STRATIGRAPHY, STRUCTURAL GEOLOGY AND PETROLEUM POTENTIAL OF CRETACEOUS AND TERTIARY ROCKS IN THE CENTRAL GRAHAM ISLAND AREA, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA

by

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Candidatus Magisterii
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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

Department of Geological Sciences

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

August, 1991

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ABSTRACT

Mapping at 1:25 000 scale on the central Graham Island has shown that Cretaceous strata are more widely distributed than previously known. This study examines the stratigraphy and structural geology of the Cretaceous rock sequence, and also addresses the petroleum potential of these units.

At the base is the Cretaceous sandstone unit. This unit is divided into three lithofacies. The massive sandstone lithofacies is a coarse grained, dark green to greenish black, massive sandstone. Parts of this lithofacies contains up to 50 % glauconite. The grey sandstone lithofacies is finer grained and has better defined bedding than the massive sandstone. It is frequently found with interlayered sandstone, siltstone, and shale. The third sandstone lithofacies is characterized by pervasive bioturbation. All three lithofacies are texturally immature, contain angular quartz and feldspar, and are rich in chlorite clay. The Cretaceous sandstone unit is interpreted as a transgressive sequence deposited on a storm dominated shelf.

Conformably overlying the sandstones are the massive friable shale and silty shale of the Cretaceous shale unit. Intervals with increased input of storm generated sandstone layers are found throughout the unit. Spherical and elliptical calcareous concretions up to over 1 m across are common. The Cretaceous shale unit represent a continuation of marine transgression with deepening of the sedimentary basin.

Turbidites forming the Skidegate Formation are interbedded with the upper part of the shale unit. This formation consists of interbedded shale, siltstone, and fine grained sandstone. Sedimentary structures are often well developed on bedding surfaces. The rocks of this unit are distal turbidites and levee deposits of a submarine fan.

Coarse clastic rocks of the Honna Formation are interbedded with the Skidegate Formation. This formation is dominated by pebbly conglomerates and coarse grained sandstones. The clast material in the conglomerate lithofacies is mainly derived from units present on the islands. The sandstone lithofacies consists of indurated, bluish, medium- to coarse-grained sandstone. This formation is richer in quartz and biotite than any other Cretaceous sandstones of the central Graham Island. The Honna and Skidegate formations are the result of deposition from a submarine fan system that was initiated in Late Cretaceous time. Deposition of shale continued after the deposition of the submarine fan-related formations terminated.

The Cretaceous rock sequence is overlain by Tertiary volcanic and sedimentary rocks. Volcanic rocks occur throughout the area, and sediments of the Skonun Formation are exposed in north.

Three major periods of deformation are recorded in the Cretaceous units. The first event was a Late Cretaceous to Early Tertiary northeast directed compression, resulting in northwest trending folds and thrust faults. The deformation was highly localized to areas were weakness zones existed in the older basement rocks.

Two periods of Tertiary block faulting activity are recognized. The first resulted in northwest-trending faults, parallel to older structures. Later Tertiary block faulting developed northeast trending faults, which are the youngest macroscopic structures in the area.

The Cretaceous rock sequence does not contain any promising hydrocarbon source or reservoir rocks. The TOC, S1, and S2 values from Rock-Eval® pyrolysis are low for all units, and the organic material present is mostly gas prone. Visual porosity is generally poor, as a result of chlorite pore-filling clay and calcite cement.

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ACKNOWLEDGEMENTS

I thank Dr. John Ross for acting as thesis supervisor, his suggestions and improvements to this manuscript is greatly appreciated. Thanks are also extended to Drs. Bill Barnes, Marc Bustin, Paul Smith, and Howard Tipper for suggestions and discussions during their tenure on the author's research committee.

Jonny Hesthammer, Peter Lewis, and Susan Taite of UBC and Charle Gamba of McMaster University are all thanked for their much appreciated influence on this project, They are also thanked for making the long field seasons in the Queen Charlotte Islands enjoyable. Regan Palsgrove is thanked for being such a helpful and cheerful office mate.

The majority of this work was carried out in close collaboration with several researchers associated with the Geological Survey of Canada's Frontier Geoscience Program for the Queen Charlotte Islands. Dr. Jim Haggart is thanked in particular for providing logistic support during the field seasons, and for innumerable discussions and suggestions that contributed greatly to this project.

Most of this work was funded by the Frontier Geoscience Program of the Geological Survey of Canada. The logistic support and technical help from Chevron Canada Resources Ltd. and funding from NSERC grants to Dr. John Ross are greatly acknowledged.

Field assistance was provided by Ian Foreman, Greg Gillstrom, Mark Hamilton, and Mike Neylan, Doni Jacklin of UBC is thanked for running my rock samples through the Rock-Eval® pyrolysis.

A warm thank goes to my parents, Eva Bergersen, Jonny Hesthammer, and Hilde Larsen who all provided much needed moral support throughout the duration of this study.

Finally, many thanks to my fellow students at UBC for making my stay in Canada memorable, in particular all the field trips, social events, and Friday evenings.

1. INTRODUCTION

1.1. Objectives

The rock sequence on the Queen Charlotte Islands ranges in age from Late Paleozoic to Quaternary. The purpose of this thesis is to study and understand the stratigraphy and structural geology of the Upper Cretaceous and Tertiary rocks of the southern Graham Island area (Figure 1-2). The petroleum potential of the Cretaceous rock sequence is also evaluated. Six months were spent on detail mapping and structural studies of the area.

The work has been compiled together with the work done by other geologists on the southern Graham Island on to a 1:50 000 scale map (Hesthammer et al., 1991a). The map is enclosed with this thesis. This thesis focuses on the Cretaceous and Tertiary rock present within the map area. For a detailed description and discussion of the Upper Triassic and Jurassic rock sequence, the reader is referred to the M.Sc. thesis work of Mr. J. Hesthammer (Hesthammer, 1991b).

1.2. Location

The Queen Charlotte Islands archipelago consists of over 150 islands, and is located about 800 kilometres north-west of Vancouver and 140 km west of the coast of British Columbia (Figure 1-1). The islands are situated between latitudes $51^{o}53'$-$54^{o}15'$ north and longitudes $130^{o}54'$-$133^{o}09'$ west. The two main islands of the archipelago are Graham Island in north and Moresby Island in south. Together these two islands account for more than 90% of the total 10,000 square kilometres land area of the island group.

From Kunghit Island in south to Langara Island in north the Queen Charlotte Islands are about 300 kilometres long.

Three physiographic features dominate the topography on the Queen Charlotte Islands. The southwestern part is dominated by the rugged, high-rise mountains of the Queen Charlotte Range. The Skidegate Plateau occupies the central parts of the islands with a more gentle topography. In the northeast is the Queen Charlotte Lowland.

The map area is located in the central part of the Graham Island, between latitudes 53°15'-53°30' north and longitudes 132°05-132°24' west (Figure 1-2). This area can be accessed on a logging road (Queen Charlotte Main) from Queen Charlotte City in the south or from Juskatla in the north. A permit from MacMillan-Bloedel logging company is required for travelling on this road during the logging season, and may be obtained from the operations office in Queen Charlotte City or in Juskatla.

1.3. Previous work

The earliest geological studies of the Queen Charlotte Islands date back to the late nineteenth century with the work of Richardson (1873) and Dawson (1880). These were followed by Ells (1906), Clapp (1914), and MacKenzie (1916) all of whom studied areas on Graham Island. Many of these earlier investigations of the islands were directed towards evaluation of coal occurrences, but no essential exploration has taken place since early in the present century. McLearn (1949, 1972) carried out thorough studies of the stratigraphy of the Queen Charlotte Islands. A renewed interest in the hydrocarbon potentials of the islands came about in the late 1950's when several oil companies started to show their interest by drilling on- and offshore wells and execute geophysical surveying. Sutherland Brown's thorough investigation of the islands resulted in the first comprehensive report (Sutherland Brown, 1968), including geological maps and cross sections, of the Queen Charlotte Islands. The first extensive study on the tectonic history of the islands and adjacent area was by Yorath and Chase (1981), shortly followed by Yorath and Hyndman (1983). Based on this tectonic outline, Yagishita (1985a,b) investigated the sedimentology of Middle to Upper Cretaceous Queen Charlotte Group. More recent studies by Haggart (1986, 1987) have refined the stratigraphy of the Middle to Upper Cretaceous rock units based on biostratigraphy. In 1987 the Geological Survey of Canada started the Frontier Geoscience Program (FGP) for the Queen Charlotte Islands and adjacent areas. When this program started in 1987 it had four primary objectives: 1) understanding the crustal processes that controlled basin development; 2) outlining the internal geology and evolutionary history of the basin; 3) establishing the character and distribution of reservoir- and source-type rock; and 4) evaluating the hazards that could affect petroleum exploration and production (Thompson, 1988). The geological remapping and geophysical surveying to present date has been compiled in four of the Geological Survey of Canada's current research papers (1988, 1989, 1990, 1991) and a special Frontier Geoscience Program report (Geological Survey of Canada, Paper 90-10, 1991). These publications contain the most recent geological and geophysical work and interpretations of the Queen Charlotte Islands, and provide excellent sources for further information.

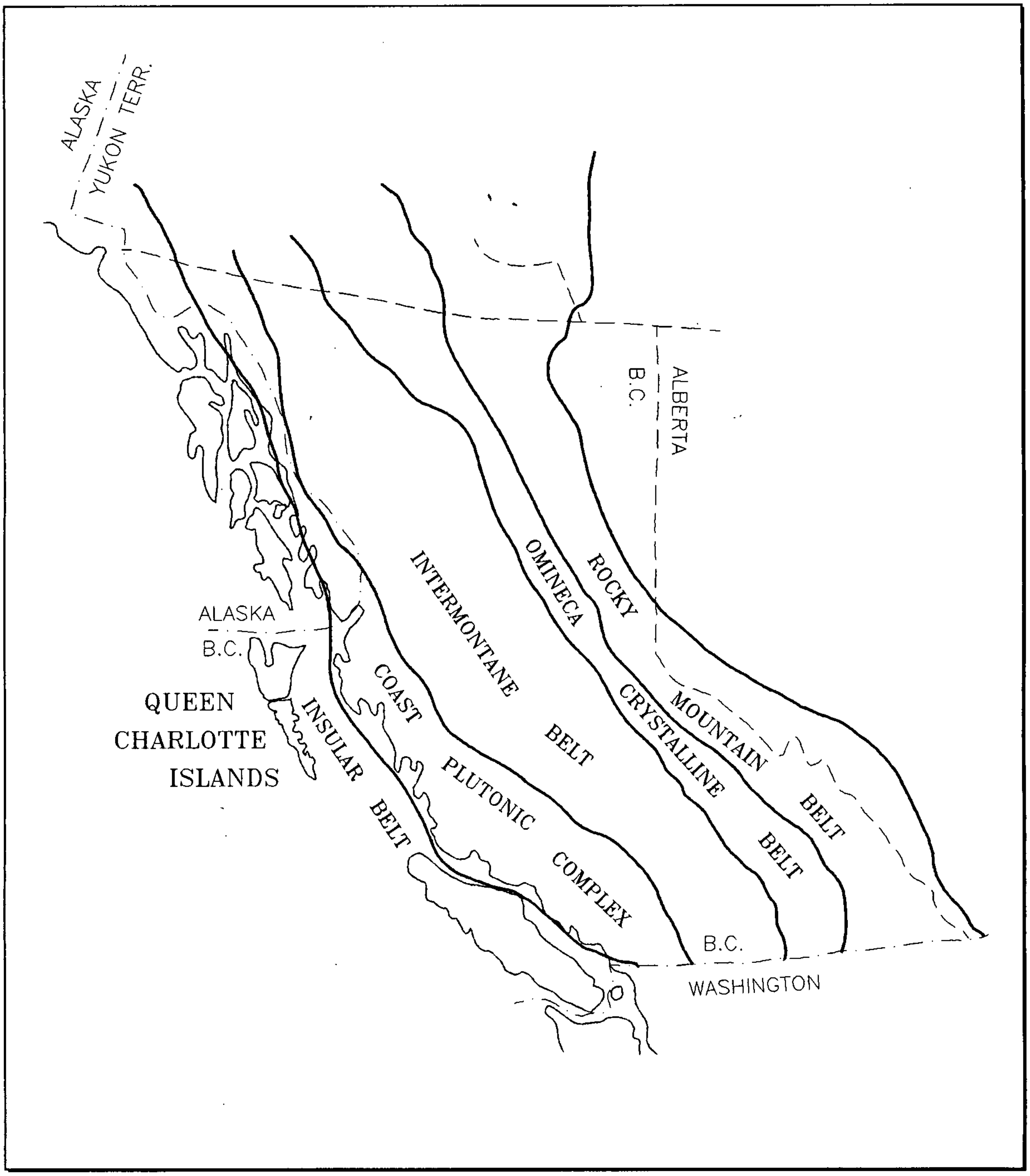


Figure 1-1. Map of western Canada showing the location of the Queen Charlotte Islands and the major tectonic belts of the Canadian Cordillera.

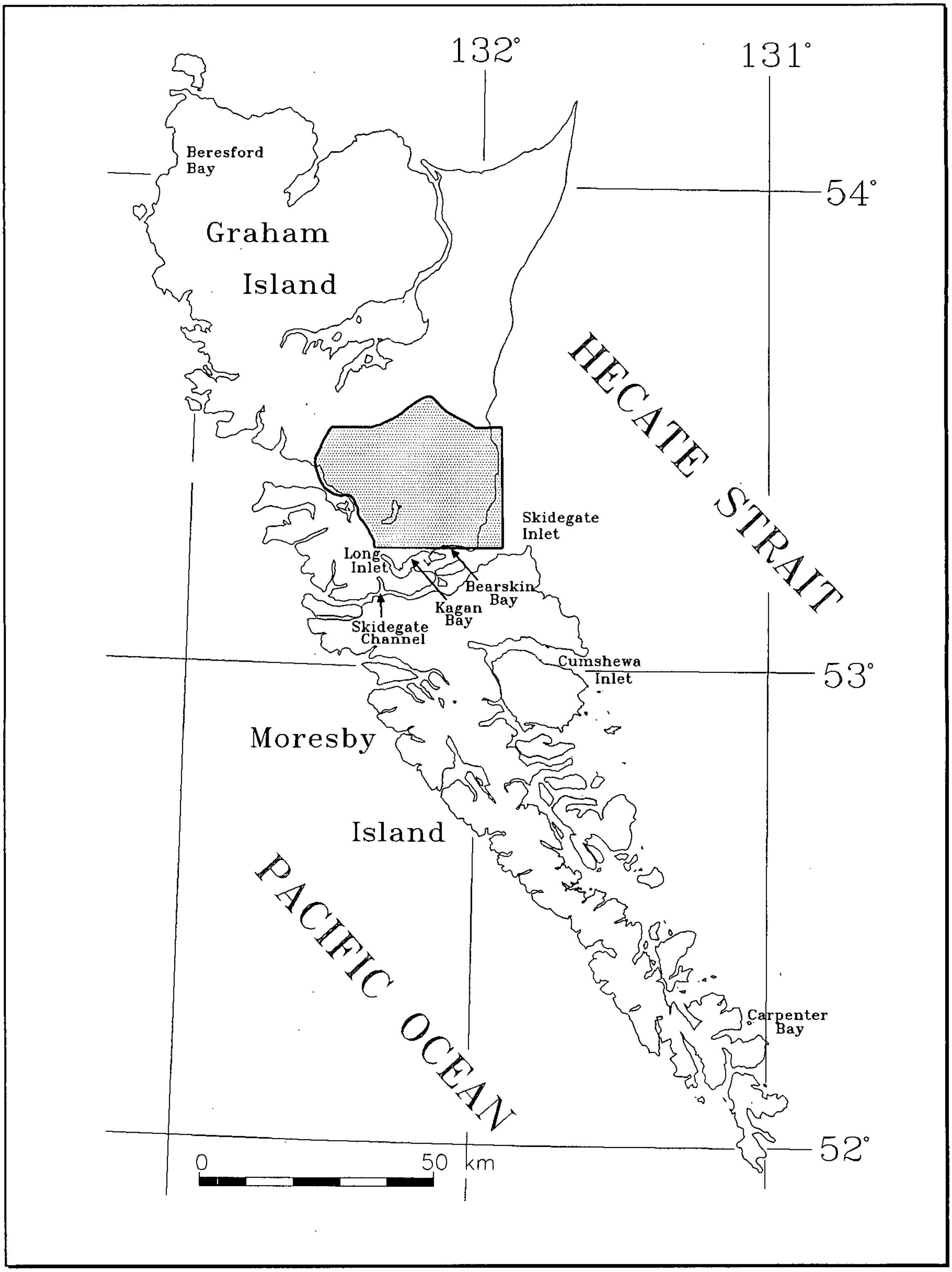


Figure 1-2. Map showing the location of the map area on southern Graham Island, and geographical areas referred to in the text.

1.4. Geological setting

The geology of the western part of Canada is divided into five major tectonic belts (Figure 1-1). These are from west to east, the Insular, Coast, Intermontane, Omineca, and Rocky Mountain belts. The Queen Charlotte Islands makes up part of the western most section of the Insular Belt. Included in this tectonic belt are several allochthonous terranes, with Queen Charlotte Islands belonging to the Wrangellia terrane (Jones et al., 1977; Monger, 1984; Gardner et al., 1988). Wrangellia, together with several other terrains, is believed to have been accreted on to the west coast of the North American tectonic plate during Jurassic time (Wernicke, 1988; van der Heyden, 1989; Thompson et al., 1991) and is recognized in several places along the coast from Alaska to Oregon (Smith and MacKevett, 1970; Vallier, 1977). East of Wrangellia is the Alexander terrain which also is a part of the Insular Belt (Jones et al., 1977). It was earlier believed that the suture between the two terrains was located within the Queen Charlotte Islands and represented by the Sandspit Fault (Yorath and Chase, 1981). More recent studies has questioned this interpretation and placed the suture zone farther east (Woodsworth, 1988).

The rock sequence on the Queen Charlotte Islands ranges in age from Carboniferous (?) and Permian to Tertiary (Figure 1-3). The Mesozoic part of the rock sequence is one of the most complete on the west coast of North America, and has been extensively studied.

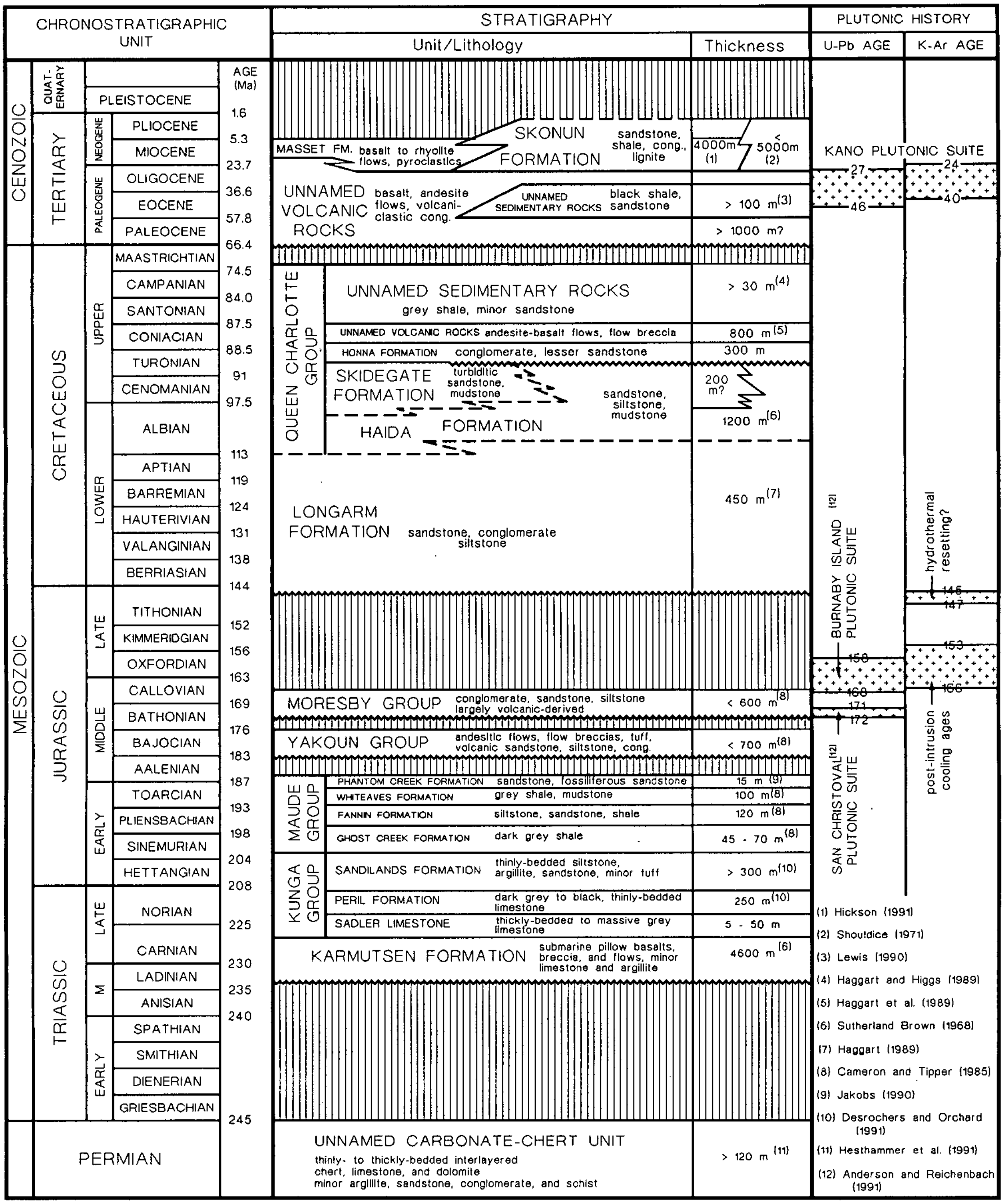


Figure 1-3. Stratigraphic column for the Queen Charlotte Islands (from Lewis et al., 1991).

Several different rock assemblages are recognized in the Queen Charlotte Islands: The oldest unit on the islands comprises an unnamed Carboniferous (?) to Permian sequence of interbedded limestone, chert, and dolomite with occasional argillite, sandstone, and conglomerate (Hesthammer et al., 1991b). Overlying this, with a possible unconformity, is the Triassic Karmutsen Formation comprising pillow basalt and breccia, flows, and minor limestone (Sutherland Brown, 1968). Subaerial pyroclastic rocks observed in the westernmost part of the islands may be part of this formation or an older unit related to the Carboniferous (?) and Permian rock sequence (Indrelid and Hesthammer, 1991). Conformably overlying the Karmutsen Formation is the interbedded limestone, shale, siltstone, and sandstone of the Upper Triassic and Lower Jurassic Kunga Group (Sutherland Brown, 1968; Cameron and Tipper, 1985). Intercalated shale, siltstone, and sandstone of the Lower Jurassic Maude Group gradationally overlies the Kunga Group (Sutherland Brown, 1968; Cameron and Tipper, 1985).

Unconformably overlying all older rocks is the Middle Jurassic Yakoun Group. This group consists of volcanic rocks and volcanic derived shale, sandstone, and conglomerate, deposited in a volcanic arc setting (Sutherland Brown, 1968; Cameron and Tipper, 1985; Hesthammer, 1991a).

The Cretaceous rock sequence in the Queen Charlotte Islands has traditionally been divided into the Lower Cretaceous Longarm Formation and the Middle to Upper Cretaceous Queen Charlotte Group, all comprising intercalated shale, sandstone, and conglomerate (Sutherland Brown, 1968). The stratigraphic scheme for the Cretaceous rock units is in the process of being revised and this will be discussed as a major topic in this thesis. Volcanic and sedimentary rocks of Late Cretaceous age have been recognized in the islands during work related to the Frontier Geoscience Program (Haggart, 1989).

Tertiary rocks in the Queen Charlotte Islands comprise two major formations. Tertiary volcanic rocks consist of the Miocene to Oligocene Masset Formation and older unnamed volcanic units (Hickson, 1991). Minor sedimentary rocks are found interbedded with these volcanic rocks. The sedimentary Skonun Formation comprises arkosic sandstone, shale, and conglomerate (Shouldice, 1971; Higgs, 1991b). A unit of Paleogene black shale and minor sandstone has been recognized in limited areas (White, 1990; Haggart et al., 1990).

Several plutonic suites of two major age spans have been identified in the islands. The San Christoval and Burnaby Island plutonic suites are of Middle to Late Jurassic age, and the Kano plutonic suite is of Early Tertiary age (Anderson and Reichenbach, 1991).

1.5. Methods of study

In the field season of 1988, nearly two months were spent in the central Graham Island area. The work concentrated almost entirely on geological mapping at 1:25 000 scale using Energy, Mines and Resources Canada's aerial photographs and topographic maps. Aerial photographs used were British Columbia Government low level series BC 77062, BC 77063, BC 77064 and BC 7842, in addition to high level series BC 86026 and BC 86114. The map sheet used was Energy, Mines and Resources Canada, Yakoun Lake, 103/F8. Preliminary reports on the work include Indrelid et al. (1991b) and Hesthammer et al. (1989).

In the lowland, exposures are limited to road cuts and quarries in logging areas and some creek and stream beds. Limited exposures result in discontinuous control on rock units. Most outcrops are accessible by car (preferably four wheel drive) and by foot. The Yakoun Lake area was accessed by boat. In higher elevated alpine areas exposures are more frequent and continuous sections could be found. Most of these areas were accessed through hikes up creeks. A five day helicopter camp was set up for mapping in the Mount Stapleton area south of Yakoun Lake.

In the summer of 1989, three more months was spent in the area. In addition to greatly expanding the mapped area, some weeks were spent collecting specific data that was to be used in the work towards a sedimentological and structural synthesis for the area. Several publications were produced from this summer's work (Gamba et al., 1990; Haggart et al., 1990; Hesthammer and Indrelid, 1990; Indrelid, 1990; Indrelid and Hesthammer, 1990). Approximately 280 hand specimens were collected, including lithological and paleontological samples. The macrofossils collected were identified by Dr. J.W. Haggart of the GSC. From the hand specimens 58 thin sections were prepared by Y. Douma, University of British Columbia, and Agat Laboratories, Calgary. 56 of the thin sections were stained with sodium cobaltrinitrite for determination of potassium feldspar and clay. All the 46 thin sections cut from sedimentary rocks were vacuum and pressure impregnated with blue epoxy resin for visual porosity estimates. Rock-Eval® pyrolysis examination was performed on shale samples from the Cretaceous shale unit, Skidegate Formation, and Honna Formation. Scanning Electron Microscope (SEM) and Energy Dispersive Spectrometer (EDS) work was generously done by Chevron Canada in their laboratory in Calgary on rock samples from different locations from central Graham Island area. The samples prepared for SEM were coated with gold to provide a conducting path to ground for excessive electrons, which results in a peak at the atomic number of gold on the graphs from the Energy Dispersive Spectrometer.

A third summer was spent in the Queen Charlotte Islands in 1990. Work included expanding the previously mapped area on central Graham Island onto map sheets: Energy, Mines and Resources Canada, Rennell Sound, 103 F/7; Port Clements, 103 F/9; and Lawn Hill, 103 G/5. The work done in the central Graham Island area has been compiled onto Geological Survey of Canada Open File 2319 (Hesthammer et al., 1991a). In addition to this a major part of the summer was spent mapping on northwestern Moresby Island and southwestern Graham Island including map sheets: Moore Channel, 103 F/16, Skidegate Channel, 103 F/1, and Chartwrite Sound, 103 F/2. This work has been compiled onto Geological Survey of Canada Open File 2318 (Indrelid et al., 1991a), and resulted in two publications on Lower Mesozoic and Paleozoic rocks of the area (Hesthammer et al., 1991b; Indrelid and Hesthammer, 1991).

The map attached with this thesis is Open File Report 2319 of the Geological Survey of Canada (Hesthammer et al., 1991a) and include some mapping done by other geologists that where working with the Frontier Geoscience Program. This mapping was mainly carried out in the western part of the area where the author also did some work. Open File Report 2319 consist of two map sheets of which only one has been included here. The legend on the map differs slightly from the stratigraphic division used in this thesis. On the map the Skidegate Formation is labeled "Ktu" and is defined as the turbidite lithofacies within the "Cretaceous shale unit". The work presented in this thesis shows that the Skidegate Formation should be kept as a separate unit and not be included as a subunit of the Cretaceous shale unit.

The area limited to detailed sedimentological and structural studies are for technical purposes called the "study area" or "central Graham Island" (Figure 1-4), and the whole map is referred to as the "map area". The study area covers the region where almost all of the Cretaceous rocks were mapped by the author.

This thesis should be read with the attached map easily available. Several references are made to specific areas on the map. Some of the figures in the thesis are only intended to indicate areas or features of special interest, this to make the use of the map easier.

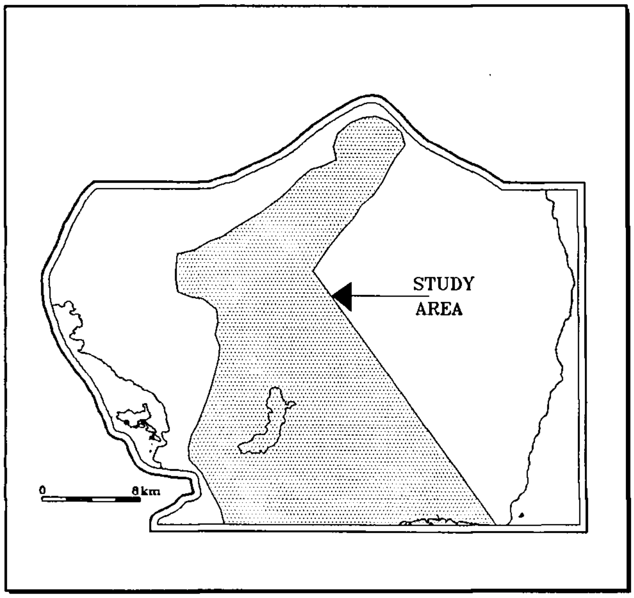


Figure 1-4. Location map showing the area where detailed stratigraphic and structural studies were done (study area).

2. STRATIGRAPHY

This thesis provides a detailed outline and discussion of stratigraphy and structural geology of the Cretaceous and Tertiary rock units exposed in the central Graham Island area on Queen Charlotte Islands. As for the Cretaceous rock units, their petroleum potential will also be addressed. For detailed description and discussion of the Triassic and Jurassic rocks of the area the readers are referred to J. Hesthammer's M.Sc. thesis (Hesthammer, 1991b).

Use of the traditional formal group and formation divisions (see "Review of traditional unit description" this chapter) proved to be troublesome in the central Graham Island area. It was particularly difficult to assign the different sandstones of the area to formations of the traditional stratigraphic scheme. Frequently the finding and classification of macrofossils were necessary to determine which formation a rock should be assigned to. Problems also arose when trying to map entirely based on the lithofacies description of the old units. The lithofacies within some of the traditional units are so similar that it was impossible to map based on these descriptions.

The problems with the traditional stratigraphic scheme is that it is more of a biostratigraphic scheme than a lithostratigraphic division. The definition of some of the old units, particularly the Haida and Longarm formations, are largely based on the assemblages of fossils found within each unit. Work done by Haggart (1991) has shown that the earlier inferred time gap between the Longarm and Haida formations is nonexistent. He reported the finds of Aptian and Albian fossils in the Queen Charlotte Islands, closing the gap between the formations.

2.1. Cretaceous rock units

2.1.1. Introduction

A stratigraphic column for all of the rocks exposed on the Queen Charlotte Islands is shown in figure 1-3, which displays the Cretaceous sequence as it was used prior to this thesis. The mapping included in this thesis was the first detailed stratigraphic work done in the central Graham Island area since the mapping of Sutherland Brown (1968) and it has shown that the extent of Cretaceous units is significantly larger than previously known (see Sutherland Brown, 1968:Fig.5 sheet B).

2.1.2. Review of traditional unit descriptions

2.1.2.1. Introduction

The understanding of the succession of units within the Cretaceous rock package in the Queen Charlotte Islands has always relied heavily on paleontological data. Lithofacies of similar appearance exist within most of the different formal formations and units, and can only be separated by fossils. Prior to the Frontier Geoscience Program the Cretaceous strata consisted of the Queen Charlotte Group and the Longarm Formation; these units were treated as distinct and separate packages. During the work under the Frontier Geoscience Program a Late Cretaceous sedimentary rock unit and a Late Cretaceous volcanic rock unit has been added to the stratigraphy. A summary of the stratigraphic units is presented below as they were understood prior to 1991. A complete review of the nomenclature of the rock sequence in the Queen Charlotte Islands is given by Woodsworth and Tercier (1991).

2.1.2.2. Longarm Formation

This formation was informally introduced by Sutherland Brown (1968). He recognized that some rock units of Cretaceous age were older than the previously defined Queen Charlotte Group. Fossil identifications by Jeletzky (in Sutherland Brown, 1968) showed that strata of Hauterivian and Barremian age were present in Long Inlet and Cumshewa Inlet, and that late Valanginian rocks were present on northern Graham Island. These rocks had previously been regarded as part of the Queen Charlotte Group, which is distributed in a north-northwest trending belt in the southern and central parts of the Queen Charlotte Islands. The Longarm Formation as described by Sutherland Brown consisted of conglomerate, lithic wacke, shale and minor volcanic rocks.

Several geologists have improved the description of the formation since the early work of Sutherland Brown and the formation is much more widely exposed on the islands than first thought (Haggart, 1989; Haggart and Gamba, 1990). On a large scale the Longarm Formation can be described as a fining upward sequence. The basal part is a transgressive conglomerate interpreted as a transgressive lag deposit (Haggart and Gamba, 1990). The conglomerate is rich in clasts from the Middle Jurassic Yakoun Group, and this lithofacies is best developed in the southern parts of the islands. The formation grades upward into sandstone and shale (Haggart, 1989; Haggart and Gamba, 1990). These sandstones are generally richer in volcanic detritus than is normal in the sandstones of the Haida Formation (Sutherland Brown, 1968; Haggart, 1991). Locally the formation is very rich in fossils. Total thickness is estimated to be about 450 metres in Long Inlet (Haggart, 1989). Haggart interpreted the Longarm Formation on Graham Island and northern Moresby Island as being deposited in a shallow marine environment. A similar setting has been proposed for the units found farther south on Moresby Island by Haggart and Gamba (1990), where they further restricted the depositional regime to a shelf and upper slope setting. In addition to the Hauterivian and Barremian age span for rocks in Cumshewa Inlet (Jeletzky, in Sutherland Brown, 1968) beds of early Aptian age grade up into rocks of the Albian Haida Formation. Haggart (1989) correlated rocks of Tithonian age on the northwest coast of Graham Island with the Longarm Formation. These beds had been recognized previously, but were not given any correlation to existing formal rock units (Jeletzky, 1984; Cameron and Tipper, 1985).

2.1.2.3. Queen Charlotte Group

Whiteaves (1883) first used the name Queen Charlotte Island Group for rock units thought to be of Cretaceous age in the Skidegate Inlet area. Later Dawson (1989) used the name Queen Charlotte Island Formation for the same rock units. Clapp (1914) defined the Queen Charlotte Series which included rock units of Upper Jurassic and Cretaceous strata in the Skidegate Inlet area. This series was divided into the Haida, Honna, and Skidegate members in ascending order. Based on faunal observations MacKenzie (1916) restricted the Queen Charlotte Group to include only Cretaceous strata, and upgraded the three members to formation status. Later work on the Queen Charlotte Group has increased the understanding of the correlation of the formations within the group (Sutherland Brown, 1968; Yagishita, 1985a; Fogarassy, 1989; and Haggart, 1991).

2.1.2.3.1. Haida Formation

Defined by Clapp (1914), the Haida Formation also included rocks that were later to be ascribed to the Longarm Formation. He described the formation as a basal fine grained sandstone grading upwards into shale. Sutherland Brown (1968) divided the formation into a lower sandstone member and an upper shale member. This division has been kept by most workers, and is useful for description of the formation. Good descriptions of this unit can be found in the work by Sutherland Brown (1968), Yagishita (1985a), Higgs and Bornhold (1988), Fogarassy (1989), Fogarassy and Barnes (1991), and Haggart (1991).

Sandstone member

The sandstone member of the Haida Formation is a fine to medium grained, greenish, cross stratified sandstone. Bioturbation can locally be extensive and the formation is rich in fossils and plant debris. Several workers have noticed a basal pebble conglomerate which is rich in clasts derived from the Middle Jurassic Yakoun Group. The thickness of the sandstone member of the Haida Formation is estimated to be 823 metres by Sutherland Brown (1968) at the type locality in Bearskin Bay. Haggart (1991) indicates that this number is overestimated due to repetition of strata caused by faulting, and suggests a thickness of about 400 m. The unit is distributed along a northwest trending belt across the northern half of the islands. No exposure has been found south of Cumshewa Inlet.

McLearn (1972) identified ammonites from most of the Albian stage, with the basal Albian missing, in Skidegate Inlet. Jones et al. (1965) found basal Albian in the Beresford Bay section, and Jeletzky (1977) summarized the fauna in the sandstone member of the Haida Formation to span the entire Albian stage.

Depositional environment for this unit is considered to be mainly shallow marine. Based on the rich and diverse mollusc fauna, together with sedimentary structures Haggart (1986, 1991) interpreted the unit as an inner shelf succession deposited during a marine transgression. Higgs and Bornhold (1988) recognized that much of the sandstone member was made up of storm deposits. Fogarassy and Barnes (1989) suggested that non-marine beds were present in the lower part of the unit, and Haggart (1986) recognized coal beds in the type section, which also supports a non-marine setting for parts of the unit. Non-marine indicators are lacking in most exposures, and the formation is dominantly marine.

Shale member

Sutherland Brown (1968) noted that the shale member of the Haida Formation conformably overlies the sandstone member, and is distributed along a 3-4 km wide belt parallel to and west of the sandstone. The unit consists mainly of a dark grey to black shale with abundant calcareous concretions. The concretions are early diagenetic (Haggart, 1991), spherical to ellipsoidal and range in size from a few centimetres to more than 50 cm. Fine to medium grained sandstone beds exist, but the mud to sand ratio is generally greater than ten to one. Basal granule conglomerate or grit lithologies with associated shell debris are sometimes present together with the sandstone layers. At one locality in Cumshewa Inlet, conglomerate is present. The shale member of the Haida

Formation is locally transitional into the Skidegate Formation. The thickness of this unit has been estimated to be 325 metres at the type locality in Bearskin Bay (Sutherland Brown, 1968), and to about 100 metres in Cumshewa Inlet (Haggart, 1986). McLearn (1972) identified ammonites of Cenomanian and Early Turonian age in Skidegate Inlet and at the type section in Bearskin Bay. This range for the unit has been confirmed by Haggart (1986), who also identified fossils of these stages elsewhere in the islands.

The depositional environment for the shale member of the Haida Formation is interpreted as being the same marine transgression as was active during deposition of the sandstone member. This shale was deposited in deeper water as a more offshore facies and is a lateral equivalent to the sandstone and locally interfingers with it. Storm deposits are present in this formation as well (Higgs and Bornhold, 1988). Haggart (1986) found sedimentary and faunal indicators for an outer shelf depositional environment, and the presence of chaotic conglomerate and slumps likely indicate a partly slope environment (Gamba et al., 1990).

2.1.2.3.2. Skidegate Formation

Clapp (1914) gave the name Skidegate Formation to a series of Cretaceous strata in the Skidegate Inlet and Long Inlet area. Early workers in the Queen Charlotte Islands interpreted this formation as being the youngest sequence of the Cretaceous age in the islands. The Skidegate Formation in Kagan Bay was thought to be the top of the Queen Charlotte Group (Richardson, 1873; Dawson, 1880). Distribution of the formation is more limited than the Haida Formation, and generally crops out in a northwest trending belt west of that formation.

The Skidegate Formation is an indurated interbedded silty shale and turbiditic sandstone, with sandstone to shale ratio generally being between ten to one and one to one. The fine to medium grained sandstone is graded and can show partial Bouma sequences. These beds are from 5 cm to more than a metre in thickness. The top part of the sandstone beds is often bioturbated and the base exhibits sole marks and usually shows channels into the underlying shale beds. Fossils are rare in this unit, but plant debris is abundant locally. Thickness of the Skidegate Formation was estimated to about 630 metres in Kagan Bay by Sutherland Brown (1968).

Sutherland Brown et al. (1983) interpreted the Skidegate Formation as lacustrine or shallow marine. Haggart (1986) reported finding marine fossils within the unit. Cameron (unpublished GSC report BEBC-1989-1) found foraminifers indicative of outer shelf to upper slope marine environment. Haggart (1989) suggested that the rocks were deposited as distal turbidites from a shallow fan complex. Gamba et al. (1990) proposed a setting restricted to levee deposits adjacent to a fan complex that is represented by the conglomerates and sandstones of the Honna Formation. The interfingering of Skidegate Formation lithologies with the Haida Formation suggests that some of the turbidites are related to a steep slope in an outer shelf setting (Haggart, 1991). The first interpretations of the Cretaceous rock units on the Queen Charlotte Islands placed the Skidegate Formation as the youngest unit. Whiteaves (1884) recognized fossils of Turonian age, which overlapped with the proposed age for the Haida Formation, but unfortunately this information was not applied by the field geologists. Haggart (1986, 1987) showed that fossils from the Skidegate Formation spanned from latest Cenomanian to (probably) Albian age, and the formation is basically of the same age as the Haida Formation.

2.1.2.3.3. Honna Formation

The Honna Formation was named by Clapp (1914) and has received attention from many geologists (Sutherland Brown, 1968; Yagishita, 1985a,b; Haggart, 1986; Higgs, 1988, 1990, 1991a,b; Fogarassy and Barnes, 1991; Gamba et al., 1990).

The dominant lithology of the Honna Formation is cobble conglomerate and medium to coarse sandstone, with minor fine grained sandstone and shale. Haggart (1986) describes the unit as a large scale fining upward sequence. The lower part made up of thickly bedded coarse conglomerate which fines gradually into sandstone and is topped off by interbedded sandstone and shale. The base of the formation has different appearances in the islands. It is observed to scour into the underlying Haida and Skidegate formations (Higgs, 1988; Fogarassy and Barnes, 1988); while interbedding with and conformable contacts towards the underlying units are also observed (Indrelid, 1990; Taite, 1990). The thickness of the formation is estimated to be 450 m in Kagan Bay (Sutherland Brown, 1968) and to 200 m in Cumshewa Inlet (Haggart, 1986). Its extent is restricted to the northern and central part of the islands.

Yagishita (1985a) interpreted the formation as deposited by a canyon-fed submarine fan, with the sources for the system being somewhere east of the present extension of the Queen Charlotte Islands. Higgs (1988, 1990, 1991a) argues that the depositional environment is that of a fan-delta extending across a narrow shelf. The fan-delta would extend from fault scarps adjacent to uplifted blocks to the east. Gamba et al. (1990) interpreted the Honna Formation as deposited by several laterally adjacent submarine fan complexes, the turbidites of the Skidegate Formation are levee deposits laterally adjacent to the Honna Formation conglomerates and sandstones. Gamba (1991) suggests that the formation shows indicators of a deepening westward depositional environment.

Due to poor fossil control the age constraints for the formation is not as well defined as for the other Cretaceous units. Some fossils have been recovered from the formation and these indicate an age range from Early Coniacian to Early Santonian (Riccardi, 1981; Haggart, 1986). Fossils of Early Turonian age have been collected from the Skidegate and Haida formations underlying conglomerates of the Honna Formation in the central parts of the islands. On the northwest coast of Graham Island the underlying units have yielded fossils of Cenomanian age. These observations suggest that the initiation of deposition of the Honna Formation started in Turonian time in the central parts of the Queen Charlotte Islands, and in Cenomanian time in more northern parts of the islands (Haggart, 1991). Other observations (Thompson et al., 1991) show conglomerate of this formation on top of Jurassic and even Triassic units. It is impossible to tell the when the initiation of the Honna Formation started in these areas.

2.1.2.4. Unnamed Upper Cretaceous sedimentary rocks

An Upper Cretaceous shale unit was first described by Haggart and Higgs (1989) for a sequence of shale located west of Slatechuck Mountain in the southwestern part of the mapped area. The unit consists of bioturbated, dark grey shale, and contains calcareous concretions up to 30 cm in diameter (Haggart 1991). Sandstones are rare in this unit, but can be present as thin beds or sandstone dykes. Thickness of the unit is estimated to be at least 30 m (Haggart and Higgs, 1989). Based on the molluscan fauna and the lack of sandstone, Haggart and Higgs (1989) proposed an outer shelf setting for the deposition of this unit. Although this shale has been recognized only in the

Slatechuck Mountain area, Haggart (1991) suggests that shale overlying the Honna Formation on the northeastern part of the islands may be correlative to this unit. Molluscs collected from this unit indicate a Late Santonian to Early Campanian age. Microfossils indicate the possibility that Maastrichtian strata may be present as well (unpublished Bujak Davies Group fossil report, 1989).

2.1.2.5. Unnamed Upper Cretaceous volcanic rocks

A Late Cretaceous volcanic succession interstratified with the Honna Formation in the western Skidegate Inlet was first reported by Haggart et al. (1989). The unit consists of volcanic debris flows, massive flows, and scoria of intermediate composition. The bottom part of the succession consists of debris flow interbedded with the Honna Formation. These flows are overlain by scoriaceous deposits and topped by massive subaerial flows. The total thickness of the volcanic package is up to 800 m, but the thickness decreases dramatically laterally and pinches out both to the east and west (Haggart, 1991). The unit was deposited in a transgressive environment with the top of the unit being subaerial (Haggart, 1991). The age control on these volcanics is poor, but based on the field relationships between the volcanics and the Honna Formation a Coniacian to Santonian age was proposed by Haggart (1991).

2.1.3. A new stratigraphic scheme

A new lithostratigraphic division for the Cretaceous rocks of the central Graham Island area is proposed instead of the earlier used unit description that was more of a biostratigraphic scheme. This new division is entirely based on lithological properties of the rocks and does not rely on identification of fossils, and thus is preferable for mapping purposes. It enables the geologist to identify the rocks in the field, instead of bringing fossils back from the field and get them identified before a decision can be made.

The new stratigraphic scheme only involved the redefinition of the shale and sandstone of the Longarm and Haida formations. The use of the Skidegate and Honna formations is kept. Haggart et al. (1991) argue that the turbidites of the Skidegate Formation should be a sub-unit of the Cretaceous shale unit. In the central Graham Island area the Skidegate Formation is as much related to the Honna Formation as to the Cretaceous shale unit. It is not believed that the turbidites are more related to the shale depositional regime than the deposition of the conglomerates and sandstones of the Honna Formation.

