MAGMATIC AND TECTONIC EVOLUTION OF THE INTERMONTANE SUPERTERRANE AND COAST PLUTONIC COMPLEX IN SOUTHERN YUKON TERRITORY

by

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ABSTRACT

The Intermontane Superterrane and Coast Plutonic Complex in southern Yukon Territory are characterized by four episodes of Mesozoic and Cenozoic magmatism which are defined by geological mapping, geochronometry, and whole rock and Sr isotopic geochemistry. Late Triassic to Early Jurassic Klotassin Episode (220-175 Ma), mid-Cretaceous Whitehorse Episode (115-106 Ma), Late Cretaceous Carmacks Episode (85-68 Ma) and Early Tertiary Skukum Episode (61-54 Ma). There was a pronounced magmatic lull between 172-120 Ma. Twenty-two U-Pb, 25 K-Ar dates and greater than 60 strontium isotopic analyses from plutonic and volcanic rocks across the study area are presented to define the timing and nature of magmatic and tectonic events. U-Pb dates are mostly concordant to mildly discordant with minor amounts of Pb-loss--older inherited components are rare.

Each magmatic episode is represented by two or more plutonic suites. The Klotassin Episode comprises the pre-accretionary Stikine and Red Ridge suites, the syn-accretionary Aishihik and Long Lake suites and the post-accretionary Bennett and Fourth of July suites. The Stikine suite is the plutonic equivalent to Lewes River Group volcanism, whereas Long Lake granites are coeval with Nordenskiold dacite. The Whitehorse Episode is composed of the Teslin, Whitehorse and Mount McIntyre suite. The Carmacks Episode is composed of felsic and mafic phases of the Wheaton River suite as well as the Carcross suite. Skukum Episode magmatism includes Nisling Range plutonic suite as well as high level rhyolite plugs that are associated with Skukum Group volcanism.

All plutonic suites have characteristics of calc-alkaline, magnetite-series, I-type subduction-related granitoids except those of the Skukum Episode which contain fluorite and have high Rb/Sr ratios (up to 100) and are akin to A-type magmas. Initial $^{87}Sr/^{86}Sr$ ratios of all suites are largely transitional (~ 0.7045) and range from 0.7035 to 0.7066. Elevated values reflect local upper crustal contamination from the pericratonic Nisling Terrane

Post-accretionary volcanic successions in southwestern Yukon Territory were deposited as part of a continental margin volcanic arc across the amalgamated terranes during Late Mesozoic time. Isotopic dating indicates that volcanism occurred episodically during mid- to Late Cretaceous time at 106, 98, 84 and 81-78 Ma. The mid-Cretaceous (106 Ma) Carbon Hill volcanic rocks comprise a few small occurrences of intermediate to felsic pyroclastic units around a comagmatic pluton. The Montana

Mountain volcanic rocks occur in a fault-bounded complex comprising 98 Ma intermediate flows and pyroclastics overlain by felsic flows that are ~13 m.y. younger. Late Cretaceous Wheaton River volcanics (81-78 Ma) consist of an extensive succession of basic to intermediate lava flows cut by 70-62 Ma rhyolite dykes and plugs. The ages of these volcanic successions provide maximum age constraints for the epigenetic precious metal deposits they host, and minimum ages for the underlying coal-bearing strata of the Tantalus Formation.

Major element geochemistry indicates that all three suites were formed from medium to high-K, calc-alkaline magmas. Initial strontium ratios vary considerably between the suites (0.7041 to 0.7061). Low ratios in the Wheaton River and Montana Mountain suites (~0.7042) indicate derivation from primitive, mantle-derived magmas. Higher initial strontium ratios in the Carbon Hill suite (~0.7052) suggest contamination from ancient continental material--probably from Nisling Terrane metasedimentary rocks.

U-Pb zircon dating of granitic cobbles, and paleocurrents in Lower Jurassic Laberge Group conglomerate of the Mesozoic Whitehorse Trough suggest provenance from a western source containing Late Triassic (*ca.* 215 to 208 Ma) plutons. Small, isotopically unevolved plutons of Late Triassic to earliest Jurassic age that intrude the Lewes River Group volcanic arc rocks along the western margin of the Whitehorse Trough are the likely source. The age dates, the lack of zircon inheritance, and the primitive initial strontium values of the clasts rule out previous suggestions that the clasts were derived from the Early Jurassic Klotassin suite batholiths which intrude Nisling Terrane rocks.

The deposition of very coarse Lower Jurassic boulder conglomerate on top of Late Triassic carbonate facies represents a dramatic change in the depositional style of the Whitehorse Trough. Sudden uplift incised a Lower Jurassic erosional disconformity into arc and arc-flanking shelf deposits along the western margin of the Whitehorse Trough. Episodic uplift resulted in paleotopographic relief in the arc sufficient to prograde coarse-grained debris flows into the basin and expose the plutonic roots of the arc throughout Early Jurassic time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Ideas presented in this thesis have been facilitated by: interactions with my co-workers at the Canada/Yukon Geoscience Office; Al Doherty of Aurum Geological Consultants, Mitch Mihalynuk of the British Columbia Geological Survey; John Dickie of Dalhousie University; and presentations at the Jurassic and Coast Range Penrose Conferences and NUNA '93. Additional thanks to John Dickie for use of his thesis material and ideas in Chapter V; Mitch Mihalynuk for allowing me access to his unpublished data; Grant Abbott for collecting some of the zircon samples and Julie Hunt and Judy Radloff who helped with petrographic examination of some thin sections. Moral support and societal deviations with Brian Mahoney and Steve Phillips smoothed out the rough edges of graduate school. Kelly Olson is thanked for drafting some of the (better) figures in this thesis and assisting with the final production of the manuscript.

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Chapter I

INTRODUCTION

The northern Canadian Cordillera is composed of numerous disparate crustal fragments that were assembled and accreted to the western margin of ancestral North America during Mesozoic time. The largest of these crustal fragments, Stikinia, together with the adjacent Cache Creek and Nisling Terranes, form a complex geological mosaic known as the Intermontane Superterrane. The nature and timing of the relations among many of the terranes is not well constrained. Further complexity is added by the Coast Plutonic Complex - a complex and poorly understood array of batholiths, plutons and orthogneiss intruded along the western margin of the Intermontane Superterrane. Numerous post-accretionary plutons and volcanic rocks were deposited throughout the amalgamated terranes. Improved comprehension of the tectonic history of southern Yukon is hindered by poorly defined nomenclature, inadequate geological mapping and the intrusion of granitic batholiths along some critical contacts.

The Whitehorse Geological Mapping Project (WGMP) mapped four 1:50 000 map sheets (105D/2, 3, 6 and 11) across the Coast Plutonic Complex, Nisling Terrane, Stikinia and Cache Creek Terrane contacts in southern Yukon Territory, southwest of Whitehorse (Figure 1.1; Doherty and Hart 1988; Hart and Pelletier 1989a, 1989b; Hart and Radloff 1990). The mapping was aimed at providing a geological framework for the numerous mineral deposits in that region. Geochronometric support was initiated by Grant Abbott of Indian and Northern Affairs in Whitehorse by awarding a contract to Richard L. Armstrong and Dipak K. Ghosh, at The University of British Columbia, to provide age dates to support the mapping of the WGMP. Dating of samples collected from sites suggested by myself and Allan Doherty (both then employees of Aurum Geological Consultants, Inc.) in the summer of 1988 was undertaken to: 1) define the timing of as many plutonic and volcanic suites as possible; 2) determine the ages of the mineralizing events; 3) determine the most cost-effective methods for dating various rock types.

Prior to the initiation of this study there were few published U-Pb zircon dates in the accreted terranes of southern Yukon and none in the Whitehorse (105D) map area. Armstrong and Ghosh provided 21 U-Pb dates, 20 K-Ar dates and more than 50 Rb-Sr analyses, that, along with additional analyses since undertaken at UBC, recent geological mapping, previous K-Ar and Rb-Sr analysis by Morrison *et al.* (1979), and geochemical analyses, provide the foundation for this thesis.

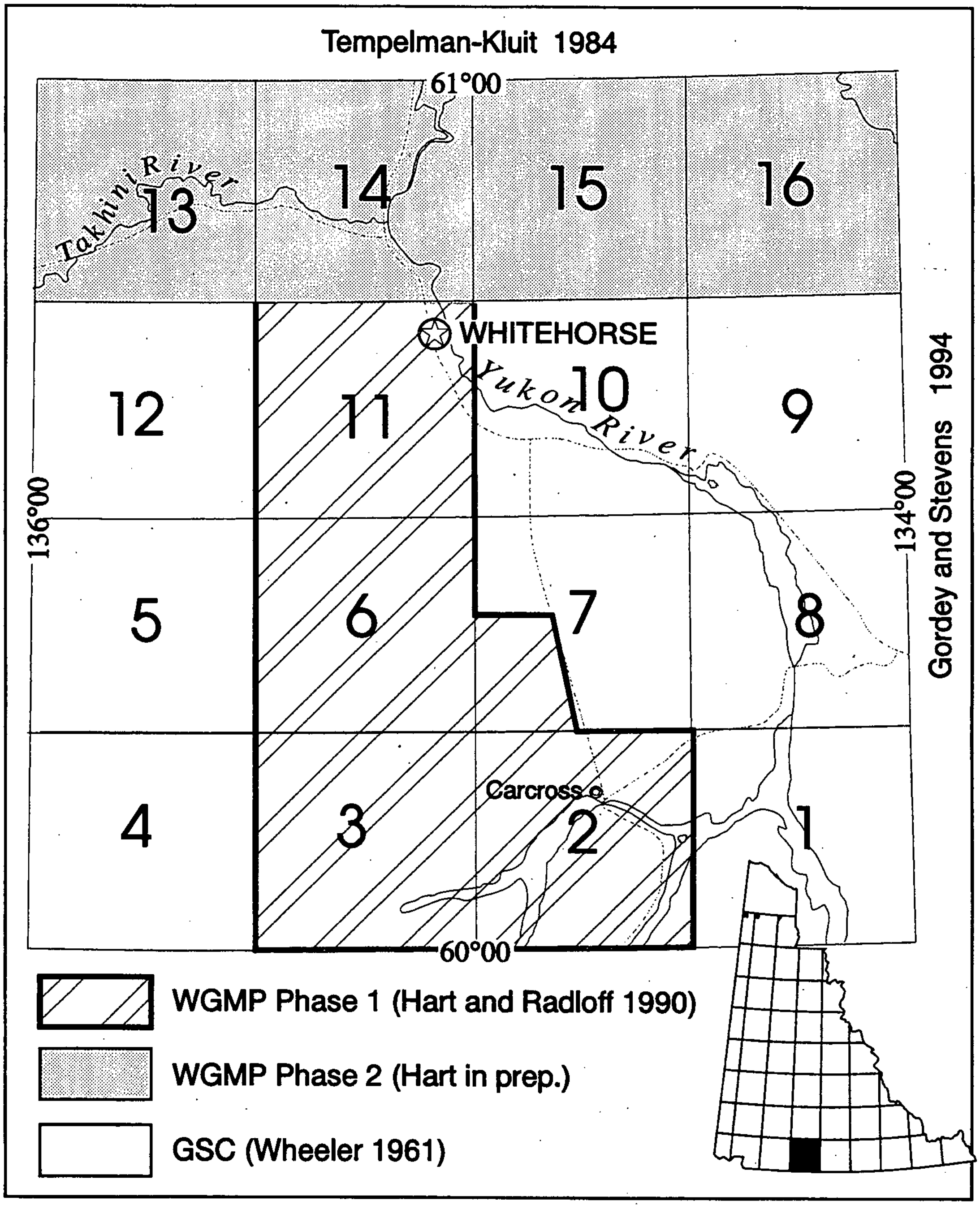


Figure 1.1 Current state of geological mapping in the Whitehorse (105D) map area. This thesis is mainly concerned with the region underlain by the mapping of Hart and Radloff (1990). The reader is referred to the 1:50 000 geological maps and reports for more detailed information.

This thesis integrates new and previous isotopic analyses with new mapping in the Whitehorse (105D) map area with an aim towards the development of a modern tectonic and metallogenic synthesis for southern Yukon. Three specific topics are addressed to achieve this goal:

1) the ages and affinities of plutonic rocks throughout southern Yukon are poorly understood. More than 25 plutons, intrude all tectonic elements in the study area, are evaluated to determine the timing and nature of pre-, syn- and post-accretionary magmatism. Definition of the suites is based upon pluton character, lithology, age determinations and Sr isotopic composition.
2) the character, age, affinity and nomenclature of post-accretionary volcanic rocks throughout southern Yukon is equivocal. An attempt is made to define the nature, age and geochemical composition of rocks correlated with the Mount Nansen and Carmacks Groups by studying three volcanic suites in the study area.
3) igneous rock clasts hosted in Early Jurassic Laberge Group conglomerates compose a large percentage of the fill of the Whitehorse Trough. The crystallization age of clasts will provide information about pre-Jurassic magmatism and the tectonic controls on Whitehorse Trough deposition.

Topics 1, 2 and 3 correspond to Chapters 3, 4 and 5 respectively and are written as stand alone papers that have subsequently been edited to conform to standard UBC thesis format. Chapter 5 was published in the R.L. Armstrong Memorial Volume, Jurassic Magmatism and Tectonics of the North American Cordillera, GSA Special Paper 299 (Hart *et al.* 1995). Dipak K. Ghosh and the late Richard L. Armstrong are co-authors on chapters 3, 4 and 5 since they are responsible for providing much of the geochronometric data contained therein. Colin I. Godwin is a co-author on Chapter 3 and helped to develop some of the concepts in that chapter. John Dickie is a co-author on Chapter 5 and was responsible for providing sedimentological data, interpretation and figures referenced therein.

The geology of four mineral deposits in the study area were evaluated during the course of this thesis (Hart 1992a, b, c, d). Additional U-Pb and K-Ar age-dating, Sr and Pb isotopic analyses of other rock units and mineral deposits in the study area were undertaken during the course of this thesis will be the subject of yet-to-be completed reports and papers.

All references or comparisons of stratigraphic ages, biostratigraphic ages and isotopic dates are based on the time scale of Harland et al. (1990).

Chapter II

TECTONIC FRAMEWORK

This study encompasses portions of three allochthonous terranes as well as the Coast Plutonic Complex (CPC) in southern Yukon Territory. The terranes include the Nisling Terrane, northern Stikinia and northern Cache Creek Terrane which collectively form the much of the northern Intermontane Superterrane (Figure 2.1). The Intermontane Superterrane refers to the group of terranes that were amalgamated prior to their accretion to the ancient continental margin of North America. Although Slide Mountain and Quesnellia are included in its traditional definition, these terranes do not occur in the study area and for the purpose of this study are not included. The nature and distribution of all these terranes, as well as the nature and timing of their interactions remain controversial.

This chapter describes the nature and distribution of the various terranes as well as the nature and timing of their interactions with each other. The data and interpretations presented elsewhere in this thesis, bear on the characterization of these terranes and the nature of the sub-crustal lithosphere as revealed by magmatism.

NATURE AND DISTRIBUTION OF TERRANES

Nisling Terrane

Previously known as the Yukon Crystalline Terrane (Tempelman-Kluit 1976, 1979), Nisling Terrane is an Upper Proterozoic and Paleozoic assemblage of pericratonic, para-autochthonous, metasedimentary rocks that are locally metamorphosed to amphibolite facies (Wheeler et al. 1991). This terrane underlies large areas in the Klondike and Aishihik Lake areas among the Yukon-Tanana Terrane and numerous smaller areas in the Coast Plutonic Complex (CPC) as discontinuous pendants that probably occur as far south as Prince Rupert (Gareau 1989; Gehrels *et al.* 1991). Together, the CPC and Nisling Terrane rocks form a complex of plutonic and metamorphic rocks herein collectively called the Coast Crystalline Complex (CCC)

The protolith, provenance, and age of metamorphism of these rocks is not certain. Metamorphism and deformation has obscured any fossil evidence that may have existed, disrupted stratigraphic relations among rock units, and reset isotopic systematics. As a result, these rocks have endured a long history of confusing nomenclature and age assignments (see Mortensen 1992 and references therein).

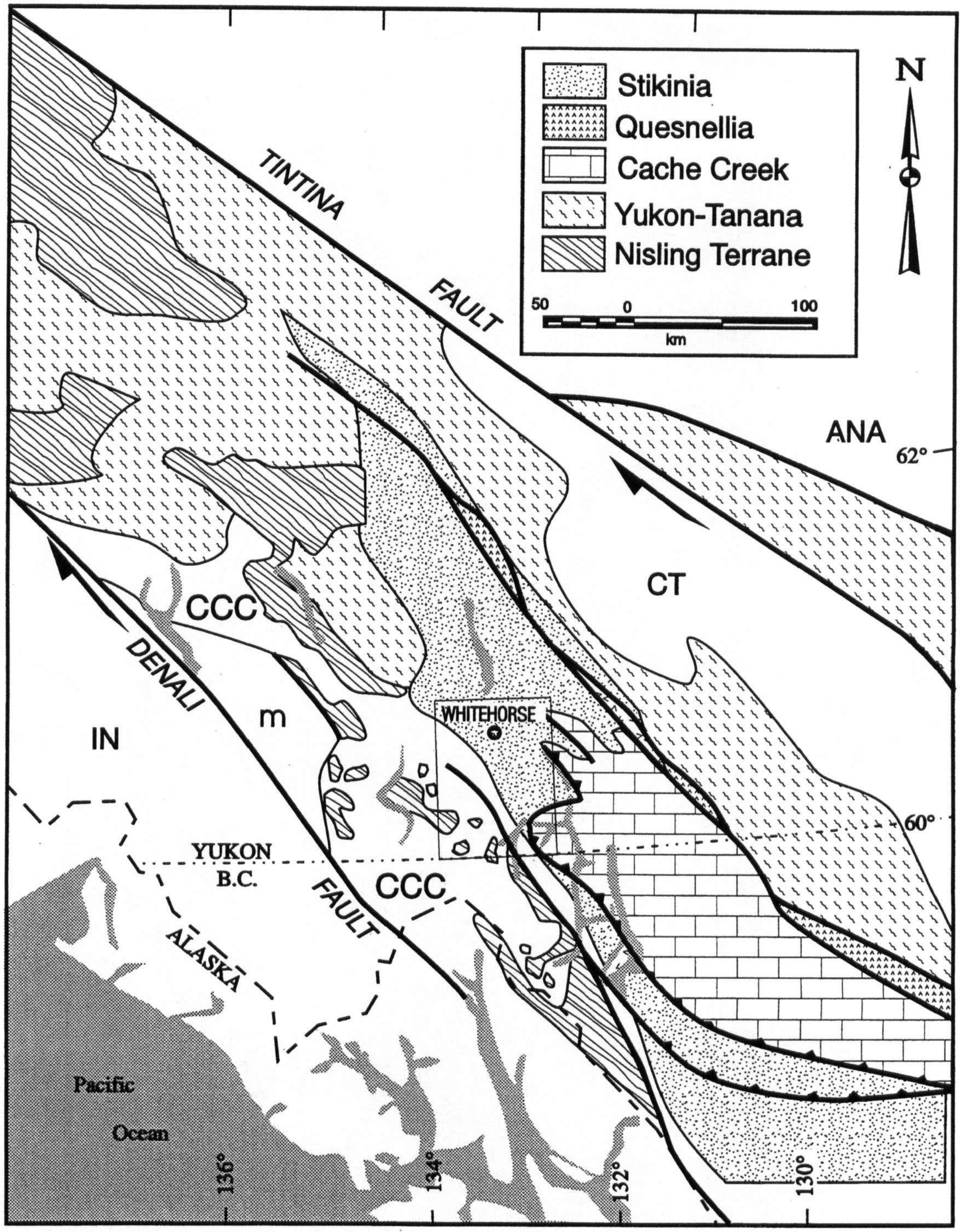


Figure 2.1 Regional tectonic setting of the southern Yukon Territory. The study area is underlain by Nisling Terrane, Stikinia and Cache Creek Terrane (which collectively comprise the northern Intermontane Superterrane) as well as the Coast Crystalline Complex (CCC). The region is also underlain by a variety of post-accretionary volcanic and intrusive rocks and hosts mesothermal and epithermal gold deposits. ANA=Ancestral North America, CT=Cassiar Terrane, IN=Insular Superterrane, m=undifferentiated metamorphic rocks. The box near Whitehorse represents the study area (see Figure 3.1).

Nisling Terrane consists of three major units. The dominant (and likely type lithology), the *Nisling assemblage* includes quartz-rich and metapelitic muscovite-, biotite- and garnet-bearing, pelitic schist with quartzite and marble. This unit is equivalent to: the biotite schist unit of Tempelman-Kluit (1976), the Nisling assemblage of Erdmer (1990) and Johnston (1993), the Aishihik assemblage of Mortensen and Erdmer (1992) and the Florence Range metamorphic suite of Currie (1990, 1991, 1992a). Age constraints are poor but suggest a dominantly Proterozoic and earliest Paleozoic range.

A carbonaceous quartz-rich package dominated by quartz-graphite schist, phyllite, mica schist, quartzite and subordinate marble, othogniess and amphibolite known as the *Nasina assemblage* (Tempelman-Kluit 1976, Mortensen 1992, Johnston 1993) is recognized in southernmost Yukon (Hart and Radloff 1990) but not in British Columbia. Age constraints indicate a Devono-Mississippian age for this unit (Mortensen 1992).

Mafic metavolcanic rocks of low metamorphic grade are included within Nisling Terrane in northernmost British Columbia (B.C.) and Yukon. In northern B.C., these rocks are the *Boundary Ranges metamorphic suite* (Mihalynuk and Rouse 1988; Mihalynuk *et al.* 1989; Mihalynuk and Mountjoy 1990). In Yukon, potentially correlative amphibolite and metavolcanics have been recognized (Tempelman-Kluit 1976; Johnston 1988; Hart and Brent 1993), but to a lesser extent than in British Columbia. Age constraints for this unit are poor, but it may be depositional on top of Nasina assemblage rocks (Mortensen 1992).

Most workers agree that rocks of the Nisling assemblage constitutes the main component of the Nisling Terrane. Because of links between Nisling assemblage and Devono-Mississippian rocks, some workers conclude that the Nisling Terrane is part of a larger crustal block known as the Yukon-Tanana Terrane (e.g., Mortensen 1992). Nisling Terrane rocks are similar to, and are considered to have affinities with Proterozoic North American strata (Tempelman-Kluit 1976). However, their present position outboard of rocks with exotic origins such as Cache Creek and Stikinia is enigmatic.

Nasina assemblage is considered to have been deposited upon Nisling assemblage and is also considered to be part of Yukon-Tanana Terrane (Mortensen 1992).

There is some controversy over the terrane affiliation of the Boundary Ranges metamorphic suite although most workers would agree that the Boundary Ranges metamorphic suite is not part of Nisling Terrane. Currie and Parrish (1993) suggest that Boundary Ranges comprise part of Stikinia.

Stikinia

The northern part of Stikinia comprises Upper Triassic volcanic arc rocks of the Lewes River Group, and arc-derived marine sediments of the Upper Triassic Lewes River and Lower to Middle Jurassic Laberge Groups (Figure 2.2).
Collectively the sedimentary units constitutes the fill of the Whitehorse Trough which is thought to have been a forearc basin above the east-facing Lewes River arc (Tempelman-Kluit 1979). Most of Stikinia has a thick, Devonian to Permian basement of variably deformed and metamorphosed oceanic sedimentary and volcanic rocks known as Stikine Assemblage (Monger 1977; Brown *et al.* 1991) upon which the Mesozoic arc and sediments lie unconformably. North of 58°N latitude this important Paleozoic basement is apparently absent and Stikinia is represented entirely by the Mesozoic arc and Whitehorse Trough sediments (Hart 1993). This has led some authors to differentiate that part of Stikinia as "Northern" Stikinia (Jackson *et al.* 1991; Gehrels *et al.* 1991). However in northernmost B.C., Mihalynuk and Rouse (1988) discovered a package of metabasite in what was previously considered to be to the Nisling Terrane (Wheeler *et al.* 1991). Subsequent dating of these and correlative rocks indicates that this unit is Late Paleozoic in age, and may be more northerly equivalents of Stikine Assemblage (Hart in Johnston *et al.* 1993, p. 56; Hart and Mortensen unpub.; Currie pers. comm. 1993).

Based upon the lithological similarities of characteristic rock types, nearly identical stratigraphy and fossil assemblages, most authors have traditionally assumed that the Upper Triassic Lewes River and Stuhini groups represented the same assemblage but were distinguished only by the Yukon-B.C. border. Recently, this assumption was challenged. Stuhini, Lewes River and Kutcho group rocks are all designated as Late Triassic volcanic units (Trs, TrL and TrKU respectively) that occur proximal to one other throughout Northern Stikinia in Yukon (Wheeler and McFeely 1991). Johnston and Thorkelson (1993) equated the Lewes River and Kutcho Groups and suggested that both groups belonged to Cache Creek Terrane and that only Stuhini Group rocks were part of Stikinia.

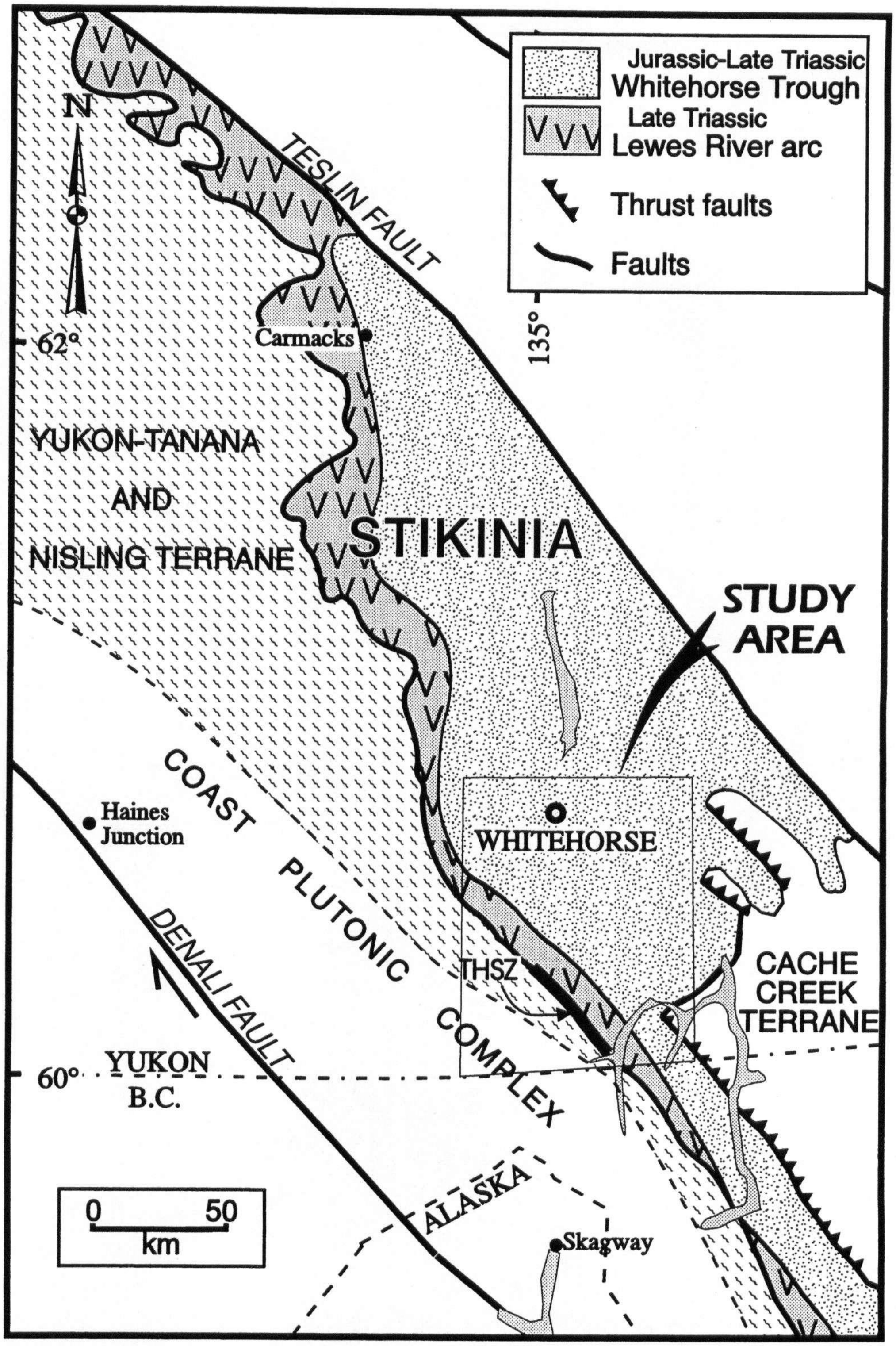


Figure 2.2 Stikinia is composed of the Upper Triassic Lewes River arc and the associated Upper Triassic to Middle Jurassic sedimentary rocks of the Whitehorse Trough. The Whitehorse Trough is composed of the sedimentary portion of the Lewes River Group and all of the Laberge Group. Whitehorse Trough is thought to have been a forearc basin above the west-dipping subduction zone that formed the Lewes River arc. The contact between Stikinia and Nisling Terrane is marked by the Tally Ho shear zone (THSZ). The figure is highly simplified.

Traditional definitions of Stikinia include numerous batholiths that were considered to be the comagmatic roots to Late Triassic Lewes River Group volcanism. These plutons however intrude rocks of the Yukon-Tanana Terrane and as a result are not separated from the adjacent terrane by a fault and cannot be considered part of Stikinia (Hart 1993a; Johnston and Thorkelson 1993). Furthermore, none of the bodies have thus far yielded a date old enough to allow it to have contributed to the Late Triassic arc. Therefore, this cannot be evidence to support the suggestion that the Lewes River arc was constructed upon a basement of Yukon-Tanana rocks (Tempelman-Kluit 1979). Consequently, the terrane diagram in Figures 2.1 and 2.2 differs from some recently published terrane maps by not including these supposedly comagmatic plutons in Stikinia.

Isotopic systematics presented herein suggest that the Lewes River/Stuhini arc north of 59°N is built upon a primitive or transitional basement. Although both Boundary Ranges metamorphic suite and Cache Creek are potential candidate terranes, depositional contacts of Mesozoic strata on Paleozoic rocks have not been observed. A lack of U-Pb inheritance and low initial $^{87}Sr/^{86}Sr$ ratios in granitic rocks intruding the Whitehorse Trough suggest that it too is built upon a primitive crust, but the affinity of this crust is unknown.

<u>Cache Creek Terrane</u>

The Cache Creek Terrane is most extensive in northern B.C. and southern Yukon where it is mainly composed of Upper Paleozoic oceanic volcanic rocks, ultramafite, carbonate and chert. It was subdivided into three sub-terranes: the Nakina, Sentinel and French Range (Monger and Berg 1984) whose contacts were thought to result from abrupt facies changes (Monger 1974, 1977). It is more likely that each of these sub-terranes is a structural panel that represent progressively higher crustal levels from west to east. The western structural sheet (Nakina) is characterized by tectonized ultramafite in the hanging wall of westerly verging thrust faults overlain by Mississippian volcanics and carbonates. The middle panel (Sentinel) is composed of Pennsylvanian and Permian chert and argillite with pillow basalt and diabase sills and olistostromal breccias. The eastern panel (French Ranges) is characterized by a succession of Upper Paleozoic carbonate and tuff overlain by a thick Mesozoic package of interbedded greywacke and chert as young as Toarcian (Cordey *et al.* 1991).

Previously known as the Atlin Terrane (Monger 1974), this package of Cache Creek Group are termed "Northern Cache Creek" to differentiate them from other occurrences of this terrane throughout the Cordillera. Recent terrane maps show the distribution of Northern Cache Creek Terrane extended more than 200 km farther north (Wheeler *et al.* 1991). Although the reason for this is uncertain, it may result from the supposed correlation of Kutcho Group (Cache Creek) with Lewes River Group (Stikinia) volcanic rocks.

Permian limestone in Cache Creek Terrane contain Verbeekinid fusulinid fauna that are different with forms found in North American or on adjacent terranes but are correlated with species in Asia (Monger and Ross 1971; Ross and Ross 1983). This suggests that at least parts of the Cache Creek ocean occupied equatorial latitudes in the west-central paleo-Pacific Ocean. Any model explaining Cordilleran terrane architecture must incorporate this peculiarity.

<u>Coast Plutonic Complex</u>

The Coast Plutonic Complex (CPC) is a 1700 km long, narrow, northwest-trending belt of granite terrane composed of a heterolithic mosaic of biotite and hornblende-bearing, magnetite-series, I-type batholiths, plutons, orthogneiss and migmatite. The granite terrane formed as a continental magmatic arc that existed episodically through Mesozoic and Early Cenozoic time (Armstrong 1988). Pendants and erosional remnants of Nisling Terrane metasediments are an integral part of this complex leading to the term <u>Coast Crystalline Complex</u> (CCC) to account for all rock types. However, the CCC (or the CPC) has no terrane affiliation other than enclosing pendants of Nisling Terrane. In southern Yukon, the eastern margin of the CCC does not form a discrete boundary but its plutons also intrude the western margin of Northern Stikinia. The CCC is abruptly truncated to the west by the Denali Fault. In southern B.C., the CPC intrudes the contact of the Intermontane and Insular Superterranes (van der Heyden 1992).

Previous isotopic dating indicates that most plutons of the CCC are mid-Cretaceous to Eocene in age, but this and other recent studies have shown increasing evidence of an Early and Middle Jurassic component (van der Heyden 1992). The CCC records an Early Tertiary history of dramatic (20 km) uplift along most of its western margin. However along its eastern margin, Eocene subaerial caldera complexes are still intact and have suffered little erosion and therefore little uplift.

TIMING AND NATURE OF TERRANE INTERACTIONS

The timing and nature of the interactions between these disparate terrane are fundamental to the understanding of Cordilleran terrane architecture and assemblage. The individual terranes that comprise the Intermontane Superterrane likely underwent a period of proximity to one another prior to amalgamation. Accretion of the amalgamated superterrane to the craton was likely responsible for reactivation of older faults and may obscure the nature and timing of deformation along original "amalgamating" structures.

