9.** Whorl shape cross-sections for late Hettangian ammonites from Taseko Lakes. All figures  $\times 0.9$ . A, *Nevadaphyllites psilomorphus* (Neumayr), GSC 127417. B, *Phylloceras* cf. *asparaense* Hillebrandt, GSC 127416. C, *Nevadaphyllites* aff. *compressus* Guex, GSC 127420. D, *Nevadaphyllites microumbilicatus* Taylor, GSC 127421. E, *Togaticeras togatum* (Neumayr), GSC 127425. F, *Eolytoceras chongi* Hillebrandt, GSC 127436. G, *Pseudaetomoceras* cf. *castagnolai* Cocchi, GSC 129022. H, *Pseudaetomoceras* sp., GSC 129026. I, *Pseudaetomoceras victoriense* sp. nov., GSC 129023. J, *Franziceras* aff. *graylockense* Taylor, GSC 129030. K, *Alsatites* aff. *bipartitus* (Hillebrandt), GSC 129014. L, *Alsatites* sp., GSC 129019. M, *Fergusonites hendersonae* sp. nov., GSC 127423. N, *Eolytoceras constrictum* sp. nov., GSC 128984. O, *Eolytoceras* aff. *guexi* Taylor, GSC 127448. P, *Discamphiceras* aff. *silberlingi* Guex, GSC 128991. Q, *Discamphiceras* sp. nov., GSC 129003. R, *Paracaloceras* (?) sp., GSC 129060. S, *Paracaloceras* sp. A, GSC 129053. T, *Metophioceras* (?) sp., GSC 129062. U, *Paracaloceras rursicostatum* Frebold, GSC 129035. V-W, Z, *Paracaloceras* aff. *varaense* Hillebrandt. V, GSC 129051. W, GSC 129048. Z, GSC 129049. X, *Paracaloceras* sp. B, GSC 129059. Y, *Gyrophioceras* cf. *mineralense* (Taylor), GSC 129033.

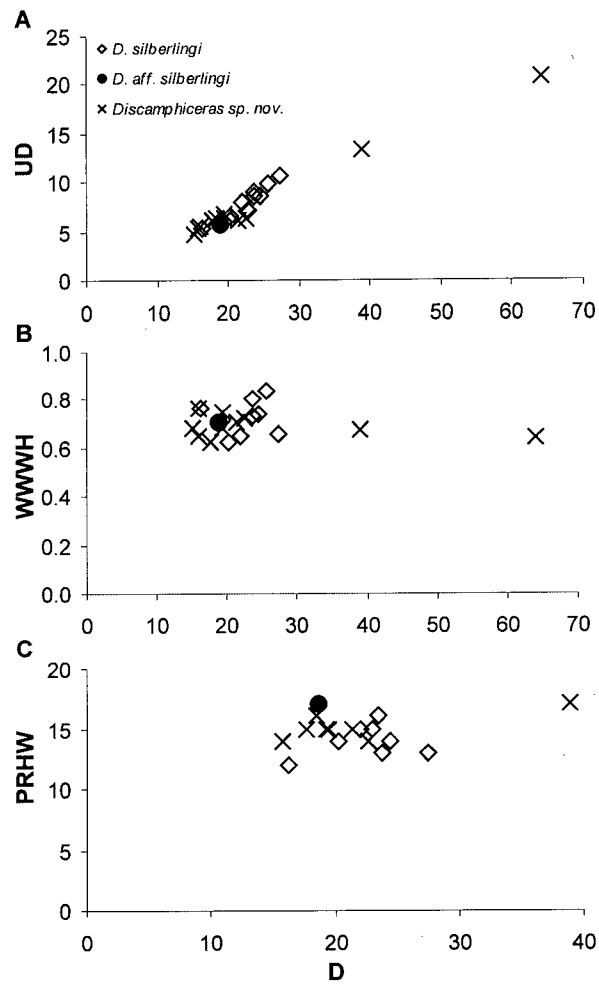


**Figure 7.10.** Traces of septal suture for late Hettangian ammonites from Taseko Lakes at whorl heights indicated. Sutures are  $\times 0.9$  unless otherwise indicated. A, *Nevadaphyllites psilomorphus* (Neumayr), GSC 127419, WH = 8 mm;  $\times 1.8$ . B, *Phylloceras* cf. *asperaense*, GSC 127416, WH = 9.2 mm;  $\times 1.8$ . C, *Togaticeras togatum* (Neumayr), GSC 127425, WH = 10.4 mm;  $\times 1.8$ . D, *Eolytoceras constrictum* sp. nov., GSC 128985, WH = 6 mm;  $\times 1.8$ . E, *Pseudaetomoceras victoriense* sp. nov., GSC 129023, WH = 21 mm. F, *Alsatites* sp., GSC 129019, WH = 5.8 mm;  $\times 1.8$ . G, *Eolytoceras chongi* Hillebrandt, GSC 127445, WH = 19.8 mm. H, *Discamphiceras* sp. nov., GSC 129003, WH = 6.1 mm;  $\times 1.8$ . I, *Paracaloceras rursicostatum* Frebold, GSC 129047, WH = 11.3 mm. J, *Paracaloceras* sp. A, GSC 129053, WH = 19.3 mm. K, *Paracaloceras* sp. B, GSC 129058, WH = 30 mm. L, *Metophioceras* (?) sp., GSC 129062, WH = 29.3 mm.

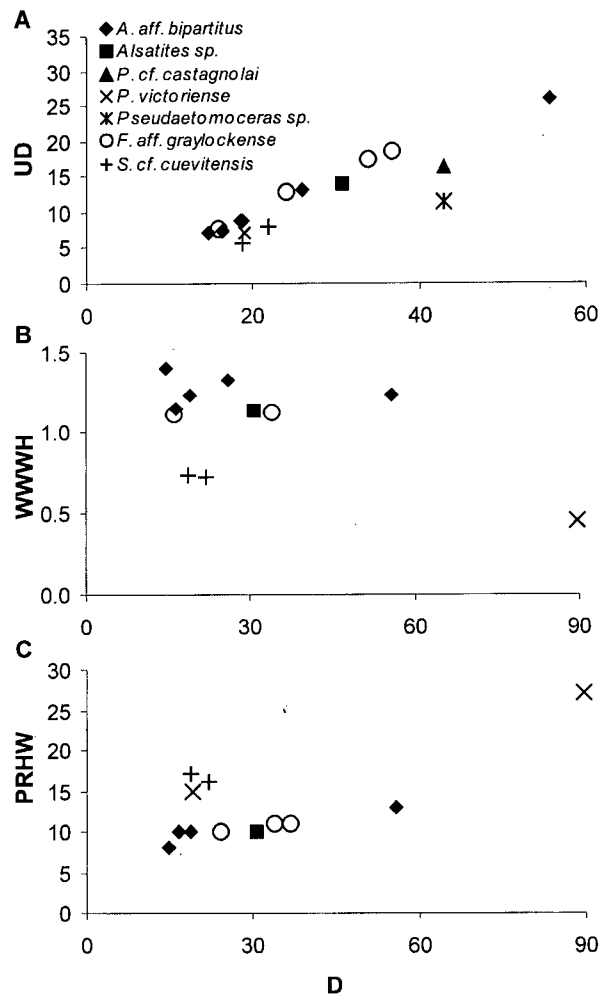




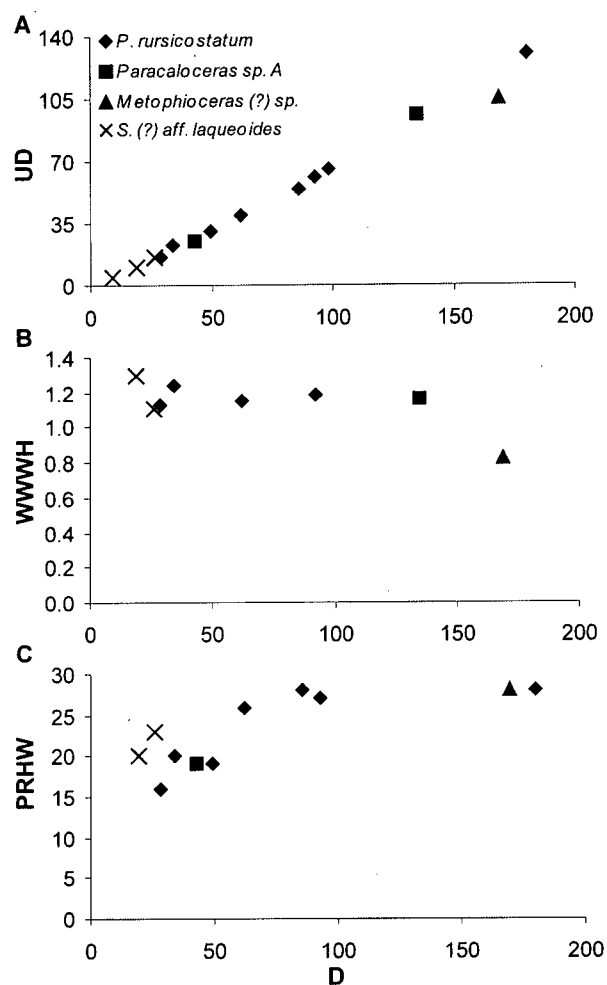
**Figure 7.11.** Plots of measurements of Phylloceratina and Psiloceratina from Taseko Lakes. A-B, *Phylloceras* (*P.*), *Nevadaphyllites* (*N.*), *Fergusonites* (*F.*), *Togaticeras* (*T.*). A, umbilical diameter (UD) versus shell diameter (D). B, whorl width whorl height (WWWH) versus shell diameter. C-E, *Eolytoceras* (*E.*). C, umbilical diameter (UD) versus shell diameter (D) of all measurable material. D, umbilical diameter (UD) versus shell diameter (D) of specimens up to 30 mm shell diameter. E, whorl width whorl height (WWWH) versus shell diameter.



**Figure 7.12.** Plots of measurements of *Discamphiceras* (D.) species from Taseko Lakes. A, umbilical diameter (UD) versus shell diameter (D). B, whorl width whorl height (WWWH) versus shell diameter. C, primary ribs per half whorl (PRHW) versus shell diameter (D).

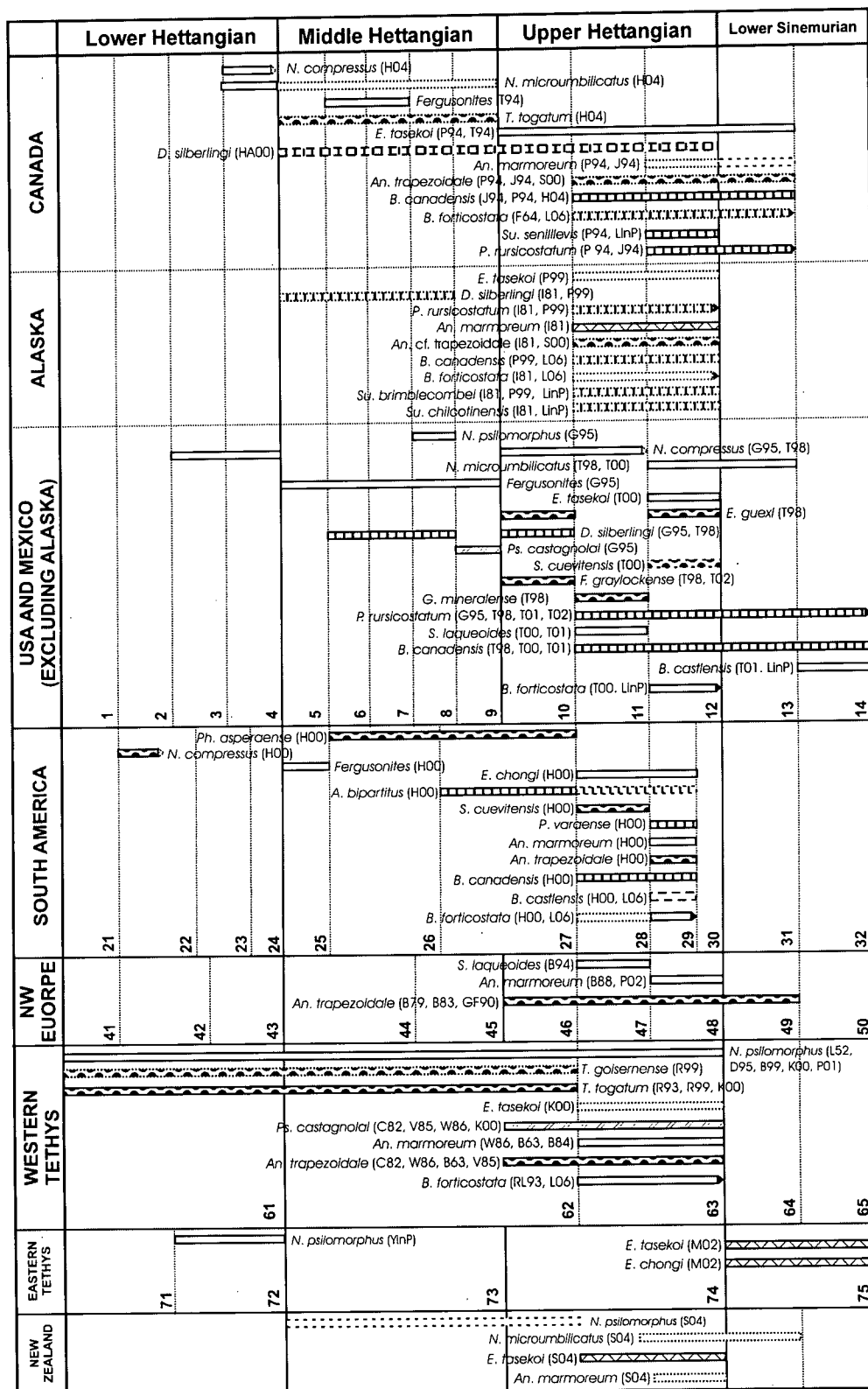


**Figure 7.13.** Plots of measurements of species of *Alsatites* (*A.*), *Pseudetaomoceras* (*P.*), *Franziceras* (*F.*) and *Schlotheimia* (*S.*) from Taseko Lakes. A, umbilical diameter (UD) versus shell diameter (D). B, whorl width whorl height (WWWH) versus shell diameter. C, primary ribs per half whorl (PRHW) versus shell diameter (D).



**Figure 7.14.** Plots of measurements of species of *Paracaloceras* (*P.*), *Metophioceras* and *Schreinbachites* (*S.*) from Taseko Lakes. A, umbilical diameter (UD) versus shell diameter (D). B, whorl width whorl height (WWWH) versus shell diameter. C, primary ribs per half whorl (PRHW) versus shell diameter (D).

**Figure 7.15.** Ranges of Hettangian ammonites known from Taseko Lakes as established in other regions. Numbered zones and subzones are the same as in Figure 2. All taxa listed in the systematics section are considered. Open nomenclature is not considered. Genus abbreviations: *A.*-*Alsatites*; *An.*-*Angulaticeras*; *B.*-*Badouxia*; *D.*-*Discamphiceras*; *E.*-*Eolytoceras*; *F.*-*Franziceras*; *G.*-*Gyrophioceras*; *N.*-*Nevadaphyllites*; *P.*-*Paracaloceras*; *Ph.*-*Phylloceras*; *Ps.*-*Pseudaetomoceras*; *S.*-*Schlotheimia*; *Su.*-*Sunrisites*; *T.*-*Togaticeras*. Sources: B63 – Blind (1963); B79 – Bloos (1979); B83 – Bloos (1983); B84 – Braga *et al.* (1984); B88 – Bloos (1988a); B94 – Bloos (1994); B99 – Böhm *et al.* (1999); C82 – Canavari (1882); D95 – Dommergues *et al.* (1995); F64 – Frebold (1964); G95 – Guex (1995); GF90 – Guérin-Franiatte (1990); H00 – Hillebrandt (2000*b-c*); H04 – Hall and Pitaru (2004); HA00 – Hall *et al.* (2000); I81 – Imlay (1981); J94 – Jakobs and Pálffy (1994); K00 – Kment (2000); L52 – Lange (1952); L06 – Longridge *et al.* (2006); LinP – Longridge *et al.* (in press); M02; Meister *et al.* (2002*a*); P94 – Pálffy *et al.* (1994); P99 – Pálffy *et al.* (1999); P01 – Pálffy *et al.* (2001); P02 – Page (2002); R93 – Rakús (1993); R99 – Rakús (1999); RL93 – Rakús and Lobitzer (1993); S00 – Smith and Tipper (2000); S04 – Stevens (2004); T94 – Tipper and Guex (1994); T98 – Taylor (1998); T00 – Taylor (2000); T01 – Taylor *et al.* (2001); T02 – Taylor and Guex (2002); V85 – Venturi (1985); W86 – Wähner (1886); YinP – Yin *et al.* (2007).



- Taseko Lakes (T.L.) Mineralense Zone (M.Z.)  
 T.L. Rursicostatum Zone (R.Z.)  
 T.L. M.Z./R.Z.  
 T.L. M.Z. Zonal level in other area uncertain (u.z.i.)  
 T.L. M.Z. uncertain species ID. in other area (u.s.i.)  
 Correlative taxa ranges into Columbae Zone in T.L.  
 Correlative taxa may range into Columbae Zone in T.L.
- T.L. R.Z. u.z.i.  
 T.L. R.Z./M.Z. u.z.i.  
 T.L. R.Z. u.s.i.  
 T.L. M.Z./R.Z. u.s.i./u.z.i.  
 T.L. R.Z. u.s.i./u.z.i.  
 talus from T.L.

**Plate 7.1.** All specimens from the Last Creek Formation. Except for 1-2, 19-20 and 30-31 all figures are  $\times 0.9$ .

Figures 1-2, *Nevadaphyllites psilomorphus* (Neumayr), GSC 127417, hypotype; Rursicostatum Zone, GSC loc. no. C-118700, Sec. B, loc. 06;  $\times 0.45$ .

Figs 3-4, *Eolytoceras constrictum* sp. nov., GSC 128984, paratype; GSC loc. no. C-143295, Sec. A, talus.

Figures 5-6, *Nevadaphyllites psilomorphus* (Neumayr), GSC 127418, hypotype; Rursicostatum Zone, GSC loc. no. 143319, Sec. A, loc. 04.

Figures 7-8, *Eolytoceras* aff. *guexi* Taylor, GSC 127447, Mineralense Zone, GSC loc. no. C-143337, Sec. C, loc. 03.

Figures 9-10, *Fergusonites hendersonae* sp. nov., GSC 127423, holotype; Rursicostatum Zone, GSC loc. no. 62362, Sec. A, loc. 06.

Figures 11-12, *Togaticeras* aff. *goisernense* Rakús, GSC 127426; Mineralense Zone, GSC loc. no. C-177632, Sec. A, loc. 02.

Figures 13-14, *Nevadaphyllites microumbilicatus* Taylor, GSC 127422, hypotype; Rursicostatum Zone, GSC loc. no. C-143296, Sec. B, loc. 02.

Figures 15-16, *Nevadaphyllites microumbilicatus* Taylor, GSC 127421, hypotype; Rursicostatum Zone, GSC loc. no. C-208992, Sec. A, loc. 09.

Figures 17-18, *Eolytoceras* aff. *guexi* Taylor, GSC 127448, Mineralense Zone, GSC loc. no. C-143322, Sec. D, talus.

Figure 19, *Eolytoceras chongi* Hillebrandt, GSC 127437, hypotype; GSC loc. no. C-143295, Sec. A, talus;  $\times 0.675$ .

Figure 20, *Eolytoceras tasekoi* Frebold, GSC 127427, hypotype; Rursicostatum Zone, GSC loc. no. C-175372, Sec. D, loc. 02;  $\times 0.675$ .

Figures 21-22, *Togaticeras togatum* (Neumayr), GSC 127425; hypotype; Mineralense Zone, GSC loc. no. C-177632, Sec. A, loc. 02.

Figure 23, *Eolytoceras tasekoi* Frebold, GSC 127428, hypotype; Rursicostatum Zone, GSC loc. no. C-118700, Sec. B, loc. 06.

Figures 24-25, *Eolytoceras constrictum* sp. nov., GSC 128985; Rursicostatum Zone, holotype; GSC loc. no. C-208961, Sec. A, loc. 15.

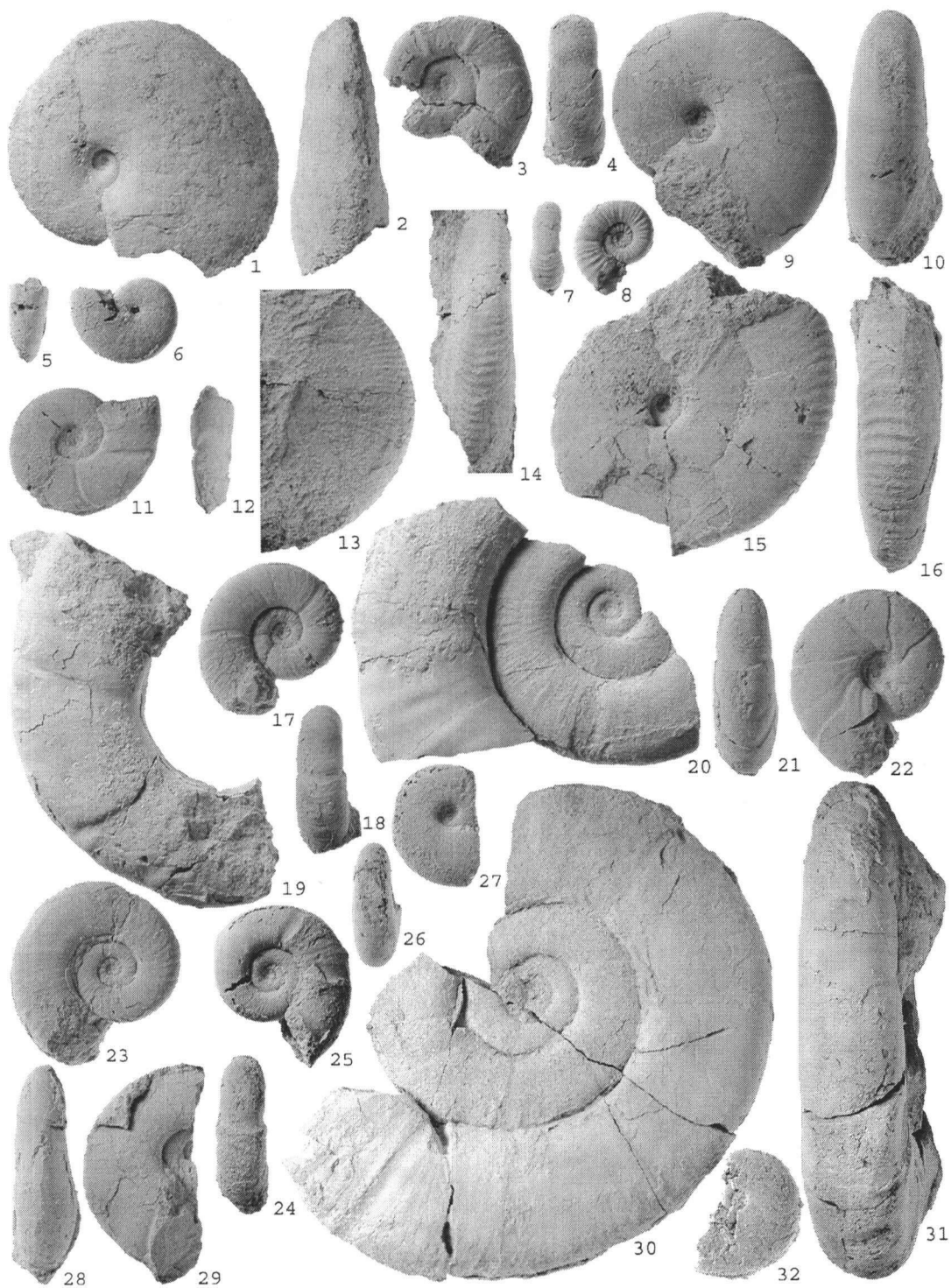
Figures 26-27, *Phylloceras* cf. *asperaense* Hillebrandt, GSC 127416; Mineralense Zone, GSC loc. no. C-143323, Sec. D, loc. 01.

Figures 28-29, *Nevadaphyllites* aff. *compressus* Guex, GSC 127420; Rursicostatum Zone, GSC loc. no. C-118700, Sec. B, loc. 06.

Figures 30-31, *Eolytoceras chongi* Hillebrandt, GSC 127436; Rursicostatum Zone, hypotype; GSC loc. no. C-175372, Sec. D, loc. 02;  $\times 0.45$ .

Figure 32, *Fergusonites hendersonae* sp. nov., GSC 127424, paratype; Rursicostatum Zone, GSC loc. no. C-208992, Sec. A, loc. 09.





**Plate 7.2.** All specimens from the Last Creek Formation. Except for 1-2 and 19-22 all figures are  $\times 0.9$ .

Figures 1-2, *Paracaloceras* sp. A, GSC 129053; Rursicostatum Zone, GSC loc. no. C-62499, Sec. A, loc. 08;  $\times 0.54$ .

Figures 3-4, *Schreinbachites* (?) aff. *laqueoides* (Hyatt), GSC 129063; Rursicostatum Zone, GSC loc. no. 118700, Sec. B, loc. 06.

Figures 5-6, *Paracaloceras* (?) sp., GSC 129060; Rursicostatum Zone, GSC loc. no. C-117234, Sec. B, loc. 05.

Figures 7-8, *Discamphiceras* aff. *silberlingi* Guex, GSC 128991; Mineralense Zone, GSC loc. no. C-143323, Sec. D, loc. 01.

Figures 9-10, *Schreinbachites* (?) aff. *laqueoides* (Hyatt), GSC 129064; Rursicostatum Zone, GSC loc. no. 118699, Sec. B, loc. 05.

Figures 11-12, *Discamphiceras* sp. nov., GSC 129003; Rursicostatum Zone, GSC loc. no. C-143319, Sec. A, loc. 04.

Figure 13, *Discamphiceras* sp. nov., GSC 129002; Mineralense Zone, GSC loc. no. C-143323, Sec. D, loc. 01; rubber peel of external mould.

Figure 14, *Discamphiceras* aff. *silberlingi* Guex, GSC 128990; Mineralense Zone, GSC loc. no. C-143323, Sec. D, loc. 01; rubber peel of external mould.

Figures 15-16, *Paracaloceras* (?) sp., GSC 129061; Rursicostatum Zone, GSC loc. no. C-175372, Sec. D, loc. 02.

Figures 17-18, *Discamphiceras silberlingi* Guex, GSC 128993; Rursicostatum Zone; hypotype; GSC loc. no. C-208991, Sec. A, loc. 05.

Figure 19, *Paracaloceras rursicostatum* Frebold, GSC 129034, hypotype; Rursicostatum Zone, GSC loc. no. C-143319, Sec. A, loc. 04;  $\times 0.54$ .

Figure 20, *Discamphiceras silberlingi* Guex, GSC 128992; hypotype; GSC loc. no. 143295, Sec. A, talus;  $\times 0.75$ .

Figures 21-22, *Paracaloceras rursicostatum* Frebold, GSC 129035, hypotype; Rursicostatum Zone, GSC loc. no. C-94770, Sec. A, loc. 17;  $\times 0.54$ .

Figures 23-24, *Gyrophioceras* cf. *mineralense* Taylor, GSC 129033; Mineralense Zone, GSC loc. no. C-143337, Sec. C, loc. 03.



**Plate 7.3.** All specimens from the Last Creek Formation. All figures are  $\times 0.9$ .

Figures 1-2, *Pseudaetomoceras victoriense* sp. nov., GSC 129023; holotype; Rursicostatum Zone, GSC loc. no. C-175326, Sec. A, loc. 13.

Figure 3-4, *Schlotheimia* cf. *cuevitensis* Hillebrandt, GSC 129027; Mineralense Zone, GSC loc. no. 143337, Sec. C, loc. 03.

Figure 5, *Pseudaetomoceras victoriense* sp. nov., GSC 129024; paratype; Rursicostatum Zone, GSC loc. no. C-143319, Sec. A, loc. 04.

Figures 6-7, *Alsatites* sp., GSC 129019; Rursicostatum Zone, GSC loc. no. C-143319, Sec. A, loc. 04.

Figures 8-9, *Alsatites* aff. *bipartitus* (Hillebrandt), GSC 129014; Mineralense Zone, GSC loc. no. C-143337, Sec. C, loc. 03.

Figures 10-11, *Schlotheimia* cf. *cuevitensis* Hillebrandt, GSC 129028; Mineralense Zone, GSC loc. no. 143337, Sec. C, loc. 03.

Figure 12, *Alsatites* aff. *bipartitus* (Hillebrandt), GSC 129013; Mineralense Zone, GSC loc. no. 177632, Sec. A, loc. 02.