Due to the lack of continuous exposures in the area, thickness estimations of the different units is very difficult. There are probably many undetected faults cutting through most of the sections in the central Graham Island area. These faults greatly increase the apparent thicknesses of the units. In the Ghost Creek area the apparent thickness of the Cretaceous sandstone unit is over 3 km. This is so much larger than any other estimates of thickness for Haida or Longarm sandstones in the Queen Charlotte Islands that it is obviously wrong. The author feel that there is not sufficient control on the structures to estimate any thicknesses of the Cretaceous strata in the central Graham Island.

2.1.3.1. Cretaceous sandstone unit

The Cretaceous sandstone unit has the most diverse lithological composition of the Cretaceous rock units in the central Graham Island. The unit is characterized by a major sandstone component with or without minor siltstone and mudstone present. This unit has been assigned by other geologists to several different formations. All the sandstones of the unit fall within either the Longarm or the Haida formations.

The diverse lithologies of the Cretaceous sandstone unit makes it difficult to present a unifying and simple description of the rocks. Three main lithologies have been singled out and are described in detail as separate lithofacies (Figure 2-1). Some mixing of rocks of the different lithofacies exists, but the three different lithofacies are mappable on mapscale in the central Graham Island area. Variations within the Cretaceous sandstone unit are then described with reference to the dominating lithologies.

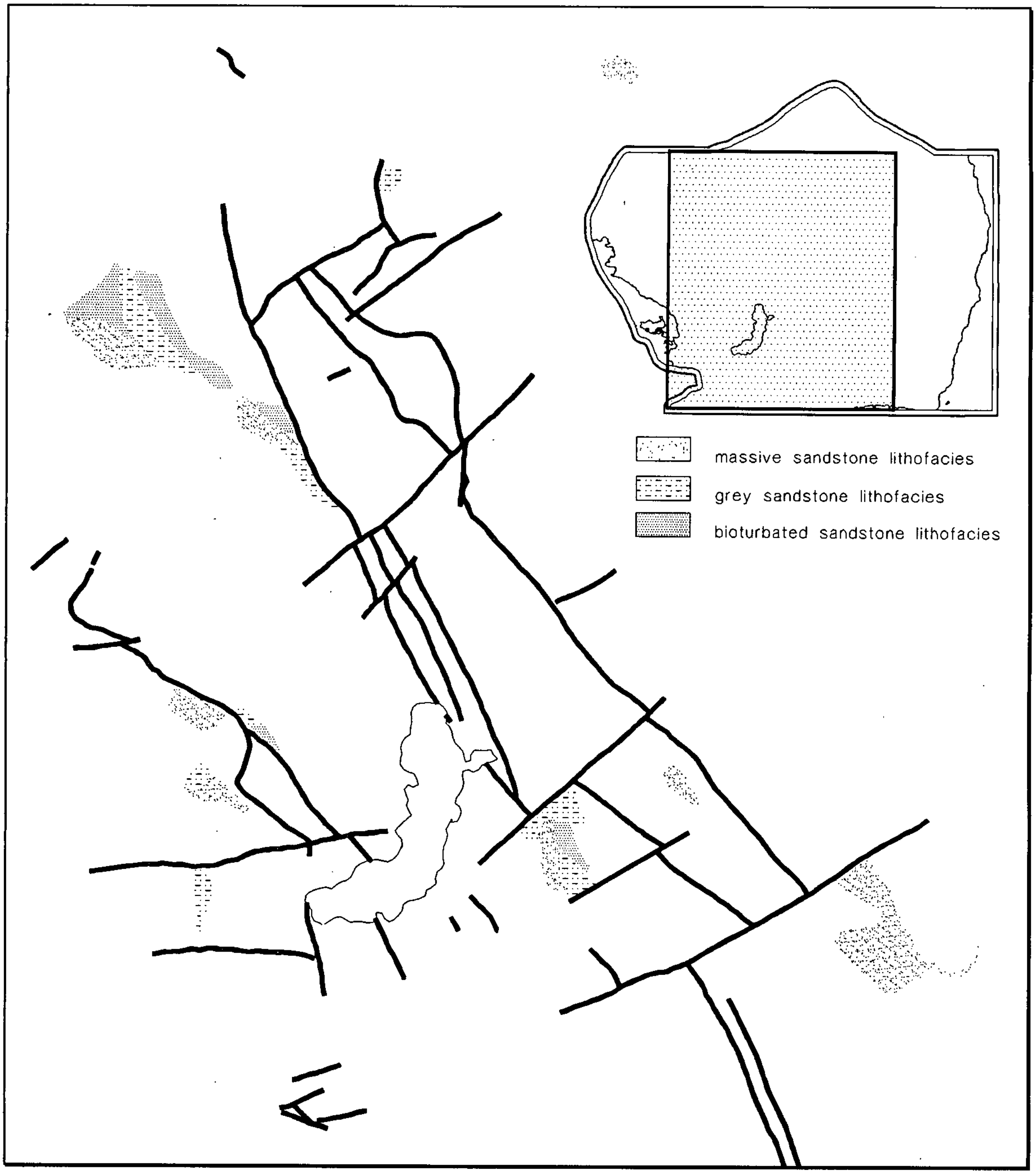


Figure 2-1. Lithofacies map for the Cretaceous sandstone unit in the central Graham Island area.

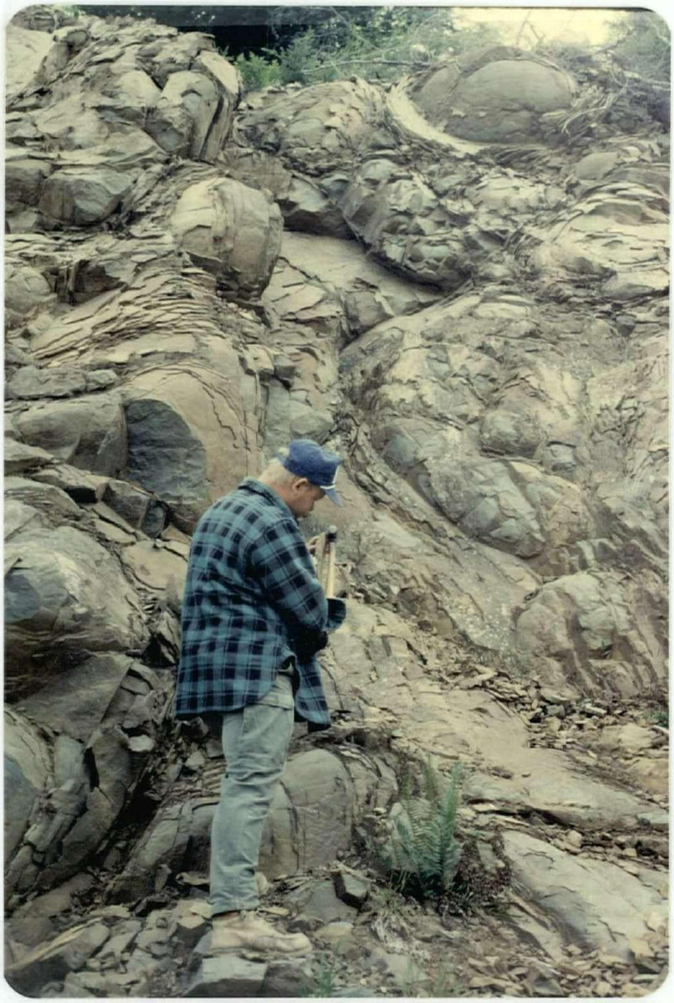


Figure 2-2. Spherical weathering appearance in the massive sandstone lithofacies.

Figure 2-3. Swaley cross-bedding in the massive sandstone lithofacies.

2.1.3.1.1. Massive sandstone lithofacies

This lithofacies is made up of medium to coarse grained, massive, and very hard sandstone. The colour is most often dark green to greenish black, but fresh surfaces can show colours ranging from light grey to almost black. Weathering appearance is often characterized by layers of spheroidal weathering, that can be peeled off like the layers of an onion (Figure 2-2). Weathering colour is dark green or greenish brown. The massive sandstone is found both without any trace of bedding and with large scale bedding separating massive sandstone bodies. Normally no primary depositional structures or bioturbation is visible, only rarely is cross-stratification and planar lamination observed. Hummocky and swaley cross-lamination occur only in a few outcrops (Figure 2-3).

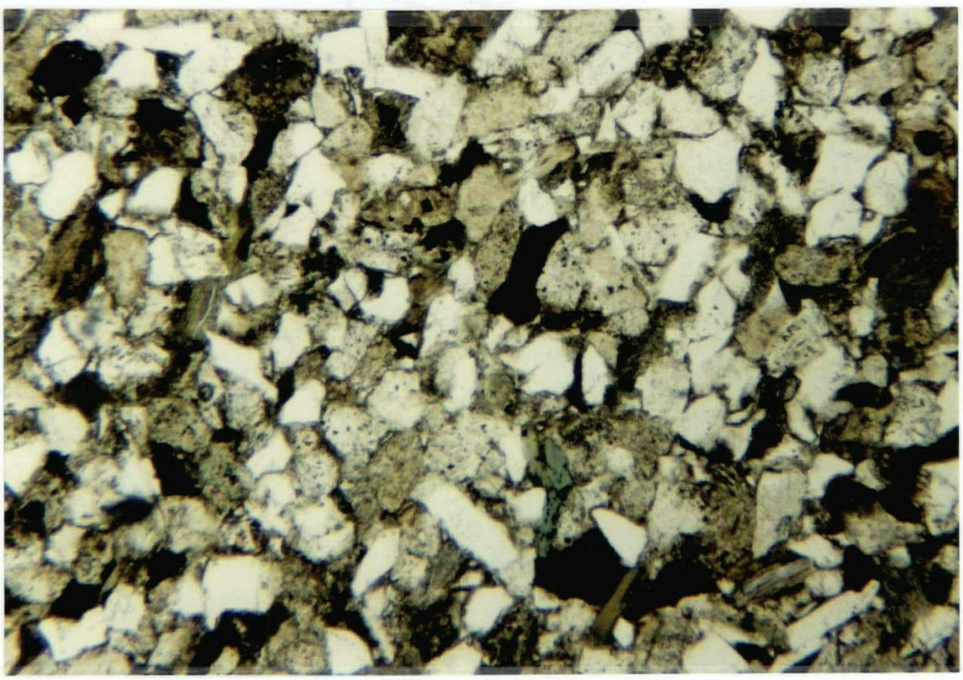


Figure 2-4. Thin section photomicrograph showing angular quartz and feldspar fragments in the massive sandstone lithofacies (plane polarized light, x70 magnification).

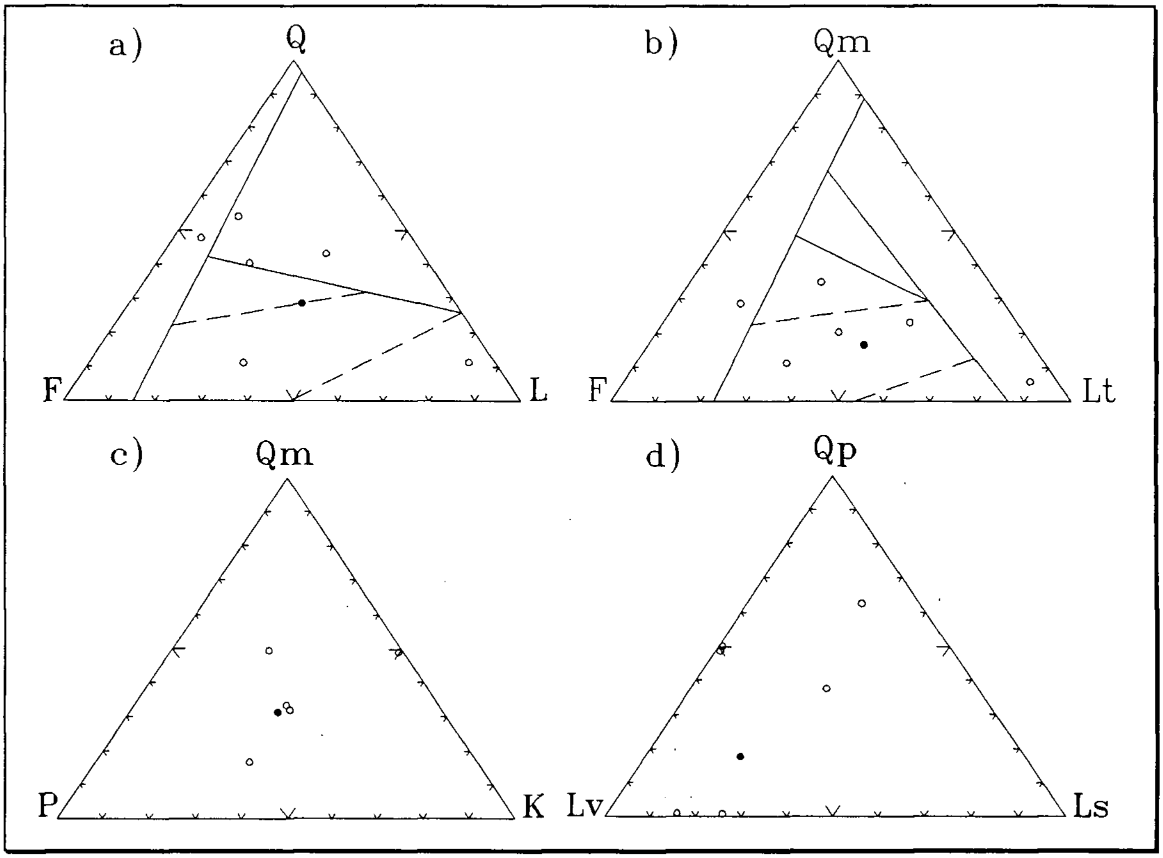


Figure 2-5. Ternary diagrams showing the relative abundance of a variety of different fragments in thin sections of the massive sandstone lithofacies (see appendix 7.1 for explanation to the abbreviations used in this diagram). a) QFL-diagram, b) QmFLt-diagram, c) QmPK-diagram, and d) QpLvLs-diagram (from Dickinson, 1982; Dickinson et al., 1982). Solid circles represent the average.

The massive sandstone lithofacies is composed of primarily quartz, feldspar and rock fragments. Most of the quartz and feldspar fragments are sub-angular to angular (Figure 2-4), indicating that the unit is texturally immature. Figure 2-5a is a ternary plot of quartzose grains (mono- and polycrystalline), feldspar, and unstable lithic fragments (Dickinson, 1982; Dickinson et al., 1982). For convenience, diagrams of this type will be referred to as QFL-plots. From figure 2-5a it can be seen that the average quartz:feldspar:rock fragment ratio is 30:30:40, although this ratio varies considerably. Quartz makes up less than 50 % of the three fragment classes in all samples, and less than 40 % of total framework grains. The quartz present is made up of both monocrystalline and polycrystalline fragments as well as chert, monocrystalline quartz is more abundant than the polycrystalline variety. Chert varies from almost none to about 20 % of total framework grains in these rocks. Figure 2-5c is a plot of monocrystalline quartz, plagioclase, and potassium feldspar. This type of diagram will from now on be referred to as QmPK-plot (Dickinson, 1982; Dickinson et al., 1982). Figure 2-5c shows that in this lithofacies the quantities of plagioclase and potassium feldspar is equal. One sample has almost no plagioclase, but that is not common in the massive sandstone lithofacies. Figure 2-5d shows polycrystalline quartzose fragments (including chert and quartzite), volcanic lithic fragments,and sedimentary lithic fragments plotted in a ternary diagram. This type of diagram is called a QpLvLs-plot (Dickinson, 1982; Dickinson et al., 1982). In the massive sandstone lithofacies more volcanic rock fragments is present than fragments of sedimentary origin. Volcanic fragments commonly outnumber the sedimentary fragments 3:1.

Glauconite is present in large amounts in some samples of the massive sandstone lithofacies, and in one sample it exceeds 50 % of the framework constituents (Figure 2-6a,b). The dark green colour in some parts of this lithofacies comes from large amounts of glauconite. Examinations using Scanning Electron Microscope also show that glauconite is in abundance in the dark green sandstone. Figure 2-7a shows the glauconite grain that the EDS spectrum in figure 2-7b is taken from. As can be seen from the figures 2-7a, and 2-8 porosity is poor in these glauconittic rich sandstones. Glauconite may form by the replacement of a variety of host material like faecal pellets, calcium carbonate pellets, and fine mud (Nockolds et al., 1978; Dietrich and Skinner, 1979). The glauconite pellets in the green sandstones may have formed in a sandy facies, or been reworked from an earlier glauconittic mud. Glauconite is restricted to warm marine water. Chlorite clay that is very common in the rest of the Cretaceous sandstone, is not as abundant in these glauconite rich rocks. EDS from the feldspar in these sandstone shows that both Na-Ca and Ca plagioclase is present.

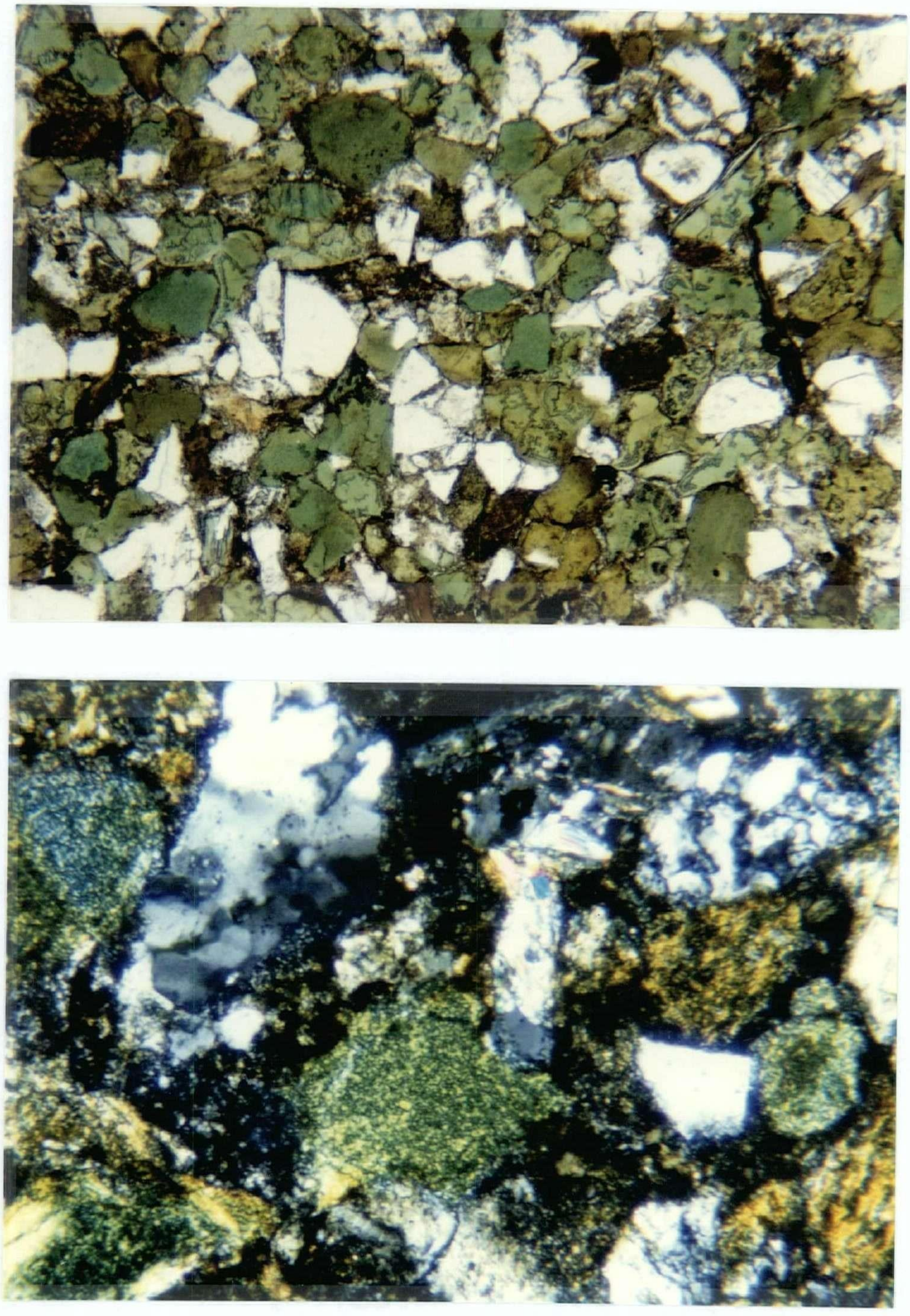


Figure 2-6. a) Thin section photomicrograph of sandstone rich in green glauconite fragments (plane polarized light , x70 magnification). b) Thin section photomicrograph of glauconite grain (crossed nicols, x280 magnification).

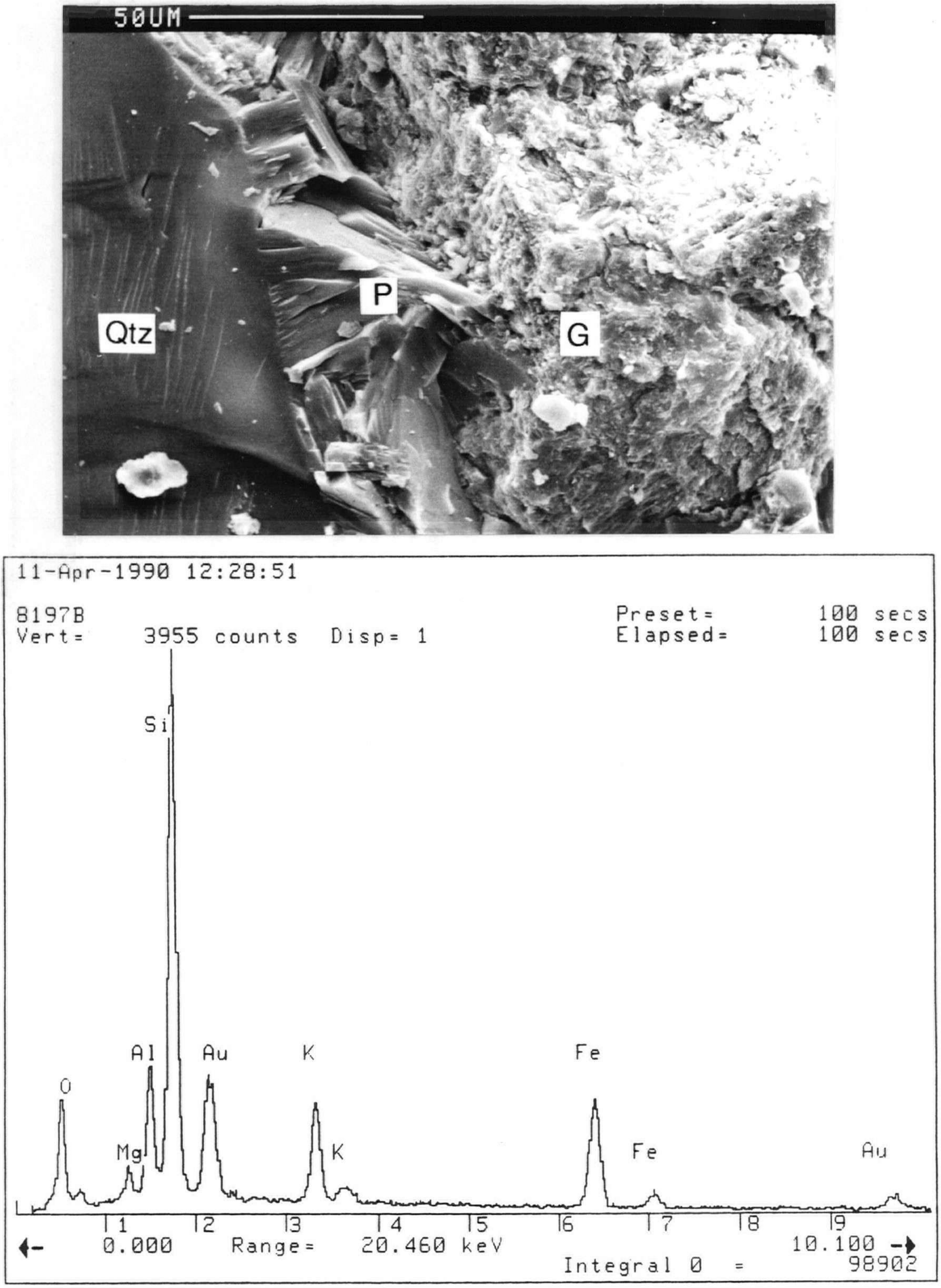


Figure 2-7. a) SEM-photomicrograph of Glauconite (G), quartz (Qtz), and plagioclase (P).
b) EDS-analysis of the glauconite grain in (a).

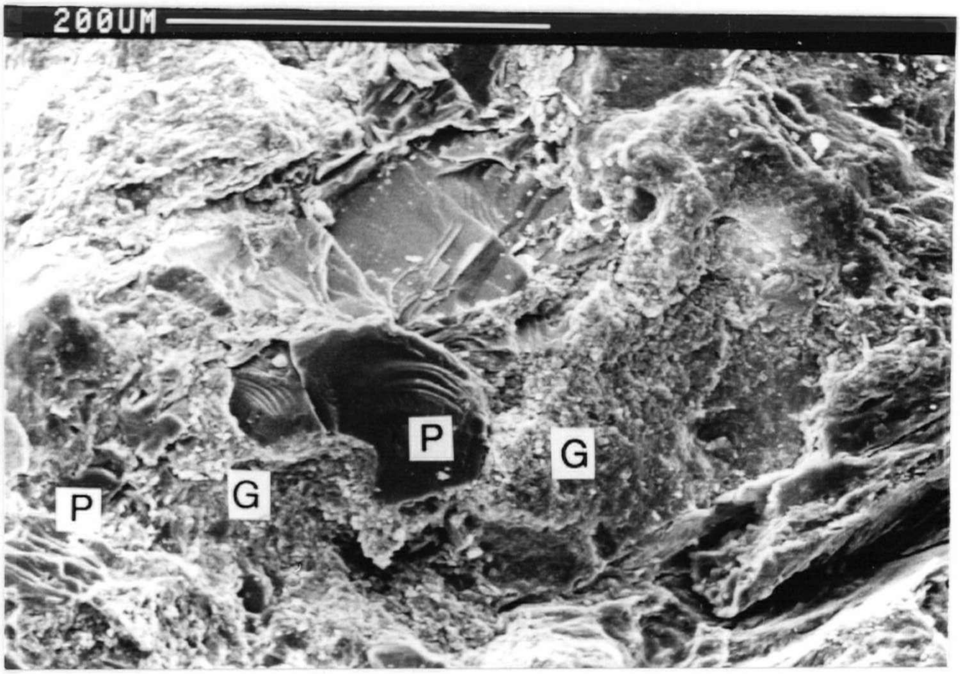
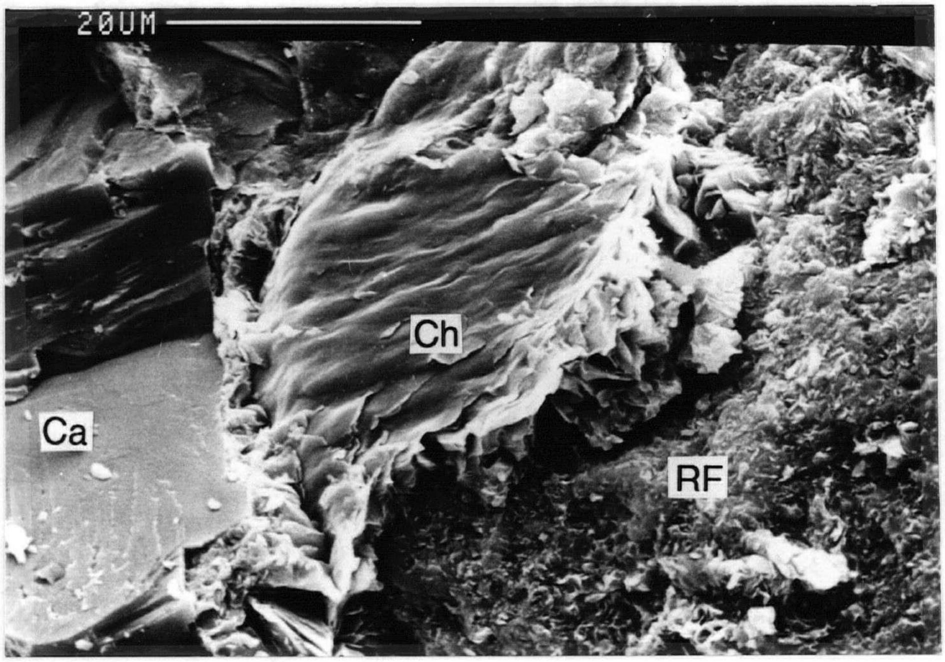


Figure 2-8. This SEM-photomicrographs shows that porosity is almost nonexistent in these glauconite rich sandstones (glauconite (G), plagioclase (P)).

In the massive sandstones that lack the abundant glauconite, chlorite is the dominant clay mineral and is present almost everywhere, either filling pore spaces or coating on mineral surfaces. The presence of chlorite also adds a greenish colour to the rock. EDS analysis (Figure 2-9b) on the clay in figure 2-9a yields a spectrum indicative of chlorite. Calcite is also found filling pore spaces, but is less plentiful than chlorite. Some of the chloritic matrix is squashed between minerals and rock fragments (Figure 2-10), and may be interpreted as pseudo-matrix (Dickinson, 1970). Pseudo-matrix is formed when less resistant rock fragments get deformed and squashed between more resistant fragments during compaction, and it is often very hard to distinguish from detrital clay. It is particularly difficult to distinguish between detrital clay and pseudo-matrix in thin sections, and in most cases is it impossible. Both pseudo-matrix and detrital clay seems to be present in the samples. Accessory fragments present includes biotite, muscovite, carbonate in the form of shell fragments, some non-transparent minerals and pieces of organic material.

Figure 2-5b is a ternary plot of monocrystalline quartz, feldspar, and total amount of aphanitic lithic fragments (including polycrystalline quartz). Plots of this type will be referred to as QmFLt-plots (Dickinson, 1982; Dickinson et al., 1982). This plot together with QFL-plots (Figure 2-11) can be used to indicate provenance of a rock based on its petrology (Dickinson, 1982; Dickinson et al., 1982). The QFL-plot for the massive sandstone lithofacies indicates derivation from a magmatic arc (Figure 2-5a). Samples plot in the undissected to dissected arc field , with most samples and the average falling in the dissected arc field. The QmFLt-plot (Figure 2-5b) also indicates a magmatic arc provenance, with the majority of samples plotting in the field of transitional arc. A few samples plot in the areas of recycled orogen and continental block provenance. This may indicate some mixing of sources, but they all plot close to the magmatic arc area and may just be small variations in lithology.



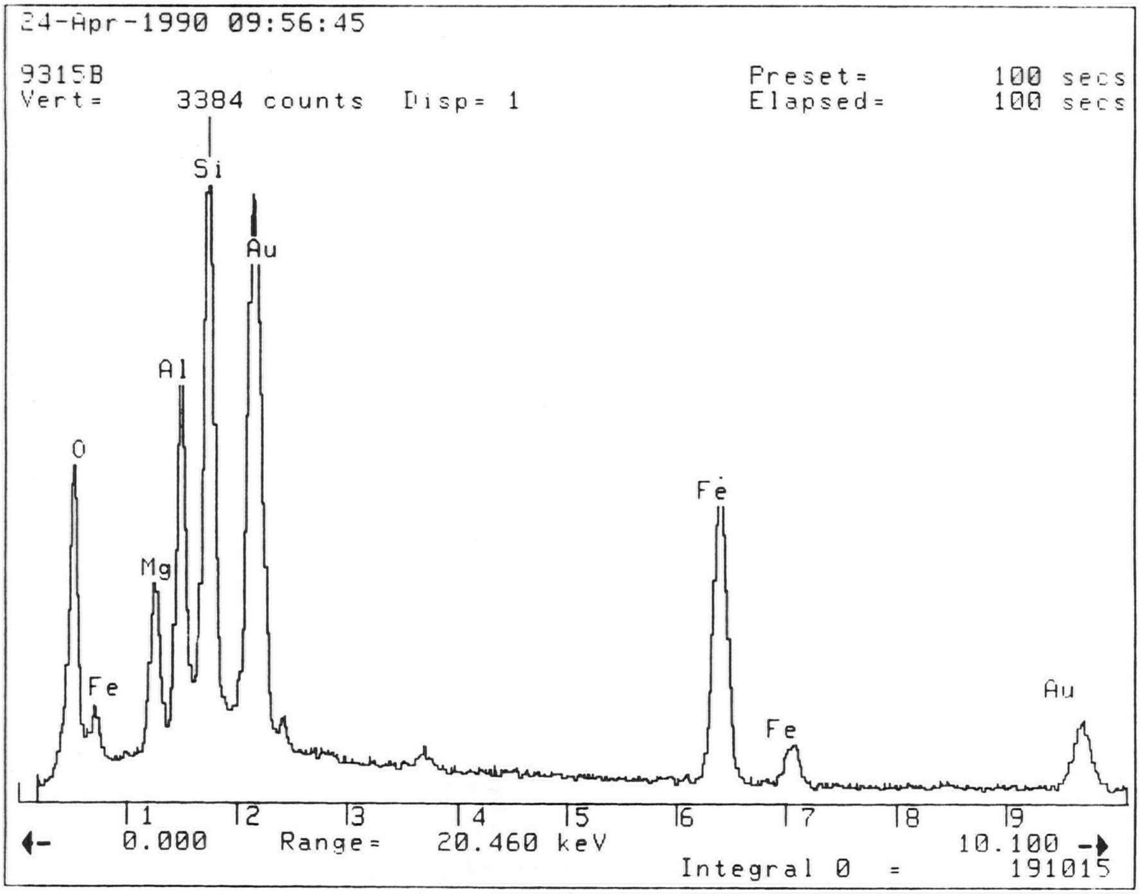


Figure 2-9. a) SEM-photomicrograph of chlorite (Ch), Carbonate (Ca), and rock fragment (RF). b) EDS-analysis of the chlorite grain in (a).

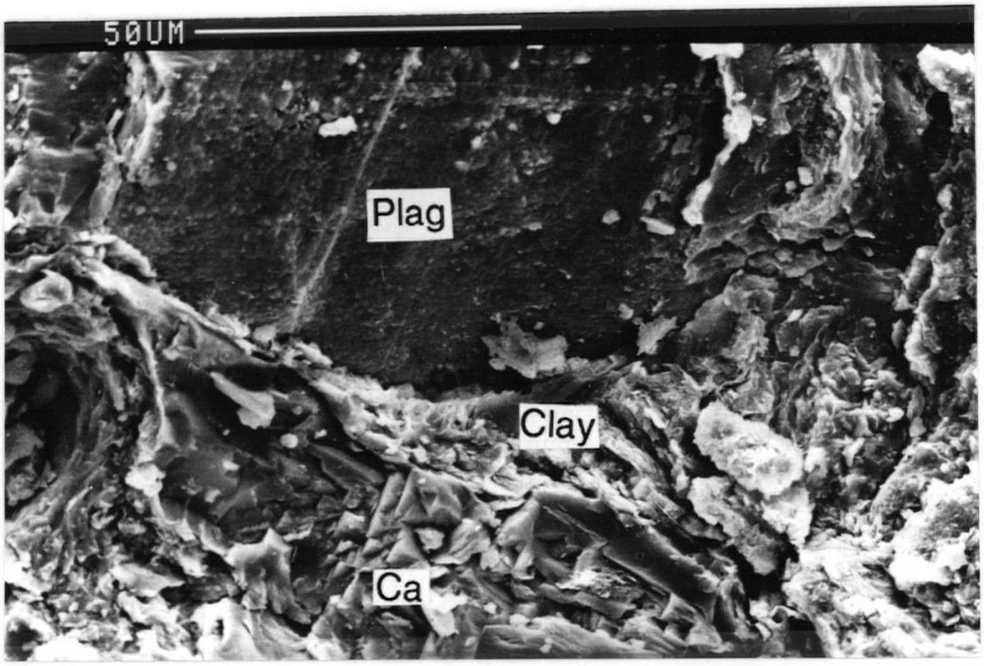


Figure 2-10. SEM-photomicrograph of clay that seems to be squashed between fragments of plagioclase (Plag) and calcite (Ca). This clay may be what is referred to as pseudo-matrix (Dickinson, 1970).

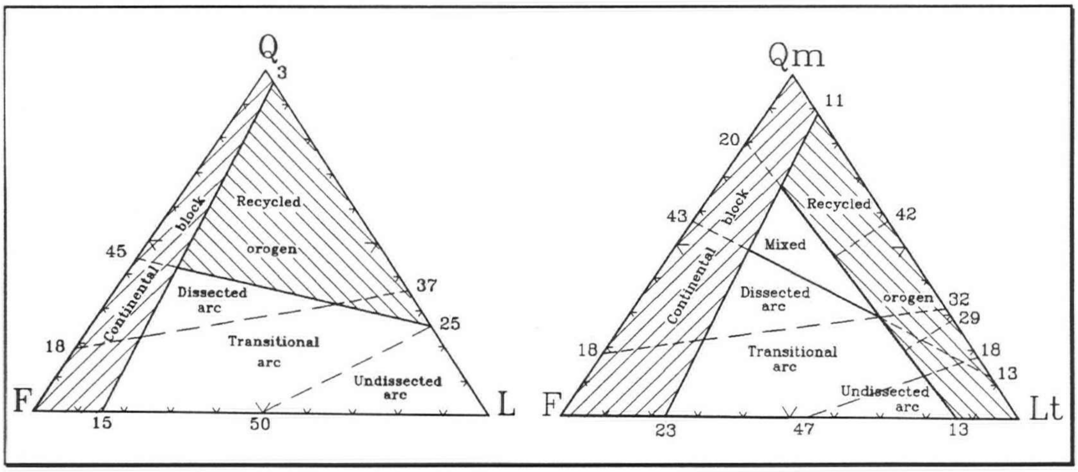


Figure 2-11. Ternary diagrams showing subdivision of inferred provenance types based on petrology (Dickinson et al., 1982). See appendix 7.1 for explanation to the abbreviations used in this diagram.

2.1.3.1.2. Grey sandstone lithofacies

Figure 2-12. An outcrop of interbedded sandstone, siltstone, and shale of the grey sandstone lithofacies. The hammer lies on a small fault.

The grey sandstone lithofacies is better stratified and contains more finer grained layers than the massive sandstone lithofacies (Figure 2-12). These lithofacies tends to be somewhat finer grained and softer than the green sandstone, although in some localities this sandstone is very well indurated. The grey sandstone is fine to medium grained with dark to light grey colour on fresh surfaces. Colours on weathered surfaces are dark brown to dark grey, and these surfaces often exhibit spheroidal weathering. Calcareous concretions and lenses are present in some areas. The grey sandstone lithofacies is frequently found interbedded with siltstone and shale units. The sandstone beds are up to a metre thick, with the siltstone and shale beds being thinner. Primary structures are rare in this lithofacies, but cross-bedding has been observed in a few outcrops. The grey sandstone is easily separated from the green massive sandstone lithofacies by its colour, hardness, and its higher amount of interlayered finer grained layers.

At two localities beds rich in large angular feldspars were interbedded with normal lithologies of the grey sandstone lithofacies. These feldspars (probably plagioclase) are particularly noticeable on weathered surfaces due to their white colour (Figure 2-13). The angular feldspars cannot have been transported far in an abrasive transport system and indicate a proximal source.

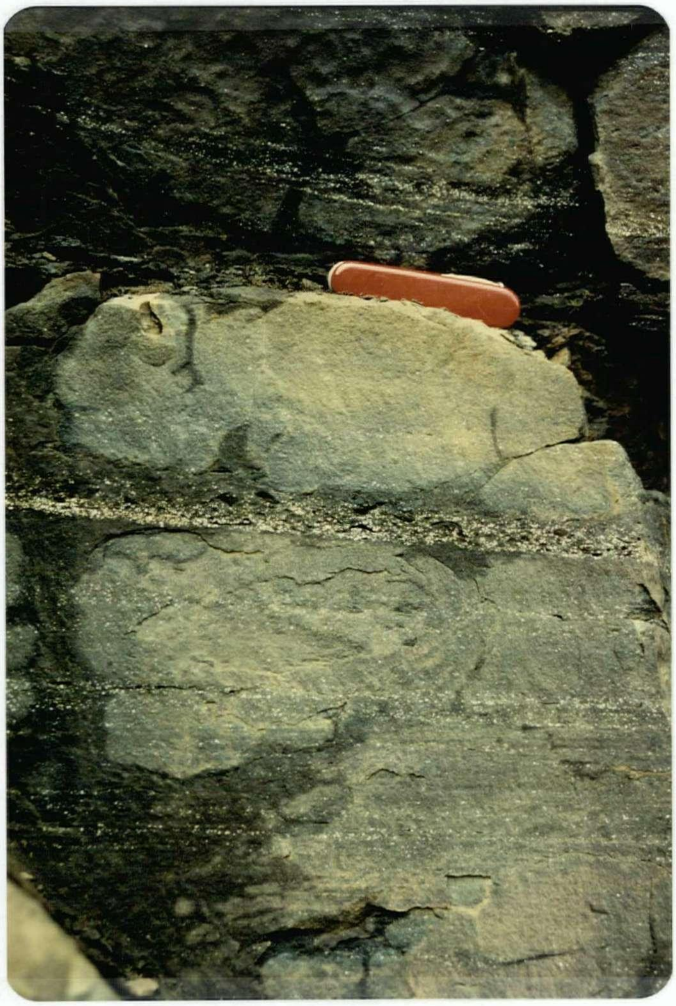


Figure 2-13. Layers rich in large angular feldspar interlayered with more normal Cretaceous sandstone lithology.

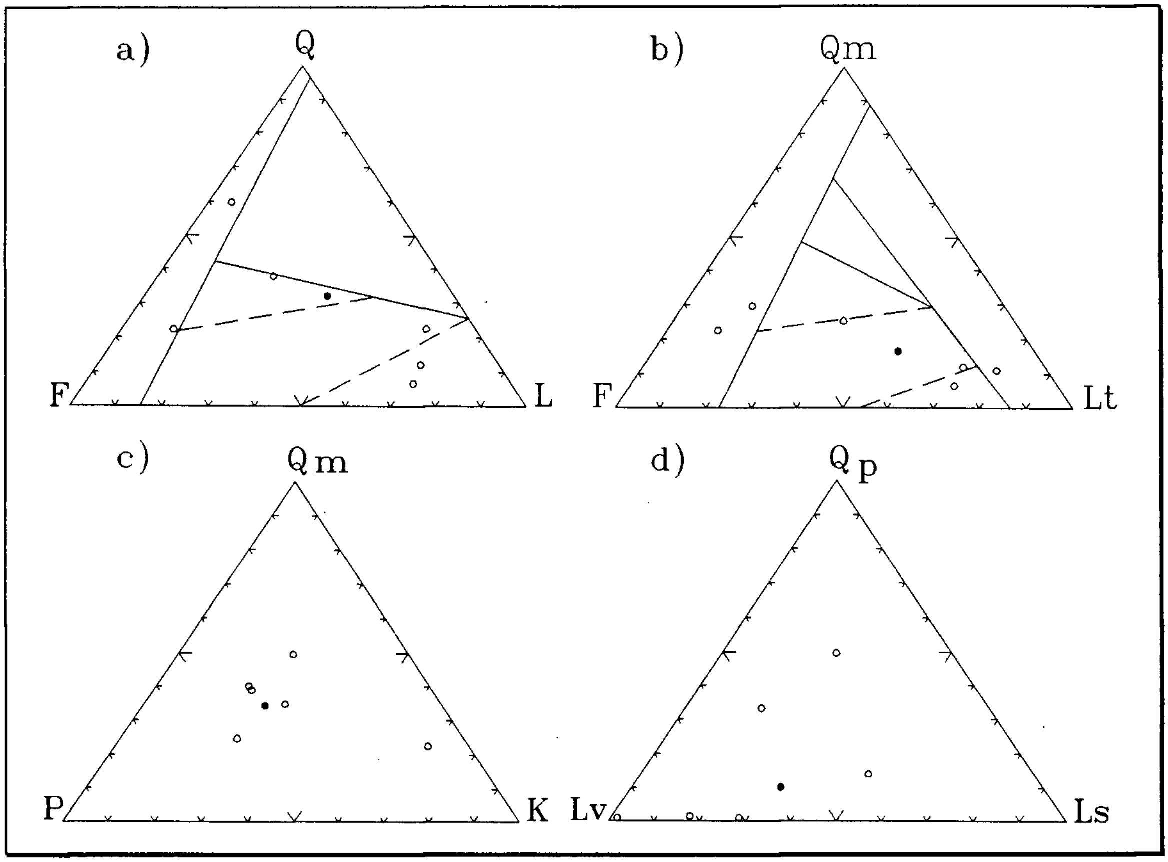


Figure 2-14. Ternary diagrams showing the relative abundance of a variety of different fragments in thin sections of the grey sandstone lithofacies. a) QFL-diagram, b) QmFLt-diagram, c) QmPK-diagram, and d) QpLvLs-diagram (from Dickinson, 1982; Dickinson et al., 1982).

Microscopy

Quartz, feldspar, and rock fragments are the most frequent grains in the grey sandstone lithofacies, the average quartz:feldspar:rock fragment ratio is 30:40:30 (Figure 2-14a). Quartz is present as monocrystalline and polycrystalline grains and chert, and makes up less than 30 % of the framework material. Monocrystalline fragments are generally more abundant than polycrystalline; chert is seldom present in amounts larger than 15 %. The QmPK-plot in figure 2-14c shows that plagioclase and potassium feldspar is present in equal amounts, except for one sample where potassium feldspar is dominant. In figure 2-14d it can be seen that volcanic rock fragments are more plentiful than sedimentary rock fragments. Volcanic fragments contribute to up to 50 % of the total framework grains in this lithofacies and generally outnumber the sedimentary fragments 2:1 to 3:1. One sample is almost depleted of quartz and sedimentary rock fragments; this sample is finer grained than an average sample would be. Fragments present in minor amounts in thin sections of this lithofacies include biotite, foraminifera (Figure 2-15), muscovite, carbonates, and fragments of organic material. In some samples carbonate fragments are the most common constituent (Figure 2-16).