Nisling Terrane-Stikinia

The contact between Nisling Terrane (and Yukon-Tanana Terrane) and Stikinia is rarely exposed as it is nearly everywhere intruded by batholiths, modified by the younger Llewellyn Fault, or the Nisling Terrane is displaced by younger CPC granites and represented only by discontinuous pendants and erosional remnants. Consequently, most suggestions of terrane juxtaposition are the result of indirect geological evidence.

Werner (1978) suggested that augite-phyric basalt dykes that cross-cut the foliation in Nisling Terrane were similar to Upper Triassic (Stuhini) volcanics -- thus indicating that Nisling Terrane metamorphism was pre-Upper Triassic. By extrapolation, this evidence would suggest that Stikinia and Nisling Terrane were amalgamated by this time.

Building upon observations of Souther (1971), Bultman (1979), and Mihalynuk and Mountjoy (1990) that found metasedimentary clasts in Upper Triassic conglomerate in Stikinia, Jackson *et al.* (1991) isotopically confirmed that the clasts were derived from Nisling Terrane and suggested a Late Triassic depositional link between the terranes. The timing of this linkage post-dates the *circa* 225 Ma granite upon which the conglomerate is deposited, but pre-dates Norian *Halobia?*-bearing limestone that stratigraphically overlies the conglomerate. Hart and Pelletier (1989a) recognized large, foliated quartzite and smaller quartz-mica schist clasts in Jurassic Laberge Group conglomerate that likely also have a source in the Nisling Terrane but the stratigraphic age of the conglomerate, and thus the timing of the linkage, is unknown.

A large, 1-4 km wide ductile shear zone, known as the Tally Ho shear zone (THSZ) was discovered along the westernmost margin of Stikinia (Doherty and Hart

1988). Detailed mapping and kinematic studies indicated that this was zone of highly strained volcanic and sedimentary rocks that recorded a history of dominantly sinistral strike-slip motion (Hart and Radloff 1990; Radloff *et al.* 1990; Hansen *et al.* 1990). Rocks of the Nisling Terrane are immediately west of this zone and are separated from Stikinia by the intervening Bennett Batholith. It intrudes the shear zone, encloses Nisling Terrane rocks as pendants and links the two terranes. Initial dating of body yielded a discordant age of 220 Ma (Baadsgaard in Doherty and Hart 1988) that led Hart and Radloff (1990) to suggest that this was the timing of Nisling-Stikinia amalgamation.

Currie and Parrish (1993) suggest that the Wann River shear zone in northern B.C., developed in response to the juxtaposition of Nisling Terrane and Stikinia. As with the Tally Ho shear zone, the Wann River shear zone records a history of sinistral motion. The fabric in the hanging wall of the 185 Ma Hale Mountain granodiorite, which includes the Nisling Terrane, is thought to be coeval with the development of the shear zone and therefore provides a maximum age for the juxtaposition. A titanite age of ~170 Ma is considered to be a post-metamorphic cooling age that provides a Middle Jurassic minimum age constraint. Evidence of older juxtapositions are discounted by Currie and Parrish with suggestions that: 1) isotopically evolved metamorphic clasts in Upper Triassic conglomerate (of Jackson *et al.* 1991) were derived from as yet undiscovered, evolved Stikinian sedimentary rocks and not the adjacent Nisling Terrane; 2) augite-phyric dykes attributable to Stikinia (of Werner 1978) cut only the Boundary Ranges metamorphic suite and not true Nisling Terrane (i.e., Florence Range suite): 3) zircons from the Bennett Batholith show evidence of both an inherited component and Pb-loss which gave rise to a meaningless, and much older date.

Johnston (1993) has suggested that plutons of the *ca.* 186 Ma Long Lake suite, which intrude Stikinian volcanic rocks and the Aishihik Batholith which intrudes Nisling Terrane rocks, provides additional evidence of an Early Jurassic linkage.

Stikinia-Cache Creek

The juxtaposition of Stikinia and Cache Creek Terrane in Yukon is along the Nahlin and Crag Lake faults. The Nahlin Fault is a northwest--trending, south and southwest directed, imbricate thrust fault that has tectonized Cache Creek ultramafite in the hanging wall. The emplacement of the Cache Creek terrane on Stikinia likely occurred after deposition of its youngest strata (late Early Jurassic; Cordey *et al.* 1991) but before sedimentological links between the terranes were established in the Bowser

Basin in upper Aalenian to Bajocian time (Ricketts *et al.* 1992; and references therein). The oldest isotopic evidence is obtained from the Fourth of July batholith that cuts and metamorphoses deformed Cache Creek at 172 Ma (Mihalynuk *et al.* 1992). These data place tight constrains on obduction to *circa* 183 to 172 Ma (using Harland *et al.* 1990). In southern Yukon, this fault dips at 65° and cuts volcanic rocks as young as 84 Ma (Hart and Radloff 1990). In northern British Columbia, strands of the Nahlin fault cut and displace the *ca.* 75 Ma Atlin Mountain pluton but is plugged by the 58 Ma Birch Mountain pluton (Mihalynuk *et al.* 1992), indicating Late Mesozoic brittle, probably strike-slip reactivation.

The Crag Lake fault is an large, >80 km long, northeast-trending fault. If Cache Creek was basement to Whitehorse Trough then the fault would have to accommodate normal, south-side-up displacement of at least 7 km -- equivalent to the thickness of Whitehorse Trough sedimentary strata . Northeast-trending fabrics in phyllite and overturned northeast-trending folds developed in Whitehorse Trough strata north of the fault are likely the result from dextral strike-slip motion along the fault (Wheeler 1961; Hart and Pelletier 1989b). The Crag Lake fault is orthogonal with, and, with minor complications, joins the northern termination of the Nahlin Fault to the Teslin Fault (Gordey and Stevens 1994). Ramping and stacking of westerly verging thrust packages may have resulted in the formation of the Crag Lake fault as a tear fault (Hart and Pelletier 1989b) that accommodated western transport of Cache Creek Terrane by dextral strike-slip motion; however the precise timing of motion on the Crag Lake Fault is not known.

Coast Crystalline Complex

Although not a terrane, the Coast Plutonic Complex and its associated metamorphic rocks certainly comprise a significant tectonic element although it seems unlikely that the CPC existed prior to terrane amalgamation. Numerous, large Early Jurassic (192-177 Ma) batholiths and plutons intrude the metamorphic rocks of Yukon-Tanana and Nisling Terranes in Yukon. This magmatic arc likely formed the proto-Coast Crystalline Complex. Plutons as old as 186 Ma also intrude Stikinia (Tempelman-Kluit 1984) and suggest that the Early Jurassic arc may have been built across the already amalgamated terranes. The oldest pluton in Cache Creek rocks is 172 Ma (Mihalynuk et al. 1992).

Chapter III

Magmatic evolution of the Intermontane Superterrane and Coast Plutonic Complex in southern Yukon Territory: Geological, U-Pb, K-Ar and Rb-Sr isotopic constraints

INTRODUCTION

The many suspect terranes that compose the northern Canadian Cordillera include the products of pre-, syn and post-accretionary magmatism. Since magmatism occurs in response to tectonism and magmas of differing compositions form in response to different tectonic processes, a knowledge of the timing and nature of magmatic rocks is integral in deciphering the tectonic evolution of the Cordillera.

Numerous batholiths, plutons, sills and dykes intrude the terranes that make up the Intermontane Superterrane. Indeed the density of these magmatic rocks is so high along the western margin of the Intermontane Superterrane that they compose a 1700 kilometre long granite terrain called the Coast Plutonic Complex (CPC). The CPC and the accreted terranes that constitute the Intermontane Superterrane in southern Yukon Territory have a poorly understood and complex pre-, syn- and post-accretionary magmatic history. The definition of individual plutons within the granite terrane of the CPC is difficult; plutons that intrude the volcanic and sedimentary rocks of the Intermontane Superterrane are more easily distinguished but are generally not well studied. Recent 1:50 000 geological mapping in the Whitehorse map-area (105D, see Wheeler 1961) by Doherty and Hart (1988), Hart and Pelletier (1989a, 1989b), Hart and Radloff (1990) and Hart and Brent (1993) has delineated more than 35 discreet plutons.

Previous isotopic dating of plutonic rocks in the eastern CPC and northern Intermontane Superterrane in southern Yukon Territory and northern British Columbia indicated that the region was the locus of episodic magmatism throughout Mesozoic and early Cenozoic time (Tempelman-Kluit and Wanless 1975; Le Couteur and Tempelman-Kluit 1976, Bultman 1979, Tempelman-Kluit 1984; Morrison *et al.* 1979; Farrar *et al.* 1988). Mid-Cretaceous, Late Cretaceous and Eocene plutonic suites were identified. A Jurassic suite was postulated on the basis of several discordant Jurassic K-Ar dates, and a Triassic suite was suggested from the presence of granitic clasts in Lower Jurassic strata. The K-Ar and Rb-Sr dating methods used in these early studies led to equivocal age ranges, particularly for Mesozoic plutons. Only two Mesozoic U-Pb zircon dates have been published from this entire belt of rocks in southern Yukon (Tempelman-Kluit and Wanless 1980; Baadsgaard in Doherty and Hart 1988). Recently published U-Pb dates (Johnston 1993; Erdmer and Mortensen 1993; Currie and Parrish 1993; Mihalynuk *et al.* 1992) present data critical to unraveling the complex geological history of the northern Canadian Cordillera.

In this chapter, 16 U-Pb zircon and 14 K-Ar dates (8 hornblende, 4 biotite and 2 whole rock) are reported along with more than 40 Sr isotopic analyses. All analyses are from plutons and batholiths of granitoid rocks that comprise the Coast Plutonic Complex that intruded the amalgamated terranes that compose the Intermontane Superterrane of the southern Yukon Territory (Figure 3.1). More than 35 individual plutons and batholiths have been identified and named (Figure 3.2). These results, combined with data from Morrison *et al.* (1979), Doherty and Hart (1988) and Mihalynuk (in press) provide a comprehensive framework in which to interpret the magmatic evolution of this region.

MAGMATIC EPISODES AND PLUTONIC SUITES

Magmatic episodes can be determined on the basis of clusters or peaks of similar isotopic age dates, reflecting the crystallization of various igneous rocks, that are separated by periods of obvious magmatic abeyance. Discrimination of magmatic episodes using age data alone is prone to error due to overlapping age ranges of protracted magmatic episodes (Figure 3.3a) and by bias introduced by non-unique K-Ar and Rb-Sr age determinations. These methods define cooling paths rather than crystallization ages and are susceptible to partial resetting, thus skewing the inferred ages of a magmatic episodes towards a younger mean or median value (Figure 3.3b).

Magmatic episodes can be divided into plutonic suites. Individual plutonic suites are defined by similarities in tectonic setting, compositional, mineralogical, textural, geochemical and isotopic characteristics of the constituent plutons. Defining the age range of a plutonic suite requires the selection of only the more reliable isotopic determinations (usually U-Pb zircon). The previous assignment of the plutonic rocks in the Whitehorse map-area into suites by Morrison *et al.* (1979) and Woodsworth *et al.* (1991) relied on K-Ar and Rb-Sr methods. This study applies U-Pb zircon dates to: (i) precisely define the ages of plutonic suites, and (ii) distinguish among temporally close, but distinct magmatic episodes. The division of magmatic rocks of the northern Cordilleran into plutonic suites is aided by fundamental work by Tempelman-Kluit (1976), Armstrong (1988) and Anderson (1988).

Isotopic age data presented in this study, in combination with previously published data, indicate that plutonic rocks in the study area represent four magmatic episodes which developed during: 1) Late Triassic to Early Jurassic (Klotassin); 2) mid-Cretaceous (Whitehorse); 3) Late Cretaceous (Carmacks) and 4) Early Tertiary (Skukum) times (Figure 3.4). Geological and geochemical means combined with

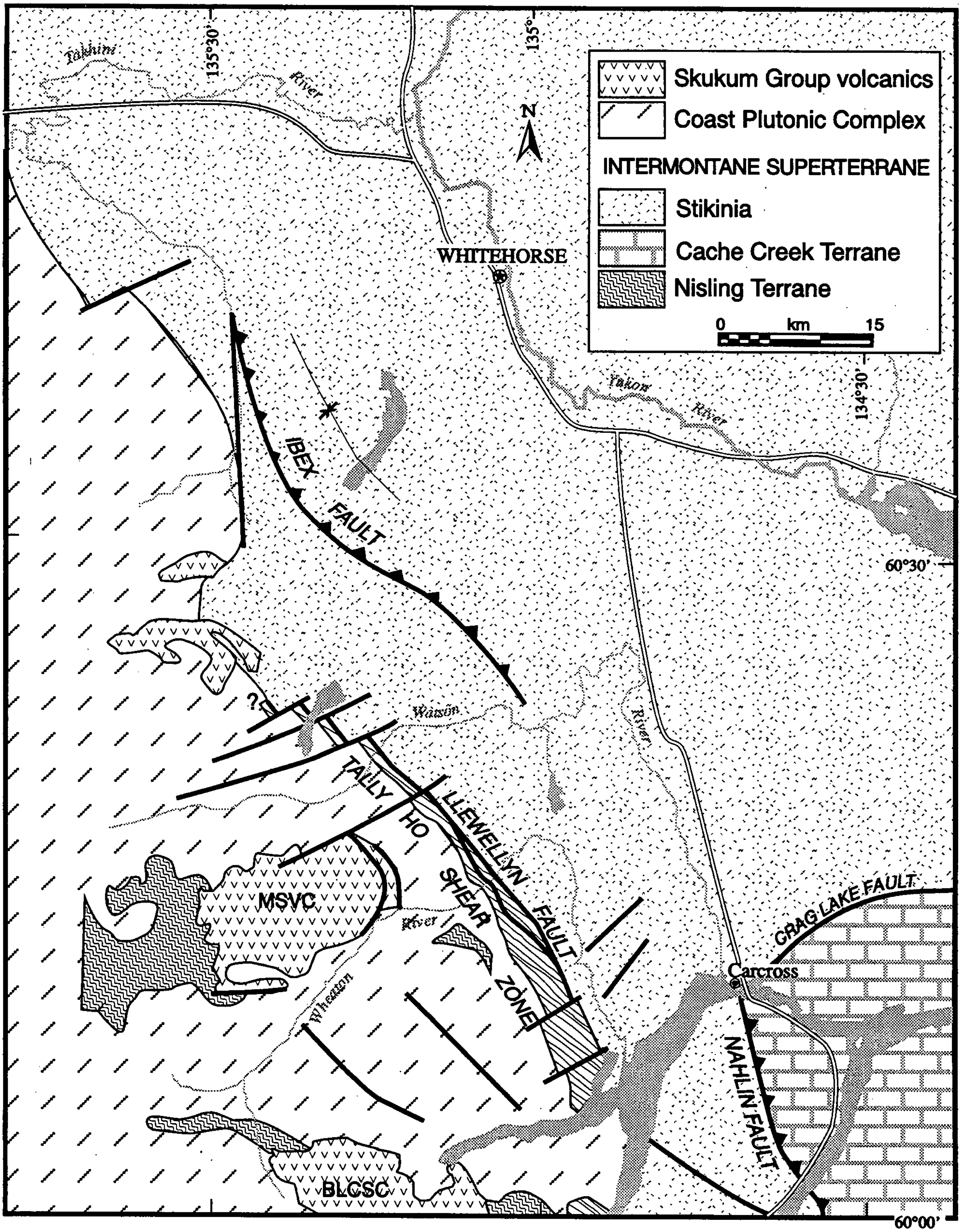


Figure 3.1 Geological setting of granitic rocks examined in this study. The region dominated by the rocks of the Coast Plutonic Complex but containing parts of Nisling Terrane and Skukum Group volcanics is known as the Coast Crystalline Complex. MSVC = Mount Skukum volcanic complex, BLCSC = Bennett Lake Cauldera Subsidence Complex.

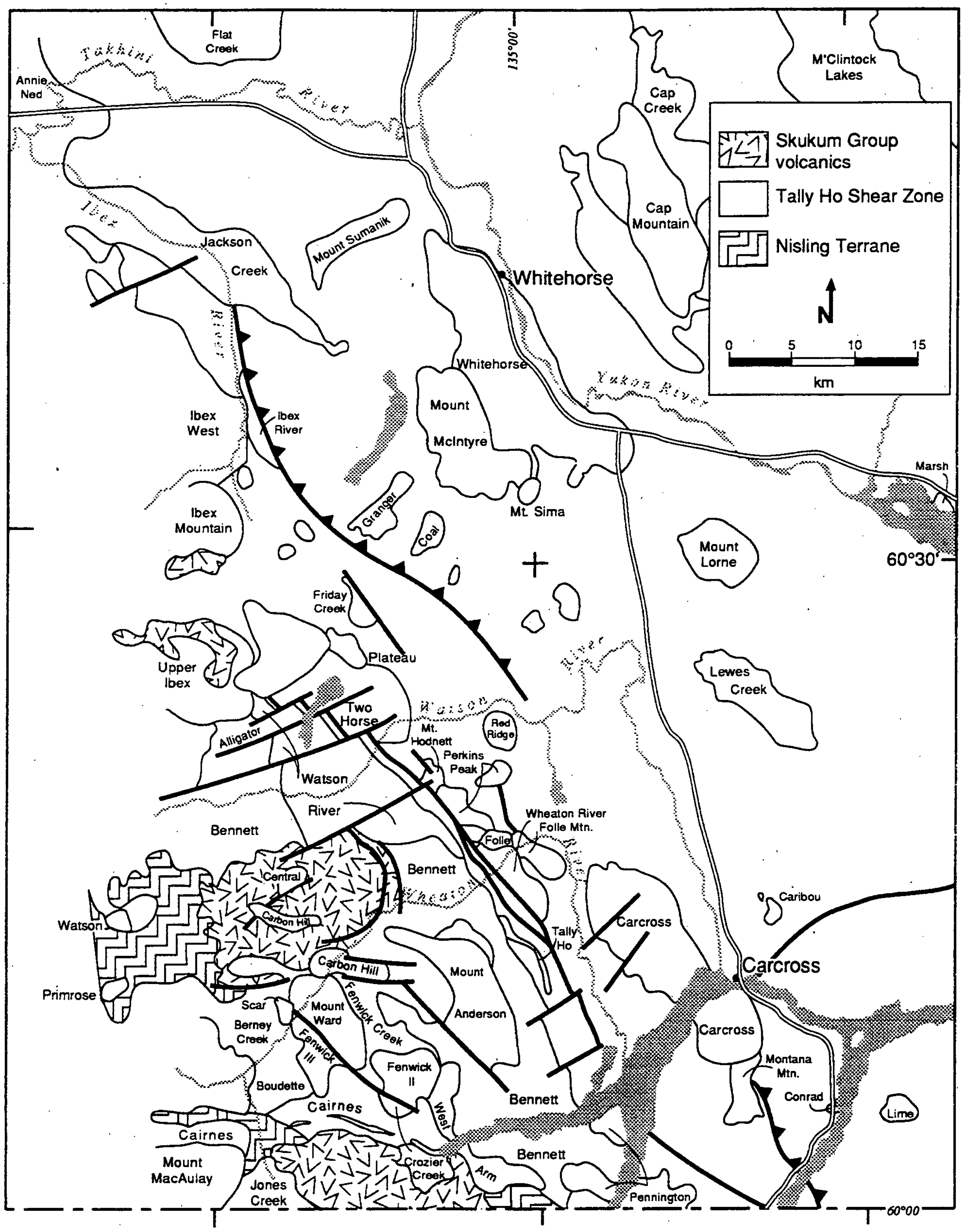


Figure 3.2 More than 35 plutons have been identified through mapping and geochronology. The names listed here are used throughout this chapter.

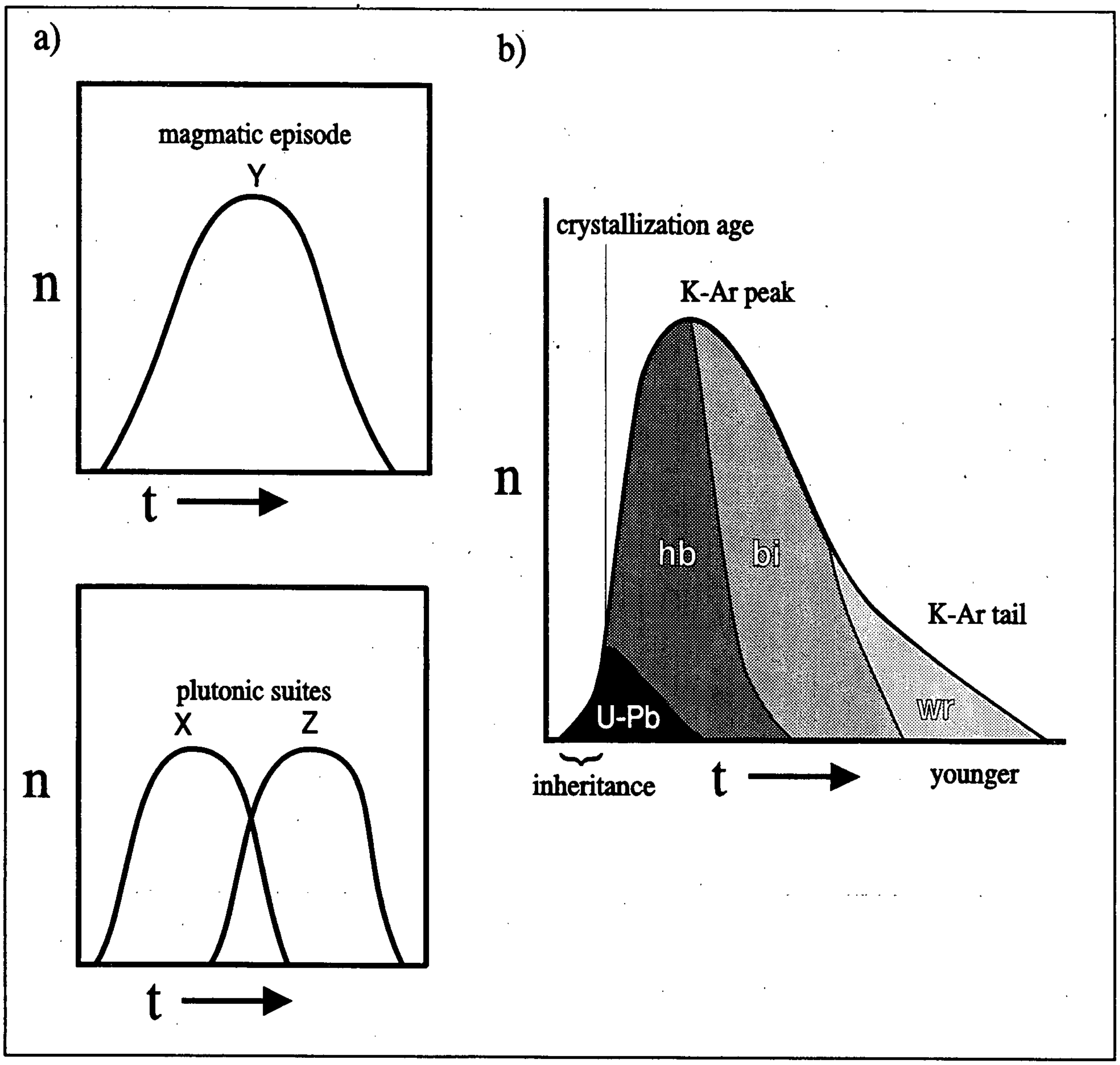


Figure 3.3a. The benefit of sub-dividing rocks of similar ages into individual suites is depicted in these hypothetical histograms of age date data. The uppermost graph apparently represents a single, long lasting magmatic event with a peak at Y. However, close examination of the rocks may indicate that two (or more) plutonic suites, with narrow time ranges but of similar age may be included in the data set with peaks at X and Z (lower graph). The magmatic histories inferred from these two graphs is quite different. The upper graph represents a magmatic episode whereas the lower graph represents plutonic suites.

Figure 3.3b. This graph represents a hypothetical histogram of age data where there are few U-Pb dates but many K-Ar dates. Simply using the peak of a histogram to determine the peak age of magmatism is misleading since K-Ar (and Rb-Sr dates) will typically define the peak but are typically skewed to lower values depending on the relative percentages of hornblende, biotite or whole rock dates.

precise U-Pb zircon geochronometry allow the differentiation of *ten* plutonic suites. Dates presented in the text are reported to the nearest integer and the two sigma errors are rounded up to the next integer. U-Pb analytical data, with concordia plots and interpretation are displayed in Appendix 1. Concordia plots are also included as figures within the text. K-Ar analytical results are in Table 3.1.

KLOTASSIN (LATE TRIASSIC TO EARLY JURASSIC) MAGMATIC EPISODE

Various plutons and batholiths that intrude northern Stikinia and Yukon-Tanana/Nisling Terrane in Yukon are interpreted to be Late Triassic to Early Jurassic in age have been attributed to the Klotassin suite (Tempelman-Kluit 1974, 1976; Wheeler and McFeely 1991; Woodsworth *et al.* 1991). Recent mapping and age dating has identified several intrusive bodies in the study area that belong to this suite. The ages span approximately 45 Ma and likely represent pre-, syn- and post accretionary magmatic events. As a result, individual plutonic suites are assigned and the entrenched term "Klotassin" is redefined as a magmatic episode to represent the long span of the numerous plutonic suites.

Most plutons and batholiths of this episode in the Yukon are poorly studied and lack precise and reliable geochronological data. This is largely a result of a dearth of published U-Pb data, increased analytical error and probability of partial resetting associated with K-Ar dates for pre-Cretaceous rocks. The compositional diversity of these bodies is the first indication that several plutonic suites may be associated with this episode. Four suites are defined and described below using representative plutons from the study area -- from oldest to youngest they are the Stikine, Red Ridge, Aishihik and Bennett plutonic suites (Figure 3.5).

Stikine Plutonic Suite (220-208 Ma)

A few small, poorly exposed, irregularly-shaped and locally northwest-trending, variably foliated plutons outcrop along the westernmost margin of the northern Stikine Terrane. They intrude Lewes River arc volcanics and are non-conformably overlain by Whitehorse Trough clastic rocks suggesting a pre-Jurassic origin. The plutons range from granodiorite to gabbro with hornblende as the dominant mafic mineral. Plutons of this suite are associated with Alaskan-type ultramafics. Three intrusive bodies, described below, are correlated with, and assigned to, the Stikine Plutonic Suite (see Woodsworth *et al.* 1991).

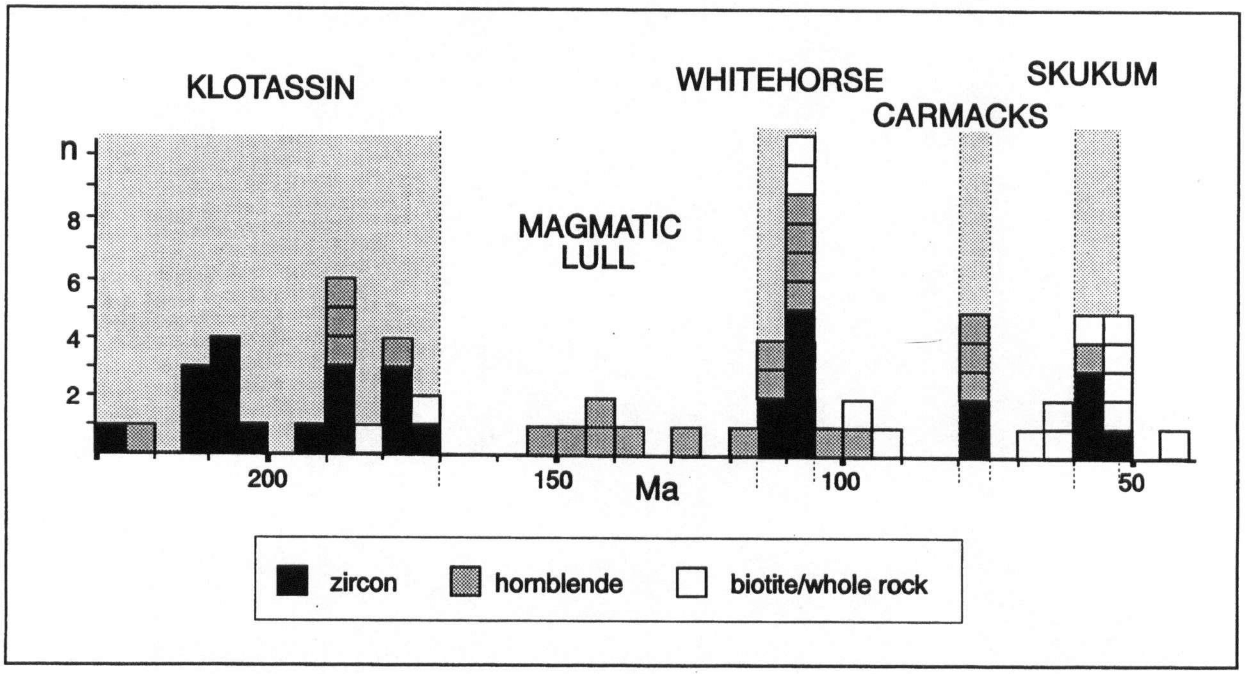


Figure 3.4 Histogram of age dates from granitic rocks determined from the Whitehorse map area and adjoining regions indicates that there are four pronounced episodes of magmatism separated by periods of magmatic abeyance. Within each of these magmatic episodes, individual plutonic suites can be identified.

TABLE 3.1 K-Ar data and dates for plutonic rocks described in this report.

Sample	Pluton Name	Rock Type	Latitude (°N)	Longitude (°W)	Material analysed	K(%) [a]	$^{40}Ar^{b}$ (cc/gm)	^{40}Ar(%)	Date±2σ^{c}	U-Pb Date Appendix 1
PRE-CRETACEOUS (RESET/COOLING) AGES										
ZR-4	Tally Ho	gabbro	60°11.9'	135°00.1'	hornblende	0.711	3.217	89.7	113±3	215
Y88-10	Alligator	hornblende granodiorite	60°21.7'	135°27.5'	hornblende	0.750	3.878	92.9	128±4	175.
Y88-30	Fenwick Ck.	hornblende diorite	60°08.4'	135°12.4'	hornblende	0.564	3.095	90.3	136±5	176
MID-CRETACEOUS PLUTONS										
Y88-26	Ibex River	hornblende granodiorite	60°35.5'	135°25.6'	hornblende	0.510	2.252	89.5	110±4	108
89CH 35-7	Mt. Hodnett	pyroxene diorite	60°20.5'	135°13.5'	hornblende	0.341	1.446	80.7	106±4	
89CH 75-1	Marsh Lake	quartz diorite	60°32.1'	134°23.2'	hornblende	0.198	0.825	73.8	104±4	
89CH 33-3	Carbon Hill	biotite granite	60°10.3'	135°14.0'	biotite/chlorite	1.48	5.688	57.6	96±15	
89CH 64-1	Mt. Granger	biotitie granodiorite	60°31.1'	135°15.5'	biotite	5.72	21.274	92.0	93.3±3.2	
LATE CRETACEOUS PLUTONS										
Y88-33-2	Red Ridge II	hornblende diorite	60°21.6'	135°04.2'	hornblende	0.421	1.348	81.4	80.6±2.8	
Y88-21	Montana Mtn.	quartz monzonite	60°05.7'	134°42.0'	hornblende	0.573	1.782	78.2	78.3±2.7	107
89CH 60-5	Carcross	biotite granite	60°14.8'	134°54.6'	biotite	6.39	17.359	95.0	68.6±2.5	
EARLY TERTIARY PLUTONS										
Y88-1	Folle	biotite granite	60°17.4'	135°00.7'	biotite	5.73	13.836	90.0	61.1±2.1	78
89CH 52-1	Pennington	quartz monzonite	60°01.5'	134°57.0'	hornblende	0.655	1.418	79.0	54.9±1.9	
"	"	" "	"	"	biotite/chlorite	1.30	2.108	73.0	41.2±2.8	
Y88-29	Crozier Ck. II	quartz monzonite	60°05.0'	135°13.5'	whole rock	3.95	7.826	90.1	50.3±1.8	
Y88-6	Crozier Ck.	quartz monzonite	60°02.9'	135°11.1'	whole rock				51.2±1.8	56

NOTES. K analyses are by D. Ghosh and D. Runkle, and Ar analyses are by J. Harakal; Geochronometry Laboratory, The University of British Columbia.

[a] Potassium was determined in duplicate by atomic absorption using a Techtron AA4 spectrophotometer on dilute sulphate solutions buffered by Na and Li nitrates. K (%) is average of at least two determinations.

[b] Argon was determined by isotope dilution using an AEI MS-10 mass spectrometer with Carey Model 10 vibrating reed electrometer, high purity ^{38}Ar spike, and conventional gas extraction and purification procedures as described by White et al. (1967).

[c] The errors reported, based on multiple analyses for K, are estimated two standard deviations as related to the calculated date. IUGS conventional decay constants (Steiger and Jäger, 1977) are $^{40}K/b = 4.962 \times 10^{-10} a^{-1}$, $^{40}K/e = 0.581 \times 10^{-10} a^{-1}$, and $^{40}K/K = 0.0001167$ atom ratio.