Figures 13-14, *Alsatites* sp., GSC 129021; Mineralense Zone, GSC loc. no. C-117491, Sec. C, loc. 03.

Figures 15-16, *Alsatites* sp., GSC 129066; Mineralense Zone, GSC loc. no. C-143337, Sec. C, loc. 03.

Figure 17, *Pseudaetomoceras* sp., GSC 129026, GSC loc. no. C-117249, Sec. C, talus.

Figures 18-19, *Franziceras* aff. *graylockense* Taylor, GSC 129030, GSC loc. no. C-143287, isol. loc. 3.

Figure 20, *Franziceras* aff. *graylockense* Taylor, GSC 129029, GSC loc. no. C-208990, Sec. C, talus.

Figure 21, *Alsatites* sp., GSC 129020; Mineralense Zone, GSC loc. no. C-117232, Sec. C, 01.

Figures 22-23, *Pseudaetomoceras* cf. *castagnolai* (Cocchi), GSC 129022, GSC loc. no. C-175327, isol. loc. 2, talus.



**Plate 7.4.** All specimens from the Last Creek Formation. Except for 1-2, 5, 8-9 and 11-13 all figures are  $\times 0.9$ .

Figures 1-2, *Metophioceras* (?) sp., GSC 129062; Rursicostatum Zone, GSC loc. no. C-143327, Sec. D, loc. 02;  $\times 0.54$ .

Figures 3-4, *Paracaloceras* sp. B, GSC 129057; Rursicostatum Zone, GSC loc. no. 175388, Sec. B, loc. 04.

Figures 5, 11, *Paracaloceras* aff. *varaense* Hillebrandt, whorl fragments from same specimen, GSC 129049; Rursicostatum Zone, GSC loc. no. C-143317, Sec. A, loc. 07; 5.  $\times 0.45$ ; 11.  $\times 0.675$ .

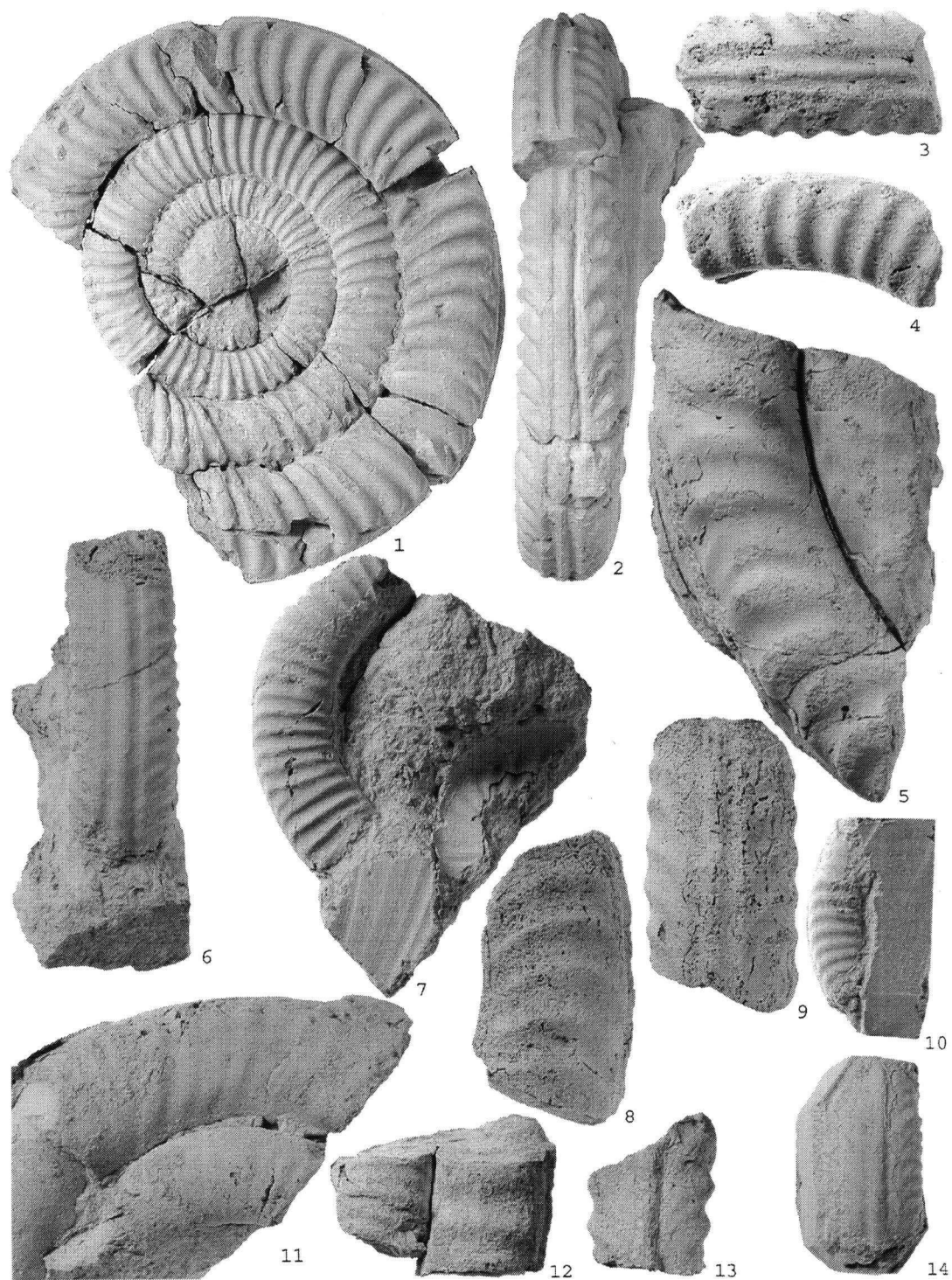
Figures 6-7, *Paracaloceras* aff. *varaense* Hillebrandt, GSC 129051, GSC loc. no. 208984, Sec. B, talus.

Figures 8-9, *Paracaloceras* sp. B, GSC 129059; Rursicostatum Zone, GSC loc. no. 118699, Sec. B, loc. 05;  $\times 0.675$ .

Figures 10, 14, *Paracaloceras* aff. *varaense* Hillebrandt, GSC 129050; Mineralense Zone, GSC loc. no. C-117237, Sec. A, loc. 03.

Figures 12-13, *Paracaloceras* aff. *varaense* Hillebrandt, 129048, GSC loc. no. C-143322, Sec. D, talus;  $\times 0.45$ .





## 7.7 References

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# 8 THE IMPACT OF ASYMMETRIES IN THE ELEMENTS OF THE PHRAGMOCONES OF EARLY JURASSIC AMMONITES<sup>1</sup>

## 8.1 Introduction

Counterbalance mechanisms were prevalent in straight-shelled Paleozoic cephalopods such as Actinoceratoids and Endoceratoids (Westermann 1998). These groups used calcium carbonate to weight their distal ends in order to orientate their soft bodies away from the dangers of the substrate while improving their hydrodynamic efficiency when moving across the ocean floor. Once cephalopod shells began to coil in the middle Paleozoic, counterbalance mechanisms became obsolete. However, some Jurassic ammonites have asymmetries in the elements of their phragmocone which raises the question as to whether a counterbalance mechanism was in effect, allowing the animal to remain upright in the water column.

Following the end-Triassic mass extinction, *Psiloceras* formed the root stock for the Jurassic and Cretaceous ammonite radiation (e.g. Guex 2006). In a typical planispirally coiled ammonite, the siphuncle usually ran centrally along the venter of the shell within the plane of bilateral symmetry. However, in many species of Jurassic ammonites, it has long been recognized that the siphuncle can be considerably offset to one side (e.g., Canavari 1882; Swinnerton and Trueman 1917; Spath 1919; Hölder 1956; Hengsbach 1986*a, b*; Guex 2001). Although some researchers believed it was of no biological importance (e.g. Diener 1912), several biological explanations have been proposed. Spath (1919, p. 116, 118 and references therein) suggested it may be one line of evidence of an attempt to change a bilaterally symmetric swimmer into a crawling benthic organism. In the case of flat ventered shells, Swinnerton and Trueman (1917) hypothesized that asymmetry allowed the siphuncle to take up a stable position along the

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ventrolateral shoulder. Hengsbach (1979, 1986a, b, 1991, 1996) proposed that an asymmetric siphuncle may be due to the presence of parasites in early ontogeny that caused displacement of the root of the siphuncle. Recent work has highlighted the role of external stress in increasing the rate of gene mutation and recombination as well as in the initiation of asymmetries (Williamson 1981; Hoffman and Parsons 1991). It seems possible that environmental stress in the earliest Jurassic may have generated asymmetry of the siphuncle in the ammonite root stock (Guex 2001). Subsequently, this character persisted intermittently within the Jurassic part of the ammonoid evolutionary radiation.

The attitude of an ammonite in the water column is a product of the location of its centres of buoyancy and mass (Trueman 1941). While the position of the centre of buoyancy is unaffected by changes within the conch, the centre of mass is dependant on the volume, density and position of individual components. Ammonites with offset siphuncles have expansion in the elements of the septal suture line on the non-siphuncle side (Fig. 8.1C). It seems possible that the displaced mass caused by the offset siphuncle may have been balanced by the mass of expanded septal faces on the opposite side of the conch, permitting the animal to stay vertical in the water. We use computer models of the earliest Sinemurian ammonite, *Badouxia columbiae* (Frebold 1967) to examine the hydrostatic implications of these siphuncular and septal face asymmetries.

## 8.2 Methods

We developed two types of computer model. The first (model 1), of a single septal face and one chamber length of siphuncle, was used to examine the effects of asymmetry within a single chamber of the ammonite's phragmocone. The second type of model is of a complete ammonite which allowed us to examine the potential effects of phragmocone asymmetries on the entire ammonite animal. In this case, two models of different shell diameter were constructed (models

2 and 3) permitting analysis of the impact of phragmocone asymmetries at different growth stages. All measurements were taken from specimens of *B. columbiae*. Abbreviations and measurements follow Smith (1986) and include maximum shell diameter (DMAX) and whorl height (WH). Details of model construction are given below.

### **8.2.1 Model 1 – Components within a single phragmocone chamber**

#### **8.2.1.1 Scanned fragment.**

Model 1 was based on an ammonite whorl fragment that had a well exposed septal face (GSC 131683, Fig. 8.1A-B). A three-dimensional scan of this fragment was created at Memorial University in St. John's, Newfoundland using a FARO platinum arm with laser line probe. Details of the scanner can be found at <http://www.faro.com/content.aspx?ct=uk&content=pro&item=1>. The scanned data were imported into the three-dimensional CAD modeling program and surface triangulation software, Geomagic. In this program, the scanned model was edited to create a three-dimensional outline of the fossil (Fig. 8.2A). Digital processing error and surface imperfections such as minor surface cracks caused by weathering were smoothed out manually. The fossil outline was exported to the surface modeling and engineering analysis software called Rhinoceros which is capable of calculating a range of geometric properties including volumes and surface areas of various geometries. Details of the program can be found at <http://www.rhino3d.com>. Several different cross-sections were taken to check for symmetry about the centreline (Fig. 8.2B). The whorl shape was found to be symmetric within reasonable error (Table 8.1).

#### **8.2.1.2 Single septal face**

Using Geomagic, the septal face was lifted off the fossil scan. Due to erosion, the ventral tips of the saddles were missing from the scan. Thus, the geometry extending from approximately the outer third of the septal face to the suture line had to be reconstructed. To do this, the outermost edges of the scanned septal face were cropped off and the innermost two-thirds of the

septal face were imported into the computer program Rhinoceros. The septal suture line directly preceding the scanned septal face (Fig. 8.1A) was used in combination with parts of a suture line from another specimen where necessary, to create a complete suture line (Fig. 8.1C). This two-dimensional suture line was projected onto the scanned shell and scaled to ensure the peaks and saddles correlated with the septal face and identifiable landmarks on the scan. Approximately 1500 lines tangent to the edge of the septal face were hand-drawn, joining the edge of the septal face to the suture line. Finally, a surface was lofted through these lines resulting in a complete septal face, composed of the scanned central part with modeled edges extending out to the superimposed suture line (Fig. 8.2C-D).

In order to calculate their thickness, thin sections were cut perpendicular to the septal faces (Fig. 8.3A) at three different shell diameters. It is well recognized that ammonite septal faces thin from the centre towards the margins of the shell (Westermann 1971). This was accounted for by measuring the thickness at the middle of each septal face as well as the thickness of the very outside edge. These thicknesses were then plotted against whorl height and the average of the two values was used to represent the thickness of the septal face at a given whorl height (Fig. 8.4A). It is well documented that ammonite septa were composed principally of aragonite (e.g. Kulicki 1996) which has usually reverted to calcite during diagenesis. Analysis of the measured septal faces using x-ray diffraction confirmed they had altered to calcite. As calcite is thicker than aragonite, the thicknesses taken from the septal face thickness chart discussed above (Fig. 8.4A) were reduced by 7.6% before being included in the model. This percentage was calculated using the following equations:

If density = mass/volume and mass is constant then

Equation 1. Volume calcite (A) =  $1 \text{ g} / 2.71 \text{ g/cm}^3 = 0.369 \text{ cm}^3$

Equation 2. Volume aragonite (B) =  $1 \text{ g} / 2.93 \text{ g/cm}^3 = 0.341 \text{ cm}^3$

Equation 3.  $A/B \times 100\% = 108.2\%$

Equation 4.  $1-(100\%/108.2\%) \times 100\%= 7.6\%$

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The area of the septal face was obtained using a built-in function within the Rhinoceros software. By multiplying the septal face surface area from the model by the adjusted thickness from the graph, a volume was established for the ammonite septal face (Table 8.2). The density used for the septal face was the same as for the shell (2.670 g/mL, Hewitt and Westermann 1996) and was used in combination with the volume to produce a mass of about 4.119 g for the modeled septal face (Table 8.2).

#### 8.2.1.3 Single chamber length of siphuncle.

The length of siphuncle within a single chamber was measured directly from the scanned fragment (25.7 degrees, 33.8 mm, Fig. 8.1). In order to calculate the diameter of the siphuncle, five polished thin sections were cut perpendicular to the siphuncle at different whorl heights (Fig. 8.3B). In each case, the siphuncle diameter was then measured and plotted against whorl height (Fig. 8.4B). A best fit line was applied to this graph and measurements were taken from this line to assign the siphuncle diameter to the model. A recent study of Cretaceous phylloceratids found that as ammonites grew, new siphuncular tissue was added in front of the last formed septum (Tanabe *et al.* 2005). Based on this, the centre of the chamber length of the siphuncle in our model was added such that it intersected the septal face. Using the model, the volume was determined by capping each end of the siphuncle and using a built-in function in Rhinoceros (Table 8.2). The siphuncular tube consists of conchiolin membranes and is very thin (Westermann 1971; Tanabe *et al.* 2005). It is primarily filled with blood vessels and surrounding epithelium (Tanabe *et al.* 2000). For this reason, the density of the siphuncle was taken as 1.055g/mL, the same as the density of the soft body of *Nautilus* (Saunders and Shapiro 1986). The product of density times volume produced a mass of about 0.239 g for the siphuncle on the model (Table 8.2).

#### 8.2.1.4 Cameral sheets.

Sheets of organic material have been discovered in the chambers of Triassic, Jurassic and Cretaceous ammonites (Grandjean 1910; Weitschat and Bandel 1991; Westermann 1992; and references therein) and may have been present in *B. columbiae*. Thus, cameral sheets are included mathematically in model 1 as a separate, optional component. Cameral sheets are broadly divided into three groups: horizontal sheets, siphuncular sheets and transverse sheets (Weitschat and Bandel 1991). Horizontal sheets are not included here as they are probably limited to Triassic ammonites with nearly spherical conchs (Westermann 1992). Siphuncular sheets are usually short and straight in Jurassic ammonites and probably functioned to attach the siphuncle to the inner shell wall whereas transverse sheets include all sheets that are subparallel to the septae including some that are suspended from the siphuncular tube (Weitschat and Bandel 1991). As both the latter two types of cameral sheets are associated with the siphuncle, in cases where the siphuncle is offset to one side, their mass would also have been displaced. Cameral sheets probably occupied a total of about 14% of cameral space (Hewitt and Westermann 1996; Kröger 2002). In model 1, 9.5% of cameral space is considered to be occupied by cameral sheets (as horizontal sheets were not present). The siphuncular sheets would have been completely offset as they surrounded the siphuncle (3% of chamber volume was allocated for these). In addition, a portion of the transverse sheets would also have been offset as some of these are suspended from the siphuncle (1.5% of chamber volume was allocated for these). Thus, in the model, 4.5% of the volume of the chambers was considered to be taken up by cameral sheets that are offset whereas the remaining 5% of chamber volume was considered to be occupied by cameral sheets that were considered central. Total chamber volume was determined directly from the model using the built-in function in Rhinoceros (Table 8.2). As cameral sheets are believed to have been organic in composition (e.g. Erben and Reid 1971; Weitschat and Bandel 1991 and references therein) and saturated with cameral liquid

(Kröger 2002), the density of the cameral sheets is considered to be 1.055g/mL, the same as the soft tissue of *Nautilus* (Saunders and Shapiro 1986). The product of density times 9.5% of total modeled chamber volume produces a mass of about 3.645 g for the cameral sheets (Table 8.2).

#### 8.2.1.5 Complete model.

Except for the optional cameral sheets that are only included in calculations, the complete model is shown in Figure 8.5. The position of the centroids of the septal face and siphuncle were calculated from the model using a built-in function within the Rhinoceros software (Fig. 8.5B). In this paper, the centroid of a component is taken as its geometric centre. In the case of the models discussed herein, all the components are considered to have had a uniform density. Thus, the centroid coincides with the centre of mass and the two terms are used interchangeably throughout the paper. For the cameral sheets, the position of the centroid is taken as the average offset distance of all the sheets weighted according to the percentages discussed above (Fig. 8.5B). The distances of offset from the centre line are indicated on the septal face in Table 8.2.

#### **8.2.2 Model 2 - Entire ammonite animal at 300 mm shell diameter**

To investigate how these asymmetries affected the entire ammonite animal, a three-dimensional model of a specimen of large shell diameter was constructed (model 2, DMAX = 300 mm). Required data included whorl dimensions as well as the surface area, thickness and number of septal faces, siphuncle diameter, shell thickness and body chamber length. Procedures used to calculate each of these components are addressed below. Direction notations for the model are indicated in Figure 8.6.

##### 8.2.2.1 Whorl dimensions.

The inner and intermediate portion of the model was created using measurements taken from the specimen of *B. columbiae* shown in Figure 8.7A (GSC 127377, DMAX = 197 mm). In addition, a fragment of the outer whorl of a large, incomplete specimen (Fig. 8.7B, GSC 131683, WH = 132.6 mm) was used to provide information for the model at large shell

diameter. This whorl fragment is from the same ammonite as the scanned fragment used as the basis for model 1 but is 360 degrees larger in size. Measurements of the distance of the generating curve from the coiling axis (Raup 1967), whorl height and whorl width were measured at a number of positions and used to provide the model dimensions. These measurements were plotted as a function of angle. The 0 degree position in the model was set as the start of the shell at maximum shell diameter ( $DMAX = 300 \text{ mm}$ ) and the first  $360^\circ$  of rotation is termed the first whorl. In other words, the angular position increases proceeding towards the umbilicus (Fig. 8.8A). The original cross-section from the scan was scaled in width and height to match the curve fit through the measured values at 45 degree increments (Fig. 8.8B). A total of seven whorls for an angle index up to 2520 degrees were drawn; however, given the very small size of the innermost whorl ( $DMAX = 1.2 \text{ mm}$ ), only the first six whorls (up to 2160 degrees) were modeled in detail and used for analysis.

#### 8.2.2.2 Septal face surface area, thickness and number.

Model 1 provided a septal face surface area of  $5098.515 \text{ mm}^3$  for a whorl height of 62.298 mm. In order to examine how septal face surface areas changed through ontogeny, two more septal face surface areas were needed. Each of these was calculated using the following equations:

Equation 1. If unknown septal face surface area = A, unknown whorl cross-section surface area = B, septal surface area of scanned face = C and scanned whorl cross-section surface area = D then  $A = (C \times B)/D$ .

However, A needs to be adjusted to take into account the simplification of the suture line as shell diameter decreases using a simplification factor (Equations 2-4).

Equation 2. If suture line length of unknown septal face = E and whorl perimeter length of unknown face = F then  $E/F = G$ .

Equation 3. If suture line length of scanned septal face = H and whorl perimeter length of scanned septal face = I then  $H/I = J$ .

In order to calculate the suture line length for Equations 2 and 3, the suture lines were drawn, flattened and then measured.

Equation 4. The simplification factor is  $G/J = K$ .

Equation 5. Therefore, the actual unknown septal face surface area (L) =  $A \times K$ .

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The two calculated surface areas as well as the septal face surface area from the scanned specimen were then plotted against whorl height (Fig. 8.9A). A curve was fitted through the three values to allow for a septal surface area estimate for each septum.

The best fit line off the graph of septal face thickness versus whorl height described for model 1 was used to assign a thickness to each septal face (Fig. 8.4A). As discussed above, the thicknesses shown on Figure 8.4A were reduced by 7.6% before being included in the model to account for the change of thickness when aragonite was altered to calcite. The number of septal faces per 360 degrees was counted in a specimen at several ontogenetic stages and then plotted against the whorl height measured at the large end of each revolution (Fig. 8.9B). For the purposes of model construction the average number of septal faces per whorl was taken as 14 and they were placed every 25.7 degrees behind the septal face at the back of the body chamber.

#### 8.2.2.3 Siphuncle diameter.

For model 1, the best fit line for the graph of siphuncle diameter plotted against whorl height was used to assign diameters to the siphuncle in the model (Fig. 8.4B).

#### 8.2.2.4 Shell thickness.

A single specimen with its shell intact was used for shell thickness measurements (Fig. 8.10, GSC 127319). Following the method used by Kröger (2002), measurements were taken at 6 different whorl heights. In each case, fragments of shell were removed by hand from 5 different



areas of the whorl; specifically, the umbilical shoulder, lower flank, midflank, upper flank and venter. Each fragment was measured using microcalipers. The average of the 5 measurements was calculated and the average thickness value was plotted against whorl height (Fig. 8.9C). A curve was fit through the measured values to allow for a shell thickness estimate at each 45 degree increment. There was a slight increase in shell thickness on the innermost whorls due to the presence of ribs in the shell (Fig. 8.9C). Similar to the data on septal face thicknesses, the thicknesses shown on Figure 8.9C were reduced by 7.6% before being included in the model to account for the change of thickness of the shell when aragonite altered to calcite during diagenesis.

#### 8.2.2.5 Cameral sheets.

Similar to the single septal face model described above, cameral sheets were considered as an optional component in the model.

#### 8.2.2.6 Body chamber length.

Body chamber length was measured at two different shell diameters. In the first case, a body chamber length of 284 degrees was measured directly off a small specimen (Fig. 8.9D, GSC 131684, WH = 25 mm). In the second case, the body chamber length had to be estimated because complete specimens of *B. columbiae* at large shell diameters are unknown. The large fragment used to create the model has approximating septa and is the final portion of a mature phragmocone (Fig. 8.7B, GSC 131683, WH = 132.6 mm). This fragment was used in combination with a second incomplete specimen where the final portion of phragmocone is missing but the body chamber is present (Fig. 8.7C, GSC 127056). By inferring the position of the septate fragment, a body chamber length of *c.* 285 degrees was obtained. Because both the observed and calculated body chamber lengths were very similar, a length of 285 degrees was adopted for the model.

#### 8.2.2.7 Model assembly.

Once the dimensions of all the components were obtained, the model was assembled using the Rhinoceros software. Whorls (containing shell and siphuncle outline) of similar absolute angle (i.e. 0, 360, 720, etc. degrees) were fitted together and rotated into position. Surfaces were then lofted over the shell, body and siphuncle outlines and ends were put onto the lofted surfaces to make volume calculations possible (Fig. 8.8B). Finally, the model was divided into whorl or half-whorl portions to facilitate easy removal for work on smaller specimens.

#### 8.2.2.8 Component masses and positions.

Volumes were obtained from the model for the shell, siphuncle and body chamber using functions built into the software (Table 8.3). The total volume of the septae was calculated as the product of the surface areas times thicknesses (Table 8.3). To obtain the volume of cameral sheets, total chamber volume was calculated by subtracting the volume of the septae from the total volume of the interior of the phragmocone obtained from the model. As in model 1, the volume of cameral sheets was included at 4.5% offset with a total of 9.5 % of chamber volume being filled. Similar to model 1, the density used for the septal faces and shell was 2.670 g/mL (Hewitt and Westermann 1996) whereas the density used for the siphuncle, cameral sheets and body chamber was 1.055g/mL (Saunders and Shapiro 1986). Density times volume provided the mass of each component (Table 8.3). The position of the centroid of each individual component in the X, Y and Z plane with respect to the origin is given in Table 8.3 (Fig. 8.11). The origin (X, Y, Z = 0, 0, 0) is the very centre of the model. In the innermost whorl, the position of the siphuncle is variable but by the next whorl the position of the siphuncle is reasonably stable and the suture line is consistently expanded on the non-siphuncle side and reduced on the siphuncle side. Thus, we considered the offset distances of the siphuncle, septal faces and cameral sheets to be the same as in model 1 (Table 8.2). Finally, the data for each component was combined and centres of buoyancy and mass were calculated for the entire ammonite animal. The centres

of mass (total X, Y and Z coordinates in Table 8.4) and buoyancy (displacement in Table 8.4) are shown in Figure 8.12. The final X, Y and Z coordinates are calculated from the total weighted coordinate for each axis divided by the total mass of the animal.

### **8.2.3 Model 3 - Entire ammonite animal at 54 mm maximum shell diameter**

To investigate how these asymmetries affected the entire ammonite animal at different growth stages, a three-dimensional model of a complete, small ammonite animal was also created (model 3, DMAX = 54 mm). Model 3 was constructed by removing the outer two whorls from model 2 and altering the position of the body chamber. The volumes were calculated using the same methods described above for model 2 and the densities used for each component are the same as in model 2 (Table 8.5). Volumes, masses and relative positions of the centroids of each component in the X, Y and Z plane are given in Table 8.5 whereas the positions of the centres of buoyancy (displacement) and mass (final X, Y and Z coordinates) are provided in Table 8.6. Once again, cameral sheets are kept optional.

## **8.3 Results and Discussion**

Ammonoids are considered to be only very slightly negatively buoyant (Westermann 1996 and references therein), yet model 2 (DMAX = 300 mm) is 3.64 % negatively buoyant if cameral membranes are not included and 4.88 % negatively buoyant if cameral membranes are included (Table 8.4). Similarly, model 3 (DMAX = 54 mm) is 1.54 % negatively buoyant if cameral membranes are not considered and 2.76 % negatively buoyant if cameral membranes are considered (Table 8.6). This discrepancy may be due to inaccuracies in the densities used for individual components, diagenetic alteration of the original material that affected the measurements or human error. Alternatively, as in most studies of ammonoid hydrostatics, we considered the body chamber to be completely full of soft tissue and this may not be accurate (Kröger 2002). Finally, the indirect method used to ascertain the mature body chamber length as

discussed above may have led to an overestimate in length. Juvenile Ammonitina generally have a longer body chamber than adult shells (Westermann 1971; Lehmann 1981) whereas in our models, the body chamber length was held constant at 285 degrees. Although model 2 does not represent a mature specimen, it does represent a specimen that is much larger than is represented in model 3 and it is possible that it would have had a shorter body chamber. This may explain the increased error in model 2 compared to model 3. Whatever the cause, these discrepancies in mass are not very large and do not have a significant affect on the results of our study.

Model 1 suggests a counterbalance mechanism may have been present which allowed the animal to remain upright with its plane of bilateral symmetry vertical in the water column. When only the siphuncle and septal face are considered, the moment created by the septal face offsets about 297 % of the moment created by the siphuncle (Table 8.2). In this case the model leans away from the direction of the siphuncle. When the optional cameral sheets are included in the model, the moment created by the septal face offsets about 36 % of the moment created by the siphuncle and cameral sheets (Table 8.2). In this case the model leans toward the siphuncle. In both cases, although the correction is not perfect, it does suggest a counterbalance may have been in effect.