The QFL-plot shown in figure 2-14a indicates that the source for this lithofacies is a magmatic arc, samples plot in the areas from dissected arc to undissected arc, with the average being in the field for a dissected arc. The QmFLt-plot of this lithofacies (Figure 2-14b) also indicates a magmatic arc source, the average of the samples plots in the field of transitional arc.

Figure 2-15. Thin section photomicrograph of foraminifera in the grey sandstone lithofacies. Note also the biotite (brown coloured) which is not a common mineral in the Cretaceous sandstone unit (plane polarized light, x280 magnification).

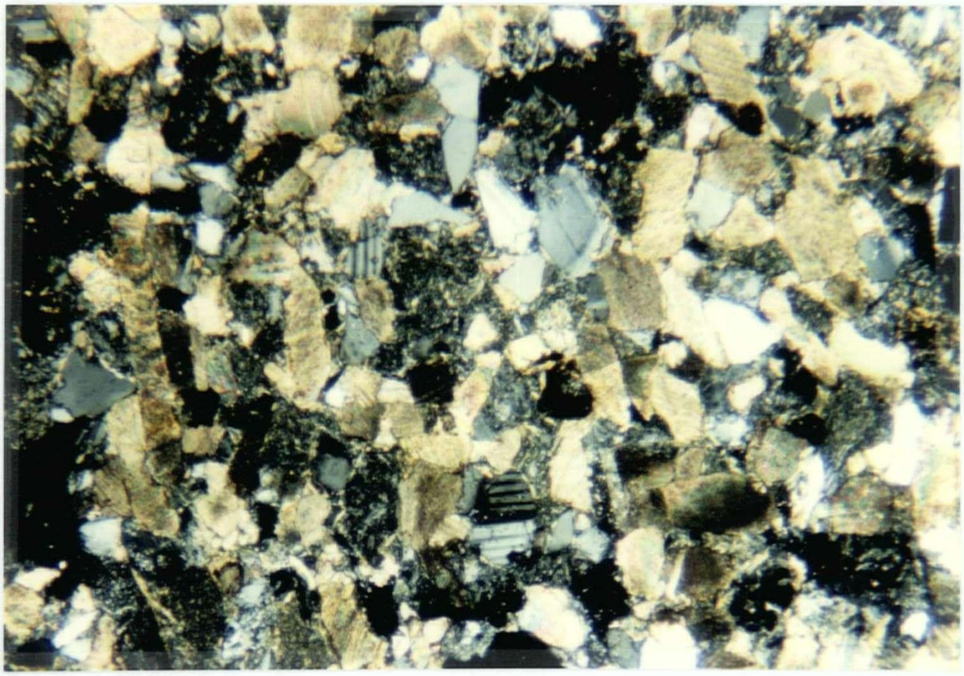


Figure 2-16. Thin section photomicrograph of the grey sandstone lithofacies rich in carbonate fragments. Note also the angularity of the quartz and feldspar (crossed nicols, x70 magnification).

2.1.3.1.3. Bioturbated sandstone lithofacies

The bioturbated sandstone lithofacies is similar in many respects to the massive sandstone lithofacies, except that it is pervasively bioturbated. These sandstones are also normally more bluish, finer grained, and softer than the massive sandstone lithofacies. They can however, also be very indurated and have most of the characteristics of the massive sandstones. Weathering appearance varies from very indurated with spheroidal surfaces to loose and poorly consolidated. The sandstones of this lithofacies are easy to distinguish with their intense bioturbation shown as black traces of finer grained material (Figure 2-17). Convolute bedding and soft sediment deformation have been observed in these sandstones; calcareous concretions are also present in some areas.

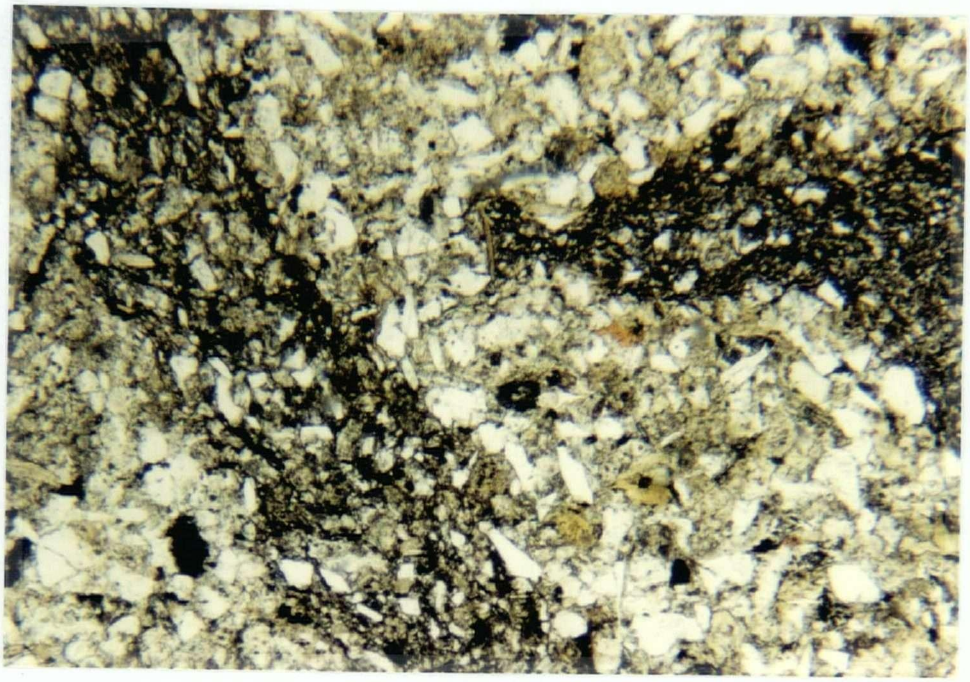


Figure 2-17. a) Typical appearance of the bioturbated sandstone lithofacies, the black traces are bioturbation. b) Microphotograph showing the finer grained nature of the bioturbation traces (plane polarized light, x70 magnification).

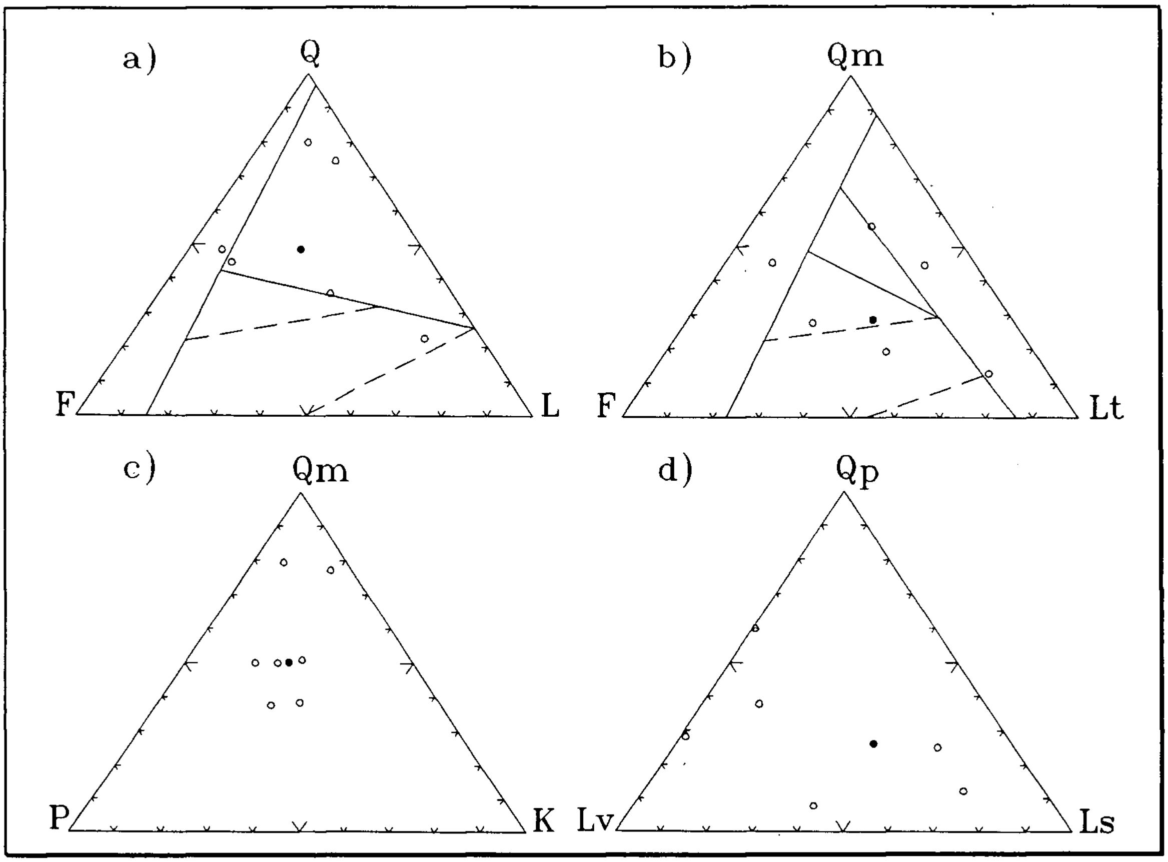


Figure 2-18. Ternary diagrams showing the relative abundance of a variety of different fragments in thin sections of the bioturbated sandstone lithofacies. a) QFL-diagram, b) QmFLt-diagram, c) QmPK-diagram, and d) QpLvLs-diagram (from Dickinson, 1982; Dickinson et al., 1982).

Microscopy

In the bioturbated sandstone the average ratio of quartz:feldspar:rock fragments is 50:25:25, indicating a higher quartz content than in the two other lithofacies of the Cretaceous sandstone unit. Quartz is present in amounts up to almost half of the total framework material, and is frequently present in amounts larger than 20 %. Both chert and monocrystalline quartz are abundant in most samples, polycrystalline quartz is less frequent. Figure 2-18c is a QmPK-plot and shows that monocrystalline quartz is far more abundant than either feldspar, and that there is, on average, slightly more plagioclase than potassium feldspar. Figure 2-18d is a QpLvLs-plot and shows that there generally is more volcanic rock fragments present than sedimentary ones. From this figure it can be seen that the amount of sedimentary rock fragments in this lithofacies tends to be higher than in any of the other lithofacies of the Cretaceous sandstone unit, with some samples having more sedimentary fragments than volcanic ones. Both the QmPK-plot in figure 2-18c and the QpLvLs-plot in figure 2-18d show that this lithofacies is more quartz rich than any of the other sandstones of the Cretaceous sandstone unit. Various forms of bioclasts and plant fragments are found throughout the unit (Figure 2-19). Calcite can be plentiful in this unit as well. Framework fragments present in minor amounts include glauconite, biotite, and muscovite.

The QFL-plot of the samples of this lithofacies (Figure 2-18a) indicates that the source for the sandstones of this lithofacies was mixed. Samples plot in the areas of recycled orogen, continental block, dissected arc and transitional arc. A plot of a sample representing the average for this lithofacies lies in the field of recycled orogen. Figure 2-18b is a QmFLt-plot and also indicates that the bioturbated sandstone lithofacies of the Cretaceous sandstone unit might have a mixed source. The samples plot in the fields of recycled orogen, continental block, and dissected arc, with the average for this lithofacies lying in the field of dissected arc. Both ternary plots for the framework modes of this lithofacies suggest that these sandstones are eroded from a variety of sources. Most of the samples from this lithofacies show an arc relationship, and most of these indicate a dissected arc as a source. The relatively higher content of quartz in this lithofacies compared to the other lithofacies of the Cretaceous sandstone unit result in plots that indicate recycled orogen and continental block providence. Based on the fact that the bioturbated sandstone lithofacies is found intermixed with the other lithofacies of the Cretaceous sandstone unit, the most likely reason for the difference in clast material is the smaller grain size of the bioturbated sandstone lithofacies.

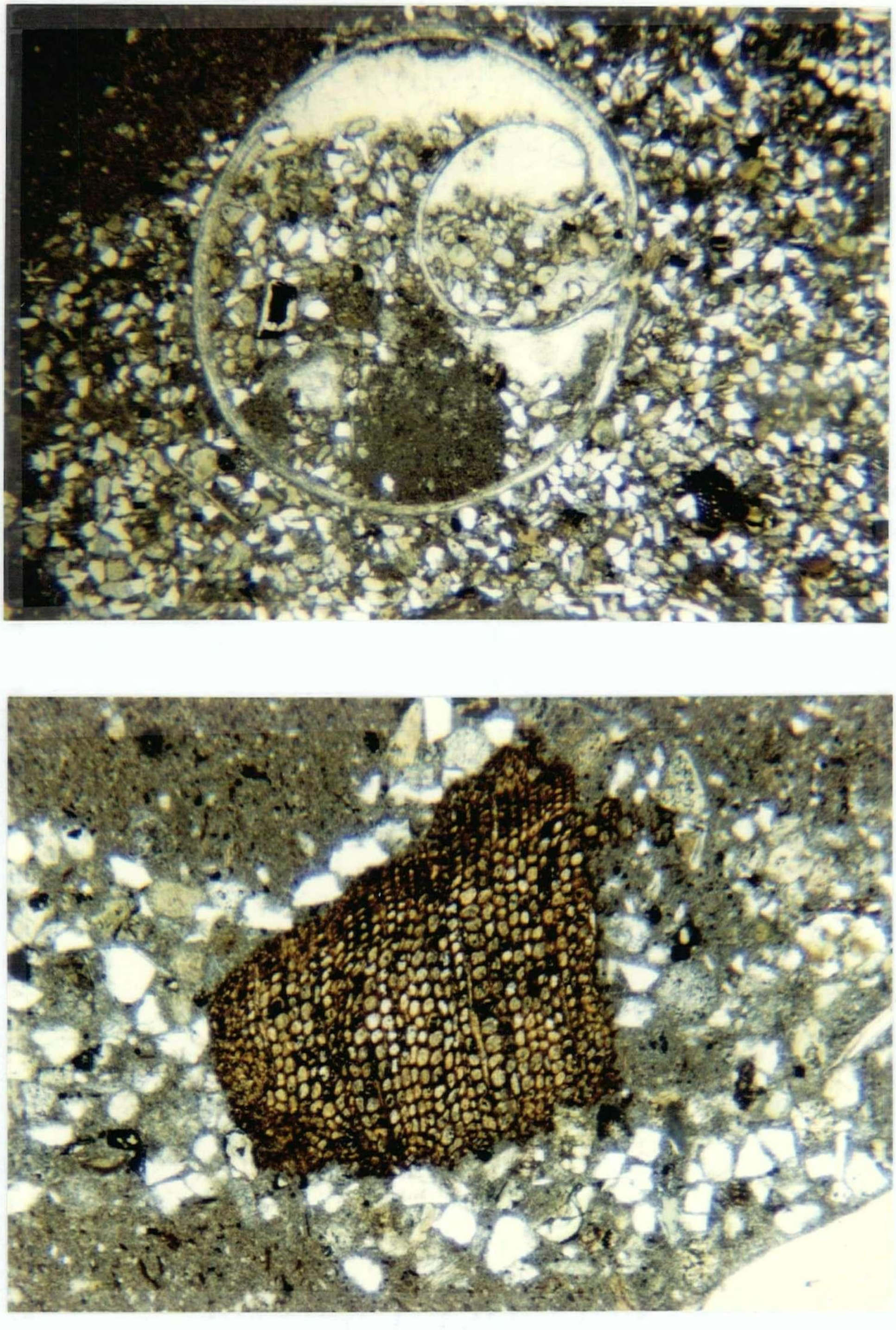


Figure 2-19. a) Geopetal structure found in the bioturbated sandstone lithofacies (plane polarized light, x28 magnification). b). Plant fragment in the bioturbated sandstone lithofacies, this indicates input of terrestrial material. Note the angularity of quartz and feldspar grain and the large amount of fine grained material (plane polarized light, x70 magnification).

Figure 2-20. A lens of bimodal pebble conglomerate in the lower left corner (dark coloured) interbedded with lithologies of the grey sandstone lithofacies.

Figure 2-21. Microphotograph of rounded pebbles of poly- and microcrystalline quartz (crossed nicols, x28 magnification).

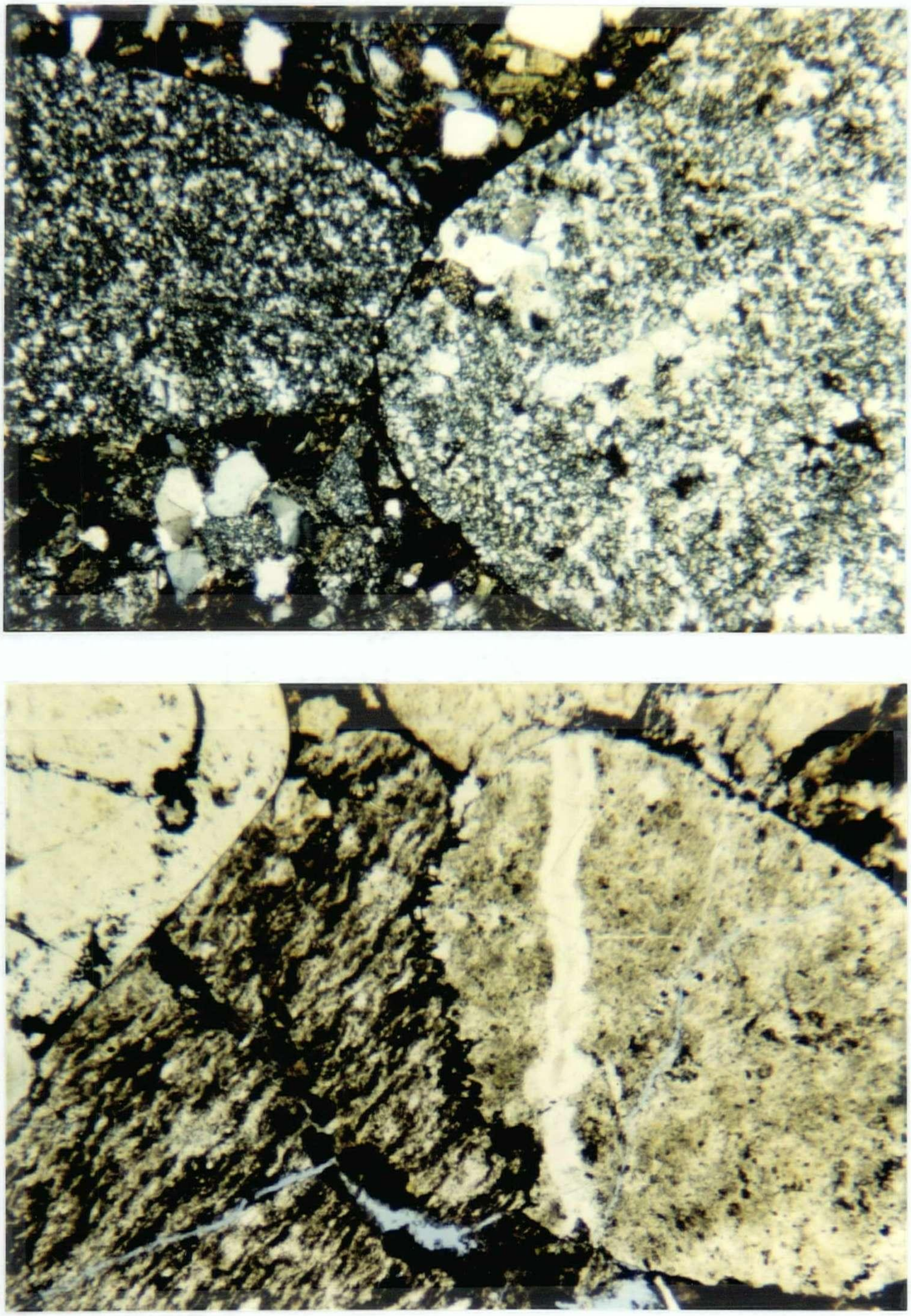


Figure 2-22. a) Pressure solution at the contact between two pebbles of microcrystalline quartz (crossed nicols, x70 magnification). b) Pressure solution at the contact between a polycrystalline quartz pebble (left) and a rock fragment. The jagged form of the contact is du to the distribution of insoluble material in the fragments (plane polarized light, x70 magnification).

2.1.3.1.4. Other lithologies

Conglomerates are present in different bedforms within the Cretaceous sandstones. Most common are irregular layers and lenses, 5 to 50 centimetres thick, of matrix supported, pebbly conglomerates. The matrix is usually a medium to coarse sandstone similar to the massive or the grey sandstone lithofacies. Clast size range from 2 to 5 centimetres and are subrounded to well rounded, only rarely are the clasts of cobble size. Clast composition is mainly volcanic with minor constituents of plutonic rocks and mud clasts.

Another common lithology is a nearly bimodal, matrix supported, well sorted, pebbly conglomerate. Clasts are mostly fine-grained or aphanitic with black and light grey colours. These conglomerates are extremely irregular with thickness varying from less than 1 centimetre to more than 10 centimetres, and they pinch out laterally over small distances (Figure 2-20). Internal sandstone layers are often present within these conglomerates. In thin sections it can be seen that many of the lighter coloured clasts are pebbles of polycrystalline and microcrystalline quartz (Figure 2-21). These quartz pebbles often shows evidence of pressure solution on contact surfaces (Figure 2-22).

Conglomerate layers with thicknesses of one to three pebbles are found as low angle crossbeds in sandstone lithologies (Figure 2-23). Some isolated pebbles and cobbles are scattered within the sandstones as well These conglomerates are mostly found intercalated with the massive sandstone lithofacies, but can also be present within the grey sandstone lithofacies.

Preservation of fossils is generally good in the Cretaceous sandstones, and includes good specimens of molluscs, particularly ammonites, bivalves, and belemnites.

Beds 2-15 centimetres thick consisting predominantly of clams are common (Figure 2-24a). Up to 45% of the total rock volume can in places be made up of clams (Figure 2-24b), with the most common being *Buchia* and *Inoceramus* (Haggart, 1989). *Inoceramus* can be preserved as large whole shells and shell fragments or as calcite prisms. These clam beds are frequently found close to the pebbly low angle crossbeds, and in some locations rounded pebbles can be found in the clam layers. These fossil rich layers are found interbedded with the massive sandstone and the grey sandstone lithofacies.

Figure 2-23. Low angle crossbeds of pebble layers in sandstone.

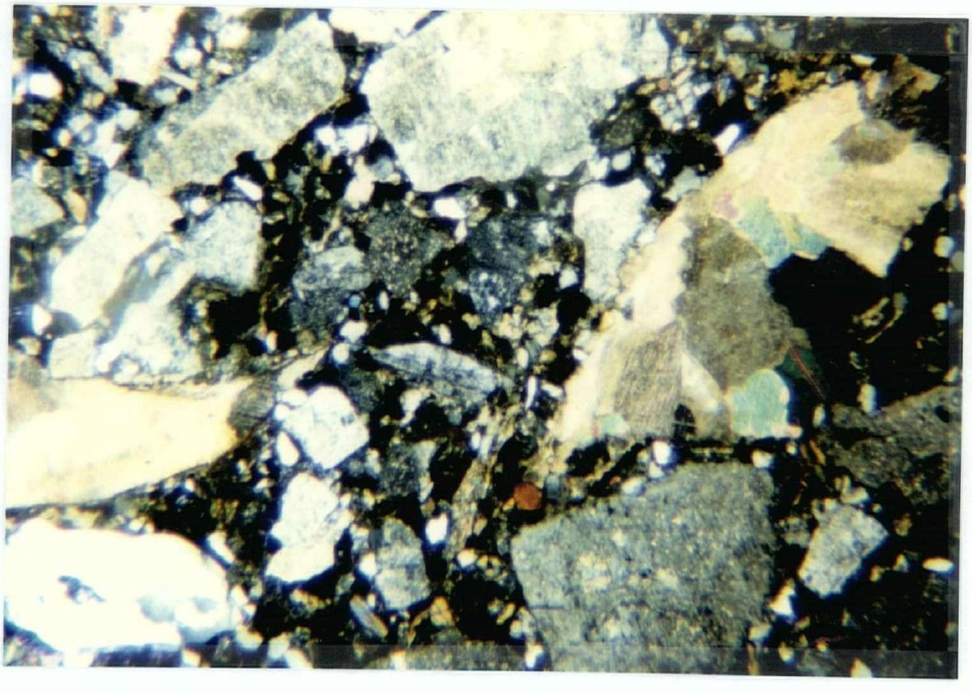


Figure 2-24. a) Sandstone with abundant shell fragments, note also the appearance of rounded pebbles. b) Microphotograph of sandstone with large broken shell fragments (crossed nicols, x28 magnification).

2.1.3.2. Cretaceous shale unit

The Cretaceous shale unit is here defined as consisting of all Cretaceous rocks that contain less than 20% sandstone and siltstone over a mappable distance (i.e. 30-40 m). Shale of this unit has traditionally mostly been assigned to the Haida Formation. The dominant lithology is a massive, friable mudstone (Figure 2-25). Colour ranges from light bluish and greenish grey to dark grey and almost black. Weathered surfaces are mostly green to brown and purplish brown. A colour combination that is often found is a purplish brown weathering surface covering a more greenish weathering with a blue grey coloured core of fresh rock. In outcrop the shale appears friable and breaks easily into small angular pieces less than one centimetre large (Figure 2-26). Small intervals of thin layers of siltstones are present and give indications of bedding orientations. In a few areas the bedding orientation is also outlined by bedding parallel foliation. In some deformed areas the luster can be very shiny and almost greasy looking, and when thermally metamorphosed by intrusions it becomes darker and harder (Figure 2-27).

Figure 2-25. Typical outcrop appearance of the Cretaceous shale unit. Some silty layers outlines the bedding in the left part of the photo.

Figure 2-26. The Cretaceous shale unit is very friable and breaks into small angular pieces.

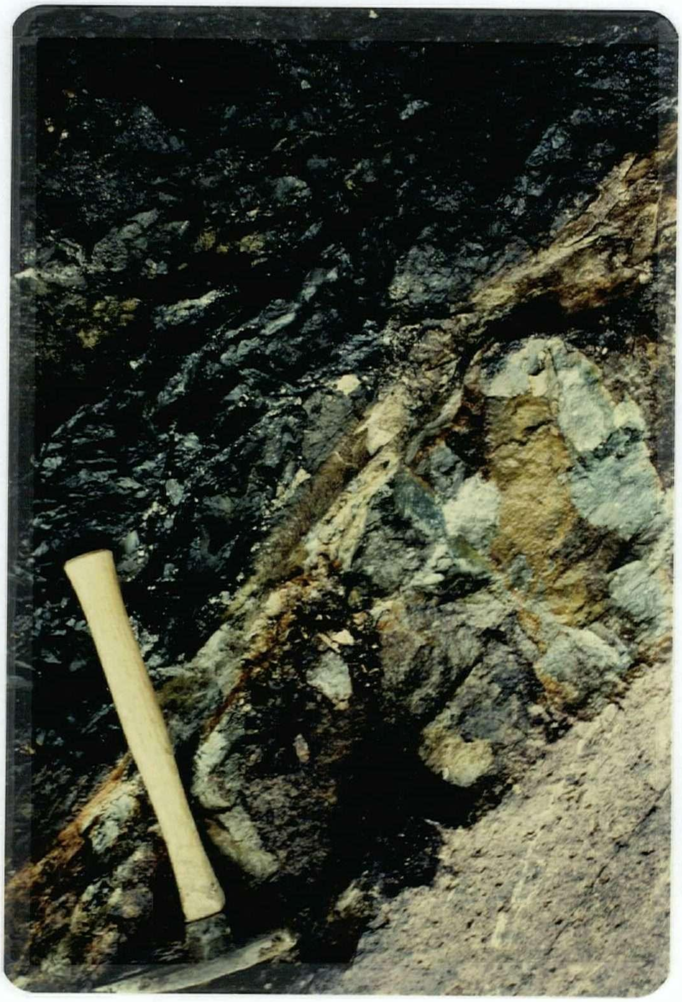


Figure 2-27. Typical dark shiny (greasy) luster of thermally metamorphosed Cretaceous shale next to an intrusion (left in picture).

Figure 2-28. Gentle folding in a sequence of sandstone rich Cretaceous shale unit. Photo is taken facing southeast.

Spherical and elliptical light grey coloured calcareous concretions in sizes from 1 cm to over 60 cm, averaging 3 to 6 cm are fairly common. Smaller black calcareous concretions are present in a few places together with larger light grey ones. Lenses and spheres of a very soft, dark reddish brown, fine-grained weathering product are found at several places. It is not clear as to the origin of these weathering phenomena.

The amount of coarser grained material of siltstone and sandstone varies within the shale facies. These intervals are up to 30 m thick and too thin to be separate map units. Sandstone layers are generally from 1 to 50 cm thick, and can locally make up about 30-35 % of the rock volume (Figure 2-28). The sandstone has a more bluish colour than the shale, and load and flame structures are sometimes present at the sandstone-shale interface.

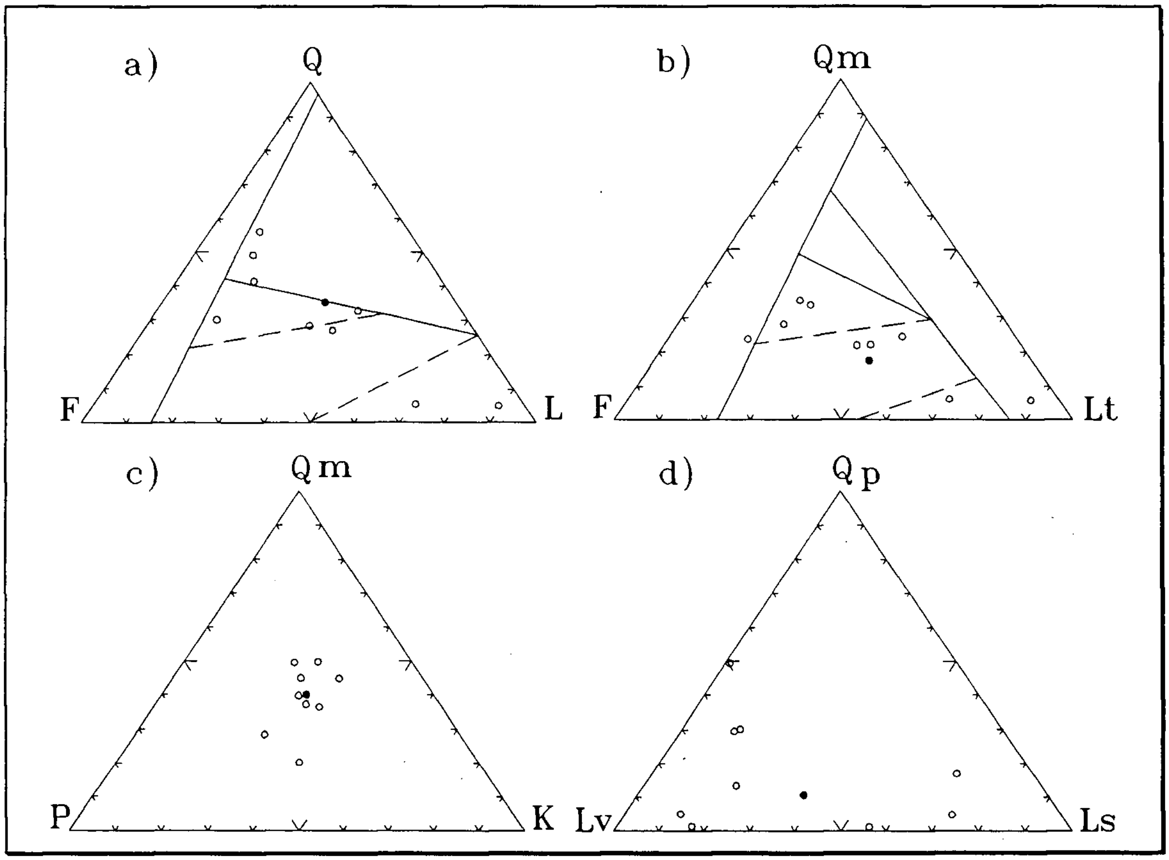


Figure 2-29. Ternary diagrams showing the relative abundance of a variety of different fragments in thin sections of sandstones of the Cretaceous shale unit. a) QFL-diagram, b) QmFLt-diagram, c) QmPK-diagram, and d) QpLvLs-diagram (from Dickinson, 1982; Dickinson et al., 1982).

Microscopy

Thin sections were cut from sandstone layers within the Cretaceous shale unit in order to compare these sandstones with sandstones of the other Cretaceous units and to find possible source rock types for these sandstones . The most numerous fragments present in a thin section of these sandstones are quartz, feldspar, and rock fragments, with the average ratio being 30:30:40 (Figure 2-29a). All samples are texturally immature with subangular to angular quartz and feldspars (Figure 2-30). Quartz is present in amounts of 20 to 35 % of total framework grains and is dominated by monocrystalline quartz which generally outnumbers polycrystalline quartz more than 4:1. Chert is present in ratios of 5 to 20 % of total framework material. The feldspar portion of the framework is equally divided between plagioclase and potassium feldspar. Figure 2-29c (a QmPK-plot) shows that the average quartz:plagioclase:potassium feldspar ratio for this formation is 40:30:30. Generally more volcanic rock fragments than sedimentary rock fragments is present, this can be seen from the QpLvLs-plot in figure 2-29d. However, some samples are richer in sedimentary fragments, and this relative increase in input from sedimentary rocks is probably both a result of changes in the source area and an increased amount of intraformational mud clasts. Grains that are represented in minor amounts in thin sections of this unit include biotite, carbonate, amphibole and organic material. Samples of the Cretaceous shale unit show a wide spread on the QFL-plot (Figure 2-29a). The average for all the samples falls in the area for dissected arc provenance. Different samples spread across the diagram from undissected to dissected arc, with a few samples located in the area for recycled orogen provenance. In the QmFLt-plot (Figure 2-29b) the average sample falls in the area of transitional arc, with the samples plotting in the fields of undissected to dissected arc, and one sample each in the fields for recycled orogen and continental block. The wide spread of the data for this unit makes the average sample plot somewhat ambiguous, and more thin section work needs to be done on the sandstones of the Cretaceous shale unit. The ternary plots of the sandstone layers of the Cretaceous shale unit indicates that there is a close petrographic similarity between this unit and the three sandstone lithofacies of the Cretaceous sandstone unit.

Scanning electron microscopy examination on sandstone layers of this unit showed that chlorite clay is plentiful in the matrix. Figure 2-31 shows chlorite filling pore space between the quartz, potassium feldspar, plagioclase, and a rock fragment which dominate these sandstones. Figure 2-32 shows grains that have altered to chlorite, and then subsequently developed an iron-oxide (hematite) coating. In addition to the abundant chlorite, microcrystalline quartz is also present as a pore filling mineral (Figure

2-33). It is not possible to tell for certain if they are chert, but chert is present in thin sections of this lithofacies.

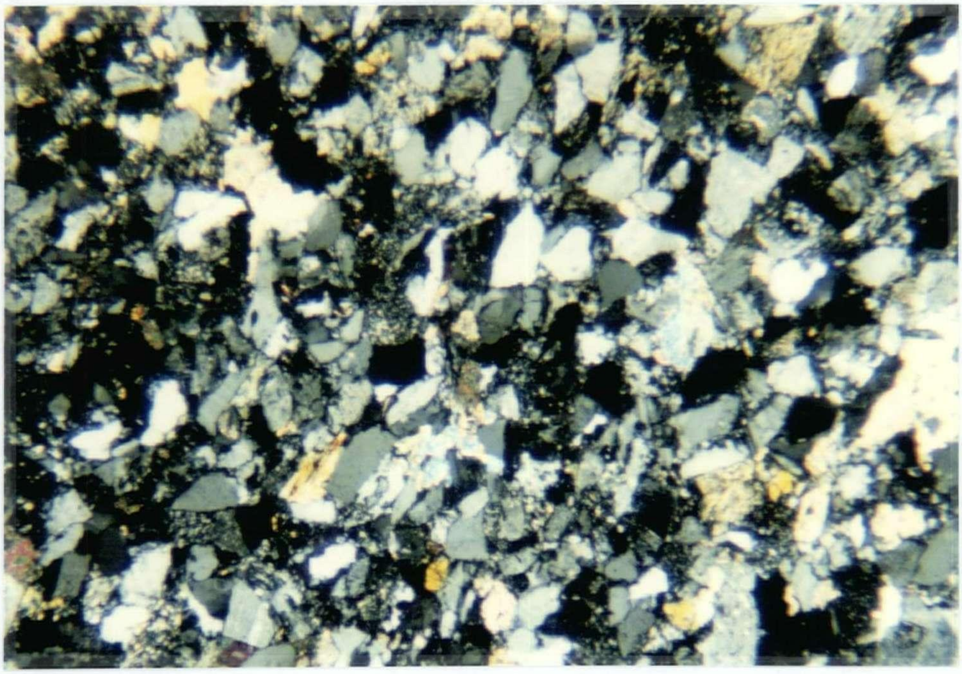


Figure 2-30. Thin section photomicrograph of texturally immature sandstone of the Cretaceous shale unit with angular quartz and feldspar (crossed nicols, x70 magnification).

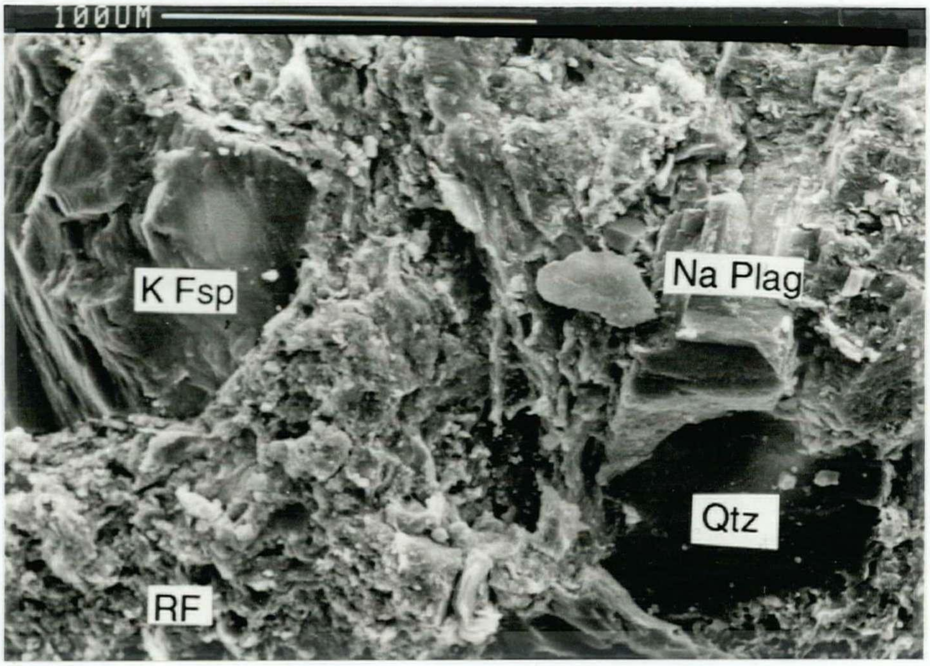
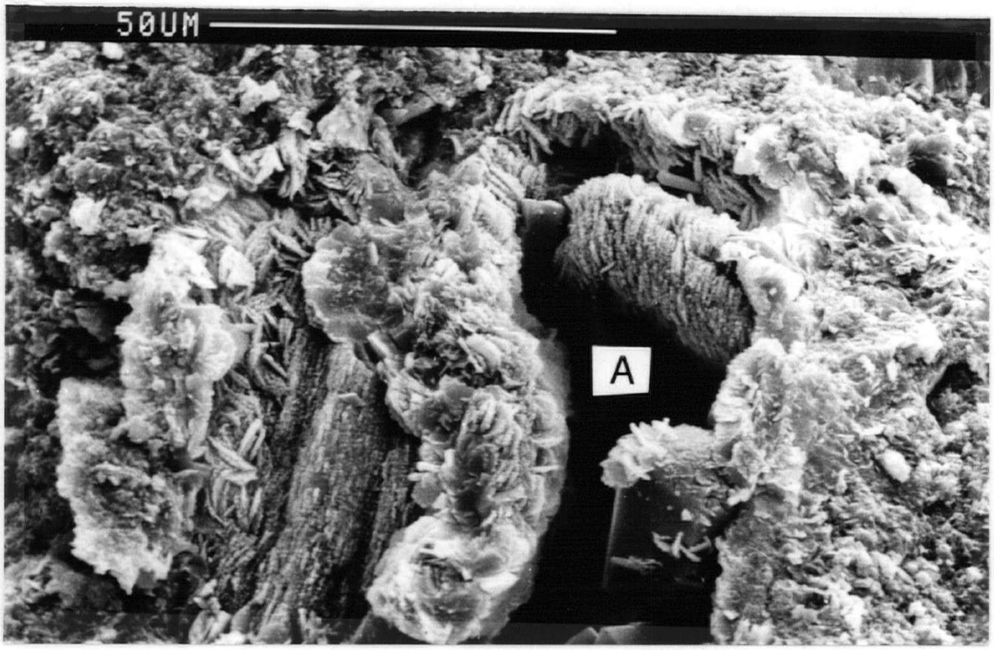


Figure 2-31. The clay between the plagioclase (Na Plag), potassium feldspar (K Fsp), quartz (Qtz), and rock fragment (RF) in this SEM photomicrograph is chlorite (center of photo).



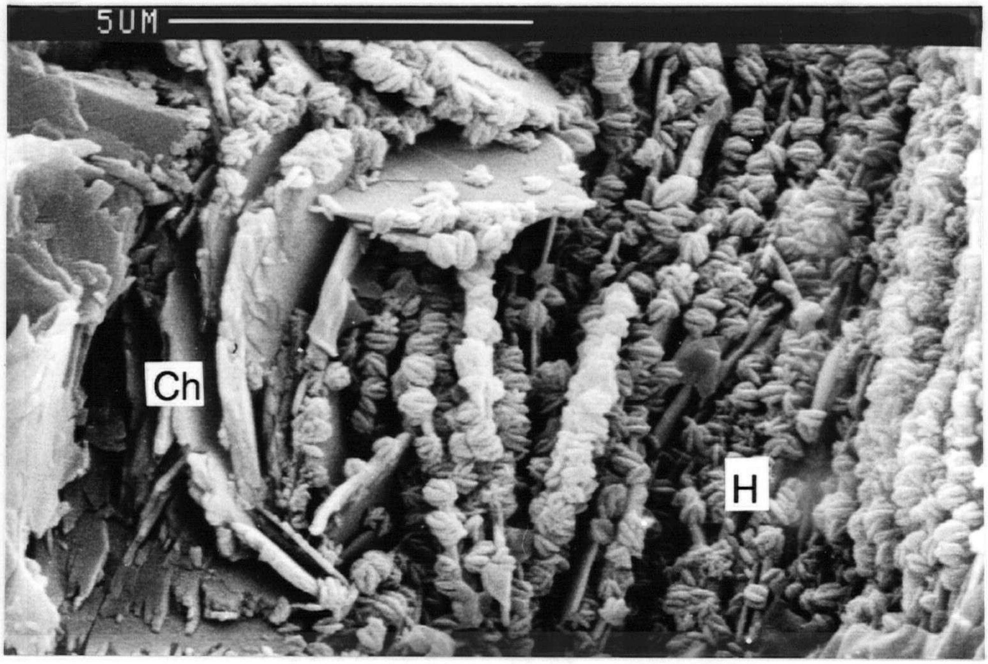


Figure 2-32. a) The chlorite in this SEM photomicrograph has developed a coating of hematite. The mineral in the cavity is apatite (A). b) A close up of the hematite (H) coating on chlorite (Ch).

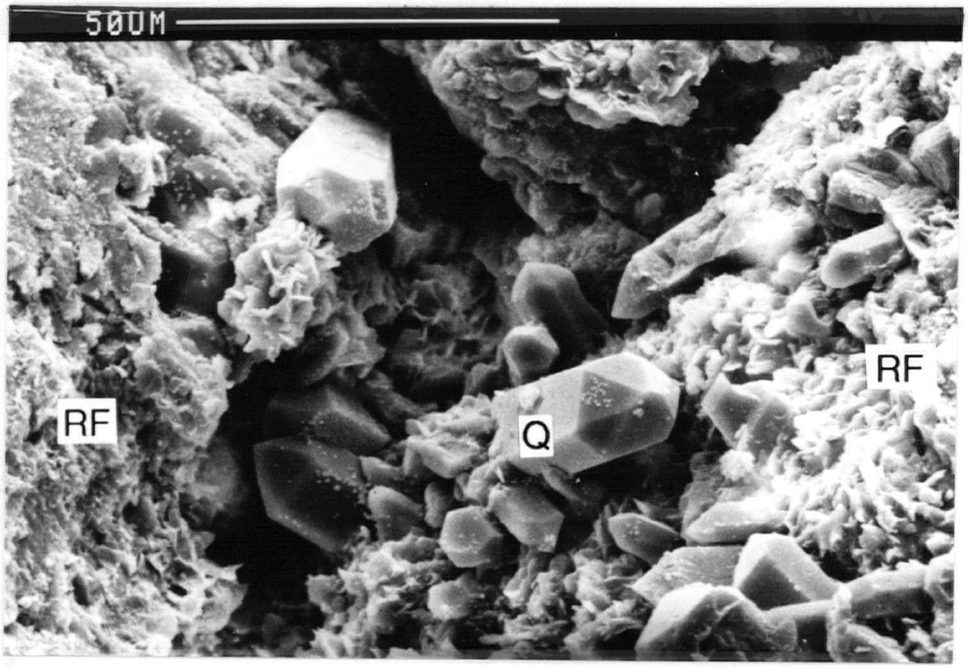


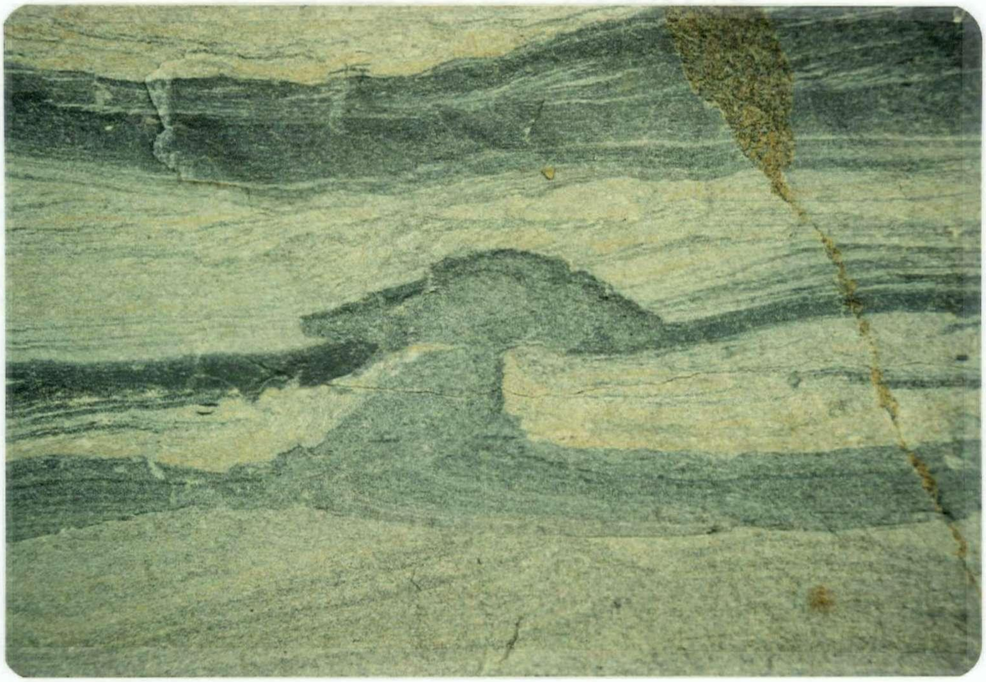
Figure 2-33. SEM photomicrograph of pore filling microcrystalline quartz (Q) in the sandstones of the Cretaceous shale unit (RF=rock fragment).