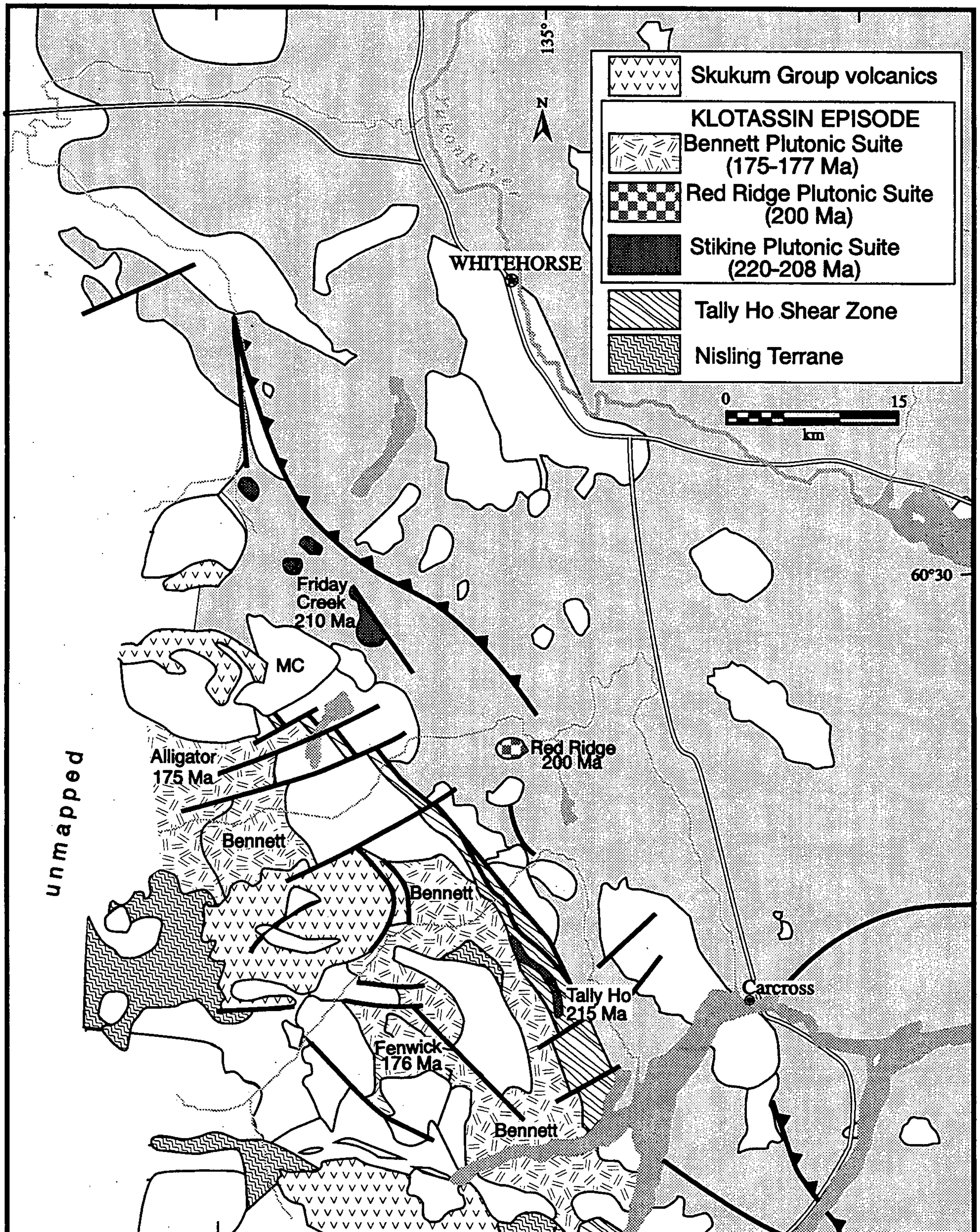


Figure 3.5 Distribution of Late Triassic to Early Jurassic Klotassin Episode plutons in the study area. Note that the Stikine plutonic suite exclusively intrudes Stikinia.

Tally Ho leucogabbro forms an 8 km long, linear pluton concordant with the deformed Lewes River Group greenstone of the Tally Ho shear zone. This body is a coarse-grained to megacrystic, foliated to gneissic, hornblende gabbro orthogneiss (Figure 3.6). The large crystal size and the varying percentages of plagioclase and hornblende (rare quartz) due to primary mineral layering tend to gives the gabbro a leucocratic appearance. The presence of remnant clinopyroxene cores in the hornblende suggest that hornblende pseudomorphed pyroxene. Epidote, a common accessory mineral, is likely secondary. Deformation was dominantly ductile and related to motion within the Tally Ho shear and Llewellyn fault zone. The Tally Ho leucogabbro displays strong mineralogical, spatial and temporal affinities with the Lewes River Group volcanic rocks. A single, highly abraded coarse-grained zircon fraction from the leucogabbro yielded a concordant U-Pb date of 214±1 Ma (Figure 3.7).

Tally Ho ultramafite is a small (<0.5 km^2) elongate, Alaskan-type ultramafic plug which appears to cut Lewes River volcanics in the Tally Ho shear zone. The body is dominated by coarse-grained clinopyroxenite with lesser wehrlite and dunite, and their tectonized and serpentinized (chrysotile) equivalents. Although this body is undated, its close spatial, mineralogical, and textural relationship with the Tally Ho leucogabbro suggests that the two may be comagmatic and coeval.

Friday Creek quartz diorite is exposed in erosional windows through Lewes River Group volcanic rocks although it is uncertain whether the contact is intrusive of non-conformable. This unit is composed of foliated to gneissic, medium-grained, acicular hornblende and biotite-hornblende quartz diorite and granodiorite. Plagioclase (oligoclase An_{23}) is typically zoned and moderately sausseritized, thus giving the weathered rock a leucocratic appearance. Large subhedral titanite is a common accessory mineral. Two zircon fractions yielded a nearly concordant U-Pb date of 210+16/-1 Ma (Figure 3.8). This indicates that the Friday Creek pluton may be comagmatic with volcanism near the top of the Lewes River Group during the latest Triassic.

Granitic clasts from the Lower Jurassic Laberge Group conglomerate were dated at 215±4, 210+6/-3, 210±8 and 208+10/-3 Ma (see Chapter V). The generally large size of these clasts indicate that the source plutons of these ages are likely proximal. However none of these clasts can be directly correlated with known plutons suggesting that the source plutons may be eroded, buried, undiscovered or displaced.

Figure 3.6 Coarse-grained, foliated, hornblende Tally Ho leucogabbro cross-cuts the fabric within the Tally Ho Shear Zone, but is itself, subsequently foliated.

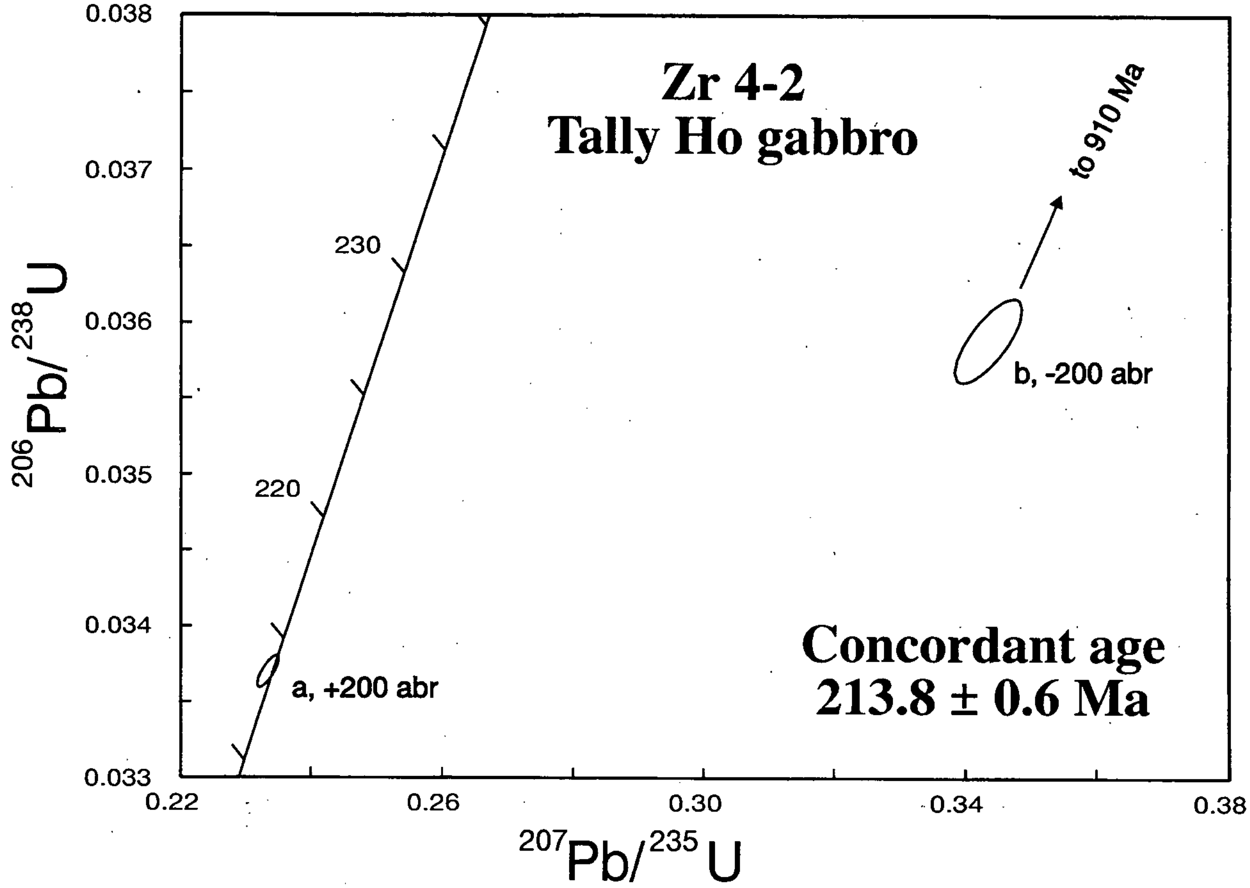


Figure 3.7 U-Pb concordia plot for the Tally Ho leucogabbro (analysis by Janet Gabites).

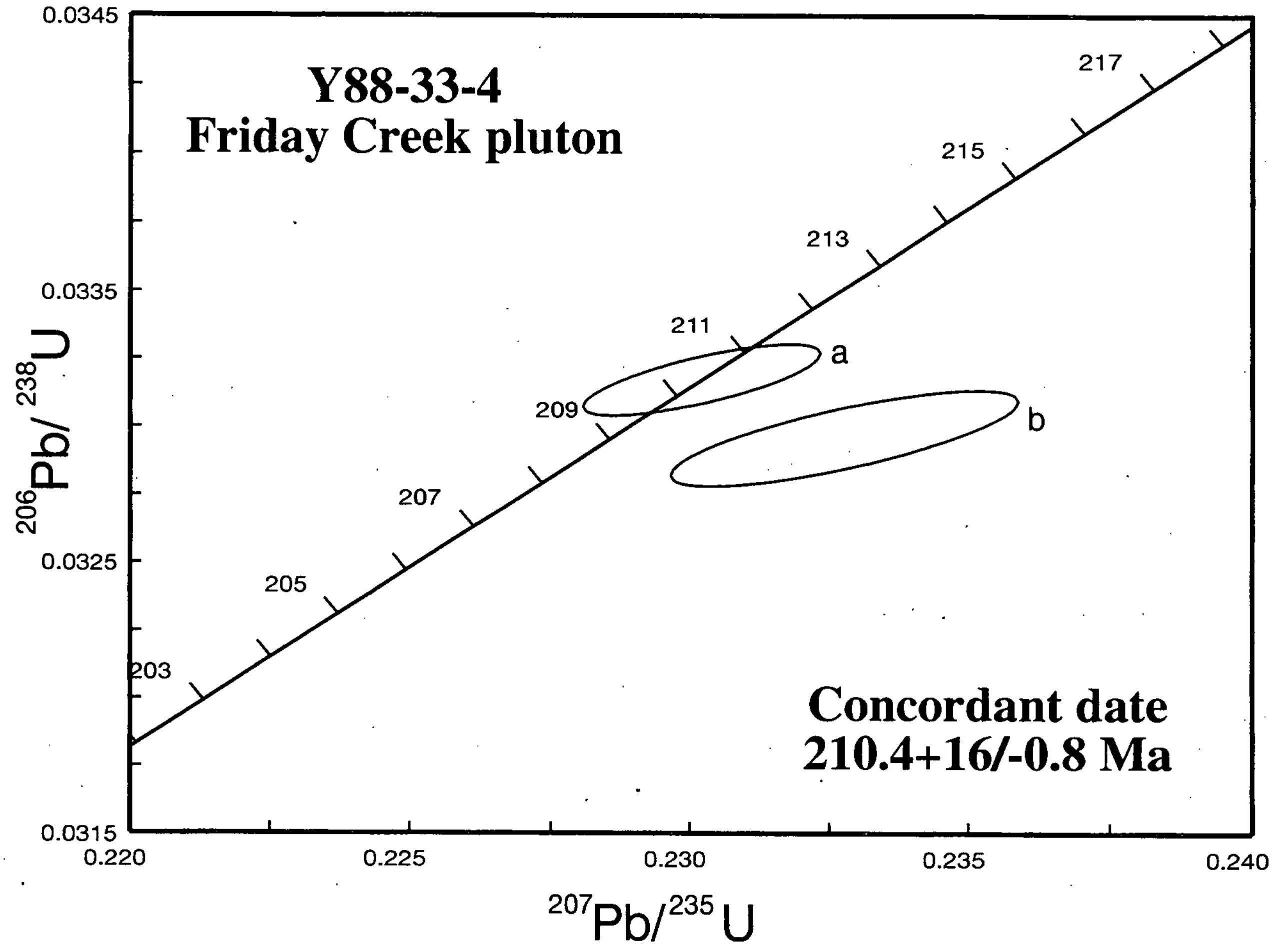


Figure 3.8 U-Pb concordia plot of the Friday Creek diorite. The data are interpreted to give an age of 210+16/-1.

Nevertheless, the dates of these clasts provide additional data for the range of this plutonic suite. The huge volume of granitic clasts in Early Jurassic conglomerate indicate that the surface exposures of this suite were previously much more extensive.

Red Ridge Plutonic Suite (200 Ma)

Red Ridge pluton is a small, resistant, medium-grained, hornblende-rich diorite and granodiorite that forms part of a circular intrusive complex exposed in an erosional window through Whitehorse Trough sedimentary rocks. Despite its limited exposure, the pluton shows several lithological and textural variations which may be indicative of multiple epizonal phases. The complex has been cut by numerous north-trending faults, shear bands and dykes. The pluton locally displays propyllitic alteration which is likely related to the porphyry-copper and polymetallic gold-silver quartz veins that are developed in, and adjacent to this intrusion.

Hornblende granodiorite at Red Ridge gives an earliest Jurassic U-Pb age of 200±1 (Figure 3.9) or at least 10 Ma after the emplacement of the youngest members of the Stikine plutonic suite, and after all Lewes River volcanism. The Red Ridge plutonic suite is defined by a small amount of data but the accuracy of the date precludes an association with any previously described suites.

Aishihik Plutonic Suite (192-185 Ma)

Although not represented in the study area, the Aishihik and Long Lake plutonic suites constitute important batholiths that occur along the eastern margin of the Coast Crystalline Complex (CCC: the area underlain by Yukon-Tanana Terrane and the Coast Plutonic Complex) and the western margin of Stikinia. These suites have been documented in the Aishihik Lake area by Johnston (1993) and Johnston and Timmerman (1994). The Aishihik plutonic suite is composed of large batholiths of homogeneous, variably foliated hornblende granodiorite that intruded Nisling Terrane rocks at deep crustal levels. The Long Lake suite comprises non-foliated, coarse-grained to megacrystic K-spar quartz monzonite that is miarolitic and intrudes the Aishihik bodies, the Nisling Terrane and Stikinia - at upper crustal levels. Both the Aishihik and Long Lake suites are *ca.* 186 Ma indicating that the region experienced rapid and substantial uplift (~25 km) at this time. As a result of this and other geological indicators, these suites are presumed to be syn-accretionary and represent the oldest plutonic linkage between Stikinia and Nisling Terrane. The range of this

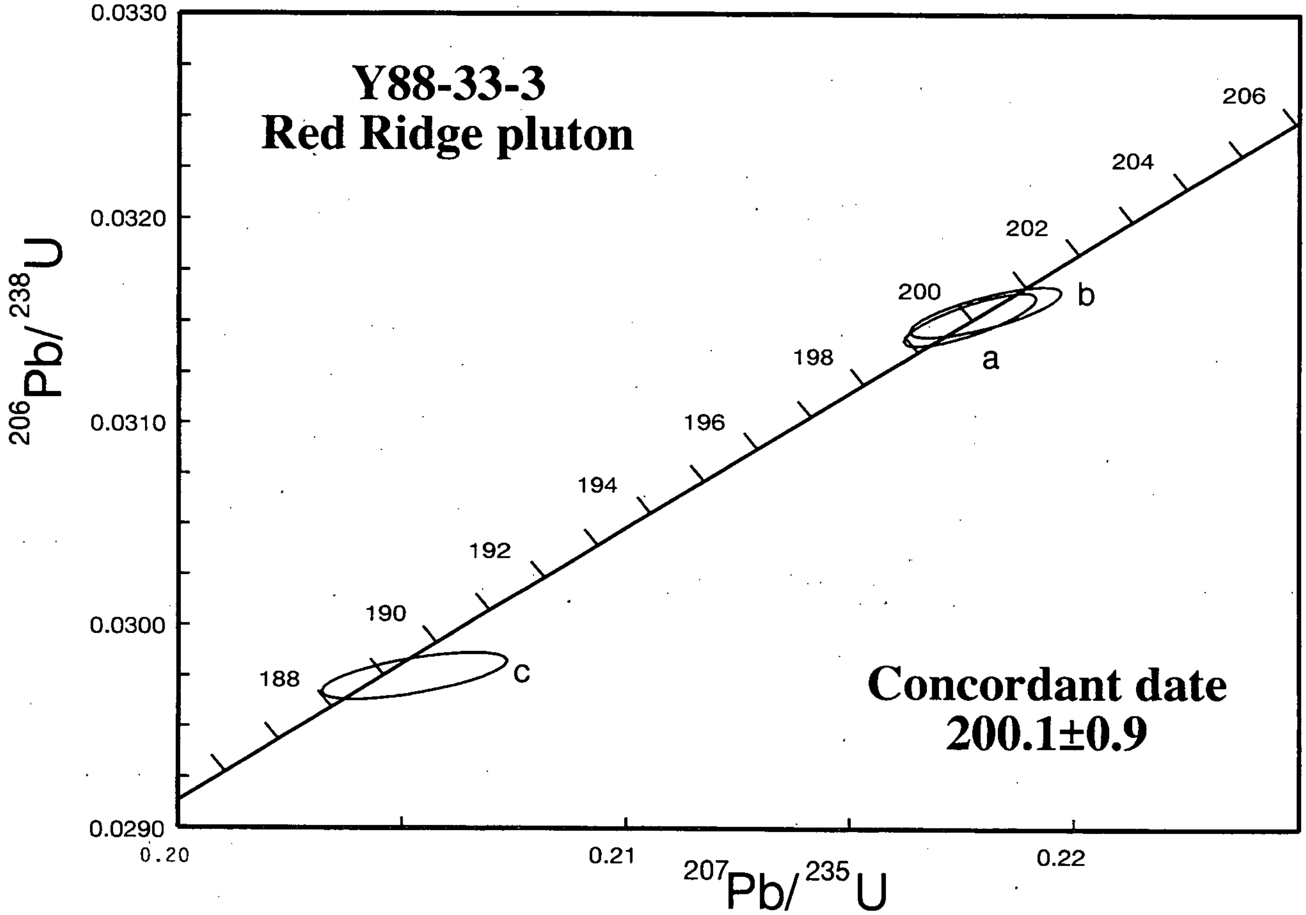


Figure 3.9 U-Pb concordia plot for the Red Ridge pluton. The 200 Ma age is unique for plutons from within the Yukon.

plutonic suite is extended by the 192 Ma age of the Minto pluton (Tempelman-Kluit and Wanless 1980).

Bennett Plutonic Suite (178-175 Ma)

Like the members of the Aishihik Plutonic Suite, the Bennett Plutonic Suite comprises batholiths that intrude Nisling Terrane and the western margin of Stikinia and is post-accretionary. Rocks of the Bennett suite display a wide variation in lithologies and textures that comprise to form phases within the larger Bennett Batholith. The most significant phases include the marginal and more mafic Alligator Lake and Fenwick Creek phases and the felsic Bennett phase. All phases contain megacrystic alkali feldspar and share close lithological and spatial similarities with the dominant Bennett phase. The contacts among the phases are gradational and as a result, their limits are poorly defined within the batholith.

Alligator Lake monzodiorite forms numerous small (<10 square kilometres), medium- to coarse-grained, weakly foliated bodies which are similar and spatially associated with foliated granodiorite border phases of the Bennett batholith. Consequently, it is poorly represented on the map (Figures 3.2, 3.5, and Hart and Radloff 1990) and much of it is included within the Bennett Batholith. This rock has many characteristics similar to the Aishihik batholith as described by (Johnston 1988, 1993). The Alligator Lake monzodiorite yields a U-Pb zircon age of 175+2/-1 Ma (Figure 3.10). The age is consistent with the inclusion of this phase in the Bennett Batholith.

The Fenwick Creek pluton covers approximately 150 km^2 and is composed of mesocratic, medium-, to coarse-grained, pervasively but weakly foliated hornblende quartz-diorite, tonalite and diorite (Figure 3.11). Sparse, pink alkali feldspar megacrysts are easily observed among the otherwise equigranular rock. This pluton gives a U-Pb date on zircon of 176+2/-1 Ma (Figure 3.12) and allows for its inclusion as a phase in the Bennett Batholith. Alkali feldspar-biotite-quartz pegmatite dikes cross-cut the foliation of the Fenwick Creek pluton and give a feldspar-whole rock Rb-Sr isochron of 159±6 Ma (R.L. Armstrong unpublished data) -- thus constraining the youngest age of the foliation.

A large portion of the CCC is underlain by tonalite to diorite that contain a high proportion (50-70%) of, generally mafic, xenoliths, which are cross-cut by numerous, felsic dikes. This complex region in the map area is mapped as the Cairnes pluton

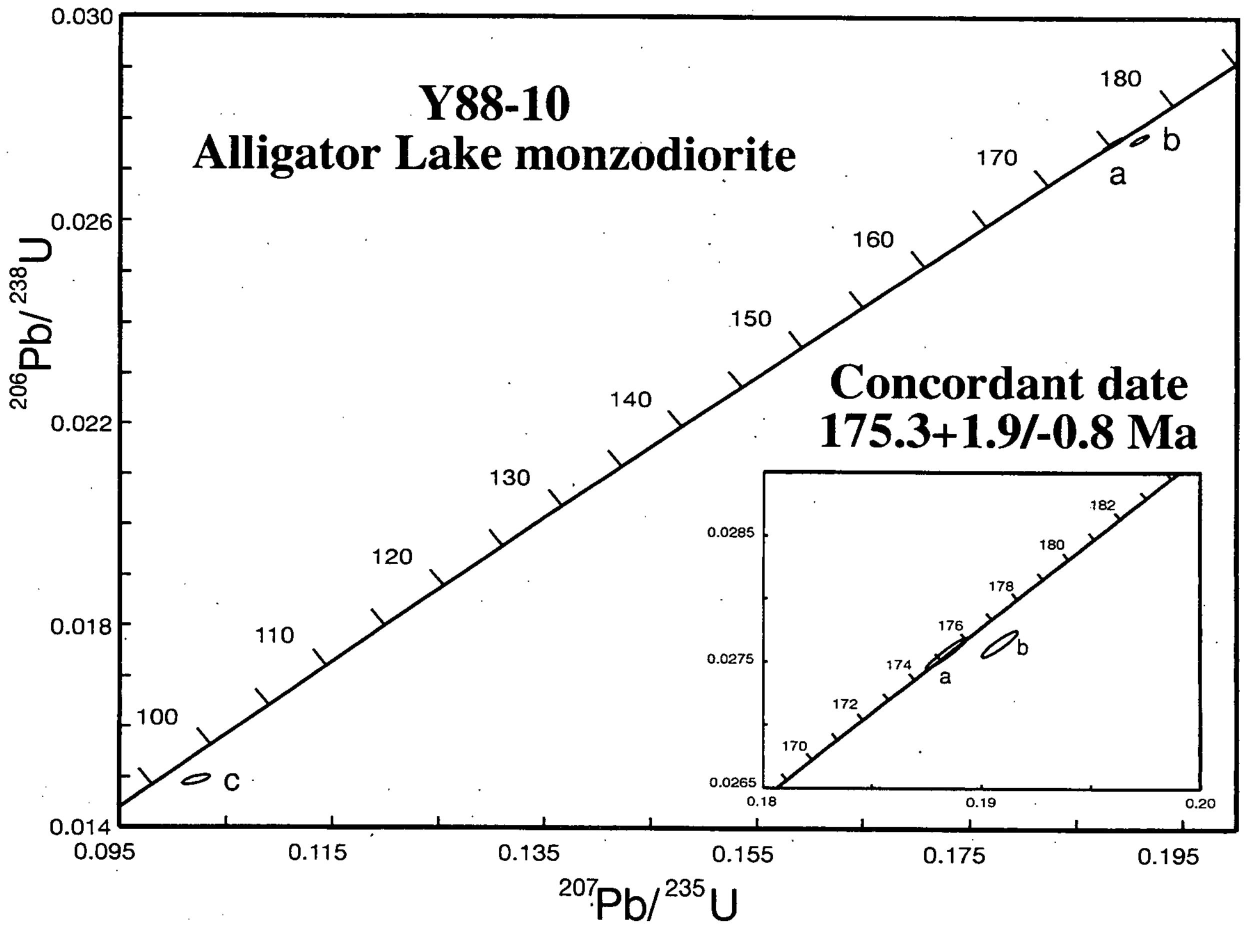


Figure 3.10 U-Pb concordia plot for the Alligator monzodiorite -- probably a phase of the Bennett Batholith.

Figure 3.11 Weakly foliated Fenwick Creek quartz diorite (176 Ma) is cut by unfoliated potassium feldspar-quartz-biotite pegmatite dykes that yield an Rb-Sr mineral-whole rock isochron of 159±6 Ma. Hammer for scale is approximately 0.35 m.

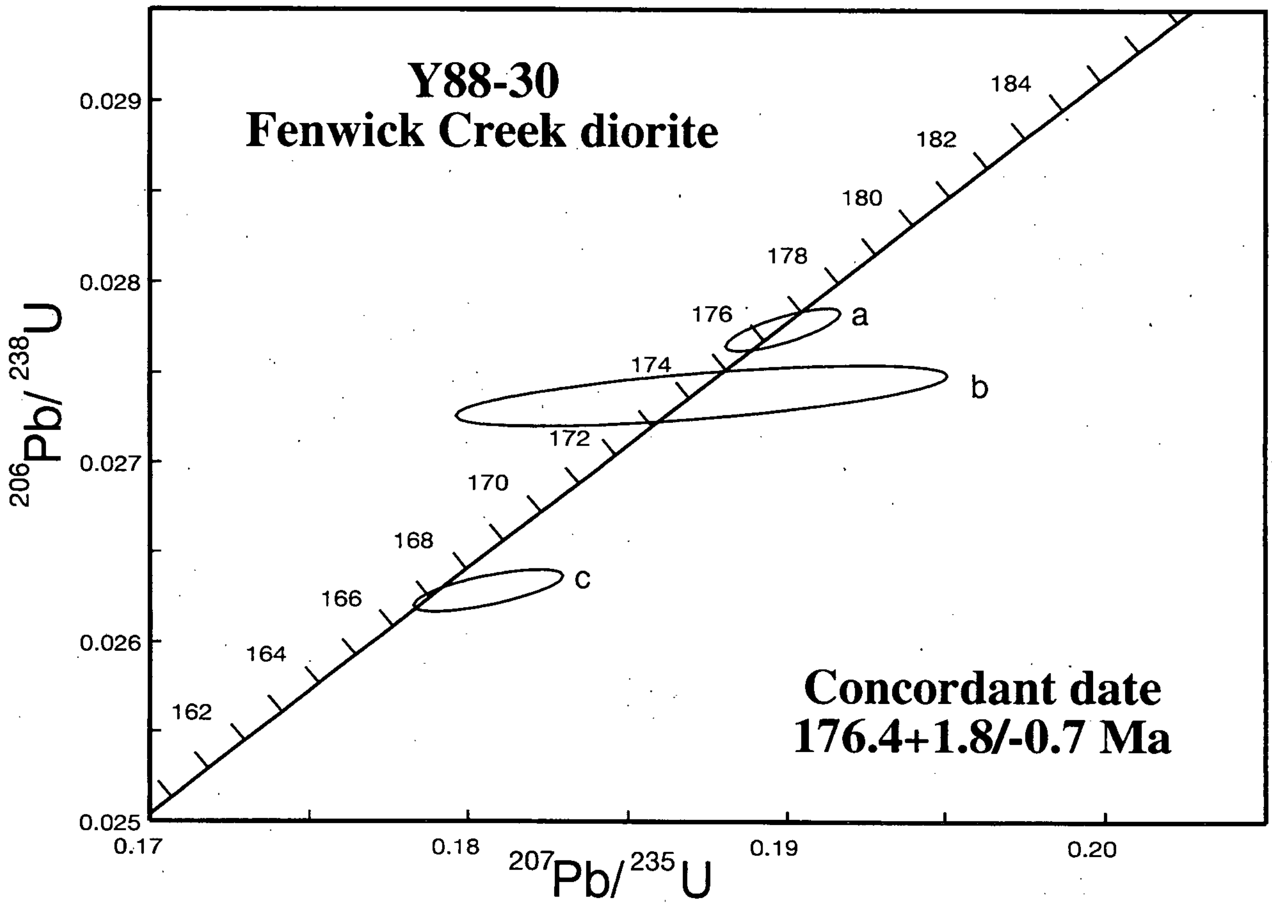


Figure 3.12 U-Pb concordia plot for the Fenwick Creek quartz diorite -- possibly a phase of the Bennett Batholith.

(Figure 3.13). These rocks were not dated but they have similarities with the Fenwick Creek phase of the Bennett Batholith as well as the Whitehorse Plutonic Suite. The emplacement age of the Cairnes pluton remains uncertain although a Jurassic or mid-Cretaceous age seems most reasonable.

Bennett batholith is the most extensive intrusive unit in the study area and may have originally underlain more than 600 km^2 prior to its displacement by younger intrusions. The body is a 50 km long, northwest-trending batholith that intrudes Stikinian rocks in the Tally Ho Shear Zone and hosts pendants of Nisling Terrane. It is composed of coarse and medium grained, leucocratic granodiorite to quartz monzonite that is characterized by large (up to 5 cm) potassium feldspar megacrysts that contain placgioclase and hornblende poikilocrysts (Figure 3.14). The percentage of megacrysts vary from a few to 70%. Megacrysts are locally aligned. Hornblende is the chief mafic mineral (10-25%) but fine-grained biotite is not uncommon. Muscovite is a primary constituent in some locations -- notably adjacent to Nisling Terrane metasedimentary rocks. Titanite and zircon are common accessory minerals. Alkali-feldspar-rich pegmatite dykes that cut adjacent plutons are likely derived from the late magmatic phases of the Bennett Batholith. Much of the batholith is cut by widely-spaced, anastamosing shear bands, but locally, cataclastic (brittle) and pervasive mylonitic (ductile) fabrics are developed. More detailed lithological descriptions are provided by Hart and Pelletier (1989b) and Hart and Radloff (1990).

The Bennett batholith was thought to be part of a Triassic suite by Morrison *et al.* (1979) and Hart and Radloff (1990). It bears a striking resemblance to the Willison pluton west of Atlin, British Columbia (Bultman 1979), and to an unnamed pluton near Bennett Lake in British Columbia (Mihalynuk and Rouse 1988). The Willison pluton gave a K-Ar hornblende age of 220 Ma (recalculated from Bultman 1979) and the pluton near Bennett Lake gave a U-Pb zircon date of *ca.* 209 Ma (M. G. Mihalynuk, unpublished data). As a result of this correlation, and lithological similarities with clasts in Early Jurassic Laberge Group conglomerate, a Late Triassic U-Pb zircon date from the Bennett batholith of 220 Ma (H. Baadsgaard in Doherty and Hart 1988) was considered reasonable (Hart and Radloff 1990). However, U-Pb systematics of the analysed zircons show evidence of Pb-loss and a Proterozoic inherited component. As a result, the validity of this date has been questioned (Currie and Parrish 1993).

Analysis of another sample from the Bennett Batholith (felsic phase) has yielded an age of *ca.* 177 Ma (Mortensen and Hart unpublished). This date is similar to the

Figure 3.13 Xenolithic, multi-phase hornblende quartz diorite, tonalite and granodiorite cut by numerous other phases including a late felsic phase are characteristic of the Cairnes pluton north of the Bennett Lake volcanic complex. It is undated but may be part of the Fenwick Creek diorite. Portion of felt marker is approximately 6 cm.

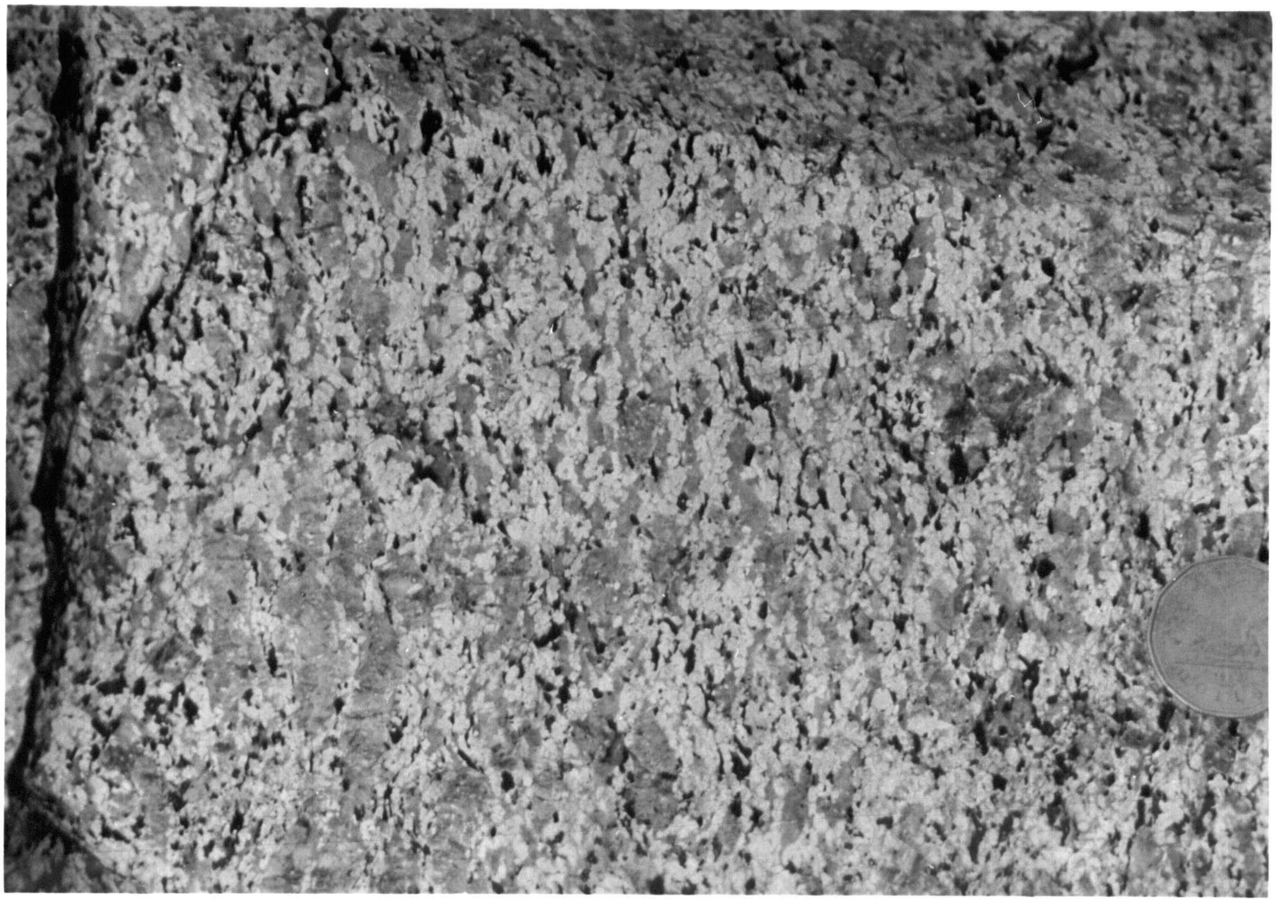


Figure 3.14a Foliated, potassium feldspar megacrystic, hornblende granodiorite characteristic of the Bennett Batholith. The foliation is not pervasive throughout the batholith but restricted to border phases and anastamosing shear bands. The foliation in this photo appears primary or "magmatic" in origin (cf. Fig. 3.6). Coin scale is 2.5 cm in diameter.