In the large model of the complete ammonite (model 2), each component of the animal has a very different centre of mass (Table 8.3; Fig. 8.11). However, the masses of the asymmetric components in the ammonite phragmocone are very low when compared to the mass of the entire animal. When cameral sheets are not considered, the mass of the siphuncle is less than 0.1 % and the septal face mass is about 1.4 % of the total mass of the animal (Tables 8.3-8.4). When cameral sheets are considered, the mass of the siphuncle is less than 0.1 %, the septal face mass is about 1.4 % and the cameral sheets made up approximately 1.2 % of the total mass of the animal (Tables 8.3-8.4). The offset of the centre of mass in the Z-plane (indicated by the final Z-coordinates in Table 8.4) is very small (0.010 mm if cameral membranes are not considered and

0.021 mm if cameral membranes are considered). The size of these numbers is partially due to the correction discussed in model 1 where the position of the centroid of the siphuncle (and the centroid of the optional cameral sheets) is counterbalanced by the position of the centroid of the septal faces in the Z-plane (Table 8.3). Nevertheless, in terms of the whole model, removing the offset mass of the septal faces only changes the flotation angle by approximately 0.20 degrees. This figure is within our range of error and demonstrates that the effects of the asymmetries in the components of the phragmocone on flotation angle are virtually negligible at large shell diameters.

Although each component of the animal has a very different centre of mass in the small ammonite model (model 3; Table 8.5), the masses of the asymmetric components in the ammonite phragmocone are very low when compared to the mass of the entire animal, similar to the situation in the large model. When cameral sheets are not considered, the mass of the siphuncle is just over 0.1% and the septal face mass is just about 0.9% of the total mass of the animal (Tables 8.5-8.6). When cameral sheets are considered, the mass of the siphuncle is just over 0.1 %, the septal face mass is just under 0.9% and the cameral sheets made up approximately 1.2 % of the total mass of the animal (Tables 8.5-8.6). The final Z-coordinates are very small at -0.001 mm if cameral membranes are not considered and 0.005 mm if cameral membranes are considered (Table 8.6). Once again, the small size of these numbers is partially due to the correction discussed in model 1 where the position of the centroid of the siphuncle (and the centroid of the optional cameral sheets) is counterbalanced by the position of the centroids of the septal faces (Table 8.5). However, in terms of the whole model, removing the offset mass of the septal faces only changes the flotation angle by approximately 0.14 degrees. Similar to the large model, this figure is within our range of error and demonstrates that the affects of the asymmetries in the components of the phragmocone on flotation angle are virtually negligible at small shell diameters.

## 8.4 Summary and Conclusions

The centroids of the internal components of the phragmocone including septal faces, siphuncle and possibly cameral sheets were offset from the centre in the Sinemurian ammonite, *B. columbiae*. When only these asymmetric components are considered in isolation, a counterbalance mechanism seems to be present. The mass of the offset siphuncle (with optional cameral sheets) is at least partially corrected by the mass of the septal faces which is displaced in the opposite direction in the Z-plane. However, when the complete animal is considered at both large and small shell diameters, the individual components within the phragmocone are very small with respect to the mass of the entire animal and the effect of the offset components is virtually negligible. Thus, the existence of a weight-balancing mechanism seems unlikely. More probably, the asymmetry in the position of the siphuncle simply forced expansion of the suture line and associated septal folding on the opposite side. Although the displaced masses on either side of the plane of bilateral symmetry did counterbalance each other to some extent, their magnitude relative to the mass of the entire animal was inconsequential.

Cross-section number	Left half (mm)	Total (mm)	Percentage
1	19.12	38.09	50.20
2	19.44	38.71	50.22
3	19.69	39.09	50.37
4	19.45	39.00	49.87

**Table 8.1.** Measurements from the cross-sections in Figure 8.1B divided down the median line.

<b>Morphological component</b>	<b>Volume (mm<sup>3</sup>)</b>	<b>Density (g/cm<sup>3</sup>)</b>	<b>Mass (g)</b>	<b>Offset distance (mm)</b>	<b>Moment of force (g*mm)</b>
<b>siphuncle</b>	226.651	1.055	0.239	5.874	1.404
<b>septal face</b>	1542.704	2.670	4.119	1.011	4.164
<b>cameral sheets</b>	3455.450	1.055	3.645	2.782	10.140

**Table 8.2.** Volumes, densities, masses, offset distances and moments of force for the morphological components of model 1.



<b>Morphological component</b>	<b>Volume (mm<sup>3</sup>)</b>	<b>Density (g/cm<sup>3</sup>)</b>	<b>Mass (g)</b>	<b>X coordinate (mm)</b>	<b>Y coordinate (mm)</b>	<b>Z coordinate (mm)</b>
<b>siphuncle</b>	1978.881	1.055	2.088	31.008	-7.141	5.365
<b>septal face</b>	14826.396	2.670	39.586	20.675	-10.518	-0.960
<b>cameral sheets</b>	31957.961	1.055	33.716	26.110	-6.250	2.542
<b>shell</b>	219446.640	2.670	585.923	17.901	37.869	0
<b>body chamber</b>	2079203.712	1.055	2193.560	16.917	44.158	0

**Table 8.3.** Volumes, densities, masses and positions of individual X, Y and Z coordinates for each morphological component of model 2.

<b>Complete model</b>	<b>Mass (g)</b>	<b>X coordinate (mm)</b>	<b>Y coordinate (mm)</b>	<b>Z coordinate (mm)</b>
<b>without cameral membranes</b>	2821.157	17.185	42.046	-0.010
<b>with cameral membranes</b>	2854.873	17.290	41.476	0.021
<b>displacement</b>	2722.024	17.612	37.305	0

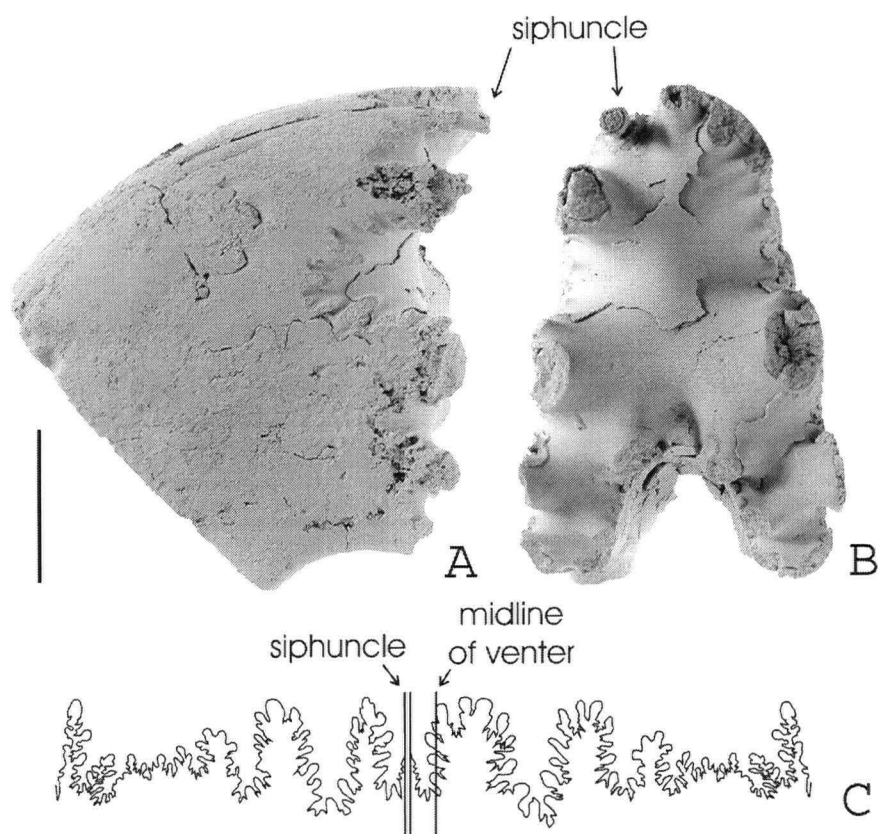
**Table 8.4.** Masses and positions of total X, Y and Z coordinates for model 2 (cameral sheets optional). Total displacement and position of centre of buoyancy is also indicated.

<b>Morphological component</b>	<b>Volume (mm<sup>3</sup>)</b>	<b>Density (g/cm<sup>3</sup>)</b>	<b>Mass (g)</b>	<b>X coordinate (mm)</b>	<b>Y coordinate (mm)</b>	<b>Z coordinate (mm)</b>
<b>siphuncle</b>	22.135	1.055	0.023	4.359	-1.005	0.962
<b>septal face</b>	62.883	2.67	0.168	3.339	-1.636	-0.203
<b>cameral sheets</b>	211.276	1.055	0.223	4.110	-1.058	0.456
<b>shell</b>	1254.856	2.67	3.350	6.443	6.097	0
<b>body chamber</b>	14319.351	1.055	15.107	3.091	7.912	0

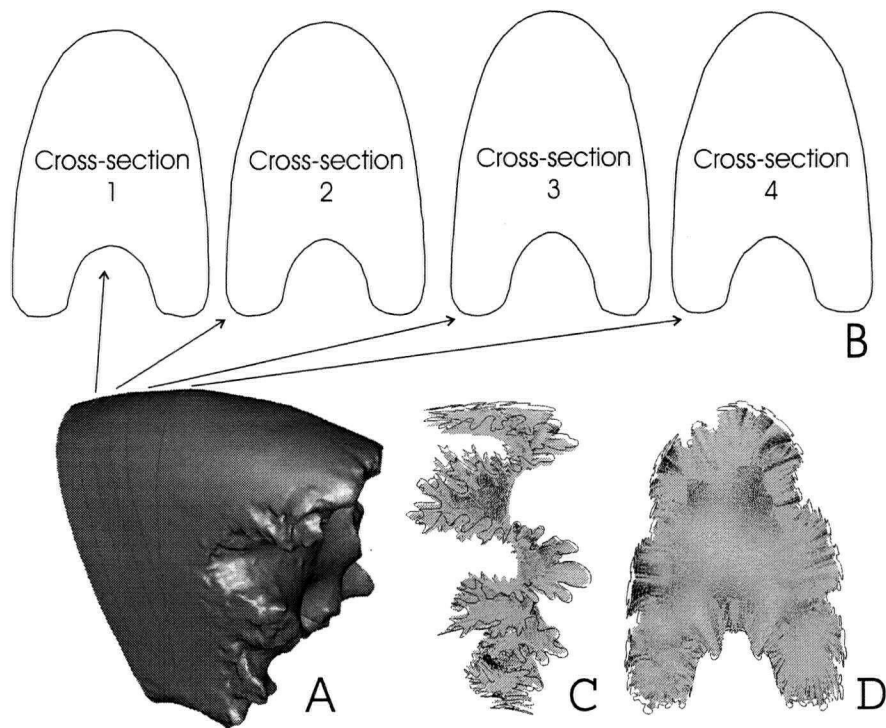
**Table 8.5.** Volumes, densities, masses and positions of individual X, Y and Z coordinates for each morphological component in model 3.

<b>Complete model</b>	<b>Mass (g)</b>	<b>X coordinate (mm)</b>	<b>Y coordinate (mm)</b>	<b>Z coordinate (mm)</b>
<b>without cameral membranes</b>	18.649	3.697	7.488	-0.001
<b>with cameral membranes</b>	18.872	3.702	7.388	0.005
<b>displacement</b>	18.366	3.444	6.654	0

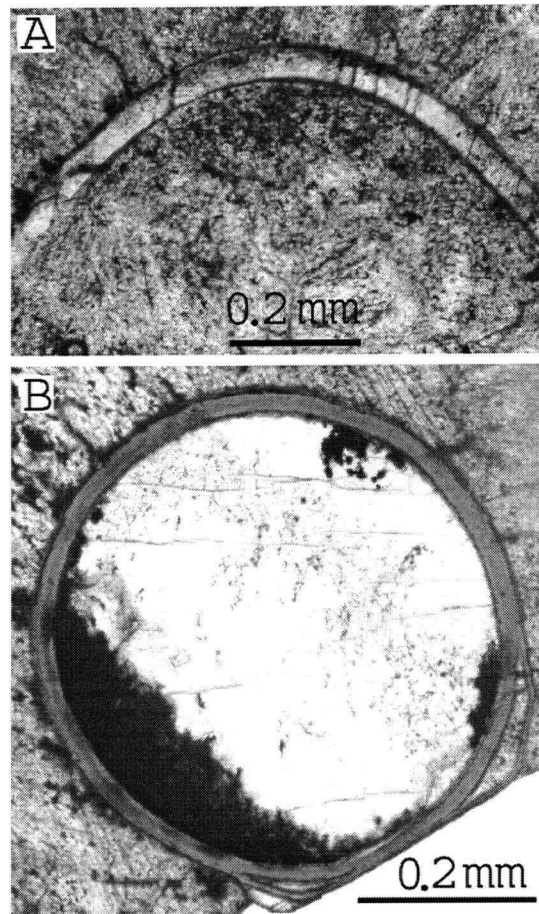
**Table 8.6.** Masses and positions of total X, Y and Z coordinates for model 3 (cameral sheets optional). Total displacement and position of centre of buoyancy is also indicated.



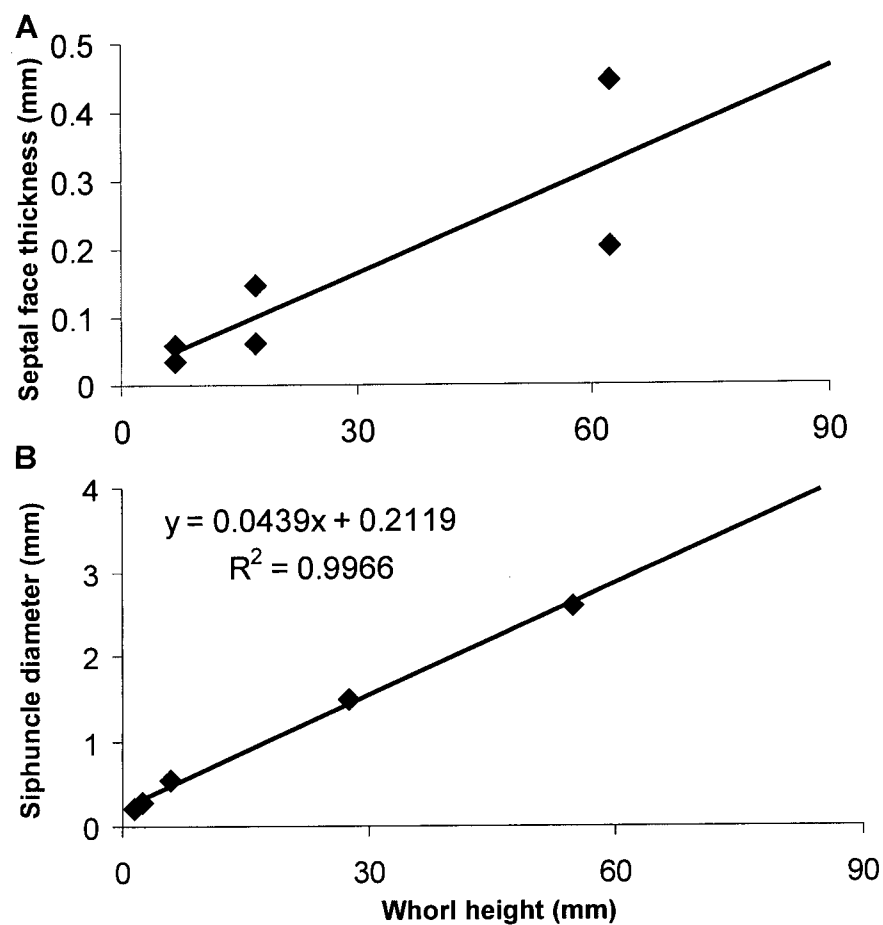
**Figure 8.1.** A-B, Scanned fragment of *Badouxia columbiae* (Frebold), scale bar = 2 cm. A, Lateral view. B, Frontal view. C, Septal suture line from *B. columbiae* used in creating model 1; scale bar = 4 cm.



**Figure 8.2.** A, Computer model of scanned fragment shown in Figure 8.1. B, Cross-sections taken from model using computer program Rhinoceros. C-D, Model of septal face with superimposed suture line. C, Lateral view. D, Frontal view.

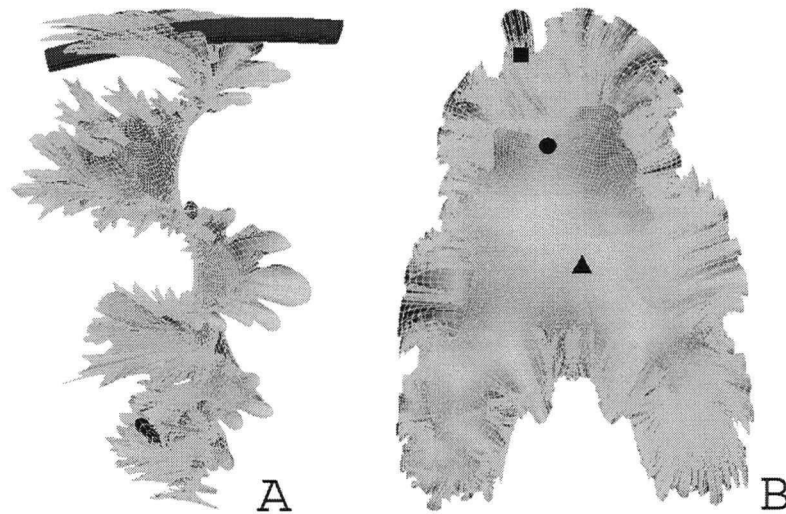


**Figure 8.3.** A, Thin section showing middle portion of septal face cut perpendicular to face. B, Thin section cut perpendicular to siphuncle.

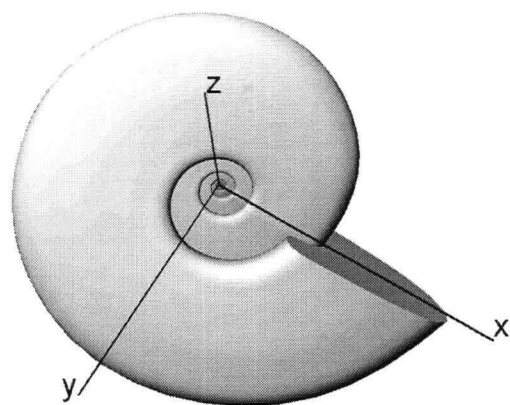


**Figure 8.4.** Plot of measurements of model components. A, Septal face thickness versus whorl height. B, Siphuncle diameter versus whorl height.

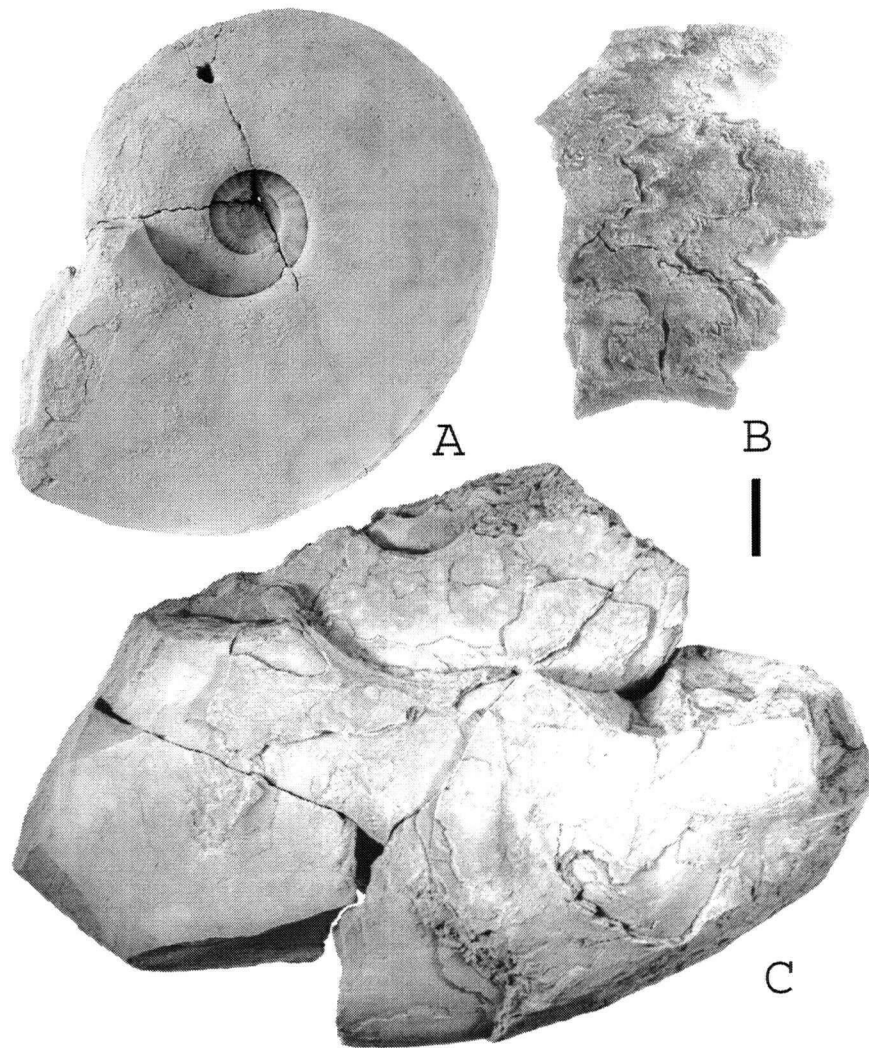




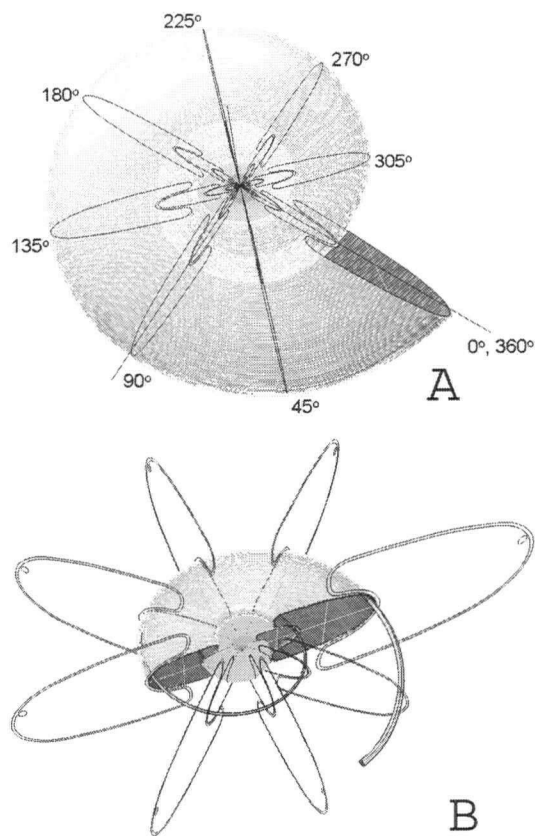
**Figure 8.5.** Completed model of single septal face including one chamber length of siphuncle. A, Lateral view. B, Front view. Triangle represents centroid of septal face, circle represents centroid of cameral sheets, square represents centroid of siphuncle.



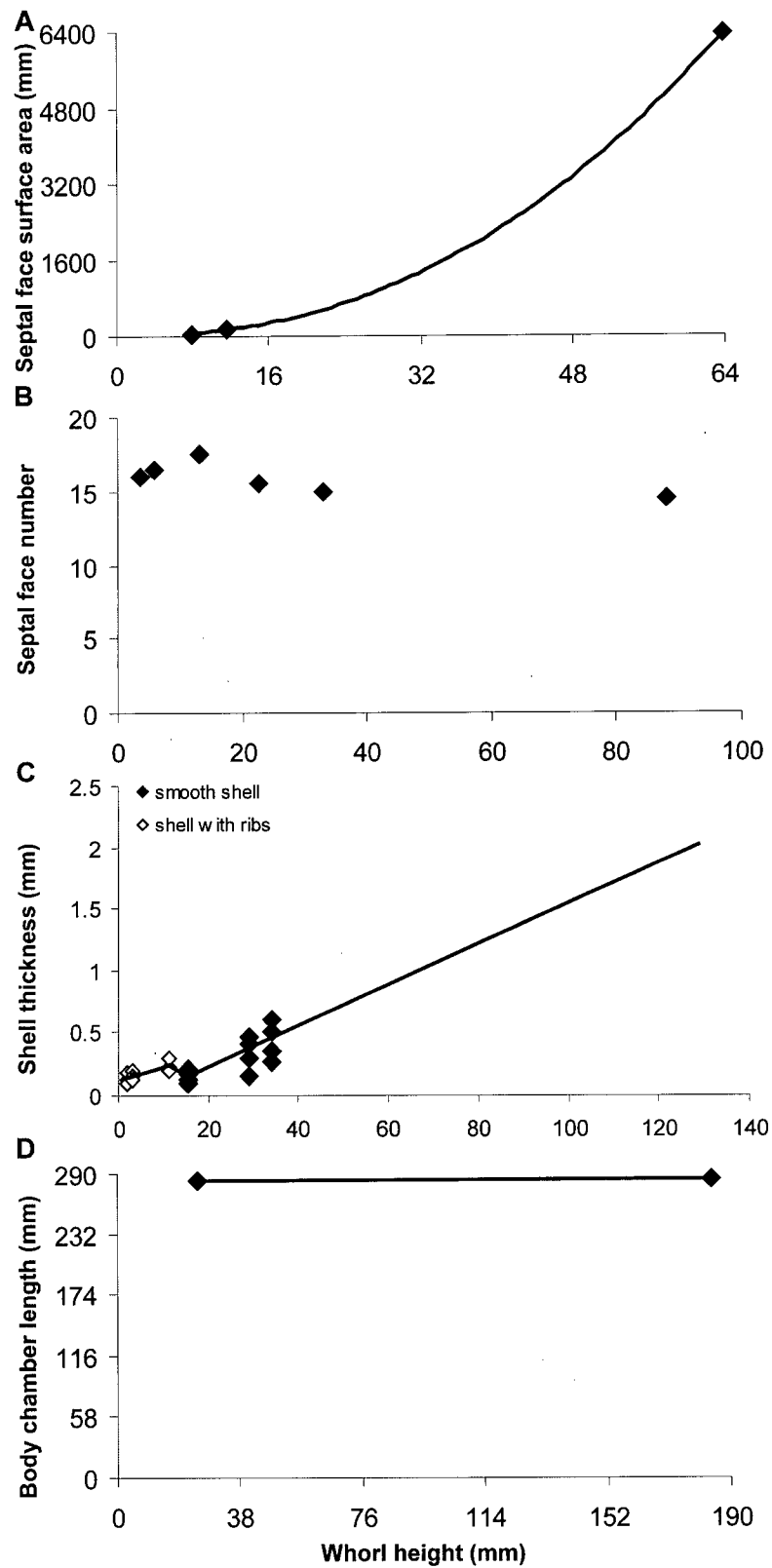
**Figure 8.6.** Direction notation for models 2 and 3.



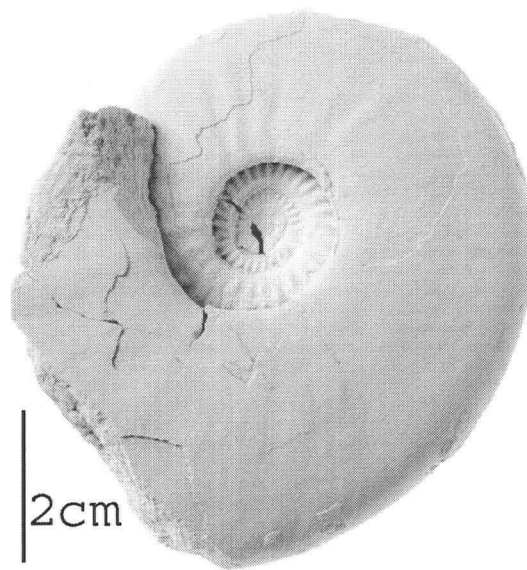
**Figure 8.7.** Specimens and fragments of *Badouxia columbiae* (Frebold). A, Specimen used for measurements of inner and intermediate whorls of ammonite models 2 and 3; scale bar = 2.5 cm. B, Fragment of large whorl used for measurements of outer whorl of ammonite model 2 and body chamber length; scale bar = 2.5 cm. C, Incomplete specimen where outermost whorl is body chamber; scale bar = 4 cm.



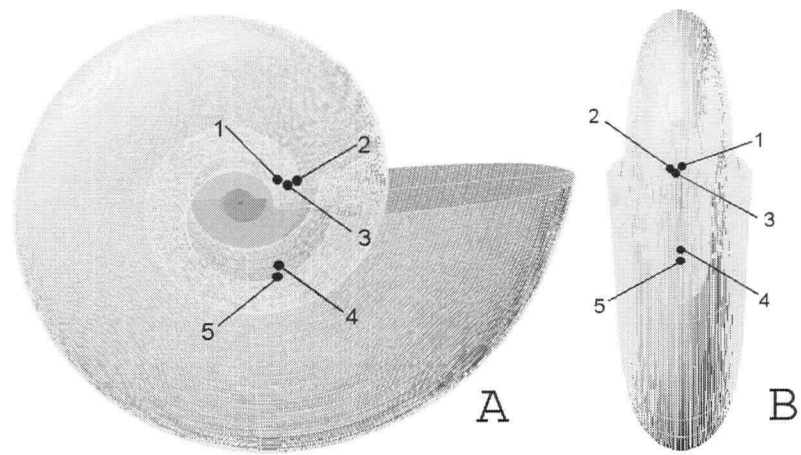
**Figure 8.8.** A, Angle convention for model assembly. B, Model assembly.