Figure 2-34. Interbedded shale, siltstone, and sandstone of the Skidegate Formation.

2.1.3.3. Skidegate Formation

The Skidegate Formation consists of thinly- to medium-bedded turbiditic shale, siltstone, and fine- to medium-grained sandstone (Figures 2-34 and 4-3). Shale and siltstone to sandstone ratio is generally about 50:50, but the sandstone content can be as high as 70%. Everything with a shale and siltstone content of 90% and higher is considered as belonging to the Cretaceous shale unit. The rock is often well indurated and does not split easily along bedding contacts. This can often be used as a way of distinguishing this formation from the Lower Jurassic Sandilands Formation, which also consists of bedded turbidites. The contact between the sandstone and the finer layers is often deformed by well developed sedimentary structures. Flame structures, load casts, sand dykes, sandballs, and convoluted bedding are particularly well developed in this formation and are a good indicator of the Skidegate Formation (Figure 2-35). None of the other formations in the Queen Charlotte Islands has as well developed and widely spread liquefaction and injection structures as the Skidegate Formation. Locally both upward coarsening and fining sequences has been observed. Evidences for slumping are found in several areas (Figure 2-36).

The sandstone layers are light bluish grey to grey and mostly less than 4 cm thick. Sandstone layers up to 1 metre thick have been observed, but are rare. Internal layering is common, as is grading and cross- and parallel-lamination. These sandstone parts are the massive or graded, the parallel laminated, and the convoluted parts of a Bouma turbidite sequence (Bouma, 1962). The shale and siltstone layers are darker coloured than the sandstone. Most of them are almost black, but they also appear in greenish and bluish colours. Sequences of thicker (20-40 cm) layers of dark shale and siltstone with thin (less than 0.5 cm) sandstone stringers are present within the more normal sequences of nicely interlayered shale siltstone and sandstone.



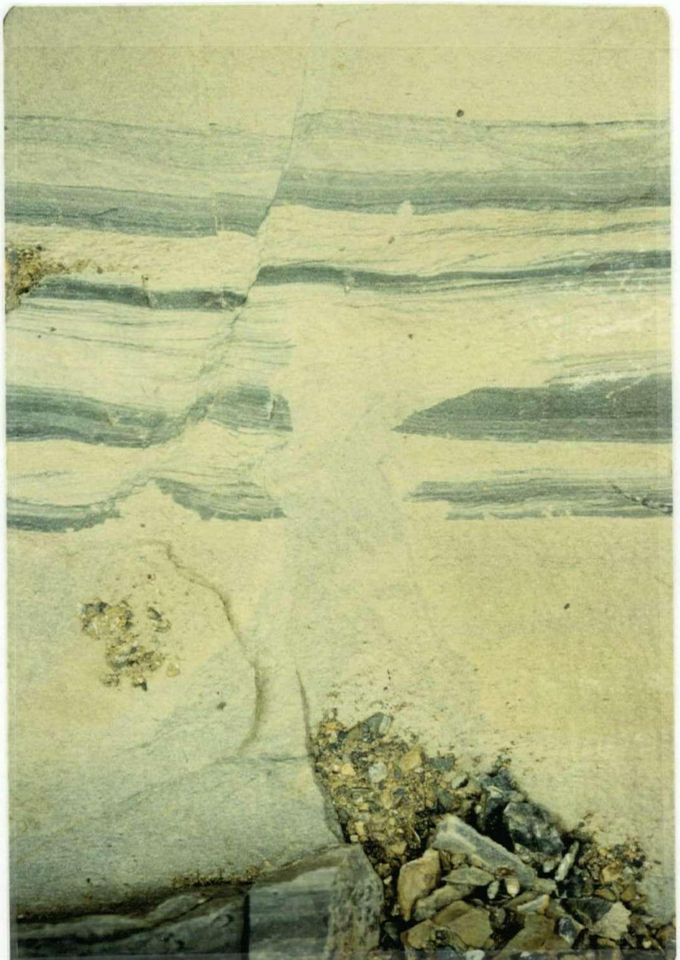


Figure 2-35. a) Injection structures like sand volcanoes or diapirs are frequent in the Skidegate Formation. b) A vertical sandstone dyke intruding several overlying layers in the Skidegate Formation. Both photos are about 15 cm across.

Figure 2-35 c) Convoluted bedding in the Skidegate Formations, photo is about 30 cm across.

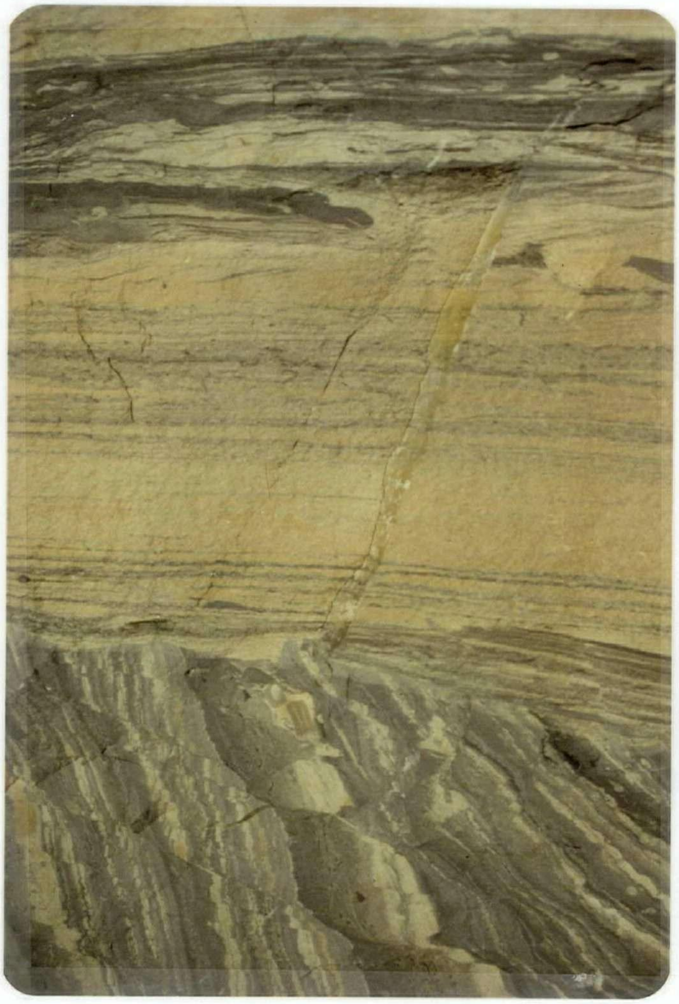


Figure 2-36. Slump structure in turbidites of the Skidegate Formation. Photo is about 50 cm across.

Microscopy

Only two thin sections were prepared from sandstone layers of the Skidegate Formation, and this low number makes any conclusions from the data uncertain since the samples might not be representative of the whole formation. The two samples plot fairly close to each other on most of the ternary plots (Figure 2-37) and a brief discussion of the plots will be presented. The average quartz:feldspar:rock fragment ratio of this formation is 30:40:30, with the total quartz ratio never exceeding 30 % of the total rock. Chert is present in amounts up to 10 % of the framework, and monocrystalline quartz grains are more plentiful than polycrystalline. The QmPK-plot in figure 2-37c shows that in the two thin sections investigated there is more potassium feldspar than plagioclase. From the QpLvLs-plot (Figure 2-37d) it can be seen that the amounts of polycrystalline quartz is constant, while the amount of sedimentary and volcanic rock fragment varies between the two samples.

The QFL-plot in figure 2-37a indicates that the source for the sandstone layers of the Skidegate Formation is a dissected to transitional arc. A dissected to transitional arc source is also indicated in the QmFLt-plot (Figure 2-37b).

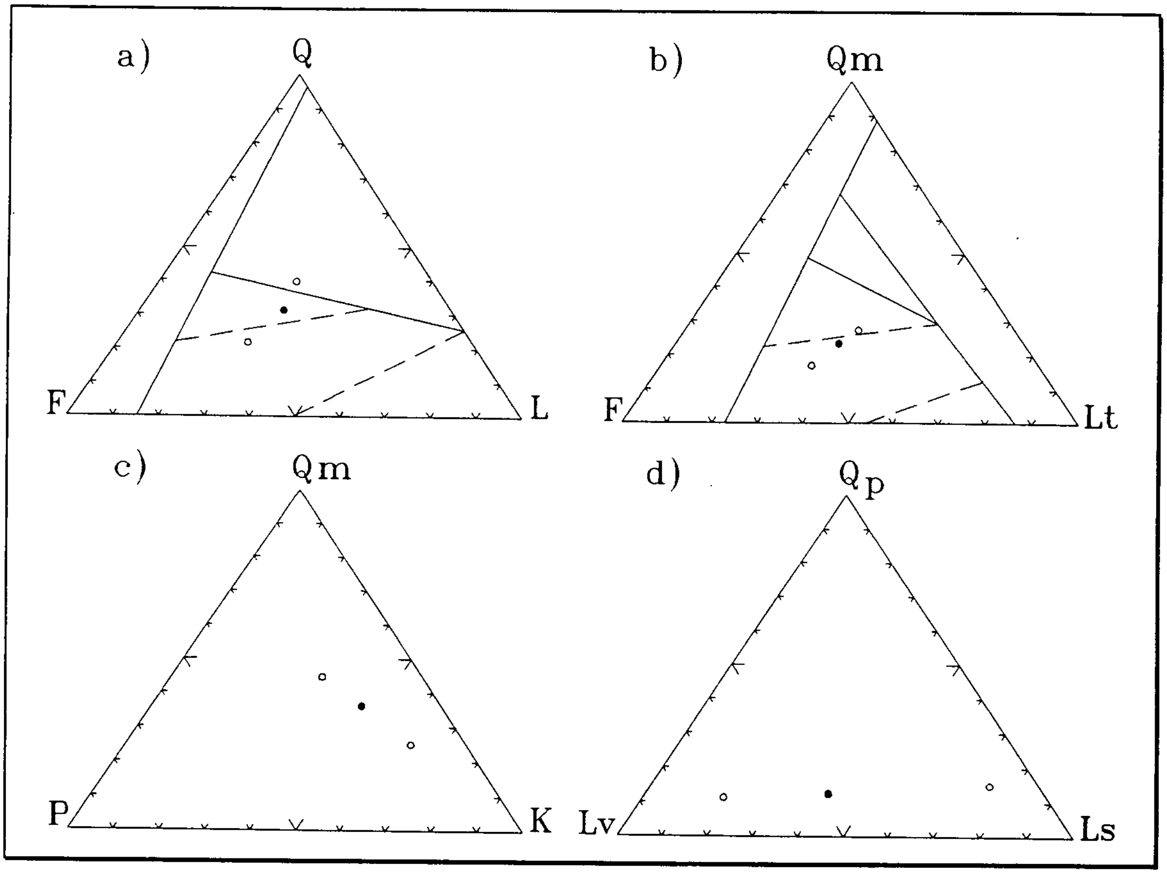


Figure 2-37. Ternary diagrams showing the relative abundance of a variety of different fragments in thin sections of sandstones of the Skidegate Formation. a) QFL-diagram, b) QmFLt-diagram, c) QmPK-diagram, and d) QpLvLs-diagram (from Dickinson, 1982; Dickinson et al., 1982).

2.1.3.4. Honna Formation

The dominant lithology of the Honna Formation is a pebble to cobble conglomerate. Minor sandstones are also present, and interbedded turbiditic shale, siltstone, and sandstone are present in small quantities. It is practical to divide the formation into two lithofacies, one dominated by conglomerate and one consisting mainly of sandstone.

2.1.3.4.1. Conglomerate lithofacies

The conglomerate facies of the Honna Formation is found in beds less than 1 m thick to massive units more than 20 m thick. These units are both matrix and framework supported, with a matrix of fine- to coarse-grained sandstone. Bedding can often be difficult to detect in the conglomerates, the best indications of beddings are sandstone layers and lenses, but in most localities sandstone is not present. In large quarries bedding can be found either defined by sandstone layers and lenses, or shown poorly on a large scale in the conglomerate. In most natural and smaller outcrops in the area it is impossible to find bedding orientation.

The clasts in the conglomerate are mostly made up of sub-rounded to well-rounded volcanic, plutonic and sedimentary clasts and more angular mud clasts; some quartzite clasts occur as well. The amount of clasts range from less than 20% to more than 80% of the total rock volume. Volcanic clasts are light green to dark green and are probably derived primarily from the Middle Jurassic Yakoun Group. Many of the volcaniclastic sedimentary clasts are probably also derived from this unit. Plutonic clast material includes input from diorite, granite, syenite, and rhyolite suites and most of these have recognized sources on the islands. Some clasts, however, do not seem to have suitable protoliths on the islands. Suggestions have been made that these clasts might have their source in the Coast Mountains on the mainland (Yagishita, 1985b; Higgs, 1988). Gamba et al. (1990) proposed a more local source, possibly from a plutonic complex now submerged in Hecate Strait. Clasts derived from rocks of sedimentary origin include limestone, mudstone, interlayered turbiditic facies, and sandstone. Limestone clasts are rare compared to the other sedimentary clasts and are derived from the calcareous parts of the Upper Triassic to Lower Jurassic Kunga Group. Angular mud clasts are very frequent near the base of the conglomerate, and are often rip-up clasts from underlying shale or turbidite facies (Figure 2-38 and 2-39). Clasts of interlayered shale, siltstone, and sandstone are angular to sub rounded with poorly developed sphericity. These clasts are either from the Lower Jurassic Sandilands Formation or the Skidegate Formation; it is impossible to tell which of the two formations a particular clast is from. Both formations are probably present in the clast material.

Figure 2-38. Large angular clasts of turbidites in the conglomerate facies of the Honna Formation.

Figure 2-39. Matrix supported conglomerate and sandstone of the Honna Formation. Note the angular mud clasts in the conglomerate.

Clast size varies from 1-2 cm up to 25-30 cm, averaging 3-4 cm. The conglomerate is well sorted within individual layers. Pebble imbrication is generally moderately to well developed and several studies have been done on paleocurrent directions (Yagishita, 1985a; Gamba et al. 1990; Higgs 1991a).

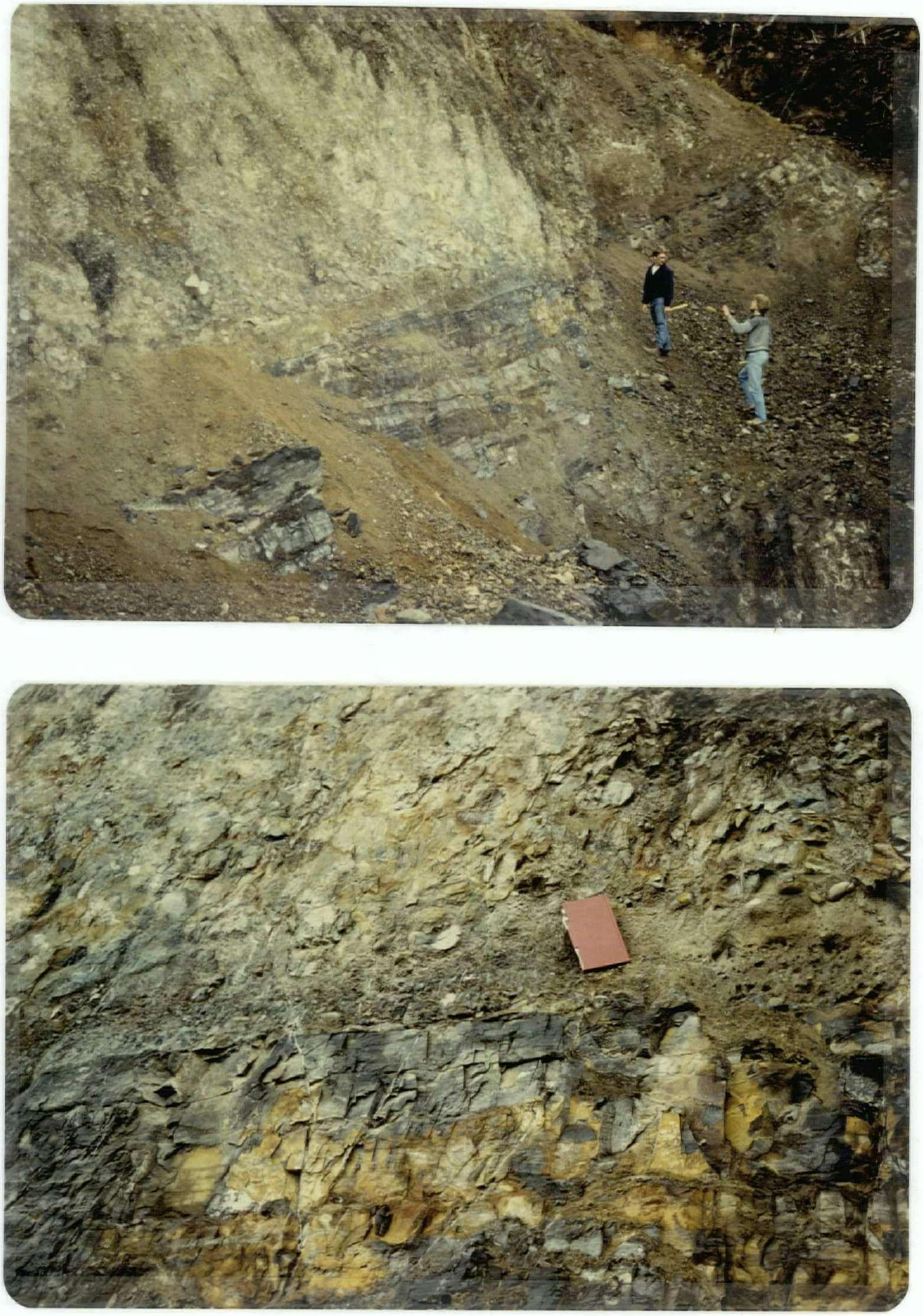


Figure 2-40. a) Conformable contact with conglomerate of the Honna Formation overlying the Skidegate Formation. b) Close up of the contact, note the difference in clast size between the lower 20 cm of the conglomerate and the higher sections.

The nature of the contact between the Honna Formation and underlying formations varies in central Graham Island. The basal part of the formation has been observed at several places. In the Ghost Creek area in northwestern part of the map, the Honna Formation lies conformably on the Skidegate Formation; no scouring into the underlying formation was visible. In the southern part of the mapped area, west of Honna River, the Honna Formation sits conformably on top of turbidites of the Skidegate Formation. Here the contact is also very abrupt with no scouring (Figure 2-40). The lowermost 20 cm of the Honna Formation immediately above the contact consists of a finer conglomerate with clasts less than 2 cm; above this the conglomerate is more like the typical conglomerate lithofacies with larger clasts. At another locality in this area the Honna Formation overlies the Skidegate Formation with a low angle unconformity. South of Yakoun Lake the Honna and Skidegate formations are interfingered. Conglomerate of the Honna Formation is overlain by turbidites of the Skidegate Formation. Good control exists on "way up" criteria and the section is not overturned. Farther south the turbidites are overlain by the Cretaceous shale unit. Parts of this shale have been dated as Santonian age (Haggart and Higgs, 1989).

Microscopy

Several thin sections were prepared from conglomerates of the Honna Formation, for the purpose of comparing the sandstone matrix of the unit to other Cretaceous sandstones. Observations reported in the following are all taken from studies of the matrix of the conglomerate and only include fragments of sand particle size and less. The average quartz:feldspar:rock fragment ratio for this unit is 25:30:45 (Figure 2-41a). Chert is relatively sparse in this unit, and the lack of or low amount of chert can be used as an indicator for rocks of the Honna Formation. The amount of monocrystalline and polycrystalline quartz is fairly even, with slightly more of the monocrystalline variety.

In individual samples the polycrystalline quartz outnumbers the other with a ratio up to 4:1; this is not observed in any of the other Cretaceous units (Figure 2-42). From figure 2-41c it can be seen that plagioclase and potassium feldspar is present in almost equal amounts in all samples, and no large variations are observed. The QpLvLs-plot in figure 2-41d shows that in the matrix of the conglomerates, volcanic rock fragments outnumber substantially the sedimentary fragments, no sample has more sedimentary than volcanic rock fragments.

The QFL-plot in figure 2-41a shows that all but one sample are concentrated in the lower right corner of the diagram. Samples of this unit plot in the area for transitional arc, with some on the boundary towards recycled orogen. In figure 2-41b all samples, but one, plot in an area close to the lower axis. The sample of this unit falls in the area of transitional arc. Average for the matrix of the conglomerate facies of the Honna Formation falls well within the field for a transitional arc providence.

Scanning electron microscopy studies of the conglomerate facies of the Honna Formation show that the primary clay in this unit is well crystallized chlorite, some microcrystalline quartz was also detected. Figure 2-43a shows a cluster of chlorite filling voids in a Na-plagioclase; an EDS spectrum of this chlorite is shown in figure 2-43b. Figure 2-44 shows the contact between a plagioclase and a rock fragment, and it can be seen that chlorite is present in large quantities both as filling between the grains and within the rock fragment. Rock fragments rich in chlorite, such as the one in figure 2-44, are probably derived either from the Middle Jurassic Yakoun Group or the Cretaceous sandstone unit. Microcrystalline quartz is also found as pore filling mineral, this can be seen in figure 2-45 where quartz is mixed with chlorite.

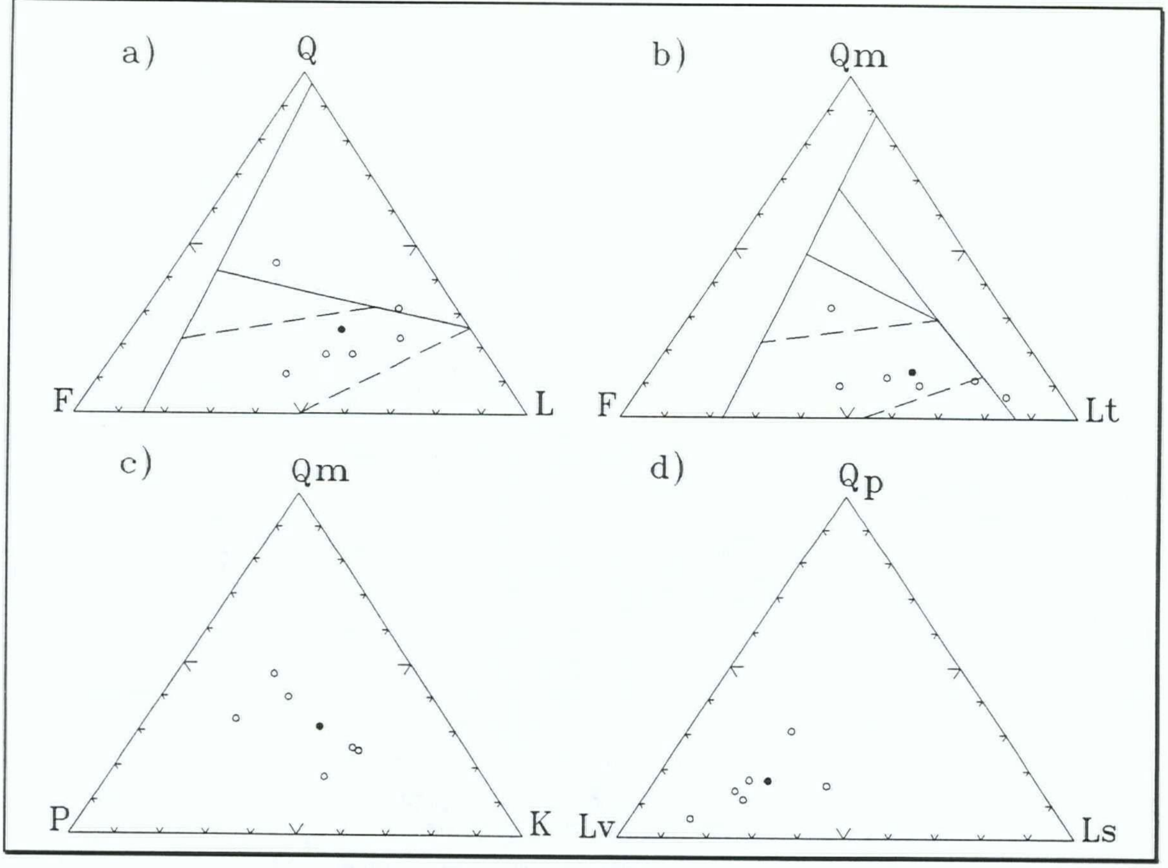


Figure 2-41. Ternary diagrams showing the relative abundance of a variety of different fragments in thin sections of matrix of the Honna Formation. a) QFL-diagram, b) QmFLt-diagram, c) QmPK-diagram, and d) QpLvLs-diagram (from Dickinson, 1982; Dickinson et al., 1982).

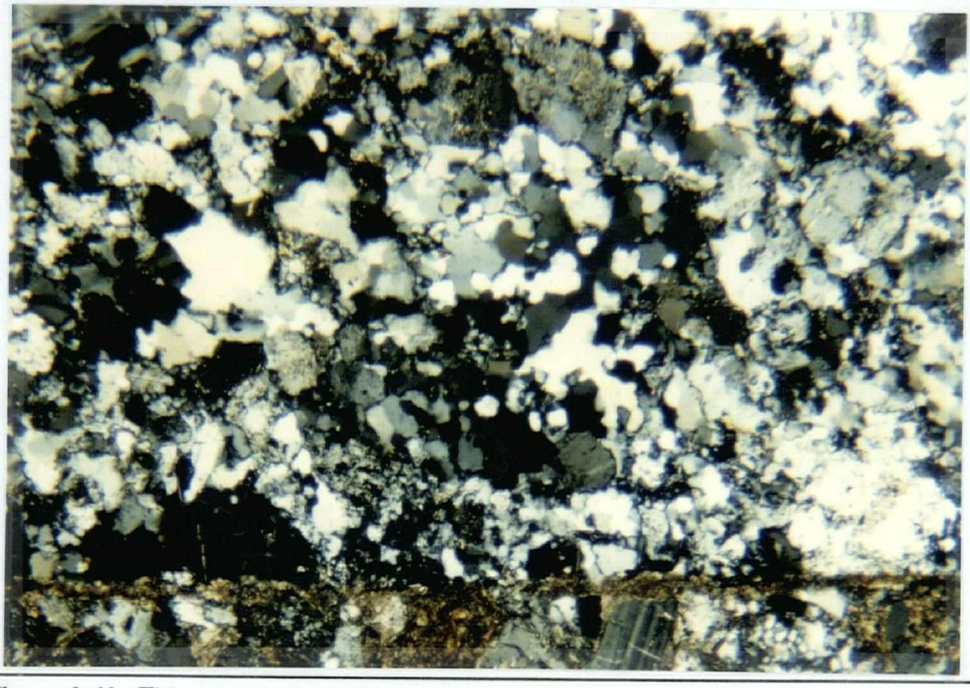
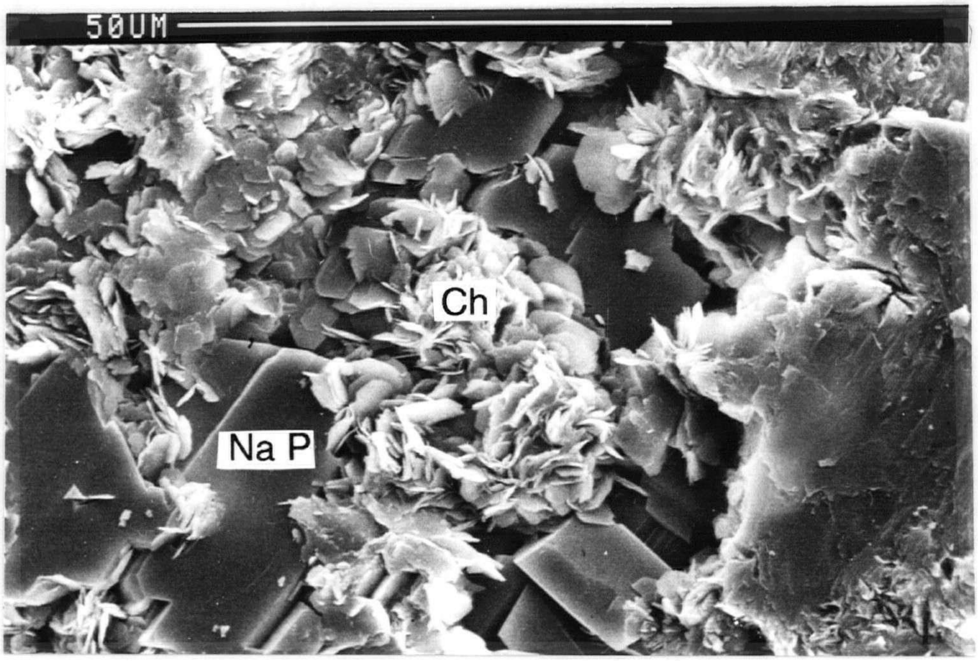


Figure 2-42. Thin section photomicrograph of some of the polycrystalline quartz grain in the matrix of the Honna conglomerates (crossed nicols, x70 magnification).



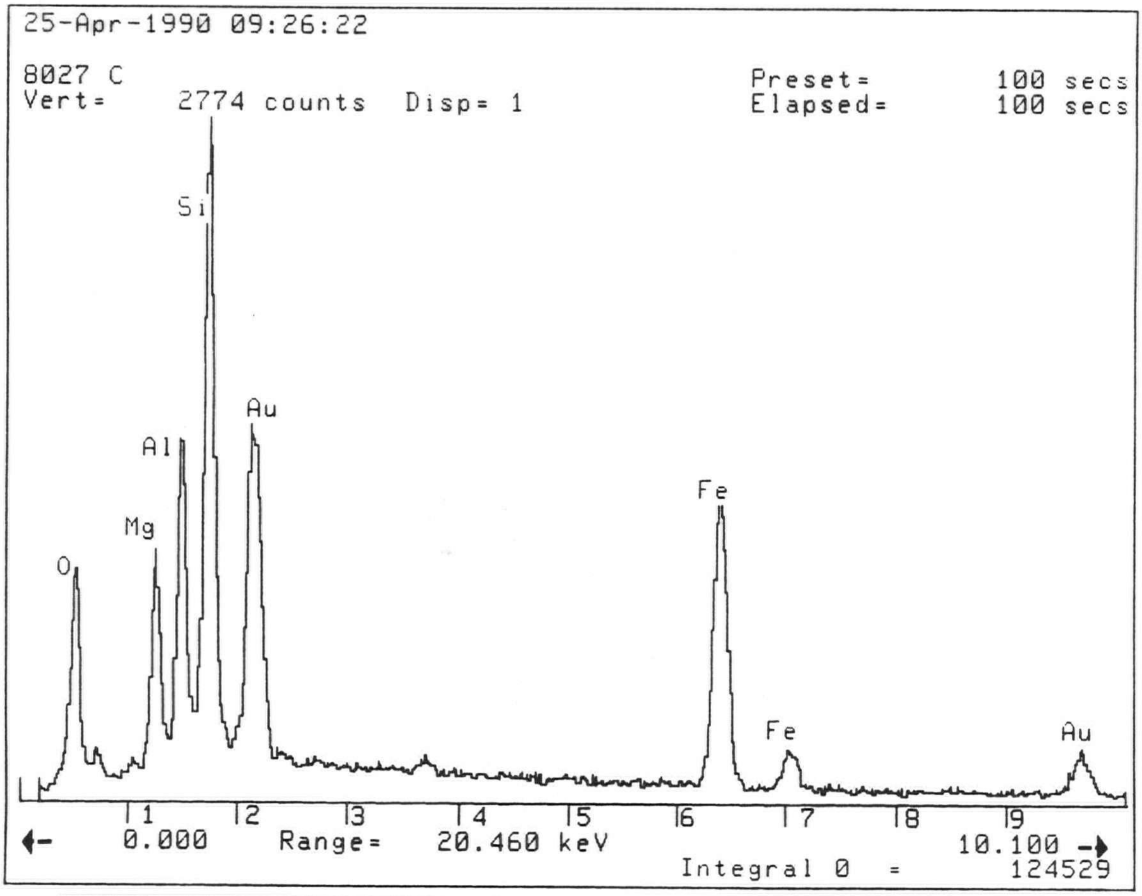


Figure 2-43. SEM-photomicrograph showing a cluster of chlorite (Ch) filling in the voids of a Na-plagioclase (Na P). b) EDS-analysis of the chlorite cluster in (a).

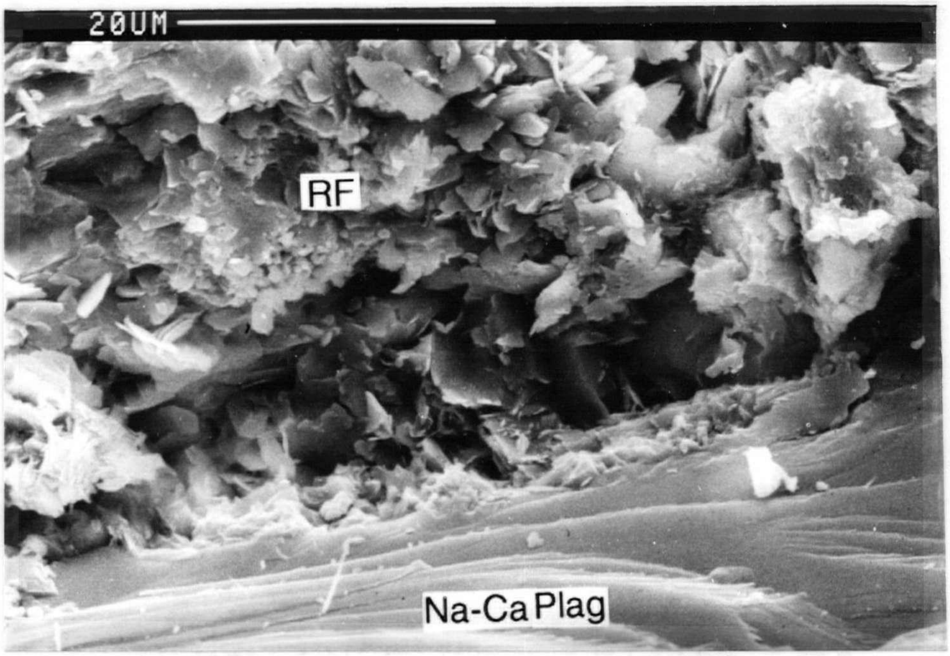


Figure 2-44. SEM-photomicrograph of rock fragment and plagioclase . Both the matrix between the two fragments and the rock fragment are rich in chlorite.

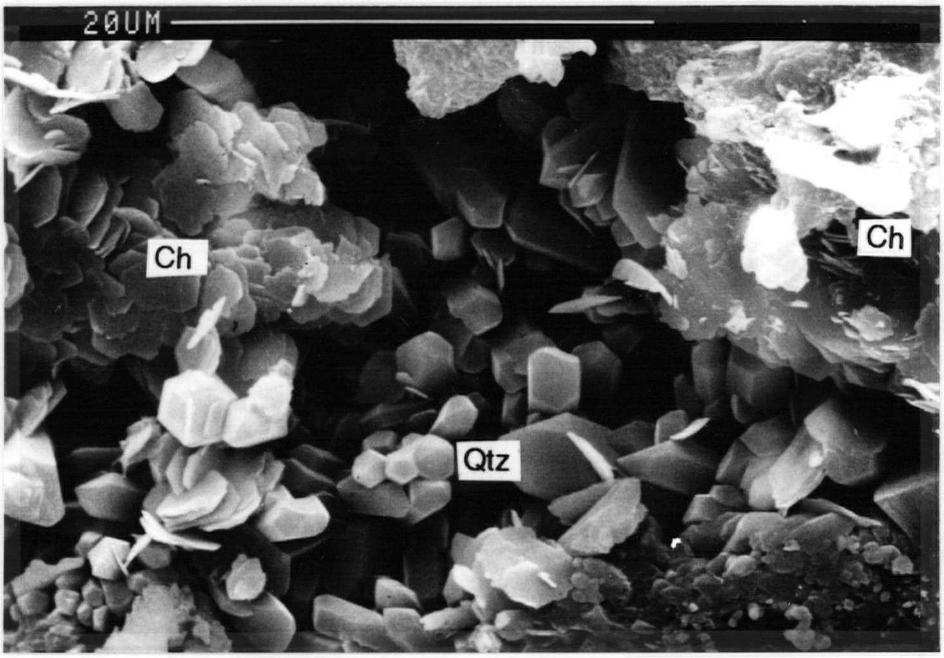


Figure 2-45. SEM-photomicrograph of the matrix of the Honna Formation conglomerate shows both chlorite (Ch) and microcrystalline quartz (Qtz) as pore filling material.

2.1.3.4.2. Sandstone lithofacies

Sandstone is found locally within conglomerates as layers and lenses less than a few metres thick and as a lithofacies that is totally dominated by sandstone. Sandstone layers and lenses within the conglomerate lithofacies are massive or parallel laminated and vary in thickness from 10 cm to 2 m (Figure 2-46). They appear as separate layers or as packages of several sandstone layers. The sandstone is rich in feldspar and the colour of fresh surfaces is generally more bluish than the sandstones of the other Cretaceous units. Pebbly layers are present within the sandstones as isolated layers or as stringers from thicker conglomerate bodies. The petrology of the sandstone is much the same as the matrix of the conglomerate.

The sandstone lithofacies of the Honna Formation is characterized by a very indurated, bluish grey to light grey, medium- to coarse-grained sandstone. Weathering is brownish, but can also occur with a greenish colour. The sandstone layers are usually massive with no internal layering, and it can often be very difficult to see any trace of bedding. Primary structures are sparse, although some sandstones show parallel- and cross-lamination. The sandstone is distinguished from other Mesozoic sandstones in the area by its hardness and its lighter colour probably due to less input from volcanic sources. Biotite is more frequent in these sandstones than any of the others in the mapped area (Figure 2-47). Large angular "rip-up" mud clasts are present in the sandstones that are near contacts with shale and turbidites. In places these clasts are over 20 cm long and are the only fragments larger than sand-grain size.

At the eastern shore of Yakoun Lake are several outcrops of a light coloured, massive, coarse sandstone (Figure 2-48). This sandstone is the most mature of any Cretaceous sandstones in the central Graham Island area. It consists almost entirely of rounded quartz and feldspar grains. Large, well rounded quartz pebbles, up to 15 cm across, are found scattered around in the sandstone. The matrix of the sandstone is very calcareous (Figure 2-49), and where the rock is extra rich in carbonate it appears as concretions (Figure 2-48). A few thin, discontinuous mudstone lamina were concentrated in a 1 metre thick zone. No fossils were found in the sandstone, but base on its textural and mineralogical maturity and location it was assigned to the Honna Formation. The sandstones of the Honna Formation is the only sandstone in the area that somewhat resembles the unit found along Yakoun Lake.

Sequences of interlayered turbiditic shale, siltstone, and sandstone are found a few places (Figure 2-50). These sequences are from 15-20 cm to 3-4 m thick and their appearance is like that of the turbidites of the Skidegate Formation. This close similarity to the Skidegate Formation is expected since these formations are observed to interfinger (Indrelid, 1990).

Figure 2-46. Interbedded conglomerate and sandstone of the Honna Formation.

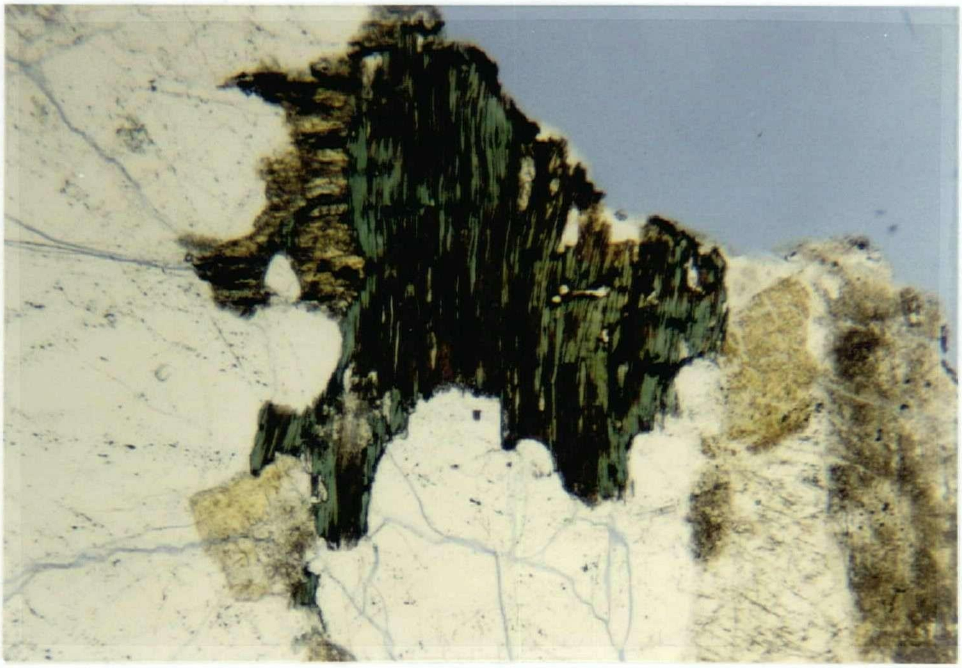


Figure 2-47. Thin section photomicrograph of a biotite in the Honna Formation (plane polarized light, x70 magnification).

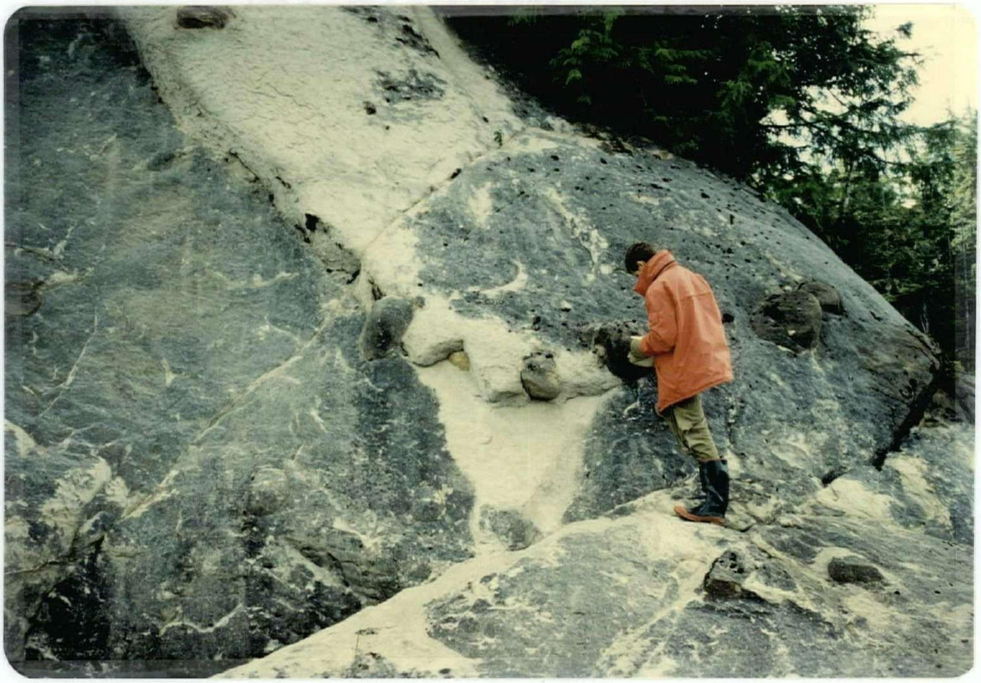


Figure 2-48. This light coloured sandstone was found on the shores of Yakoun Lake. The brownish coloured spheres are parts of the sandstone richer in calcite.

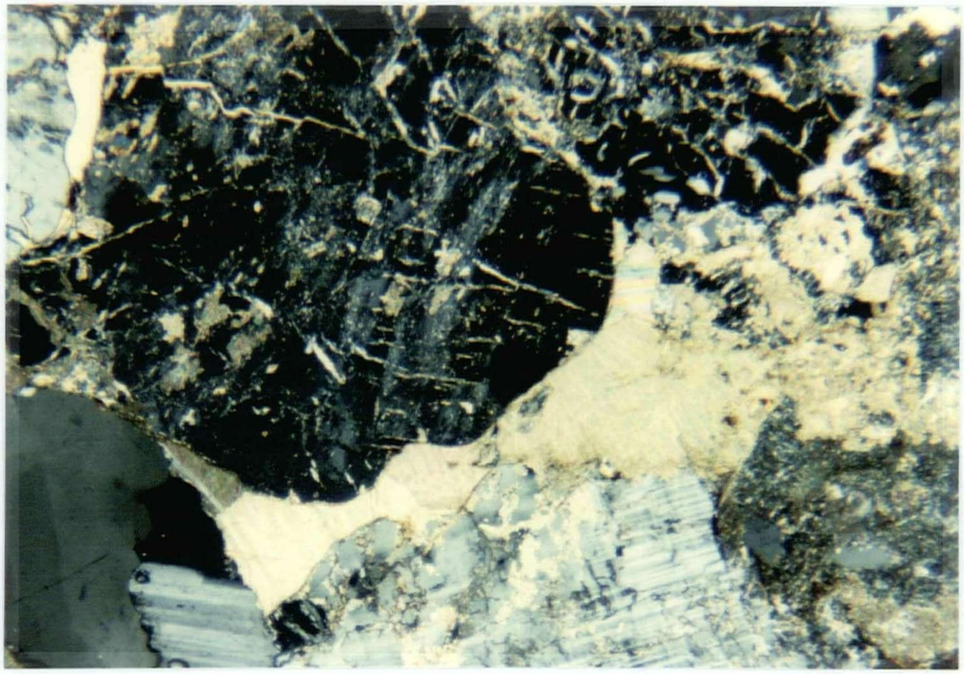


Figure 2-49. Thin section photomicrograph of the light coloured sandstone in figure 2-48 Note the sphericity of the grains and the calcite infilling (crossed nicols, x70 magnification).