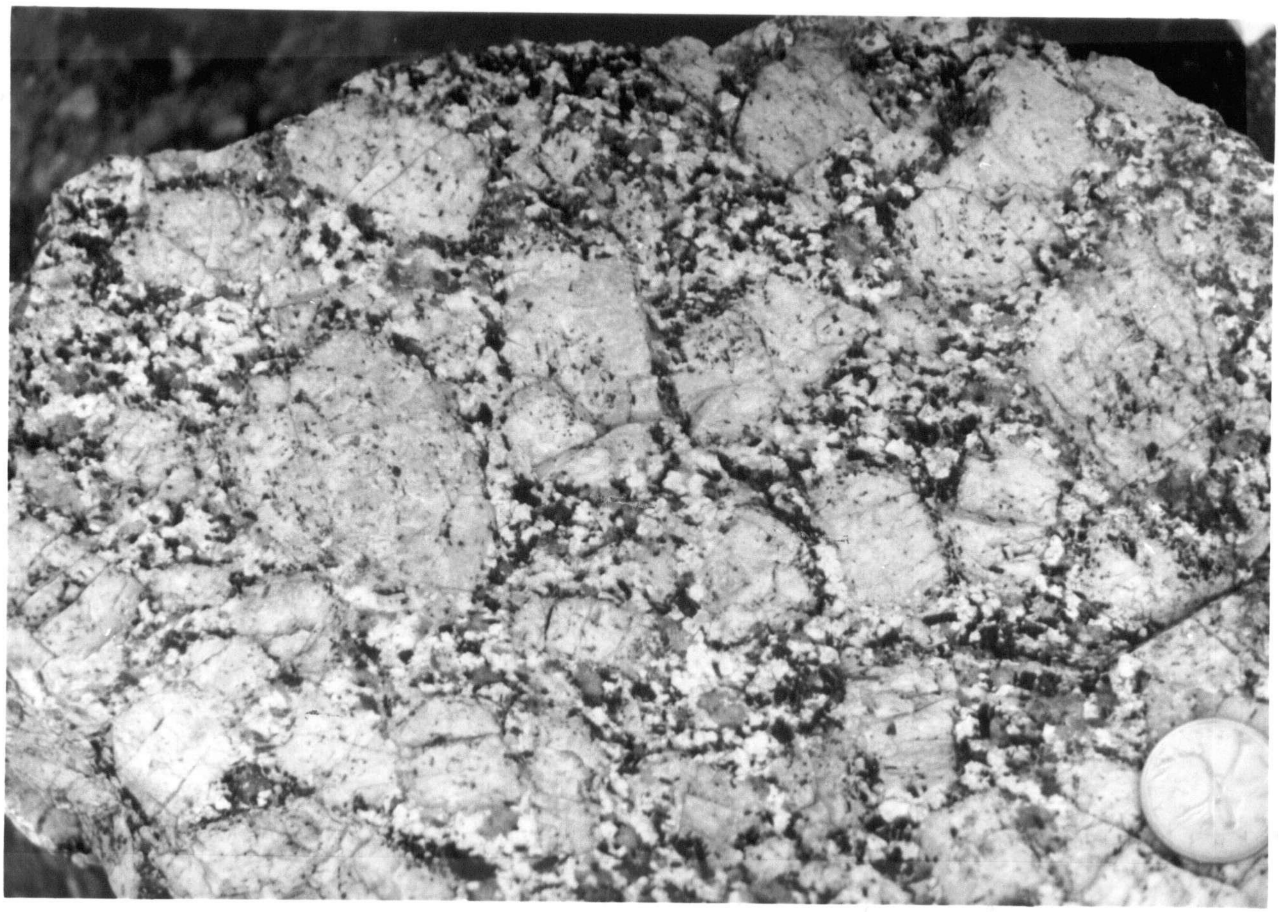


Figure 3.14b Bennett Batholith with large megacrysts showing the typical hornblende and plagioclase poikilocrysts that mimic zoning in the alkali feldspar. Coin scale is 2.0 in diameter

Fenwick Creek and Alligator Lake phases, and together with the Bennett phase are considered to constitute a single, large, poly-phase batholith. This batholith is lithologically similar to the diverse phases associated with the older (186 Ma) Aishihik and slightly younger (172 Ma) Fourth of July plutonic suites as described by Johnston (1993) and Mihalynuk et al. (1992), respectively. Although it is possible that all three suites may represent portions of a single protracted episode, the suites are maintained separated until further dating requires re-evaluation. Because the Bennett Batholith intrudes Nisling Terrane rocks and Stikinia (along the Tally Ho shear zone), its age constrains the timing of amalgamation between these two terranes to pre-177 Ma.

WHITEHORSE (MID-CRETACEOUS) MAGMATIC EPISODE

Mid-Cretaceous plutons and batholiths intrude all terranes and ancestral North America in Yukon. This episode also represents the most areally extensive magmatic episode in the Yukon Territory.

In the northern Intermontane and Coast Belts, mid-Cretaceous plutons and small batholiths are typically exposed over areas of 20-200 square kilometres each. They are northwest-trending, sub-parallel to the overall structural grain of the region and are post-tectonic. They include rocks of the Coffee Creek plutonic suite, Nisling Range granodiorite (Tempelman-Kluit 1974, 1976), Klotassin granodiorite (Godwin 1975) and the Whitehorse plutonic suite (Morisson *et al.* 1979, Woodsworth *et al.* 1991).

Two compositionally distinct, and essentially contemporaneous, mid-Cretaceous plutonic suites are defined in the study area (Figure 3.15). The Whitehorse plutonic suite includes the Whitehorse, Mount Anderson, Watson River, Boudette, Berney Creek, Ibex plutons and several smaller unnamed and undated plutons in the eastern CCC. The Mount McIntyre plutonic suite includes the smaller Montana Mountain, Carbon Hill, Mount Granger and Mount Ward plutons as well as the Mount McIntyre pluton and several satellite stocks southwest of Whitehorse.

Whitehorse Plutonic Suite (112-108 Ma)

The mid-Cretaceous Whitehorse plutonic suite comprise several large, elliptical, northwest-trending plutons composed of medium-grained, euhedral biotite and hornblende, granodiorite and quartz diorite (Figure 3.16). They intrude the CCC, northern Stikinia and Cache Creek Terrane. Compositionally dominated by granodiorite and quartz diorite, they also include tonalite, diorite and monzodiorite with

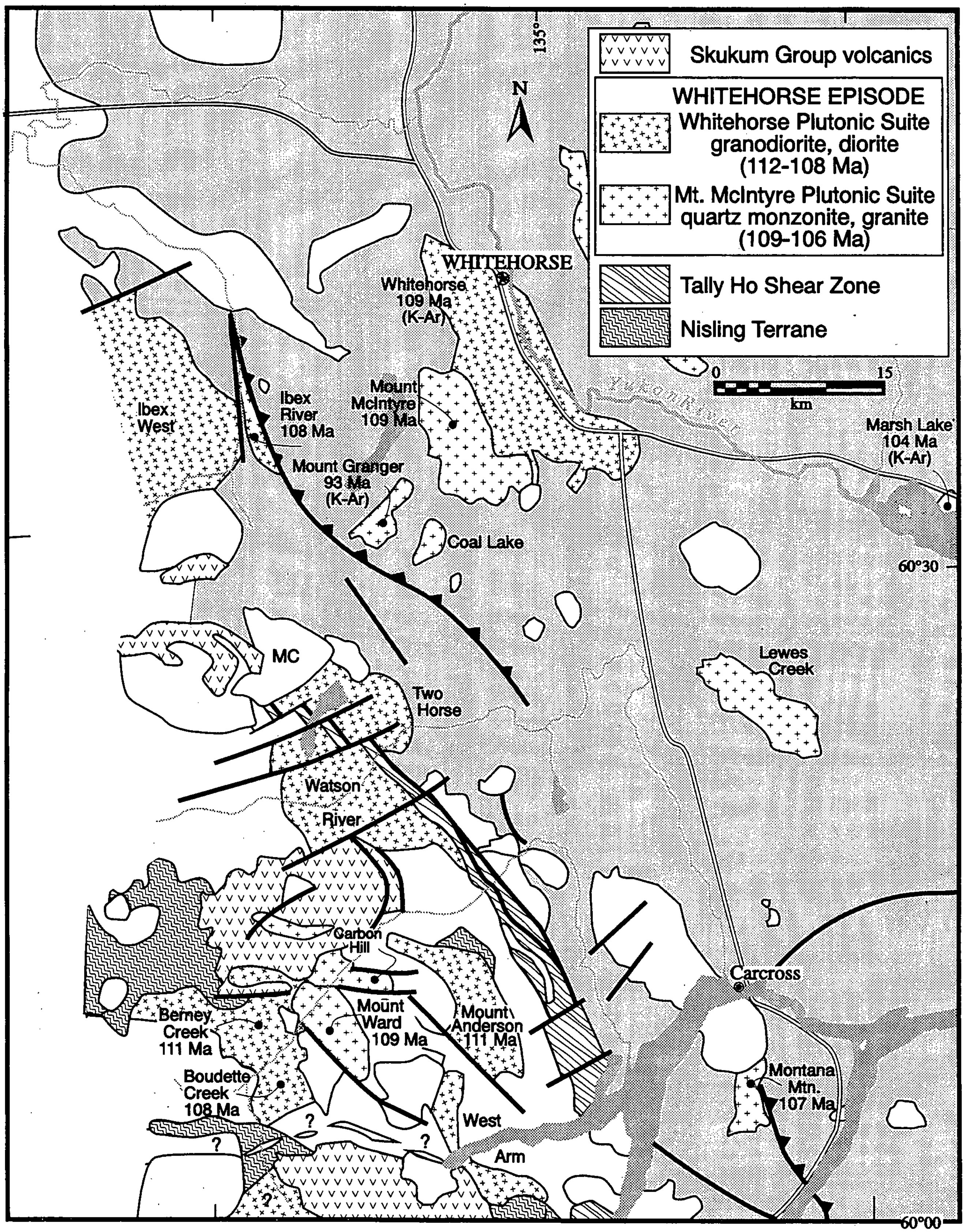


Figure 3.15 Distribution of the mid-Cretaceous Whitehorse Magmatic Episode. It is composed of the Whitehorse and Mount McIntyre plutonic suites and intrudes all terranes.

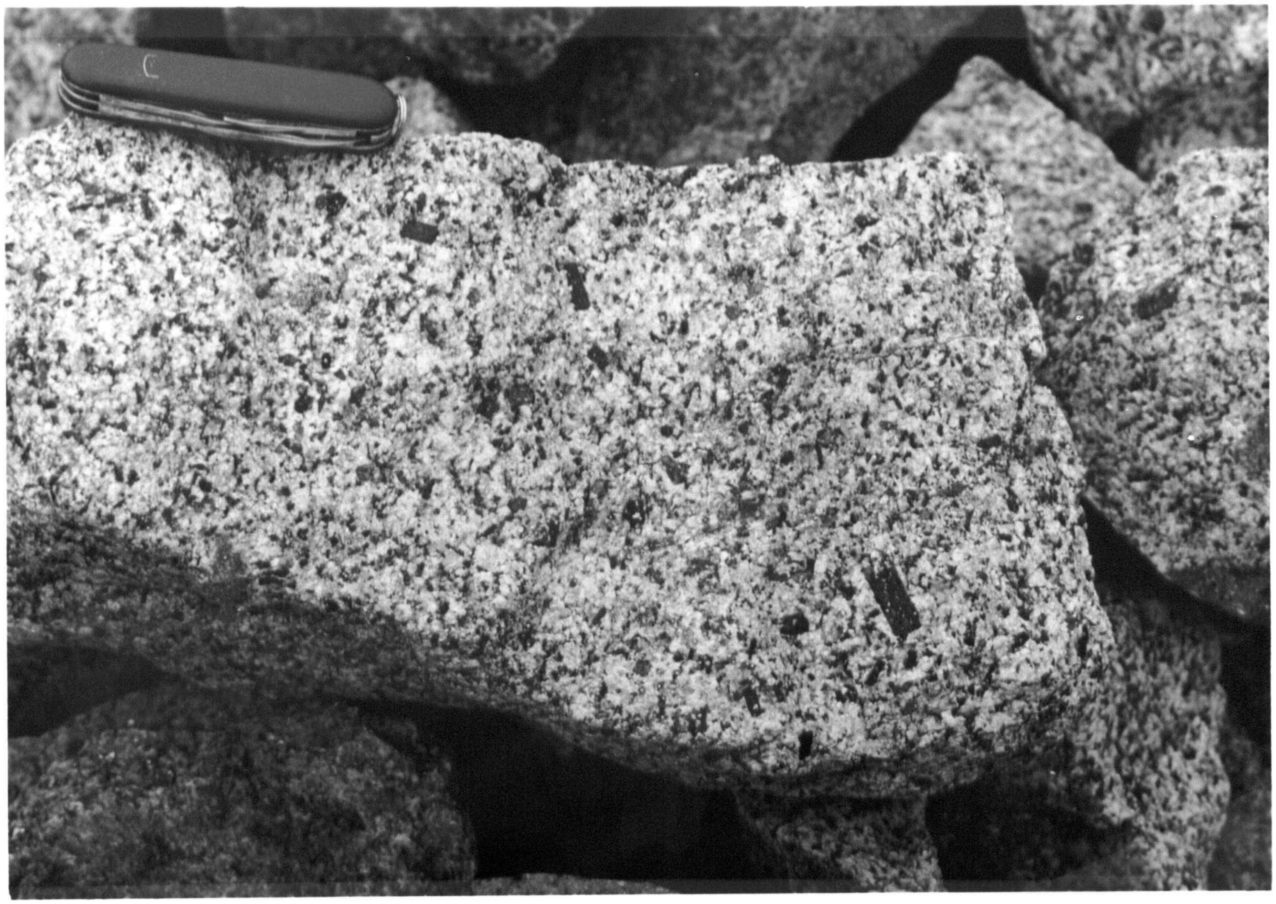


Figure 3.16 An excellent example of euhedral lath-shaped hornblende and book-like biotite granodiorite typical of the Whitehorse Plutonic Suite.

rare gabbro. The larger plutons are typically zoned from mafic-, and xenolithic-rich margins to leucocratic cores. Common accessory minerals include magnetite, titanite, apatite and zircon.

Whitehorse batholith is a zoned intermediate pluton about 100 square kilometres in area that intrudes Upper Triassic volcanic and sedimentary rocks of Stikinia. Its margins are steep sided to inward-dipping (Morrison 1981). The interior of the pluton is a uniform, massive, medium-grained biotite-hornblende granodiorite (An_{28}). The margins are coarser grained, hornblende-rich and notably more mafic (An_{37}). This bimodal nature is further emphasised by two geochemically distinct ranges for SiO_2 (52-56% and 60-68%; Morrison 1979, Hart unpublished data). Much of the hornblende contains clinopyroxene cores. The more mafic margins and clinopyroxene cores in hornblende may be the result of the incorporation of augite-bearing xenoliths derived from the Lewes River Group volcanic rocks.

The Berney Creek, Mt. Hodnett and Ibex River plutons are the most mafic plutons of this suite. At Berney Creek, the pluton comprises dominantly hornblende quartz diorite, but contains numerous hornblende gabbro and hornblendite phases. The Mt. Hodnett pluton is a small plug that intrudes Lewes River volcanic rocks and is composed of mainly hornblende-clinopyroxene diorite and gabbro. The Ibex River pluton is an elongate, fault-bounded body dominated by pyroxene-hornblende diorite and gabbro locally contains significant hypersthene. Some exposures are strongly magnetic (in hand sample and on aeromagnetic maps). The Boudette pluton is dominated by hornblende granodiorite, but clots of hornblendite suggest it may be a less mafic phase of the adjacent Berney Creek pluton.

The Mount Anderson and Watson River plutons are characterized by sub-equal amounts (total approximately 15%) large euhedral phenocrystic biotite and hornblende, but are notably less mafic than the other plutons of this suite. The leucocratic granodiorite phases of the Watson River pluton, and a few unnamed plutons of the Whitehorse suite east of the Tally Ho shear zone are the most mafic-poor. This variety is dominated by holocrystalline plagioclase and contains approximately 5% brown biotite and a few percent of hornblende. This rock resembles that in the core of the Whitehorse pluton.

Rocks of the Whitehorse plutonic suite are characterized by a narrow range of U-Pb ages from 108-111 Ma. The Berney Creek hornblendite gives a date of 111±1

Ma and the Ibex pluton yields a date of 108±2 Ma, the Boudette pluton provides a 108+3/-1 Ma date (Figure 3.17). The Mount Anderson pluton, whose original age was reported as 119+7/-3 (Baadsgaard in Doherty and Hart 1988) is reinterpreted at 111±3 Ma (J. Mortensen, pers. comm. 1991). The Mount Hodnett plug gives a K-Ar date of 106±4 Ma on hornblende

The Whitehorse plutonic suite was named after the Whitehorse batholith which has consistently yielded mid-Cretaceous K-Ar ages (116-108 Ma; Morrison *et al.* 1979). The precise age of the Whitehorse batholith is unknown as a U-Pb date has not been determined. It is probably slightly older than the 109 Ma date that was determined from a concordant K-Ar biotite-hornblende mineral pair (Morrison *et al.* 1979). The Whitehorse pluton is closely associated with numerous skarn deposits of the Whitehorse Copper Belt (Morrison 1981). Elsewhere in the region, plutons of this suite host weakly-developed porphyry copper style mineralization.

Mount Mcintyre Plutonic Suite (109-106 Ma)

Several small to medium-sized (up to 100 km^2), elliptical to circular, mid-Cretaceous plutons compositionally similar to the Mt. McIntyre pluton are included in this suite. Plutons attributed to this suite intrude northern Stikinia and the CCC. Although essentially coeval (and cospatial) with the Whitehorse plutonic suite, the Mount McIntyre suite is compositionally and texturally distinct.

This suite is characterized by dark orange-grey weathering, pink, potassic alkaline, peraluminous granite, quartz monzodiorite, quartz monzonite and quartz syenite (SiO_2=62-72%; Hart unpublished data). Texturally variable, granophyric to holocrystalline, acicular hornblende-alkali feldspar granite is characteristic of this unit (Figure 3.18). Accessory minerals include apatite, spinel and zircon.

Compositional and textural variations are most strongly evident in roof and border phases of the plutons intruding Stikinia. Those exposures are typically more mafic, may contain xenocrystic clinopyroxene, olivine and spinel and may have biotite-rich margins when compared to plutons of the CCC. Locally, pink alkali feldspar may be supplanted with grey-translucent alkali feldspar and the rock will tend towards quartz syenite. As a rule, quartz contents are higher in core phases than in marginal phases.

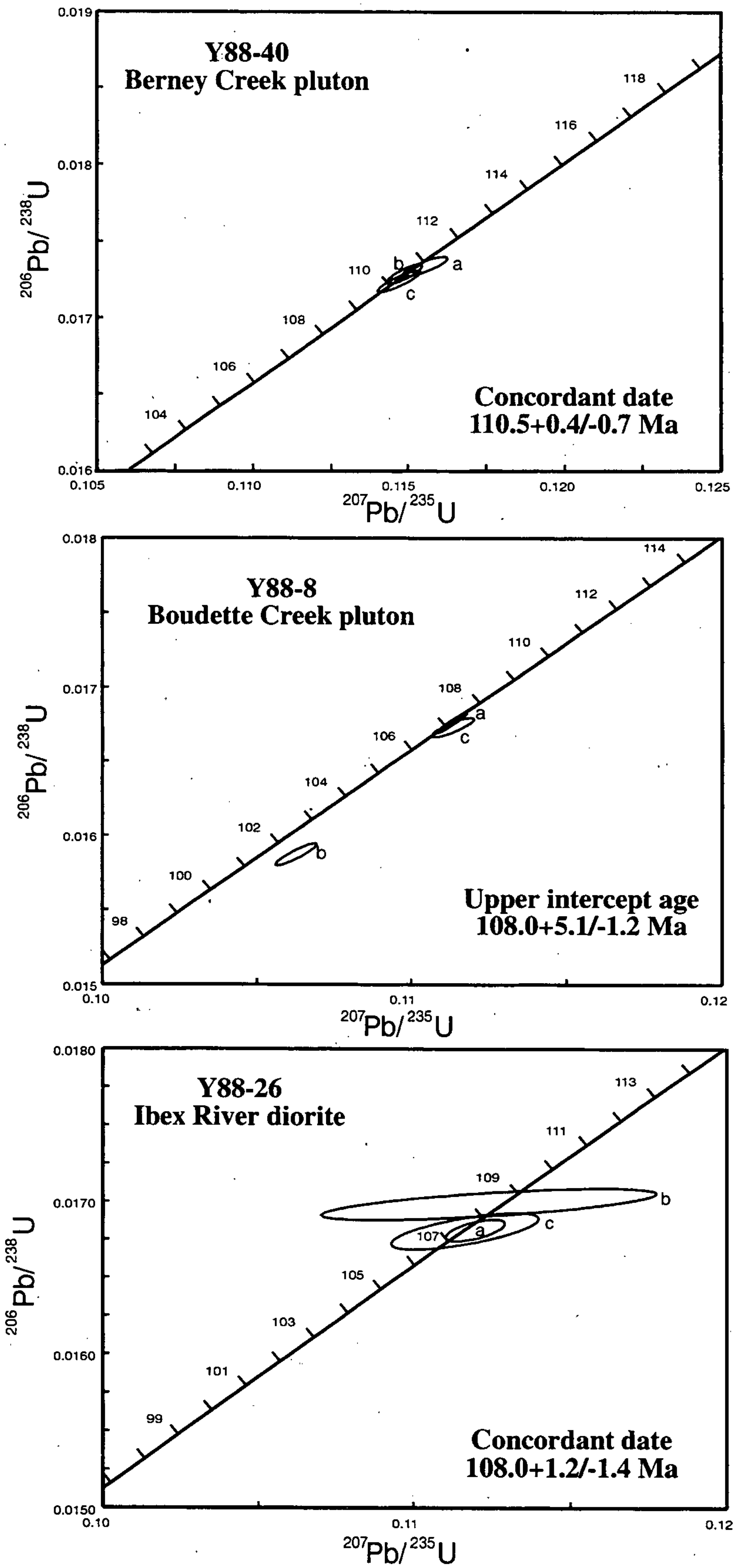


Figure 3.17 U-Pb concordia plots of the mid-Cretaceous Berney Creek, Boudette Creek and Ibex River (west of Bonneville Lakes) plutons.

Figure 3.18 Pink granophyric syenite with acicular hornblende and miarolitic cavities is typical of border phases in the McIntyre plutonic suite and indicative of intrusion at upper crustal levels.

All plutons of this suite have been variably propylitized. Plagioclase is sausseritized, biotite is chloritized but the potassium feldspar is generally unaltered.

Mount McIntyre pluton underlies approximately 30 square kilometres but is comagmatic with numerous small, circular, high-level, satellitic stocks. The batholith intrudes the western contact of the Whitehorse batholith, and Jurassic Laberge Group sedimentary rocks. Although cross-cutting relationships with the Whitehorse batholith can be demonstrated, many contacts appear gradation and it is often unclear whether some exposures belong to the Whitehorse batholith or are border phases to the Mount McIntyre pluton. The Mount McIntyre pluton is dominated by medium-grained, hornblende-biotite granodiorite, but has an orange-weathering, very pink, finer grained, granophyric quartz monzonite and quartz-poor granite core. The satellite stocks are biotite-rich. Graphic and variable textures in the granite, as well as miarolitic cavities provide additional evidence of epizonal emplacement.

Mount Granger pluton is the largest of the satellite stocks of the Mount McIntyre batholith. It intrudes Laberge Group argillite and has a grey-brown appearance due to a higher proportion of medium and coarse-grained biotite.

Montana Mountain pluton intrudes the contact between northern Stikinia and Cache Creek Terrane. It is a pale orange-weathering, pink to mauve, medium-grained, equigranular biotite and hornblende granite (Figure 3.19). The mauve appearance is due to the pervasive chloritization of the mafic minerals.

Carbon Hill pluton intrudes a succession of coeval volcanic rocks which sit on the Bennett batholith and Nisling Terrane metamorphic rocks in the CCC. The Carbon Hill pluton forms recessive orange, granular weathering, medium-grained, equigranular, red to pink, biotite quartz monzonite and granite. Granitic textures and quartz content and are highly variable reflecting changing conditions typical in a high-level magma chamber. The pluton is cut by numerous east-trending faults and is pervasively phyllically altered (Figure 3.20). Plagioclase, and locally alkali feldspar, are extensively sausseritized, and biotite is chloritized. Some zones are composed almost entirely of granular quartz and fine-grained sericite.

The Mount Ward pluton forms light rusty-orange, recessive weathering exposures of biotite and lesser hornblende granite and quartz monzonite.

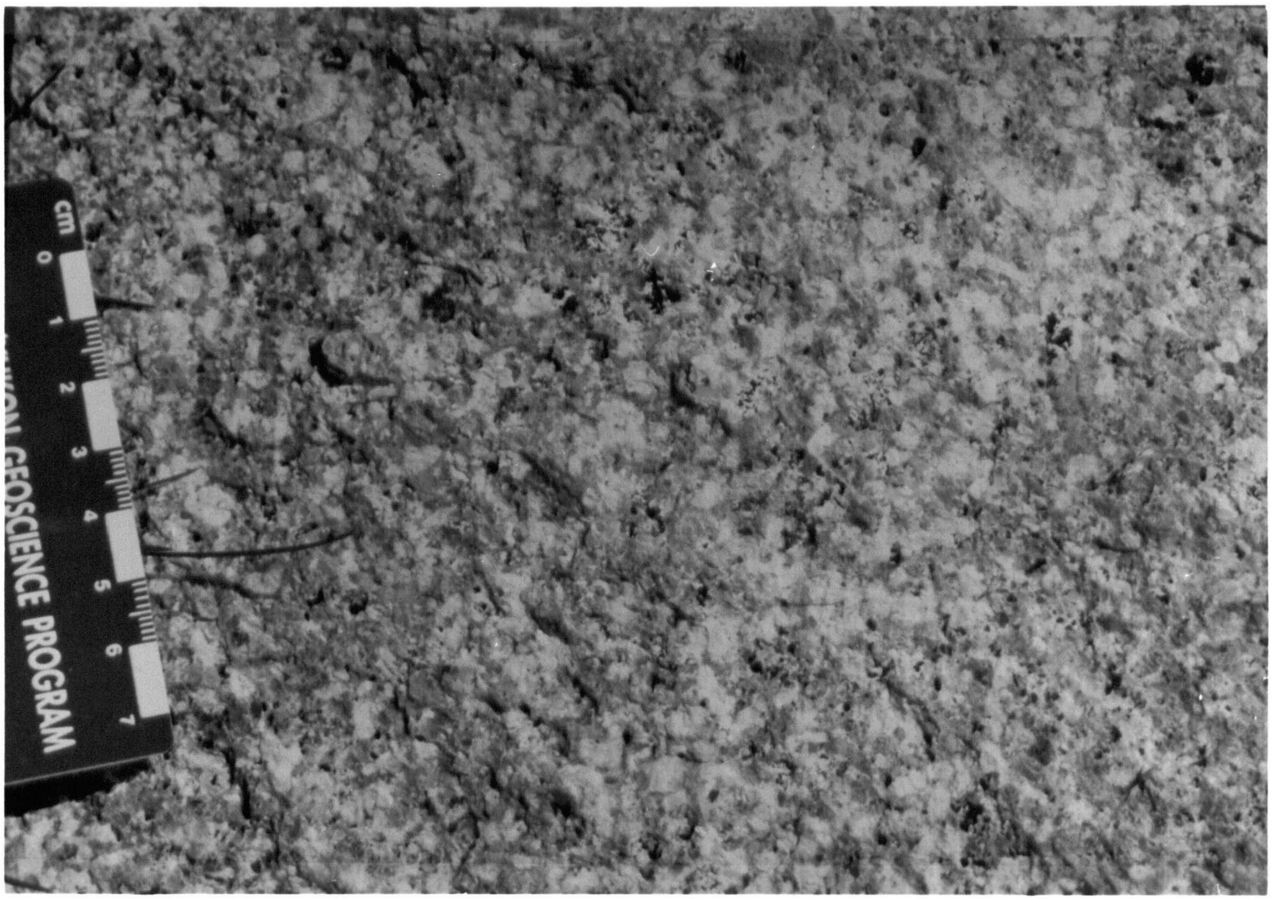


Figure 3.19 Pink, medium to coarse grained, equigranular granite and quartz monzonite is more characteristic of the Mount McIntyre suite. It is usually quartz-rich with more abundant biotite than hornblende.

Figure 3.20 Looking east towards the Carbon Hill pluton. The upper portions of Carbon Hill are covered with a thin veneer of volcanic rocks that are coeval with the underlying pluton. This suggests that the Mount McIntyre plutonic suite may be comagmatic with the Mount Nansen Group volcanics. In addition, the region in the photograph has undergone intense phyllic alteration and contains vivid jarrositic gossans and porphyry-style gold mineralization (Hart 1992a).

It is characterized by coarse-grained quartz and plagioclase among finer-grained aggregates of pink alkali feldspar.

U-Pb zircon ages suggest that the Mount McIntyre plutonic suite was emplaced during a narrow time span of 109-106 Ma, including: 109±1 Ma for the Mount McIntyre pluton, 107±1 Ma from the Montana Mountain pluton and 109±1 Ma from the Mount Ward pluton (Figure 3.21). K-Ar dates from this suite are typically reset as displayed by a date on chloritic biotite from the Carbon Hill pluton of 96±12 Ma, a hornblende date from Mount McIntyre of 93±4 Ma (Morrison *et al.* 1979), and a coarse-grained biotite separate from Mount Granger gave a date of 94±4 Ma.

The Mount McIntyre suite includes the pink granophyric quartz monzonite unit of Wheeler (1961) and Morrison *et al.* (1979). Similar-looking pink quartz monzonite plutons near Aishihik Lake are Early Jurassic in age (Tempelman-Kluit 1974, 1976; Johnston 1993; Long Lake suite of Woodsworth *et al.* 1991); and those near Bennett Lake are Paleocene (see Crozier Creek pluton below) and not part of the Mount McIntyre suite.

LATE CRETACEOUS (CARMACKS) MAGMATIC EPISODE

The Late Cretaceous magmatic episode in the southern Yukon Territory and northern British Columbia is poorly understood and its age range is poorly defined . Late Cretaceous K-Ar dates obtained by previous workers provide little concordancy, and in fact span throughout most of Late Cretaceous time from 64-84 Ma (Morrison *et al.* 1979; Bultman 1979; Christopher and Pinsent 1982; Grond *et al.* 1984; Lowey *et al.* 1986; Barker *et al.* 1986; Mihalynuk unpublished; Hunt and Roddick 1988, 1991, 1992). A few small Late Cretaceous plutons are locally associated with Carmacks Group volcanic rocks, whose range is also similarly poorly constrained.

Five plutons of this suite identified in the study area (Figure 3.22) are mainly biotite granite in composition (e.g., Folle Mountain pluton), but include hornblende diorite (e.g., Wheaton River pluton). The granites intrude Stikinia, but are also found in the CCC north and south of the study area. Lithologic bimodality in the Late Cretaceous igneous suite is also noted by Mihalynuk (in press).