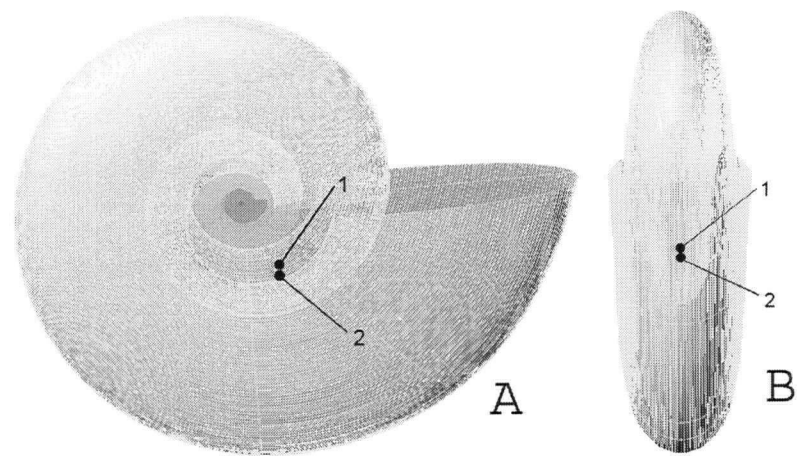
**Figure 8.9.** Plot of measurements of model components. A, Septal face surface area versus whorl height. B, Septal face number versus whorl height. C, Shell thickness versus whorl height. D, Body chamber length versus whorl height.



**Figure 8.10.** Specimen of *Badouxia columbiae* (Frebold) used for shell thickness measurements.



**Figure 8.11.** Model showing centres of mass for each element of animal; 1. septal faces, 2. siphuncle, 3. cameral membranes, 4. shell, 5. body chamber. A, Lateral view. B, Ventral view.



**Figure 8.12.** Model showing centres of buoyancy and mass for animal; 1. centre of buoyancy, 2. centre of mass. A, Lateral view. B, Ventral view.



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## 9 CONCLUSION

### 9.1 Summary of Results

This series of papers provides the first detailed systematic analysis of Hettangian ammonites from the terranes of British Columbia (BC). In total, 90 different species or taxonomic groups are described representing 32 genera (Fig. 9.1). Thirteen new species are recognized including *Fergusonites hendersonae*, *Paradasyceras carteri*, *Eolytoceras constrictum*, *Pleuroacanthites charlottensis*, *Ectocentrites pacificus*, *Curviceras haidae*, *Franziceras kennecottense*, *Pseudaetomoceras victoriense*, *Sunrisites brimblecombei*, *S. chilcotinensis*, *S. senililevis*, *Badouxia castlensis* and *B. forticostata* (Longridge *et al.* 2006, in press *a*, *b*).

Collections from measured sections in the Queen Charlotte Islands (QCI) and the Taseko Lakes area establish the stratigraphic range of each taxon. This information was used to update the Hettangian and lowest Sinemurian portion of the zonation of Taylor *et al.* (2001) for the western cordillera of North America, making it more accurate and complete with respect to Canadian successions (Longridge *et al.* 2006; Longridge *et al.* in press *b*). This work also necessitated changes to the status of several zones. The Oregonensis Zone was re-named the Mineralense Zone. The Canadensis Zone was abandoned and its previously defined Rursicostatum and Columbiae Subzones were raised to the level of full zones (Longridge *et al.* 2006).

In the QCI, radiolarian faunas underwent a dramatic turnover across the Triassic-Jurassic transition where rich and diverse forms were primarily replaced by an abundant low diversity fauna composed of very simple forms. The early Hettangian ammonite fauna from the area permits an approximate correlation with sections in other areas that do not contain radiolarians. The Kunga Island section has provided a useful radiometric date to constrain the T-J boundary (Pálffy *et al.* 2000*a*, *b*). The section can be correlated with a section at Kennecott Point where a

carbon isotope curve shows a negative peak just below the radiolarian turnover (Ward *et al.* 2001, 2004; Williford *et al.* 2007). Based on these strengths, the section on Kunga Island was proposed as the Global Stratotype Section and Point if radiolarians are selected as the primary standard for defining the boundary or as a parastratotype section to assist with characterizing the Triassic-Jurassic transition if radiolarians are not selected (Longridge *et al.* 2007; in press *c*).

Correlations are made between the Hettangian and lower Sinemurian of the terranes of BC and other areas (Longridge *et al.* in press *b*). Except for the definitive occurrence of the Spelae Zone, all Hettangian zones as well as the lowest Sinemurian Columbiae Zone of the North American Zonation are present in the BC terranes. This permits ready correlation with contemporaneous strata from elsewhere in North America. Detailed correlations between the BC terranes and South America, New Zealand, western and eastern Tethys, and northwest Europe are also presented (Longridge *et al.* in press *b*).

The lateral distribution of ammonite faunas support previous conclusions that the Cadwallader, Wrangellia and Peninsular terranes were in the northern Hemisphere and the eastern Pacific during the Hettangian. Similarities between taxa and diversity levels in the Hettangian faunas from the QCI and Nevada support earlier assessment of a significant northward displacement for Wrangellia relative to the craton since Early Jurassic time. The distribution of species of *Sunrisites* suggest there may have been some longitudinal separation between the BC craton and the Cadwallader, Wrangellia and Peninsular terranes and suggest that the Hispanic Corridor may have been open during the Hettangian (Longridge *et al.* in press *a*).

Probable sexual dimorphism is recognized in several species from the BC terranes including *Eolytoceras chongi*, *Sunrisites chilcotinensis*, *S. brimblecombei*, *S. senililevis*, *Badouxia canadensis*, *B. forticostata* and *B. columbiae* (Longridge *et al.* 2006, in press *a, b*). It is also possible that *E. cf. praecursor* is dimorphic and that *Kammerkarites frigga* and *K. haploptychus*

are a dimorphic pair. The principal signs of sexual dimorphism within the fauna are bimodal size distribution and variocostation.

In *B. columbiae*, the centroids of the internal components of the phragmocone including the septal faces, siphuncle and possible cameral sheets were offset from the median line. When these asymmetric components are considered in isolation, a counterbalance mechanism seems to be present. The mass of the offset siphuncle (with optional cameral sheets) is at least partially corrected by the mass of the septal faces which is displaced in the opposite direction in the vertical plane. However, when the complete animal is considered at both large and small shell diameters, the individual components within the phragmocone are very small with respect to the mass of the entire animal and the effect of the offset components is virtually negligible.

## **9.2 Significance of Research**

### **9.2.1 Hettangian ammonites in time – vertical distribution**

#### **9.2.1.1 Models of recovery from mass extinction.**

According to Kauffman and Harries (1996), ecological generalists are one of the common survivors of mass extinctions. These groups tend to have: broad geographical ranges; large niche sizes; relatively primitive morphology; and species with long stratigraphic ranges. Also, they usually occur consistently but rarely in great numbers over broad paleogeographic areas and often show limited post-extinction diversification (e.g., Kauffman and Erwin 1995; Kauffman and Harries 1996). The Phylloceratina which survived the end-Triassic mass extinction are good examples of this lifestyle (Fig. 9.2). The traditional model of adaptive radiation following mass extinction suggests that recovery represents a refilling of empty niches and a return to pre-extinction equilibrium (e.g., Sepkoski 1984; Erwin 2000, 2001; and references within). In the initial aftermath, biodiversity is low and geographically widespread taxa prevail. This survival interval is followed by the rapid appearance of new taxonomic groups that may have significant

regional differences. Repopulating follows an exponential curve and the greater the extinction the longer the recovery interval (Fig. 9.3). This pattern may be visible in the ammonites where the early Hettangian genus *Psiloceras* dominates and is a widespread and morphologically variable taxa (e.g. Guex 1987). Species of this genus arose under environmentally stressed conditions and rapidly diversified to begin the early recovery and repopulation of global biotas. *Psiloceras* is the ancestor to several genera in the late early Hettangian and early middle Hettangian which show considerable regional differences and may represent the beginning of the recovery interval (Figs 9.3-9.4). An alternate view is given by Kirchner and Well (2000), who claim that on average, extinctions do not trigger immediate evolutionary rebounds. Instead, the recovery rate is controlled by the internal dynamics of the diversification process and is independent of the magnitude of the extinction. They suggest the average recovery time from an extinction is about 10 million years. This time frame appears to be true of the recovery from the end-Triassic extinction in the ammonites. Only one ammonite superfamily arises in the early Hettangian. By c. 3 million years later, in the late Hettangian, there are three new ammonite superfamilies, by the Sinemurian there are five new superfamilies and by the lower Pliensbachian, c. 10 million years post-extinction, there are six new superfamilies (Fig. 9.2; Page 1996; Pálffy *et al.* 2000b). This brings the total number of Pliensbachian superfamilies to seven which is similar to the number of superfamilies found in the Norian and early Rhaetian stages of the late Triassic (Fig. 9.2; Page 1996).

#### 9.2.1.2 Phylogeny methodology

There are two principal methods for constructing phylogenies. The first is a stratophenetic approach where morphological and stratigraphic occurrence data are used to construct a likely phylogeny and time is an integral component. This is a qualitative method and emphasizes ancestor-descendant relationships. The other method is cladistic analysis where sister-groups are discovered based on shared derived characteristics which are inferred to have arisen in the latest

common ancestor. This is a quantitative method based on the most parsimonious distribution of characters and is independent of time. The stratophenetic approach is used here principally because the Hettangian global database was not comprehensive enough in terms of number of species as well as morphological data for a comprehensive cladistic analysis.

#### 9.2.1.3 Hettangian ammonite radiation.

Only two ammonite groups survived the end-Triassic mass extinction. The first is the heteromorph *Choristoceras*. Most species of this genus occur in the latest Triassic although rare survivors persisted into the earliest Hettangian (e.g., Guex 1980, 1995; Tozer 1994; Taylor *et al.* 2000; Longridge *et al.* 2007; Yin *et al.* 2007). The second group, the Phylloceratina, were reasonably morphologically conservative and long ranging, surviving from the Triassic until the Cretaceous (e.g., Arkell *et al.* 1957; Rakús 1993a; Guex 2006). The Psiloceratina which arose in the earliest Hettangian includes the Ammonitina and Lytoceratina of classic authors (*sensu* Guex 1987) and formed the basis for the remarkable Jurassic radiation. Classic authors believed the Psiloceratina were probably derived from the late Triassic Phylloceratina (Pompeckj 1895; Wähner 1882-1898; Diener 1908, 1922; Spath 1914, 1924; Arkell 1950). Recent work has supported this view suggesting *Eopsiloceras* probably arose from the Late Triassic phylloceratid *Rhacophyllites* (*sensu lato*) and gave rise to *Psiloceras* which formed the root stock of all other Jurassic and Cretaceous ammonites of the order Psiloceratina (e.g., Guex 1982, 1987, 1995, 2006; Guex and Rakús 1991) (Fig. 9.4). One possible exception to this is the early Hettangian psiloceratid ammonite *Neophyllites* which may have arisen directly from *Eopsiloceras* (Guex 2006).

The problem of how the ammonites diversified from the basal Hettangian rootstock has been the subject of significant debate and constructing a phylogeny for Hettangian ammonite genera has proved difficult. Hettangian ammonites are relatively rare in the world and this scarcity as well as differences in opinion on taxonomy at the generic level have compounded the problem.

A phylogeny for the Hettangian Phylloceratina was proposed by Rakús (1993a) and modified by Hillebrandt (2000a). Comparatively recent work on Hettangian ammonite faunas from areas of North and South America has added significantly to the data from the classic successions in northwest Europe and the Mediterranean areas. These studies have culminated in the proposal of two separate phylogenies for the principal Hettangian genera of the Psiloceratina (e.g., Guex 1981, 1987, 1989, 1995; Taylor 1998; Guex *et al.* 2000; Hillebrandt 2000a). For the sake of simplicity, the latest version of the proposal based on recent systematic studies in the United States will be termed the North American phylogeny herein (Guex *et al.* 2000; Fig. 9.5). Similarly, the phylogeny based on studies primarily in Chile and Peru will be termed the South American phylogeny (Hillebrandt 2000a; Fig. 9.6).

The diverse and relatively complete Hettangian ammonite fauna from the BC terranes as well as new work from other areas requires changes to the most recently proposed versions of the Hettangian ammonite phylogeny. Furthermore, the two phylogenies for the Psiloceratina discussed above have many similarities but there are also important differences. In light of these issues, an updated phylogeny is proposed for Hettangian ammonites (Fig. 9.4). Revisions that warrant comment are indicated by numbers beside the genera on Figure 9.4 and discussed below. North American zones are shown in Figure 9.1.

1. The range of *Fergusonites* is extended upwards from the middle upper Hettangian to include *F. hendersonae* from the Rursicostatum Zone in Taseko Lakes (Chapter 7; Figs 9.1, 9.6).
2. *Psiloceras* is restricted to the lower Hettangian with the exception of *P. perezii* from the middle Hettangian of South America (Hillebrandt 2000c). Hillebrandt (pers. comm., 2007) has suggested that the first *Psiloceras*, *P. spelae*, may be the 'missing link' between the phylloceratids and the psiloceratids in that it shares characteristics of both groups. As discussed by Guex (1987), *Psiloceras* showed a very strong potential for



variability including species that differed widely in ribbing style and volution. The genera that arose from *Psiloceras* probably originated from different *Psiloceras* species although which species was the ancestor to which descendant genus is uncertain.

3. The range of *Neophyllites* is extended downwards from the lower middle lower Hettangian to the basal Hettangian due to the occurrence of the genus in Tibet (Yin *et al.* 2007; Figs 9.1, 9.5-9.6). The genus may have arisen from *Eopsiloceras* or *Psiloceras* (Guex 2006).
4. In the South American phylogeny, the ancestor to *Eolytoceras* is uncertain. *Euphyllites* is given as the first possibility due primarily to the presence of two species from the Russian Federation which are interpreted as possible intermediate forms, "*Psiloceras vilingense*" and *Pleuropsiloceras suberugatum* (Efimova *et al.* 1968; Guex 1987; Guex *et al.* 1998; Hillebrandt 2000a). *Pleuroacanthites* is given as the second possibility and this genus is considered to be the definitive ancestor in the North American phylogeny. As discussed by Guex (1995, p. 59), *E. praecursor* is the oldest *Eolytoceras* and shows a juvenile stage that is nearly identical to that of *P. mulleri* whereas the adult stage is very close to *E. tasekoi*. The case for the latter ancestor is strengthened somewhat as *E. cf. praecursor* occurs in both the Coronoides and Pleuroacanthitoides zones in the QCI whereas in Nevada, it is only recognized by a single specimen from the Pleuroacanthitoides Zone (Guex 1995). Thus, the QCI occurrences bridge the stratigraphic gap to *P. mulleri* which is limited to the lower middle Hettangian Mulleri and Occidentalis zones in Nevada (North American zones shown in Fig. 9.1). Thus *Pleuroacanthites* is considered the more likely ancestor here.

Due to the presence of *E. cf. praecursor* in the QCI, the range of *Eolytoceras* is extended downwards from the upper middle Hettangian to include the Coronoides and Pleuroacanthitoides zones (Chapter 4; Figs 9.1, 9.5-9.6).

5. In the South American phylogeny, *Eolytoceras* is the ancestor of *Analytoceras*.

Hillebrandt (2000a, p. 108) claims that the two genera are closely related because *Eolytoceras* is restricted to the eastern Pacific and appeared before *Analytoceras* which is a Tethyan genus. Although Meister *et al.* (2002) have recently recognized *Eolytoceras* in Vietnam, these occurrences do not occur until the Sinemurian and are probably a separate dispersal event. In the North American phylogeny, *Pleuroacanthites* is the ancestor of *Analytoceras*. Guex (1995, p. 59) comments on the presence of intermediate forms between *Pleuroacanthites biformis* and *Analytoceras articulatum* that are described by Wöhner (1894, pl. IX, figs 1-2) and suggests this is direct evidence for a phyletic relationship between these two genera. This interpretation is adopted here.

6. In both the South and North American phylogenies, the ancestor to *Ectocentrites* is *Tayloricites* and both these genera are limited to the upper Hettangian. However, in the QCI, *E. pacificus* occurs in the middle middle and upper middle Hettangian (Chapter 4; Fig. 9.1). Thus, *Tayloricites* is too young to be the ancestor to *Ectocentrites*. A specimen from the Mulleri/Occidentalis zones in the QCI, 'Genus indet. species nov.' (Chapter 4, pl. 4.2, fig. 8) has weakly swollen, rursiradiate ribs on the inner whorls which show occasional weak tubercles. On the outer whorl, ribbing becomes less coarse and more crowded with ventrolateral swellings on some ribs. This specimen may be an intermediate form between the ancestral *Pleuroacanthites* line with its rursiradiate and swollen ribs on the inner whorls and the descendant *Ectocentrites* line with its finer tuberculate ribs. This would be an example of peramorphosis where the descendant resembles the adult stage of the ancestor.
7. The range of *Mullerites* is extended downwards to include *M. cf. pleuroacanthitoides* from the Pleuroacanthitoides and Sunrisensis zones in the QCI (Chapter 4; Figs 9.1. 9.5-9.6).

8. The ancestry of *Alsatites* may be one of the most difficult problems in reconstructing the phylogeny of Hettangian ammonites (Guex *et al.* 2000) because species of the genus show characteristics of several older genera (e.g. Spath 1924). In the South American phylogeny, the ancestor to *Alsatites* is *Laqueoceras* which arose from *Kammerkarites*. Guex (1987, 1995) places *Laqueoceras* in synonymy with *Alsatites* and this approach is adopted here (see Chapter 7). Based on this taxonomic revision, the ancestor to *Alsatites* in the South American phylogeny would be *Kammerkarites*. This allocation is principally because '*Laqueoceras* (?) *intermedianum*' from South America is similar to some species of *Kammerkarites* in cross-section, umbilical width and sculpture (Hillebrandt 2000a, p. 72) and may be an intermediate form between the two genera (Hillebrandt 2000a, p. 107). In the current North American phylogeny, the ancestor to *Alsatites* is *Caloceras*. This assignment is a revision of the previous analyses of the North American group (Guex 1987, 1995; Taylor 1998) where *Alsatites* was believed to have been the descendant of *Pleuroacanthites*. Similarities between species of *Alsatites* and the genera *Caloceras* and *Pleuroacanthites* are well recognized (e.g. Spath 1924). The North American groups' revised assignment was based on a new discovery of *Alsatites* in a stratigraphically lower position to the genus *Mullerites* which was previously believed to be an intermediate between *Pleuroacanthites* and *Alsatites* (Guex *et al.* 2000). Due to the similarities between several species of *Alsatites* and *Caloceras*, *Caloceras* is considered to be the ancestor here.

The range of *Alsatites* is extended upwards to include *Alsatites* aff. *bipartitus* and *Alsatites* sp. from the basal Rursicostatum Zone in Taseko Lakes (Chapter 7; Figs 9.1, 9.5-9.6).

9. Although *Alpinoceras* is often placed in synonymy with *Paracaloceras* (e.g. Arkell *et al.* 1957; Donovan *et al.* 1981) it is maintained as a separate genus here as it has ribbing that

can be irregular, dense and weak compared with the stronger more regular ribbing of *Paracaloceras*. It also has differences in the suture line including a ventral lobe that is shorter or equal in length to the first lateral lobe rather than longer (Bloos 1994; Hillebrandt 2000a, p. 83).

10. In the North American phylogeny, *Pseudaetomoceras* is the descendant of *Alsatites*. Guex (1995) claims the origin of the genus is in the group *A. proaries*. In the South American phylogeny *Pseudaetomoceras* is derived from the genus *Alpinoceras* whose ancestor is *Alsatites*. This discrepancy remains unresolved.
11. In the South American phylogeny the ancestor to *Sunrisites* is *Psiloceras*. According to Hillebrandt (2000a, p. 106, 2006b, p. 38), *Sunrisites* does not show alsatitid type ribbing as would be the case if it were derived from the Alsatitinae but instead shows psiloceratid type ribbing and is very similar morphologically to some species of *Psiloceras*. For example the South American form *S. peruvianus* is difficult to distinguish from *P. cf. crassicostatum* (*Caloceras crassicostatum* in Guex 1995) (Hillebrandt 2000a, p. 106). In the North American phylogeny, *Sunrisites* is derived from *Alsatites*. Guex (1995, p. 50) describes the juveniles of *S. sunrisensis* and *A. nigromontanus* as practically indistinguishable up to 30 mm shell diameter. Furthermore he comments on the presence of intermediate forms between *A. nigromontanus* and *S. hadroptychus* that were already noted by Wöhner (1886, p. 216). The latter approach is adopted here because a stratigraphic gap of a full middle Hettangian zone separates *P. cf. crassicostatum* from *S. peruvianus* (Hillebrandt 2000a) in South America. Furthermore, Hillebrandt (2000a, p. 107) describes the similarity of the form '*Laqueoceras*' (?) '*intermedianum*' with *Sunrisites* and the ribbing style of the inner whorls can be quite similar between '*L.*' (?) '*intermedianum*' and *S. chilensis* (e.g. Hillebrandt 2000a, pl. 2, fig. 1 and Hillebrandt 2000b, pl. 10, fig. 1).

12. In the North American phylogeny *Paracaloceras* arises directly from *Alsatites*. In the South American phylogeny, the ancestor to *Paracaloceras* is most closely related to *Peudaetomoceras* which arose from *Alpinoceras*. Hillebrandt (2000a, p. 83, 107) describes *Paracaloceras varaense* from South America that shows characteristics of both *Alpinoceras* and *Paracaloceras*. Although the South American intermediate may be slightly too young, it shows a close relationship between the two genera and this approach is adopted here.
13. The range of *Gyrophioceras* includes the species recognized from the Sunrisensis Zone through the lower Sinemurian in the QCI (Chapter 4; Fig. 9.1).
14. The range of *Schreinbachites* is tentatively extended upwards from the middle upper Hettangian to include *S.* (?) aff. *laqueoides* from the Rursicostatum Zone in Taseko Lakes (Chapter 7; Figs 9.1, 9.6).
15. The range of *Franziceras* is extended upwards from the middle middle Hettangian to include *F.* aff. *graylockense* from the Mineralense Zone in Taseko Lakes (Chapter 7; Figs 9.1, 9.5).
16. In the North American phylogeny, *Psiloceras* is considered to be the direct ancestor to *Discamphiceras* because the two genera share many characteristics including a relatively simple suture line of the psilonotum type that is often asymmetric, spiral lines on the internal mould, and a nodose nucleus in some species (Guex 1987, 1995). In the South American phylogeny, *Discamphiceras* is derived from *Kammerkarites* based on the presence of transitional forms between the two genera, e.g. *K. chinchillaensis* and *D. pleuronotum* (Hillebrandt 2000a, p. 105, 2000b, p. 4). As suture lines can also be simple and asymmetric in *Kammerkarites* (e.g. Hillebrandt 2000b, p. 16) and many species of the genus have a nodose nucleus (e.g. Chapter 4; Hillebrandt 2000b), the South American approach is adopted here.

The range of the *Discamphiceras* is extended upwards to include the occurrence of *D. silberlingi* and *D. sp. nov.* from the Mineralense and Rursicostatum zones in Taseko Lakes (Chapter 7; Figs 9.1, 9.5-9.6). Species of *Discamphiceras* are also recognized from the Lower Sinemurian in Vietnam (Meister *et al.* 2002).

17. In the North American phylogeny, the ancestor to *Saxoceras* is *Kammerkarites* and Guex (1987, p. 466; 1995, p. 35) considers *Storthoceras* to be a synonym of *Saxoceras*. In the South American phylogeny, the ancestor to *Saxoceras* is *Curviceras*. Hillebrandt maintains *Saxoceras* and *Storthoceras* as valid genera based on differences in morphology and biogeography. *Saxoceras* has ribs that are not interrupted on the internal whorls and is principally a northwest European form whereas *Storthoceras* has interrupted ribs on the inner whorls and is mainly a Tethyan form (Hillebrandt 2000b, p. 23). The South American approach is adopted here.
18. Guex (1995, p. 22) considers *Curviceras* to be a possible microconch of *Kammerkarites* (Guex 1995, p. 22). Hillebrandt (2000b, p. 19) suggests that *Curviceras* differs from *Kammerkarites* in having more sigmoidal, prorsiradiate ribs that clearly curve forward over the venter. In the South American phylogeny, *Curviceras* is derived from *Psiloceras* (Hillebrandt 2000a, p. 105) from which it differs in having clear ribbing that projects onto the venter (Hillebrandt 2000b, p. 19).
19. *Storthoceras* and *Curviceras* are very closely related and in the South American phylogeny, *Storthoceras* is considered the ancestor of *Curviceras*. According to Hillebrandt (2000b, p. 23), *Storthoceras* differs from *Curviceras* principally in having ribs that are more sharply projected forward on the venter. As discussed by Guex (1995, p. 35), the type species of the two genera differ only in the ribbing on the inner whorls which is ventrally continuous in *Storthoceras extracostatum* and is interrupted in

*Saxoceras portlocki*. This similarity suggests *Storthoceras* may be the descendant of *Saxoceras*.

20. In the North American phylogeny, *Schlotheimia* is derived from *Saxoceras*. According to Guex (1995, p. 58), most authors (e.g., Spath 1924, Schindewolf 1925, Lange 1941) agree with this interpretation as part of a series showing proterogenetic development of the ventral sulcus as well as similarities in the suture line in the adults. In the South American phylogeny *Schlotheimia* is derived from *Storthoceras*. Hillebrandt (2000a, p. 105, 2000b, p. 36) describes a transitional form (*Schlotheimia* (?) sp. A. of Hillebrandt 2000b) which is an intermediate between *Storthoceras* and *Schlotheimia*.

### **9.2.2 Hettangian ammonites in space – lateral distribution**

The Canadian terranes are in an unusual biogeographic setting which means they contain many forms with east-Pacific distributions as well as forms with affinities to species from New Zealand, western and eastern Tethys and, less commonly, northwest Europe. Some of this data is presented in various chapters throughout the thesis (Chapters 2, 4-7). For the sake of simplicity, the complete record is combined here in Figure 9.7.

### **9.2.3 Paleobiology**

#### **9.2.3.1 Siphuncle and septal face asymmetries.**

A siphuncle that is offset from the midline of the venter showing corresponding asymmetry in the septal suture is currently recognizable in species of many Hettangian genera including *Neophyllites*, *Psiloceras*, *Euphyllites*, *Eolytoceras*, *Caloceras*, *Alsatites*, *Sunrisites*, *Badouxia*, *Kammerkarites*, *Franziceras*, *Discamphiceras*, *Paradiscamphiceras*, *Kammerkaroceras*, *Curviceras* and *Storthoceras* (e.g., Neumayr 1879; Canavari 1882; Wähner 1882-1898; Spath 1919, 1924; Lange 1941, 1952; Frebold 1951, 1967; Wiedmann 1970; Schlegelmilch 1976; Hengsbach 1986a, b; Bloos 1981, 1994, 1996, 1999; Taylor 1988; Guex 1989, 1995; Guerin-Franiatte 1990; Guex and Rakús 1991; Rakús 1993b; Böhm *et al.* 1999; Bloos and Page 2000;

Hillebrandt 2000*a-c*; Longridge *et al.* 2006, in press *a, b*; Yin *et al.* 2007; and references therein) (Fig. 9.4) and may be discovered in additional genera with close observation. There are two main hypotheses for the cause of these asymmetries. The first, proposed by Hengsbach (1979, 1986*a, b*, 1991, 1996), favors an infestation of parasites shortly after the time of hatching. He suggests that parasites located in the soft body, at or near the siphuncle, caused a constant displacement of the root of the siphuncle and thus, of the ventral lobe of the suture. He claims that the degree and direction of offset were controlled by the location and size of the site of infestation and further suggests that after the death of the parasites, the asymmetry would have been too well established to correct in subsequent growth. The second hypothesis is that of Guex (2001) who suggests that environmental stress in the earliest Jurassic may have generated asymmetry of the siphuncle in the ammonite root stock. Recent work has highlighted the role of external stress in increasing the rate of gene mutation and recombination as well as in the initiation of asymmetries (Williamson 1981; Hoffman and Parsons 1991). These asymmetries may have been retained in the genetic code of the basal root stock and had sporadic expression in the Jurassic part of the ammonoid evolutionary radiation.