Figure 2-50. Outcrop photo of Honna Formation conglomerate interbedded with (right hand part of photo) and overlain by (to the right of the truck) turbidites.

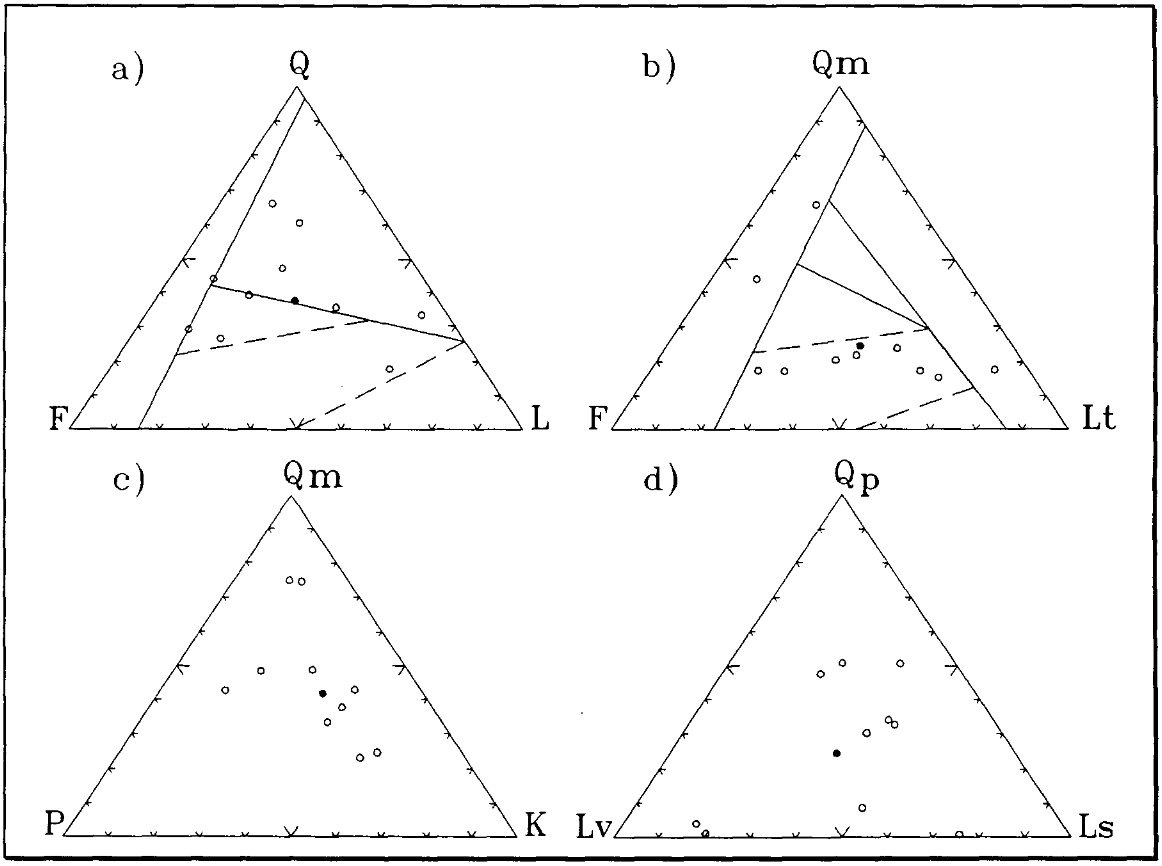


Figure 2-51. Ternary diagrams showing the relative abundance of a variety of different fragments in thin sections of the Honna Formation sandstone lithofacies. a) QFL-diagram, b) QmFLt-diagram, c) QmPK-diagram, and d) QpLvLs-diagram (from Dickinson, 1982; Dickinson et al., 1982).

Microscopy

As for most Cretaceous sandstones in the central Graham Island area the sandstone lithofacies of the Honna Formation are dominated by quartz, feldspar and rock fragments. The average quartz, feldspar and rock fragment ratio of the Honna Formation sandstone lithofacies is 40:30:30 (Figure 2-51a). The quartz portion can be up to 50 % of the total framework grains, but generally makes up less than 40 %. Chert is rare in this lithofacies. Even though monocrystalline quartz is more common than polycrystalline quartz overall, the polycrystalline variety is more abundant in this lithofacies than any other units in the area (Figure 2-52). Polycrystalline quartz makes up as much as 20 % of total framework grains in some samples, and is frequently present in amounts higher than 10 %. The QmPK-plot (Figure 2-51c) shows that potassium feldspar is more common than plagioclase. This figure also shows that two of the samples are very high in their relative amounts of monocrystalline quartz. The plot in figure 2-51d show that the sandstone lithofacies of the Honna Formation generally contains more sedimentary rock fragments than volcanic ones. The relatively high content of sedimentary rock fragment in this formation distinguishes this sandstone lithofacies from other Cretaceous sandstones. Fragments represented in minor amounts in this unit include muscovite, carbonate and organic material.

Figure 2-51a shows a QFL-plot which indicates that the sandstone lithofacies have mixed sources. Samples of the unit plot in the areas of dissected and transitional arc, recycled orogen and a basement uplifted continental block. The average of all the samples plots in the field for dissected arc. In the plot shown in figure 2-51b the samples of this unit plot in the area for transitional arc, continental block and recycled orogen providence. The spread in indications of sources for this unit might be the result of input from different source areas. Other explanations could be local variations within the same source area or just variations within the sandstones. More samples need to be examined to get a valid statistical result.

Scanning electron microscopy investigations of the sandstone on the eastern shore of Yakoun Lake confirm that this unit is almost barren of pore filling clays, but contains abundant calcite. The clays that are present are not of a pore filling nature, but rather seem to be in the form of grain rimming (Figure 2-53a). The EDS spectrum (Figure 2-53b) of the clay in figure 2-53a shows that the clay is rich in potassium, indicating that it is probably illite. Although clay is sparse in these sandstones most pore space is filled in with calcite as shown in figures 2-54 and 2-49.

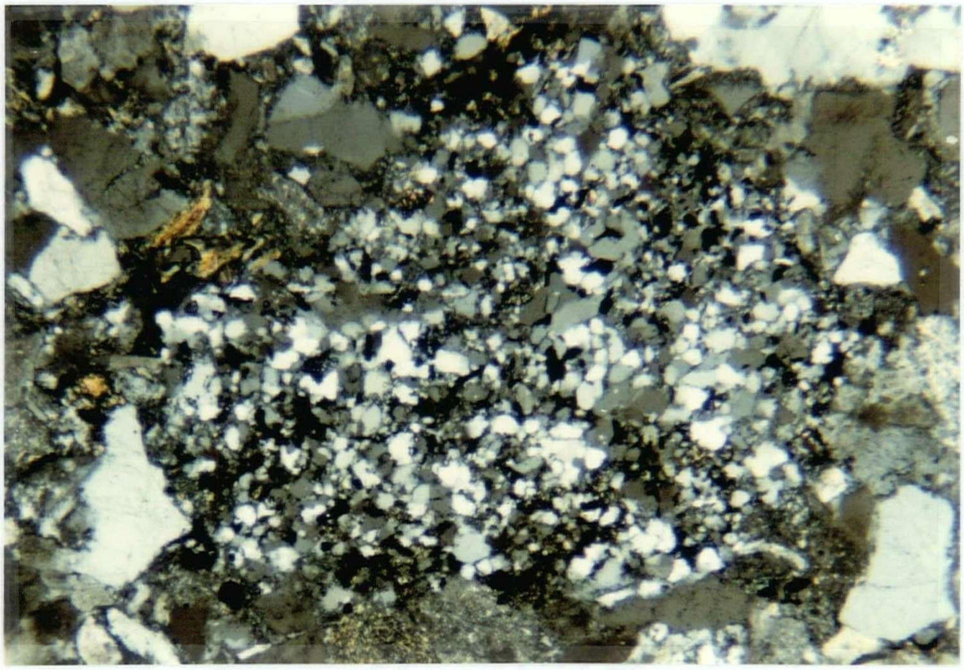


Figure 2-52. Polycrystalline quartz is frequently found in the sandstone lithofacies of the Honna Formation. (Thin section photomicrograph, crossed nicols, x70 magnification).

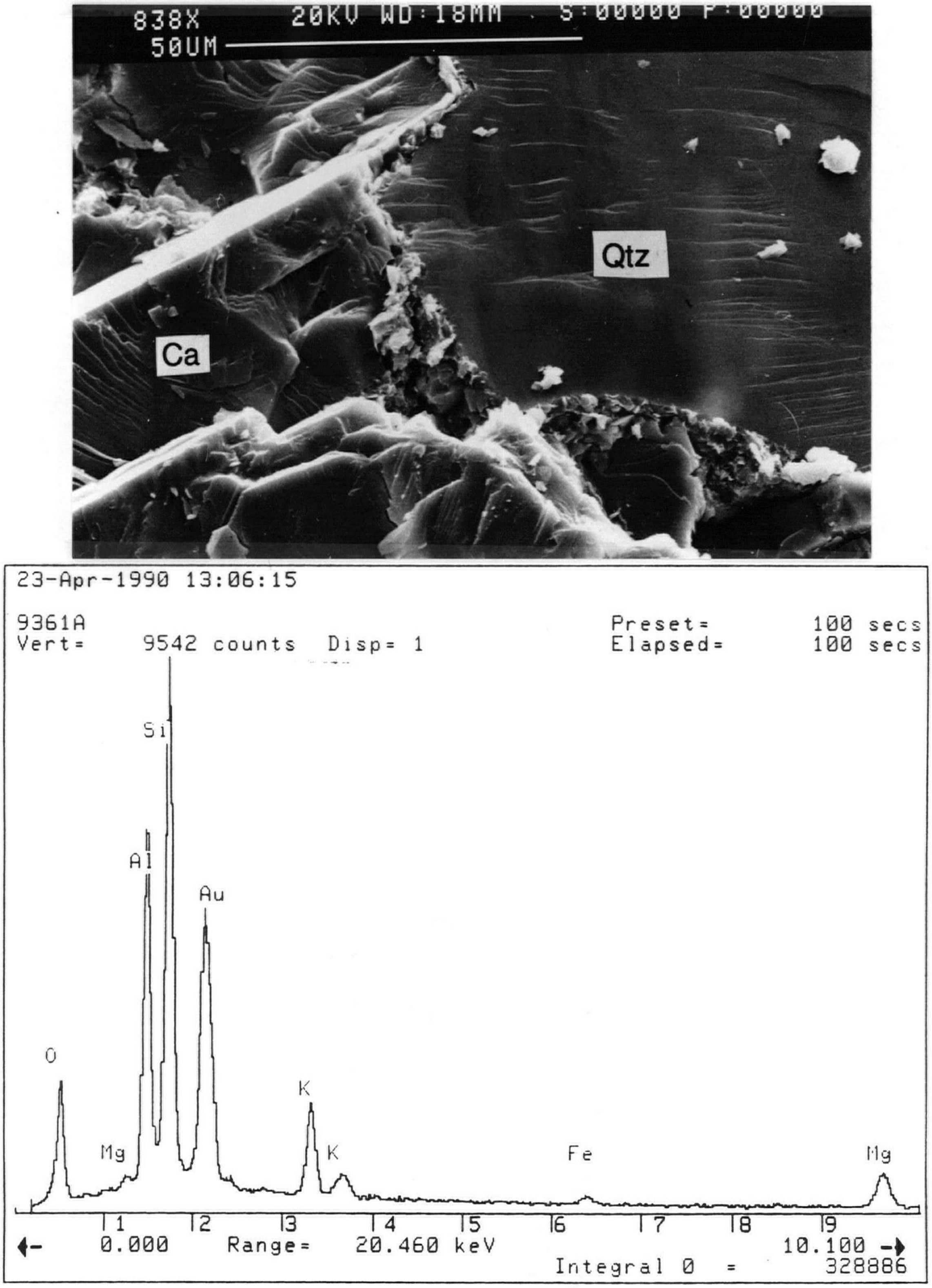
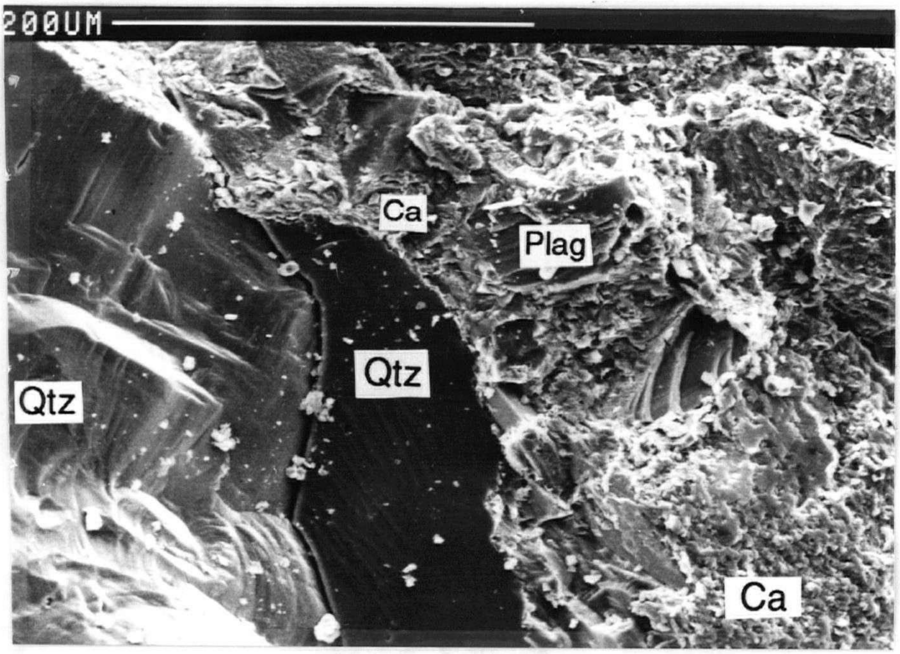


Figure 2-53. a) The clay present in the pore space between the quartz (Qtz) and calcite (Ca) in this sample is more of a grain rimming nature than pore filling. b) EDS-analysis of the clay present in (a). The high amount of potassium might indicate that this is illite.



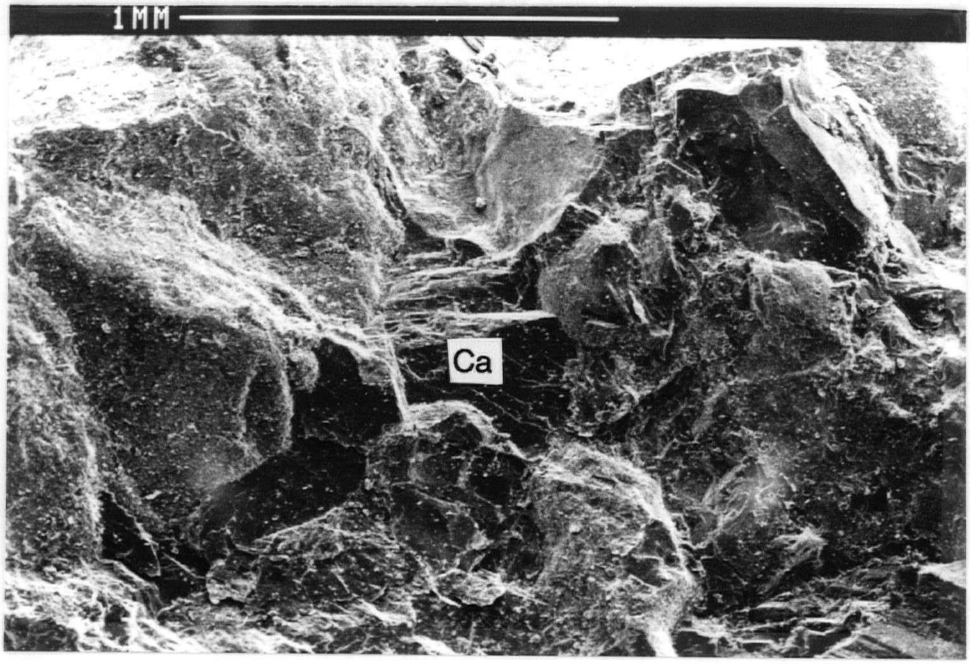


Figure 2-54. a) SEM-photomicrograph showing calcite (Ca) filling in the space between quartz (Qtz) and plagioclase (Plag). b) SEM-photomicrograph showing calcite filling between weathered grains.

2.1.3.5. Summary and discussion

Lower Cretaceous rocks in the central Graham Island area represent a transgressive sequence deposited in a westward deepening fore-arc basin. The initiation of upper Cretaceous Honna Formation deposition represents a change from a quiet marine shelf setting to a more energetic depositional setting. The volcanic arc situated in the Queen Charlotte Islands area during Jurassic time (Hesthammer, 1991a,b), migrated eastwards creating the Coast Plutonic Complex on the mainland, leaving the Queen Charlotte Islands region in a fore-arc setting in Cretaceous time.

The Cretaceous sandstone unit represent the basal part of a transgressive depositional sequence. The three lithofacies of the unit are mappable, and are probably related to each other both laterally and vertically. Due to the lack of continuous exposures it is impossible to work out a detailed sedimentological hypothesis for the Cretaceous sandstone unit. The Cretaceous units of the central Graham Island area are cut by numerous faults that makes any interpretation of detailed facies distribution and relations ambiguous. The bioturbated sandstone lithofacies might be correlative to the "bioturbated sandstone lithofacies" of Haggart and Gamba (1990) and the Haida sandstone of Taite (1991). The grey sandstone lithofacies might be correlated with the "sandstone/siltstone storm deposits lithofacies" and "laminated siltstone and mudstone lithofacies" of Haggart and Gamba (1990). The Cretaceous sandstone unit in the central Graham Island area is more complex than the transgressive sequence suggested by Haggart and Gamba (1990) for the southern parts of the islands. The bioturbated sandstone lithofacies does not always lie stratigraphically lower than the other facies as it does in the southern areas. The Cretaceous sandstone unit is however the start of a transgressive sequence that continues with the deeper water shale deposits.

The Cretaceous shale unit is interlayered with the upper parts of the sandstone unit and conformably overlies it. The shale represents a deepening of the basin. The interbedded sandstones within the unit probably represent deposits from storm events. These interbedded sandstones exhibit a close petrological similarity to the underlying arc-derived Cretaceous sandstone unit. The only difference between the sandstone of this unit and the underlying unit is the amount of clay in the matrix. Chlorite is not as abundant in the Cretaceous shale unit, and this increase the visual porosity in some areas.

The Cretaceous shale unit is locally interfingered with and overlain by turbidites of the Skidegate Formation. In the Ghost Creek area the Cretaceous shale is overlain by turbidites, while west of the Honna River turbidites of the Skidegate Formation are overlain by a shale unit. The presence of slumping within the Skidegate Formation may indicate a slope setting, but parts of the formation may have been deposited on a shelf as the continuation of the shale deposits. The Skidegate Formation is in all areas related to the coarse clastics of the Honna Formation as well as to the Cretaceous shale unit, and it is suggested that the formation represents distal turbidites and levee deposits of a submarine fan. The Honna Formation is the coarser deposits related to the channelized parts of the fan.

The depositional environment and the cause of the sudden input of coarse clastics into the basin during late Cretaceous time have been a topic of controversy. In the northern parts of central Graham Island area the Honna Formation overlies the Skidegate Formation, and in south the formations are interbedded with each other.

A low stand of sea level is known to trigger the initiation of submarine fans (Vail et al.,1977; Posamentier et al., 1988). The global sea level chart of Vail et al. (1977) and Haq et al. (1987) exhibits a global eustatic sea level drop contemporaneous to the initiation of the Honna Formation in Early Coniacian time. However, in a fore-arc basin setting the tectonic activity likely overprints the effect of eustatic sea-level changes. The initiation of coarse clastic deposition of the Honna Formation may be the result of the onset of a Late Cretaceous deformation event that is responsible for the block faulting observed elsewhere in the islands (Thompson and Thorkelson, 1989; Thompson et al., 1991). Lewis (1991) suggested that the Honna Formation are foredeep deposits derived from the Late Albian (Crawford et al., 1987) Prince Rupert thrust system. This thrust system is only a few million years older than the Honna Formation.

The coarse clastics of the Honna Formation were primarily derived from the pre-Cretaceous succession presently exposed on the Queen Charlotte Islands. Some plutonic clasts have been assigned to sources in the Coast Plutonic Complex located on the mainland (Yagishita, 1985b; Higgs, 1988). Thompson et al. (1991) documented a progressive shift in magmatic activity away from the Queen Charlotte Islands in Jurassic time towards the Coast Plutonic Complex in Cretaceous to Tertiary time. Clasts within the Honna Formation that do not seem to have a source on the Queen Charlotte Islands may have been derived from magmatic sources that are submerged in the Hecate Strait area east of the islands. This eliminates the need for long-distance transport of Honna clasts from the Coast Plutonic Complex located on the mainland. The higher quartz content in the Honna Formation is likely related to progressive dissection of the magmatic arc.

The occurrence of Late Cretaceous (Santonian shale) overlying the Honna Formation in the southern part of the map area indicate that the deposition of shale may have been continuous in the deeper western part of the basin while the submarine fan deposits occurred in the east. Deposition of coarse clastics may have been active east of the islands while the Cretaceous shale unit was deposited within the area of the present

Queen Charlotte Islands. It is also possible that the deposition of coarse clastics, represented by the Honna Formation, ended abruptly resulting in quieter shale deposition, which resulted in the Santonian shale unit.

All the lithologies studied in thin sections have a magmatic arc providence. This shows that the main source for the Cretaceous sediments in the Queen Charlotte Islands is the Middle Jurassic Yakoun Group, which is the remnant of a volcanic arc (Hesthammer, 1991a,b).

2.2. Tertiary rock units

2.2.1. Introduction

The Tertiary rock sequence of the central Graham Island is included in this thesis to provide a complete description of the rock units present in the area. The Tertiary section was not as thorough and detailed studied as the Cretaceous rock units.

The Tertiary strata in the central Graham Island area comprise volcanic and sedimentary rocks. The traditional division of Tertiary rocks in the Queen Charlotte Islands has been into the Masset and Skonun formations. The Masset Formation comprises mainly volcanic rocks with minor intercalated sediments (Sutherland Brown, 1968; Hickson, 1991). Hickson defined the Masset Formation more specifically as volcanic rocks of Late Oligocene to Early Pliocene age. Due to poor age control on Tertiary volcanics in most of the central Graham Island area no attempt will be made to separate the volcanic rocks into several units. The Skonun Formation consists of arkosic sandstones, shales, and conglomerates and is considered to be of Late Miocene to Late Pliocene age (Sutherland Brown, 1968; Shouldice, 1971; Higgs, 1991b,c).

2.2.2. Volcanic rocks

2.2.2.1. Previous work

The succession of Tertiary volcanic rocks in the Queen Charlotte Islands was named Masset Formation by MacKenzie (1916). He stated that these volcanic rocks overlie the sedimentary rocks of the Skonun Formation. Dawson (1880) treated both the sedimentary and volcanic units together as one package. Ells (1906) and Clapp (1914) discussed Tertiary volcanic and sedimentary rocks separately, but did not assign them any formation names. Sutherland Brown (1968) provided the first detailed description of the formation. He described the Masset Formation as a package comprising thin flows of columnar basalt and basalt breccia, thick sodic rhyolite ash flow tuffs, and welded tuff breccias and breccias of mixed basalt and rhyolite clasts.

Work on the petrochemistry of the Masset Formation by Hamilton (1985) and Dostal and Hamilton (1988) showed that the formation ranges in composition from that typical of T-MORB to metaluminous rhyolite. More recent work by Souther and Jessop (1991) indicates a more alkalic to MORB chemistry for dyke swarms that are related to the Tertiary volcanic rocks. This result support the findings reported by Timms (1989) for Tertiary flows and sills on northwest Graham Island.

The most recent study of the Masset Formation was carried out by C.J. Hickson of the Geological Survey of Canada under the Frontier Geoscience Program. Her results and interpretations are used as definition and divisions of Masset Formation and older Tertiary volcanic rocks. The following general description of the Masset Formation is based on the work done by Hickson (Hickson, 1988, 1989, 1990a,b, 1991; Hickson and Lewis, 1990; Lewis and Hickson, 1990; Lewis et al., 1990), and most of her work is related to rocks exposed on northwestern Graham Island. The southern limit of the area studied by Hickson (Hickson, 1990a) is identical with the northern border of the map over southern Graham Island, and it borders to the north of the area studied in this thesis.

The Masset Formation consist of aphyric to feldsparphyric, intercalated mafic to felsic lava flows and pyroclastic rocks. The suite is of tholeitic to calc-alkaline composition. Mafic rocks are the most voluminous of the Masset Formation and consist of multiple flows with individual flow thickness ranging from 2 to 30 metres. The flows appear mainly as aphanitic-aphyric lavas or aphanitic lavas with plagioclase phenocrysts. Plagioclase is the dominant phenocryst phase. Pyroxene can be found infrequently, and olivine is rare. Felsic parts of the Masset Formation are dominantly pyroclastic flows with thickness ranging from 10 to 200 metres. Welded tuffs dominate and are often found containing spherulites (up to 3 cm in diameter) and lithophysae (up to 10 cm in diameter). The dominant phenocryst phase is plagioclase, which is consistently present in the flows. Rare phenocrysts found in the felsic units include quartz, pyroxene, potassium feldspar, and opaques. Occasional sedimentary units are present in the Masset Formation and include lahars and reworked primary volcanic rocks. The formation contains some nonmarine, probably fluvial deposits. These sedimentary units range from fine grained sandstone and siltstone to coarse grained conglomerate.

Sutherland Brown (1968) noted that the Masset Formation overlies all older strata with an angular unconformity, and that it is overlain by and interfingers with the Miocene to Pliocene Skonun Formation in the eastern areas. Based on these observations he assigned a Paleocene to Miocene age to the Masset Formation. Young (1981) suggested, based on K-Ar dating that the formation could be as old as Cretaceous. Based on additional K-Ar dating Hamilton (1985) and Cameron and Hamilton (1988) restricted the age to Early Eocene to Late Miocene. Hickson (1991) defined the Masset Formation as volcanic rocks of Late Oligocene to Early Pliocene age. The peak eruption for the formation occurred during a five million years period from 20 to 25 Ma. Based on lithological and geochronological evidence she excluded volcanic rocks older than Late Oligocene from the formation. Larger plagioclase phenocrysts and phenocrysts of hornblende distinguish these older volcanic units from the Masset Formation, and they are clearly of a different suite. Some or all of these older volcanic rocks might be a part of the volcanic assemblage that includes the Upper Cretaceous to Lower Tertiary volcanic rocks in the Long Inlet area (Haggart et al., 1989), which is described in the section of "Unnamed Upper Cretaceous volcanic rocks".

Hickson (1991) interpreted the Masset Formation as resulting from orogenic volcanism during the Late Oligocene to Early Pliocene. In Eocene time the motion of the Pacific Plate with respect to the North American Plate changed from dominantly convergent to transform (Engebretson et al., 1986). During the convergent motion the subducting slab may have initiated calc-alkaline, arc type, volcanism. After the change in plate motion the volcanism may have become more alkalic. But this does not reflect the complete nature of the Masset Formation volcanics, where both calc-alkaline and alkalic volcanism have occurred simultaneously (Hickson, 1991). The triple junction of the Farallon, Kula, and North American plates is believed to have been located north of the Queen Charlotte Islands in Miocene time. During oblique subduction this triple junction migrated southward, passed the location of the Queen Charlotte Islands to its present site, generating magma production and eruption of the Masset Formation in the Queen Charlotte Islands (Hickson, 1991).

Other interpretations for the initiation of the Masset Formation include an "edge effect" on the subducting Farallon Plate (Stacy, 1974); wrench tectonics along the Sandspit and Rennell-Luscoone fault systems (Young, 1981); mantle hotspot (Yorath and Chase, 1981); and rifting (Yorath and Hyndman, 1983).

2.2.2.2. Tertiary volcanics in central Graham Island

Except in the southernmost part of the mapped area, all exposures of Tertiary volcanic rocks are located in the western part of the central Graham Island area. No Tertiary volcanics are found east of Yakoun River. Tertiary volcanic rocks are located as large continuous volcanic sheets in two major areas and as separate smaller sheets on some mountain tops. These rocks make a large continuous cover on the mountain range south of Yakoun Lake. This area will from now on be referred to as "the Mount Stapleton area". The other large continuous sheet of Tertiary volcanic rocks is located in the northwestern part of the thesis area, north of King Creek. The volcanic rocks in this area are the continuation of the extensive Tertiary volcanic cover on northern Graham Island that has been mapped and described by Hickson (1988, 1989, 1991). In addition, isolated exposures of Tertiary volcanic rocks are found on mountain tops in the area in between the larger volcanic sheets.

For field identification purposes the Tertiary volcanic flow rocks of the central Graham Island were divided in to felsic, intermediate, and mafic flows. This subdivision is entirely based on field observations and does not involve chemical classification of any kind. The classification of a particular flow would depend on its colour and phenocryst assemblage.

Common for all the Tertiary volcanic flows is that they are harder than most other rocks in the area. Weathering surfaces of these rocks are often very irregular and rough with small sharp edges and points. The hardness and weathering appearance is the best way of separating these rocks from the volcanic rocks of the Middle Jurassic Yakoun Formation. One or several dominant fracture orientations are often observed. The overall dominant phenocryst assemblage is plagioclase, that is present in lath-like, sub- to euhedral crystals. The phenocrysts are seldom larger than 2-3 mm. Calcite amygdules are not abundant, but are present in all three flow types. These amygdules are generally spherical with little or no indication of flattening. Open, unfilled vesicles are rare in the Tertiary volcanics of the central Graham Island area. Individual flow tops and bottoms are generally difficult to locate, often because of the lack of good brecciation in these parts of the flows. Columnar jointing is present, but it is not widespread (Figure 2-55).

Figure 2-55. Columnar joints in Tertiary volcanic rocks.

Volcanic flows of intermediate composition dominate the Tertiary section in the central Graham Island area. Weathered surfaces of these rocks have a dark brown to black colour. Fresh surfaces show a medium to light greenish coloured aphanitic groundmass with white feldspar phenocrysts. From thin section investigations it can be seen that the feldspar phenocrysts are mostly plagioclase (Figure 2-56).

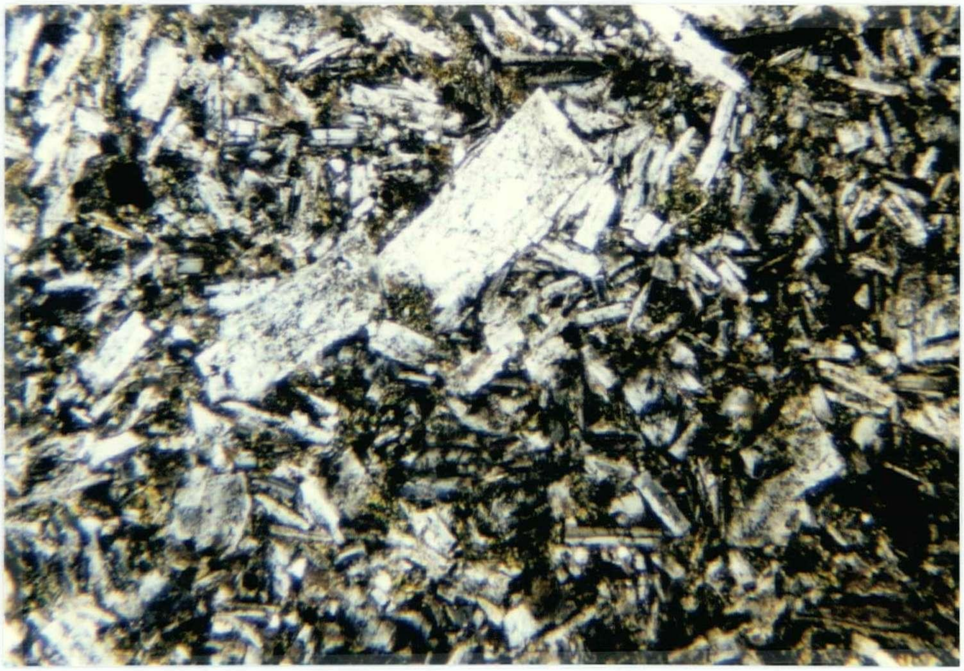


Figure 2-56. The dominant phenocryst phase in the Tertiary volcanic rocks is plagioclase, this thin section photomicrograph is from an intermediate flow (crossed nicols, x70 magnification).

The felsic flows are lighter coloured than the intermediate ones. Most outcrops are light grey coloured on weathered surfaces, but the colour ranges from white to light and dark grey. On fresh surfaces the felsic flows are aphanitic white, light grey, or light blue. Plagioclase is the dominant phenocryst phase (Figure 2-57), but can be difficult to detect due to the light colour of the groundmass. On closer examination the phenocrysts can be picked out on the basis of their more shiny luster. When amygdules are found in the felsic flows they are nearly always filled with calcite, but the flows are quartz amygdaloidal in rare instances. Flow banding is especially common in the felsic volcanics around Yakoun Lake. The flow banding is mostly present as shades of grey and white (Figure 2-58), but in a few localities it is shown in more spectacular colours like red, blue, and white.

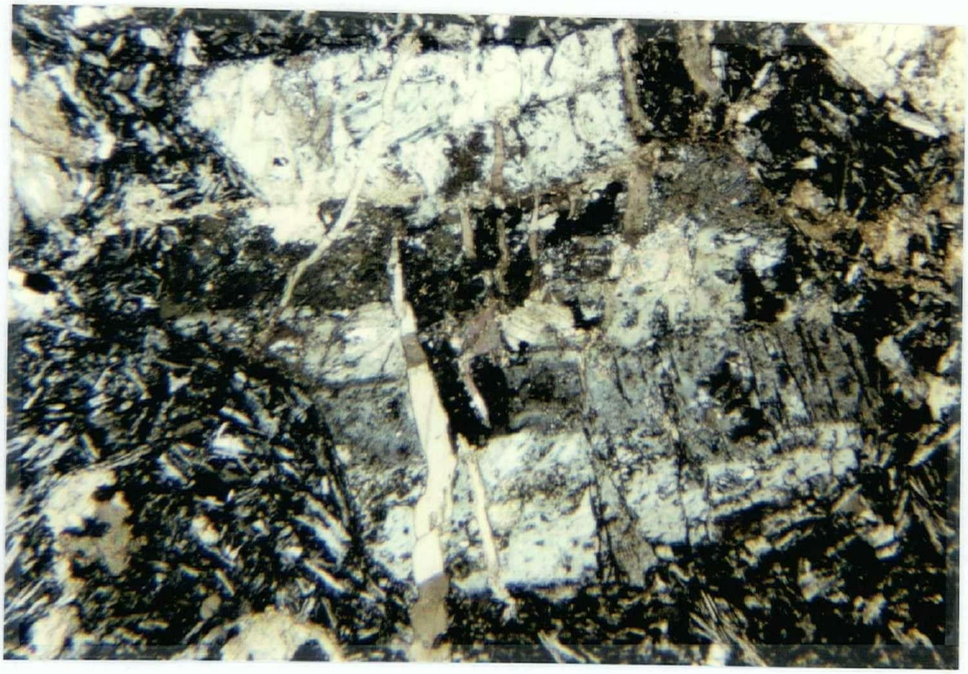


Figure 2-57. Thin section photomicrograph of a Tertiary volcanic showing one large and several smaller feldspars. The large feldspar has calcite filled fractures (crossed nicols, x70 magnification).

Figure 2-58. Flow banding in Tertiary volcanic rocks.

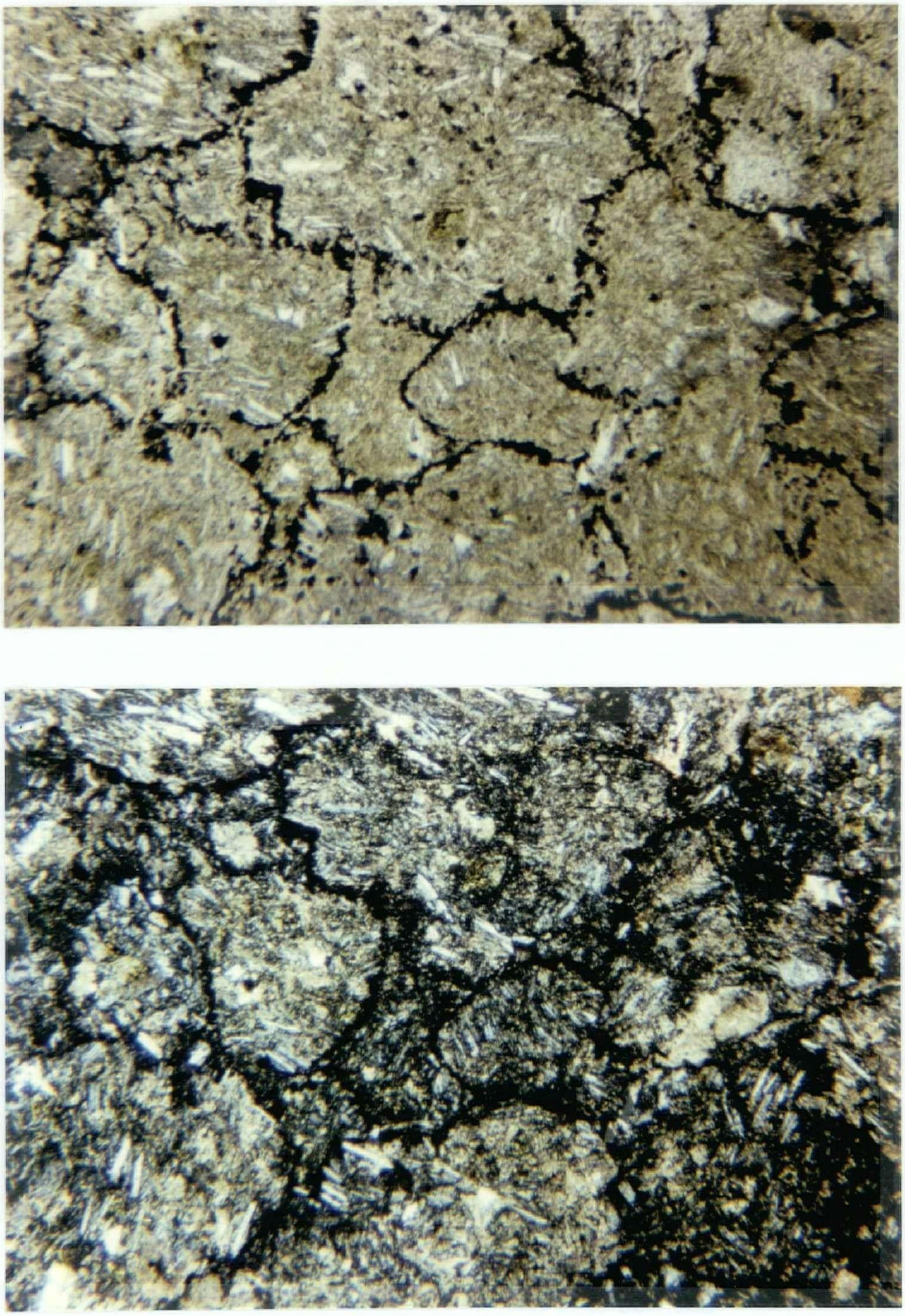


Figure 2-59. Thin section photomicrographs of a Tertiary sedimentary rock. All clasts are volcanic with feldspar phenocrysts. The black rim on the grains is probably a weathering product. a) plane polarized light; b) crossed nicols; both x70 magnification.

Mafic flows are dark green to black coloured on fresh surfaces. Weathered surfaces of the mafic flows are almost always dark coloured. The groundmass is aphanitic with plagioclase as the dominant phenocryst assemblage; other phenocrysts include pyroxene, biotite, and amphibole. Olivine phenocrysts were reported by Sutherland Brown (1968), but were not found in any of the Tertiary volcanic rocks in the central Graham Island area during this study. A few quartz amygdaloidal flows have been observed, but calcite dominates as amygdules.

Minor volcanic conglomerates and coarse sandstones are found interbedded with the Tertiary volcanic rocks in the Yakoun Lake area. The fragmental nature of these sediments is easy to recognize on weathered surfaces where the clasts are dark brown coloured and the matrix is lighter brown. On less weathered surfaces the clasts are medium green and the matrix light green coloured. On fresh surfaces it can be seen that the clast material is entirely made up of angular to subrounded, aphanitic volcanic fragments. The mean clast size varies from about 3 mm to about 1 cm; the maximum clast size is 12-14 cm. Sorting is poor, and the conglomerates are framework supported. Most clasts have plagioclase phenocrysts, or calcite filled amygdules. Calcite is present in various amounts as cement in the conglomerates. The sediments are very tightly packed and matrix is sparse (Figure 2-59).

Tertiary volcanic rocks in the Mount Stapleton area were the object of a stratigraphic and structural study by a group of geologists involved with the Frontier Geoscience Program, including the author. Some of the results of this work have been published (Haggart et al., 1990). Recent studies, including thin sections descriptions, were not included in the publication and are presented here. In addition to the common volcanic flows, this study revealed some interesting lithologies in the Tertiary section, both of volcanic and sedimentary origin. The Tertiary rocks of this area consist of intermediate-composition flows, flow breccias and minor volcanic conglomerate and sandstone.

The volcanic flows are identical to those described from the other areas, but flow banding is more common than elsewhere. Locally these flows display columnar jointing. Volcanic breccias in the area have a dark green groundmass with feldspar phenocrysts. The groundmass often shows flow textures such as alignment of phenocrysts and flow banding. Clast material is mainly made up of light coloured aphanitic, felsic volcanics. Other clasts include mafic volcanics and volcanic glass. The clasts are angular to subrounded and up to 25 cm in diameter (Figure 2-60).

Figure 2-60. Volcanic lapilli-block breccia with large felsic clasts, the clasts show a defined alignment.

On the northeast side of Mount Stapleton is a well exposed outcrop of an 30 metre thick sedimentary section (Haggart et al., 1990). This section is overlain and underlain by successions of volcanic flows and breccias similar to the one just described. The sediments consist of interbedded conglomerate and sandstone. The conglomerate is massive- to reverse-graded, poorly sorted, and framework supported. The tabular conglomerate beds are up to 2.5 m thick, with erosional bases. Clast material is dominated by light coloured, aphanitic felsic volcanics. Minor amounts of the clasts are mafic volcanics, volcanic glass, granitoids, sandstones, and mudstones. The clasts are subangular to rounded and can be up to 12 cm large, average clast size is 3 cm. The sandstones are coarse grained, trough cross-stratified to horizontally bedded and up to one metre thick.

Figure 2-61. Planar lamination and low angle cross-lamination in Tertiary sediments.

Sedimentary rocks are also present in other parts of the area, as sandstone units up to 15 metres thick. Cross-stratification and grading is commonly present, and bed thickness ranges from 2-50 cm (Figure 2-61). On weathered surfaces the clasts are light brown coloured and the matrix is darker brown. The rocks are monotonous dark greenish grey coloured on dry fresh surfaces, but on wet fresh surfaces a light green coloured fine grained matrix surrounding dark and light green clasts can be seen. Thin sections of these sandstones shows that the fragments are entirely of volcanic origin. Plagioclase phenocrysts are common in all of the clasts (Figure 2-62). These rocks are somewhat similar to the rocks in the Yakoun Lake area, but the clast material is more diverse in the Mount Stapleton region.

No attempt was made to work out a detailed stratigraphic column of the area, because limited time was spent on mapping the Tertiary volcanics and the alpine nature of the mountain range limits the accessibility. A sedimentary section in the Mount Matlock area yielded pollen indicating mid-Miocene to pre- Quaternary age (Haggart et al., 1990). These sediments are overlain by volcanic rocks, that are substantially younger than the main eruptive period for the volcanic rocks of the Masset Formation. There is no other age control on the section, but it is likely that the rest of the section in the Mount Stapleton area is of the same age span. The topographic features of this alpine area (Figure 2-63) with steep mountain sides, cliffs, narrow edges and peaks are very different from the gently plunging hills of northern Graham Island which is underlain by Masset Formation volcanic rocks (Hickson, 1991:Fig.9). This might indicate that the volcanic section present in the Mount Stapleton area is not correlative to the rocks that are representative for the main eruption period for the Masset Formation on northern Graham Island. The difference in topographic relief between the two areas might also be a result of more intense erosion of the higher elevated areas south of Yakoun Lake.