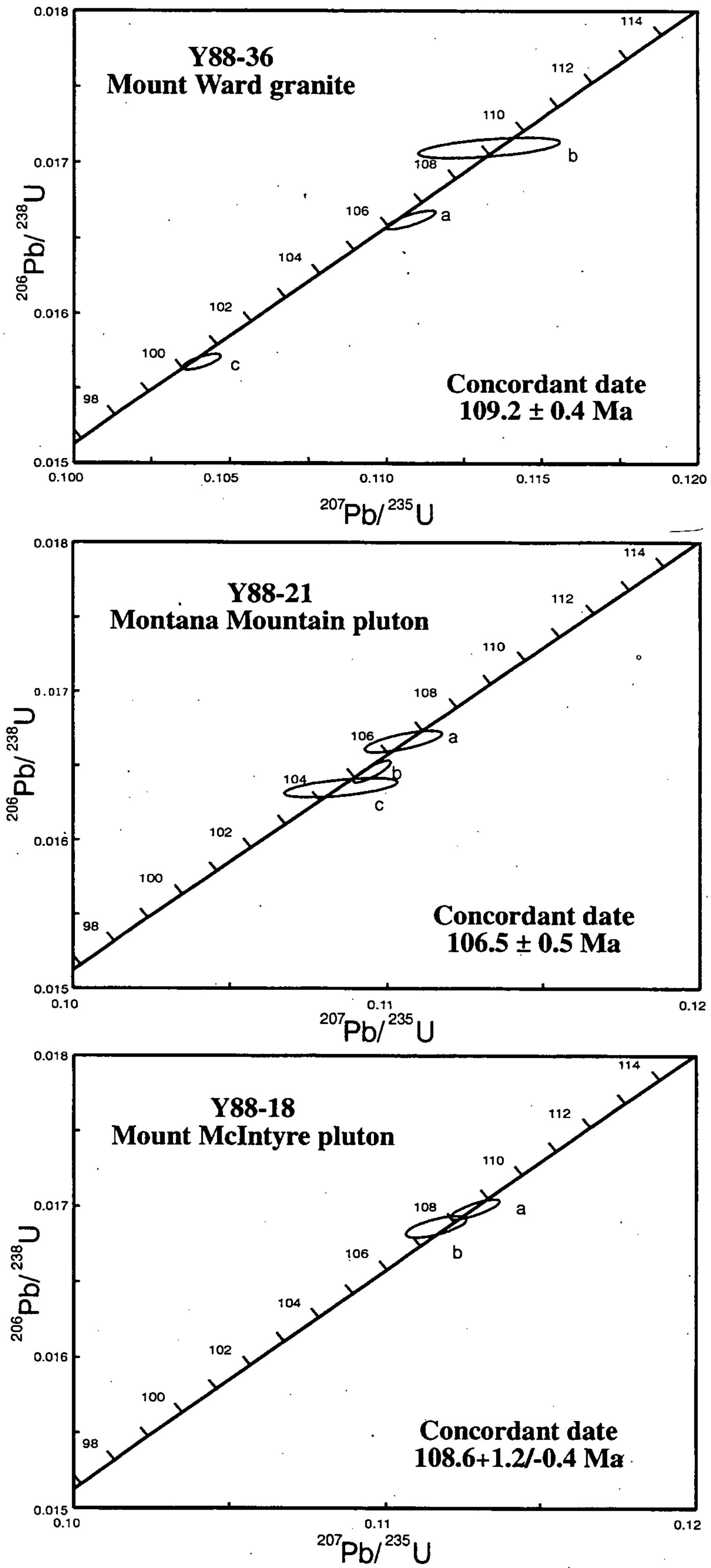


Figure 3.21 U-Pb concordia plots for the mid-Cretaceous Mount Ward, Montana Mountain and Mt. McIntyre plutons of the Mount McIntyre plutonic suite.

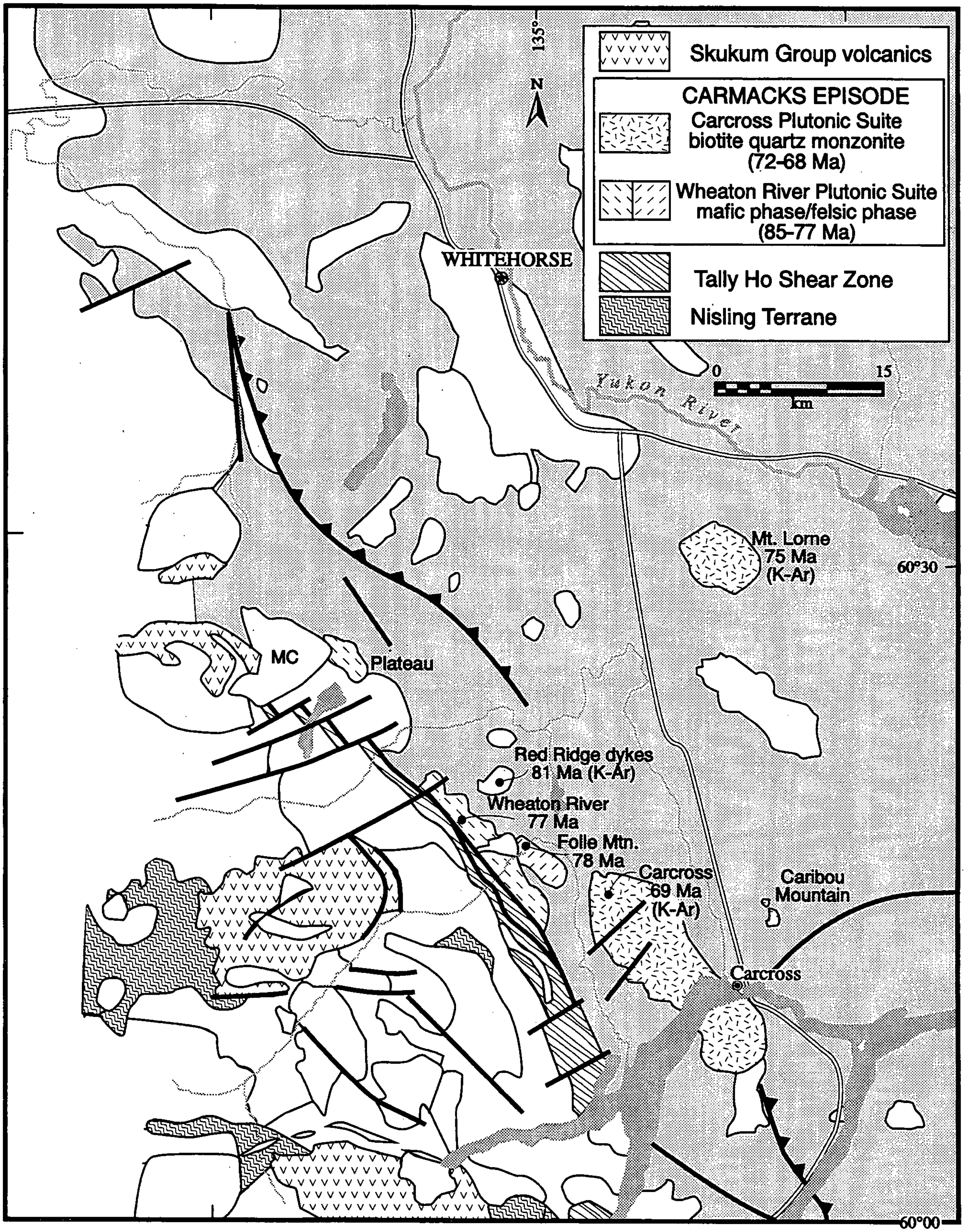


Figure 3.22 Distribution of the Late Cretaceous Carmacks Magmatic Episode in the study area. Most of the Wheaton River Plutonic Suite are proximal to the Tally Ho Shear Zone whereas the younger Carcross Plutonic Suite are farther east.

Wheaton River Plutonic Suite (85-75 Ma)

Folle Mountain pluton is a small subcircular body which intrudes apparently coeval volcanic rocks as part of a volcano-plutonic complex. Though the intrusion is dominated by coarse-grained, equigranular, alkali feldspar-rich, biotite quartz monzonite and granite, numerous textural variations including granophyric and porphyritic felsite suggest intrusion at a high-level . The felsite comprises numerous complex and cross-cutting dykes and sills. Much of the northern portion of the complex is represented by a distinctive dacite porphyry in which tabular plagioclase up to 1 cm long are densely distributed among a fine-grained grey matrix.

Wheaton River pluton includes several small, elongate bodies of medium-grained, equigranular, hornblende diorite and quartz diorite along the eastern margin of the Tally Ho shear-Llewellyn fault zone. The pluton is chloritized, moderately foliated, and cut by numerous faults and several anastamosing shear bands associated with the adjacent Llewellyn fault. Emplacement of the Wheaton River pluton may have been synchronous with motion in the Llewellyn fault zone, and was subsequently cut by it.

The Folle Mountain pluton gives a U-Pb zircon age of 78±1 Ma and the Wheaton River pluton yields a nearly identical age of 77±1 Ma (Figure 3.23). Dykes at Red Ridge yielded a hornblende K-Ar age of 81±3 Ma. The Mount Lorne pluton was dated at 75±3 Ma (Morrison *et al.* 1979). Precise U-Pb zircon dates of 84.7, 83.8 and 81.3 Ma on the Windy Arm volcanics (see Chapter IV), Surprise Lake pluton and Table Mountain volcanic rocks (Mihalynuk *et al.* 1992) respectively, support 85-75 Ma K-Ar and Rb-Sr dates previously determined from the region (Morisson *et al.* 1979; and dates recalculated from Bultman 1979).

The name Wheaton River plutonic suite was chosen because the plutons are comagmatic with the Wheaton River volcanic rocks of the Carmacks Group (see Chapter IV). This suite is coeval with the Windy-Table volcanic suite of Mihalynuk (in press).

Carcross Plutonic Suite (72-68 Ma)

K-Ar dates on several granitic bodies and volcanic rocks in southern Yukon and northern British Columbia imply a possible latest Cretaceous magmatic suite. The data set is not large, lacks reliable U-Pb dates and is represented by only one body in the study area.

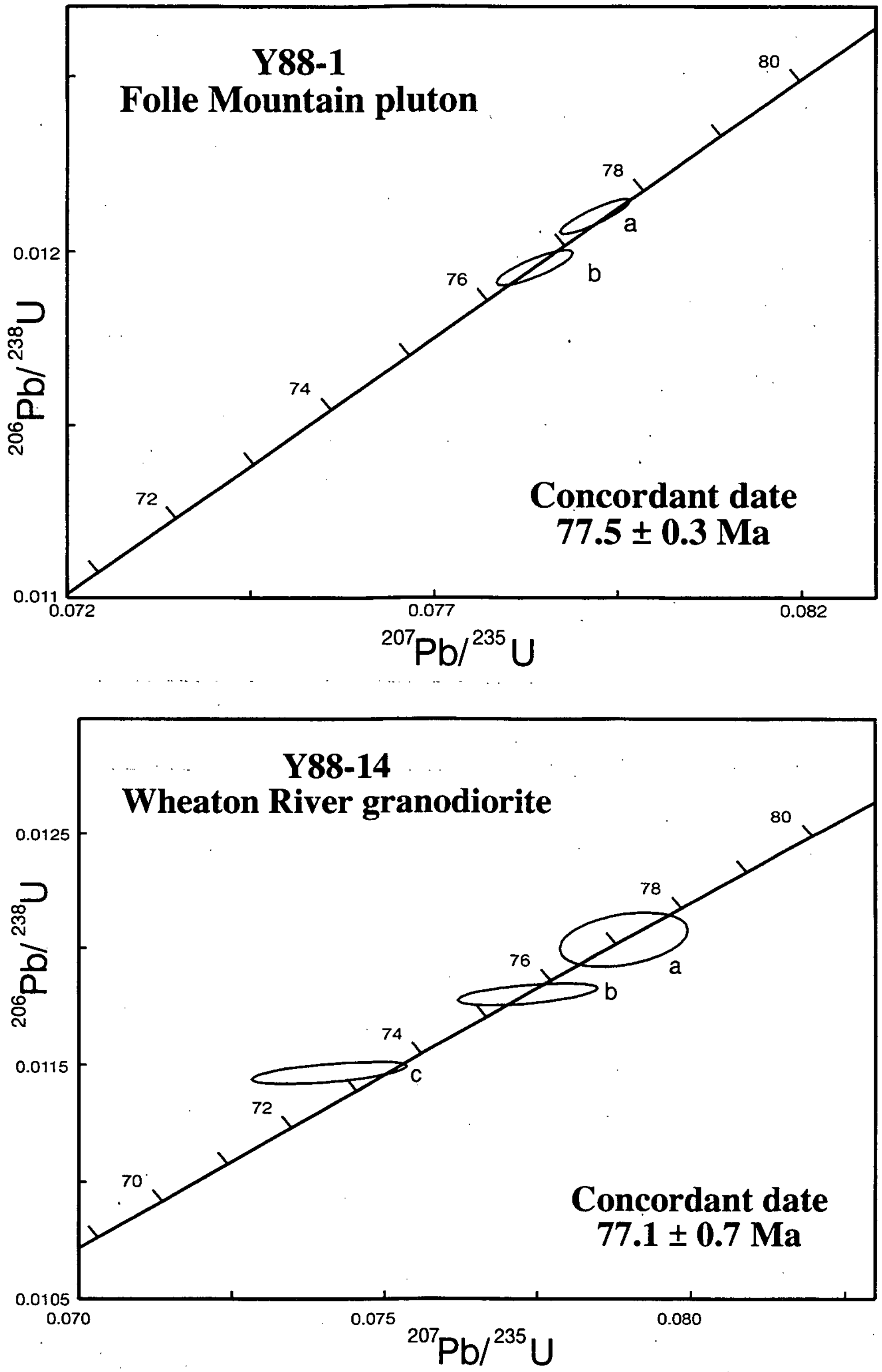


Figure 3.23 U-Pb concordia plots of the Late Cretaceous Wheaton River and Folle Mountain plutons.

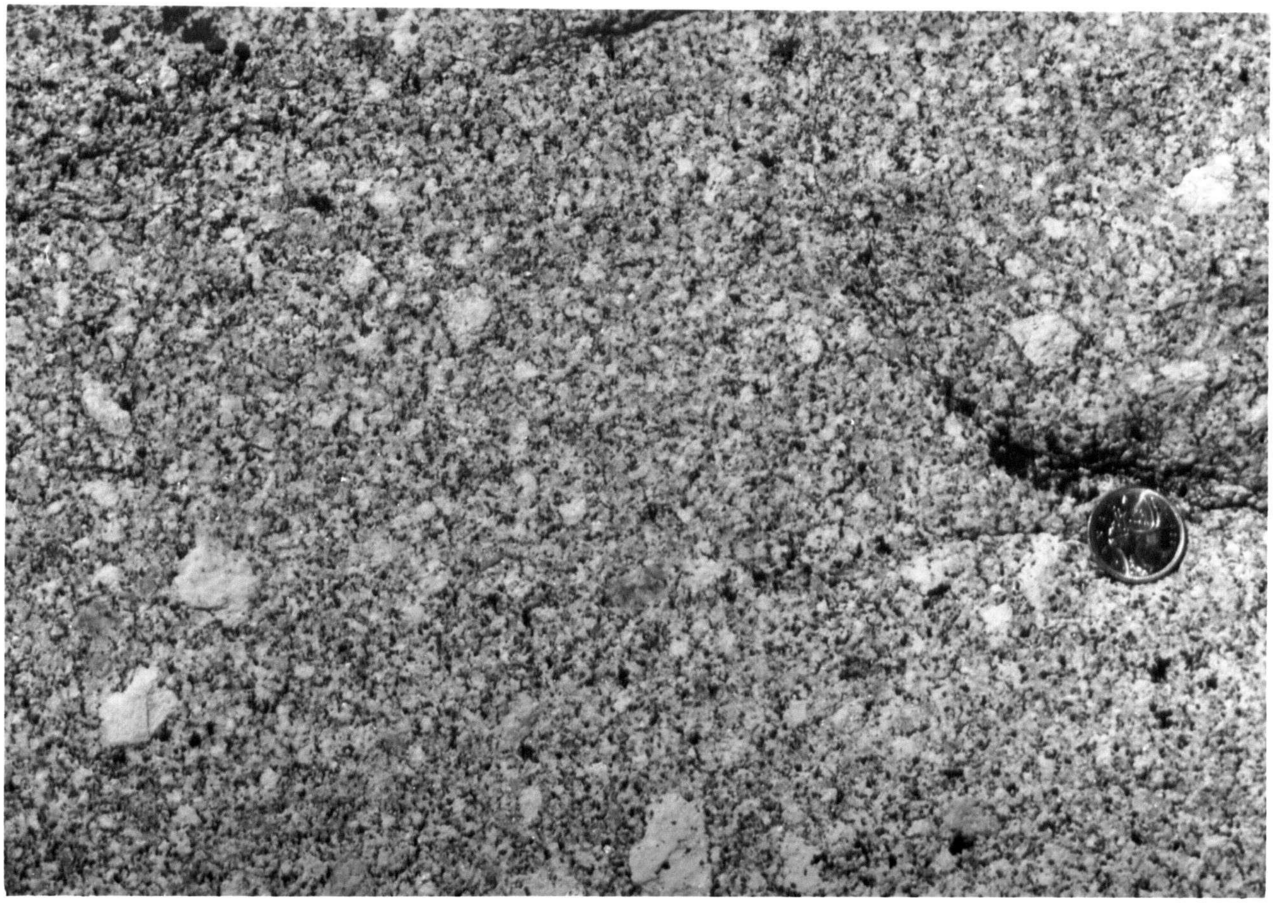


Figure 3.24 Large, white alkali feldspar megacrysts are sparsely distributed in, but diagnostic of, the biotite granite and quartz monzonite of the Carcross pluton.

Carcross pluton is a 20 km elongate, northwest-trending body which underlies 100 km^2 and intrudes western Stikinia, Cache Creek Terrane and mid-Cretaceous Montana Mountain volcanics. Coarse-grained equigranular biotite quartz monzonite with sparse accumulations of white alkali feldspar megacrysts are typical (Figure 3.24).

K-Ar biotite dates from the south and north ends of the batholith give values of 64.3±2.2 Ma (Morisson *et al.* 1979) and 68.6±2.5 Ma, respectively. The older date, from a coarser-grained biotite fraction, is probably closer to the true age. Similar reported K-Ar dates include 62-71 Ma for dykes in the Wheaton River area (see Chapter IV); 65.6 Ma from a granite in northern British Columbia (recalculated from Bultman 1979) and several *ca.* 71 Ma dates from central Yukon Territory (recalculated from Godwin 1975; Tempelman-Kluit and Wanless 1975; Tempelman-Kluit 1984). The validity of this age range is supported by a 72 Ma U-Pb zircon date from a batholith in the CCC near the Yukon Territory-B.C. border (Barker *et al.* 1986). Reset hornblende (66.5 Ma) and biotite (62.0 and 63.3 Ma) ages from this pluton (Barker *et al.* 1986; Hunt and Roddick 1991) indicate that partially reset K-Ar dates may be characteristic of this region of the CCC.

Available data suggests that two Late Cretaceous plutonic suites, at 85-77 and *ca.* 72-68 Ma, may be distinguished. However, the limited sampling and lack of reliable data cannot preclude to possibility of a single protracted magmatic event.

EARLY TERTIARY (SKUKUM) MAGMATIC EPISODE

The Early Tertiary (Paleogene) magmatic episode is widespread throughout the CCC and the westernmost Intermontane Superterrane (Figure 3.25). The character of this magmatic episode changes dramatically from west to east. In the western CPC, plutons emplaced at this time formed large, tonalitic, sill-like bodies (Brew 1983, 1994; Erdmer and Mortensen 1993). In the centre of the CCC they form large batholiths which commonly exceed 300 square kilometres. Along the CCC's eastern margin, medium-sized (25-100 square kilometer) circular, granite plutons, rhyolite stocks and northeast-trending rhyolite dyke swarms associated with intermediate to felsic caldera-style volcanic complexes are characteristic. The small plutons increase in size to the north and are associated with a diminishing volcanic component. The few representatives of this episode in the Intermontane Superterrane are small (<5 square kilometres) and occur as high-level rhyolite plugs and dykes with subaereal rhyolite flows and tuff. Two suites are recognized within this episode-- Nisling Plutonic Suite and the Skukum plugs.

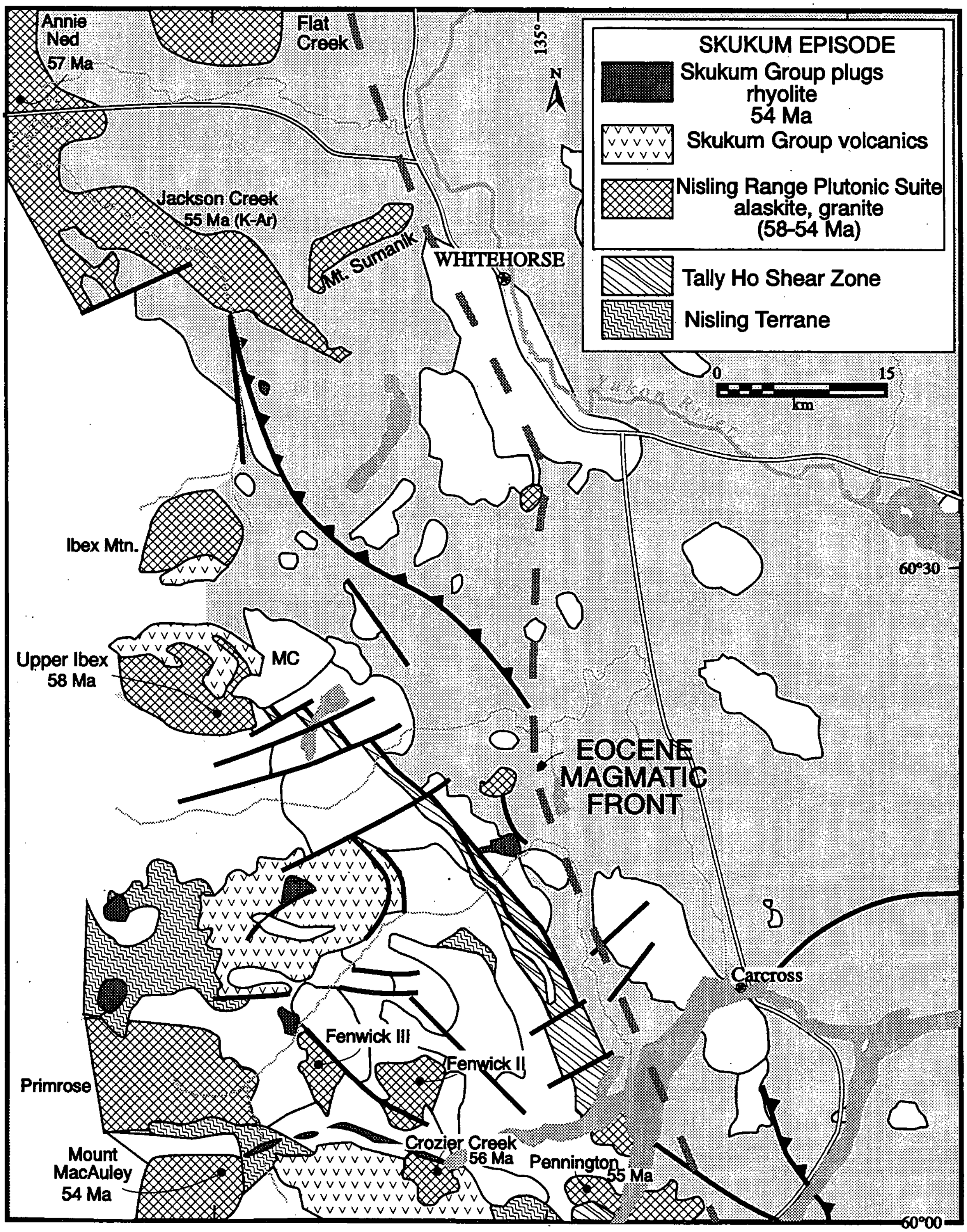


Figure 3.25 Distribution of the Paleogene Skukum Magmatic Episode in the study area. Rocks of this episode are not found east of Whitehorse or Carcross and this limit (dashed line) marks the Early Tertiary magmatic front. MC=Miles Canyon basalt.

Nisling Plutonic Suite (58-54 Ma)

The Nisling Plutonic Suite occurs along a north-northwest-trending zone of large batholiths and smaller, discordant, circular plutons with associated rhyolite plugs and dike swarms on the eastern margin of the CCC. The plutons locally intrude co-eval, subaerial, cauldera-type volcanic complexes of the Skukum (Sloko) Group. Rocks of the Nisling suite are easily recognized in the field by their buff, spheroidal and recessive weathering surfaces and widely spaced, often horizontal joint sets (Figure 3.26). The plutons are composed of coarse-grained, miarolitic, oversaturated, leucocratic granite, alaskite, rhyolite and granite porphyry with euhedral, smoky grey quartz (Figure 3.27). The granites often have the appearance of a crowded euhedral porphyry. Aplitic and pegmatitic leucogranite phases and dikes are common in the plutons' margins. A distinctive pink quartz monzonite composes a few plutons (Pennington and Crozier Creek). They are composed of recessive orange weathering, textural variability, miarolitic alkali-feldspar granite, quartz syenite and quartz monzonite with dark pink, red or orange potassium feldspar and chalky white plagioclase phenocrysts.

Throughout the Nisling suite, biotite is the dominant mafic mineral and is locally brown. Hornblende is usually finer grained than biotite and occurs in small clots. Zircon, apatite and fluorite are common accessory minerals. The occurrence of miarolitic cavities and their association with rhyolitic dyke swarms and subaerial volcanics indicate an epizonal origin for these plutons. This suite is comagmatic with ring dykes of the Bennett Cauldera, the Skukum rhyolite plugs, and rhyolite dyke swarms throughout the Wheaton and Watson River areas (Lambert 1974; Smith 1983; Pride and Clark 1985). Mineral occurrences in these plutons include molybdenum (on fracture surfaces and as rosettes in quartz veins), fluorite veins and vugs, and quartz-chalcedony-fluorite veins with erratic gold values (Yukon Minfile 1992).

The Ibex, Annie Ned, MacAuley Creek, Perkins Peak, Jackson Creek, and Mount Sumanik plutons, as well as numerous rhyolite and quartz-feldspar porphyry plugs and dykes, constitute this suite in the study area. U-Pb zircon dating of these bodies give ages ranging from 54±1 Ma for the Mount MacAuley pluton to 57±1 for the Annie Ned pluton (Figure 3.28). Also included in this range is a U-Pb date of 58+4/-1 for the Ibex pluton (H. Baadsgaard in Doherty and Hart 1988) and numerous K-Ar and Rb-Sr dates between 52 and 60 Ma (Table 3.3; Morrison *et al.* 1979; Pride and Clark 1985; Armstrong, Ghosh and Hart unpublished).

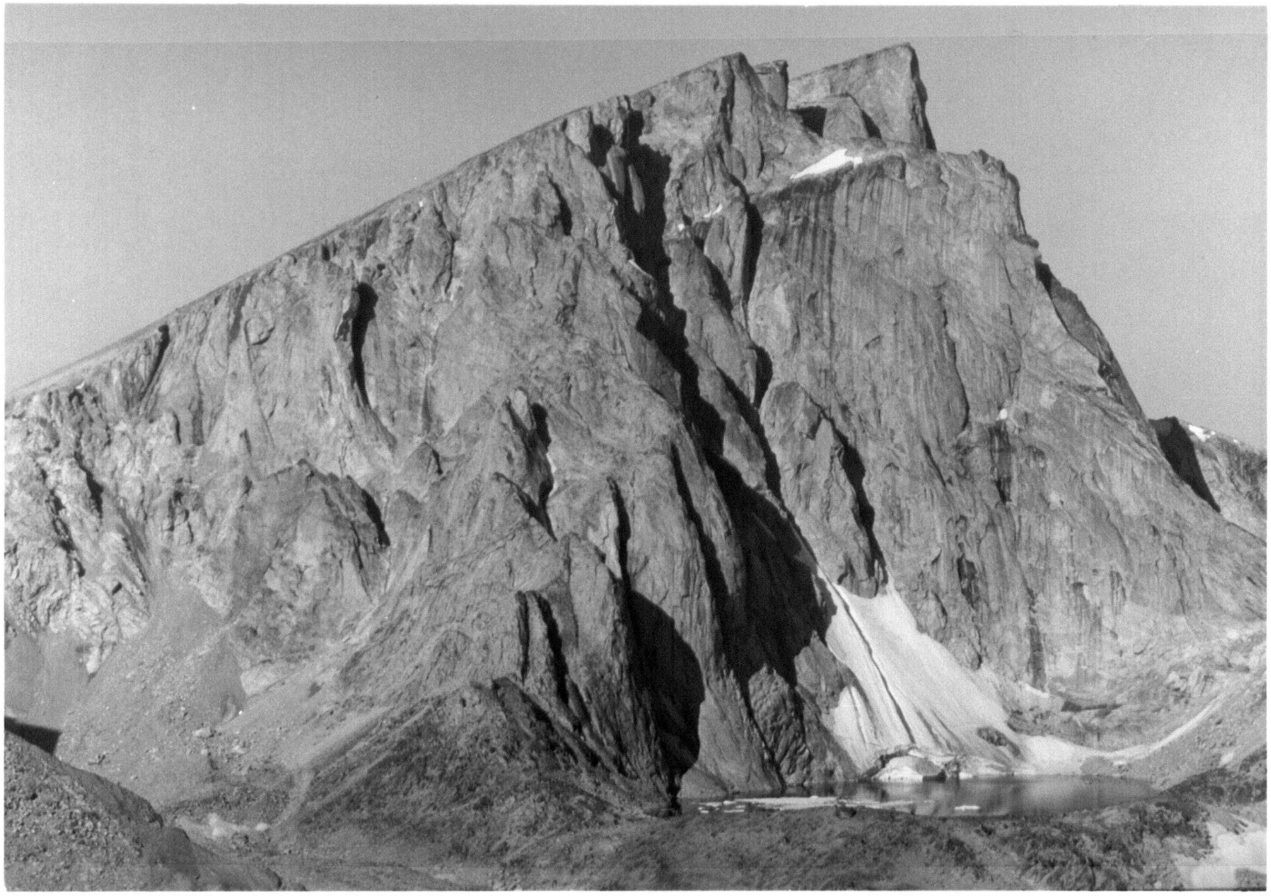


Figure 3.26 This unnamed mountain (8055' - just west of the study area) is composed of coarse grained Nisling Range alaskite. It is buff orange weathering with well-defined, widely spaced and locally horizontal, joint sets.

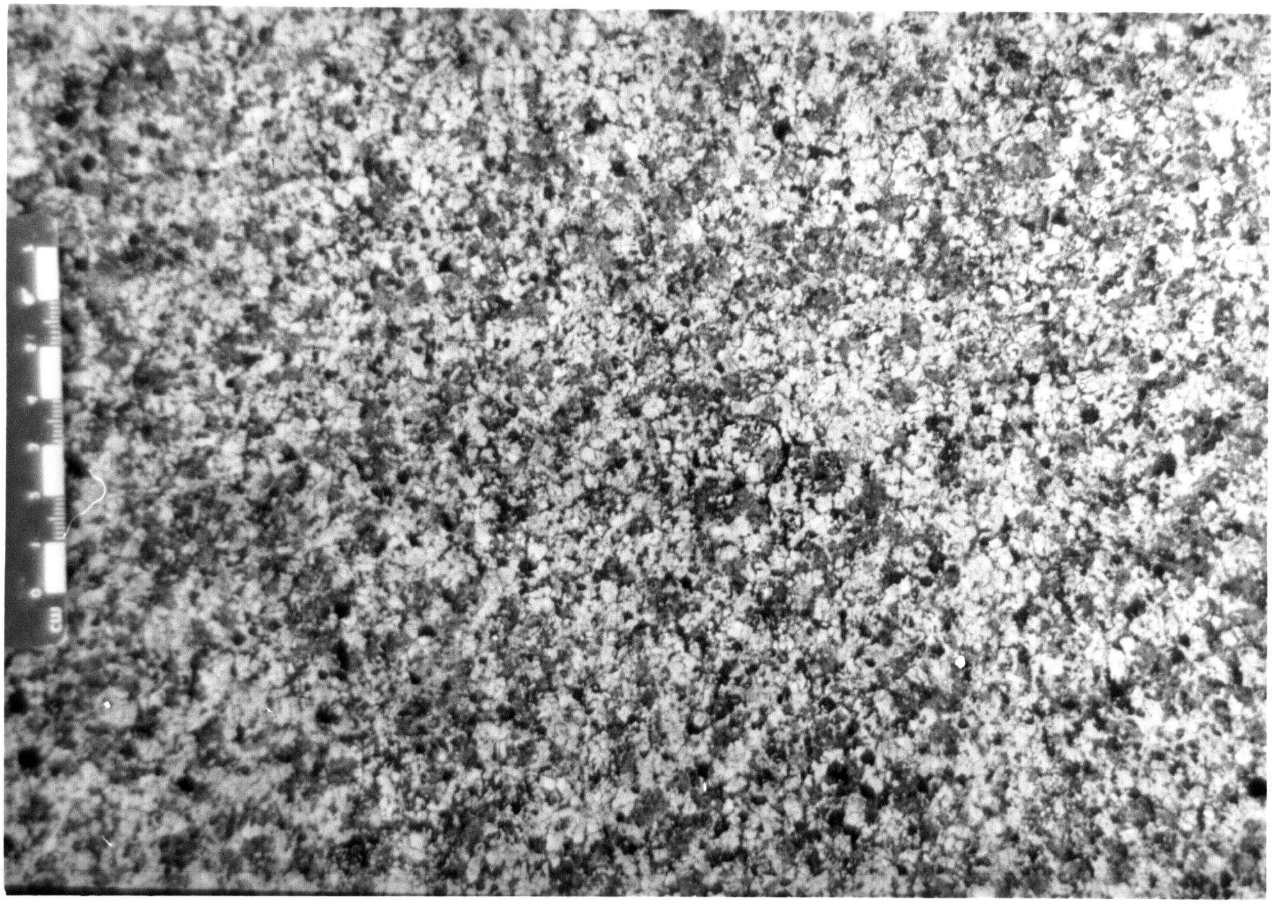


Figure 3.27 Nisling Range Plutonic Suite includes a wide range of felsic rock types with wide ranging textural character. Common to all representatives of this suite are euhedral, smoky grey quartz. This coarse-grained and equigranular is characteristic of the mid-levels of the pluton.