Both theories are plausible and it is difficult to identify which is correct based on the current data. Asymmetries are not always recognized in closely related, contemporaneous forms. Triassic genera that are ancestral to the Jurassic ammonites (Tozer 1994) and the oldest *Psiloceras* species, *P. cf. spelae* from Austria (Hillebrandt in press, pers. comm. 2007) and *P. tibeticum* from Tibet (Yin *et al.* 2007, text-fig. 9) have a virtually central suture line. This pattern could be due to either the Triassic and basal Jurassic forms pre-dating the evolution of a new parasite or alternatively to the encoding of a central siphuncle and suture in the genome. However, asymmetries also do not occur in the Hettangian Phylloceratoidea (e.g., Neumayr 1879; Wähner 1898; Rakús 1993*a*, 1999; Böhm *et al.* 1999; Hillebrandt 2000*c*; Longridge *et al.* in press *b*) (Fig. 9.4). Furthermore, siphuncular asymmetry is only intermittently expressed at



the generic level in the Psiloceratina (Fig. 9.4). For example this characteristic is prevalent in species of *Schreinbachites* (Bloos 1994, 1996) but has not been recognized in species of *Alpinoceras* or *Paracaloceras* which are the ancestral genera (Fig. 9.4). Similarly siphuncular asymmetry is sporadic at the species level where not all species of a genus consistently show asymmetry.

In many Hettangian ammonites, the side of the shell to which the siphuncle is offset is inconsistent and the degree of offset is highly variable even within the same species. Furthermore, these species often show extensive biogeographic ranges. For example, specimens of the late Hettangian ammonite *Badouxia canadensis* are found throughout the eastern Pacific and virtually always have an offset siphuncle, although the side and degree of offset are highly variable (e.g., Hillebrandt 2000b; Hall and Pitaru 2004; Longridge *et al.* 2006). Hengsbach (1996) claims that the side of the organism on which the malformation occurs should vary with a parasitic cause whereas it should not vary with a genetic cause. Nevertheless, it seems improbable that a parasite would cause siphuncular offset in virtually 100 percent of individuals of a single species spread over a wide geographic range.

External influences can affect the position of the siphuncle. For example, in a specimen of *Eolytoceras* from Taseko Lakes (GSC 127429), the external lobe and siphuncle switch sides from right to left of the median line between shell diameter of *c.* 21 mm and 22.5 mm. The position then begins to 'correct' as growth continues and by the end of the preserved specimen, the siphuncle is nearly central. This disturbance was probably caused by an injury to the animal but the fact that the position begins to correct suggests that the position may have been influenced by genetics rather than an external influence such as parasites. This also suggests that the assertion of Hengsbach (1986a), that the siphuncle would continue to be displaced even with the death of the parasite, is incorrect.

#### 9.2.3.2 Sexual dimorphism

Davies *et al.* (1996, p. 501) claim that sexual dimorphism is not a dominant feature during the Hettangian. Although dimorphism is still not thoroughly documented during this interval, it is becoming better recognized and has been suggested for species from many genera including *Nevadaphyllites*, *Paradasyceras*, *Neophyllites*, *Psiloceras*, *Eolytoceras*, *Tayloricites*, *Waehneroceras*, *Kammerkarites*, *Curviceras*, *Storhoceras*, *Saxoceras*, *Schlotheimia*, *Pleuroacanthites*, *Ectocentrites*, *Alsatites*, *Discamphiceras*, *Sunrisites* and *Badouxia* (e.g., Rakús 1975, 1993a, Callomon 1981; Guex 1981; Longridge *et al.* 2006, in press a, b; and references therein). Furthermore, Davies *et al.* (1996, p. 501) state that microconchs bearing mature modifications were not apparent until the Toarcian. However, signs of mature modifications are present in the microconchs of several Hettangian taxa. For example, Rakús (1975) describes *Curviceras subangulare* [*Waehneroceras (Curviceras) subangulare* in Rakús] and *Waehneroceras tenerum* as microconchs with a peristomal constriction and Guex (1981, 1995) describes a *Pleuroacanthites mulleri* microconch with a contracted bodychamber and microconchs of *Discamphiceras antiquum* with constrictions preceding their apertures. Mature modifications are particularly prevalent in *Badouxia* (Longridge *et al.* 2006; Chapter 5) where eight mature and complete microconch specimens belonging to three different *Badouxia* species show various modifications. These can include septal approximation, uncoiling of the umbilical seam and the possession of a rostrum as well as the presence of a constriction and effacement of ribbing on the body chamber (Longridge *et al.* 2006, pl. 1, figs 11-12, 17-18, pl. 2, fig. 1, pl. 3, figs 1-2, 11-12, pl. 4, figs 8-10).

### **9.3 Future Research**

There are several areas where future research would be useful. Firstly, detailed systematic studies of faunas from other areas could improve our understanding of the radiation of the

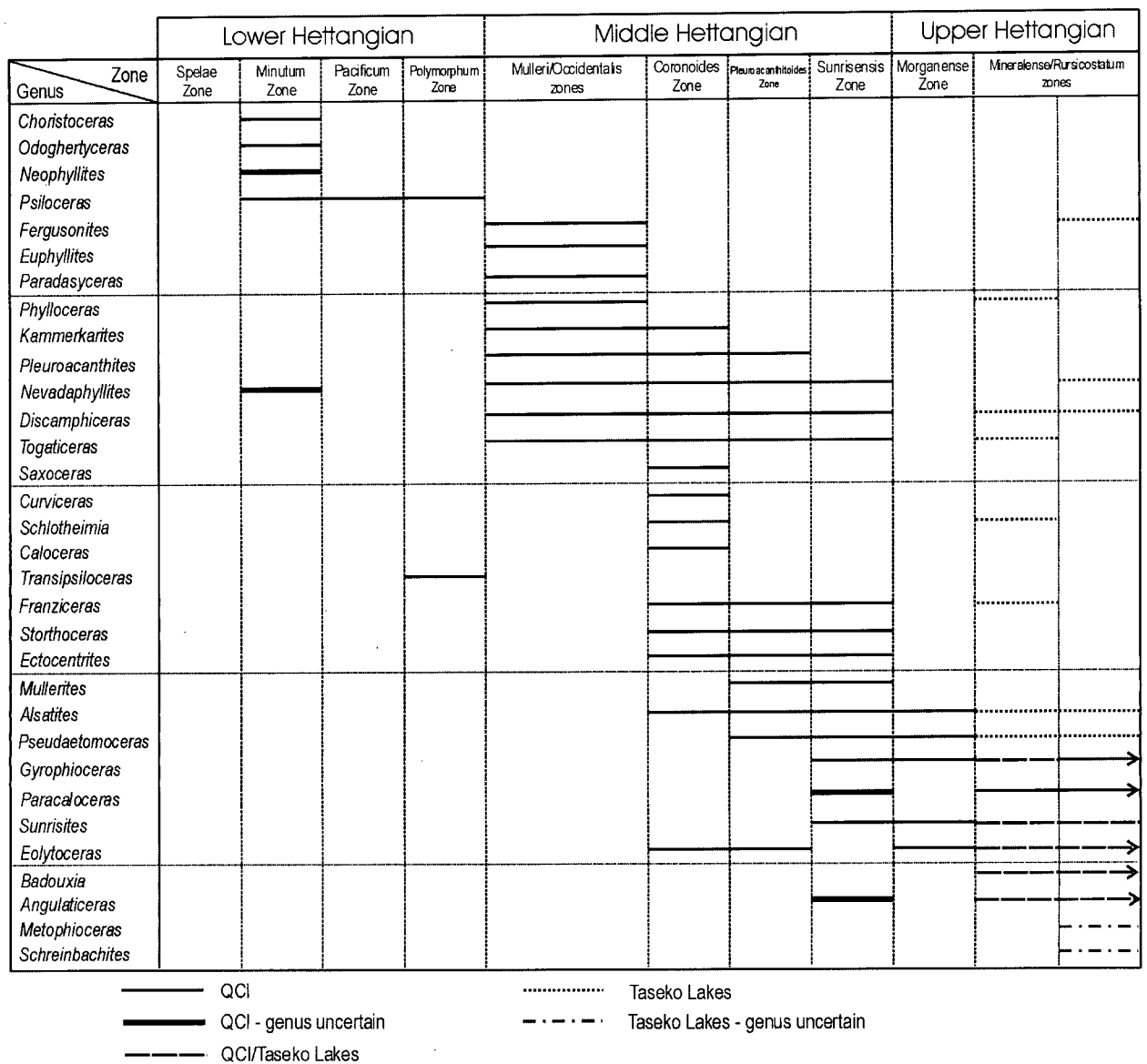
ammonites during the Hettangian as well as provide further data for paleobiogeographic and paleobiological studies. Two areas that have immediate potential are Alaska and the Russian Federation. Publications from both areas suggest there are numerous Hettangian faunas present, although at this point detailed taxonomic work is limited (e.g., Polubotko and Khudoley 1960; Repin 1977, 1984; Imlay 1981; Dagys 1996; Pálffy *et al.* 1999).

Secondly, geochronometric studies from the Hettangian sections in BC could produce radiometric dates. This process has been successful in the very latest Triassic at Kunga Island where a date of  $199.6^{+0.3}$  Ma was obtained and is used to constrain the T-J boundary (2000a, b). It has also been effective in a section in Alaska where dates of  $200.4^{+2.7}_{-2.8}$ ,  $197.8^{+1.2}_{-0.4}$  and  $197.8^{+1.0}$  Ma were attained in the middle and middle to late Hettangian although in this area the biostratigraphic control is not as good as in the BC sections (Pálffy *et al.* 1999). Work is underway to refine the T-J boundary date from Kunga Island (Pálffy and Mundil 2006) and a middle Hettangian volcanic ash is currently being analyzed from a section at Kunga Island (Pálffy, pers. comm., 2007). The calibration of biochronology from this study and geochronologic data would greatly improve the geological timescale. The correlations between the BC successions and those of other areas proposed in this thesis would then take on added importance as they would permit correlation of rocks and events on all scales as well as improved measurement of the rates of geological and paleobiological processes worldwide during the Hettangian.

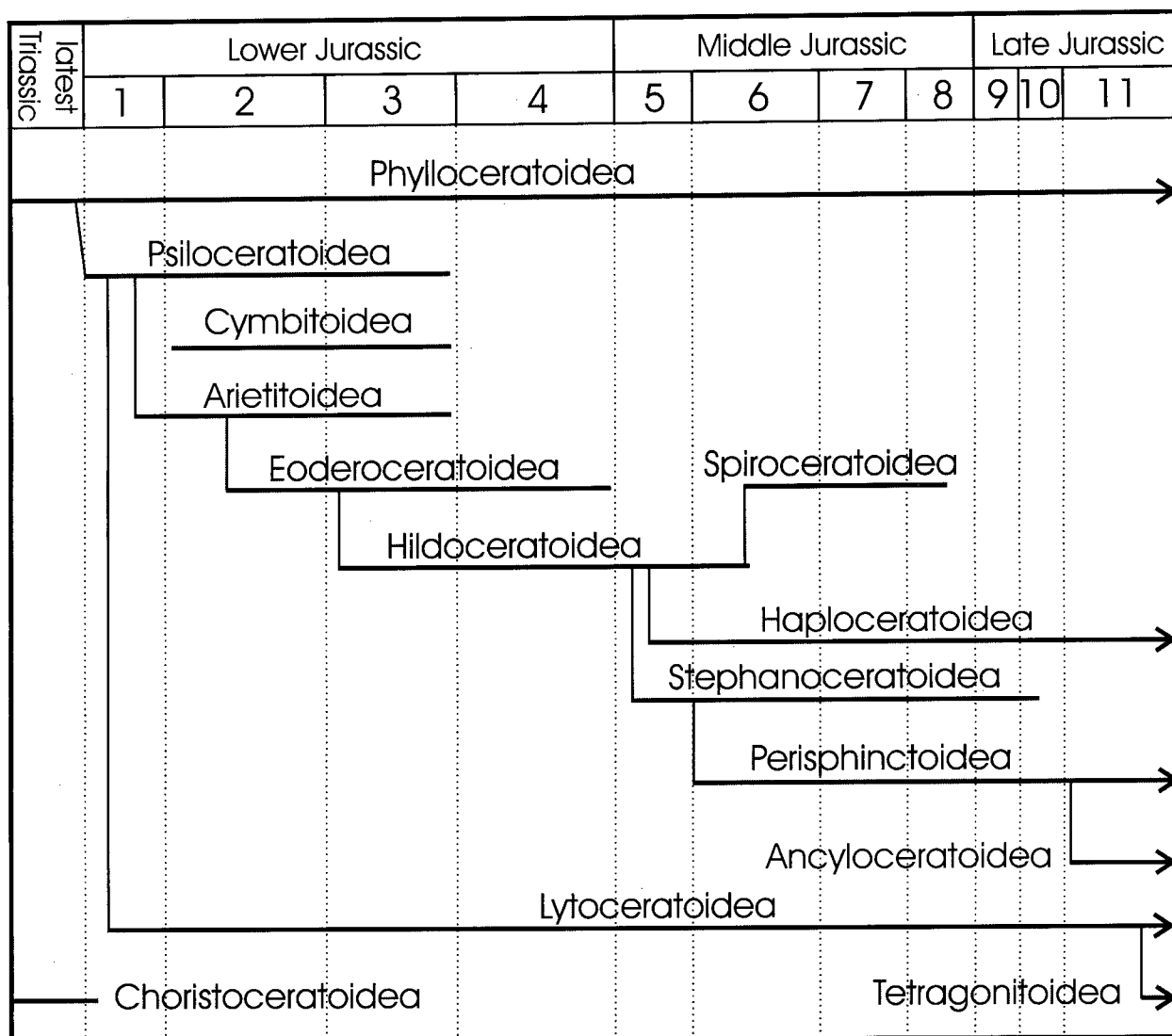
Thirdly, it may be possible to establish the cause of siphuncle asymmetry in Hettangian ammonites by completing a detailed study of the characteristic in all Hettangian species. At this point, it is difficult to separate a parasitic cause from a genetic cause. This thesis includes observations of instances where the siphuncle is offset as well as some general contributions to our understanding of the problem. Nevertheless, a detailed analysis at the species level may

provide further insight on whether this characteristic follows evolutionary lines or is the result of an external parasitic influence.

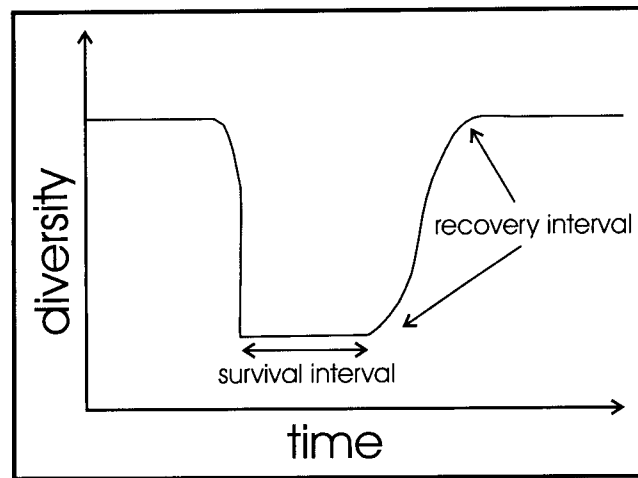
Finally, a cladistic study of Hettangian ammonites could be useful to test the current phylogeny (Fig. 9.4) and help resolve instances of uncertainty. Cladistic analyses on ammonoids from other time intervals have resulted in changes to the phylogenies created by more traditional methods (e.g., Moyne and Neige 2004; McGowan and Smith 2007). Furthermore, a cladistic analysis of ammonoids recently undertaken by McGowan and Smith (2007) indicated a reduction in the proposed extinction rate from *c.* 85% to *c.* 60% across the Permian-Triassic boundary. A similar study of Rhaetian and Hettangian ammonite faunas could be used to test the currently accepted level of extinction across the T-J boundary. The existence and growth of computer databases and the increasing number of systematic studies make cladistic analysis an obvious next step.



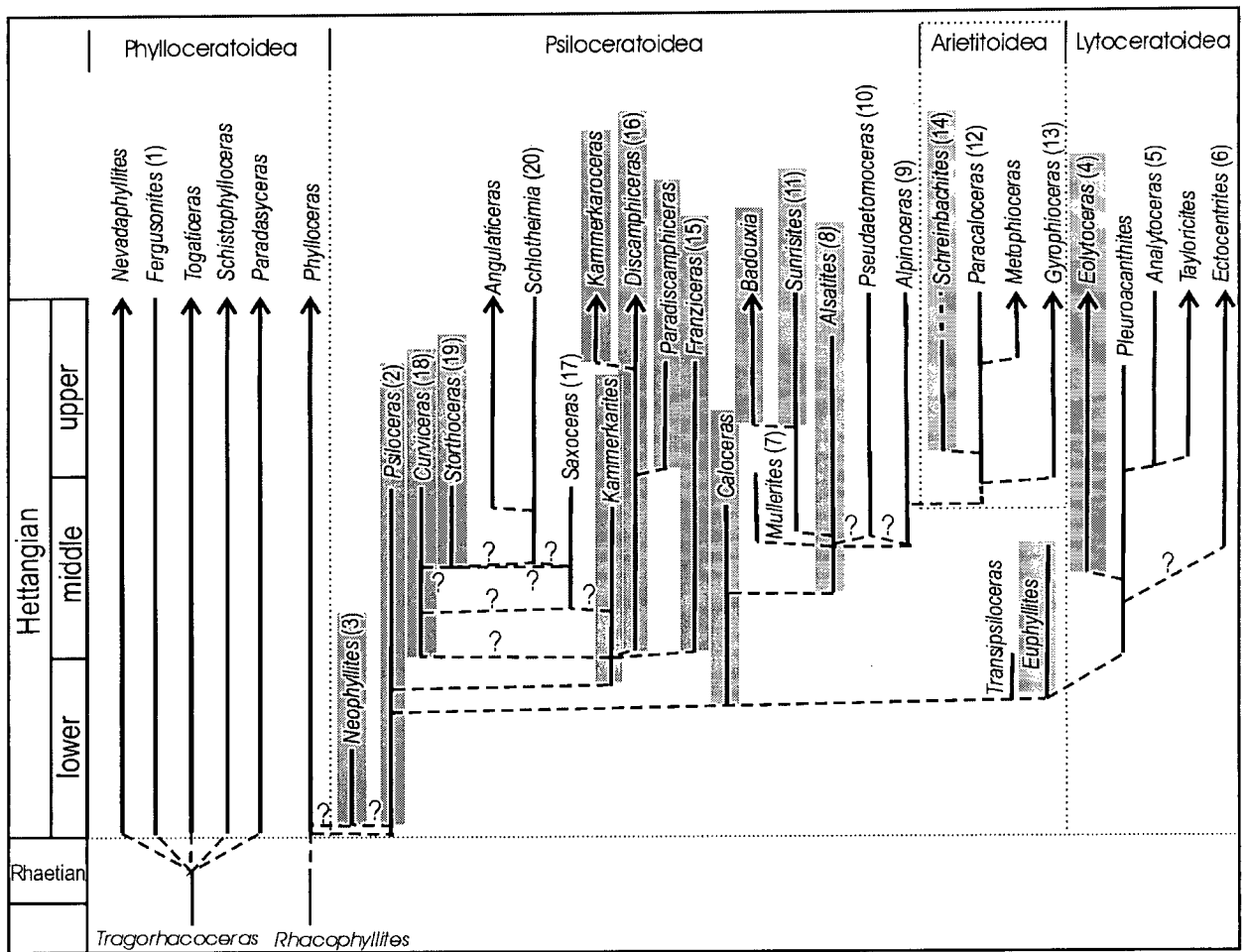
**Figure 9.1.** North American Zones (Taylor *et al.* 2001; Longridge *et al.* 2006) showing Hettangian ammonite genera present in the Queen Charlotte Islands (QCI) and Taseko Lakes. Mineralense and Rursicostatum zones are combined for QCI fauna and kept separate for the Taseko Lakes fauna. Resolution is at the zonal level.



**Figure 9.2.** Hettangian ammonite superfamilies in the Jurassic. 1 = Hettangian, 2 = Sinemurian, 3 = Pliensbachian, 4 = Toarcian, 5 = Aalenian, 6 = Bajocian, 7 = Bathonian, 8 = Calovian, 9 = Oxfordian, 10 = Kimmeridgian, 11 = Tithonian. Modified from Page (1996).

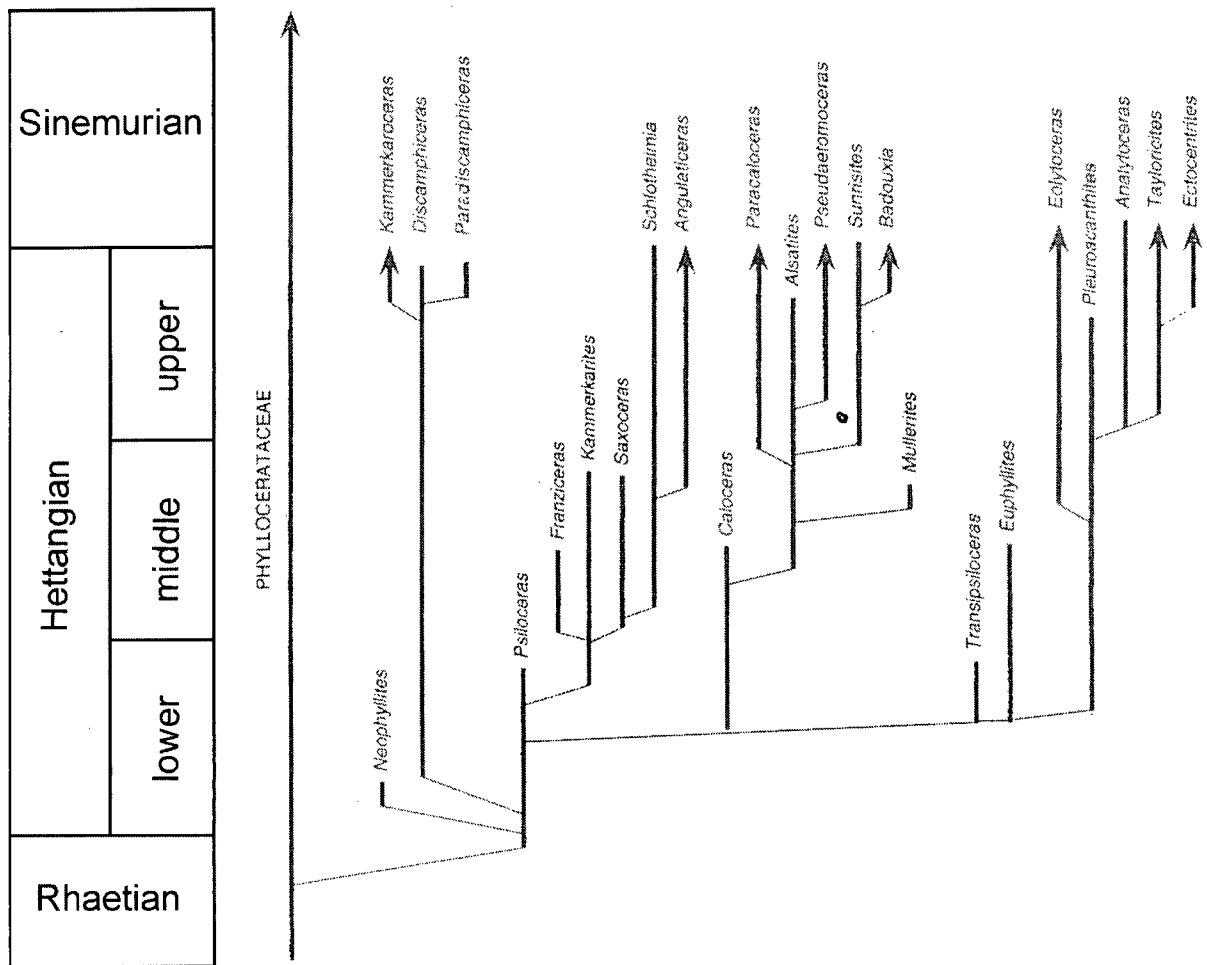


**Figure 9.3.** Model of adaptive radiation following mass extinction. Adapted from Erwin (2000).

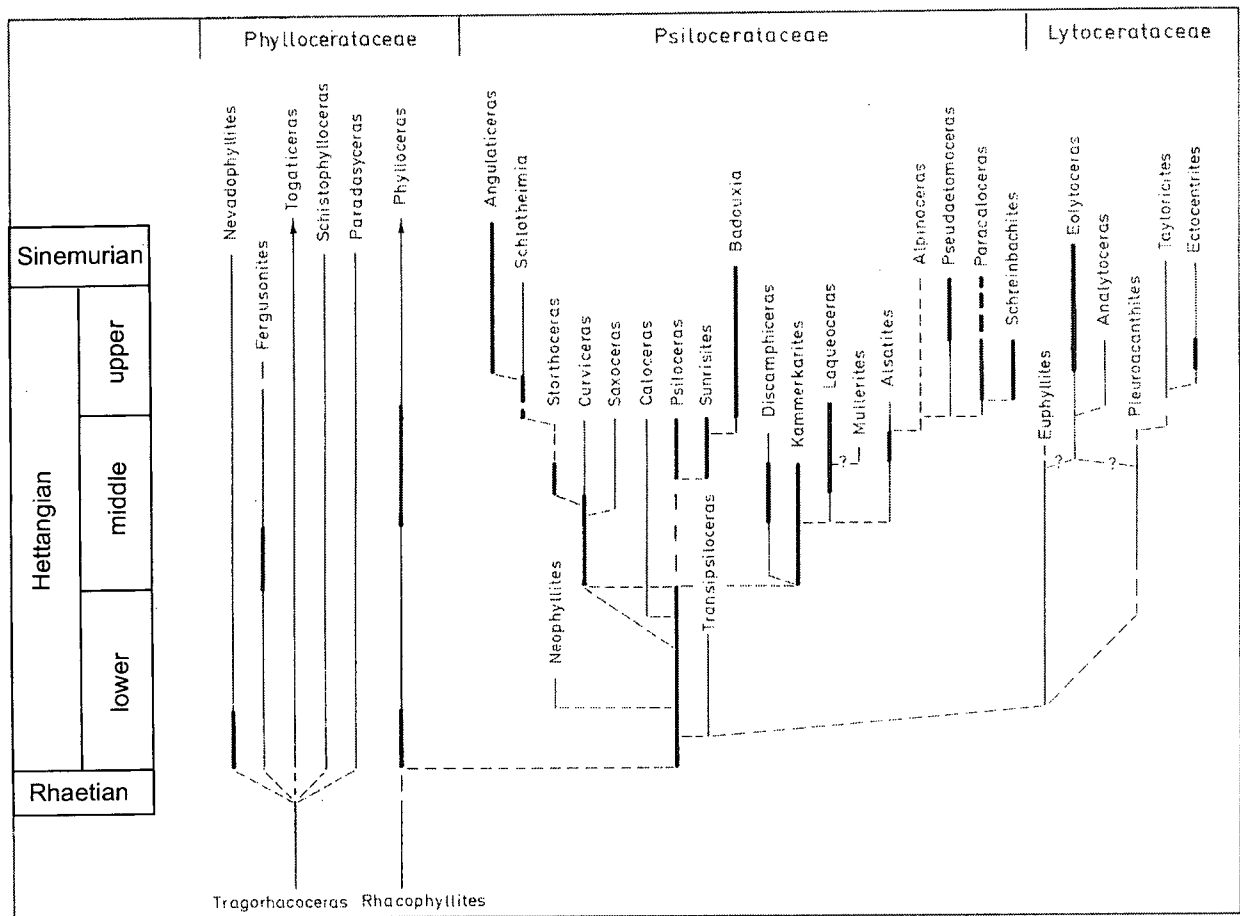


**Figure 9.4.** Phylogeny of Hettangian ammonites. Genera where some or all species have an asymmetric siphuncle and suture are indicated in grey. Numbers indicate instances of discussion in the text. Adapted from Rakús 1993a; Guex, 1995; Hillebrandt 2000a.





**Figure 9.5.** Phylogeny for Hettangian ammonites based on recent systematic studies in the United States. Modified from Guex *et al.* (2000, p. 112).



**Figure 9.6.** Phylogeny for Hettangian ammonites based on South American faunas; thicker lines indicate instances of genera found in South America. Modified from Hillebrandt (2000a, p. 106).