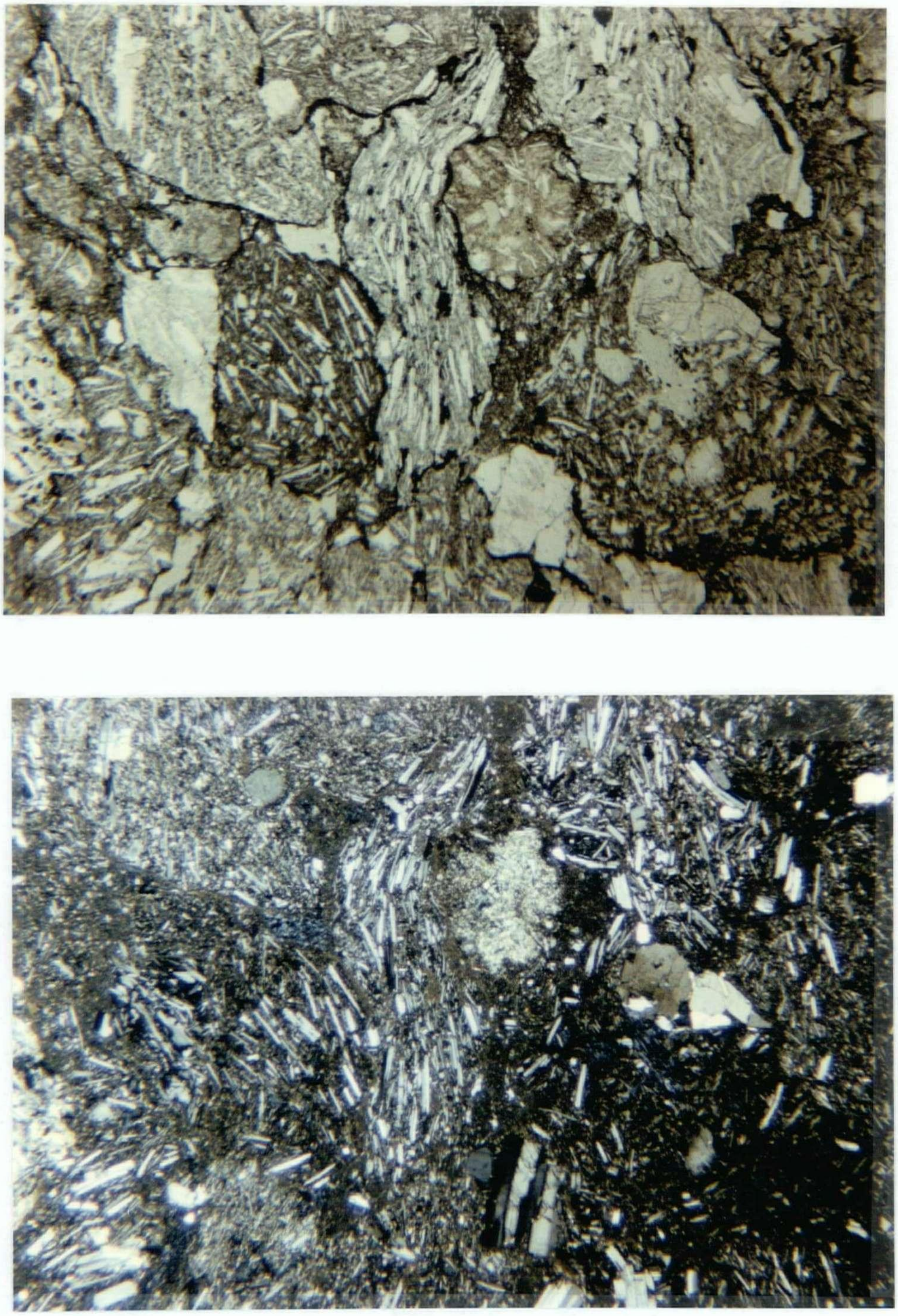


Figure 2-62. Thin section photomicrographs of a sedimentary rock of the Tertiary rock sequence in the Mount Stapleton area. a) plane polarized light; b) crossed nicols; both x70 magnification.

Figure 2-63. The Mount Stapleton area is alpine with steep cliffs and narrow edges, this is quite different from the topography of northern Graham Island where the Tertiary Masset Formation dominates.

Figure 2-64. Cross bedded sandstone of the Skonun Formation.

2.2.3. Skonun Formation

The Skonun Formation was named by MacKenzie (1916) for rocks found on the north coast of Graham Island. He believed that these rocks were older than the Masset Formation. Sutherland Brown (1968) described the Skonun Formation as marine and non-marine calcareous sandstone, shaley mudstone, and minor conglomerate. He also recognized that the unit was younger than the Masset Formation, and assigned a Miocene to Pliocene age for the formation. Cameron and Hamilton (1988) noted that the formation probably interfingers with the upper Masset Formation.

Access to the Skonun Formation is very limited; only a few exposures are known, but the formation shows up in drill cores of the Cinola gold property (Champigny and Sinclair, 1982) and in several onshore and offshore boreholes. The thickness of the formation was estimated to about 200 m by Sutherland Brown (1968). Later investigations have shown that the formation is up to 5000 m thick on the offshore areas east of the Queen Charlotte Islands (Shouldice, 1971).

New logging roads in the northeastern part of the map area have improved the amounts of outcrops in this area immensely. A sequence of parallel and cross bedded coarse grained, grey coloured sandstone was found overlying a fissile, light grey mudstone.

Outcrops of Skonun Formation includes a 12-15 m high cliff on the east side of Yakoun River. Here medium to coarse grained sandstone is overlain by a 2 m thick mudstone. The sandstone is tabular cross-bedded with the set of cross-beds being up to 1 m thick. Some rounded pebbles are found as well.

Several outcrops of the Skonun Formation are found along new logging roads west of Yakoun River in the northernmost part of the central Graham Island area. A large quarry exhibits an excellent exposure of the sandstones of the formation. These sandstones are medium to coarse grained and horizontal to tabular cross-bedded (Figure 2-64). Each set is here 1-1.5 m thick. Several other quarries and road cuts in the area also expose this rock type. Quartz is more abundant in this formation than in any other in the map area. Potassium feldspar and plagioclase is also a common constituent, together with rock fragments and mica. The sandstones are poorly lithified, but is still harder that the Quaternary till that dominates the northeastern map area. One of the locations mapped as Skonun Formation was also visited by Sutherland Brown (1968), and he reported the find of fossils at this locality. Higgs (1991b) reported finds of Miocene molluscs from an outcrop along Yakoun River.

Outcrops of the Tertiary Skonun Formation was also found in the easternmost part of the map area, in Chinuckundl Creek. The lithologies here included a coarse mica rich sandstone that grades upward into a conglomerate that is overlain by a mudstone. The conglomerate is poorly sorted and clast supported. Clasts material is made up of subrounded to rounded aphanitic volcanic, plutonic, and green feldspar-phyric volcanic fragments. Another outcrop consists of a dark grey and light grey coloured mudstone.

2.3. Intrusive rocks

Intrusive rocks are found all over central Graham Island. Dyke and sill rocks range in composition from felsic to mafic with the majority being of intermediate composition, and are mostly aphanitic to feldspar-phyric. Weathered surfaces of these rocks are light grey to dark brownish grey and green coloured. On fresh surfaces the rocks have colours ranging from pinkish red to dark green. The rocks are much harder that most of the rock units of the area, and easy to distinguish from all units except rocks of the Tertiary volcanic package. Dykes range in thickness from about 10 cm to more than 10 metres with sharp contacts with their host rocks.

The most common phenocryst phase present in the igneous rocks is sub- to euhedral plagioclase. Other less common minerals that appears as phenocrysts includes pyroxene and quartz. The phenocrysts of any assemblage rarely exceed 3 mm in length. Chlorite and other micas are often found as weathering replacements of the phenocrysts. Vesicles are found in sizes up to 4 mm. Quartz and calcite amygdules are rare.

The dykes in the central Graham Island area are probably of two different ages. One assemblage is the feeders of the Middle Jurassic Yakoun Group volcanism. The dykes that are observed to cut through Cretaceous strata are related to the Tertiary volcanism.

A few larger plutonic bodies are found within the area. Most of the plutonic bodies are fine to medium grained, equigranular diorites and monzonites. Good descriptions of these rocks are given by Anderson and Greig (1989), Anderson and Reichenbach (1989; 1991), and no effort will be spent on description and discussion of plutonic rocks in this thesis.

3. STRUCTURES

3.1. Introduction

The structural history of the Queen Charlotte Islands contains several major deformational events. Mapping and structural studies have led to the recognition of at least five main episodes of deformation in central Graham Island. These five are:

1) Middle Jurassic compression that resulted in northwest trending folds and thrust/reverse faults.

2) Late Jurassic and Early Cretaceous extensional faulting leading to northwest striking normal faults.

3) Late Cretaceous to Early Tertiary northeast directed compression resulting in northwest striking faults and folds.

4) Tertiary extensional faulting giving rise to northwest striking faults.

5) Later Tertiary block faulting leading to northeast and east striking normal faults and strike-slip faults.

Most of the deformation recorded in the rock units of the central Graham Island took place prior to deposition of the Tertiary rock package. As a result very few deformational structures are observed in the Tertiary volcanic rocks of the area. The description and discussion of structural geology in the central Graham Island area will focus on the Cretaceous units and only rarely are references made to the Tertiary part of the sequence.

The structural geology of the Cretaceous rocks in the study area is dominated by macroscopic (map scale) faults and folds (Figure 3-1) . Due to limited and poor exposures of bed rock in the area most of the major structures are never seen in outcrop.

However, the regional map pattern requires several faults with large offset to be present within the area. These faults are oriented in two major sets; a northwest trending set cut by a younger northeast to east trending fault set.

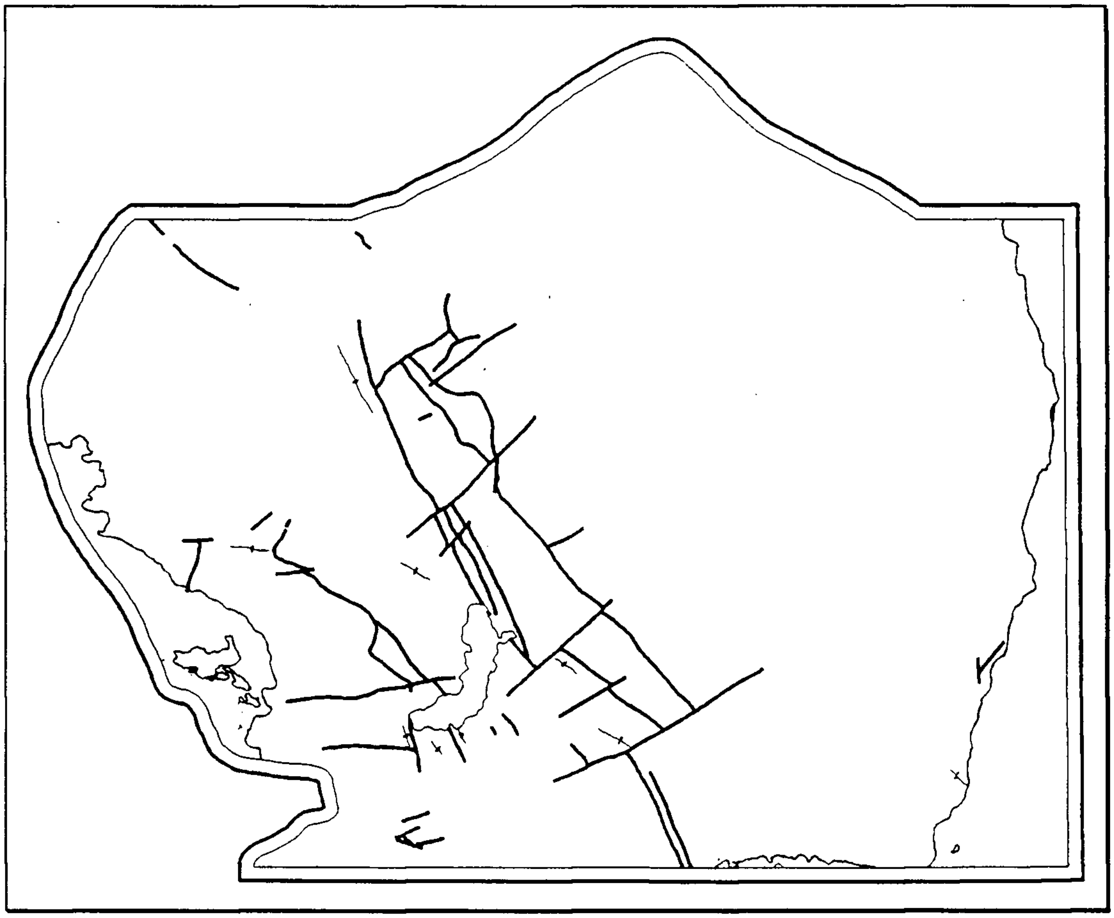


Figure 3-1. Map showing the major macroscopic structural elements of the central Graham Island area.

Mesoscopic structures (outcrop scale) recorded in the Cretaceous section are dominated by steeply dipping faults with an offset of 5-20 cm; rarely does the offset of the faults exceed one metre (Figure 2-12). These faults are in some areas spaced only tens of centimetres apart, and total offset over a zone of such faults can be tens of metres. Where absolute movement on the fault planes is possible to determine, a majority of the mesoscopic faults have a strike-slip component (Figure 3-2). Most folds observed on outcrop scale are gentle with no development of axial planar cleavage. Only rarely are mesoscopic folds abundant and exhibit axial planar cleavage. Classification of folds are mostly given with reference to their interlimb angle and the terms defined by Fleuty (1964) will be used (Table 3-1). Microscopic structures are rarely observed in thin sections or by use of Scanning Electron Microscope.

Term	Inter limb angle
gentle	180^{o} - 120^{o}
open	120^{o} - 70^{o}
close	70^{o} - 30^{o}
tight	30^{o} - 0^{o}
isoclinal	0^{o}

Table III-I. Table showing the fold classification used in this thesis (from Fleuty, 1964).

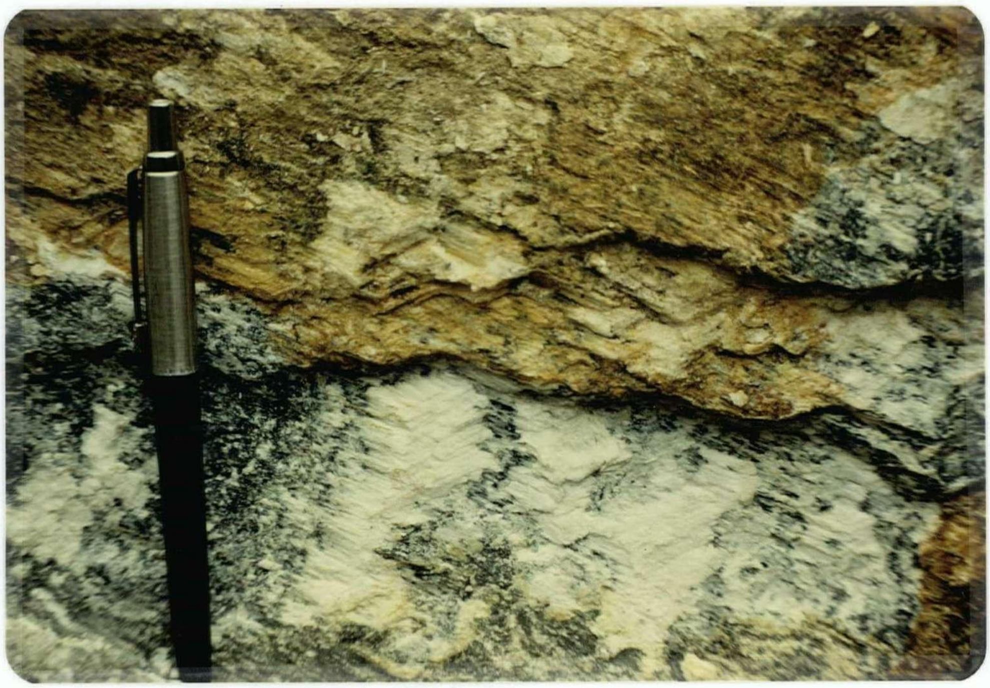


Figure 3-2. Most of the faults observed in outcrops have a major strike-slip component as the latest movement of the fault surface. The fault in this photo shows calcite slikensides in a herring-bone pattern, indicating that two different directions of movement has taken place.

3.2. Description

The structural study will focus on macroscopic structures. The study area has been divided into six structural domains based on the nature of the map scale structures present within each domain (Figure 3-3). Areas of Cretaceous rocks outside of these structural domains, mainly the outliers in the northwestern part of the study area, are too small for detailed structural studies. Some of the domains are bounded by large scale faults and contacts with older and younger rock units. The extent of other domains is not as specifically defined. Due to limited exposures their boundaries are more vague. Each of the six domains will be described separately starting in north.

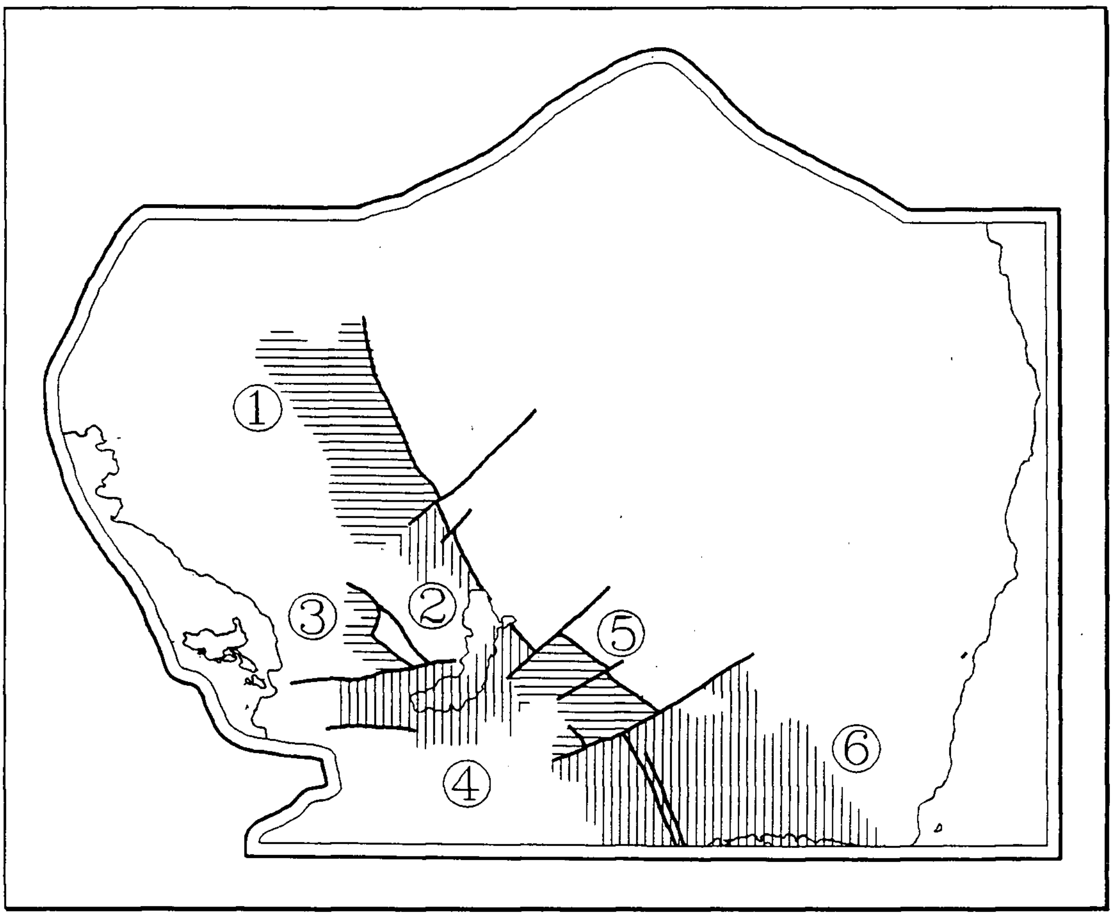


Figure 3-3. Map showing the location of the different structural domains.

3.2.1. Structural domain 1 (Ghost Creek area)

Domain 1 is located in the area from Ghost Creek in the north to Demon Creek in the south (Figure 3-3). The domain is limited to the north by a sheet of Tertiary volcanic rocks, and in the west by the stratigraphic contact towards the underlying Middle Jurassic Yakoun Group. The eastern limit of the domain is a northwest striking fault juxtaposing the Cretaceous rocks next to rocks of Early to Middle Jurassic age. In the south, domain 1 borders to the intensely deformed rocks of domain 2 and a Tertiary pluton. The limit towards domain 2 is somewhat indistinct, but the extension of the northeast striking fault south of Demon Creek is used as the boundary between the two domains.

The rocks exposed within this domain includes a full sequence from Cretaceous sandstone at the base overlain by Cretaceous shale, Skidegate Formation, and topped by the conglomerate of the Honna Formation.

A northwesterly trending bedding orientation is fairly consistent within the whole domain, and this shows up on the stereographic net of figure 3-4. The poles to bedding orientations are clustered in the southwestern part of the lower hemisphere of the stereographic net, which indicates a northwesterly bedding trend with dip towards the northeast. The least variable dip orientation is found in the sandstones in the western part of the domain where the dip is consistently towards the northeast. The dip ranges from less than 20^{o} to more than 80^{o} and averages about 30^{o}. In the northernmost area the bedding in the Cretaceous sandstone is northwesterly. Farther east, along the ridge made up of the Honna Formation, bedding measurements outline a northeast trending syncline. The bedding dip of the Cretaceous shale and turbidites in the King Creek valley in the northeasternmost part of the domain is towards the southwest, and outlines the eastern limb of the syncline.

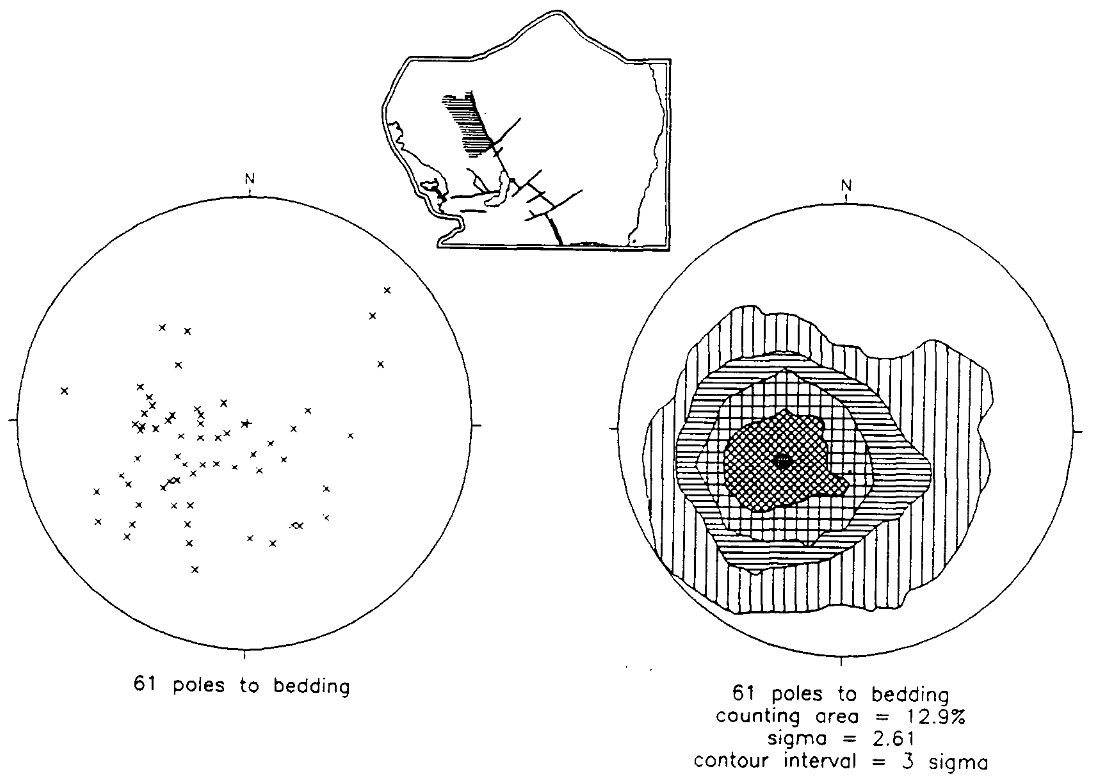


Figure 3-4. Stereonet-plot of the poles to bedding measurements in domain 1.

Bedding measurements along the northeast striking fault that defines the eastern limit of the domain are notably inconsistent, probably due to the several hundred metres offset along this fault. This fault cuts the entire Cretaceous section and is the result of a Late Cretaceous or Tertiary deformation period. Even though this is a major fault with substantial offset it does not show up in any topographic features. This is a common problem when trying to locate the macroscopic faults of the central Graham Island area. This fault is over 20 kilometres long and cuts through most of the central Graham Island area. It is offset by several younger northeast striking faults, and ends towards one of these faults in the southern part of the map. This major northwest striking normal fault cuts several older sub-parallel thrust/reverse faults (described by Hesthammer, 1991b). It also cuts a northeast striking normal fault just east of domain 1. The age control of this fault is limited to the age span between the end of deposition of the Honna Formation and the onset of Tertiary volcanism.

3.2.2. Structural domain 2 (Phantom Creek area)

This domain consists of the intensely folded Cretaceous shale around Phantom Creek and the easternmost part of the road leading from the Yakoun River valley to Rennell Sound on the west coast of Graham Island (Figure 3-3). In the north the domain borders domain 1 and in the east it is bounded by the continuation of the macroscopic fault that also confines domain 1. The southern limit of the domain is the shore of Yakoun Lake and Tertiary volcanic rocks. A Tertiary pluton marks the western extent of domain 2.

The Cretaceous shale unit in this area is among the most intensely deformed Cretaceous rocks in the central Graham Island area. The rocks are folded in open to close northwesterly trending folds. Poles to bedding measurements of domain 2 are shown in figure 3-5, and they lie along a crudely defined great circle with an orientation about 040/55 NW. This great circle indicates a fold axis trending towards the southeast with a rough estimate of its orientation being 130/35.

Southwest dipping axial planar cleavage, possibly indicating a fold vergence towards the northeast, has earlier been reported (Indrelid, 1990). This observation has been supported further by the finding of southwesterly dipping axial planar cleavage along Phantom Creek. The majority of the bedding in this domain dips towards the northeast, however, which is more indicative of a southwesterly vergence. A few axial planar cleavages with a northeast dip are present as well. These are found in the same area as southwest dipping cleavages and represents fanning of the cleavage. No consistent interpretation of overall fold vergence can be deduced from the bedding and cleavage orientations together.

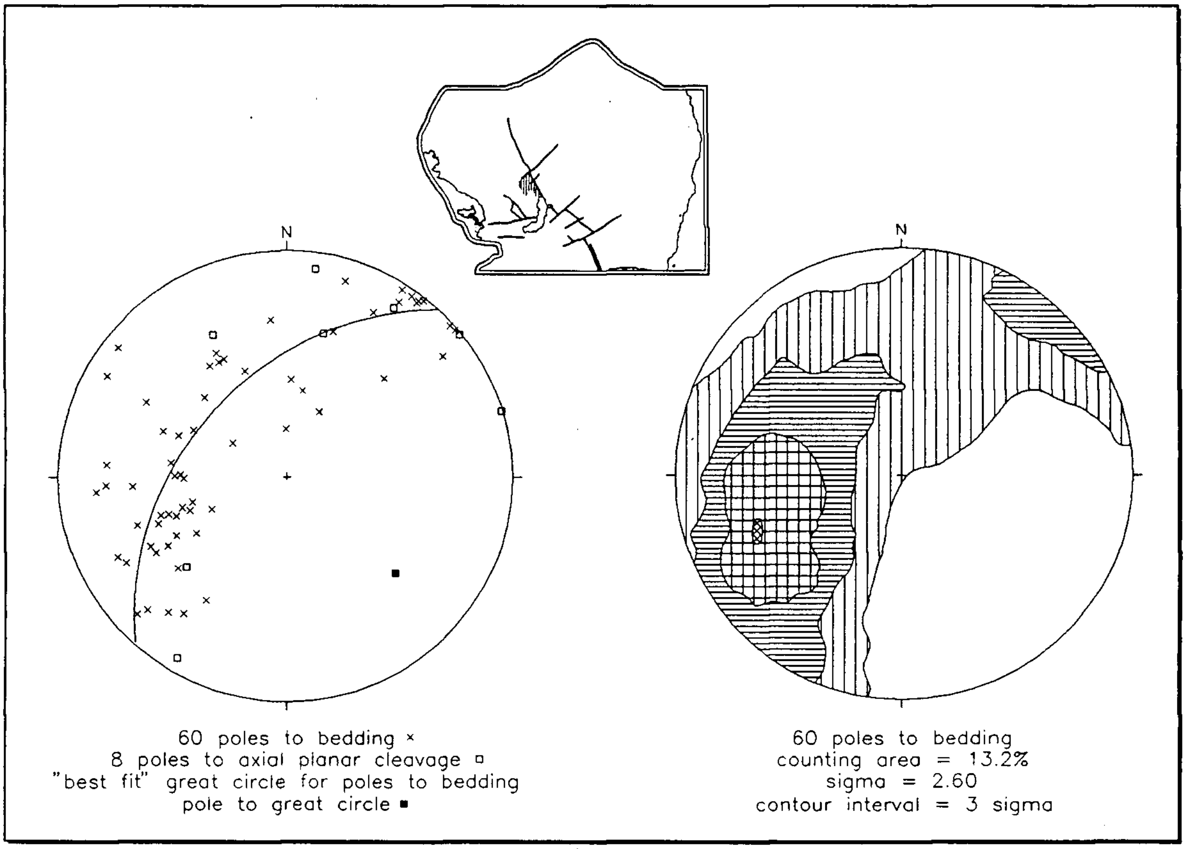


Figure 3-5. Stereonet-plot of the poles to bedding measurements in domain 2.

The folds become tighter and more plentiful towards the northeast and culminates close to the domain bounding northwest striking fault (Figure 3-6). The intense folding of the Cretaceous unit in this domain coincides with the presence of two northeast striking faults located in the eastern area of the domain. Both these faults cut the earlier described major northwest striking normal fault. Information on these faults is best collected from the area farther east where they cut rocks of Triassic and Jurassic age

(Hesthammer, 1991b; Indrelid et al., 1991b). North of the northernmost of the two faults the Cretaceous shale unit is juxtaposed with the Sandilands Formation, and south of it the shale is juxtaposed towards the Yakoun Group. This geometry cannot be accounted for purely by strike-slip faulting and a normal offset with south side down is inferred as the major part of the displacement along the fault. The southern fault has less offset and has been interpreted as a strike-slip fault on the map.

Along the road in the southwestern part of the domain folds are of gentle to open nature (Figure 2-28). Due to the massive character of most of the rocks along the road it is difficult to determine if any large scale faults are present, but based on the extensive amount of the Cretaceous shale unit along the road it is inferred that some repetition of section has occurred by faulting. These faults may be located along some of the many steep gullies in the hillside east of the road.

3.2.3. Structural domain 3 (Rennell Sound road west)

This domain consists of the Cretaceous sandstone and shale units exposed along western part of the road towards Rennell Sound and on the hill south of this road (Figure 3-3). A few outcrops of the sandstone is also found along Sandstone Creek south of the hill. Domain 3 is bounded by the limit of the study area to the north, but from the map it can be seen that the Cretaceous sandstone unit extends farther north. To the east the domain is limited by a reverse fault thrusting the Middle Jurassic Yakoun Group on top of the Cretaceous unit. The domain's southern limit is a east-west striking normal fault in the Sandstone Creek valley, and its western limit is the contact towards the Yakoun Group.

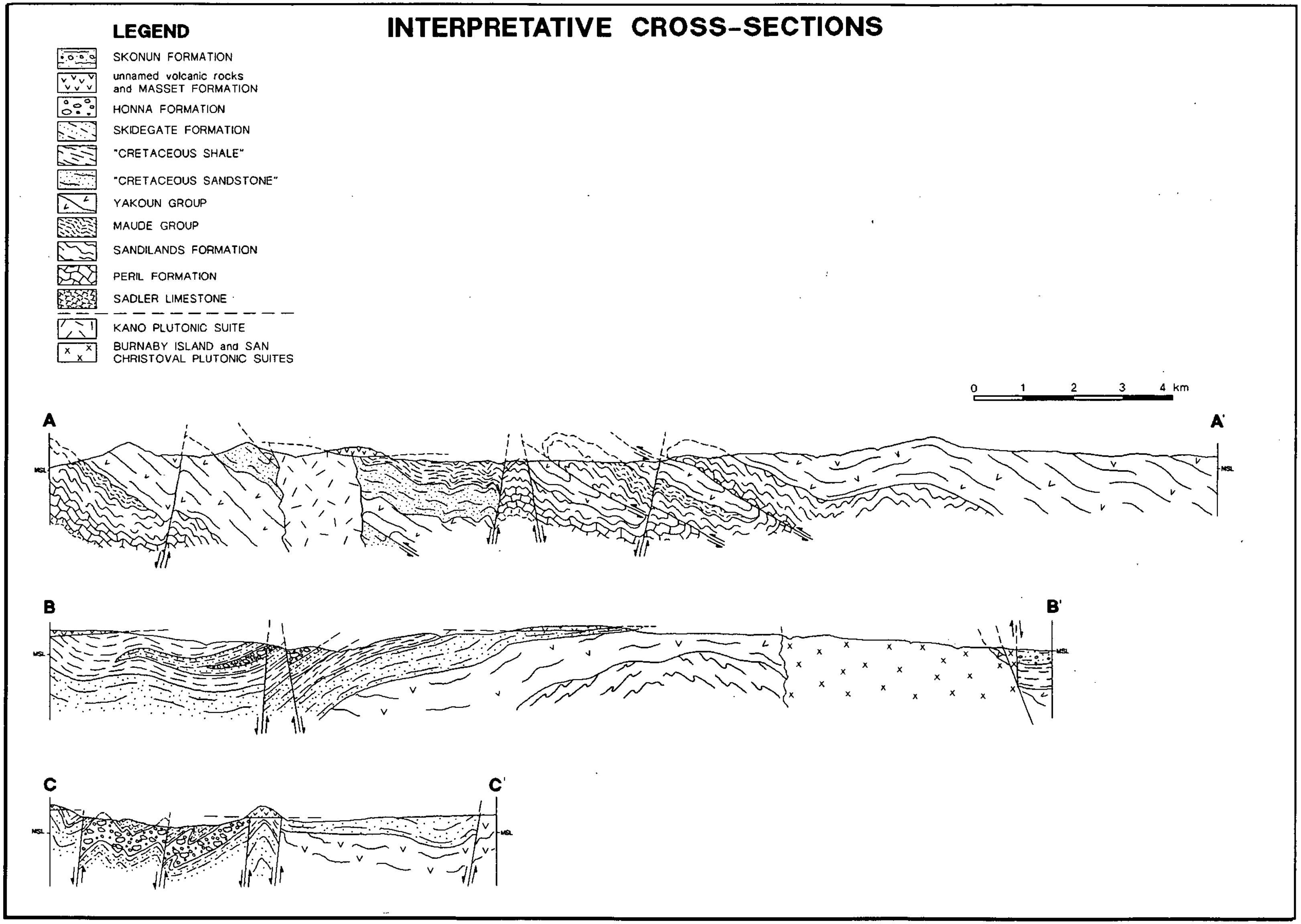


Figure 3-6. Interpretative cross-sections; see attached map for location of section lines.

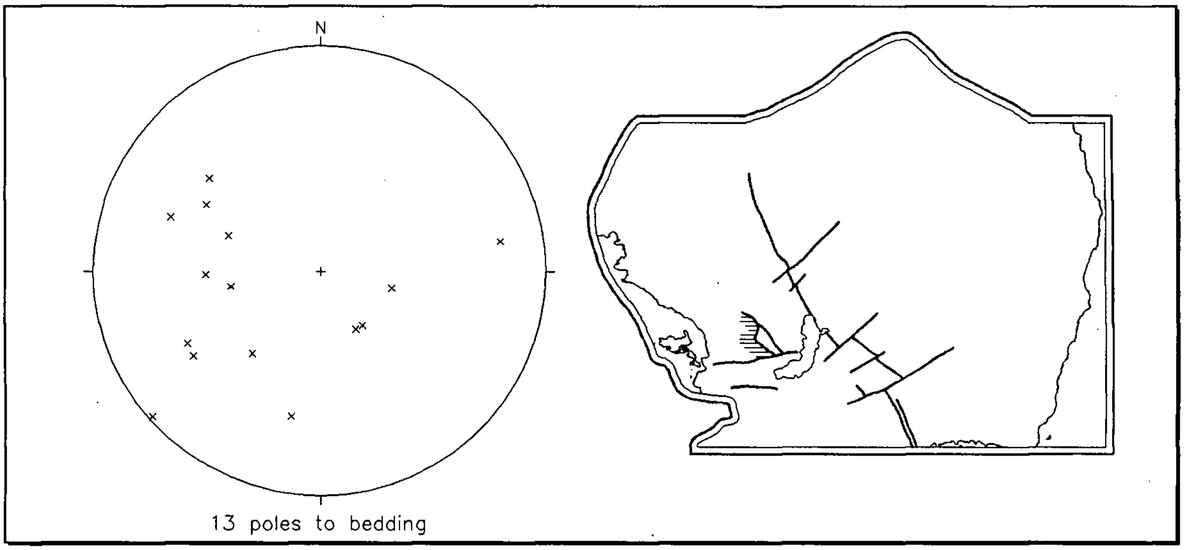


Figure 3-7. Stereonet-plot of the poles to bedding measurements in domain 3.

The low number of bedding orientations in this domain makes any conclusions from the stereographic net ambiguous (Figure 3-7), and the majority of structural interpretations are based on map pattern only. Most of the rocks in this domain have a easterly dip component (Figure 3-6), with only three observations having a dip towards the west. It can be seen from the map that the Cretaceous sandstone unit is folded into an anticline on the hill top south of the road. This anticline has a northwest plunging fold axis.

The dip of the reverse/thrust fault placing Jurassic rocks on top of strata of Cretaceous age can be roughly calculated from the map pattern. This form of calculation should be carried out where the control on the fault trace on the surface is best. Calculation of the dip of the fault surface at the road and the hill side south of the road gives values from 20^{o}-40^{o}, with dip towards the east. Similar values result from calculations from the area north of the study area. It is inferred on the map that the fault has steeper and almost vertical dip in areas outside the study area. The thrust fault is cut by later east striking faults that appear to be normal faults.

A thin band of the Cretaceous sandstone is also found some hundred metres to the east of the thrust fault, but this area is too small to be considered as a structural domain. Data collected from this area is not sufficient for any satisfactory structural study. It should be noted that a normal fault that juxtaposes the Cretaceous sandstone unit against rocks of the Yakoun Group is cut by and thus is older than the thrust fault of domain 3.

3.2.4. Structural domain 4 (Yakoun Lake area)

Rocks of this domain are mainly found south and west of Yakoun Lake, but a few outcrops are also located on the north side of the lake (Figure 3-3). The domain is bounded in north by the fault running parallel to Sandstone Creek. To the east it is limited by Tertiary volcanic rocks. Farther south the domain goes gradually into the less deformed rocks of domain 5. The rocks in Baddeck Creek are regarded as the eastern limit for structural data of domain 4. In the south the Cretaceous rock units are overlain by a thick cover of Tertiary rocks. To the west the domain is limited by the outline of the study area. Tertiary rocks cover part of the Cretaceous strata within the domain as well.

Rocks of this domain are made up of a complete sequence of Cretaceous rocks including the Cretaceous sandstone and shale units, and the Skidegate and Honna formations.

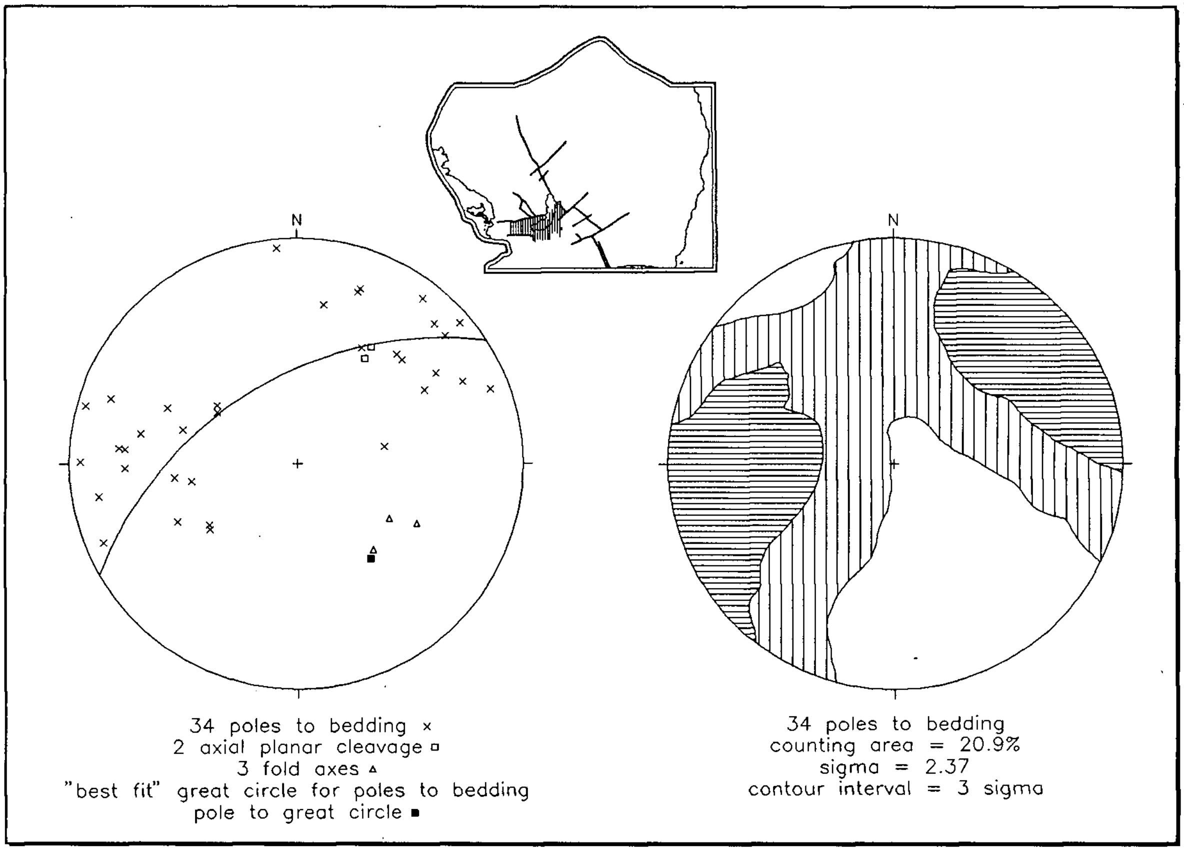


Figure 3-8. Stereonet-plot of the poles to bedding measurements in domain 4.

The rocks found along the southwestern shore of Yakoun Lake are among the most intensely deformed Cretaceous rocks of central Graham Island area (Figure 3-6). The rocks are folded into close northwest trending folds, with locally overturned bedding. The wavelengths of the folds are several hundred of metres. Figure 3-8 shows that the poles to bedding planes are concentrated in two clusters, each representing one limb of the folds. A good estimate for a great circle representation of the data is hard to find because of the poor grouping within each cluster of data. A best fit of great circles has a range in strike orientation of approximately 050-080. The dip of a best fitted great circle is between 40-60^{o} towards the northwest. These data indicate that the fold axis plunges moderately (30-50^{o}) towards the southeast.

A few outcrops in the area showed axial planar cleavage and fold axes of small scale folds with wavelength of less than a metre. Fold axes were observed in the Cretaceous shale unit along the lower parts of Sandstone Creek. The average of the measured fold axes is about 120/45, which is close to the pole for the great circle of poles to bedding data (Figure 3-8). This indicates that the rocks on the north side of Yakoun Lake (which do not have numerous bedding measurements) belong to the same structural domain as those on the south side. The measurements from two locations with axial planar cleavage (Figure 3-9) gives an average of 120/51 SW. Poles to these foliations falls about 90^{o} away from the fold axes, and within one of the clusters of bedding measurements.

Figure 3-9. Photo of the foliation observed in the Cretaceous shale unit south of Yakoun Lake.

The fold axes and the cleavage observed in outcrop scale in some of the Cretaceous rocks of the area have an orientation that suggests that they were formed by the same deformational event as created the macroscopic folds of domain 4. A better indication of the overall fold orientation and geometry is found when one use the poles of bedding measurements together with the observations of small scale fold axes and cleavage. On a stereonet the poles to the cleavage should fall on the same great circle as poles to bedding, and the fold axes should be located near the pole of this great circle. When all the data is integrated on the stereographic net the great circle representing the fold orientation of the area is approximately 060/45 NW (Figure 3-8).

Three faults striking parallel to the fold belt are present in the vicinity of Trap Hill on the south shore of Yakoun Lake. Another fault runs east-west along Sandstone Creek and it is among the youngest macroscopic structures present in the central Graham Island area. This fault must have several hundred metres offset with the south side faulted down. At the hilltop north of the fault, the Middle Jurassic Yakoun Group is present at 670 metres elevation and at the shores of Yakoun Lake the Late Cretaceous Honna Formation crops out at about 100 metres elevation. This fault cuts both the thrust fault and the fault east of the thrust that were described under domain 3. The age of this fault is limited to post Honna Formation depositional time. It is not known if this fault cuts the Tertiary rocks east of Sandstone Creek. A fault farther south on the north side of Mount Matlock is parallel to the one along Sandstone Creek and this fault cuts the Tertiary rock units. Both these faults have a relative displacement downwards of the southern fault block.

3.2.5. Structural domain 5 (Stanley Lake area)

This domain is located in the area from Etheline Creek in the north to Stanley Lake in the south (Figure 3-3). Its northern boundary is a northeast striking fault that has dropped down relatively the Cretaceous units of the southeastern block. In the east, the extent of the domain is limited by a northwest striking fault, and in the south it is limited by a fault similar to the northern one. To the west the domain is bounded by Tertiary rocks in the southernmost parts and in the northern half the domain grades westward into the intensely deformed rocks of domain 4. Domain 5 includes all of the different Cretaceous rock units.

A northeast striking fault cuts through the central parts of the domain. Cretaceous sandstone north of this fault has an overall dip towards the northeast, except for the eastern most part where the unit is folded into a gentle macroscopic northwest trending syncline. The most interesting structures of domain 5 are found south of the fault. The intensity of deformation increases towards the east in this area. In the central part the Cretaceous shale unit is folded into a gentle northwest trending anticline. This anticline has the same trend as the syncline in the sandstones north of the fault In the easternmost part the rock sequence is mostly eastward dipping, with a few westward dipping beds indicating that some folding have taken place. A northwest striking fault juxtaposes a down dropped western block of Cretaceous sandstone unit next to Cretaceous shale unit overlying rocks of the Honna Formation. This fault is cut by the earlier described northeast striking fault. Bedding east of this fault dips consistently in an easterly direction, increasing towards west, with maximum dip near 60°.

The domain bounding faults in the north and south are both northeast striking normal faults with relative displacement of the south side down. They both cut the long northwest striking normal faults that are traced through most of the central Graham Island area, They also cut a northwest striking thrust/reverse fault farther east in the area (Hesthammer, 1991b). These two faults are also younger than the northwest trending folds and faults of domain 5.

3.2.6. Structural domain 6 (Honna River area)

Domain 6 is the southernmost structural domain of the Cretaceous rocks in the central Graham Island area (Figure 3-3). In the north the domain is separated from domain 5 by a northeast striking fault that offsets the southern block (domain 6) down. The eastern limit of the domain is a contact with the Yakoun Group, and in the west it is bounded by the overlying rocks of Tertiary age. The domain is limited in the south by the limit of mapping involved in this thesis, but the structures have been shown to extend southward to Skidegate Inlet, and onto Lina and Maude Islands (Thompson and Lewis, 1990).