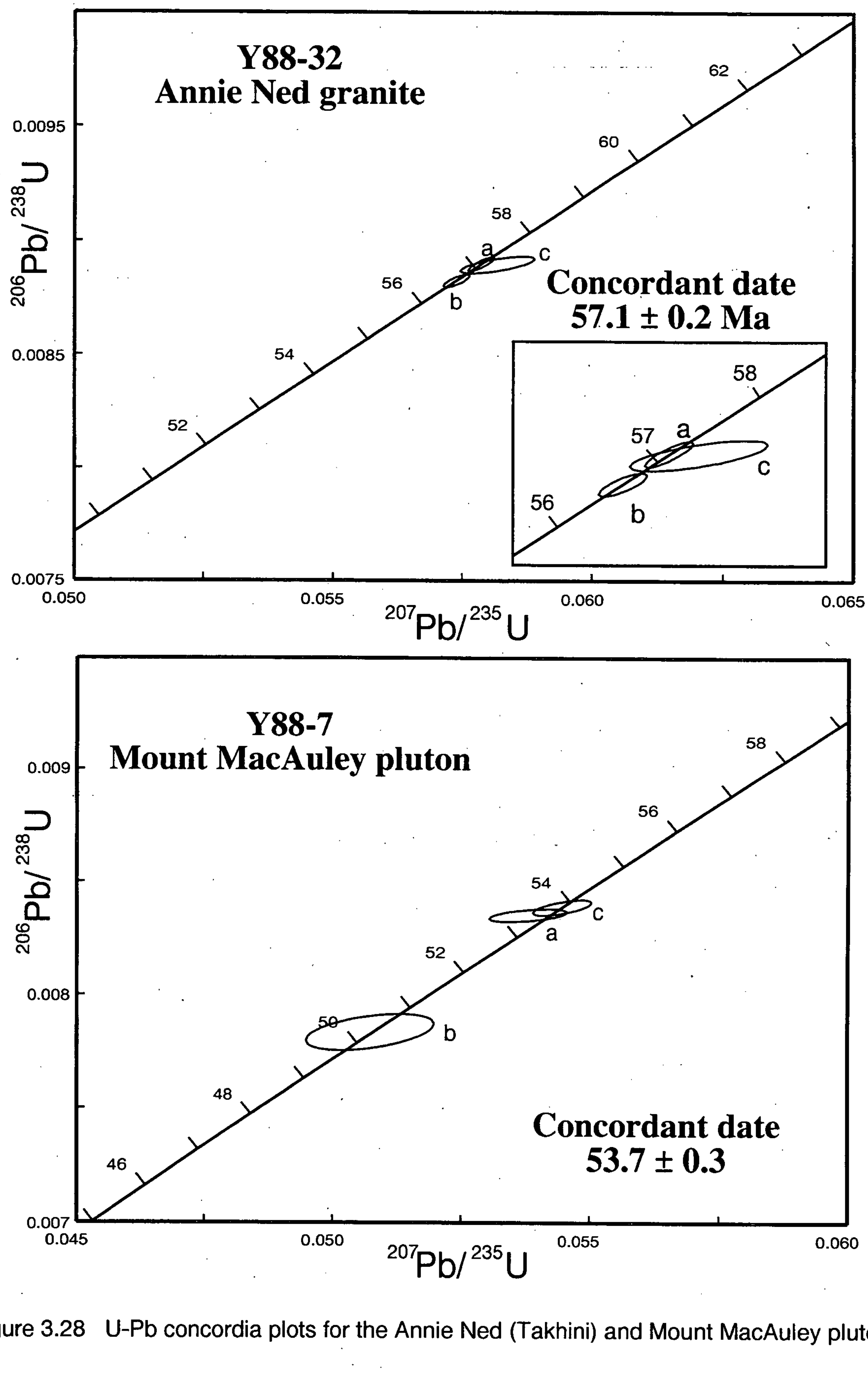


Figure 3.28 U-Pb concordia plots for the Annie Ned (Takhini) and Mount MacAuley plutons.

The distinctive quartz monzonite plutons give similar ages. The Crozier Creek pluton gives a U-Pb age of 56±1 Ma (Figure 3.29). A hornblende K-Ar date on the Pennington pluton is 55±2 Ma. These dates are the same as the lithologically similar pink quartz monzonite of Currie (1992b, 1993; 55.7 Ma U-Pb zircon) and Switzer plutonic suite of Mihalynuk (in prep) northern British Columbia, and may compose a sub-suite of the of the Nisling Plutonic Suite.

The Nisling Plutonic Suite is named after the lithogically and temporally similar to the Nisling Range Alaskite suite of Tempelman-Kluit (1974, 1976). Reliable ages from throughout the range of the Nisling Range plutonic suite ranges from *ca.* 54 to 58 Ma.

<u>Skukum Plugs (53 Ma)</u>

Numerous small (<1km^2), bright rusty weathering rhyolite and quartz feldspar porphyry plugs and dyke swarms occur throughout the CCC portion of the study area (Figure 3.30; Smith 1983). They locally contain quartz stockworks and fluorite. They are considered to be the last magmatic phase in the area and related to Skukum Group volcanism although they are not always proximal to a volcanic centre. A single sample from several of the plugs gave an Rb-Sr isochron age of 53.3 Ma (Pride and Clark 1985). This is in good agreement with other ages from the region, however since the samples came from several different bodies and the validity of the age is questionable.

THERMOCHRONOLOGY

The lowest temperature at which minerals rapidly lose argon has been dubbed the "threshold temperature" (Armstrong 1966) and "closure temperature" (Dodson 1973; Parrish and Leaman 1991). Intrinsic properties of each mineral determine the temperature at which argon will be retained. Temperature increases associated with regional and contact metamorphic events drive off argon in a mineral and effectively reset the isotopic clock. The resulting K-Ar mineral dates may be completely reset to the time of final mineral cooling below its closure temperature, or partially reset by some unknown amount between the crystallization and metamorphic age. An understanding of these principles allows the development of a thermochronometric history of a region that ultimately aids in the interpretation of K-Ar and Rb-Sr dates and assists in the selection of suitable methods and materials for future geochronometric studies.

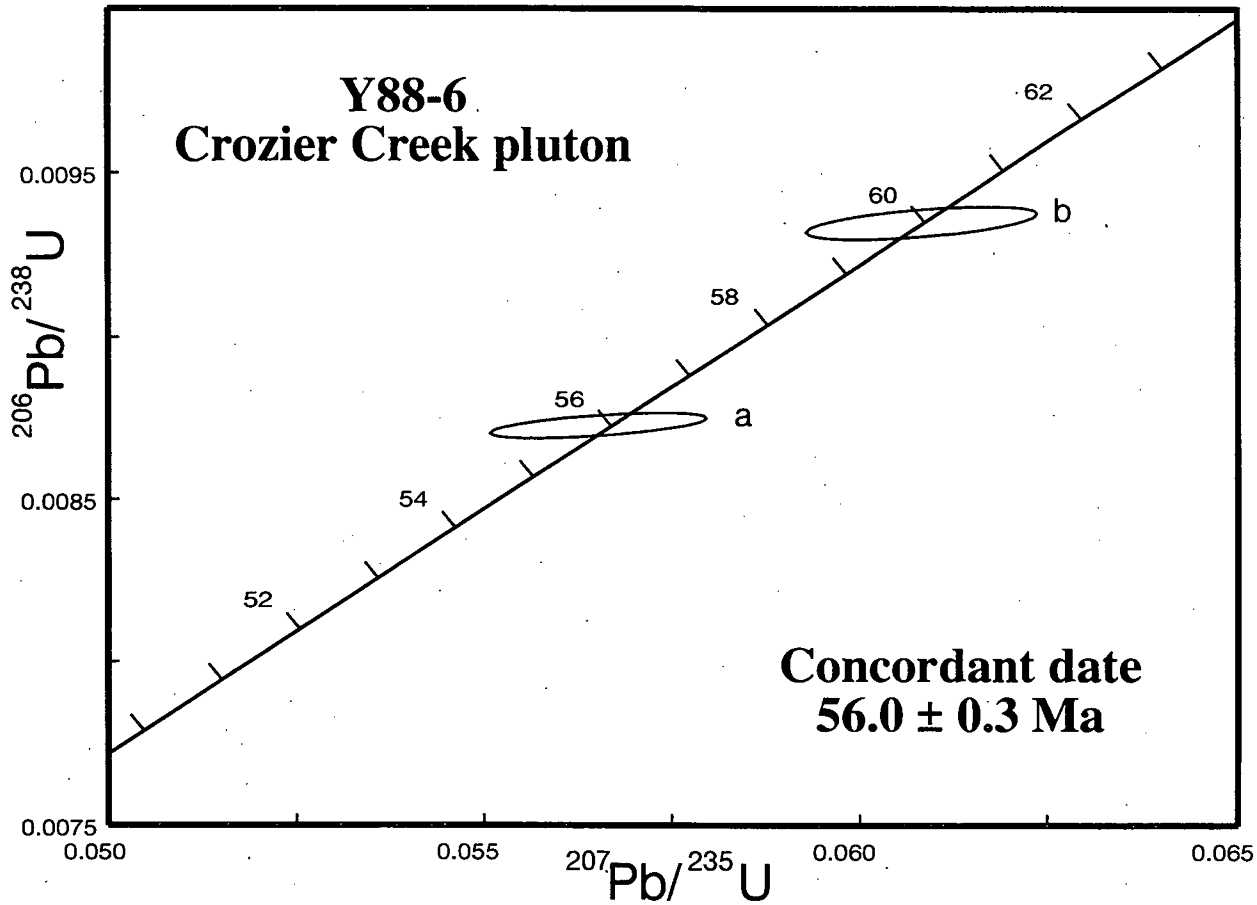


Figure 3.29 U-Pb concordia plot of the Crozier Creek pluton.

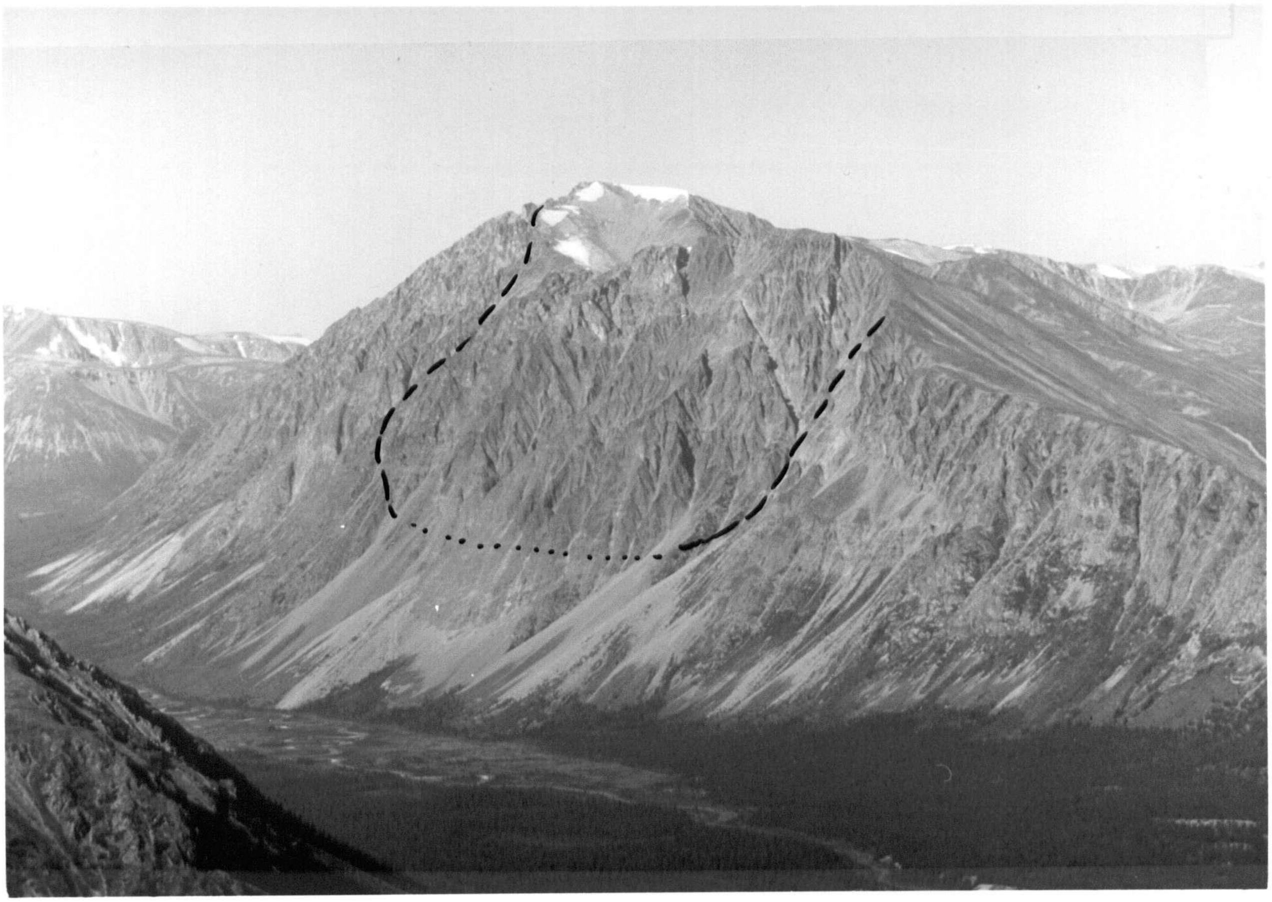


Figure 3.30 Looking south towards Mount McNeil, the bright rusty orange weathering Paleogene Scar rhyolite and quartz-feldspar porphyry plug (outlined) intrudes the mid-Cretaceous Berney Creek diorite

Age dates from this study and Morrison *et al.* (1979) are plotted according to the Ar closure temperatures of the dated materials (Figure 3.31). Partial or complete resetting of the K-Ar system is particularly characteristic of the Late Triassic and Early Jurassic rocks in the CCC and western Stikinia portions of the study area . Hornblende K-Ar ages, from rocks dated by U-Pb methods as Late Triassic or Early Jurassic, yield mid-Cretaceous dates between 144 and 113 Ma. Mid-Cretaceous to Eocene U-Pb zircon dates are essentially concordant with K-Ar hornblende and biotite ages, although there are some notable exceptions.

Significantly younger K-Ar ages from Late Triassic to Early Jurassic indicates that either: 1) Middle Jurassic to Early Cretaceous regional thermal overprinting was sufficient to reset hornblende and gradually cooled through the hornblende closure temperature (530°C) throughout early mid-Cretaceous time; or 2) a mid-Cretaceous thermal overprint associated with mid-Cretaceous magmatism was sufficiently high to partially, and variably reset existing K-Ar hornblende dates. Early Jurassic hornblende K-Ar ages and concordant biotite-hornblende K-Ar ages obtained from the axial region of Stikinia in Yukon (Tempelman-Kluit 1984; Hart and Mortensen unpublished data) indicate that this thermal event was restricted to the CCC. The regional thermal event may be the result of: 1) a Middle Jurassic to Early Cretaceous regional metamorphic event; 2) uplift of the CCC and westernmost Stikinia through the K-Ar hornblende isotherm at post-144 Ma, 2) partial resetting during an increase in the regional thermal gradient associated with extensive mid-Cretaceous magmatism; or 4) any combination of these factors.

Concordant (within error) mid-Cretaceous U-Pb zircon and K-Ar hornblende and biotite dates indicate that mid-Cretaceous magmas in the CCC and Stikinia cooled from >800°C to below 280°C quickly. This essentially precludes the possibility of the mid-Cretaceous partial resetting hypothesis proposed above -- since biotite ages are concordant with hornblende ages, the country rocks must have been cool (below 280°C). Where discordant zircon-hornblende ages occur in mid-Cretaceous plutons, they can be attributed to localized thermal contact aureoles of adjacent younger (Late Cretaceous or Early Tertiary) plutons. This is particularly evident in the Montana Mountain pluton where hornblende in a 107 Ma (zircon) pluton gives a K-Ar date of 78 Ma. It is probable that this reflects partial resetting by the *ca.* 68 Ma Carcross pluton.

In other cases, K-Ar dates that are too young, particularly on biotite, result from hydrothermal alteration which robs the biotite of potassium as it alters it to chlorite and

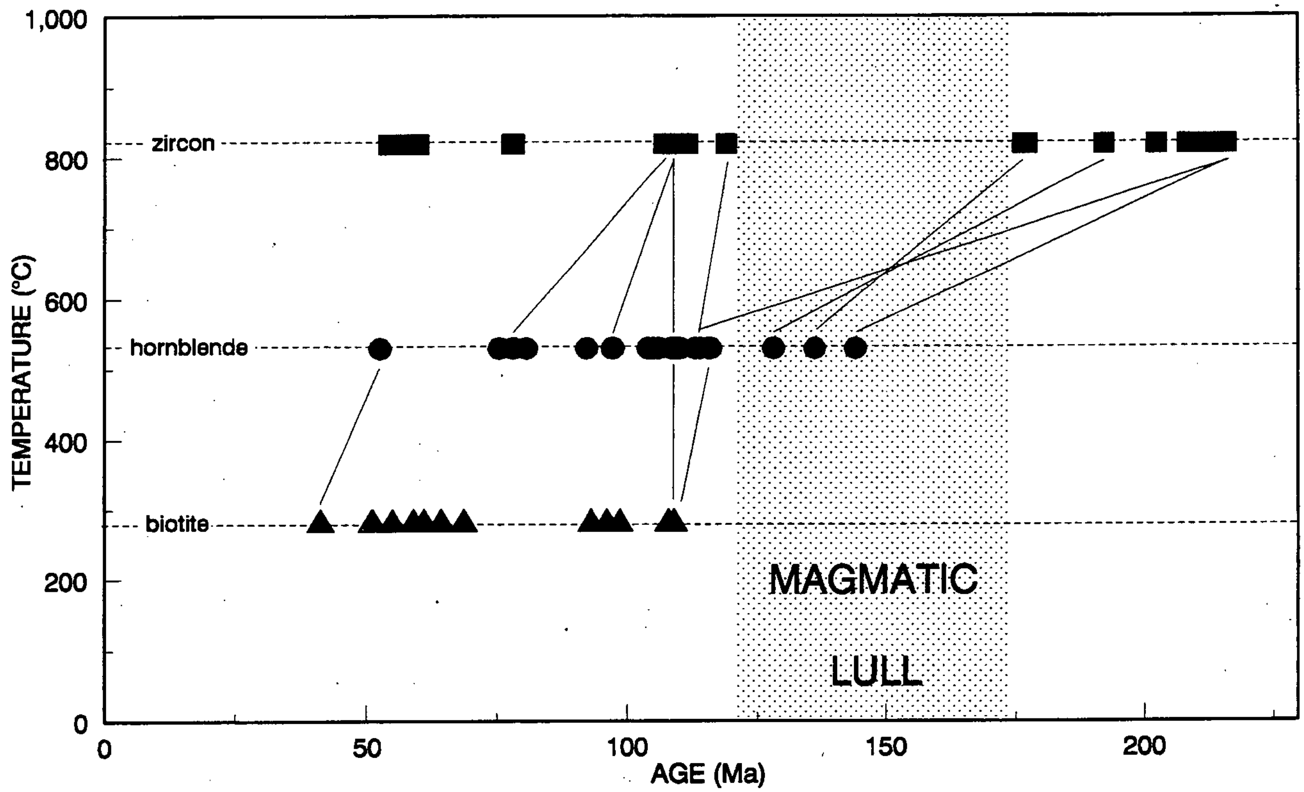


Figure 3.31 Thermochronometric plot of data from the Whitehorse map area indicates that, except for localized exceptions, mid-Cretaceous and younger rocks have nearly concordant U-Pb zircon, hornblende and biotite K-Ar dates. However, the K-Ar ages of Late Triassic and Early Jurassic rocks are all reset to Early Cretaceous time. This suggests that the region experienced a Jurassic thermal event that cooled through the hornblende closure temperature (530°C) during Early Cretaceous time, or that the mid-Cretaceous magmatic episode is responsible for variably resetting older K-Ar systems.

destroys the sites that host radiogenic Ar. This is evident in samples 89CH 33-3 and 89CH 52-1, where the variably chloritized biotite have unusually low potassium contents (i.e., ~1.5% instead of 6%) and the biotite K-Ar date is 10-20% less than expected. Hydrothermal alteration has also affected the Rb-Sr isotopic systematics of granites in the Whitehorse area giving rise to erroneous isochrons and initial Sr ratios (Dagenais 1984; Hart and Hunt 1994).

Because there are no biotite ages older than 110 Ma, and most biotite dates from mid-Cretaceous plutons are nearly concordant with the hornblende date, it is likely that the entire study area had passed through the biotite isotherm (280°C) by 110 Ma. This precludes the possibility of early Tertiary resetting due to dramatic uplift of the eastern CCC. However, two to three million year old discordance between early Tertiary K-Ar hornblende and biotite (or whole rock) dates are common, particularly in the volcanic, as opposed to plutonic, rocks (i.e., Lambert 1974; McDonald and Godwin 1986). Although the Early Tertiary magmatic event is often considered responsible for widescale partially resetting of isotopic dates, no evidence is seen here to support large scale thermal resetting and argon loss during the Paleocene.

INITIAL STRONTIUM DATA

Strontium initial ratios ($^{87}Sr/^{86}Sr$; SIR) for igneous rocks provide clues about the site of magma genesis and/or the processes of contamination of magmas (Faure 1986). Strontium isotopes have proven useful in discerning areas underlain by Precambrian basement from those consisting of juvenile crust (Kistler and Peterman 1978, Armstrong *et al.* 1977). A ratio of 0.706 or greater is generally considered to indicate the assimilation of, genesis from or contamination by, older crust or lithosphere. Values of 0.704 or less are considered to represent generation from an uncontaminated mantle source. Intermediate values require more complex interpretations.

Forty-two new SIR determinations on Mesozoic and Early Tertiary plutonic rocks from the study area are presented (Table 3.2). Most of these SIR values are primitive to transitional and range between 0.7035 and 0.7057, but locally exceed 0.7060. Nine previous SIR analyses on granitic rocks in the Whitehorse area are also in this range (0.7044-0.7055; Morrison *et al.* 1979) as is an initial ratio determined from five Eocene rhyolite plugs south of Whitehorse in the CPC (0.7053; Pride and Clark 1985).

TABLE 3.2 Whole rock strontium data for Mesozoic and Cenozoic plutonic rocks from Whitehorse map area (105D)

Sample	Rock Type	Pluton Name	Sr[a] (ppm)	Rb[a] (ppm)	$^{87}Rb/^{86}Sr$[b]	$^{87}Sr/^{86}Sr$[c] observed	age[d] (Ma)	$^{87}Sr/^{86}Sr$ initial$\pm 2\sigma$
LATE TRIASSIC TO EARLY JURASSIC (KLOTASSIN) MAGMATIC EPISODE								
Stikine Plutonic Suite								
ZR 4-1	hornblende gabbro	Tally Ho	760	79.5	0.302	0.70449	215	0.70356±8
ZR 4-2	hornblende gabbro	Tally Ho	655	93.2	0.412	0.70477	215	0.70351±8
ZR 4-3	hornblende gabbro	Tally Ho	652	73.9	0.328	0.70429	215	0.70328±6
ZR 4-3 rerun	hornblende gabbro	Tally Ho	663	70.7	0.308	0.70438	215	0.70343±8
Y88-33-4	hornblende-biotite granodiorite	Friday Creek	831	66.7	0.232	0.70454	210	0.70385±4
Red Ridge Plutonic Suite								
Y88-33-3	hornblende diorite	Red Ridge	755	75.2	0.288	0.70473	200	0.70391±6
Bennett Plutonic Suite								
Y88-10	hornblende granodiorite	Alligator	877	27.7	0.091	0.70526	174	0.70504±4
ZR 2-1	biotite-hornblende granodiorite	Bennett	963	79.0	0.237	0.70579	177	0.70519±8
ZR 2-2	biotite-muscovite granite	Bennett	672	152	0.654	0.70848	177	0.70683±3
ZR 2-3	biotite-hornblende granodiorite	Bennett	940	92.3	0.284	0.70582	177	0.70510±5
92CH 70-1	biotite-hornblende granodiorite	Bennett	807	94.7	0.339	0.70605	177	0.70510±3
Y88-30	hornblende diorite	Fenwick Creek	670	105	0.451	0.70579	176	0.70466±8
Y88-30F	K-spar from pegmatite dyke	cuts Fenwick Creek pluton	600	348	1.680	0.70857	170	0.70451±6

TABLE 3.2 (cont.) Whole rock strontium data for Mesozoic and Cenozoic plutonic rocks from Whitehorse map area (105D)

Sample	Rock Type	Pluton Name	Sr[a] (ppm)	Rb[a] (ppm)	$^{87}Rb/^{86}Sr$[b]	$^{87}Sr/^{86}Sr$[c] observed	age[d] (Ma)	$^{87}Sr/^{86}Sr$ initial±2σ
MID-CRETACEOUS (WHITEHORSE) MAGMATIC EPISODE *Whitehorse Plutonic Suite*								
Y88-8	biotite-hornblende quartz diorite	Boudette Creek	555	67.8	0.353	0.70681	108	0.70626±8
WHA8[h]	biotite-hornblende granodiorite	Boudette Creek	545	73.7	0.391	0.7069	109	0.7063±3
Y88-26	hypersthene-hornblende diorite	Ibex River	1014	11.6	0.033	0.70428	109	0.70422±4
Y88-40	hornblende quartz diorite	Berney Creek	520	82.5	0.459	0.70529	111	0.70456±4
MD43-14	hornblende quartz diorite	Mt. Anderson	600	73.3	0.353	0.70540	111[e]	0.70484±8
ZR 3-2	biotite-hornblende granodiorite	Mt. Anderson	550	66.2	0.348	0.70555	111	0.70500±4
ZR 3-3	biotite-hornblende granodiorite	Mt. Anderson	526	73.4	0.402	0.70560	111	0.70496±4
ZR 3-1	biotite-hornblende granodiorite	Watson River	680	48.7	0.207	0.70503	111	0.70470±3
Y88-19	hornblende granodiorite	Whitehorse	933	42.3	0.131	0.70435	111[e]	0.70414±4
WHB 1[h]	quartz monzonite	Whitehorse	1031	35.0	0.098	0.7047	111[e]	0.7045±3
WHB 2[h]	biotite-hornblende granodiorite	Whitehorse	651	42.5	0.188	0.7046	111[e]	0.7043±3
WHB 3[h]	biotite-hornblende granodiorite	Whitehorse	732	33.4	0.133	0.7048	111e	0.7046±3
WHB 5[h]	hornblende quartz diorite	Whitehorse	822	48.3	0.170	0.7044	111[e]	0.7041±3
91CH 75-1	hornblende diorite	Marsh Lake	980	95.0	0.280	0.70734	104hb	0.70692±3[i]
89CH 35-7	pyroxene diorite	Mount Hodnett	310	117	1.092	0.70598	106hb	0.70434±4
89CH 58-1	biotite-hornblende granodiorite	Ibex west	621	91.9	0.428	0.70524	110[e]	0.70457±3

TABLE 3.2 (cont.) Whole rock strontium data for Mesozoic and Cenozoic plutonic rocks from Whitehorse map area

Sample	Rock Type	Pluton Name	Sr[a] (ppm)	Rb[a] (ppm)	$^{87}Rb/^{86}Sr$[b]	$^{87}Sr/^{86}Sr$[c] observed	age[d] (Ma)	$^{87}Sr/^{86}Sr$ initial$\pm2\sigma$
MID-CRETACEOUS (WHITEHORSE) MAGMATIC EPISODE (cont.)								
Mount McIntyre Plutonic Suite								
Y88-18	quartz monzonite	Mount McIntyre	136	125			109	
WHA 6A[h]	quartz monzonite	Mount McIntyre	384	75.3	0.567	0.7051	109	0.7042±3
Y88-36	biotite granite	Mount Ward	298	112	1.084	0.70618	109	0.70450±4
89CH 33-3	biotite-hornblende quartz monzonite	Carbon Hill	332	104	0.906	0.70615	109[e]	0.70474±4
Y88-21 av. of 2 runs	biotite-hornblende granodiorite	Montana Mountain	182	162	2.60	0.70717	107	0.70321±3[i]
89CH 64-1	biotite granodiorite	Mount Granger	423	156	1.07	0.70567	94bi	0.70424±6
LATE CRETACEOUS (CARMACKS) MAGMATIC EPISODE								
Wheaton River Plutonic Suite (mafic phases)								
Y88-14	hornblende diorite	Wheaton	436	78.1	0.519	0.70532	77	0.70475±4
Y88-33-2	hornblende diorite	Red Ridge dike	445	19.7	0.128	0.70450	81hb	0.70435±6
WHA 7[h]	quartz monzonite	Mt. Lorne	387	102	0.764	0.7052	75hb	0.7044±4
Wheaton River Plutonic Suite (felsic phases)								
Y88-1	biotite granite	Folle Mountain	165	196	3.45	0.70827	78	0.70444±6
Carcross Plutonic Suite								
89CH 60-5	biotite granite	Carcross	416	110	0.765	0.70582	68bi	0.70508±4
WHA 9[h]	quartz monzonite	Carcross	430	109	0.732	0.7057	68[e]	0.7050±3

TABLE 3.2 (cont.) Whole rock strontium data for Mesozoic and Cenozoic plutonic rocks from Whitehorse map area

Sample	Rock Type	Pluton Name	Sr^a (ppm)	Rb^a (ppm)	$^{87}Rb/^{86}Sr^b$	$^{87}Sr/^{86}Sr^c$ observed	age^d (Ma)	$^{87}Sr/^{86}Sr$ initial±2σ
		EARLY TERTIARY (SKUKUM) MAGMATIC EPISODE						
		Nisling Range Plutonic Suite						
Y88-6	biotite granite	Crozier Creek	45.1	80.7	5.18	0.70918	56	0.70506±6
89CH 52-1	biotite granite	Pennington	379	50.6	0.3862	0.70482	55hb	0.70452±3
Y88-28	biotite leucogranite	Fenwick II	4.9	174	103	0.78912	57^e	$0.70575±22^i$
Y88-29A	quartz monzonite	Fenwick II	21.1	182	24.9	0.72454	55wr	$0.70509±8^i$
Y88-35A	leucogranite	Fenwick III	654	71.7	0.317	0.70512	55^e	0.70487±4
Y88-7	biotite granite	Mount MacAuley	28.3	166	16.99	0.71849	54	$0.70546±9^i$
Y88-32A	biotite quartz monzonite	Annie Ned	306	124	1.173	0.70587	57	0.70492±6
Y88-32B	aplite dike	Annie Ned	56.8	155	7.90	0.71126	57^e	0.70485±8
WHA 1^h	biotite granite	Annie Ned	6.3	153	70.6	0.7578	54^e	$0.7040±4^{g,i}$
(rerun 1993)	biotite granite					0.75835	54^e	$0.70426±3^i$
WHA 4^h	biotite granite	Jackson Creek	361	123	0.987	0.7056	55bi	0.7048±4
Y88-16	biotite granite	Perkins Peak	173	155	2.59	0.70768	55^e	0.70566±4
rerun	biotite granite	Perkins Peak	172	153	2.59	0.70756	55^e	0.70554±4
CH88 58-4	alaskite	Upper Ibex	25.1	193	22.3	0.72250	56^e	$0.70476±24^i$
		Skukum Group Plugs						
53	rhyolite plug	Primrose	262	102	1.13	0.7061	53^e	0.7052
108	rhyolite plug	Watson	13.9	145	30.1	0.7293	53^e	0.7066^i
67	rhyolite plug	Berney	7.30	169	67.3	0.7547	53^e	0.7041^i
48	rhyolite plug	Central	8.07	173	62.3	0.7519	53^e	0.7050^i
52	rhyolite plug	Central	2.71	145	156	0.8287	53^e	0.71063^i
76	rhyolite plug	Central	9.14	72.7	72.7	0.7581	53^e	0.70307^i
101	rhyolite plug	Folle	103	185	5.18	0.7093	53^e	0.7054
n=7		All plugs				MSWD=4.5	53.3	0.7053^f

NOTES: Analyses by D.K. Ghosh, R.L. Armstrong, C.J.R. Hart, Dita Runkle and K. Scott at The University of British Columbia except Skukum Group plugs (Pride and Clark 1985).

[a] Sr and Rb concentrations were determined by duplicate analyses of pressed-powder pellets using X-ray fluorescence. Mass absorption coefficients were obtained from Mo Kα Compton scatter measurements. Rb and Sr concentrations have $\pm 1\sigma$ errors of 5%.

[b] $^{87}Rb/^{86}Sr$ ratios by XRF have $\pm 1\sigma$ error values of 2% for samples with both concentrations over 50 ppm and $^{87}Rb/^{86}Sr$ divided by the lowest concentration for samples with concentrations below 50 ppm (effectively ±1 ppm lower limit on concentration uncertainty).

[c] Sr isotopic composition was measured on unspiked samples prepared using standard ion exchange techniques. $^{87}Sr/^{86}Sr$ isotopic analyses reported to four decimals were determined prior to 1982. Sr isotopic measurements were made on a National Bureau of Standard (NBS) type 30 cm radius, 60° sector mass spectrometer designed and constructed by H. Faul and automated by R. L. Armstrong with a Nova 1210 computer. The $\pm 2\sigma$ errors for $^{87}Sr/^{86}Sr$ are 0.0002 for values with four decimal figures. After 1982, Sr isotopic measurements were made on a Vacuum Generators Isomass 54R mass spectrometer (with upgraded source, focus and detector electronics) linked with a Hewlett-Packard HP-85 computer. Errors for values with five decimal figures are reported individually. Blanks contain approximately 0.8 and 6 ng of Rb and Sr respectively. Meaured Sr isotope analyses are normalized, assuming $^{86}Sr/^{88}Sr$ ratio of 0.1194, and further adjusted so the Eimer and Amend standard gives a $^{87}Sr/^{86}Sr$ ratio of 0.70800±0.00002 and the NBS Sr standard $SrCO_3$ (SRM 987) gives a ratio of 0.71019±0.00002. $\lambda = 1.42 \times 10^{-11}\ a^{-1}$ (Steiger and Jäger, 1977).

[d] Initial $^{87}Sr/^{86}Sr$ ratios are calculated using U-Pb zircon date, or K-Ar date where material abbreviations are given.

[e] Initial $^{87}Sr/^{86}Sr$ ratio calculated using estimated crystallization age

[f] Initial $^{87}Sr/^{86}Sr$ ratio calculated from Rb/Sr isochron

[g] Average of two or more samples

[h] Recalculated from Morrison et al. 1979 using new age data from this study.

[i] Geologically unreasonable initial $^{87}Sr/^{86}Sr$ ratio OR value is too dependant upon the crystallization age used to calculate the initial ratio (i.e., high Rb/Sr). Not used in figures or statistical calculations.

Abbreviations: bi=biotite, hb=hornblende, wr=whole rock.