<b>Other areas of North America<sup>1</sup></b>	<i>Choristoceras minutus</i> , <i>Odoghertyceras deweveri</i> , <i>Neophyllites</i> (?) sp., <i>Nevadaphyllites psilomorphus</i> , <i>N. compressus</i> , <i>N. microumbilicatus</i> , <i>Togaticeras togatum</i> , <i>Fergusonites striatus</i> , <i>Psiloceras</i> ex. gr. <i>tilmanni</i> , <i>P. marcouxii</i> , <i>P. polymorphum</i> , <i>Transipsiloceras transiens</i> , <i>Discamphiceras silberlingi</i> , <i>D. antiquum</i> , <i>D. submesogenos</i> , <i>Alsatites</i> ex. gr. <i>proaries</i> , <i>A. liasicus</i> , <i>Pseudaetomoceras doetzkirchneri</i> , <i>P. castagnolai</i> , <i>Angulaticeras</i> (?) <i>dumitricai</i> , <i>A. ventricosum</i> , <i>A. marmoreum</i> , <i>A. cf. trapezoidale</i> , <i>Eolytoceras tasekoi</i> , <i>E. guexi</i> , <i>Saxoceras</i> cf. <i>portlocki</i> , <i>Kammerkarites frigga</i> , <i>K. rectiradiatus</i> , <i>K. haploptychus</i> , <i>K. praecoronoides</i> , <i>K. ex. gr. megastoma</i> , <i>Euphyllites occidentalis</i> , <i>Franziceras coronoides</i> , <i>F. graylockense</i> , <i>Paracaloceras rursicostatum</i> , <i>P. aff. rursicostatum</i> , <i>Mullerites pleuroacanthitoides</i> , <i>Gyrophioceras morganense</i> , <i>G. mineralense</i> , <i>G. aff. supraspiratum</i> , <i>Pleuroacanthites biformis</i> , <i>Storhoceras garfieldense</i> , <i>Badouxia forticostata</i> , <i>B. canadensis</i> , <i>B. castlensis</i> , <i>Sunrisites</i> cf. <i>brimblecombei</i> , <i>S. cf. chilcotinensis</i> , <i>Schreinbachites</i> (?) aff. <i>laqueoides</i> , and possibly <i>Schlotheimia cuevitensis</i>
<b>South America<sup>2</sup></b>	<i>Psiloceras tilmanni</i> , <i>P. planocostatum</i> , <i>Odoghertyceras deweveri</i> , <i>Nevadaphyllites compressus</i> , <i>Phylloceras asperaense</i> , <i>Fergusonites</i> cf. <i>striatus</i> , <i>Kammerkarites chinchillaensis</i> , <i>Discamphiceras</i> aff. <i>antiquum</i> , <i>D. aff. pleuronotum</i> , <i>Storhoceras australe</i> , <i>Alsatites</i> cf. <i>liasicus</i> , <i>A. bipartitus</i> , <i>Eolytoceras chongi</i> , <i>Schlotheimia cuevitensis</i> , <i>Sunrisites chilensis</i> , <i>Paracaloceras varaense</i> , <i>Angulaticeras</i> (?) cf. <i>cachinensis</i> , <i>A. marmoreum</i> , <i>A. trapezoidale</i> , <i>A. cf. ventricosum</i> , <i>Badouxia canadensis</i> , <i>B. forticostata</i> , and possibly <i>K. frigga</i> and <i>B. castlensis</i>
<b>New Zealand<sup>3</sup></b>	<i>Nevadaphyllites psilomorphus</i> , <i>N. microumbilicatus</i> , <i>Angulaticeras marmoreum</i> and possibly <i>Kammerkarites frigga</i> , <i>Eolytoceras tasekoi</i> and <i>A. ventricosum</i>
<b>Western Tethys<sup>4</sup></b>	<i>Nevadaphyllites psilomorphus</i> , <i>Togaticeras togatum</i> , <i>T. goisernense</i> , <i>Ectocentrites petersi</i> , <i>Pleuroacanthitoides biformis</i> , <i>Pseudaetomoceras castagnolai</i> , <i>P. doetzkirchneri</i> , <i>Eolytoceras</i> cf. <i>tasekoi</i> , <i>Discamphiceras pleuronotum</i> , <i>Alsatites proaries</i> , <i>Kammerkarites haploptychus</i> , <i>K. frigga</i> , <i>K. megastoma</i> , <i>Gyrophioceras praespiratissimum</i> , <i>G. supraspiratum</i> , <i>Angulaticeras ventricosum</i> , <i>A. marmoreum</i> , <i>A. trapezoidale</i> and possibly <i>Badouxia forticostata</i>
<b>Eastern Tethys<sup>5</sup></b>	<i>Nevadaphyllites</i> cf. <i>psilomorphus</i> , <i>Pleuroacanthites</i> aff. <i>biformis</i> , <i>Discamphiceras pleuronotum</i> , <i>Kammerkarites frigga</i> , <i>Eolytoceras</i> aff. <i>tasekoi</i> and <i>E. aff. chongi</i>
<b>Northwest Europe<sup>6</sup></b>	<i>Kammerkarites haploptychus</i> , <i>K. megastoma</i> , <i>Caloceras bloomfieldense</i> , <i>Saxoceras portlocki</i> , <i>Alsatites liasicus</i> , <i>Angulaticeras ventricosum</i> , <i>A. trapezoidale</i> , <i>A. marmoreum</i> and <i>Schreinbachites laqueoides</i>

**Figure 9.7.** Species from other areas with affinities to forms from the Canadian terranes.

<sup>1</sup>Chapters 2-8; Frebold 1951, 1967; Guex 1980, 1995; Imlay 1981; Jakobs and Pálffy 1994; González-León *et al.* 1996; Taylor 1998, 2000; Pálffy *et al.* 1999; Hall *et al.* 2000; Taylor *et al.* 2001; Taylor and Guex 2002; Guex *et al.* 2002; Hall and Pitaru 2004; Longridge *et al.* 2006, 2007, in press *a-c*. <sup>2</sup>Chapters 2-5, 7; Hillebrandt 1990, 1994, 2000*a-c*, and references therein; Guex *et al.* 1998; Smith and Tipper 2000; Longridge *et al.* 2006, 2007, in press *b-c*. <sup>3</sup>Chapters 4, 7; Stevens 2004; Longridge *et al.* in press *b*. <sup>4</sup>Chapters 4, 5, 7; Neumayr 1879; Wähner 1882-1898; Canavari 1888; Lange 1952; Blind 1963; Braga *et al.* 1984; Venturi 1985; Rakús 1993*a*, *b*, 1999; Rakús and Lobitzer 1993; Dommergues *et al.* 1995; Böhm *et al.* 1999; Kment 2000; Pálffy *et al.* 2001; Bertinelli *et al.* 2004; Longridge *et al.* 2006, in press *b*. <sup>5</sup>Chapters 4, 7; Yin *et al.* 2007; Meister *et al.* 2002; Longridge *et al.* in press *b*. <sup>6</sup>Chapters 4, 7; Lange 1941; Donovan 1952; Dean *et al.* 1961; Blind 1963; Elmi and Mouterde 1965; Schlegelmilch 1976; Bloos 1979, 1983, 1988*a*, 1994; Hodges 1986; Guerin-Franiatte 1990; Smith and Tipper 2000; Page 2002; Longridge *et al.* in press *b*.

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## **APPENDIX A: LOCALITIES FOR AMMONITE AND RADIOLARIAN COLLECTIONS FROM CHAPTER 2**

Information given below includes locations for the latest Rhaetian to early Hettangian radiolarians and early Hettangian ammonites from the Queen Charlotte Islands (QCI). Latitude and longitude are given for each location. Relevant GSC and other locality numbers are provided. Refer to Figure 2.1 for locations.

### **Section I**

Kennecott Point, northwest Graham Island. NTS 103F/14, Zone 8, 53°54.829', 133°09.188'.

A4: GSC loc. C-127013; collected 38 m above the base of section.

A3: GSC loc. C-175301; collected 27.7 m above the base of section.

A2: GSC loc. C-177353; collected 26.7 m above the base of section.

A1: GSC loc. C-177351; collected 25.5 m above the base of section.

R13: GSC loc. C-156843 (88-CNA-KPD-5); collected 30.7 m above base of section.

R12: GSC loc. C-303615 (99-CNA-1.6); collected ~28 m above base of section.

R11: GSC loc. C-303615 (99-CNA-2.0); collected 27.85 m above base of section.

R10: GSC loc. C-303614 (99-CNA-2.9); collected 27.52 m above base of section.

R9: GSC loc. C-156839 (88-CNA-KPD-4A); collected 26 m, above base of section.

R8: GSC loc. C-303612 (99-CNA-7.4A); collected 25.81 m above base of section.

R7: GSC loc. C-177383 (90-TD-11A); collected 24.3 m above base of section.

R6: GSC loc. C-156879 (90-CNA-KPD-5); collected 22.8 m above base of section.

R5: GSC loc. C-303608 (99-CNA-20.7); collected 21 m above base of section.

R4: GSC loc. C-305687 (01-HFB-011); collected 20.5 m above base of section.

R3: GSC loc. C-303607 (99-CNA-22.2); collected 20.0 m above base of section.

R2: GSC loc. C-156878 (90-CNA-KPD-4); collected 19.7 m above base of section.

R1: GSC loc. C-304606 (99-CNA-32.1); collected 14.4 m above base of section.

## **Section II**

Kennecott Point, northwest Graham Island. NTS 103F/14, Zone 8, 53°54.762', 133°09.248'.

A5: GSC loc. C-156968, 156969, 156970; collected 18.9 m above base of section

A4: GSC loc. C-175321; collected 18.2 m above base of section.

A3: GSC loc. C-156340, C-156967; collected 16.8 m above base of section.

A2: GSC loc. C-156966; collected 15.9 m above base of section.

A1: GSC loc. C-056952, 056953; location somewhat uncertain but between 15 m and 17.5 m above base of section.

R3: GSC loc. C-305433 (00-CNA-KPF-3); collected 14.2 m above base of section.

R2: GSC loc. C-305432 (00-CNA-KPF-2); collected 12.33 m above base of section approximately equivalent lithologically to level R7 in Section I.

R1: GSC loc. C-305431 (00-CNA-KPF-1); collected 6.5 m above base of section.

## **Section III**

Kunga Island, southeast side. NTS 103 B/13, Zone 9; 52°45.573', 131°33.638'.

A7: GSC loc. C-159351; collected 19.35 m above base of section.

A6: GSC loc. C-175325; collected 18.75 m above base of section.

A5: GSC loc. C-210792; collected 17.2 m above base of section.

A4: GSC loc. C-175324; collected 15.85 m above base of section.

A3: GSC loc. C-175323; collected 15.55 m above base of section.

A2: GSC loc. C-175302; collected 13.2 m above base of section.

A1: GSC loc. C-175322; collected 6.45 m above base of section.

R8: GSC loc. C-305413 (00-CNA-15.5); collected 16.45 m above base of section.

R7: GSC loc. C-304141 (98-CNA-D-3); collected 10.15 m above base of section.

R6: GSC loc. C-305412 (00- CNA-6.79); collected 7.74 m above base of section.

R5: GSC loc. C-305411 (00- CNA-6.5); collected 7.45 m above base of section.

R4: GSC loc. C-173357 (89-CNA-SKUD-339), C-303576 (97-CNA-SKUD-5), C-304137 (98-CNA-1), and C-305409 (00- CNA-6.3A); collected 7.25 m above base of section.

R3: GSC loc. C-305406 (00- CNA-3.85); collected 4.80 m above base of section.

R2: GSC loc. C-305405 (00- CNA-3.6); collected 4.55 m above base of section.

R1: GSC loc. C-164696/11, C-173288, C-303575, C-305404 ((87-CNA-SKUD-11, 89-CNA-SKUD-26, 97-CNA-SKUD-4, 00- CNA-2.8B, respectively); collected 3.75 m above base of section.

Radiolarians are figured also from GSC loc. C-173332 (89-CNA-SKUE-6) on the southeast side of Kunga Island, and QC-543 (collected by E.A. Pessagno, P.A. Whalen and C. Blome) on the north side of Kunga Island; see Carter *et al.* (1998) for further details.

## **APPENDIX B: LOCALITIES FOR AMMONITE, RADIOLARIAN AND CONODONT COLLECTIONS FROM CHAPTER 3**

Collections from Kunga Island, QCI, southeast side unless otherwise indicated (= section 5 in Carter 1993; section SKUD in Carter *et al.* 1998; section III (partial) in Longridge *et al.* 2007). NTS 103 B/13, Zone 9; 52°45.573', 131°33.638'. Relevant GSC numbers are provided.

Location shown on Figure 3.1 (section 1).

### **Radiolarian collections**

R1-R9 are Rhaetian faunas from the *Globolaxtorum tozeri* Zone (R1 marks the base of zone); collections R10-R16 are lower Hettangian faunas from the *Canoptum merum* Zone.

R16: GSC loc. C-305413; collected 93.45 m above base of section.

R15: GSC loc. C-304141; collected 87.15 m above base of section.

R14: GSC loc. C-305412; collected 84.74 m above base of section.

R13: GSC loc. C-305411; collected 84.45 m above base of section.

R12: GSC loc. C-173357, C-303576, C-304137, and C-305409; collected 84.25 m above base of section.

R11: GSC loc. C-305406; collected 81.80 m above base of section.

R10: GSC loc. C-305405; collected 81.55 m above base of section.

R9: GSC loc. C-164696/11, C-173288, C-303575, C-305404; collected 80.75 m above base of section.

R 8: GSC loc. C-303574, C-305402; collected 79.3 m above base of section.

R 7: GSC loc. C-173286, C-173287, C-303573; collected 79.1 m above base of section.

R 6: GSC loc. C-305401; collected 78.45 m above base of section.

R 5: GSC loc. C-303572; collected 77.85 m above base of section.



R4: GSC loc. C-173285; collected 78.9 m above base of section.

R 3: GSC loc. C-303571; collected 75.2 m above base of section.

R 2: GSC loc. C-173280; collected 60.75 m above base of section.

Kennecott Point. GSC loc. C-164674 (87- CNA-KPA-12) and ; C-140489 (87- CNA-KPA-17; section 1, Carter 1993). GSC loc. C-140496 (87- CNA-KPB-1; section 9, Carter *et al.* 1998)

R 1: GSC loc. C-164696/11; collected 56.0 m above base of section.

Additional GSC localities for figured radiolarians on plate 1 include:

Kunga Island, southeast side. GSC loc. 164696/13 (87-CNA-SKUB-13; section 2, Carter 1993), C-164674 (87-CNA-SKU-SP-1; section 6, Carter 1993), and C-173332 (89-CNA-SKUE-6; section 2, Carter *et al.* 1998).

Louise Island. GSC loc. C-127798 (86-CNA-SP-1/1; section 4, Carter 1993).

### **Conodont collections**

C1-C5 are Rhaetian faunas from the *Globolaxtorum tozeri* radiolarian Zone.

C5: GSC loc. C-303573, C-173287; collected 79.1 m above base of section.

C4: GSC loc. C-173284; collected 75.9 m above base of section.

C3: GSC loc. C-173282; collected 68.1 m above base of section.

C2: GSC loc. C-173281; collected 66.05 m above base of section.

C1: GSC loc. C-173280; collected 60.75 m above base of section.

### **Ammonite collections**

A1-A7 are early Hettangian faunas; A1 is possibly from the Spelae Zone, A2-A3 are from the Minutum and Pacificum zones, and A4-A7 are from the Polymorphum Zone.

A7: GSC loc. C-159351; collected 96.35 m above base of section.

A6: GSC loc. C-175325; collected 95.75 m above base of section.

A5: GSC loc. C-210792; collected 94.2 m above base of section.

A4: GSC loc. C-175324; collected 92.85 m above base of section.

A3: GSC loc. C-175323; collected 92.55 m above base of section.

A2: GSC loc. C-175302; collected 90.2 m above base of section.

A1: GSC loc. C-175322; collected 83.45 m above base of section.

## **APPENDIX C: LOCALITY INFORMATION FOR AMMONITE COLLECTIONS FROM CHAPTER 4**

Information given below includes locations for the middle and late Hettangian ammonite specimens from the QCI. Latitude and longitude are given in addition to a brief description of each location. Relevant GSC and other locality numbers are provided. Refer to Figure 4.1 for locations.

### **Section A**

Kennecott Point. [53°54'47.0', 133°09'9.8'; 53°54'44.7', 133°09'10.9']

Localities exposed on a wave cut platform consisting of A01 to A14 in a stratigraphic sequence.

Section begins above large fault.

A01: GSC locality C-157640; A02: C-157641, C-156903, C-156998, C-156323, 177354; A03: C-156905; A04: C-156302; A05: C-156906, C-156301, C-156346, C-156344; A06: C-156907, C-156304; A07: C-157642, C-156999; A08: C-156908; A09: C-156997; A10: C-157643; A11: C-156909; A12: C-156910; A13: C-156911, C-157000; A14: C-156912.

### **Section B**

Kennecott Point. [53°54'44.7', 133°09'10.9'; 53°54'43.3', 133°09'12.2']

Localities exposed on a wave cut platform consisting of B01 to B24 in a stratigraphic sequence.

Base of section is beside a large boulder. Section begins with concretionary beds that are approximately the same level as the concretionary beds in section A.

B01: GSC locality C-156985, C-156334, C-156339; B02: C-156986; B03: C-156987; B04: C-157636, C-156988; B05: C-156989; B06: C-156990; B07: C-156991, C-156992, C-156333; B08: C-156993; B09: C-156994; B10: C-157635, C-157638, C-156995, C-156913, C-156332; B11: C-156914, C-157639; B12: C-156915, C-156303; B13: C-157633, C-156916, C-156311;

B14: C-156310; B15: C-156917, C-156309; B16: C-157630, C-156919, C-156308; B17: C-156960; B18: C-156959, C-156306; B19: C-157632, C-156921, C-156305; B20: C-157623, C-157634, C-156918, C-156314; B21: C-156924, C-156312; B22: C-156925, C-156926, C-156313; B23: C-157672, C-156927, C-156321; B24: C-157637, C-156928, C-156929.

### **Section C**

Kenecott Point. [53°54'44.7', 133°09'10.9'; 53°54'44.0', 133°09'10.3']

Localities exposed on a wave cut platform consisting of C01 to C06 in a stratigraphic sequence.

Section is slice faulted against section B.

C01: GSC locality C-156322; C02: C-156320; C03: C-156319; C04: C-156318; C05: 156317; C06: 156316.

### **Section D**

Kenecott Point. [53°54'44.7', 133°09'10.9'; 53°54'42.3', 133°09'08.2']

Localities exposed on a wave cut platform consisting of D01 to D04 in a stratigraphic sequence.

D01: GSC locality C-156324; D02: C-156326; D03: C-156327; D04: C-156328.

### **Section E**

Kenecott Point. [53°54'38.9', 133°09'15.1'; 53°54'38.1', 133°09'12.8']

Localities exposed on a wave cut platform consisting of E01 to E08 in a stratigraphic sequence.

E01: GSC locality C-159251, C-159291; E02: C-159290; E03: C-159289; E04: C-159288; E05: C-159287; E06: C-159252; E07: C-159286, C-175211; E08: C-159285.

### **Section F**

Kenecott Point. [53°54'40.3', 133°09'07.3'; 53°54'39.5', 133°09'07.2']

Localities exposed on a wave cut platform consisting of F01 to F07 in a stratigraphic sequence. Section ends at a boulder field around a large boulder but continuation traceable by a marker bed further northwest, offset several meters by a strike-slip fault.

F01: GSC locality C-156420, C-175219; F02: C-156419; F03: C-156416, C-175218; F04: C-156406, C-156414, C-175216; F05: C-156405; F06: C-156404; F7: C-156403.

## **Section G**

Kennecott Point. [53°54'42.3', 133°09'08.2'; 53°54'41.1', 133°09'07.6']

Localities exposed on a wave cut platform consisting of G01 to G05 in a stratigraphic sequence. North of a boulder field, around a large boulder. Base of section is a bed with abundant *Chondrites*.

G01: GSC locality C-175208; G02: C-175204; G03: C-175203; G04: C-175202; G05: C-175201.

## **Section H**

Kunga Island. [52°45'34.4', 131°33'38.3'; 52°45'36.1', 131°33'36.0']

Localities exposed in supratidal region consisting of D01 to D04 in a stratigraphic sequence. Beds steeply dipping to overturned.

H01: GSC locality C-159352; H02: C-159354; H03: C-159355; H04: C-159356; H05: C-159357; H06: 159360.

## **Section I**

Kunga Island. [52°45'36.3', 131°33'38.7'; 52°45'36.9', 131°33'37.1']

Localities exposed in supratidal region consisting of D01 to D04 in a stratigraphic sequence. Beds steeply dipping to overturned.

I01: GSC locality C-159363; I02: C-159370.

## APPENDIX D: AMMONITE MEASUREMENTS FROM CHAPTER 4

Measurements are given below for all measured specimens from the QCI. Instances where the measurement is approximate are marked by the letter c. in front of the number. Abbreviations and measurements follow Smith (1986) and include shell diameter (D), umbilical diameter (UD), whorl width (WW), whorl height (WH), umbilical diameter as a ratio of shell diameter (U), ratio of the whorl width to the whorl height (WWWH) and primary ribs per half whorl (PRHW).

### *Phylloceras cf. asperaense*

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129066	26.2	26.2	5.3	0.20	9.5	13.6	0.70
129067		36.7	6.8	0.19		17.5	

### *Paradasyceras carteri*

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129072	42.6	42.6	7.8	0.18		21	
129073		32.8	6.5	0.20		16.2	
129074		29.9	5.8	0.19		14	
129075		20.8	4.7	0.23		9.3	
129076		20.5	4.3	0.21	c.6.8	9.2	0.74
129071		c.42	7.7	0.18		c.20.5	
129077	30.5	30.5	5.6	0.18		15	
129078		25.5	5.9	0.23		11.6	
129079	13.7	13.7	3	0.22		6.4	
129080		25.5	5.6	0.22		12.5	
129070		21	5	0.24		9.4	

### *Fergusonites striatus*

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129083		23.2	5.8	0.25	8.5	10.1	0.84
129081		27.2	6	0.22		11.6	
129084		19.4	4.2	0.22	7.2	9.3	0.77
129085		24	5.6	0.23		11	
129086		25	6	0.24		12.6	
129087	c.24	c.24	5.5	0.23		11.4	
129088		17.1	3.5	0.20	6.1	7.8	0.78
129089		13.5	2.5	0.19		6.2	
129090	18.1	18.1	3.2	0.18	6.8	8.5	0.80

129091	28.8	28.8	6.8	0.24		12.6	
129082	30.5	30.2	6.8	0.23	10.3	13.6	0.76
129092		20	4.5	0.23	7	9	0.78
<b><i>Nevadaphyllites psilomorphus</i></b>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH
129093		34.2	4.5	0.13			
129094	68.2	68.2	10.9	0.16		35.8	
129095	32	32	5	0.16		15.5	
129096		27.2	4	0.15	10.1	14.5	0.70
129097		35.4	5.4	0.15		18.2	
129098		40.2	6.8	0.17		20.6	
<b><i>Nevadaphyllites sp.</i></b>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH
129101		c.34	c.5	0.15			
<b><i>Nevadaphyllites aff. compressus</i></b>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH
129099		31.1	6.7	0.22		15.6	
<b><i>Togaticeras togatum</i></b>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH
129106		c.33	c.6.2	0.19			
129104		24	c.4	0.17		12	
129107		21.2	3.7	0.17		9.6	
129108		c.21.5	3	0.14		10.7	
129109		14.5	2.5	0.17		6.9	
129110		17.6	4.3	0.24		7.5	
129105		17.6	3.1	0.18		8	
129111		16.7	3	0.18		7.9	
129112		19.8	3.5	0.18		10.3	
129113		17.2	3.2	0.19		7.8	
129114		18	3.2	0.18		9	
<b><i>Eolytoceras cf. tasekoi</i></b>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH
129150		53.7	20.3	0.38		19.5	
129151		24	7.5	0.31		9.7	
129152		56	23.5	0.42		17.7	
129153		32	11	0.34		12	
107365		89	36.2	0.41		30.5	
107367		75.5	27	0.36		29	
<b><i>Eolytoceras aff. constrictum</i></b>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH # FLARES
107374		83	30.4	0.37		28.7	7
107373		79.2	33.6	0.42		24.7	6

***Eolytoceras cf. praecursor***

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129127		51	25.7	0.50		15.4	
129129		77	38.5	0.50		21	
129130		29.3	13.7	0.47		9.5	
129131						3.4	
129132		46	21.9	0.48		14	
129128		54.3	28	0.52		15.2	
129133		49.5	c.26.2	0.53		c.12.5	
129134		26.2	11.9	0.45		8.3	
129135		c.24.6	11	0.45		7.2	

***Ectocentriles pacificus***

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129119		34.5	11	0.32		13	
129120		35	11	0.31		14.5	
129121		38	14	0.37		14	
129122		27.5	8	0.29		9.5	
129117	26.7	26.7	9	0.34		10	
129123		c.35	c.12	0.34		15.4	
129124		24.5	8.6	0.35		10	
129125		16	5.4	0.34		6	
129126		29	8.4	0.29		12	

***Pleuroacanthites cf. biformis***

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129138		59.2	29.5	0.50			
129139		c.79.8	43	0.54		20.5	
129137		203	119	0.59			

***Pleuroacanthites sp.***

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129148		c.48	c.22.8	0.48		c.15.2	

***Pleuroacanthites charlottensis***

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129144		44.3	25.5	0.58		11	
129143		23.8	12.1	0.51		6.3	
129145		27.4	13.1	0.48		7.4	
129146		27.5	13.6	0.49		8	
129147		26.4	13.6	0.52		7.2	

***Euphyllites occidentalis***

GSC #	DMAX	D	UD	U	WW	WH	WWWH
129154		80.7	35.5	0.44		26	
129155					25.5	32	0.80
129158		119.6	58.5	0.49		33	



129159		17.8	6.9	0.39		6.2		
129160		c.71	36.5	0.51				
129156	c.200	c.195	c.110.9	0.57				
129161		172	88.5	0.51				
129157		18.7	6.7	0.36		6.5		
<b><i>Caloceras aff. bloomfieldense</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129162		62	39	0.63		13		19
<b><i>Alsatites ex gr. proaries</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130713	45.2	45.2	24	0.53		11		21
130714		49	21.8	0.44		18.5		
130716		44.5	c.20.2	0.45		13.9		11
130717		46.3	22.1	0.48		14		13
130712	48.2	48.2	25.4	0.53		11		c.22
<b><i>Alsatites aff. proaries</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130703		43.4	25.8	0.59		10		26
130704		30.1	17.4	0.58		7		21
130705		39.8	24.8	0.62		8.5		27
130706	50	50	31.5	0.63		11		c.27
130707		21.5	9	0.42		6.5		15
130708		21	10.8	0.51		6		c.15
130709		41	24	0.59		9		26
130710		37	23	0.62		8		25
<b><i>Alsatites cf. liasicus</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130699	36.1	36.1	23.7	0.66		6.1		23
130700		c.47.8	c.31.4	0.66		c.8.4		
130701		31.1	20.7	0.67		5.3		
<b><i>Mullerites cf. pleuroacanthitoides</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130718		22.4	12.9	0.58		4.8		19
130720		88	52.8	0.60		19		20
130721		71	41	0.58		17.2		
130722		33	17.8	0.54		7		18
130723		28	14	0.50		8		15
130724		55.2	29.2	0.53		13.8		18
130719	c.80	c.80	44	0.55		c.18.3		21
<b><i>Discamphiceras silberlingi</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129163		34.5	12.5	0.36		12.1		13

130672	28.9	10.5	0.36		9.8		
130671	19.5	7	0.36		6.3		
130670	28.8	10	0.35		10.3		11.5
129169	41	14.6	0.36		14.5		
129170	22	7	0.32		9		11
130673	27.8	8.4	0.30		10.7		12
129173	39	16.7	0.43		18.1		
129175	24.9	9.5	0.38		8.8		11
130674	19.8	5.5	0.28		7		11.5
129179	41.1	14.1	0.34		15		
129167	30	8	0.27		8		15
129180	19.5	7.4	0.38		6.5		11
129177	22.1	6.2	0.28		9.7		
130669	24.4	9.1	0.37		8.3		11
129171	22.2	5.7	0.26		9.7		14
129168	43.4	12.2	0.28		17.2		11.5
129165	18.4	6	0.33		7		
129172	38.5	12	0.31		15		13
129164 69	69	25	0.36		25		13
129176	33	11.5	0.35		11.5		
129178	21	5.2	0.25		9		
129174	26	7.8	0.30		10.4		13
129166	28.7	9.4	0.33		10.7		
<i>Discamphiceras aff. pleuronotum</i>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH PRHW
130678		24	7.5	0.31		10	12
130677		c.34	11.9	0.35		13.4	
130679		c.25.6	9.3	0.36			14
130680		c.60.5	c.23	0.38		c.22.5	
<i>Discamphiceras aff. antiquum</i>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH
130696		34	8.4	0.25		15	
130697		66	18.5	0.28		22	
130698		25.5	7	0.27		12	
<i>Discamphiceras cf. submesogenos</i>							
GSC #	DMAX	D	UD	U	WW	WH	WWWH
130682	37.3	37.3	c.9.3	0.25		16	
130683		21.5	5.8	0.27		10	
130684		37.5	c.9	0.24		18.6	
130685		22	6.8	0.31		9	
130686		23	6	0.26		11.4	
130687		21.2	6.5	0.31		12	