Domain 6 consists of a complete section from Cretaceous sandstone unit in east through rocks of the Cretaceous shale unit, Skidegate Formation and Honna Formation. From the map it is clear that the general trend of bedding in the area is towards the northwest, and dip is mostly towards the southwest. This is also obvious from figure 3-10, where the majority of poles to bedding are clustered in the upper right part of the diagram. The center of this cluster gives a average bedding orientation of approximately 140/20 SW.

Major structural elements of domain 6 are two northwest striking macroscopic faults (Figure 3-6). Both faults have displaced the central block up relative to the other fault blocks. And both faults have juxtaposed rocks of the Skidegate Formation next to rocks of the Honna Formation. Calculation of minimum thickness of the Honna Formation on the eastern side of the eastern most fault is about 350 metres (were section line B crosses the domain). The Skidegate Formation is at least 80 metres thick on the other side of this fault. Together these calculations indicate a total offset of more than 400 metres on this fault. There is no Honna Formation exposed on the west side of the western fault so is impossible to calculate the offset along this fault. Both these macroscopic faults are older than the northeast striking fault that separates domains 5 and 6.

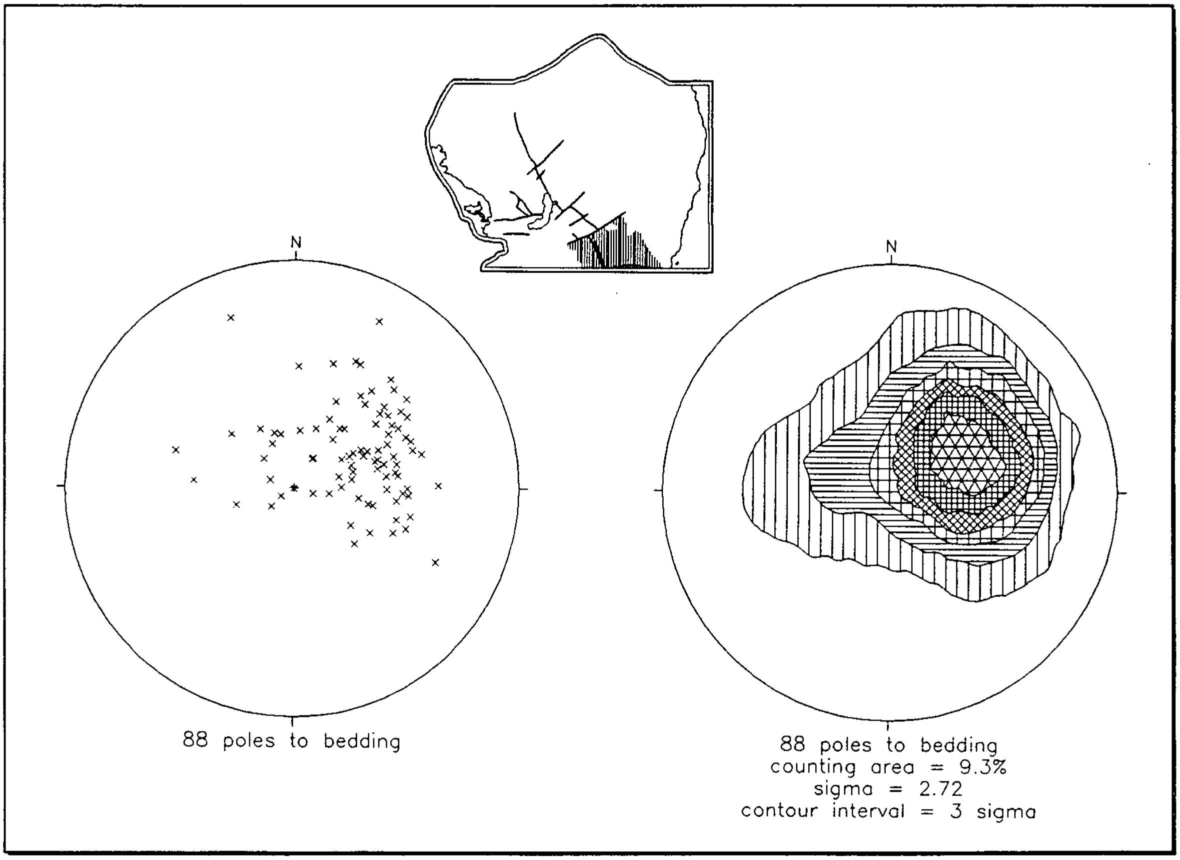


Figure 3-10. Stereonet-plot of the poles to bedding measurements in domain 6.

3.3. Structural synthesis

3.3.1. Introduction

The first phase of deformation that involved the major part of the Cretaceous rocks in the central Graham Island area was a Late Cretaceous to Early Tertiary event. There are however, indications from the map that some deformation may have preceded this event. These indicators are not conclusive enough to support a hypotheses of a total separate event. The findings that attest these earlier deformations are nevertheless of such an interest and significance that they will be presented and discussed.

The clue to this early deformation is found in domain 3 and north of there. A thrust fault that places the Middle Jurassic Yakoun Group on top of the Cretaceous sandstone unit cuts an older northwest striking fault. The thrust fault is assumed to be a result of the same deformation that created the majority of northwest trending compressional structures in the area. The other fault must then be a remnant of an older deformation event caused by a northwest-southeast directed extensional or compressional regime. There is no other structure within the central Graham Island that can be correlated with this fault, and any more detailed interpretations are not credible from the data.

Studies of rocks elsewhere on the islands shows that there has been several phases of compression and block faulting after deposition of the Cretaceous strata. Four phases of deformation have been recognized by Lewis (1990) in Late Cretaceous and Tertiary rocks of the Long Inlet area. These are : 1) Late Cretaceous to Early Tertiary compression; 2) extensional faulting postdating the above shortening, and predating Eocene/Oligocene time; 3) Oligocene compression; and 4) post-Oligocene block faulting.

Both periods of compression were northeast directed, and it is impossible to relate the compression observed in central Graham Island to a specific compressional event. The accurate time control on deformational events of Late Cretaceous and Tertiary time is only possible in the Long Inlet area, where good control exists on the absolute age of the rock units. The four different phases of deformation might account for the observed geometry of domain 3. If the thrust fault is related to the second of the northeast directed compressions (and not the Late Cretaceous to Early Tertiary event), then the fault that is cut by the thrust is related to the first period of block faulting.

3.3.2. Late Cretaceous to Tertiary compression

The first deformation that had regional effects on the Cretaceous rocks of the central Graham Island area was a Late Cretaceous to Tertiary compressional event. This compression is especially notable in domain 2 and 4, and is also recorded in the rocks of domain 1 and 5. The syncline on the ridge in domain 1 is interpreted as being the result of this compression, as is the folding in the Cretaceous sandstone and shale units of domain 5 (Figure 3-11). These structures all have a northwest trend. These folds are the only folds of their domain, no other structures are directly structurally related to any of them.

Structures in domain 2 and 4 have the same northwesterly trend, and the deformation is more intense in these areas. Both axial planar cleavage and small scale folds are developed in parts of these domains. Bedding in domain 4 is vertical to overturned in places (Figure 3-6). Wavelength of the folds in these domains varies from less than 10 metres to some hundred metres.

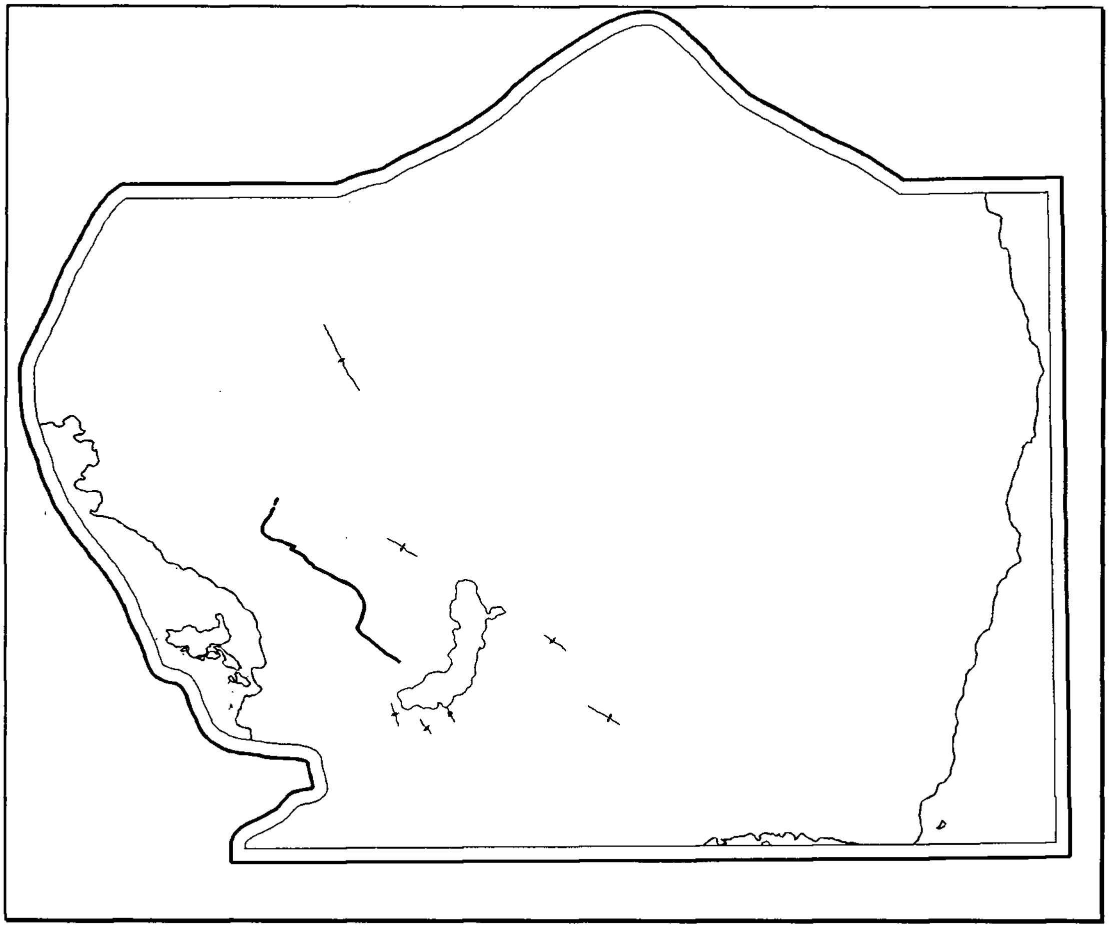


Figure 3-11. Map showing the mesoscopic structures of the Late Cretaceous to Early Tertiary compressional deformation event.

Even though there is a distinct difference in style and intensity of deformation between the two different sets of domains, it is believed that the structures are products of the same deformational event. Shortening of the Cretaceous units in the central Graham Island is not accommodated homogeneously throughout the area, but rather located in a few strongly deformed belts. These belts take up the dominant amount of strain, and large areas seem to be almost unaffected by the compression. Location of these deformation zones is probably related to older structures that have become reactivated. These older structures are remnants of Middle Jurassic or older deformation events (Hesthammer, 1991b; Lewis, 1991), and they acted as zones of weaknesses in the crust, that were favorable for further deformation at the initiation of a new compressional regime. Deformation of Cretaceous rock units elsewhere in the islands is also located in strongly deformed zones separated by gently deformed areas. This is very notable in the Kagan Bay and Long Inlet area southwest of the map area (Lewis, 1988, 1991; Thompson and Thorkelson, 1989).

The intensity of folding in domain 2 (Figure 3-6) is likely a result of the reactivation of the large northwest striking fault east of the domain. This fault was probably active during the Middle Jurassic deformation event (Hesthammer, 1991b) and seems to have been reactivated at several later stages of the structural history of the area. The deformation, recorded the pre-Cretaceous rocks of the central Graham Island (Hesthammer, 1991b), has the same orientation as the younger structures. At least one deformation period recorded in the Triassic and Jurassic rocks of the area preceded deposition of the Cretaceous units. This event resulted in northwest trending folds and thrust faults and northeast trending strike-slip faults (Hesthammer, 1991b; Hesthammer et al., 1991a; Indrelid et al., 1991b). Reactivation of older structures during the compression in Late Cretaceous to Tertiary time, resulted in the folding of the Cretaceous rocks on the west side of the fault.

It is likely that the thrust fault in domain 3 also relates to this Late Cretaceous to Tertiary deformation event (Figure 3-11). This fault and the folds in domain 4 are both cut by a later east-west striking fault along Sandstone Creek.

Limited exposures and data available from the central Graham Island area makes any attempt at determining the absolute timing of this deformation impossible. Work elsewhere in the island especially along shorelines has constrained this deformation event to Late Cretaceous and Early Tertiary or Oligocene age (Lewis, 1990; Thompson et al., 1991).

3.3.3. First period of Tertiary block faulting

The study area is cut by several northwest striking macroscopic faults. The most prominent one makes up the eastern boundary of domain 1, 2, 4, and 5. This fault displaces Cretaceous rocks on the western block down relative to the Jurassic rocks of the eastern block (Figure 3-12). It also marks the eastern limit for structural studies of this thesis. Other faults of the same generation include the two faults of domain 6, the faults in the western part of domain 5, and the faults on the south shore of Yakoun Lake in domain 4. All these faults strikes towards the northwest (Figure 3-12).

The long northwest striking fault that limits domain 1, 2, 4, and 5 has not been directly observed in central Graham Island, but the distribution of rocks requires this fault to be present throughout the study area. From map patterns and geometric relations to other faults of the area, it is inferred that this is a steeply dipping normal fault. Offset along the fault is greatest in domain 5, where it juxtaposes rocks of the uppermost Triassic and Lower Jurassic Sandilands Formation against conglomerate of the Upper Cretaceous Honna Formation. The Cretaceous section is at least 1000 metres thick in this area, which gives a minimum displacement on the fault. This fault is likely a reactivated older structure that was active in the earlier Jurassic deformation as well (Hesthammer, 1991b).

None of the other macroscopic faults is exposed, and it is not possible to obtain information on fault offset from outcrops. Offset on one of the faults in domain 6 is at least 400 metres. It is not possible to get accurate calculations on the offset of the other faults, but neither are larger than the easternmost fault. It is impossible to verify that these faults are reactivated older structures are influenced by deeper, older structures, but it seems likely based on the deformation style in the rest of the area.

The deformation responsible for the northwest striking normal faults is younger than the Late Cretaceous to Early Tertiary compression. It is not possible to determine to which of the two block faulting periods of Lewis (1990) it relates to.

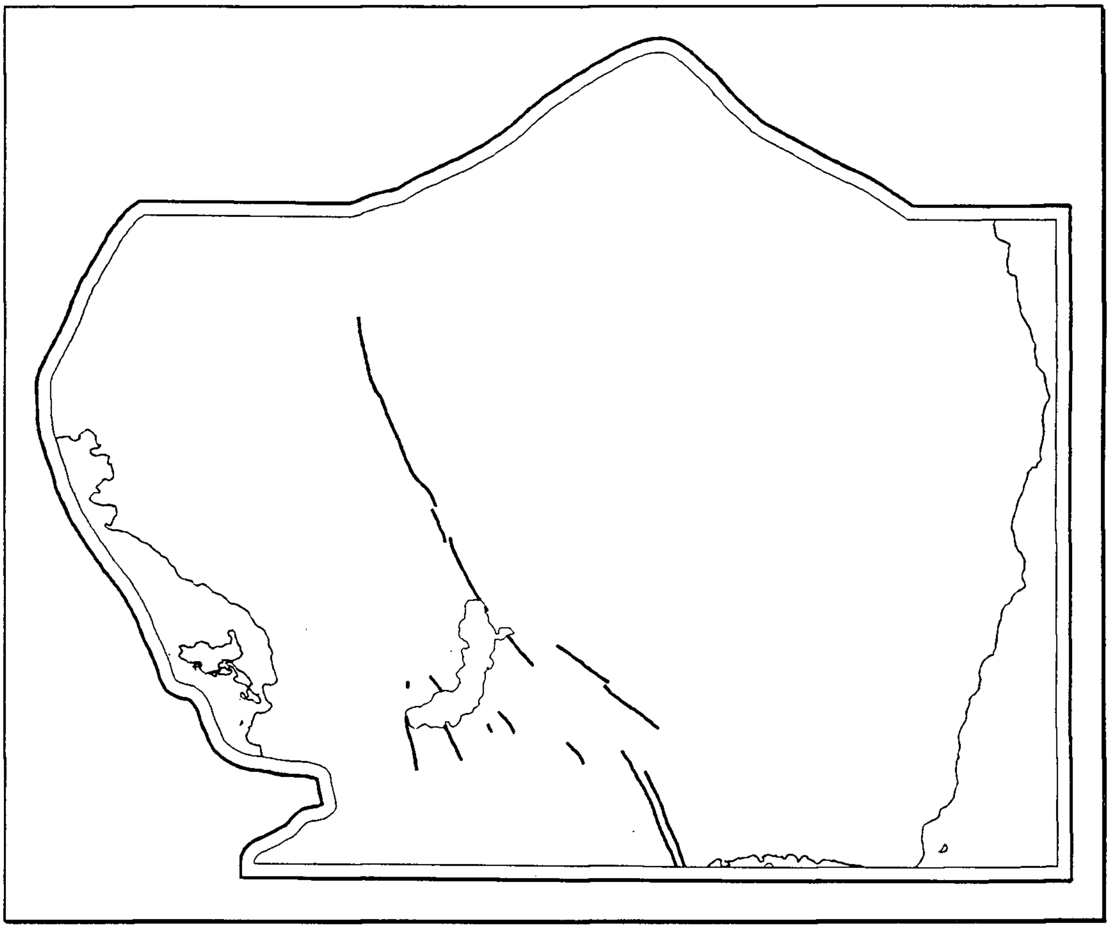


Figure 3-12. Map showing the mesoscopic structures of the first period of Tertiary block faulting event.

3.3.4. Second period of Tertiary block faulting

Cutting both the northwest trending folded deformation belts of the compression phase and the northeast trending block faults is a set of northeast striking faults (Figure 3-13). To this category belongs the fault that separates domains 4 and 5, and domain the domain 5 and 6. The fault that makes up parts of the border between domains 1 and 2, and the fault south of it also are part of this set. Most of these faults have their southern block relatively downdropped. There is most likely a major dip-slip component on these faults, although strike-slip can account for the offset on some faults.

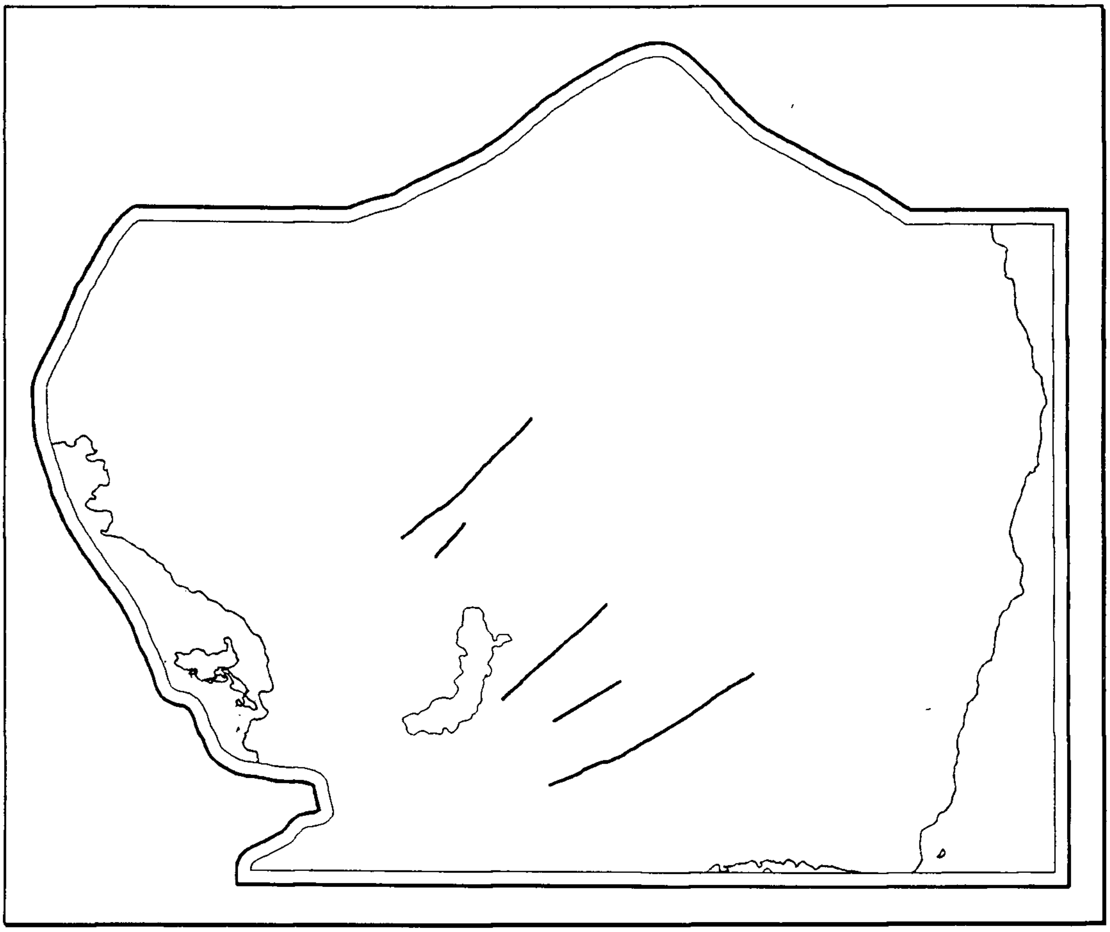


Figure 3-13. Map showing the mesoscopic structures of the second period of Tertiary block faulting event.

The northeast striking faults have been interpreted as strike-slip faults on the lateral edges of thrust sheets involved in the Middle Jurassic shortening event (Hesthammer, 1991b, Indrelid et al. 1991b). These faults are later reactivated and extended, and in addition new faults developed parallel to the older ones. Reactivation of one of the older faults and the initiation of a new one, might have influenced the folding in domain 2. The intensity of deformation is closely related to the position of the two northeast trending faults. Farther north in domain 1, the folding is not nearly as strong.

Timing of this deformation is poorly constrained. It is not known if these faults cut any of the Tertiary rocks in the central Graham Island area. If the northeast striking faults do cut the Tertiary rock package the faults might be of the same age as the one in Sandstone Creek and on Mount Matlock.

Third period of Tertiary block faulting (?).

The faults along Sandstone Creek and north of Mount Matlock are not parallel with the ones farther east (Figure 3-14). The southernmost of these two cuts through the Tertiary section, and is located less than a kilometre south of a location that yielded pollen of probable mid-Miocene or younger age (Haggart et al., 1990). These field observations suggest that there is evidences for block faulting of Neogene age in the central Graham Island area. Lewis (1990) observed block faulting of post-Oligocene age farther south on Graham Island, in the Long Inlet area. In the easternmost part of the map area a fault cuts the Skonun Formation which is believed to be of Upper Oligocene to Lower Pliocene, which dates this fault as possible Neogene as well.

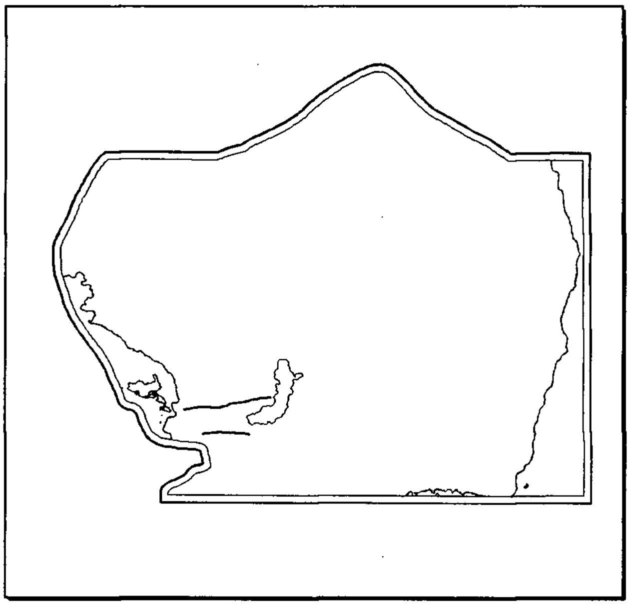


Figure 3-14. Map showing the mesoscopic structures of the third (?) period of Tertiary block faulting event.

The fault in Sandstone Creek is parallel to the one on Mount Matlock, but does not have a good age constraint from the field data. The only connection between the two faults is their orientation, and there are no other macroscopic faults with similar orientation. The fault in Sandstone Creek has more offset than the one farther south, and if they are of the same origin it shows that the offset on the Neogene faults can be large. It should be stressed however, that this is based on only two faults and that more data is needed to build a solid proof for this deformation in the central Graham Island area.

The more easterly trend of these faults might be a result of preexisting structures in the basement rocks. And if these faults are of the same generation as the northeast trending ones, it constrains the timing for this fault set to Neogene or younger.

4. PETROLEUM POTENTIAL

When the Frontier Geoscience Program of the Geological Survey of Canada was initiated one of the main objectives was to establish the character and distribution of source- and reservoir-type rocks. These properties have been studied by several other geologists, but no one has directed these problems to the Cretaceous rock sequence in the central Graham Island area. The following chapter deals with the potential that the Cretaceous rocks in this area might have for petroleum exploration. The work presented here is only a brief study to investigate if any promising units are present that can warrant a more detailed study at a later stage.

This study involves Rock-Eval® pyrolysis for determination of possible rock units with source rock potential. Visual porosity estimates from thin section studies and Scanning Electron Microscope investigation was used to study the reservoir potential of the Cretaceous rock units in the central Graham Island area.

4.1. Source rock potential

The rock column in the Queen Charlotte Islands contains a thick sequence of sedimentary rocks which includes several potential source rock units. Numerous oil seeps have been observed that indicates hydrocarbons have been generated. These hydrocarbons may have accumulated in commercial quantities (Cameron and Tipper, 1985; Bustin and Macauley, 1988, Snowdon at al., 1988, Vellutini, 1988; Hamilton and Cameron, 1989).

Bustin and Macauley (1988) studied the source rock potential of the Lower Jurassic oil shales of the Sandilands and Ghost Creek formations in the central Graham Island and Skidegate Inlet area, and documented good prospects for these rock units. Snowdon et al. (1988) looked at the oil seeps in the Tertiary strata. A regional study of the source potential for the entire stratigraphic sequence in the islands was done by Vellutini (1988) and Vellutini and Bustin (1991). The work of Vellutini spanned the complete stratigraphic column and samples were collected over wide areas. Due to the relatively limited area covered by the Frontier Geoscience Program mapping at the time and the extent of his study, Vellutini did not sample the Cretaceous section in the central Graham Island area. The present study is not intended to be a complete investigation of the petroleum source potential of the Cretaceous sequence, but rather a supplement to the work done by Vellutini (1988).

4.1.1. Methods

Shale samples were collected from outcrops during the 1989 field season, and the samples from 15 outcrops were analyzed by Rock-Eval® pyrolysis (Espitaliè et al., 1977;

Peters, 1986). Geochemical data from Rock-Eval® pyrolysis (Espitaliè et al., 1977) can be used to determine type, quantity, and thermal maturity of organic matter in sedimentary rocks (Tissot and Welte, 1984). Attempts were made to only use the freshest and least weathered parts of the samples in order to avoid problems with oxidation of the organic matter and contamination of the samples. "Whole rock" samples were crushed prior to analyses. Two series of analyses the were performed on crushed samples from each outcrop to minimize flaws and uncertainties in the method. Numbers gained from the two different runs of samples were fairly consistent in most of the measured and calculated parameters (Appendix 7.2). However, one series of analyses appears not to have recorded the S3 peaks properly resulting in unusable results for quality of organic matter (QOM).

Measured parameters

Several data that are provided by the Rock-Eval® pyrolysis can be used to indicate potential hydrocarbon source rocks (Appendix 7.2). The S1 peak (mg HC/g rock) is representative for the hydrocarbons distilled from the whole rock, and is a measure of free hydrocarbons (oil and gas) released during pyrolysis. The S2 peak (mg HC/g rock) represents hydrocarbons produced by cracking of heavy hydrocarbons (kerogens) during pyrolysis, and indicates the samples' potential for producing hydrocarbons. Depletion of S1 and S2 often occurs in outcrop samples, where the organic matter oxidizes. The S3 peak (mg HC/g rock) is a measure of quantity of volatilized carbon dioxide produced by cracking of kerogens during pyrolysis.

T_{max} is the temperature at which maximum hydrocarbon generation may occur during pyrolysis. This temperature corresponds to the maximum on the S2 peak, and is the temperature at which the largest amount of hydrocarbons are released by thermal cracking. The temperature reflects the degree of thermal maturation. Oil production is initiated at T_{max} temperatures between 430-435^{0}C for Type II and III organic matter. Oil production ends at the T_{max} value of 450^{0}C for type II and at 465^{0}C for Type III organic matter (Espitaliè et al., 1977).

Total organic carbon content (TOC) is found by oxidation of the residual organic matter in air and is found by summing the S1, S2, and S3 peaks (Espitaliè et al., 1977). Depletion of S1 and S2 often occurs in outcrop samples, where the organic matter oxidizes. The production index (PI) is defined as S1/(S1+S2).

Calculated parameters

In addition to the parameters measured directly from the Rock-Eval® pyrolysis, some calculated parameters can be used to determine the quality of source rocks (Appendix 7.2). The hydrogen index (HI) is defined as S2/TOC, and corresponds to the quantity of pyrolyzable hydrocarbons from the S2 peak relative to the total organic carbon (TOC). The oxygen index (OI) is defined as S3/TOC, and reflects the quantity of carbon dioxide from S3 relative to total organic carbon (TOC). OI values can be questionable for samples with TOC <0.5% (Peters, 1986). The hydrogen index and oxygen index are together used to classify organic matter in a hydrogen index/oxygen index (HI/OI) diagram (Espitaliè et al., 1977). Samples with low HI and OI values are overmature and it is not possible to determine the type of the organic matter. Values of HI over 600 mg HC/g C_{org} are indicative of oil prone Type I organic matter; values between 300 and 600 mg HC/g C_{org} suggest oil and gas prone Type II organic matter and HI values less than 300mg HC/g C_{org} indicate gas prone Type III organic matter (Espitaliè et al., 1977).

The quality of organic matter (QOM) is defined as (S1+S2)/TOC and is used to measure thermal maturity and to determine the type of organic matter. The QOM vary with the type of organic matter, degree of maturity, and effects of hydrocarbon migration (Espitaliè et al., 1985). High QOM values indicate an immature to mature hydrogen-rich type of organic matter.

4.1.2. Results

The following discussion focuses on the hydrocarbon source potential of selected Cretaceous units. A hydrocarbon source rock is a stratum that is capable of producing migratable hydrocarbons (Conford, 1984). This potential is primarily controlled by quantity, quality, and thermal maturation of the organic matter in the stratum (Espitaliè et al., 1977; Durand and Monin, 1980; Conford, 1984; Tissot and Welte, 1984; Espitaliè et al., 1985).

The measured and calculated source rock parameters from the Rock-Eval® pyrolysis is summarized in appendix 7.2. T_{max} is only reported in samples where the S2 value is higher than 0.2 mg HC/g C_{org} which is considered the minimum value for accurate T_{max} determination (Peters, 1986). Two sets of data are presented from each outcrop sample.

All samples that were tested by Rock-Eval® pyrolysis are argillaceous and that has one important effect on the results. For argillaceous samples that contain less than 0.5% TOC (which is the case for most of the samples here) the data will be affected by the adsorption of pyrolytic compounds onto the surface of clay particles (Peters, 1986). This effect tends to lower the HI and S2 values and increase the T_{max} and OI values.

This should be kept in mind when interpretations and comparison between different parameters are made.

4.1.2.1. Cretaceous shale unit

Almost every shale sample that was tested by Rock-Eval® pyrolysis have a S2 value that is too low to allow an accurate estimation of T_{max}; only two samples had S2 >0.2 mg HC/g C_{org}. The two values that were given by the test are very inconsistent with each other, and are regarded to be of too poor quality for any conclusions to be made. The low PI value (<0.02) indicates that the strata are thermally immature.

HI values in the range from 0-61 mg HC/g C_{org}, and S2/S3 values averaging 1.6 indicate that the rocks of this lithology are gas prone when producing hydrocarbons. A couple of samples have some potential for producing oil, but the average for the shale is gas prone.

The low value of TOC (<0.47%, average is 0.25%),S1 (<0.04 mg HC/g rock), and S2 (< 0.026 mg HC/g rock) indicates that the Cretaceous shale is a poor source rock with very limited potential of having generated hydrocarbons in commercial quantities.

4.1.2.2. Skidegate Formation

Only a few samples of the Skidegate Formation were examined by Rock-Eval® pyrolysis, and the limited number of data makes any major conclusions presumptive. No sample had an high enough S2 to calculate the T_{max} with assured accuracy. The PI value is zero in all samples and indicates that the Skidegate Formation is immature in the central Graham Island area.

The average HI value is 1.5 mg HC/g C_{org} with maximum value being 6 mg HC/g C_{org}, together with the low S2/S3 value (<0.16) indicates that the Skidegate Formation is gas prone.

The TOC values are in the range of 0.13-1.06% for the samples of the Skidegate Formation. Of the two different locations tested, one has TOC values up to 1.06% indicating that it is a good source rock. The S1 and S2 values for this locality both equal zero which implies that the rock is a very poor source rock. This apparent contradiction may result from a relatively high S4 value in the calculation for TOC (TOC=[0.83x(S1+S2)+S4]/10, where S4 is amount of CO_2 produced during oxidation). Low S1 and S2 values can be expected from outcrop samples due to oxidation of the organic matter. The TOC value will also increase if there is recycled organic matter present in the samples. Recycled organic matter will result in a high TOC with no corresponding high S1 and S2 values (Peters, 1986). The other locality of Skidegate Formation has a TOC of less than 0.15%, this together with low S1 (<0.1 mg HC/g C_{org})and S2 (0.01 mg HC/g C_{org}) values also suggests a poor source rock potential for these rocks.

4.1.2.3. Honna Formation

The two sample locations examined by Rock-Eval® pyrolysis from the Honna Formation are both from the same outcrop. One is from the mud parts of a turbidite facies intercalated with typical Honna Formation conglomerates. The other sample comes from turbidites conformably overlying the conglomerates (Figure 2-40). The top of these turbidites is not exposed and it cannot be determined if these also are turbidite facies within the normal Honna Formation lithologies or if they are part of a thicker sequence of Skidegate Formation overlying the conglomerate. Indications for interbedded nature of the Skidegate and Honna formations have been recorded by field mapping.

The S2 values were sufficiently high in all four samples for determination of T_{max}. The values for T_{max} are consistent and average about 485°C, this temperature is indicative of thermally overmature strata. The PI values averages about 0.05 and all recorded PI are lower than 0.1 indicating that the same rocks are thermally immature. Both T_{max} and PI are partly dependent on other factors than maturity and both are rather crude measurements for thermal maturity of source rocks. T_{max} will change with weathering and oxidation of samples (oxidation gives higher T_{max}). Immature rocks dominated by recycled organic matter will have a higher T_{max} than what is expected as actual maturity of the sediment (Peters, 1986). When the results from Rock-Eval® pyrolysis are contradictory as in this case, conclusions on thermal maturity of a hydrocarbon source should be supported by use of other analyses such as vitrinite reflectance and thermal alteration index.

The HI values for the turbiditic shale interbeds in the Honna Formation are all lower than 68 mg HC/g C_{org}, which suggests that the rocks are gas prone. The S2/S3 parameter was found only for two samples and the two values are not agreeable. One value (S2/S3 = 4.75) implies that this sample is gas and oil prone, the other result (S2/S3 = 36.5) suggests that sample is very oil prone. Both these samples are however gas prone according to their HI values. This contradiction probably resulted from the S2/S3 values being too high. HI is defined as S2/TOC, and if high S2 parameter was the reason for the anomalous high S2/S3 value, then HI should also be high which is not the case. This indicates that the problem is due probably to inaccurate measurement of S3. The S3 parameter was obviously a problem in one of the two series of analysis, and might have been inaccurate in both series. The S3 parameter is very susceptible to instrumentation problems (Peters, 1986).

The TOC level for these rocks are the best ones for any of the samples examined. The average TOC is 1.03%, with the values falling in the range form 0.72 to 1.51%, indicating a fair to good source of hydrocarbons. The S1 and S2 parameters do not support this optimism for good source rock potential. Low S1 values (<0.2 mg HC/g C_{org}) and low S2 values (<0.8 mg HC/g C_{org}) both classify these rocks as poor source rocks. The problem with relating the values of TOC and the S1 and S2 peaks here is probably due to the same reason as was discussed in the paragraph dealing with source rock potential of the Skidegate Formation.

4.2 Reservoir rock potential

The rock sequence in the Queen Charlotte Islands contains several sandstone units that have been examined for hydrocarbon reservoir potential. The abundance of pore filling clay is the major contributor to the reduction of porosity and also the main reason why not many prospective reservoir rock units have been found in the islands.

The primary target for hydrocarbon reservoir in the Queen Charlotte Basin is the Tertiary Skonun Formation (Shouldice, 1971; Higgs, 1989). Yorath and Cameron (1982) suggested that the middle to Upper Cretaceous rock sequence in the Queen Charlotte Islands might contain promising reservoir potential. Haimila and Procter (1982) suggested that the middle to Upper Cretaceous could hold reservoir potential in Dixon Entrance, Hecate Strait, and Queen Charlotte Sound. Fogarassy (1989) found that the "basal Haida" had good reservoir potential and that the "lower Haida sandstone" was of marginal potential for petroleum reservoir rock. It is unclear exactly which lithology the "basal Haida" is and whether this lithology occurs in central Graham Island at all. He also concluded that no other Cretaceous rock units was prospective for hydrocarbon reservoir.

4.2.1. Methods

The studies for potential hydrocarbon reservoir rocks involved estimate of visual porosity in thin sections. All thin sections of sedimentary rocks were vacuum impregnated with blue dyed epoxy resin to aid in visual porosity estimates (Yanguas and Paxton, 1986). Ten % visual porosity is regarded as the minimum requirement for a rock unit to be classified as a good reservoir rock. The evaluation of per cent porosity in a given thin section was based purely on visual estimate. The author did not feel that a point count would significantly increase the validity of the results. To get full value of a point count more thin sections would be needed because the uncertainties in having a low number of samples would overshadow the accuracy of the point count procedure. Scanning Electron Microscope and Energy Dispersive Spectrometer were used to study the pore spaces and pore filling material.

4.2.2. Results

4.2.2.1. Cretaceous sandstone unit

Thick sections of sandstones are observed at numerous localities in the study area, and several thin sections were cut from this unit. Porosity in outcrop samples of this unit is very poor (Figures 2-6, 2-8, 2-9, 2-10, 2-16, 2-17, and 2-19). The porosity is never seen to surpass 5% and is frequently less than 1%. Most samples are rich in chlorite clay, which effectively plugs pore spaces. Where chlorite has not destroyed the porosity, calcite cement fills the inter-clast areas. There are good sources for calcite within the sandstone unit, which is rich in carbonaceous fossil fragments (Figure 2-24).

The conglomerate lithology of the Cretaceous sandstone unit is the rock type with the best observed secondary porosity. Several thin sections of the conglomerate facies show extensive dissolution of potassium feldspars (Figure 4-1). It has been shown by Surdam et al. (1984) that dissolution of aluminosilicate and carbonate can occur during thermal maturation of kerogen. There is a possibility that the observed secondary porosity was developed by a process other than dissolution at surface to sub-surface level. Fogarassy (1989) suggested that secondary porosity might have an influence on the prospect of Cretaceous rocks in the Queen Charlotte Islands. The eventuality for favorable development of dissolution porosity increases where the Cretaceous rock units are deposited in close proximity to the good source rocks of early Jurassic age.

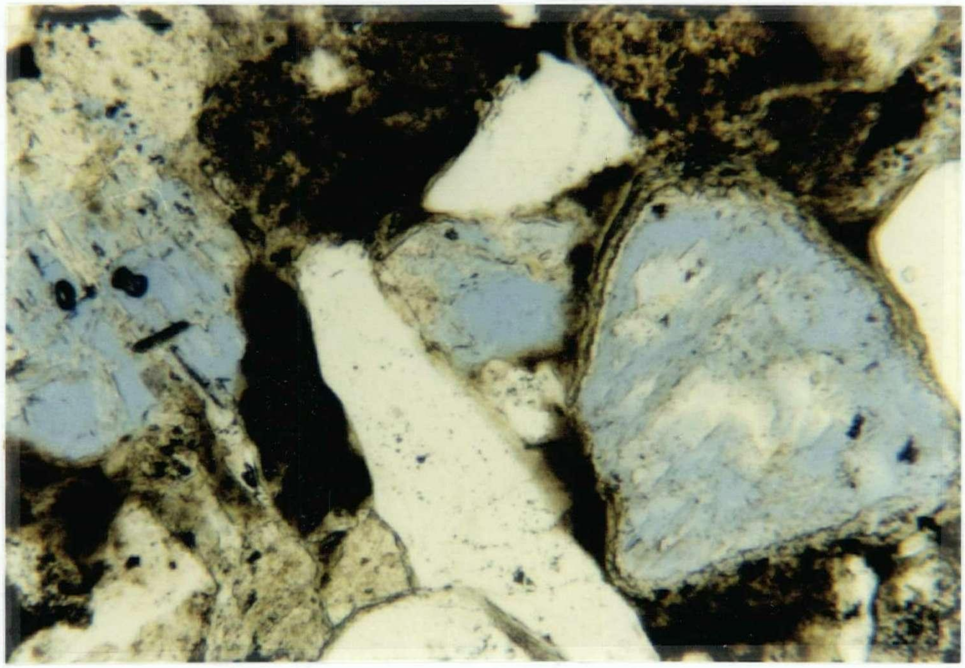


Figure 4-1. Thin section photomicrograph of the pebble conglomerate facies of the Cretaceous sandstone unit. The amount of secondary porosity development observed here is the highest found in any units of the central Graham Island area (plane polarized light, x280 magnification).

4.2.2.2. Cretaceous shale unit

The best porosity observed in any of the Cretaceous rocks in the central Graham Island area is in the sandstone layers of the Cretaceous shale unit. On average the porosity does not surpass 4-6%, but in extreme cases the visual porosity in these sandstone can exceed 20% (Figure 4-2). These sandstone layers have generally less chlorite clay than the sandstone of the Cretaceous sandstone unit. Strata extremely rich in fossil fragments which can be found in the sandstone unit are also less common in the sandstones of the shale unit.

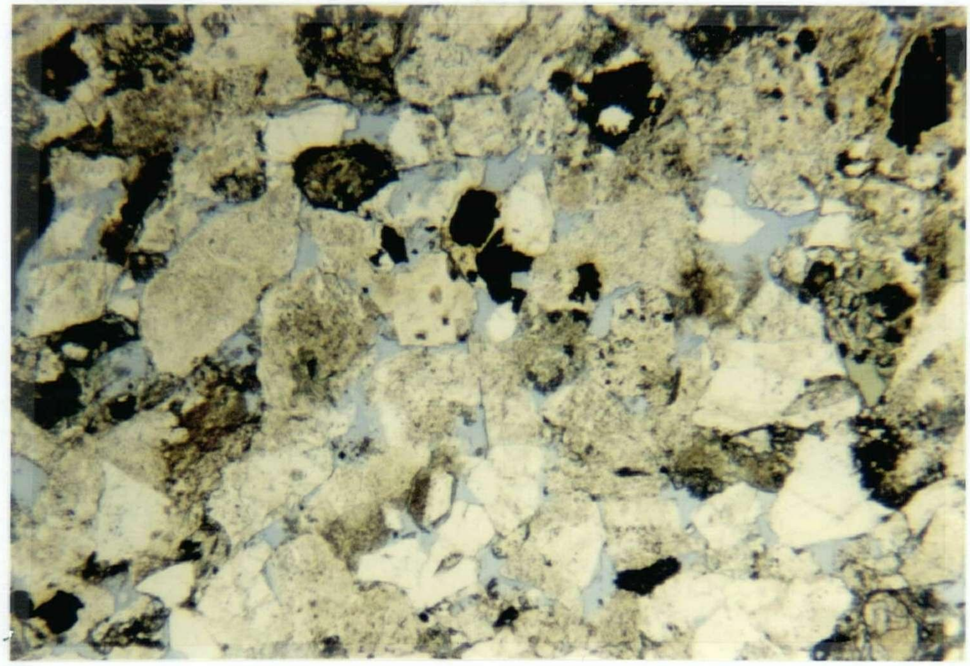


Figure 4-2. Thin section photomicrograph showing good porosity in a sandstone of the Cretaceous shale unit. Porosity is shown as blue epoxy (plane polarized light, x70 magnification).

Sandstone layers in the shale unit are normally 50 centimetres to one metre thick and are found interbedded with siltstone and shale in up to 30 metres thick interval. In these intervals up to 35 % of the rock volume are sandstones. These sandstone beds are over- and underlain by shale that might operate as an effective seal when hydrocarbons make their way into the sandstone layers. The problems in targeting these sandstones as potential hydrocarbon reservoir rocks are the limited abundance and thickness of suitable intervals.

4.2.2.3. Skidegate Formation

The Skidegate Formation is not a prospect as a hydrocarbon reservoir rock. Its thinly bedded shale-siltstone-sandstone character, together with almost no visual porosity (Figure 4-3) give it very poor reservoir properties. The sandstone layers are seldom thicker than 4-5 centimetres, and porosity has not been observed to be more than 3%.

Figure 4-3. Thin section photomicrograph showing the typical lack of porosity in the Skidegate Formation. The photo covers a fining upward sequence from sandstone to shale (plane polarized light, x70 magnification).

4.2.2.4. Honna Formation

As is characteristic for almost all Cretaceous units in the central Graham Island area, porosity is sparse in the rock units of the Honna Formation. The sandstones of this unit have a very low level of pore filling clay compared to the rest of the Cretaceous sandstones. However, most pore spaces have been filled with carbonate cement. The Honna sandstone found on the eastern shore of Yakoun Lake has a very high content of quartz and feldspar compared to the mean for Cretaceous sandstones, but the potential for a high porosity percentage is ruined by extensive calcite cementation (Figures 2-49 and 2-54).

4.3 Summary

The Cretaceous strata of the central Graham Island area are neither good source rocks nor reservoir rocks. The TOC, S1, and S2values of the Rock-Eval® pyrolysis for the units are too low to make the strata potential prospects for hydrocarbons. The Cretaceous strata are mostly prone to produce gas when thermally maturated, only a few samples were oil prone.