SIR values define a restricted range for suites of the Klotassin Episode but values for younger suites span much wider ranges (Figure 3.32). Generally elevated values occur in plutons intruding the CCC compared with lower values in plutons within and east of the Tally Ho shear zone which intrude Stikinia and Cache Creek rocks (Figure 3.33). The THSZ approximates the locus of the 0.705 isopleth. Some SIR from plutons west of the shear zone have values exceeding 0.7065, but their distribution is erratic and values approximating 0.704 are also present in this area.

Taking regional variations into account the following generalization can be made: 1) The Stikine and Red Ridge plutonic suites have low SIR values (<0.7039); 2) The Bennett suite is the oldest suite to contain locally elevated values (>0.706); 3) The Whitehorse and Mount McIntyre suites are the oldest suites that occur on both sides of the THSZ and, as a result, have a wide range of values; 4) Plutons west of the THSZ structure have average SIR values that are 0.0007 greater than plutons to the east, as well as higher Rb/Sr ratios; 5) The Skukum Episode rocks shows a similar spatial pattern with slightly higher SIR values west of the THSZ; 6) In general, there is an increase in Rb/Sr with decreasing age. This feature is particularly pronounced in Skukum Episode plutons that have erratic, but locally extremely high Rb/Sr ratios (Figure 3.34). This is chiefly a function of exceptionally low Sr contents rather than elevated Rb. Comparing the felsic and mafic plutons of the Whitehorse magmatic episode and the Wheaton plutonic suite indicate that the felsic phases have higher Rb/Sr but both phases have similar SIR.

Within-pluton variation of SIR can be assessed for the more comprehensively studied Whitehorse pluton and the Bennett Batholith. The Whitehorse pluton, which intrudes Stikinian rocks, exhibits only a small internal variation of ±0.0005 among six lithologically dissimilar and widely spaced samples. Conversely, the Bennett Batholith, which intrudes the CCC, has an internal variation of ±0.0017 among four samples of the same phase and ±0.0022 among all six samples from within the batholith.

<u>Interpretation</u>

The distribution of elevated SIR values in the CCC reflects contamination from ancient and radiogenic rocks of the Nisling Terrane. Plutons intruding Stikinia have SIR values that are mainly <0.7045 which suggest a relatively uncontaminated primitive mantle source for the magmas. The Late Triassic Stikine and Red Ridge suites intrude, and are broadly coeval with the Lewes River volcanic arc. SIR values of the Late

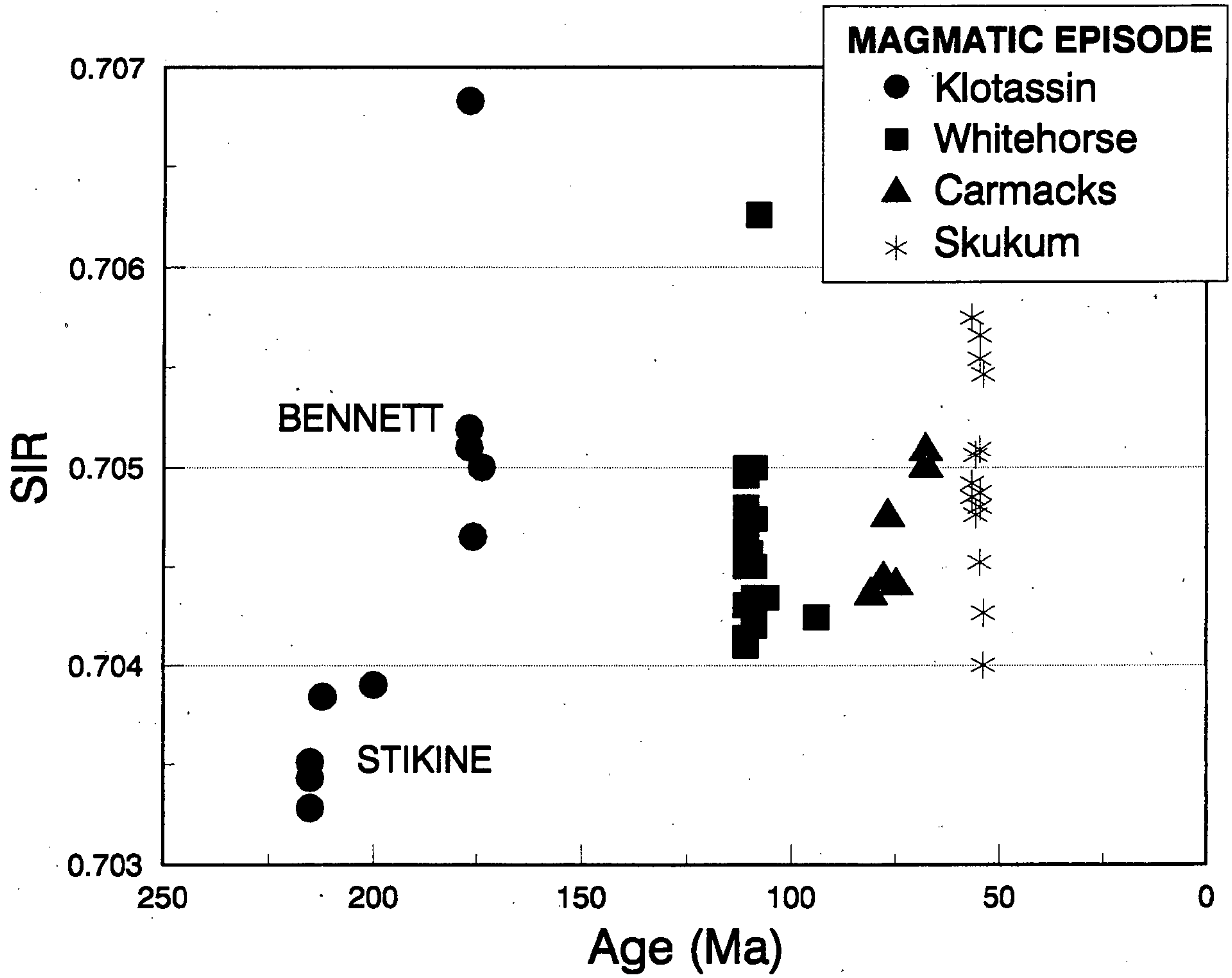


Figure 3.32 Plot of strontium initial ratio (SIR) versus age indicates that only the individual suites of the Klotassin episode have characteristic SIR values. The other episodes have a wide range of values that reflects the isotopic character of the basement (see Figure 3.33).

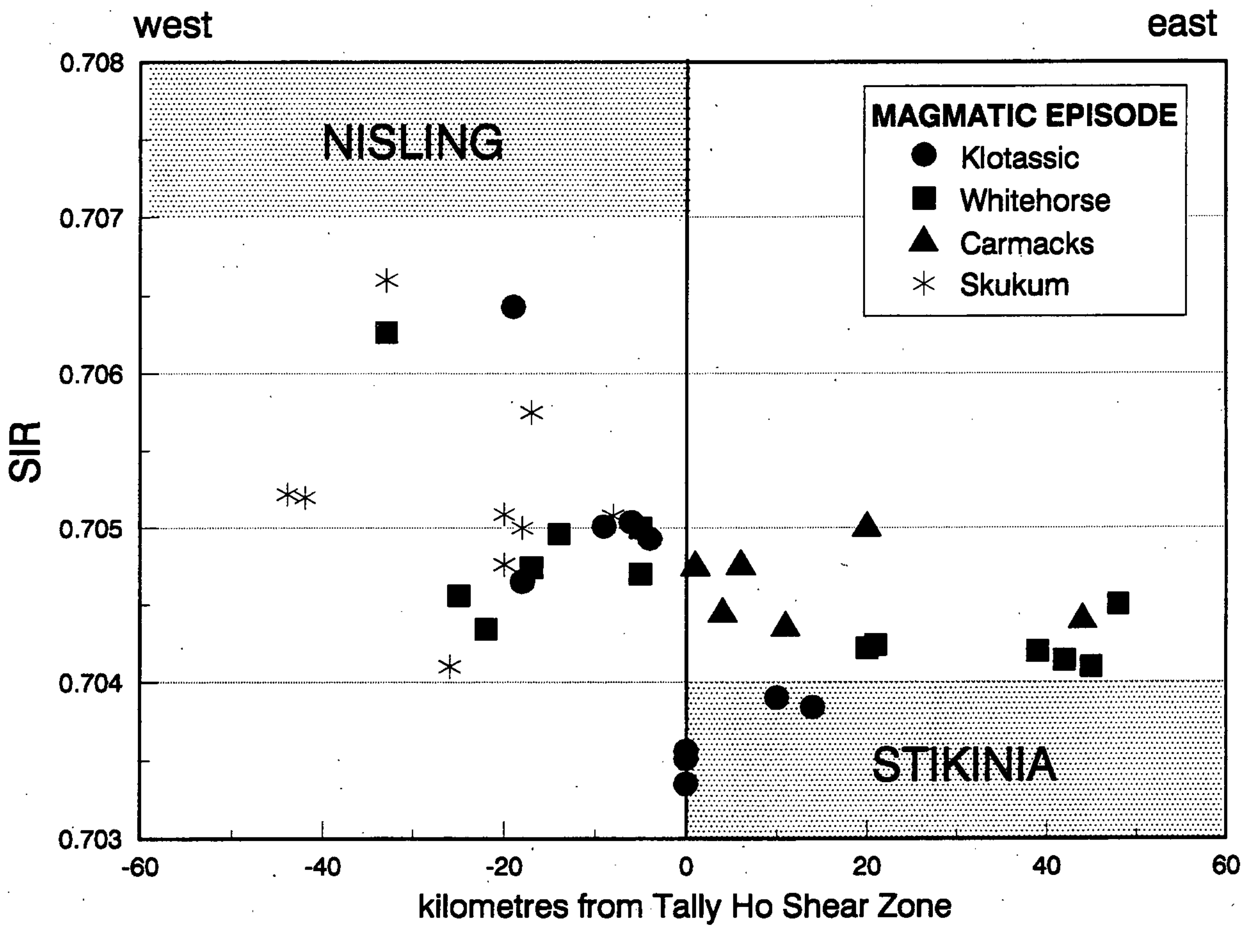


Figure 3.33 Plot of strontium initial ratio (SIR) versus location, west or east of the Tally Ho Shear Zone, indicates that granitic rocks west of the shear zone have slightly elevated and more erratic ranges than rocks east of the shear zone (West: av. 0.70511±47; East av. 0.70441±37 [one sigma errors]). Since the THSZ separates Nisling Terrane from Stikinia, the variation in SIR values west of the shear zone is thought to reflect variable amounts of contamination from radiogenic Nisling Terrane. However since the effect is variable and localized, Nisling Terrane rocks probably do not form a thick basement in this region but are present only in the upper crustal levels.

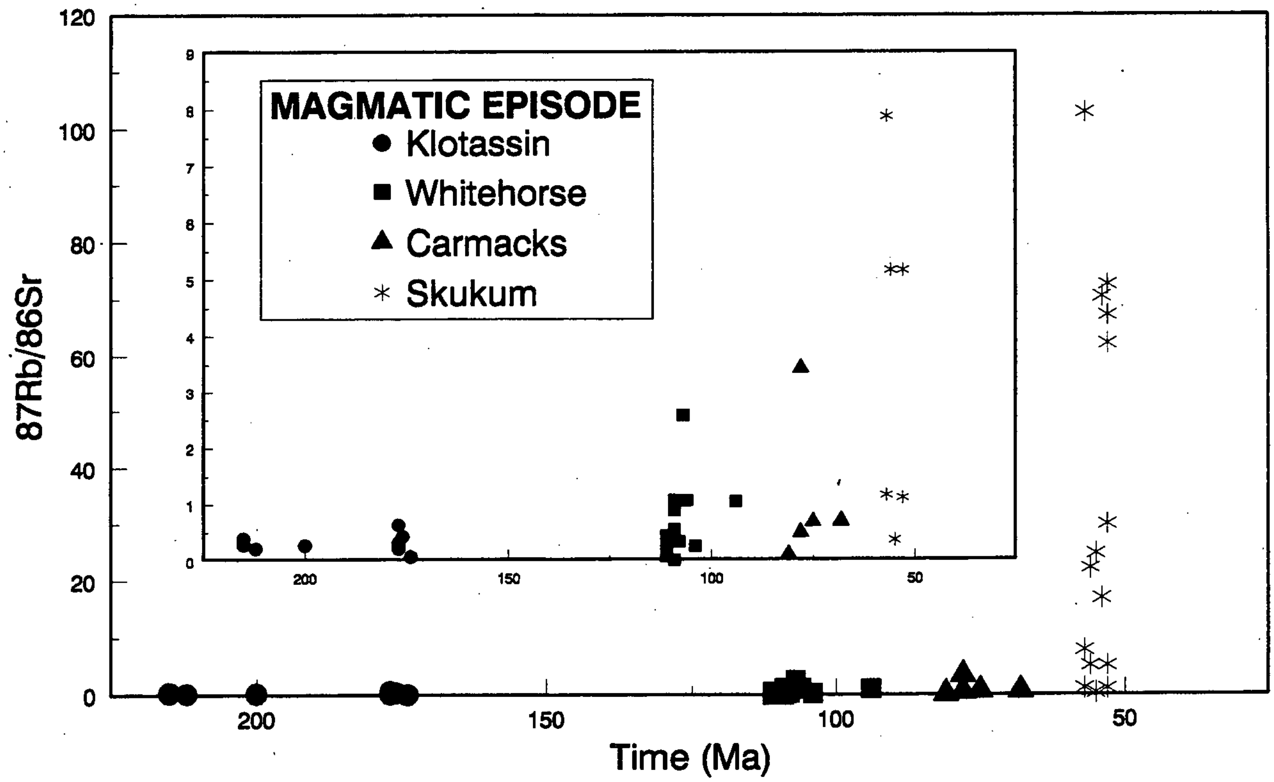


Figure 3.34 Plot of $^{87}Rb/^{86}Sr$ versus age indicates that most granitic rocks in the study area generally have low rubidium to strontium ratios except those of the Skukum Episode which have erratic and extremely high ratios. This is a characteristic of highly evolved and fractionated magmas typical characteristic of A-type granites. The inset contains the same data but has an expanded Y-axis to better display the low $^{87}Rb/^{86}Sr$ data.

Triassic magmas are primitive and show no evidence of interaction with an older, more radiogenic continental crust in their basement (cf. Tempelman-Kluit 1979).

The variation in ratios of the Bennett suite reflect erratic contamination that is localized and likely results from heterogeneous upper crustal contamination. If contamination was at mid- to lower crustal levels, homogenized initial ratios would be expected. Contamination by radiogenic country rocks during stoping and inclusion of xenoliths into the magmatic body is more pronounced along the plutons' margins and roof. As a result, Nisling Terrane during the Early Jurassic was probably not thick and did not occur at mid- to deep structural levels. The implication is that Nisling Terrane was probably not the basement but existed as a thin, upper crustal assemblage.

The generally transitional values of the Whitehorse, Carmacks and Skukum episodes (0.7041-0.7052) result from variable amounts of localized contamination in the CCC but the higher SIR ratios from plutons intruding Stikinia (*ca.* 0.7046) reflect contributions from a tectonically thickened and isotopically maturing Mesozoic crust. By Early Tertiary time the lower crust was radiogenic enough and sufficiently thick to alter the strontium isotope composition.

The erratic and extreme Rb/Sr ratios in the Skukum Episode result from Sr depletion in highly fractionated epizonal magmas. Locally, the ratios are so high that the calculated SIR is extremely age-dependent such that variations up to ±0.001 result from 1 Ma age differences. In some cases, SIR values calculated from the zircon date of the pluton is geologically unreasonable, but if the biotite K-Ar age is used, then the SIR is acceptable (i.e. Sample WHA1 @ 58 Ma=0.6997; @55 Ma=0.7048 with $^{87}Rb/^{86}Sr$=70.6). Although the pluton's SIR values are calculated back to the U-Pb zircon age where possible, it is probable that the parent radionuclide, ^{87}Rb, remained mobile and was not "set" until the rock cooled below a certain threshold temperature. Biotite and alkali feldspar are the major hosts for Rb (Shirey 1991). Open system Rb mobility is thought to be quenched in magmas at approximately 700°C (Harrison *et al.* 1979). In whole rocks , the length of time between zircon U-Pb closure, at about 850°C, and whole rock Rb closure represents the error in any calculated SIR. This error will be pronounced in rocks which endure slow cooling histories and for rocks with high $^{87}Rb/^{86}Sr$ ratios. Since rocks of the Skukum magmatic episode were emplaced during a time of extension and elevated geothermal gradients, SIR calculated from hornblende K-Ar ages, whose closure temperature more closely approximates Rb closure, may be more accurate.

Weak alteration, probably associated wiith advective hydrothermal circulation, has affected many of the sampled plutons -- particularly the Pennington pluton, and most of the Mount McIntyre plutonic suite. Alteration preferentially affects unstable minerals such as plagioclase which contains Sr, and biotite and alkali feldspar which contain Rb. Hydrothermally altered rocks typically have depleted Sr values and elevated Rb/Sr ratios. The extremely low Sr contents of many of the plutons, of the Skukum Episode in particular, increases the probability of increasing the $^{87}Sr/^{86}Sr$ ratio since radiogenic ^{87}Sr is typically in K sites in potassium-bearing minerals like biotite and alkali feldspar (Faure and Powell 1972).

In all cases throughout this study, the IUGS decay constant of $1.42 \times 10^{-11} a^{-1}$ (Steiger and Jager 1977) was used. A slightly smaller decay constant of $1.402 \times 10^{-11} a^{-1}$, proposed by Minster *et al.* (1982), results in a 0.0001 to 0.0006 increase in the SIR values of Early Tertiary rocks with $^{87}Rb/^{86}Sr$ ratios greater than 10.

Unlike most of the Cordillera where higher values are found approaching the craton, SIR values in the study area show moderate increases towards the west (Figure 3.33; Armstrong 1988). The region of elevated SIR values extends as far west as the Denali Fault and terminates easterly, against the western margin of Stikinia. Except for small and local perturbations (which may be resolved with better age control), the 0.705 isopleth at this latitude is coincident with the Tally Ho shear zone. These limits define a narrow region of elevated values in the CCC which extend south from the main body of the Yukon-Tanana Terrane and was called the "southern prong" by Morrison *et al.* (1979). SIR values of granitic rocks at this latitude are variable whereas SIR values of granitic rocks farther north (63°N) are consistently greater than 0.706 (LeCouteur and Tempelman-Kluit 1976). It is suggested that elevated SIR values resulting from contamination diminish towards the south because the Nisling Terrane was not the basement in this region but was a thin, upper crustal tectonic assemblages ("flakes") at this and more southerly latitudes.

DISCUSSION

A compilation of all geochronometric data indicate that magmatism in the accreted terranes in southern Yukon Territory form four magmatic episodes with peaks at 213, 110, 80 and 56 Ma (Table 3.3). All plutonic suites, except for those of the Skukum Episode, have characteristics similar to calc-alkaline, magnetite-series, I-type granites whose genesis is subduction-related. In combination with dates from adjacent regions (Currie 1992b, Jackson 1992; Johnston 1993, Mihalynuk in press; Mihalynuk et

TABLE 3.3 Compilation of isotopic dates and strontium initial ratios (SIR) from plutonic rocks in the Whitehorse map area (105D)

Pluton	Sample	U-Pb zircon	K-Ar hornblende	K-Ar biotite	K-Ar whole rock	Rb-Sr n>1	SIR *average	
LATE TRIASSIC TO EARLY JURASSIC (KLOTASSIN) MAGMATIC EPISODE (228-175 Ma)								
Stikine Plutonic Suite (220-208 Ma)								
Laberge clast	Y88-31E	215±4					0.70416	
Tally Ho	ZR4-1,2,3	215±1	113±4				0.70345*	n=3
Friday Creek	Y88-33-4	210.4+16/-0.8					0.70385	
Laberge clast	Y88-31A	208+10/-3					0.70417	
Laberge clast	Y88-44B	210+6/-3					0.70498	
Laberge clast	Y88-44A	210±8					0.70485	
Laberge clast	WHA 11[a]		144±5				0.7048	@210 Ma
Red Ridge Plutonic Suite (200 Ma)								
Red Ridge	Y88-33-3	200.1±0.9					0.70391	
Bennett Plutonic Suite (178-175 Ma)								
Alligator Lake	Y88-10	175.3+1.9/-0.8	128±4				0.70504	
Fenwick Creek	Y88-30	176.4+1.8/-0.7	136±5			159±6	0.70466	
Bennett	ZR2-1,2,3[b]						0.70571*	@177 Ma
MID-CRETACEOUS (WHITEHORSE) MAGMATIC EPISODE (115-106 Ma)								
Whitehorse Plutonic Suite (112-108 Ma)								
Mount Anderson	ZR3-2, 3 [b,c]	111±3					0.70498*	n=2
Watson River	ZR3-1 [b,c]						0.70470	@111 Ma
Berney Creek	Y88-40	110.5+0.4/-0.7					0.70456	
Boudette Creek	Y88-8	108.0+2.8/-1.2					0.70626	
Boudette Creek	WHA 8[a]		113±4				0.7063	
Hodnett	89CH 35-7		106±4				0.70434	
Marsh Lake	89CH 75-1		104±4					
Ibex River	Y88-26	108.0+1.2/-1.4	110±4				0.70422	
Whitehorse	WHB 1[a]		116±4	109±4		116±20	0.7045	
Whitehorse	WHB 5[a]		109±4	108±4			0.7041	
Whitehorse	WHA 5[a]		105±4				0.7045	

TABLE 3.3 (cont.) Compilation of isotopic dates and strontium initial ratios (SIR) from plutonic rocks in the Whitehorse map area (105D)

Pluton	Sample	U-Pb zircon	K-Ar hornblende	K-Ar biotite	K-Ar whole rock	Rb-Sr n>1	SIR *average
Mount McIntyre Plutonic Suite (109-106 Ma)							
Mount McIntyre	Y88-18	108.6+1.2/-0.4					
Mount McIntyre	WHA 6A[a]		97.3±3.3				0.7042
Montana Mountain	Y88-21	106.5±0.5	78.3±2.7				
Carbon Hill	89CH 33-3			96±15			0.70474
Mount Granger	89CH 64-1			93.3±3.2			0.70424
Mount Ward	Y88-36	109.2±0.4					0.70450
LATE CRETACEOUS (CARMACKS) MAGMATIC EPISODE (85-68 Ma)							
Wheaton River Plutonic Suite (85-75 Ma)							
Folle Mountain	Y88-1	77.5±0.3		61.1±2.1			0.70444
Wheaton River	Y88-14	77.1±0.7					0.70475
Red Ridge dykes	Y88-33-2		80.6±2.8				0.70435
Mount Lorne	WHA 7[a]		75.3±2.8				0.7044
Carcross Plutonic Suite (72-68 Ma)							
Carcross	89CH 60-5			68.6±2.5			0.70508
Carcross	WHA 9[a]			64.3±2.2			0.7050
EARLY TERTIARY (SKUKUM) MAGMATIC EPISODE (61-54 Ma)							
Nisling Range Plutonic Suite (58-54 Ma)							
Upper Ibex	ZR1[b,c]	58.1+4/-1					
Annie Ned	Y88-32A	57.1±0.2					0.70492
Annie Ned	WHA 1[a]			51.2±2.0			
Jackson Creek	WHA 4[a]			55.0±1.9			
Mount MacAuley	Y88-7	53.7±0.3					0.70546
Skukum plugs	several[d]					53.3±1.1	0.7053
Crozier Creek	Y88-6	56.0±0.3			51.2±1.8	56.4±1.5	0.70506
Fenwick II	Y88-29A				50.3±1.8		0.70509
Pennington	89CH 52-1		54.9±1.9	41.2±2.8			0.70452
Bennett ring dyke	12017[e]				52±3		

NOTES: All data from this study except:

[a] includes data from Morrison et al. 1979; (WHA and WHB samples).

[b] ZR samples same as those from Baadsgaard in Doherty and Hart 1988.

[c] includes data from Baadsgaard in Doherty and Hart 1988 (ZR samples).

[d] includes data from Pride and Clark 1985 (Skukum plugs).

[e] includes data from Lambert 1974 (sample 12017).

al. 1992), magmatic peaks occur at *ca.* 215, 185, 110, 80 and 55, with a pronounce lull centred at 150 Ma. The time between peaks (and the lull) is in almost every case 30-40 Ma suggesting periodicity to magmatism and by extension, the subduction processes that generate magmas.

The dominant plutonic rock type in the study area is a biotite-hornblende granodiorite, but the lithological range is extreme -- from clinopyroxenite to syenite to true granites. Plutonic suites can be recognized according to field relationships and lithological character but have been confirmed and refined using geochronometry and Sr isotopic ratios. However, coeval plutons may be lithologically dissimilar since most magmatic episodes are apparently bimodal with a slightly older mafic suite cut by a more felsic and more potassic, suite. This is particularly true of the Whitehorse and Carmacks magmatic episodes.

<u>Klotassin</u>

Late Triassic and Early Jurassic plutonic rocks in the northern Cordillera are traditionally assigned to the Klotassin suite (Wheeler and McFeely 1991). As shown in this report, rocks attributed to Klotassin suite actually encompass several plutonic suites which represent a protracted and episodic magmatism from between 215-172 Ma. It would be fitting to name one of the plutonic suites after the Klotassin batholith, but that body is poorly dated, yields dominantly Cretaceous dates and is associated with nomenclature controversies (Godwin 1975; Tempelman-Kluit 1975; Tempelman-Kluit and Wanless 1980). Since the name is entrenched in the literature, it is suggested that Klotassin be kept to designate the broad Late Triassic to Early Jurassic magmatic episode and not a specific plutonic suite

The Klotassin magmatic episode is composed of the pre-accretionary (Stikine and Red Ridge), syn-accretionary (Aishihik and Long Lake) and post-accretionary (Bennett) plutonic suites. The Stikine, Red Ridge and Aishihik suites are dominated by moderately foliated hornblende granodiorite. The Stikine suite is coeval with, and likely the plutonic roots of, the Lewes River Group arc volcanics. Recognition of Stikine suite plutons in the study area extends the range of this suite as defined by Woodsworth *et al.* (1991) northward into the Yukon. The Red Ridge pluton hosts a porphyry copper occurrence and is contemporaneous with the alkalic Copper Mountain suite of British Columbia.

The lack of zircon inheritance and primitive strontium ratios in the Stikine and Red Ridge plutonic suites suggests that they, and their associated volcanic rocks intruded, were generated from and interacted with oceanic, or transitional crust. This contradicts Tempelman-Kluit (1979) who suggested that the Lewes River arc was built upon pericratonic crust represented by Nisling Terrane.

The Long Lake and Bennett suites are dominated by megacrystic K-spar, quartz monzonite plutons that intrude Nisling Terrane and Stikinia, and locally have elevated initial Sr ratios, an inherited zircon component and contain muscovite. These suites provide evidence of an Early Jurassic magmatic link between these two terranes. The felsic coarse-grained quartz monzonitic batholiths with megacrystic potassium feldspar megacrysts of the Long Lake and Bennett suites may result from melts formed during decompression associated with rapid uplift during this epoch (Johnston 1993).

Magmatic Lull

The Jura-Cretaceous magmatic lull is represented in this region by a *ca.* 50 Ma period between 175-115 Ma (Table 3.3). Any K-Ar or Rb-Sr dates in this period probably represent cooling ages associated with uplift or metamorphism. U-Pb age dating from adjacent areas places tighter regional constraints on the timing of the lull. In the Teslin River area east of Whitehorse, plutons give dates of *ca.* 120 Ma (Mortensen *et al.* 1995). In the Tagish Lake area in northern British Columbia, an unusual date of 127 Ma was reported (Currie 1992b). These dates push the lower limit of the lull to *ca.* 127 Ma.

The lull defined in the study area is includes the Cordilleran-wide lull defined by Armstrong (1988) between 135 and 125 Ma. The lull is particularly well developed in the Yukon Territory where most K-Ar and Rb-Sr dates in this range result from Jura-Cretaceous cooling of the Yukon-Tanana Terrane (Wilson 1985; Hansen *et al.* 1989; Hansen *et al.* 1991) or are partially reset by the mid-Cretaceous magmatic episode.

Whitehorse

The mid-Cretaceous Whitehorse magmatic episode is the most voluminous in the study area and throughout the entire Yukon. Mid-Cretaceous plutonic suites intruding ancestral North America (Selwyn, Tombstone and Cassiar) are slightly younger than granitic rocks emplaced in the accreted terranes (Mortensen *et al.* 1995).

Unlike K-Ar ages from the Whitehorse Plutonic Suite that are 2-4 Ma less than the U-Pb age, those from the Mount McIntyre suite are typically greater than 10 Ma less than the U-Pb age. These young K-Ar dates are likely the result of extensive low temperature hydrothermal alteration of the granites. Minerals from granites throughout the Mount McIntyre suite display shifted $\delta^{18}O$ values consistent with extensive isotopic exchange with meteoric waters (Dagenais 1984). The K-Ar dates obtained from these minerals probably reflect the timing of this large scale hydrothermal alteration.

The mid-Cretaceous magmatic episode in the Whitehorse area is not younger than 106 Ma. However, to the south and north of the study area, mid-Cretaceous U-Pb dates on granitic bodies are as young as *ca.* 102 Ma are reported (Currie 1992b; J. Mortensen pers. comm. 1993). Similarly, the maximum age of the Whitehorse magmatic episode is extended from *ca.* 116 Ma values in the Whitehorse area to *ca.* 123 Ma in the Teslin area (Gareau and Mortensen 1993; J. Mortensen pers. comm. 1993) and to an unusual age of 127 Ma in British Columbia (Currie 1992b).

The potassic Mount McIntyre plutonic suite is essentially coeval with the hornblende-rich Whitehorse plutonic suite. However, where contact relationships are exposed, the Mount McIntyre suite cuts, and is therefore younger than rocks of the Whitehorse suite. The spatial, temporal, textural and geochemical relations of these two suites suggests that the Mount McIntyre suite is a higher level, more fractionated? daughter of the parent, Whitehorse magma. Volcanic rocks of the Mount Nansen Group have close spatial and temporal relations with Mount McIntyre suite plutons and are considered to be comagmatic equivalents (Figure 3.35).

<u>Carmacks</u>

The Late Cretaceous episode is poorly constrained and represents plutons in the study area and throughout the Yukon. However, this episode has the greatest amount of volcanic rocks associated with it, which presumably obscure their plutonic roots. Dating of granitic and volcanic rocks yield a range of ages from 84 to 61 Ma (Table 3.2; Table 4.5). The bulk of these ages are *ca.* 71 Ma. This episode may represent long and protracted magmatism which lasted through to the Early Tertiary or may be skewed towards younger ages by partial resetting by younger thermal events or hydrothermal alteration. Additional U-Pb dating will alleviate this uncertainty.

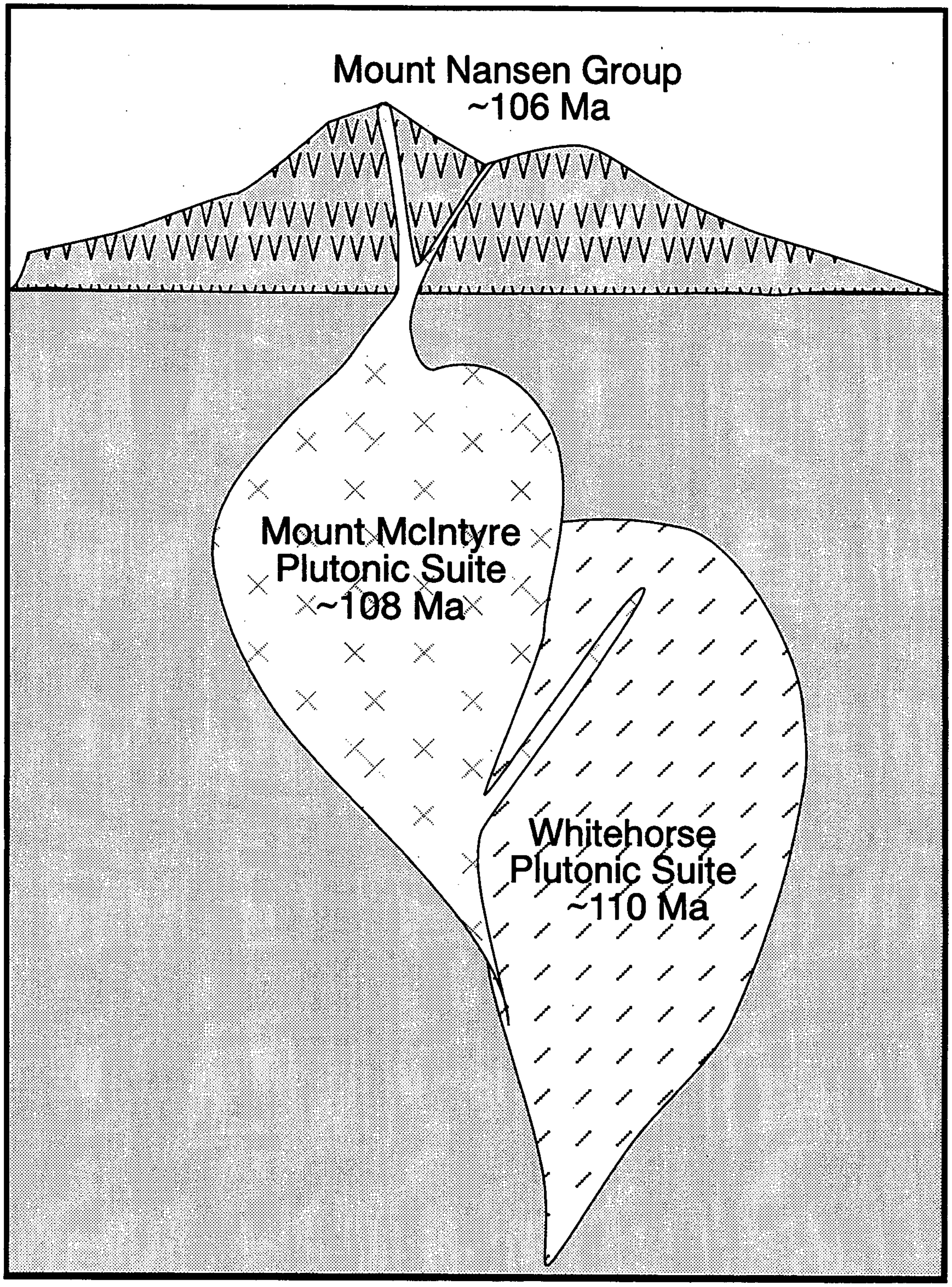


Figure 3.35 Relations and timing between the Whitehorse and Mount McIntyre plutonic suites and the Mount Nansen Group volcanics suggest that they are comagmatic. The older and more mafic Whitehorse quartz diorite is cut by slightly younger, higher level and potassic Mount McIntyre quartz monzonite which in turn is coeval with Mount Nansen Group volcanics.