130688	27	7.8	0.29	11
130681	63.6	17.3	0.27	26
130689	35.2	c.8	0.23	16.5
130690	c.36.5	c.9.2	0.25	15
130691	22	5.9	0.27	9.7
130692	29	8.1	0.28	12
130693	28.2	8.3	0.29	11.2
130694	42.5	11.6	0.27	18.4

***Sunrisites cf. chilensis***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130729		25	10.3	0.41		8.5		
130728		45	21	0.47		14.5		
130730		40	19	0.48		11.5		11
130731		41.5	21	0.51		12		
130732		77	41	0.53		20		
130727		91	43.5	0.48		26		14
130733		45	22	0.49		13.4		12
130734		23.2	10	0.43		7.1		9

***Sunrisites cf. senililevis***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
107385		67	31	0.46		22		9

***Badouxia canadensis***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
107392		48.8	24	0.49		15.7		14
107393		28.3	13.5	0.48		47.7		13
107397	28.7	28.7	7.8	0.27		11.3		

***Pseudaetomoceras cf. doetzkirchneri***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130739		26.8	10.4	0.39		10.4		17
130740		17	6	0.35		6		15
130738		26.5	10.6	0.40		8.8		18

***Storthoceras cf. australe***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130755		39	16	0.41		12.5		18
130756		30.5	12.8	0.42		10		16
130757		33	14	0.42		10		17
130758		30	11.7	0.39		9.8		16
130759		18.4	6	0.33		7.2		13
130760		26.2	10	0.38		9.1		c.15
130761		32	12.8	0.40		10.8		
130762		21.7	7.5	0.35		8		

***Storthoceras aff. garfieldense***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130743		22	7	0.32		8.3		15
130742		56.2	26	0.46		17.1		22
130744		20.4	6.5	0.32		8.5		15
130745		22.3	7.3	0.33		8.1		14
130746		21.5	6	0.28		9		14
130747		14	4.1	0.29		5.8		13
130748		41.2	15.5	0.38		14		18
130749		29	9	0.31		10.1		14
130750	16.5	16.5	5.2	0.32		6		14
130751		28	10	0.36		9.2		18
130752		c.34	11.5	0.34		13		17
130753		c.30.4	11	0.36		11.9		19
130741		23.3	8	0.34		9		14
130754		30.3	10.5	0.35		11.1		17
<b><i>Saxoceras aff. portlocki</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130769		37.2	15.6	0.42		11.4		15
130770		31.2	12	0.38		10.9		16
130771		40	16.3	0.41		13		16
130767		31	12.6	0.41		10.8		18
130766		33	13.2	0.40		11.7		
130772		28.6	11	0.38		10		17
130768	18.7	18.5	6.5	0.35		6.8		17
<b><i>Curviceras haidae</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130763		63	28.8	0.46		19.9		c.17
<b><i>Kammerkarites sp. nov.</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130773		40	19.6	0.49		10.5		19
130774		c.100.2	59	0.59		21.2		26
<b><i>Kammerkarites cf. chinchillaensis</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	
130776		61	24	0.39		21		
<b><i>Kammerkarites cf. frigga</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130777		36	14.5	0.40				c.17
130779		32.5	14	0.43				14
130780		16.5	5.5	0.33				13
130778	18.3	18.3	7.1	0.39	5.7	6	0.95	11
130781		22	7.5	0.34				14
130782		23	7.5	0.33				14

130783	22.5	7.5	0.33					15
130784	16	5.5	0.34					12
130785	28.5	11.5	0.40					15
130786	28	10	0.36					14
130787	35	14	0.40					16
130788	17.5	6.5	0.37					15
130789	22.5	8	0.36					12
<b><i>Kammerkarites cf. haploptychus</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130790		261	154	0.59		58		
130792		71	34.8	0.49		20		27
130791		c.93.5	c.46	0.49		26		
<b><i>Kammerkarites cf. rectiradiatus</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130675		96	c.36	0.38		34		16
<b><i>Kammerkarites aff. megastoma</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130794		146	81	0.55		37.5		25
<b><i>Franziceras kennecottense</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130807		35	15.5	0.44		11.5		
130808		32	13.5	0.42		10.5		c.11
130805		37	15.8	0.43		11.5		13
130809		40.3	18	0.45		18.3		
130810		26.8	11.3	0.42		8.2		13
130811		40.8	17.7	0.43		12.5		15
130812		36.2	17.3	0.48		10		12
130813		25	11	0.44		7.5		12
130814		50	23.5	0.47		16		12
130815		21.1	9.6	0.45		6.3		11
130816		26.4	11.9	0.45		8		11
130817		34.5	13.6	0.39		12		13
130818		47.4	c.22.5	0.47		c.13		14
131665		c.29.2	12.3	0.42				12
131666		36	16.5	0.46		10.5		13
130806		57.5	27	0.47		17.5		16
131667		48	21	0.44		14.5		14
<b><i>Franziceras cf. coronoides</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
130798		51.5	24	0.47		15		12
130799		14.2	5.7	0.40		4.4		7
130797		c.52.5	25.5	0.49		14.5		

130803	46.8	23	0.49		12.8	
130800	32.3	15.8	0.49		9.3	10
130801	21.4	9.8	0.46		5.7	8
130802	21.7	9.8	0.45		6.3	9
130795	c.85	c.40	0.47		28	12

***Schlotheimia* sp.**

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
131668	24.7	24.7	10.5	0.43		7.1		16
131669		18	7.2	0.40		5.8		15
131670		16.1	6.4	0.40		5.4		15
131671		16.2	6.8	0.42		5		13
131672		26.6	c.11	0.41		8.5		16

***Angulaticeras* cf. *ventricosum***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
107376		28.1	5	0.18		15.2		18

***Angulaticeras* (?) cf. *dumitricai***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
131676		31	8.2	0.26		13.5		19
131674		41.5	12.2	0.29		18.2		20
131677		18.5	6.5	0.35		7		15
131675		28.7	7.4	0.26		13.6		19
131678		25.5	c.7.1	0.28		11.1		22

***Gyrophioceras* aff. *praespiratissimum***

GSC #	DMAX	D	UD	U	WW	WH	WWWH
131679		53	34.5	0.65		10.2	

***Paracaloceras* (?) sp.**

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
131681		51	29	0.57		11.3		17
131682		28	15.8	0.56		7		16

***Gyrophioceras* cf. *supraspiratum***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
107400		69.5	50.3	0.72		10.2		27

***Paracaloceras* cf. *rursicostatum***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
107402		61.5	35	0.57		12.4		26
107413		60	35	0.58		13		22

## APPENDIX E: LOCALITY INFORMATION FOR *BADOUXIA* COLLECTIONS FROM CHAPTER 5

Information given below includes locations for all figured and/or measured specimens of *Badouxia* from Taseko Lakes. Latitude and longitude are given where possible in addition to a brief description of each location. Relevant GSC and other locality numbers are provided. Refer to Figure 5.2 for locations.

### Section A

Castle Pass. [51°05'157", 122°57'671"; 51°05'206", 122°57'664"]

Localities exposed on the main saddle at Castle Pass consisting of A01 to A15 in a stratigraphic sequence and A16 and A18 from talus.

A01: GSC locality C-117236; A02: GSC locality C-117237; A03: GSC locality C-143319; A04: GSC locality C-177633, GSC locality C-177635, GSC locality C-208991; A05: GSC locality 62362 (Section 1 of Frebold 1967); A06: GSC locality C-208993; A07: GSC locality 62499 (Section 1 of Frebold 1967); A08: GSC locality C-208992; A09: GSC locality 62345 (Section 1 of Frebold 1967); A10: GSC locality C-143313; A11: GSC locality C-143312; A12: GSC locality C-143311; A13: GSC locality C-208994; A14: GSC locality C-143308; A15: GSC locality C-208961; A16: GSC locality C-208983; A17: GSC locality C-203169, GSC locality 94770; A18: GSC locality C-143295

### Section B

Castle Pass. [51°05'196", 122°57'816"; 51°05'241", 122°57'736"]

Localities exposed approximately 100 m west of the main saddle at Castle Pass consisting of B01 to B07 in a stratigraphic sequence and B08 from talus.

B01: GSC locality C-117233, C-208960; B02: C-143296; B03: C-143304; B04: C-208958; B05: C-175388; B06: C-118699, C-117234; B07: C-118700, C-117235; B08: C-175397, C-208984.

### **Section C**

Castle Pass. [ $51^{\circ}05'02.13''$ ,  $122^{\circ}57'49.44''$ ;  $51^{\circ}05'06.02''$ ,  $122^{\circ}57'50.53''$ ]

C01: GSC locality C-143337; C02: C-117249

### **Section D**

Castle Pass. [ $51^{\circ}05'157''$ ,  $122^{\circ}57'671''$ ;  $51^{\circ}05'180''$ ,  $122^{\circ}57'661''$ ]

Localities exposed immediately east of the main saddle at Castle Pass consisting of D01 and D02 *in situ* and D03 from talus.

D01: GSC locality C-143324; D02: C-143327, C-177636, C-175372; D03: C-143322

### **Section E**

Last Creek. [ $51^{\circ}05'493''$ ,  $123^{\circ}00'719''$ ;  $51^{\circ}05'481''$ ,  $123^{\circ}00'706''$ ]

Localities exposed approximately 100 m east of the head of Last Creek consisting of E01 to E03 in a stratigraphic sequence and E04 from talus.

E01: GSC locality C-208963, C-208955; E02: C-208964; E03: C-208988; E04: C-208956, C-208957

### **Section F**

Last Creek. [ $51^{\circ}05'416''$ ,  $123^{\circ}00'714''$ ;  $51^{\circ}05'432''$ ,  $123^{\circ}00'754''$ ]

Localities exposed on the north-east side near the head of Last Creek consisting of F01 to F08 in a stratigraphic sequence and F09 from talus.



F01: GSC locality C-175380, C-117064; F02: C-117066; F03: 62409 (Section 5 of Frebold);  
F04: C-117067; F05: 62328 (Section 5 of Frebold); F06: C-208976; F07: C-117069; F08: 56622  
(exact locality uncertain); F09: 94222, 94223, 94236, C-175373, C-208974

## **Section G**

Last Creek. [ $51^{\circ}05'38.4''$ ,  $123^{\circ}00'75.9''$ ;  $51^{\circ}05'41.3''$ ,  $123^{\circ}00'76.3''$ ]

Localities exposed on the south-west side near the head of Last Creek consisting of G01 to G10  
in a stratigraphic sequence and G11 from talus.

G01: GSC locality 62404 (Section 3 of Frebold, 1967); G02: 62432 (Section 3 of Frebold  
1967); G03: C-175389; G04: 62406 (Section 3 of Frebold 1967); G05: 94231; G06: 94206;  
G07: 62402 (Section 3 of Frebold 1967); G08: 94228; G09: 62430 (Section 3 of Frebold 1967),  
C-117074; G10: C-117075; G11: C-175398, GSC locality 56448

Stream Talus from Head of Last Creek

Talus including material from Section E, F and G above. Collection C-208954 consists of 2  
specimens coming from one small block.

GSC locality 11189, GSC locality C-175363, GSC locality C-208954

## **Isolated Locality 1**

Locality on right bank of Spruce Lake Creek, 0.3 km from the mouth.

GSC locality 2106 (Locality of Frebold 1951).

## **Isolated Locality 2**

[approx.  $51^{\circ}02'45''$ ,  $122^{\circ}58'18''$ ].

Locality on Tyaughton Creek around 1.5 km west of Spruce Lake Creek.

GSC locality 62504 (Isolated locality 2 of Frebold 1967)

### **Isolated Locality 3**

[approx. 51°02'45", 122°57'50"].

Locality on Tyaughton Creek approximately 1 km west of Spruce Lake Creek. Study of the *Badouxia* fauna from this locality supports the interpretation of Tozer (pers. comm. in Frebold, 1967). The two relevant collections from this site are part of a faulted sequence and probably do not represent a continuous stratigraphic sequence.

GSC locality 1404 (Locality of Frebold 1951), GSC locality 56393 (Section 7 of Frebold 1967), GSC locality 56394 (Section 7 of Frebold 1967)

### **Isolated Locality 4**

[approx. 51°04'42", 122°59'13"].

Locality on the ridge approximately 1.5 km south-west of Castle Peak.

GSC locality 62445 (Isolated locality 11 of Frebold 1967)

### **Isolated Locality 5**

[approx. 51°04'45", 123°01'200"].

Isolated locality on a Last Creek tributary about 1 km south of the sections at the top of Last Creek.

GSC locality 1349 (Locality of Frebold 1951).

### **Isolated Locality 6**

[approx. 51°05'05", 122°59'00"].

Locality on the saddle around 1.2 km west of Castle Mountain.

GSC locality 62448 (Isolated locality 7 of Frebold 1967)

## **Isolated Locality 7**

Locality about 400 m east of the head of Last Creek

GSC locality 62478 (Isolated locality 1 of Frebold 1967)

## **Isolated Localities 8 and 9**

These localities were previously documented as stratigraphic sections (locality 8 is equivalent to sections 4 and 6 of Frebold, 1967 and locality 9 is equivalent to section 2). However, more recent work has revealed poorly resolved structural complications which impede their use as continuous sections. For the purposes of this study, collections from these areas are considered to be isolated and unrelated.

### **Isolated locality 8**

Localities exposed at the top of Last Creek on the north-east side directly below Section E.

GSC locality 56416 (Section 6 of Frebold 1967), 62354 (Section 4 of Frebold 1967), 62467 (Section 4 of Frebold, 1967), 62502 (Section 4 of Frebold 1967), C-117085, C-117086, C-117087, C-117088, C-175379, C-175395, C-208967, C-208968, C-208973 (talus)

### **Isolated locality 9**

Localities exposed at the top of Last Creek on the south-west side directly below Section F.

GSC locality 62487 (Section 2 of Frebold 1967), 62466 (Section 2 of Frebold 1967), GSC locality 62494 (Section 2 of Frebold 1967), 62479 (Section 2 of Frebold 1967)

## **Isolated Locality 10**

Isolated locality on a ridge west of Last Creek.

GSC locality 56466.

## **Isolated Locality 11**

[51°05'550", 123°00'719"].

Locality exposed approximately 120 m east of the head of Last Creek above Section D on the north-east side. This may be a short section. This locality bears material from the Columbiae Subzone and may be a short section.

GSC locality C-208956 (talus).

### **Isolated Locality 12**

[51°05'980", 123°00'707"].

Locality about 1.5 km north of Last Creek.

GSC locality C-208962

## APPENDIX F: MEASUREMENTS FOR *BADOUXIA* COLLECTIONS FROM CHAPTER 5

Measurements are given below for all measured specimens of *Badouxia* from Taseko Lakes.

Instances where the measurement is approximate are marked by the letter c. in front of the number. Abbreviations and measurements follow Smith (1986) and include shell diameter (D), umbilical diameter (UD), whorl width (WW), whorl height (WH), umbilical diameter as a ratio of shell diameter (U), ratio of the whorl width to the whorl height (WWWH) and primary ribs per half whorl (PRHW).

### *Badouxia canadensis*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
11206B	18.1	18.1	8.2	0.45	6	5.6	1.07	10
11206D		44.5	15.3	0.34		18.0		13
20068	52.5	49.8	16.4	0.33		19.7		
20067	59	58.4	19.7	0.34	19.3	22.3	0.87	
117240		18.5	7.3	0.39	6.3	6	1.05	11
127238	34	33	13.8	0.42	9.3	10.1	0.92	12
127124	25.8	25.8	11.2	0.43	7.8	8.1	0.96	13
127159		26.2	10.9	0.42		8.4		11
127170		46.3	20.2	0.44	14.1	11.0	1.28	11
127177		32.2	12.1	0.38		12.3		
127168		29.1	13.2	0.45	c.8.7	8.8	0.99	11
127162	57.6	57.6	21.5	0.37	c.18.4	22.0	0.84	
127021	62.1	62.1	29.9	0.48	14.3	18.1	0.79	14
127176	46.2	46.2	19.7	0.43	c.13.5	15.2	0.89	11
127167		34.3	13.1	0.38	12.2	12.8	0.95	
127171	36.7	33.2	15	0.45	10.3	11.5	0.90	12
127158		17.6	7.9	0.45	5.2	5.6	0.93	12
127179	21.3	17.2	7.4	0.43	6.3	5.9	1.07	11
127178	28	28	11.5	0.41	8.2	9.8	0.84	11
127173		31.2	12.3	0.39		11		13
127125	24	22.5	10.7	0.48	6.3	7.3	0.86	11
127169	38.3	38.3	15	0.39		13.4		12
127019	21.5	21.5	8.4	0.39	7	7.5	0.93	12
127161	26.8	26.8	11.8	0.44	8.5	8.9	0.96	13

127262		25.2	9.8	0.39	8.8	8.9	0.99	
127166	48.8	48.6	22.6	0.47	14.1	15.0	0.94	14
127156		40.2	15.5	0.39	11.6	14.4	0.81	12
127175	31	31	14.1	0.45	9.6	10	0.96	12
127157		32.4	12.8	0.40		11		12
127270		56.2	25.4	0.45	15.5	18.2	0.85	15
127271	23.3	23.3	10.5	0.45	c.7.7	7.6	1.01	11
127153	14.6	14.6	6.3	0.43	4.2	5.2	0.81	12
127163	43.4	43.4	14.8	0.34		16		13
127164		14.1	5.8	0.41	3.9	4.7	0.83	10
127165	22.7	22.4	9.6	0.43		7.1		12
127148	40.9	40.9	20.6	0.50	11.9	12.1	0.98	13
127155		c.14.5	7.1	0.49	4.9	4.1	1.20	11
127172		50	16.9	0.34	13.4	19.3	0.69	
127272	49	49	24	0.49	c.13.0	14	0.93	15
127274	29	27.8	11.6	0.42		10		12
127273	48.5	48.5	20.1	0.41	13.8	16.5	0.84	13
127275		36	15.3	0.43	11.4	12.1	0.94	13
127160	23.8	20.3	8.6	0.42	6.1	6.5	0.94	13
127151	17	16.3	6.3	0.39	5	5.8	0.86	11
127152		22.2	8.1	0.36	7.4	8	0.93	9
127150	32.6	32.6	13.5	0.41	10	11.5	0.87	11
127258		56.7	20	0.35		21		
127149		20.6	7.6	0.37	6	7.2	0.83	10
127147		51.3	17.4	0.34	15.2	20.5	0.74	10
127256		c.81.0	28.5	0.35	23.5	30.5	0.77	
127154	31.7	31.7	15.8	0.50	7.9	8.7	0.91	14
127174	69	67.4	24.6	0.36	c.21.0	24.5	0.86	
127255	67.4	62.2	18.8	0.30	20.3	25.6	0.79	
127112	38.2	38.2	14.3	0.37		15		
127094		43.5	17.2	0.40		15.6		15
127093	42.6	42.6	17.8	0.42		13.4		12
127248	c.156.0	c.156.0	50.8	0.33	42	62.5	0.67	
127113	57.2	51.9	20.3	0.39	15	18.8	0.80	12
127107	41.6	39.6	15.9	0.40	11	13.7	0.80	
127095	c.30.0	c.30.0	13.8	0.46		9.6		12
127260	30.6	27.8	11.4	0.41	7.6	9.7	0.78	10
127123	30	29.8	12.5	0.42		10.2		14
127239	54.3	53.2	25.2	0.47	13.4	15.4	0.87	15
127026		19.3	8.2	0.42	5.9	6	0.98	12
127245	49.2	47.3	19.1	0.40		16.2		12

127098	c.65.5	63	23.7	0.38	18.3	22.8	0.80	13
127115	53.7	53.7	23	0.43	16	17	0.94	12
127106	55.8	55.8	25.3	0.45	13.4	17.4	0.77	
127092		c.45.5	c.21.5	0.47	c.12.0	13.8	0.87	12
127108	41.1	41.1	15.6	0.38	13.9	14.5	0.96	12
127015		33.5	13.5	0.40	10.2	12	0.85	11
127120	29.6	29.6	12.9	0.44	8.8	9.9	0.89	13
127110	42.4	41.4	14.6	0.35	c.14.0	15.7	0.89	12
127114	c.41.0	35.2	13.5	0.38	12.8	12.6	1.02	10
127268		43.2	16.6	0.38	c.14.0	14.5	0.97	11
127269	31.5	31.5	12.8	0.41	10.1	10.5	0.96	12
127116	49.9	48.6	21.3	0.44	13.5	14.9	0.91	15
127111	32.3	31.5	11.8	0.37	11.3	11.7	0.97	12
127109		42	17.1	0.41	13.1	13.8	0.95	12
127020	c.43.6	c.43.0	c.20.8	0.48	12.1	13.1	0.92	13
127103	20.2	19.8	8.6	0.43	5.9	6.4	0.92	13
127138		47.4	19.4	0.41	13.4	15.5	0.86	13
127117	32.7	32.5	14.9	0.46	8.9	9.3	0.96	12
127253	81.1	81.1	31.1	0.38		29.4		14
127146		57.2	20.2	0.35	16	21.7	0.74	11
127266		25.9	11.5	0.44		8.5		12
127096		67.8	25.6	0.38	20	23.6	0.85	
127122		25.6	12.5	0.49	7.4	6.9	1.07	12
127142	46.3	45.1	18.7	0.41	12	15.3	0.78	14
127126		32	15	0.47		9.5		
127263	c.52.3	51.8	19	0.37	15.2	19.3	0.79	12
127129	45.5	41.3	17.4	0.42		13		11
127139	27.8	27.8	11.5	0.41	10.5	10	1.05	13
127127	35.8	34.8	13.2	0.38		12.9		10
127135		35.3	12.7	0.36	11.2	13.9	0.81	10
127130	41.5	38.1	16	0.42		13.4		10
127140	c.32.3	c.31.0	c.12.1	0.39		10.4		11
127136		31.1	13.6	0.44	7.7	9.7	0.79	12
127131		48.1	21.8	0.45		15		
127128	35	34.4	12.9	0.38		12.5		12
127143	47.5	47.5	20.7	0.44		15.2		11
127134	c.44.4	c.44.4	18.9	0.43		14.9		15
127099		26.3	11.4	0.43	8	8	1.00	12
127121	45.2	41.5	14	0.34	12.4	15.7	0.79	11
127118	17.1	15.8	6.7	0.42	4.6	5.8	0.79	11
127119		25	10	0.40	7.9	8.9	0.89	11

127259	40.2	40.2	14.2	0.35	13	15.2	0.86	13
127145	36.7	35.5	15.9	0.45	10.4	11.5	0.90	
127133		57.1	27.4	0.48		16.3		15
127254		60.3	20	0.33		25		14
127097		c.51.0	21.3	0.42		17		14
127102	25.5	25.5	12.3	0.48	7.2	7.3	0.99	11
127141		60.5	28	0.46		16.9		14
127014	34.8	34.8	16.4	0.47	10.2	11	0.93	13
127267		22	9.8	0.45		7.2		12
127268		c.22.0	c.8.6	0.39		6.8		11
127144		28	11.8	0.42		9.8		11
127132		18.5	7.3	0.39	5.7	6.5	0.88	11
127104	24	24	11	0.46	6.9	7.6	0.91	11
127101	34.5	34.5	16.5	0.48	9	10.5	0.86	12
127100	40	38.6	18.5	0.48	10.6	11	0.96	15
127025		119	38	0.32	35	45.4	0.77	
127024		c.131.0	43.4	0.33	42	51.6	0.81	
127105	47.4	47.4	21.5	0.45	12.4	16	0.78	14
127265	35.9	35.9	16	0.45	12.3	12.1	1.02	13
127022		61.5	28	0.46	17.5	19	0.92	14
127276		20.8	7.9	0.38	5.9	7.2	0.82	11
127277	24.3	22.6	9.4	0.42	6.6	7.8	0.85	11
127278	23.9	18.3	6.2	0.34	5.6	6.6	0.85	12
127279	20.1	20.1	18.7	0.93	5.5	6.1	0.90	11
127280	25.5	25.5	10.5	0.41	c.7.5	8.6	0.87	12
127281	37.5	37.5	14.8	0.39		12.6		13
127282	25.9	24.7	9.7	0.39		8.8		12
127283	25	25	10.1	0.40		9.2		14
127284	22.8	21.2	8.4	0.40		7.2		12
127016	52	50.1	22.4	0.45	13.6	15.8	0.86	13
127200	42.0	42.0	14.3	0.34	15.0	16.0	0.94	
127209	48.3	48	21.5	0.45	15	15	1.00	12
127257	c.180.0	c.180.0	c.40.0	0.22	51	78	0.65	
127187	c.45.8	c.45.8	c.17.6	0.38	14	17.8	0.79	16
127193	37.5	36.7	16.5	0.45	11.1	11.2	0.99	12
127196	45.7	45.7	16.3	0.36	16.1	17.7	0.91	13
127186	46.3	45.8	19.1	0.42	12.7	15.2	0.84	12
127212	51.4	48.0	20.8	0.43	14.0	15.5	0.90	12
127211		c.45.7	20.5	0.45	12.8	14.5	0.88	12
127214	c.33.0	28.0	13.0	0.46	8.1	8.3	0.98	12
127091	c.41.0	36	16	0.44	10.2	11.8	0.86	13



127202	c.38.2	c.37.5	c.16.5	0.44	11	13	0.85	12
127219		54.5	17.7	0.32	18.4	21	0.88	
127220	44.2	43.5	17.9	0.41	12.6	14.8	0.85	11
127090	c.60.7	c.56.8	c.27.9	0.49	14.8	17.9	0.83	15
127018		c.70.5	c.25.0	0.35	22.4	26.1	0.86	13
127189		57	21.1	0.37	18.5	20.5	0.90	
127246	56.7	56.0	22.8	0.41	17.4	20.0	0.87	
127252	64.8	63.3	23.2	0.37	20.6	23.9	0.86	14
127184		c.56.6	24.7	0.44		20.4		
127227	44.8	42.6	18.9	0.44	12	13.8	0.87	13
127180	71	68.4	24.3	0.36		26.6		
127250	c.65.2	c.65.2	25.6	0.39	21	23.9	0.88	
127017	c.70.2	c.70.2	29.1	0.41	c.23.3	23.5	0.99	
127264	52.7	50.2	23.7	0.47	13.2	14.8	0.89	13
127183	76.5	76.5	30	0.39	c.25.0	27.1	0.92	12
127194		49.1	20.9	0.43	14	16	0.88	12
127188		c.42.2	c.19.8	0.47	10.3	12.8	0.80	
127226	41.6	41.6	15.4	0.37	13	14.6	0.89	12
127201	35.5	35.5	13.7	0.39	12.0	12.9	0.93	11
127013	c.110.5	101.6	31.2	0.31	c.40.0	46.3	0.86	
127217	31.5	31.2	14.1	0.45	c.9.2	10.0	0.92	11
127208	32.6	31.9	13.3	0.42	10.2	11.1	0.92	11
127251		64.4	29	0.45	17.8	19.6	0.91	14
127218	32	30.9	15.5	0.50	8.1	8.2	0.99	11
127027	57.7	57.3	18.7	0.33	19.3	23.1	0.84	
127210	c.56.2	c.55.5	c.25.7	0.46	14.6	17.3	0.84	14
127204	c.71.9	42.6	21.6	0.51	11.2	12	0.93	11
127249	62.5	62.5	20.3	0.32	20.7	24.8	0.83	
127222	c.60.0	c.60.0	22.1	0.37	19.1	23.5	0.81	
127213		39.6	17.3	0.44	c.11.3	c.12.4	0.91	
127215	52	51.0	22.1	0.43	14.9	16.4	0.91	15
127203	32.8	27.4	11.1	0.41	8.1	9.1	0.89	13
127205		28.8	12.5	0.43	8.2	9.3	0.88	12
127261		20.6	8.7	0.42		6.9		12
127216		27	13	0.48		8.2		13
127197	35.7	35.7	16.7	0.47	9.4	11.0	0.85	11
127221	22.9	22.5	10	0.44	7.5	7.1	1.06	12
127206	34.6	33.6	14.5	0.43	10	10.9	0.92	11
127182	c.65.0	c.65.0	23.4	0.36	21.5	23.8	0.90	
127195	53.3	53.3	18.5	0.35	16.5	20.6	0.80	12
127192	48.8	46.4	17.4	0.38	14.2	16.0	0.89	13