The porosity of the Cretaceous units in surface outcrops are very low. Most samples have less than 3% visual porosity in thin sections. The pore spaces are mostly filled with clay minerals, chiefly chlorite clay. In some of the sandstones of the Honna Formation, where chlorite is not as abundant as in the other units, the pore spaces are filled with calcite. Best porosity was observed in the sandstones of the Cretaceous shale unit. Locally the porosity in these sandstones were excellent, exceeding 20% in one area. Secondary porosity is generally not well developed, but has enhanced the visual porosity in a few samples of the Cretaceous sandstone unit.

5. CONCLUSIONS

The major conclusions and contributions to the understanding of stratigraphy, structural geology, and petroleum potential of the Cretaceous rock sequence in the central Graham Island are:

1) Detailed mapping of the central Graham Island area has shown that Cretaceous rocks are more widely distributed throughout the area than previously recognized.

2) The Cretaceous rock sequence of the area is divisible into four major units, some of which can further be divided into mappable lithofacies. The proposed new stratigraphical scheme is based on lithological properties of the rocks and eliminates the need for fossil identification for geological mapping.

3) The base of the Cretaceous section consist of the Cretaceous sandstone unit, which can be divided into three lithofacies; massive sandstone, grey sandstone, and bioturbated sandstone lithofacies. Each of the three lithofacies is lithological distinct.

4) Conformably overlying and locally interbedded with the Cretaceous sandstone unit is the shale, silty shale, and minor sandstone interbeds of the Cretaceous shale unit.

5) Turbidites of the Skidegate Formation are interbedded with the upper part of the Cretaceous shale unit. In the southwestern part of the study area, the Cretaceous shale unit overlies the Skidegate Formation.

6) Coarse clastic rocks of the Honna Formation locally overlie, interfinger with, and underlie rocks of the Skidegate Formation. There is always a close spatial relationship between these two formations.

7) The first major deformation recorded in Cretaceous strata is a northeasterly directed compression. Deformation of the Cretaceous strata is localized in highly deformed belts separated by areas of almost undeformed rocks. The location of the deformation belts in the Cretaceous rock sequence is closely related to older weakness zones in the underlying Triassic and Jurassic rocks.

8) The first Tertiary block faulting event resulted in northwesterly-trending faults parallel to the older compressional structures.

9) Younger Tertiary block faulting created northeast and east trending faults, cutting all other structures in the area.

10) The Cretaceous rock sequence in the central Graham Island area does not contain any potentially good hydrocarbon source rocks. The TOC, S1, and S2 values from Rock-Eval® pyrolysis are low for all units.

11) Visual porosity is very low in Cretaceous sandstones. The only rocks that show some promising porosity are sandstones of the Cretaceous shale unit, where visual porosity locally exceeds 20 %.

6. REFERENCES

Anderson, R.G. and Greig, C.J.
1989: Jurassic and Tertiary plutonism in the Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 95-104.

Anderson, R.G. and Reichenbach, I.
1989: A note on the geochronometry of Late Jurassic and Tertiary plutonism in the Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 105-112.

1991: U-Pb and K-Ar framework for Middle to Late Jurassic (172->158 Ma) and Tertiary (46-27 Ma) plutons in Queen Charlotte Islands, British Columbia; *in* Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia, Geological Survey of Canada, Paper 90-10, p. 59-87.

Bouma, A. H.
1962: Sedimentology of some flysh deposits. Amsterdam, Elsevier, 168p.

Bustin, R.M. and Macauley, G.
1988: Organic petrology and Rock-Eval pyrolysis of the Jurassic Sandilands and Ghost Creek formations, Queen Charlotte Islands; Bulletin of Canadian Petroleum Geology, v. 36, p. 168-176.

Cameron, B.E.B. and Hamilton, T.S.
1988: Contributions to the stratigraphy and tectonics of the Queen Charlotte Basin, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 221-227.

Cameron, B.E.B. and Tipper, H.W.
1985: Jurassic stratigraphy of the Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 365, 49 p.

Champigny, N. and Sinclair, A.J.
1982: The Cinola gold deposit, Queen Charlotte Islands, British Columbia; *in* Geology of Canadian Gold Deposits, R.W. Hodder and W. Petruk (ed.), Canadian Institute of Mining and Metallurgy, Special Volume 24, p. 243-254.

Clapp, C.H.
1914: A geological reconnaissance on Graham Island, Queen Charlotte group, B.C.; Geological Survey of Canada, Summary Report, 1912, p. 12-40.

Conford, C.
1984: Source rocks and hydrocarbons of the North Sea; *in* Introduction to the Petroleum Geology of the North Sea; Glennie, K.W. (ed.), London, 236p.

Crawford, M.L., Hollister, L.S., and Woodsworth, G.J.
1987: Crustal deformation and regional metamorphism across a terrane boundary, Coast Plutonic Complex, British Columbia; Tectonics, v. 6, p. 343-361.

Curran, H.A.
1985: Biogenic structures: their use in interpreting depositional environments; Society of Economic Paleontologists and Mineralogists, Special Publication, No. 35.

Dawson, G.M.

1889: On the earlier Cretaceous rocks of the northwest portion of the Dominion of Canada; American Journal of Science, 3rd Series, v. 38, p. 120-127.

1880: Report on the Queen Charlotte Islands, 1878; Geological Survey of Canada, Report of Progress for 1878-79, p. 1B-239B.

Dickinson, W.R.

1970: Interpreting detrial modes of graywacke and arkose; Journal of sedimentary petrology, v. 40, No. 2, p.695-707.

1982: Composition of sandstones *in* circum-Pacific subduction complexes and fore-arc basins; American Association of Petroleum Geologists, Bulletin, V. 66, No. 2, p. 121-137.

Dickinson, W.R., Beard, E.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindgerg, F.A., and Ryberg, P.T.

1982: Provenance of North American Phanerozoic sandstones in relation to tectonic setting; Geological Society of America, Bulletin, v. 94, p. 222-235.

Dietrich, R V. and Skinner, B.J.

1979: Rocks and rock minerals, John Wiley and Son, New York, 319p.

Dostal, J. and Hamilton, T.S.

1988: Oceanic volcanism in the western Canadian continental margin: Masset Formation (U.Eocene-U,Miocene); Geological Association of CAnada, Annual Meeting, St. John's, Newfoundland, Program with Abstracts, v. 13, p. A33.

Durand, B. and Monin, J.C.

1980: Elemental analysis of kerogens (C,H,O,N,S,Fe) ; *in* Kerogen, Durand, B. (ed), Paris, Editions Technip, p. 113-142.

Ells, R.W.

1906: Report on Graham Island, B.C.; Geological Survey of Canada, Annual Report, New Series, v. 16, 1904, Part B, p. 1-46.

Engebretson, D.C., Cox, A., and Gordon, R.G.

1986: Relative motions between oceanic and continental plates in the Pacific basin; Geological Society of America, Special Paper 206.

Espitalie, R., Deroo, G., and Marquis, F.

1985: Rock-Eval pyrolysis and its implications; Institut Francais du Petrole, reprint No. 27299, 132 p.

Espitalie, R, Madec, M. and Tissot, B

1977: Source rock characterization method for petroleum exploration; 9th Annual Offshore Technology Conference, Huston, Texas, p.439-444.

Fleuty, M.J.

1964: The description of folds; Proceedings of the Gkeological Association of London, v. 75, p. 461-492.

Fogarassy, J.A.

1989: Stratigraphy, diagenesis and petroleum reservoir potential of the Cretaceous Haida, Skidegate and Honna formations, Queen Charlotte Islands, British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, 177 p.

Fogarassy, J.A.S. and Barnes, W.C.

1988: Stratigraphy, diagenesis and petroleum reservoir potential of the mid- to Upper Cretaceous Haida and Honna formations of the Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 265-268.

1989: The middle Cretaceous Haida Formation: a potential hydrocarbon reservoir in the Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 47-52.

1991: Stratigraphy and diagenesis of the mid- to Upper Cretaceous Queen Charlotte Group, Queen Charlotte Islands, British Columbia; *in* Evolution and Petroleum Potential of the Queen Charlotte Basin, British Columbia. Geological Survey of Canada, Paper 90-10, p. 279-294.

Frey, R.W.

1975: The study of trace fossils, a synthesis of principles, problems, and procedures in; Springer-Verlag, Berlin, 562 p.

Frey, R.W. and Pemberton, S.G.

1984: Trace fossil facies models; *in* Facies models, Walker, R.G. (ed.), p. 189-207.

Gamba, C.A.

1991: An update on the Cretaceous sedimentology of the Queen Charlotte Islands, British Columbia; *in* Current Research, Part F, Geological Survey of Canada, Paper 91-1A, p. 373-382.

Gamba, C.A., Indrelid, J., and Taite, S.

1990: Sedimentology of the Upper Cretaceous Queen Charlotte Group, with special reference to the Honna Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 67-73.

Gardner, M.C., Bergman, S.C., Cushing, G.W., MacKevett, E.M.,Jr., Plafker, G., Campbell, R.B., Dodds, C.J., McClelland, W.C.,and Mueller, P.A.

1988: Pennsylvanian pluton stitching of Wrangellia and the Alexander Terrane, Wrangell Mountains, Alaska; Geology, v. 16, p. 967-971.

Haggart, J.W.

1986: Stratigraphic investigations of the Cretaceous Queen Charlotte Group, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Paper 86-20, 24 p.

1987: On the age of the Queen Charlotte Group of British Columbia; Canadian Journal of Earth Sciences, v. 24, p. 2470-2476.

1989: Reconnaissance lithostratigraphy and biochronology of the Lower Cretaceous Longarm Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 39-46.

1991: A synthesis of Cretaceous stratigraphy, Queen Charlotte Islands, British Columbia; *in* Evolution and Petroleum Potential of the Queen Charlotte Basin, British Columbia. Geological Survey of Canada, Paper 90-10, p. 253-277.

Haggart, J.W. and Gamba, C.A.

1990: Stratigraphy and sedimentology of the Longarm Formation, southern Queen Charlotte Islands, British Columbia; *in* Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 61-66.

Haggart, J.W. and Higgs, R.
1989: A new Late Cretaceous mollusc fauna from the Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 59-64.

Haggart, J.W., Lewis, P.D., and Hickson, C.J.
1989: Stratigraphy and structure of Cretaceous strata, Long Inlet, Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 65-72.

Haggart, J.W., Indrelid, J., Hesthammer, J., Gamba, C.A.,and White, J.M.
1990: A geological reconnaissance of the Mount Stapleton-Yakoun Lake region, central Queen Charlotte Islands, British Columbia; *in* Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 29-36.

Haggart, J.W., Taite, S.P., Indrelid, J., Hesthammer, J., and Lewis, P.D.
1991: Some thoughts on stratigraphic nomenclature for the Cretaceous rocks of the Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 91-1A, p. 367-371.

Haimila, N.E. and Procter, R.M.
1982: Hydrocarbon potential of offshore British Columbia; Geological Survey of Canada, Open File 824, 28 p.

Hamilton, T.S.
1985: Volcanics of the Cenozoic Masset Formation: implications for geological and tectonic evolution of the Queen Charlotte Islands, British Columbia, Canada; Geological Society of America, Cordilleran Secton, Annual Meeting, Program with abstracts, Vancouver, British Columbia, May 8-10, p, 359.

Hamilton, T.S. and Cameron, B.E.B.
1989: Hydrocarbon occurrences on the western margin of the Queen Charlotte Basin; Bulletin of Canadian Petroleum Geology, v. 37, p. 443-466.

Haq, B.U., Hardenbol, J., and Vail, P.R.
1987: Chronology of fluctuating sea levels since the Triassic; Science, v. 235, p. 1156-1167.

Hesthammer, J.
1991a: Lithologies of the Middle Jurassic Yakoun Group in the central Graham Island area, Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 91-1A, p. 353-358.

1991b: Stratigraphy and structural geology of Upper Triassic and Jurassic rocks in the central Graham Island area, Queen Charlotte Islands, British Columbia; unpublished M.Sc. thesis, University of British Columbia, Vancouver, B.C.

Hesthammer, J., and Indrelid, J
1990: Stratigraphy and structural geology of central Graham Island, Queen Charlotte Islands, British Columbia; Cordilleran Geology and Exploration Roundup, Vancouver, B.C., February 6-9, Programs and Abstracts.

Hesthammer, J., Indrelid, J., and Ross, J.V.
1989: Preliminary structural studies of the Mesozoicrocks of central Graham Island, Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 19-22.

Hesthammer, J., Indrelid, J., Lewis, P.D., and Haggart, J.W.

1991a: Geology of southern Graham Island (map sheets 103F8 and 103G4, and parts of map sheets 103F7 and 103 F9), Queen Charlotte Islands, British Columbia; *in* Open File Report 2319, Geological Survey of Canada.

Hesthammer, J., Indrelid, J, Lewis, P.D., and Orchard, M.J.

1991b: Permian strata on the Queen Charlotte Islands; *in* Current Research, Part A, Geological Survey of Canada, Paper 91-1A; p. 321-329.

Hickson, C.J.

1988: Structure and stratigraphy of the Masset Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 269-274.

1989: An update on structure and stratigraphy of the Masset Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 73-79.

1990a: Geology, Port Clements, British Columbia; Geological Survey of Canada, Map 6-1990, scale 1:50 000.

1990b: Geology Awun Lake, British Columbia, Geological Survey of Canada, Map 7-1990, scale 1:50 000.

1991: The Masset Formation on Graham Island, Queen Charlotte Islands, British Columbia; *in* Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia, Geological Survey of Canada, Paper 90-10, p. 305-324.

Hickson, C.J. and Lewis, P.D.

1990: Geology, Frederick Island (west half), British Columbia, Geological Survey of Canada, Map 8-1990, scale 1:50 000.

Higgs, R.

1988: Sedimentology of the Honna Formation, Upper Cretaceous fan-delta conglomerates; *in* Higgs, R. (compiler), "Some aspects of the petroleum potential of the Queen Charlotte Islands",, Canadian Society of Petroleum Geologists' field guide to Sequences, Stratigraphy, Sedimentology: Surface and Subsurface Technical Meeting, Calgary, Alberta, p. 14-21.

1989: Sedimentological aspects of the Skonun Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 87-94.

1990: Sedimentology and tectonic implications of Cretaceous fan-delta conglomerates, Queen Charlotte Islands, Canada; Sedimentology, v. 37, p. 83-103.

1991a: Sedimentology of the Honna Formaiton, northern Queen Charlotte Islands, and implications for pertoleum exploration, *in* Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia, Geological Survey of Canada, Paper 90-10, p. 295-304.

1991b: Sedimentology, basin-fill architecture and petroleum geology of the Tertiary Queen Charlotte Basin; *in* Evolution and Petroleum Potential of the Queen Charlotte Basin, British Columbia. Geological Survey of Canada, Paper 90-10, p. 337-371.

Higgs, R. and Bornhold, B.D.

1988: Stop 7. Haida Formation, Onward Point; *in* Higgs, R. (compiler), Some aspects of the petroleum geology of the Queen Charlotte Islands; Canadian Society of Petroleum Geologists, Field Trip Guide to Sequences, Stratigraphy, Sedimentology: Surface and Subsurface Technical Meeting, p. 69-72.

Indrelid, J.

1990: Stratigraphy and structures of Cretaceous units, central Graham Island, Queen Charlotte Islands, British Columbia; *in* Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 5-10.

Indrelid, J., and Hesthammer, J.

1990: Mesozoic geology of central Graham Island: Implications for petroleum potential in the Queen Charlotte Basin; Geological Association of Canada/Mineralogical Association of Canada; Joint Annual Meeting, Vancouver, B.C., May 16-18, Program with Abstracts.

1991: Lithologies of a Paleozoic or lower Mesozoic volcanic rock assemblage on the Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 91-1A, p. 331-335.

Indrelid, J., Hesthammer, J., and Lewis, P.D.

1991a: Geology of northwestern Moresby Island and western Skidegate Channel (parts of map sheets 103F1, 103F2, and 103 C16), Queen Charlotte Islands, British Columbia; Open File Report 2318, Geological Survey of Canada.

Indrelid, J., Hesthammer, J., and Ross, J.V.

1991b: Structural geology and stratigraphy of Mesozoic rocks of central Graham Island, Queen Charlotte Islands, British Columbia; *in* Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia, Geological Survey of Canada, Paper 90-10, p. 51-58.

Jeletzky, J.A.

1984: Jurassic-Cretaceous boundary beds of western and arctic Canada and the problem of the Tithonian-Berriasian stages in the Boreal Realm; *in* G.E.G. Westermann (ed.), Jurassic-Cretaceous Biochronology and Paleogeography of North America, Geological Society of America Bulletin, v.82, p. 815-822.

1977: Mid-Cretaceous (Aptian to Coniacian) history of Pacific slope Canada; Palaeontological Society of Japan, Special Papers, No. 21, p. 97-126.

Jones, D.L., Murphy, M.A., and Packard, E.L.

1965: The Lower Cretaceous (Albian) ammonite genera Leconteites and Brewericeras; U.S. Geological Survey, Professional Paper 503-F, p. 1-21.

Jones, D.L., Silberling, N.J., and Hillhouse, J.

1977: Wrangellia-a displaced terrane in northwestern North America; Canadian Journal of Earth Sciences, v. 14, p. 2565-2577.

Lewis, P.D.

1990: New timing constraints on Cenozoic deformation in the Queen Charlotte Islands, British Columbia; *in* Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 23-28.

1991: Structural geology and processes of deformation in the Mesozoic and Cenozoic evolution of the Queen Charlotte Islands; unpublished Ph.D. thesis, University of British Columbia, Vancouver, B.C.

Lewis, P.D. and Hickson, C.J.
1990: Geology, Langara Island (west half) British Columbia. Geological Survey of Canada, Map 9-1990, scale 1:50,000.

Lewis, P.D., Hesthammer, J., Indrelid, J. and Hickson, C.J.
1990: Geology, Yakoun Lake, British Columbia, Geological Survey of Canada, Map 5-1990, scale 1:50 000.

Lewis, P.D, Haggart, J.W., Anderson, R.G., Hickson, C.J., Thompson, R.I., Dietrich, J.R., and Rohr, K.M.M.
1991: Triassic to Neogene geologic evolution of the Queen Charlotte Basin; Canadian Journal of Earth Sciences (in press).

MacKenzie, J.D.
1916: Geology of Graham Island, British Columbia; Geological Survey of Canada, Memoir 88, 221 p. Contains Map 176A, Graham Island (1:253 440) and Map 177A, Southern Portion of Graham Island (1:126 720).

McLearn, F.H.
1949: Jurassic formations of Maude Island and Alliford Bay, Skidegate Inlet, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 12, 19 p.

1972: Ammonoids of the Lower Cretaceous sandstone member of the Haida Formation, Skidegate Inlet, Queen Charlotte Islands, western British Columbia; Geological Survey of Canada, Bulletin 188, 78 p., plates.

Monger, J.W.H.
1984: Cordilleran tectonics: a Canadian perspective; Bulletin, Society of geology, France, v. 7, t. XXVI, no. 2, p. 255-278.

Nockolds, S.R., Knox, R.W.O'B., and Chinner, G.A.
1978: Petrology for students; Cambridge University Press, Cambridge, 435p.

Peters, K.E.
1986: Guidlines for evaluating petroleum source rock using programmed pyrolysis; American Association of Petroleum Geologists, 70, p. 318-329.

Posamentier, H.W., Jervey, M.T., and Vail, P.R.
1988: Eustatic controls on clastic deposition 1-conseptual framework; *in* Sea Level Changes an Integrated Approach, Society of Economic Paleontologists and Mineralogists, Special Ppublication 42, p. 109-124.

Riccardi, A.C.
1981: An Upper Cretaceous ammonite and inoceramids from the Honna Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part C, Geological Survey of Canada, Paper 81-1C, p. 1-8.

Richardson, J.
1873: Report on the coal-fields of Vancouver and Queen Charlotte Islands; Geological Survey of Canada, Report of Progress for 1872-1873, p. 32-65.

Shouldice, D.H.
1971: Geology of the western Canadian continental shelf; Bulletin of Canadian Petroleum Geology, v. 19, p. 405-436.

Smith, J.G., and MacKevett, E.M., Jr.
1970: The Skolai Group in the McCarthy B-4, C-4, and C-5 quadrangels, Wrangell Mountains, Alaska; United States Geological Survey Bulletin, 1274-Q, p. Q1-Q26.

Snowdon, L.R., Fowler, M.G., and Hamilton, T.S.
1988: Progress report on organic geochemistry, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 251-253.

Souther, J.G. and Jessop, A.M.
1991: Dykeswarms in the Queen Charlotte Islands, British Columbia,, and implications for hydroacarbon exploration; *in* Evolution and Petroleum Potential of the Queen Charlotte Basin, British Columbia. Geological Survey of Canada, Paper 90-10, p. 465-487.

Stacey, R.A.
1974: Plate tectonics, volcanism and the lithosphere in British Columbia, Nature, v. 250, p. 133-134.

Surdam.R.C., Boese, S.W., and Crossey, L.J.
1984: The chemistry of secondary porosity; *in* ClasticDiagenesis, D.A McDonalds and R.C. Surdam, eds.; American Association of Petroleum Geologists Memoir 37, p. 127-149.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p. Contains Figure 5, sheets A, B, and C, Geology of the Queen Charlotte Islands (1:125 000).

Sutherland Brown, A., Yorath, C.J., and Tipper, H.W.
1983: Geology and tectonic history of the Queen Charlotte Islands; Geological Association of Canada, Annual Meeting, Victoria, Field Trip Guidebook, Trip 8, 21 p.

Taite, S.
1990: Observations on structure and stratigraphy of the Sewell Inlet-Tasu Sound area, Queen Charlotte Islands, British Columbia; *in* Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 19-22.

1991: Geology of the Sewell Inlet-Tasu Sound area, Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 91-1A, p. 393-399.

Thompson, R.I.
1988: Introduction to the Frontier Geoscience Program, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E., Geological Survey of Canada, Paper 88-1E, p. 207-208.

Thompson, R.I and Lewis, P.D.
1990: Geology, Skidegate Channel, British Columbia.Geological Survey of Canada, Map 4-1990, scale 1:50,000.

Thompson, R.I. and Thorkelson, D.
1989: Regional mapping update, central Queen Charlotte Islands, British Columbia; *in* Current Research, Part H, Geological Survey of Canada, Paper 89-1H, p. 7-11.

Thompson, R.I., Haggart, J.W., and Lewis, P.D.
1991: Late Tiassic through early Teritary evolution of the Queen Charlotte Basin, British Columbia, with a perspective on hydrocarbon potential; *in* "Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia",Geological Survey of Canada, Paper 90-10, p. 3-29.

Timms, C.E.

1989: The origin and setting of Tow Hill, Queen Charlotte Islands; B.Sc. thesis, McMaster University, Hamilton, Ontario, 79p.

Tissot, B.P. and Welte, D.H.

1984: Petroleum occurence and formaiton; Springer-Verlag, Berlin, 699p.

Vail, P.R., Mitchum, R.M., and Thompson, S.

1977: Part four: global cycles of relative changes in sea level; *in* Seismic Stratigraphy-Application to Hydrocarbon Exploration, American Association of Pertoleum Geologists, Memoir 26, p.83-89.

Vallier, T.L.

1977: The Permian and Triassic Seven Devils Group, western Idaho and northeastern Oregon; United States Geological Survey Bulletin, 1437, 58 pp.

van der Heyden, P.V.

1989: U-Pb and K-Ar geochronometry of the Coast Plutonic Complex, 53^{o} to 54^{o}N, British Columbia, and implications for the Insular-Intermontane Superterrane boundary; Ph.D. thesis, University of British Columbia, Vancouver, 392 p.

Vellutini, D.

1988: Organic maturation and source rock potential of Mesozoic and Tertiary strata, Queen Charlotte Islands, British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, 262 p.

Vellutini D. and Bustin, R.M.

1991: Source rock potential of Mesozoic and Tertiary strata of the Queen Charlotte Islands, British Columbia; *in* "Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia",Geological Survey of Canada, Paper 90-10, p. 381-409.

Wernicke, B.

1988: Escape hypothesis for the Stikine block; Geology, v. 16, p. 461-464.

White, J.

1990: Evidence of Paleogene sedimentation on Graham Island, Queen Charlotte Islands, west coast Canada, Canadian Journal of Earth Sciences, v.27, p. 533-538.

Whiteaves, J.F.

1883: On the Lower Cretaceous rocks of British Columbia; Proceedings and Transactions of the Royal Society of Canada, v. 1, sec. IV, p. 81-86, 3 figures.

1884: On the fossils of the coal-bearing deposits of the Queen Charlotte Islands collected by Dr. G.M. Dawson in 1878; Geological Survey of Canada, Mesozoic Fossils, v. 1, Part 3, p. 191-262.

Woodsworth, G.J.

1988: Karmutsen Formation and the east boundary of Wrangellia, Queen Charlotte Basin, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 209-212.

Woodsworth, G.J., and Tercier, P.

1991: Evolution of stratigraphic nomenclature in Queen Charlotte Islands; *in* Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia, Geological Survey of Canada, Paper 90-10: 151-162.

Yagishita, K.
1985a: Mid- to Late Cretaceous sedimentation in the Queen Charlotte Islands, British Columbia: lithofacies, paleocurrent and petrographic analyses of sediments; Ph.D. thesis, University of Toronto, Ontario.

1985b: Evolution of a provenance as revealed by petrographic analyses of Cretaceous formations in the Queen Charlotte Islands, British Columbia, Canada; Sedimentology, v. 32, p. 671-684.

Yanguas, J.E. and Paxton, S.T.
1986: A new technique for preparation of petrographic thin sections using ultraviolet-curing adhesive; Journal of Sedimentary Petrology, v. 56, p. 539-540.

Yorath, C.J. and Cameron, B.E.B.
1982: Oil off the west coast?; Department of Energy, Mines and Resources, GEOS, Department of Energy, Mines and Resources, Ottawa, v. 11, no. 2, p. 13-15.

Yorath, C.J. and Chase, R.L.
1981: Tectonic history of the Queen Charlotte Islands and adjacent areas - a model; Canadian Journal of Earth Sciences, v. 18, p. 1717-1739.

Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

Young, I.F.
1981: Structure of the western margin of the Queen Charlotte Basin, British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, 380 p.

7. APPENDICES

7.1. Thin section data

Explanation of coloumn headings.

C = chert.

Q = quartz (Qm+Qp).

Qm = monocrystalline quartz.

Qp = polychrystalline quartz (including chert).

L = lithic fragments (Lv+Ls).

Lv = volcanic lithic fragments.

Ls = sedimentary lithic fragments.

F = feldspar (Fp+Fk).

Fp = plagioclase feldspar.

Fk = potassium feldspar.

Ch = chlorite.

Mu = muscovite.

Ca = calcite.

Bi = biotite.

OM = organic material.

Am = amphibole.

Gl = glauconite.

Li = limonite.

Cretaceous sandstone unit

SAMPLE	C	Q	Qm	Qp	L	Ls	Lv	F	Fp	Fk
8186		20	20	0	10	0	10	60	40	20
8190		10	8	2	60	10	50	15	10	5
8195		10	9	1	30	5	25	50	30	20
8197 B		20	10	10	10	0	10	20	10	10
9022 A		30	20	10	20	5	15	30	20	10
9055	5	5	5	0	75	20	55	5	0	5
9078 F	5	15	9	6	50	40	10	10	7	3
9084	10	40	25	25	10	0	10	40	20	20
9142 C	15	30	20	10	35	15	20	25	15	10
9169 B		32	30	2	5	0	5	30	15	15
9209		20	10	10	60	35	25	10	5	5
9315 A	15	40	20	20	5	0	5	40	20	20
9315 B	15	30	15	15	25	12	13	15	9	6
9511	15	15	8	7	2	1	1	15	8	7
9519		5	5	0	55	15	40	17	2	15
9545	20	40	17	23	5	1	4	5	1	4
9610 B	20	33	12	23	9	7	2	3	2	1
9650 A	5	15	10	5	3	2		10	6	4

SAMPLE	Ch	Mu	Ca	Bi	OM	Am	Gl	Li
8186			5	5	M			
8190	5	3	3		4			
8195			M	5	5		M	
8197 B				M			50	
9022 A	4		11	5	M			
9055	5		5					
9078 F	4		15	3			3	
9084	10			M	M			
9142 C	10			M			M	
9169 B	9	5		17	4			
9209	6		2		2			
9315 A	13			2				
9315 B	10		20	M			M	
9511	8		60	M				
9519	11		10	2				
9545			50	M	M			
9610 B			55					
9650 A	2						55	15

Cretaceous shale unit

SAMPLE	C	Q	Qm	Qp	L	Ls	Lv	F	Fp	Fk
9033 C	15	50	25	25	10	0	10	30	10	20
9034	20	45	20	25	12	2	10	35	15	20
9035 B	2	22	20	2	13	3	10	50	30	20
9044 C		30	25	5	12	2	10	30	15	15
9087	5	25	20	5	40	5	35	30	15	15
9417		20	15	5	25	20	5	25	12	13
9420 B		5	5	0	80	45	35	5	2	3
9438 B	10	30	20	10	40	30	10	20	10	10
9549		5	5	0	60	10	50	20	10	10

SAMPLE	Ch	Mu	Ca	Bi	OM	Am	Gl	Li
9033 C	5			5				
9034	5			3				
9035 B	5		5	5				
9044 C	5		20	M	3			
9087	5		M	M	M	M		
9417	5		20	3	2			
9420 B	5		3		2			
9438 B	10			M				
9549	15							

Skidegate Formation

SAMPLE	C	Q	Qm	Qp	L	Ls	Lv	F	Fp	Fk
9377 A	10	30	20	10	25	5	20	25	10	15
9470		17	12	5	21	17	4	34	7	27

SAMPLE	Ch	Mu	Ca	Bi	OM	Am	Gl	Li
9377 A	3		10	7				
9470	12		9	6	M			

Honna Formation; conglomerate lithofacies

SAMPLE	C	Q	Qm	Qp	L	Ls	Lv	F	Fp	Fk
8027 C		10	8	2	35	5	30	40	17	23
8029		20	10	10	55	25	30	15	8	7
9373 B		15	8	7	45	10	35	25	8	17
9523 A		15	10	5	40	10	30	30	10	20
9601		25	5	20	45	15	30	10	7	3
9638	10	35	26	9	20	5	15	30	18	12

SAMPLE	Ch	Mu	Ca	Bi	OM	Am	Gl	Li
8027 C	10	M	5	M				
8029	5		M	5		M		
9373 B	7		5	3				
9523 A	M		10	5	M			
9601			15	5				
9638	M		10	5				

Honna Formation; sandstone lithofacies

SAMPLE	C	Q	Qm	Qp	L	Ls	Lv	F	Fp	Fk
9361 A		40	20	20	20	15	5	40	15	25
9361 C		35	35	0	8	6	2	37	15	22
9363 A		30	30	0	5	1	4	10	5	5
9363 B		20	13	7	15	10	5	40	10	30
9367		25	15	10	10	5	5	50	15	35
9372		17	15	2	60	10	50	20	5	15
9523 B		30	15	15	35	20	15	20	15	5
9626 B	15	40	15	25	20	13	7	25	8	17
9626 C	20	50	15	35	17	7	10	16	10	6
9627	10	30	15	15	55	30	25	5	2	3

SAMPLE	Ch	Mu	Ca	Bi	OM	Am	Gl	Li
9361 A				M				
9361 C				8	5			
9363 A	2	M	43	10	M			
9363 B	3		20	2				
9367	5		10					
9372	M		3	M	M			
9523 B	4		6	5				
9626 B	5		3	5	2			
9626 C	5		5	7				
9627	5		2	3				

7.2. Rock-Eval® pyrolysis data

Skidegate Formation

LOC	Tmax	S1	S2	S2/S3	TOC	PI	HI	OI	S1+S2	QOM
9002	*	0.09	0.01	0.16	0.15	0.00	6	40	0.10	0.67
9002	*	0.07	0.00	*	0.13	0.00	0	8	0.07	0.54
9428	*	0.00	0.00	0.00	1.06	0.00	0	33	0.00	0.00
9428	*	0.00	0.00	0.00	1.02	0.00	0	25	0.00	0.00
Average	*	0.04	0.002	0.05	0.60	0.00	1.5	26.5	0.04	0.30
		n=4	n=4	n=3	n=4	n=4	n=4	n=4	n=4	n=4

Honna Formation

LOC.	Tmax	S1	S2	S2/S3	TOC	PI	HI	OI	S1+S2	QOM
9529A	482	0.11	0.38	4.75	0.72	0.04	52	11	0.49	0.68
9529A	487	0.01	0.43	*	0.64	0.04	67	0	0.44	0.69
9529B	484	0.09	0.23	36.5	1.51	0.06	48	1	0.32	0.21
9529B	485	0.07	0.76	*	1.24	0.06	61	0	0.83	0.66
Average	485	0.07	0.45	20.6	1.03	0.05	57	3	0.52	0.56
	n=4	n=4	n=4	n=2	n=4	n=4	n=4	n=4	n=4	n=4

Cretaceous shale

LOC	Tmax	S1	S2	S2/S3	TOC	PI	HI	OI	S1+S2	QOM
9030	*	0.01	0.03	1.00	0.26	0.00	11	11	0.04	0.15
9030	*	0.00	0.09	*	0.24	0.00	37	0	0.09	0.37
9143	*	0.03	0.15	2.50	0.37	0.01	40	16	0.18	0.49
9143	*	0.02	0.12	*	0.46	0.00	21	0	0.14	0.30
9148	*	0.01	0.00	0.00	0.00	0.00	*	*	0.00	*
9148	*	0.01	0.00	*	0.01	0.00	0	0	0.01	1
9388	*	0.01	0.00	0.00	0.12	0.00	0	158	0.01	0.08
9388	*	0.02	0.03	0.16	0.10	0.00	30	188	0.05	0.50
9419	*	0.02	0.02	0.06	0.22	0.00	9	140	0.04	0.18
9419	*	0.00	0.03	0.21	0.18	0.00	16	77	0.03	0.17
9423	*	0.01	0.00	0.00	0.05	0.00	0	100	0.01	0.20
9423	*	0.01	0.04	*	0.08	0.00	50	0	0.05	0.62
9438	*	0.01	0.00	0.00	0.03	0.00	0	33	0.01	0.33
9438	*	0.00	0.00	*	0.03	0.00	0	0	0.00	0.00
9470	450	0.03	0.20	*	0.42	0.01	47	0	0.23	0.55
9470	*	0.02	0.18	*	0.45	0.01	40	0	0.20	0.44
9538	*	0.03	0.09	*	0.34	0.01	26	0	0.12	0.35
9538	*	0.02	0.15	*	0.35	0.01	42	0	0.17	0.49
9640	*	0.03	0.19	9.50	0.46	0.01	41	4	0.22	0.48
9640	*	0.03	0.06	*	0.47	0.00	12	0	0.09	0.19
9652	103	0.04	0.26	4.33	0.42	0.02	61	14	0.30	0.71
9652	*	0.02	0.11	*	0.34	0.01	32	0	0.13	0.38
Average	276	0.02	0.08	1.6	0.25	0.004	24.5	35.3	0.10	0.38
	n=2	n=22	n=22	n=11	n=22	n=22	n=21	n=21	n=22	n=21

Geochemical parameters describing level of thermal maturation

MATURATION	**PI** S1/(S2+S3)	T_{max} (°C)	R_o (%)
Top of oil window	0.1	435-445	0.6
Bottom of oil window	0.4	470	1.4

Geochemical parameters describing source rock generative potential

QUANTITY	**TOC** (Weight %)	**S1** $mgHC/gC_{org}$	**S2** $mgHC/gC_{org}$
Poor	0.0-0.5	0.0-0.5	0.0-2.5
Fair	0.5-1.0	0.5-1.0	2.5-5.0
Good	1.0-2.0	1.0-2.0	5.0-10.0
Very good	2.0+	2.0+	10.0+

	S1 + S2
no oil source rock	<2
medium source rock potential	2 - 6
good source potential	>6

	QOM
low	< 1.4
moderate	1.4 - 3.0
high	> 3.0

Geochemical parameter describing type of hydrocarbon generated

TYPE	**HI** (mg hc/gC_{org})	**S2/S3** *
Gas	0-150	0-3
Gas and oil	150-300	3-5
Oil	300+	5+

* Assumes a level of thermal maturation equivalent to R_0=0.6%

7.3. Fossil report

Report No.JWH-1991-12

Report on Jurassic and Cretaceous fossils from the Queen Charlotte Islands of B.C. (NTS map-area 103 F), submitted for identification in 1991 by Mr. Jarand Indrelid of the University of British Columbia, Vancouver (17 lots).

All references to paleontologic data and age determinations must quote the authorship of the report, and the unique GSC locality number of the fossil collection.

Reference to, or reproduction of, paleontologic data and age determinations in publications must be approved by the author of the fossil report prior to manuscript submission. Substantial use of paleontologic and age data in publications should be reflected in the authorship.

IDENTIFICATIONS

Field No.HFB-89-V-9520 GSC loc.**C-173911**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 675500 E, 5912800 N
Slope south of Rennell Sound road
Longarm Formation
Siltstone/fine-grained sandstone

Fossils: ostreiid bivalve fragments
bivalve fragments, indeterminate
ammonite fragments, indeterminate

Age: Indeterminate, but ammonite fragments bear resemblance to inflated Middle Jurassic forms and not to any taxa presently known from the Cretaceous of the Queen Charlotte Islands. On the basis of the preserved fragments alone, suggested correlation is with the Yakoun Group. Collection referred to T.P. Poulton, Calgary, for further study.

Field No.HFB-89-V-9210B GSC loc.**C-173913**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 679400 E, 5927400 N
West of Yakoun River, between Ghost Creek and Marie Lake

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Longarm Formation
Massive, fine-grained sandstone with grit

Fossils: *Steinmanella?* sp.
ammonite fragment, indeterminate
bivalve shell fragments, indeterminate

Age: Cretaceous?

Field No.HFB-89-V-9120B GSC loc.**C-173916**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 687600 E, 5912400 N
Falls Creek near crossing of Yakoun Main (see GSC loc.**C-173920**, below)
Longarm Formation
Mudstone with sandy grit stringers

Fossils: possible ammonite impression
anomiid bivalve
pectinid bivalve
belemnoid, showing depressed cross-section

Age: The material is not generically identifiable by the writer. However, the belemnoid and the pectinid bivalve are distinct from all other Lower Cretaceous forms known to the writer from the Queen Charlotte Islands. It is thus suggested that a correlation with Jurassic rocks may be more appropriate. Given the geographic proximity of GSC loc.**C-173920** (below) with the present collection it is suggested that both may be pre-Cretaceous in age. Collection referred to T.P. Poulton, Calgary.

Field No.HFB-89-V-9161 GSC loc.**C-173917**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 684300 E, 5912400 N
Slopes east of Etheline Creek
Longarm Formation
Fine- to medium-grained sandstone with pebbles

Fossils: *Acrioceras?* sp.
Barremites sp.

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knobby trigoniid bivalve fragments, indeterminate
bivalves, indeterminate

Age: Hauterivian or Barremian, probably Barremian.

Field No.HFB-89-V-9078 GSC loc.**C-173918**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 676200 E, 5921100 N
North slope of Ghost Creek
Haida Formation
Fine-grained sandstone

Fossils: *Brewericeras* cf. *hulenense* (ANDERSON, 1938)
Puzosia sp.
bivalve shell fragments

Age: Probably late Early Albian.

Field No.HFB-89-V-9055 GSC loc.**C-173919**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 692400 E, 5909300 N
Mountain slope southeast of Skowkona Creek
Longarm Formation
Dirty, coarse-grained conglomeratic sandstone with rounded volcanic and sedimentary pebbles

Fossils: ammonite fragment, inflated with coarse ribbing

Age: Indeterminate. The inflated and coarsely-ribbed aspect of the ammonite is unusual for the Cretaceous ammonites of the Queen Charlotte Islands and is readily identified with Middle Jurassic stephanoceratids. This, coupled with the lithology of the sample, suggests to the writer that a correlation with the Yakoun Group is more likely. Collection referred to T.P. Poulton, Calgary, for further study.

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Field No.HFB-89-V-9120A GSC loc.**C-173920**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 687600 E, 5912400 N
Falls Creek near crossing of Yakoun Main (see GSC loc.**C-173916**, above)
Longarm Formation
Fine-grained sandstone

Fossils: bivalve fragments, indeterminate
gastropod, indeterminate
fragment of knobby trigoniid bivalve, indeterminate

Age: Jurassic or possibly Cretaceous. See comment above under GSC loc.**C-173916**. Collection referred to T.P. Poulton, Calgary.

Field No.HFB-89-V-9080 GSC loc.**C-173921**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 677400 E, 5920800 N
Ghost Creek area
Haida Formation
Silty fine-grained sandstone, locally hematitic

Fossils: *Anagaudryceras sacya* (FORBES, 1846)
Cleoniceras (Grycia?) perezianum (WHITEAVES, 1876), smooth, involute form
Puzosia cf. *skidegatensis* MCLEARN, 1972
decapod claw

Age: Middle Albian (Jeletzky, 1977).

Field No.HFB-89-V-9084 GSC loc.**C-173922**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 676800 E, 5921500 N
Slope north of Ghost Creek
Haida Formation
Fine-grained sandstone

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Fossils: *Acila (Truncacila) demessa* var. *haidana* PACKARD, 1936
Puzosia? sp.
Grammatodon (Nanonavis) cumshewaensis (WHITEAVES, 1900)
Goniomya sensu lato
anomiid bivalve
gastropod, indeterminate

Age: Albian to Cenomanian. Correlation with Haida Formation is appropriate.

Field No.HFB-89-V-9142 GSC loc.**C-173923**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 678100 E, 5918400 N
Hill between Phantom and Demon creeks
Longarm Formation
Dirty, fine-grained sandstone

Fossils: desmoceratid ammonite, possibly *Barremites?* sp.

Age: The poorly preserved specimen precludes positive identification and age assignment. However, *Barremites* would indicate an Hauterivian to Barremian age.

Field No.HFB-89-V-9056 GSC loc.**C-173940**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 692400 E, 5909400 N
Slope south of Skowkona Creek
Longarm Formation?
Granular sandstone

Fossils: partial belemnite molds

Age: Jurassic-Cretaceous. As belemnites are not known from Haida Formation strata it is likely that this locality is of the Longarm Formation.

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Field No.HFB-89-V-9519 GSC loc.**C-173941**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 675600 E, 5912900 N
Slope south of Rennell Sound road
Longarm Formation?
Dirty, fine-grained sandstone

Fossils: *Acrioceras?* sp.
Pleuromya? sensu lato sp.
anomiid bivalves (abundant)
ammonite fragments, indeterminate
bivalve shell debris
venerid bivalve, indeterminate
trigoniid? bivalve

Age: The ammonite genus *Acrioceras*, to which the specimen in the collection is considered to likely belong, ranges in age from Late Hauterivian to Early Aptian (Wright, 1957). The collection is not determinable beyond this level although *Acrioceras* is commonly found in the Barremian of the western Canadian Cordillera (Jeletzky, 1970) and California (Anderson, 1938).

Field No.HFB-89-V-9022 GSC loc.**C-173942**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 676500 E, 5913800 N
Rennell Sound road
Longarm Formation?
Fine- to medium-grained sandstone with rounded pebbles to 2 cm

Fossils: *Inoceramus* cf. *paraketzovi* EFIMOVA, 1963?
Inoceramus? sp.
tellinid bivalve, indeterminate
wood fragments

Age: Possibly Hauterivian. The identity of the fragment is inconclusive but bears the coarse, ovate ribbing typical of the *paraketzovi* species group. This species is found in Hauterivian strata of NE USSR (Efimova, 1963; Vereschagin *et al.*, 1965) and the form *I.* cf. *paraketzovi* is widespread in the western Canadian Cordillera in rocks of approximately

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Hauterivian age (Jeletzky, 1970; Haggart, 1989). The probable age of the fossil supports correlation with the Longarm Formation.

Field No.HFB-89-V-9115 GSC loc.**C-173943**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 690800 E, 5909500 N
Slope south of Skowkona Creek
Haida Formation?
Dirty, fine-grained sandstone

Fossils: coarsely ribbed ammonite fragment, possibly belonging to Family Desmoceratidae
thick-shelled gastropod

Age: Indeterminate, possibly Cretaceous.

Field No.HFB-90-JI-9315 GSC loc.**C-187452**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 684900 E, 5930500 N
East of Yakoun River at north edge of sheet
Longarm Formation
Dirty, medium- to coarse-grained conglomeratic sandstone with rounded pebbles

Fossils: trigoniid bivalve fragments, *Myophorella* sp. or *Steinmanella* sp.

Age: Jurassic to Cretaceous. Lithology, especially the presence of rounded to sub-rounded andesitic and other volcanic clasts, suggests possible correlation with the Yakoun Group.

Field No.HFB-90-JI-9420 GSC loc.**C-187460**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 678100 E, 5908900 N
Several 100 meters southwest of Yakoun Lake

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Longarm Formation
Slightly hornfelsed mudstone

Fossils: *Inoceramus* cf. *paraketzovi* EFIMOVA, 1963?

Age: Possibly Hauterivian. See comments under GSC loc.**C-173942**, above. The probable age of the fossil and the enclosing lithology, suggest correlation with the upper part, or shale facies, of the Longarm Formation (Haggart, 1989; Haggart, 1991).

Field No.HFB-89-JI-9610 GSC loc.**C-187487**

Locality: British Columbia, Queen Charlotte Islands
Lat. - N; Long. - W
NTS: 103 F/8 (Yakoun Lake)
UTM: Zone 8, 677200 E, 5913400 N
Slope south of Rennell Sound road
Longarm/Haida Formation
Fine-grained sandstone

Fossils: possible ammonite mold fragment

Age: Indeterminate.

REFERENCES

Anderson, F.M.
1938: Lower Cretaceous deposits in California and Oregon; Geological Society of America, Special Papers No.16, 339 pp., 84 pls.

Efimova, A.F.
1963: Nizhnemelovye peletsipody iz bassejna r. Eropol; Materialy po geologii i polezn. Iskopaemy Severo-Vostoka SSSR, Byp.16, Magadan [In Russian].

Haggart, J.W.
1989: Reconnaissance lithostratigraphy and biochronology of the Lower Cretaceous Longarm Formation, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Paper 89-1H, p.39-46.

1991: A synthesis of Cretaceous stratigraphy, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Paper 90-10, p.253-277.