127225		74.2	29.2	0.39		26.3		
127198	40.5	39.9	16.3	0.41	12.0	13.5	0.89	13
127199	37.5	36.9	15.3	0.41	10.8	12.3	0.88	
127247	42.5	42.5	15.2	0.36	c.13.2	16	0.83	11
127023	20.1	19.5	6.3	0.32	6.9	7.7	0.90	11
127224	40.2	33.8	16.5	0.49	9.8	10.5	0.93	15
127223		32.6	15.2	0.47	8.8	10.5	0.84	11
127185	47.8	47.8	19.5	0.41	15.4	16.5	0.93	15
127244		24.1	10.5	0.44	7.9	8.5	0.93	11
127242		29.8	12.5	0.42	9.3	10.5	0.89	12
127243	28.7	28.7	12.2	0.43	8.6	10	0.86	11
127241	27.4	27	11.3	0.42	8.2	9.2	0.89	12
127235	49.1	49.1	22	0.45	13	14.8	0.88	14
127234		43.8	19.5	0.45	12.3	13.6	0.90	12
127237	41.1	41.1	14.8	0.36	13.2	15.3	0.86	17
127232	36.6	35	14.2	0.41	10.6	13	0.82	14
127233	21	21	8.5	0.40	6.9	7.5	0.92	11
127229	51.2	50.4	21.2	0.42	14	17.4	0.80	15
127228		54.8	19.9	0.36	17.2	21	0.82	
127230	56.9	56.9	25.6	0.45	15.3	17.1	0.89	14
127231	38.3	38.3	16.7	0.44	10.4	12.8	0.81	13
127236	45.8	44.5	18	0.40	13.5	14.5	0.93	14
127181	56.5	54.6	23.5	0.43		16.4		12

***Badouxia canadensis* transient A**

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
19947	89	85.6	32.1	0.38	24.5	32	0.77	12
20049	57.4	57.4	24.1	0.42	18	19.8	0.91	14
127312		17.3	7.0	0.40	5.7	5.8	0.98	12
127313	20	19.6	7.6	0.39	c.6.0	6.7	0.90	11
127309		21.5	9.1	0.42	7.6	6.9	1.10	13
127310		28.2	11.6	0.41				10
127311	68	68	23.8	0.35	20.5	25	0.82	12

***Badouxia canadensis* transient B**

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127031	80.8	76.8	33.7	0.44	22.8	25	0.91	15
127028	64.3	61.5	28.8	0.47	15.2	18.8	0.81	15
127033	56.5	56	25	0.45		18		16

***Badouxia castlensis***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
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127083	25.3	24.3	9.9	0.41	7.4	8.8	0.84	13
127089	c.36.7	c.36.7	16	0.44	11.5	12.5	0.92	c.14
127080		20.6	7	0.34	c.6.0	7.1	0.85	13
127091		50	19.9	0.40		18.6		c.17
127056	52.6	52.6	20.2	0.38	13.6	18.3	0.74	16
127090		38	14	0.37		14.7		15
127081		32.1	14.1	0.44	8.6	9.4	0.91	
127034		59	23.9	0.41	16.2	19.6	0.83	
127059	c.47.8	38.9	17.4	0.45	11	11.7	0.94	13
127088	43.3	43.3	16.4	0.38		15.2		14
127086		34	14.8	0.44	10	11.2	0.89	
127085		39.4	17.5	0.44	11.3	12.8	0.88	
127087	51.6	50.2	21.4	0.43	15.8	16.7	0.95	12
127057	43	42	17.3	0.41	11.8	14.7	0.80	14
127058	24.3	24.3	10.2	0.42	6.1	8	0.76	14
127030	39.2	37.8	14.3	0.38	11.8	13.5	0.87	15
127082		35.3	12.3	0.35	c.10.6	13.8	0.77	c.13
127084	37.3	36.7	15.5	0.42	10.7	11.7	0.91	13

***Badouxia forticostata***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
11206A		23	9.6	0.42	6.5	7.2	0.90	12
11206F		62.6	25	0.40	18.5	22.4	0.83	14
127300	28.4	28.4	11.6	0.41	9.3	10.4	0.89	12
127303	53.7	51.7	21.4	0.41		18.3		11
127048	47	47	20	0.43		15.5		11
127288	31	31	11.5	0.37	10.9	11.2	0.97	11
127293		29.8	11.5	0.39	7.8	10.3	0.76	12
127295	23.9	23.5	9.4	0.40		8.3		13
127294		28.3	10.5	0.37	8.1	10	0.81	11
127297	c.24.7	c.23.0	c.10.0	0.43	7.7	8.3	0.93	11
127047					9.5	19.2	0.49	
127296		27.3	11.3	0.41	9.4	9.1	1.03	13
127302	44.2	43	18.2	0.42	11.4	14.4	0.79	11
127301	34.5	34.5	13.8	0.40	9	11.7	0.77	11
127039		43.7	16.3	0.37	14	15.8	0.89	12
127035	63.8	63.8	21	0.33	19.2	26.6	0.72	
127285		c.66.0	26.5	0.40	21.3	27.2	0.78	12
127298		39.2	14.8	0.38		13.8		11
127304	82	82	27.1	0.33	25.8	33.5	0.77	
127049	49.7	48.6	20.4	0.42		13.5		12

127292	25.7	25.7	11.3	0.44	8	8	1.00	12
127037	39.5	39.5	16.6	0.42		14.2		10
127043	73.1	72.3	35	0.48	17.3	20.6	0.84	11
127040		23.1	10.4	0.45	6.9	8.1	0.85	9
127308	30.2	30.2	12.5	0.41	9.6	9.6	1.00	12
127291	27.8	27.8	11.3	0.41	8.6	9	0.96	11
127290		25.8	10.6	0.41	8.7	9.3	0.94	12
127289		30.6	12.3	0.40	8.2	10.3	0.80	12
127307	20.2	19.6	8	0.41	6.3	6.9	0.91	13
127042	29.3	29	10.9	0.38	9.9	11	0.90	11
127305	28.1	28.1	12	0.43		9		12
127299		21.2	9.1	0.43	6.9	7	0.99	11
127306		c.61.8	23.2	0.38	c.19.4	c.23.6	0.82	12
127286		c.77.5	34.5	0.45		27.2		14
127045	61.5	61.5	28.8	0.47	13.7	18	0.76	11
127287		23.4	11.1	0.47	6.1	7.2	0.85	11
127046	80.3	80.3	36	0.45		24.5		12
127041	36	36	15.3	0.43	9.1	11.7	0.78	10

***Badouxia columbiae***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
19924	46.1	45	15	0.33	16	18.8	0.85	12
19919	62.5	59	20	0.34	c.19.0	23	0.83	18
19921	55	55	18.2	0.33	17	20	0.85	15
19920	52.5	52.5	17.6	0.34	c.16.7	20.2	0.83	15
19925	61.2	61.2	22.8	0.37	19	23.5	0.81	13
127322	37	33.8	11.1	0.33	11.2	13	0.86	15
127336	c.54.3	c.54.3	c.19.5	0.36		c.22.0		c.14
127333	35.5	33.6	13	0.39	9.8	11.5	0.85	15
127317	53.3	53.3	23.2	0.44	13.5	17.2	0.78	16
127370		29.5	12.4	0.42	8.5	10.4	0.82	
127362	46.8	46.8	14.8	0.32	16.2	19	0.85	16
127055	42.5	39.2	15.5	0.40	11.5	13.5	0.85	17
127366	44.3	41	12.1	0.30		16		13
127332		21.8	7.3	0.33	7.2	8.7	0.83	12
127054	50.3	50	18.8	0.38	14.4	18.1	0.80	18
127315	63	60.3	21	0.35	19.8	23.7	0.84	15
127328	37.1	36.3	13.7	0.38	10	13.5	0.74	13
127325	36	33.1	12	0.36	8.6	11.5	0.75	c.13
127372	53.4	53.4	17.3	0.32	18.4	22	0.84	14
127340	75.6	73.6	23.6	0.32		31.5		

127358		19.7	8	0.41		c.6.6		13
127051	c.56.0	47.8	12	0.25	15.3	22	0.70	12
127324		c.54.0	c.23.6	0.44	15.1	19.2	0.79	c.16
127361	50.1	48.9	16.7	0.34	c.16.5	18.8	0.88	15
127342		30.4	10	0.33	c.10.0	12.4	0.81	15
127354	32.4	32.4	12.7	0.39	9	11	0.82	14
127363	39	38	13	0.34	11.9	14.6	0.82	16
127349	41.1	41.1	12.8	0.31	c.13.0	17.4	0.75	13
127359	35.8	35.8	13	0.36	10.5	13.6	0.77	16
127345	27.7	26	8.5	0.33	8.8	10.6	0.83	12
127368	41.7	40	12.5	0.31		16.3		14
127375		53.6	16.7	0.31	18.1	22.5	0.80	15
127337	48.9	45.2	15.2	0.34		17		12
127334	43.5	43.5	16.5	0.38		14.8		16
127380	31.6	31.6	11.9	0.38	9	11.2	0.80	15
127382		52.4	20.1	0.38	18.7	18.8	0.99	16
127321	50.5	49.3	21.6	0.44	13.6	15.9	0.86	16
127319	73.6	72.1	19	0.26	24	33.8	0.71	
127331		19.9	6.4	0.32	6.4	7.8	0.82	14
127367	51.1	47.7	20.6	0.43	12.2	16	0.76	18
127314	63.2	57.9	20.3	0.35	18.1	22.9	0.79	
127339	c.82.5	c.82.5	c.26.4	0.32		c.34.5		
127376		c.220.0	47.8	0.22	63.3	102.1	0.62	
127365		42.8	14	0.33	15	18	0.83	16
127330		34.5	12.1	0.35	11.2	13.2	0.85	13
127351		38.2	13.5	0.35	11.9	14.8	0.80	17
127316	58.2	58.2	24.5	0.42	16.3	20.1	0.81	16
127052	52.1	49.3	14.5	0.29	16.3	21.1	0.77	12
127377	200	200	44.3	0.22	62	92.7	0.67	
127340	c.49.0	c.47.0	c.20.5	0.44	c.13.4	c.15.0	0.89	16
127373	51.5	48.5	19	0.39	14	16.5	0.85	16
127335	44	44	15.5	0.35	12.9	16.6	0.78	16
127338		c.52.0	c.20.5	0.39		c.18.0		c.16
127323	c.74.0	c.73.0	20	0.27	26.5	c.36.0	0.74	
127378		30.8	10.6	0.34	c.9.8	12.5	0.78	
127360		34.5	10.7	0.31	11.6	14.9	0.78	15
127371		23.6	7.1	0.30	7	8.5	0.82	13
127352	39.3	38.4	11.8	0.31	12.3	16.4	0.75	13
127356	21.7	21.7	7.5	0.35	7.2	8.1	0.89	17
127355	27.7	27.7	8.5	0.31		10.7		12
127379		194	c.34.4	0.18	64.2	94.5	0.68	

127346	33	32.4	10.4	0.32	10.8	13.3	0.81	12
127348		c.49.1	14.7	0.30	c.16.5	22	0.75	11
127353		32.5	9.8	0.30	10.7	14.4	0.74	14
127369	31.7	31.3	12.6	0.40	8.7	10.4	0.84	17
127343	48	45.7	14.9	0.33	15	17.8	0.84	15
127364	40	40	14.5	0.36	12.4	15.4	0.81	16
127347	60.4	58	18.2	0.31	19.2	23.3	0.82	16
127341	c.47.8	c.45.5	17.7	0.39	14.3	16.5	0.87	17
127318		38.9	10.7	0.28	13.4	17.5	0.77	
127357	17.6	17.6	6	0.34	5.3	6.7	0.79	14
127326	39	33.5	10.2	0.30	11.2	14.1	0.79	12
127350	51.3	50.8	17.1	0.34	16.3	21.6	0.75	12
127381		20.7	7.2	0.35	6.4	7.4	0.86	13
127374	33.7	33.7	11.6	0.34		12.8		12
127344	45.1	42.6	15.8	0.37		15.2		17
127320	36.7	36.4	15.3	0.42	9.2	12	0.77	17
127327	53.1	51.7	17.4	0.34		20.9		15
127329	45	45	15.5	0.34	13.5	16.5	0.82	14
127050	c.188.0	c.188.0	47.5	0.25	60	80.6	0.74	
127053		56.3	26.1	0.46	12.8	16.9	0.76	

## **APPENDIX G: LOCALITIES FOR *SUNRISITES* COLLECTIONS FROM CHAPTER 6**

Information given below includes locations for all specimens of *Sunrisites* from Taseko Lakes. Latitude and longitude are given where possible in addition to a brief description of each location. Relevant GSC and other locality numbers are provided. Refer to Figure 6.2 for locations.

### **Section A**

Castle Pass. [51°05'09.25', 122°57'40.16'; 51°05'12.22', 122°57'39.50']

Localities exposed on the main saddle at Castle Pass consisting of A01–A11 in a stratigraphic sequence and A12 and A13 from talus.

A01: GSC locality C-177632; A02: C-117237, C-143320; A03: C-143319; A04: C-143318, C-177633, C-177635; A05: 62362 (Section 1 of Frebold, 1967); A06: C-208982, C-208993; A07: C-143315; A08: C-143309; A09: C-143308; A10: C-208985; A11: C-208961; A12: C-203169; A13: C-143295, C-117239

### **Section B**

Castle Pass. [51°05'11.46', 122°57'48.58'; 51°05'14.28', 122°57'44.10']

Localities exposed approximately 100 m west of the main saddle at Castle Pass consisting of B01 to B02 in a stratigraphic sequence and B03 from talus.

B01: GSC locality C-117233; B02: C-208958; B03: C-175396

### **Section C**

Castle Pass. [51°05'02.13', 122°57'49.44'; 51°05'06.02', 122°57'50.53']

Localities exposed southwest of the main saddle at Castle Pass consisting of C01–C03 in a stratigraphic sequence and C04 from talus.

C01: GSC locality C-117246; C02: C-143337, C-117248; C03: C-117490; C04: C-117249

## **Section D**

Castle Pass. [51°05'09.25', 122°57'40.16'; 51°05'10.48', 122°57'39.40']

Localities exposed immediately east of the main saddle at Castle Pass consisting of D01 to D02 in a stratigraphic sequence and D03 from talus.

D01: GSC locality C-143324; D02: C-143327, C-177636, C-175372; D03: C-143322, C-177637

## **Isolated Locality 1**

[approx. 51°02'27', 122°57'30'].

Locality on Tyaughton Creek approximately 1 km west of Spruce Lake Creek. Study of the *Badouxia* fauna from this locality supports the interpretation of Tozer (personal commun. in Frebold, 1967). The two relevant collections from this site are part of a faulted sequence and probably do not represent a continuous stratigraphic sequence. This is the same locality as isolated locality 3 in Longridge et al. (2006).

GSC locality 56393 (Section 7 of Frebold, 1967)

## **Isolated locality 2**

[approx. 51°05'29.24', 122°58'30.36'].

Saddle on ridge approximately 1.6 km west of Castle Mountain. This locality may be in a stratigraphic section but the rocks are severely disrupted tectonically so we treat it as an isolated locality.

GSC locality 117230, 143287



## **APPENDIX H: LOCALITY INFORMATION FOR AMMONITE COLLECTIONS FROM CHAPTER 7**

Information given below includes locations for all figured and/or measured specimens from Chapter 7 from the late Hettangian in Taseko Lakes. Latitude and longitude are given where possible in addition to a brief description of each location. Relevant GSC and other locality numbers are provided. Refer to Figure 7.1 for locations.

### **Section A**

Castle Pass. [51°05'157", 122°57'671"; 51°05'206", 122°57'664"]

Localities exposed on the main saddle at Castle Pass consisting of A01 to A15 in a stratigraphic sequence and A16 to A18 from talus.

A01: GSC locality C-117236; A02: C-177632; A03: C-117237, C-143320; A04: C-143319; A05: C-143318, C-177633, C-177635, C-208991; A06: 62362 (Section 1 of Frebold 1967); A07: C-208993, C-208982, C-143316, C-143317, C-177634; A08: 62499 (Section 1 of Frebold 1967); A09: C-208992; A10: C-143313; A11: C-208994; A12: C-143308; A13: C-175326; A14: C-117241; A15: C-208961; A16: C-208983; A17: C-203169, 94770; A18: C-143295; C-117239.

### **Section B**

Castle Pass. [51°05'196", 122°57'816"; 51°05'241", 122°57'736"]

Localities exposed approximately 100 m west of the main saddle at Castle Pass consisting of B01 to B06 in a stratigraphic sequence and B07 from talus.

B01: GSC locality C-117233, C-208960; B02: C-143296; B03: C-208958; B04: C-175388; B05: C-118699, C-117234; B06: C-118700, C-117235; B07: C-175397, C-208984, C-175396.

## **Section C**

Castle Pass. [51°05'037", 122°57'829"; 51°05'105", 122°57'848"]

Localities exposed southwest of the main saddle at Castle Pass consisting of C01 to C05 in a stratigraphic sequence and C06 from talus.

C01: GSC locality C-117232; C02: C-117246; C03: C-143337, C-117491, C-117248; C04: C-117245; C05: C-117490, C-117247; C06 C-117249, C-117489, C-208990.

## **Section D**

Castle Pass. [51°05'157", 122°57'671"; 51°05'180", 122°57'661"]

Localities exposed immediately east of the main saddle at Castle Pass consisting of D01 to D02 in a stratigraphic sequence and D03 from talus.

D01: GSC locality C-143323; D02: C-143327, C-177636, C-175372; D03: C-143322, C-177637.

## **Isolated locality 1**

[approx. 51°02'45", 122°57'50"]. Locality on Tyaughton Creek approximately 1 km west of Spruce Lake Creek.

GSC locality 56393 (Section 7 of Frebold 1967; isolated locality 3 of Longridge *et al.* 2006)

## **Isolated locality 2**

[51°05'206', 122°57'664']. South side of main saddle at Castle Pass (across the saddle from the bottom of section A).

GSC locality C-175327

### **Isolated locality 3**

[approx.  $51^{\circ}05'29.24''$ ,  $122^{\circ}58'30.36''$ ]. Saddle on ridge approximately 1.6 km west of Castle Mountain. This locality may be in a stratigraphic section but the rocks are severely disrupted tectonically so we treat it as an isolated locality.

GSC locality C-117230, C-143287

### **Isolated locality 4**

[ $51^{\circ}05.493''$ ,  $123^{\circ}00.719''$ ;  $51^{\circ}05.481''$ ,  $123^{\circ}00.706''$ ]. Locality exposed approximately 100 m east of the head of Last Creek. This collection was probably in place although it may be ex situ.

GSC locality C-208955 (Section E locality 01 of Longridge *et al.* 2006)

# APPENDIX I: AMMONITE MEASUREMENTS FROM CHAPTER 7

Measurements are given below for measured specimens from Taseko Lakes. Instances where the measurement is approximate are marked by the letter c. in front of the number.

Abbreviations and measurements follow Smith (1986) and include shell diameter (D), umbilical diameter (UD), whorl width (WW), whorl height (WH), umbilical diameter as a ratio of shell diameter (U), ratio of the whorl width to the whorl height (WWWH) and primary ribs per half whorl (PRHW).

## *Phylloceras cf. asperaense*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127416		21.8	4.1	0.19	7.1	10.4	0.68	

## *Nevadaphyllites microumbilicatus*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127421	55.1	55.1	6.6	0.12		29.2		

## *Nevadaphyllites aff. compressus*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127420		37	8.9	0.24				

## *Nevadaphyllites psilomorphus*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127417		98.5	11.7	0.12	c.31	56.4	0.55	
127417		c.77.3	8.3	0.11	22	44.7	0.49	
127419		17.7	2	0.11	5.6	9.6	0.58	
127418		17.9	2	0.11	5.6	9.8	0.57	
127418					6.5	10.6	0.61	

## *Fergusonites hendersonae*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127424	24.1	21	3.5	0.17	7.4	10.7	0.69	
127423	45.1	37.8	4.9	0.13	13.2	20.5	0.64	

## *Togaticeras aff. goisernense*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127426	28.8	28.8	9.7	0.34		10.6		

## *Togaticeras togatum*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127425	32.6	30.9	7.2	0.23	10.8	14.2	0.76	

## *Eolytoceras tasekoi*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
20059		52.5	18.4	0.35	14.2	21.5	0.66	
20060		51.5	21.4	0.42	15	17	0.88	
127428		31.2	12.5	0.40		11.1		
127429	30.1	30.1	11.6	0.39	10	11.5	0.87	
127430		19.5	7.4	0.38	7.1	6.9	1.03	
127431		23.2	10.5	0.45	7	8.9	0.79	
127432		16	5.3	0.33	4.1	6	0.68	
127433		13.7	5	0.36	4.2	5	0.84	
127434		21	7.6	0.36	7.9	8	0.99	

*Eolytoceras chongi*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
20063	137	c.131	56.5	0.43	36	44.1	0.82	
20063		100.4	42.4	0.42	28.5	34	0.84	
20065		c.52.6	c.20.1	0.38		c.19		
20064	52.5	52.5	23.3	0.44	13.2	16.6	0.80	
127436		188	83.8	0.45	43	56.7	0.76	
127438		52.5	20.1	0.38	16.6	19.2	0.86	
127439		53.3	20.5	0.38	16.1	19.8	0.81	
127440		65	25	0.38	19	24.2	0.79	
127441		72.2	32	0.44	21	23.8	0.88	
127442	19	19	6.8	0.36	6.4	6.6	0.97	
127443		22.8	8.1	0.36	7.9	8.6	0.92	
127444		23.5	9	0.38	7.3	7.9	0.92	

*Eolytoceras aff. guexi*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
127447		15.9	6.6	0.42	5	5.4	0.93	
127448	28.2	27.3	10.4	0.38	8.6	9.8	0.88	
128981		15.4	6.2	0.40	5	5.5	0.91	
128982		12.1	4.5	0.37	3.2	3.9	0.82	
128983		8.5	3.5	0.41	2.7	2.9	0.93	

*Eolytoceras constrictum*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
128984		28.1	11.5	0.41	10.8	10.1	1.07	
128985		25.5	10.9	0.43	8.1	9	0.90	
128986		29.8	11.8	0.40	9	10.9	0.83	
128987		26.6	11.3	0.42	8.3	9.8	0.85	
128988		12.6	4.5	0.36	4.7	4.8	0.98	
128989		16.4	5.8	0.35	5.5	5.8	0.95	

*Discamphiceras aff. silberlingi*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
128991		18.7	5.8	0.31	5.2	7.4	0.70	17

*Discamphiceras silberlingi*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
128993		23.8	8.1	0.34	c.5.5	8.7	0.63	14
128993	27.4	27.4	10.7	0.39	c.6.4	9.7	0.66	13
128994	23.7	23.7	9.1	0.38	6.1	7.6	0.80	13
128995		24.4	8.7	0.36	6.8	9.2	0.74	14
128996		20.2	6.5	0.32	5.2	8.4	0.62	14
128997	17	16.3	5.3	0.33	5.2	6.8	0.76	12
128998	25.3	23.5	8.7	0.37	6	8.2	0.73	16
128999		22.9	7.2	0.31		9.2		c.15
128999		c.31	c.9.3	0.30				
129000		22	7.9	0.36	5.6	8.7	0.64	15
129000		c.34	c.12	0.35				
129001		25.7	9.8	0.38	8.3	9.9	0.84	

*Discamphiceras sp. nov.*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129002		c.64	c.20.7	0.32				
129003	25.2	21.4	6.1	0.29	6	9.4	0.64	15
129004	19.3	19.3	6.7	0.35	c.5.5	7.8	0.71	15
129005	38.9	38.9	13.4	0.34	c.10.8	14.5	0.74	c.17
129005		13.9	4.3	0.31	c.4	5.1	0.78	c.10
129006	19.4	19.4	6.3	0.32	5.2	7.7	0.68	c.15
129007	16	15.9	5.5	0.35	4.3	6.3	0.68	
129008	23.3	22.6	6.4	0.28	6.4	9.9	0.65	c.14
129009	18.8	17.7	6.1	0.34	4.9	6.8	0.72	15
129010	18	15.2	4.8	0.32	4	6.4	0.63	
129011	c.15.8	c.15.8	5.4	0.34	4.3	c.6.3	0.68	c.14
129012	c.18.4	c.18.4	c.6.4	0.35	4.9	6.4	0.77	16

*Pseudaetomoceras cf. castagnolai*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129022		c.43	c.16.2	0.38		c.15		

*Pseudaetomoceras victoriense*

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129023		c.89.5	43.6	0.49	c.11.1	c.24.4	0.45	27
129023			45.2					28
129023			23.5					29
129023			15.8					25
129023			11					20
129023			7					15
129023			4.5					12
129024	19.5	19	7.2	0.38		5.6		15
129024			7					15

129024			4.1					12
129025			6.4					12
<b><i>Pseudaetomoceras</i> sp.</b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129026		c.43	c.11.5	0.27		c.17		
<b><i>Alsatites</i> aff. <i>bipartitus</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129013	57.5	55.7	25.9	0.46				13
129014		26	13.1	0.50	9.2	7.5	1.23	
129015		18.8	8.9	0.47	6.9	5.2	1.33	10
129016		14.7	7.1	0.48	5.3	4.3	1.23	8
129017		16.4	7.5	0.46	7	5	1.40	10
129018	18.4	18.4	8.8	0.48	6.3	5.5	1.15	
<b><i>Alsatites</i> sp.</b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129019	31	30.6	14	0.46	11.4	10	1.14	12
<b><i>Schlotheimia</i> cf. <i>cuevitensis</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129027		17.5	6.3	0.36	5.4	7.2	0.75	15
129027		21.9	8	0.37	6	8.3	0.72	16
129028		18.7	5.8	0.31	5.6	7.7	0.73	17
<b><i>Franziceras</i> aff. <i>graylockense</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129029		36.8	18.4	0.50				11
129030	33.9	33.9	17.3	0.51	10.2	9.1	1.12	11
129031		15.9	7.6	0.48	5.2	4.7	1.11	
129032		24	12.7	0.53				10
<b><i>Paracaloceras</i> <i>rursicostatum</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
56416		c.180	129.5					28
56416			91.5					27
56416			60.8					26
56416			39.8					25
56416			20.9					22
56416			16.3					22
56416					32.6	33.3		
56416					24.6	24		
129035	c.110.6	c.110.6	c.73.5	0.66	22.5	19.1	1.18	
129035		c.92.5	c.60.6	0.66	c.19.5	c.16.4	1.19	27
129036		85.8	54.2	0.63		16.3		28
129037	c.94.7	c.62.1	c.39.5	0.64	14	c.12.1	1.16	26
129037			c.60					27

129038	c.98	c.66					
129039	49.2	31	0.63		10.6		19
129039		27					19
129039		22					17
129039		12.7					14
129040		27.8					20
129040		21.3					17
129040		16.3					15
129040		8.5					12
129041	28.6	16.1	0.56	7.1	6.3	1.13	16
129041		12					13
129042				14.8	13.6	1.09	
129043	34.2	22.2	0.65	8.7	7	1.24	20
129043	30	18.8	0.63	7.9	6	1.32	19
129044		41					24
129044		21					17
129045		39.4					24
129045		26					25
129045		14.9					18
129045		8.3					14
129046		41					25
129046		15					18
129046		8					15
129046		64					27
129046		94					28

***Paracaloceras aff. varaense***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129048					44.1	41.1	1.07	
129048					39.5	32	1.23	
129049					60	53	1.13	
129049					34	32	1.06	
129049					38	34	1.12	
129051					17.3	15.9	1.09	

***Paracaloceras sp. A***

GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129053		c.135	95.7	0.71	22.1	19	1.16	
129053		74.5	47.9	0.64				
129053			46.8					23
129053			31					20
129053			18.3					19
129053			14					17
129054			c.23					17



129054					26.7	c.23.7	1.13	
129054					17	c.16	1.06	
129055	43		24.8	0.58		10		19
129056					17	16	1.06	
129056					18.3	17.3	1.06	
<b><i>Metophioceras (?) sp.</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129062		169	105.5	0.62	28.1	34.3	0.82	28
129062			67.5					27
129062			52.5					25
129062					22.8	26.3	0.87	
129062			42.5		15.2	16	0.95	22
129062			41					22
			31					21
<b><i>Schreinbachites (?) aff. laqueoides</i></b>								
GSC #	DMAX	D	UD	U	WW	WH	WWWH	PRHW
129063	26.6	26.2	16.2	0.62	6.2	5.6	0.62	23
129064	19.1	19	10.4	0.55	5.7	4.4	0.55	c. 20
129065		9	4.5	0.50			0.50	