Except for rocks of the Montana Mountain volcanic complex, there are few U-Pb dates on zircon between 80 and 105 Ma. Accordingly, K-Ar dates in this range should be evaluated with caution.

Skukum

The Early Tertiary (Skukum) magmatic episode was traditionally considered to be Eocene in age -- approximately 55-50 Ma (Lambert 1974; Morisson *et al.* 1979, Bultman 1979). However, U-Pb dating of zircon indicates that the event is largely Late Paleocene (60-54 Ma). The Early Tertiary Nisling Range alaskite suite was originally considered to be comagmatic with Mount Nansen Group volcanics (Tempelman-Kluit, 1976). As a result of this and previous studies, it is now clear that the Nisling Range suite is time equivalent with, and form the plutonic roots to, the Skukum (Sloko) Group volcanics. Early Tertiary plutonic (and volcanic) rocks are limited to the CCC and the westernmost margin of the Intermontane Superterrane. In Yukon, this feature marks the eastern magmatic front of this, the Early Tertiary Skukum magmatic episode.

Skukum episode plutons are fluorite-bearing, generate associated silts and waters that are anomalously high in U and F (Tempelman-Kluit and Currie 1977; GSC 1985), are high in Rb, low in Sr and have associated Mo mineralization. These characteristics indicated that the Skukum suite is highly fractionated and has characteristics of A-type granites as described by Pitcher (1982) and Anderson (1988). The extensive dyke swarms typical of this suite indicate that this episode was coincident with, and likely the result of, upper crustal extension.

CONCLUSIONS

Mapping and geochronology have identified more than 30 plutons in the Coast Crystalline Complex, Stikinia and Cache Creek Terrane in southern Yukon. The plutons are divisible into 11 plutonic suites that represent four Late Triassic to Early Tertiary magmatic episodes. Late Triassic and Early Jurassic plutonic suites define pre-, post and syn accretionary suites that together represent the Klotassin magmatic episode. Mid-Cretaceous suites represent the short-lived Whitehorse magmatic episode. The Late Cretaceous suites represent a poorly defined and protracted Carmacks magmatic episode associated with extensive volcanic rocks. The various igneous rocks of the Early Tertiary Skukum magmatic episode are essentially coeval and occupy Late Paleocene time. A pronounced magmatic lull from early Middle Jurassic to mid-Cretaceous time is defined.

Thirty-one isotopic dates from twenty-four plutonic units identified by recent mapping in the southern Yukon Territory include 17 U-Pb and 14 K-Ar dates which help define the four magmatic episodes and ten plutonic suites. U-Pb zircon geochronometry from this study, Johnston (1993), Mihalynuk (in press), Mihalynuk et al. (1992), Anderson and Bevier (1992), and Tempelman-Kluit and Wanless (1980) indicate that the Klotassin magmatic episode is episodic and spans *circa* 220-172 Ma. This magmatic episode is divisible into five plutonic suites in the northern Cordillera -- Stikine (220-208 Ma), Red Ridge (200 Ma), Aishihik (192-185 Ma), Bennett (178-175) and Fourth of July (172 Ma).

The mid-Cretaceous magmatic episode (115-106 Ma) comprises two lithologically distinct plutonic suites. The older and more mafic Whitehorse plutonic suite (112-108 Ma) is associated with numerous skarn deposits of the Whitehorse Copper Belt. The slightly younger Mount McIntyre suite (109-106 Ma) is a higher level, more fractionated and potassic suite that is coeval with mid-Cretaceous Mount Nansen Group volcanics.

None of the plutons intruding the northern Stikinia, or the Whitehorse Trough, were determined to contain anomalously elevated SIR values or an inherited zircon component. This suggests that Nisling Terrane rocks were not present beneath northern Stikine Terrane and the Whitehorse Trough. This evidence places limits on the tectonic models proposed for the assembly of accreted terranes in the northern Cordillera. In an effort to account for the presence of pericratonic material outboard of suspect and exotic terranes, some authors have proposed that the suspect terranes were thrust over and on top of pericratonic assemblages during accretion (Monger 1977; Gehrels *et al.* 1991).

The poorly defined Late Cretaceous Carmacks magmatic episode (85-68 Ma) is mainly represented by volcanic rocks and a wide range of K-Ar dates. U-Pb dates from this study and Mihalynuk *et al.* (1992) affirm magmatism during the period of 85-77 Ma which is extended to 75 Ma to include numerous K-Ar dates and thus define the duration of the Wheaton River plutonic suite. The Carcross plutonic suite (72-68 Ma) remains poorly defined but may represent plutonic equivalents to Carmacks Group volcanism (see Chapter 4).

The Early Tertiary magmatic episode (61-54 Ma) is represented by epizonal plutons of the Nisling Range plutonic suite (58-54 Ma), coeval Skukum Group volcanism and associated rhyolite plugs and dyke swarms. Magmas of the Early Tertiary episode were not emplaced as a typical continental magmatic arc, but were generated and emplaced during an extensional tectonic regime and have some A-type geochemical characteristics and locally contain a small component of radiogenic continental crust.

Chapter IV

Geology, geochronometry and geochemistry of mid- and Upper Cretaceous volcanic rocks (Mount Nansen and Carmacks groups)

INTRODUCTION

Scattered occurrences of poorly understood, locally gold-bearing, post-orogenic upper Mesozoic volcanic rocks form a 500 km long, north-northwest trending belt across the accreted terranes of southern Yukon Territory (Figure 4.1). Each volcanic succession is dominated by intermediate pyroclastic rocks, lava flows and breccias, but the characteristics of each succession varies so considerably that only rarely can convincing lithological correlations be made among the sites. This has resulted in a confusing history of nomenclature, and age assignments which have ranged from Triassic to Pliocene. Previous geochronometric studies, relying on K-Ar and Rb-Sr methods, gave a wide range of ages that dated some of the volcanic successions as mid-, Late Cretaceous or Early Tertiary (51-116 Ma; Grond *et al.* 1984 ; Lowey *et al.* 1986; Tempelman-Kluit 1984). The broad range of the dates emphasizes a complex geological history for these rocks.

The age of these volcanic rocks is critical to aiding our understanding of the post-accretionary, tectonic regime in the Northern Cordillera because few other rocks were deposited at this time. The volcanic rocks overlie an erosional surface which defines the paleo-physiography of the region. Many of the volcanic successions are moderately well layered and potentially provide useful sites to address outstanding paleomagnetic controversies regarding large-scale Cretaceous displacements of accreted crustal fragments (Beck *et al.* 1981; Marquis and Globerman 1988; Butler *et al.* 1989; Butler 1990; Marquis *et al.* 1990; Irving and Thorkelson 1990; Irving and Wynne 1991a, 1991b). To be useful in addressing the above problems, confident age assignments are required.

These volcanic rocks are also metallogenically important. Many Late Mesozoic volcanic successions in southern Yukon host apparently co-genetic gold-silver vein deposits (e.g., Montana Mountain, Mt. Nansen, Mt. Freegold) whereas their associated sub-volcanic intrusives host bulk tonnage gold-copper-molybdenum porphyry deposits (e.g., Casino). Limited geochemical studies of the volcanic rocks (Grond *et al.* 1984; McInnes *et al.* 1988) indicate that they are in part alkaline and shoshonitic, and suggest potential metallogenic links between alkaline volcanics and the mineralization. Geochronology and geochemistry of these rocks will better constrain metallogenic models and assist in exploration efforts directed towards the discovery of more of these deposit types.

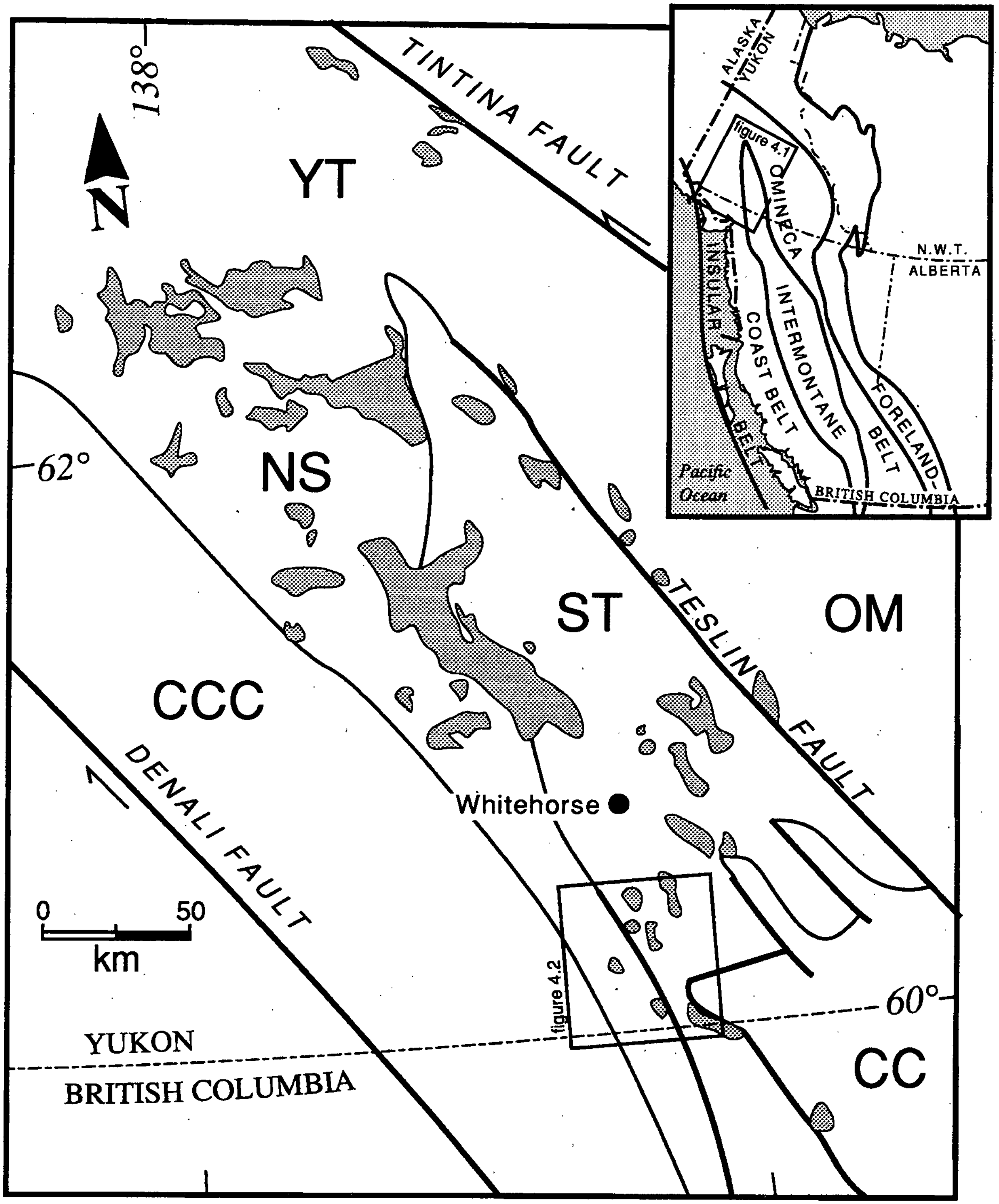


Figure 4.1. Regional tectonic setting and distribution of Upper Mesozoic volcanic rocks (shaded) in southern Yukon Territory. Includes Mount Nansen, Carmacks and Hutshi groups from Wheeler and McFeely (1991). CC=Cache Creek Terrane; NS=Nisling Terrane; CCC=Coast Plutonic Complex; ST=Stikine Terrane; YT=Yukon Tanana Terrane; OM=undifferentiated rocks of the Omineca Belt.

Three main successions of disconformable, post-accretionary volcanic rocks (previously mapped as Hutshi Group by Wheeler 1961) were identified during recent 1:50 000 geological mapping in the southern Yukon Territory (Doherty and Hart 1988; Hart and Pelletier 1989a, 1989b; Hart and Radloff 1990). This paper reports on the geology and geochemistry of the Carbon Hill, Montana Mountain and Wheaton River volcanic suites, and presents 10 K-Ar dates and two U-Pb zircon dates to constrain the timing of volcanism. The zircon dates are the first obtained from these rocks in the Yukon Territory.

Nomenclature

Confusing nomenclature and age assignments have plagued studies of Upper Mesozoic volcanic rocks in the northern Canadian Cordillera for over half a century (see discussions in Grond *et al.* 1984; Marquis and Globerman 1988). Carmacks (Cairnes 1910), Mount Nansen (Bostock 1936) and Hutshi groups (Cairnes 1910) were among the names given to post-orogenic volcanic rocks throughout the Yukon Territory that are still in current use (see Wheeler and McFeely 1991). Age assignments for these volcanic rocks ranged from Triassic to as young as Pliocene (Bostock 1936; Bostock and Lees 1938; Tempelman-Kluit 1976, 1978, 1980a) since they lacked paleontologic or isotopic age control.

Traditionally, the term "Carmacks Group" was assigned to volcanic successions containing basalt flows in the upper part of their section (Cairnes 1910; Bostock 1936; Tempelman-Kluit 1975; Churchill 1980). Mount Nansen Group was typically differentiated from Carmacks Group by its higher proportion of felsic pyroclastic material and characteristic heterolithic breccias (Tempelman-Kluit 1974; Roots 1981). Hutshi Group included volcanic rocks now recognized as variably belonging to the Late Triassic Lewes River, Early Jurassic Laberge and Early Tertiary Skukum Groups (Cockfield and Bell 1926; Bostock and Lees 1938; Wheeler 1961), as well as the Cretaceous Carmacks and Mount Nansen Groups.

Mount Nansen Group was considered by Tempelman-Kluit (1974, 1976, 1980a) to be cogenetic with alaskite plutons dated as Late Cretaceous to Eocene (67-52 Ma) by K-Ar and Rb-Sr methods (Tempelman-Kluit and Wanless 1975; Le Couteur and Tempelman-Kluit 1976). Tempelman-Kluit (1980a) recognized that the Mt. Nansen Group was stratigraphically lower than Carmacks Group. Five K-Ar dates and one Rb-Sr date for Mount Nansen and Carmacks Group rocks indicated that both groups were essentially contemporaneous at 73 to 68 Ma (Grond *et al.* 1984). Other rocks mapped as Carmacks Group however, yielded a mid-Cretaceous K-Ar date (Stevens *et al.* 1982, p. 20). Additional whole rock K-Ar dates from west-central Yukon yielded Late Cretaceous ages of 69-65 Ma for rocks correlated with the Carmacks Group (Lowey *et al.* 1986). Hutshi Group rocks in the Whitehorse area were assumed by Wheeler (1961) to be broadly mid-Cretaceous in age. Skukum Group refers to caldera-forming volcanic centres which are Early Tertiary in age and limited to the eastern parts of the Coast Crystalline Complex.

Current convention (Wheeler and McFeely 1991; following Tempelman-Kluit in Stevens *et al.* 1982, p.20-21 and Tempelman-Kluit 1984) assigns various volcanic rocks with mid-Cretaceous dates to the Mt. Nansen Group. Those rocks with Late Cretaceous ages are assigned to the Carmacks Group. Hutshi Group rocks are considered broadly equivalent to the Carmacks Group (Wheeler and McFeely 1992), however the term is redundant and should be abandoned.

LOCAL GEOLOGY

Mid- and Late Cretaceous volcanic rocks in the southern Yukon Territory were deposited as part of a post-accretionary continental margin arc across Stikinia, Yukon-Tanana and Cache Creek terranes. The volcanic rocks are dominated by subaerial basaltic andesite to dacitic lava flows, breccias and pyroclastic material. Rhyolite typically occurs as stratigraphically younger flows or crosscutting dykes and plugs. Basalt is not uncommon, but is volumetrically less significant. The volcanic rocks were deposited as large strato-volcanoes unconformably upon an uplifted and locally dissected plateau.. Block faulting led to the preservation of the volcanics as tilted sections with local angular unconformities, in grabens or half-grabens. Although generally fresh, the volcanic rocks are locally metamorphosed to lower greenschist facies and affected by low temperature hydrothermal alteration. Both types of alteration are related to contact zones adjacent to probable comagmatic, hypabyssal and epizonal intrusive complexes.

Three volcanic successions previously mapped as Hutshi Group by Wheeler (1961) were studied -- Carbon Hill, Montana Mountain and Wheaton River successions (Figure 4.2).

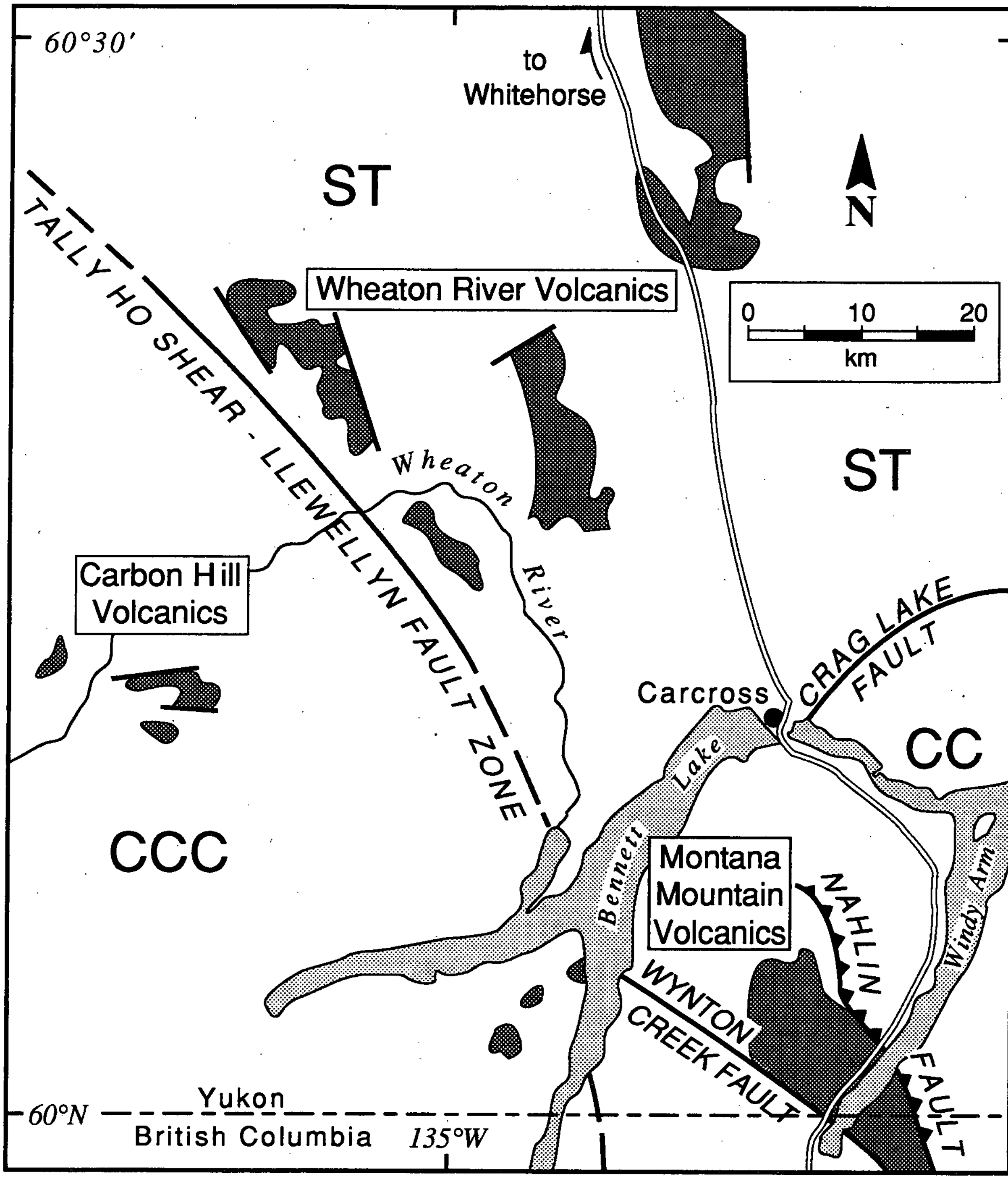


Figure 4.2. Distribution of the Carbon Hill volcanics, Montana Mountain volcanic complex and Wheaton River volcanics. THS-LFZ=Tally Ho Shear-Llewellyn Fault Zone; WCF=Wynton Creek Fault; NF=Nahlin Fault; CLF=Crag Lake Fault. Other symbols are in caption of Figure 4.1.

Carbon Hill volcanics occur as several small, nearly flat-lying erosional remnants in the Carbon Hill area. They encompass approximately five square kilometres, have a minimum estimated thickness of 300 m and were deposited on an erosional surface presently between 1350 and 1500 metres above sea level. They consist of drab to orange-brown weathering, vitreous blue-grey lithic tuff, welded tuff and brecciated, feldspar-phyric sub-aerial andesite to dacite lava and pyroclastic flow rocks. Pillowed basalt in the lowest part of the succession appears conformable with the underlying Tantalus Formation clastic strata (Figure 4.3). This basal volcanic and sedimentary package unconformably overlies Nisling Terrane metasedimentary rocks and an Early Jurassic batholith. The Carbon Hill pluton intrudes the Carbon Hill volcanics but is cut by volcanic dykes. These conflicting relations suggest a probable co-genetic relationship.

Numerous gold and silver-bearing antimony-quartz veins are hosted by the Carbon Hill volcanics in east-trending brittle shear zones (Hart 1992a). In addition, intense porphyry-style phyllic alteration, which weathers to form vivid orange and yellow jarositic gossans underlie several square kilometres of the volcanic rocks and the comagmatic pluton. Locally these altered rocks contain high gold grades (Hart 1992a).

Montana Mountain volcanic complex (MMVC) forms an isolated, mostly fault-bounded elongate graben near the Yukon Territory - British Columbia border (Figure 4.2). It covers approximately 45 square kilometres and unlike the Carbon Hill or Wheaton River volcanics, forms a single contiguous occurrence. Total stratigraphic thickness of the complex is greater than 1200 metres (Roots 1982). The volcanic complex has been studied in detail by Roots (1981, 1982) and more recently by Hart and Pelletier (1989a), and Hart and Radloff (1990).

Three units make up the complex. From oldest to youngest they are: 1) massive to poorly layered, dark green and maroon, autobrecciated andesitic lava flows, heterolithic breccia and pyroclastic rocks (Figure 4.4); 2) rusty weathering, yellow and orange, flow-banded rhyolite, rhyolite tuff and breccia (Figure 4.5); and 3) subordinate occurrences of dark, massive, resistant, hornblende-phyric basaltic andesite plugs and dykes. Rusty weathering, light coloured rhyolite flows dominate the western and southern portion of the complex adjacent to Windy Arm of Tagish Lake and are the stratigraphically youngest rocks.

Figure 4.3. Basaltic andesite pillows such as these are typical in the basal portion of the Carbon Hill volcanics and conformably overlie Tantalus Formation siliciclastic rocks. Note hammer for scale.

Figure 4.4. Angular heterolithic breccia in an andesitic matrix that characterize much of the Montana Mountain volcanic complex. Coin is approximately 2 centimetres across.

Figure 4.5. View towards the southwest of a ridge of felsic tuffs of the Montana Mountain volcanic complex, with Cache Creek Terrane rocks in background. Sample Y88-5 was obtained from the bench marked with the star. (Photo courtesy of Charlie Roots.)

The volcanic rocks rest unconformable upon folded Whitehorse Trough clastic strata of the Lewes River and Laberge Groups and abut Cache Creek Terrane rocks. The eastern margin of the volcanic complex is juxtaposed with Cache Creek Terrane along the Nahlin Fault. The western limit of the complex is defined by the Wynton Creek Fault. Both faults have been reactivated by younger strike-slip motion that has imparted a fracture cleavage in the brittle Montana Mountain volcanic complex rocks. The northeastern, and topographically lower portions of the complex are intruded by granitic plutons. Hydrothermal alteration associated with the plutons, has propylitically altered much of the complex.

More than 20 polymetallic mesothermal gold veins are hosted by intermediate to felsic flows and tuff, and the pluton at Montana Mountain. The largest of these vein deposits, the Venus (Walton 1987), has been mined several times throughout this century. More than 1.2 million grams of gold and 39 million grams of silver have been recovered from the Montana Mountain deposits (Hart and Radloff 1990).

Wheaton River volcanics are exposed in several large successions, that are dissected and separated by the Wheaton and Watson River valleys (Figure 4.2). The exposures exceed 100 square kilometres in area. These rocks consist of at least 600 m of resistant, blue-grey, green to black, thickly bedded to massive, porphyritic to aphanitic, vitreous andesite and dacite flows, tuff and lesser epiclastic sediments (Figure 4.6). Outcrops east of the Wheaton River are dominated by purple and green volcaniclastic agglomerate, laharic breccia and tuff. The succession here is cut by numerous rhyolite dykes, the Late Cretaceous Carcross pluton and several east-trending normal faults. As with the rocks of the Montana Mountain volcanic complex, the Wheaton River volcanics were deposited on folded strata of the Lewes River and Laberge groups (Figure 4.7). Locally, basal epiclastic rocks grade down into siliciclastic strata of the underlying Tantalus Formation. The base of the volcanic successions are presently at approximately 1775 metres above sea level.

Numerous polymetallic silver-rich veins are hosted in hypabyssal andesite plugs and late rhyolite dykes of the Wheaton River volcanics and adjacent Jurassic sedimentary rocks (Idaho Hill, Yukon Minfile 1992). Gold-rich zones of quartz-chalcopyrite-galena occur in silicified feldspar-phyric flows at their contact with their comagmatic(?) pluton (Mt. Wheaton, Yukon Minfile 1992).

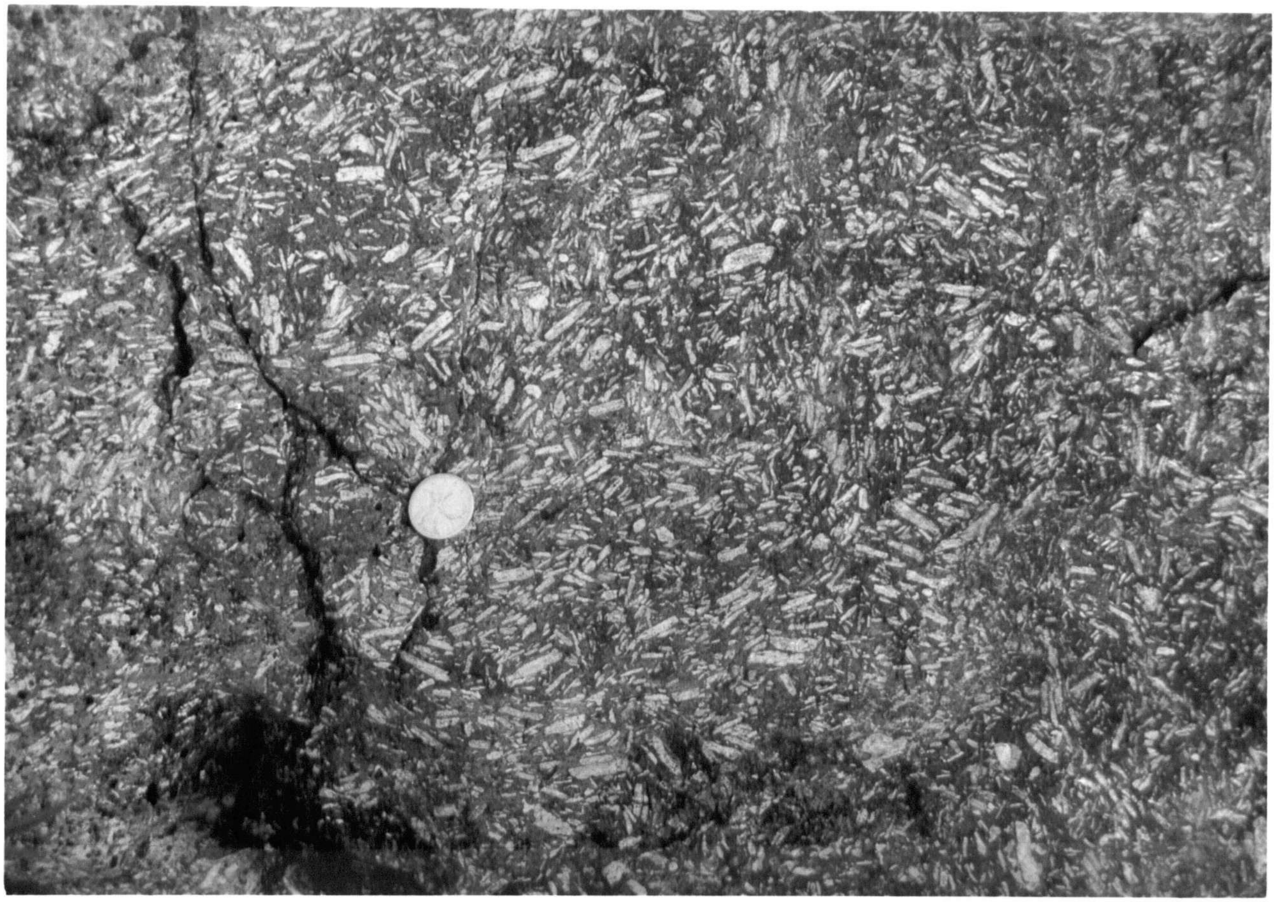
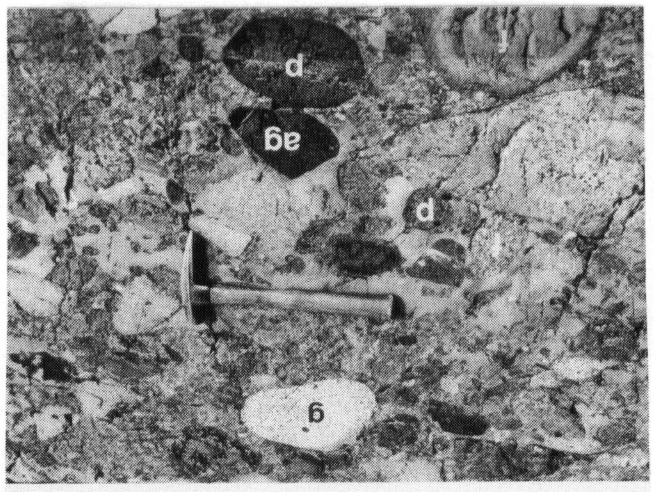


Figure 4.6. Trachytic, large bladed feldspar andesite porphyry such as this is characteristic of the Wheaton River volcanics. Coin is approximately 2.5 centimetres in diameter.



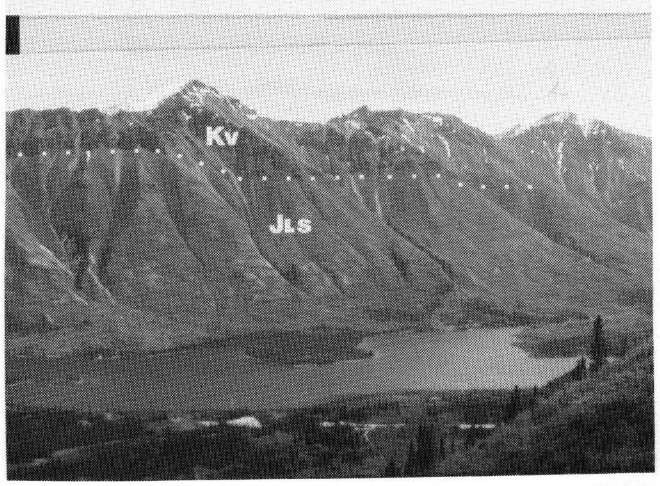


Figure 4.7. View towards the southwest of Grey Ridge, where sub-horizontal Upper Cretaceous Wheaton River volcanic rocks unconformably overlie folded Lower Jurassic Laberge Group clastic strata of the Whitehorse Trough. The unconformity is at 1775 metres above sea level. The field of view is about 8 kilometres. Relief between Annie Lake and large peak on top of Grey Ridge is approximately 1.4 kilometres.

Several small hypabyssal, feldspar porphyry andesite plugs, and andesite flows and tuff which overlie Tantalus Formation clastic rocks near Bennett Lake were originally considered equivalent to the proximal Montana Mountain volcanic complex (Hart and Radloff 1990). However, the Bennett Lake exposures are lithologically similar to the Wheaton River volcanics and are here correlated with them. Wheaton River volcanics are lithologically similar to Carmacks Group volcanics in the Miners Range (Churchill 1980; Hart and Brent 1993).

LITHOGEOCHEMISTRY

New major element oxide analyses for 30 whole rocks from all three volcanic suites in the study area are presented in Table 4.1. Fresh, unaltered samples were used in all cases except for the Montana Mountain volcanic complex which is locally overprinted by phyllic alteration. Approximately half of the samples from Montana Mountain complex have greater than 3% LOI (loss on ignition). However, rocks with high LOI, from all localities, do not show any obvious depletion or enrichment of high-field strength elements such as K, Rb or Sr which are particularly mobile during hydrothermal alteration. Furthermore, there is no obvious depletion in Na which typically accompanies phyllic alteration. This suggests that high LOI samples have likely retained much of their primary geochemical signature.

Rocks of all three suites follow a dominantly calc-alkalic trend (Figure 4.8a). Lithogeochemical classification indicates that all three suites are sub-alkalic in nature (Figure 4.8b). Wheaton River volcanics are dominated by slightly silica oversaturated basaltic andesite and andesite with some slightly alkalic basaltic trachyandesite. The MMVC is dominantly dacitic and rhyolitic compositions. The few Carbon Hill samples indicate intermediate compositions.

All three complexes are dominantly medium to high-K series volcanics with a few sample in or near the shoshonitic field (Figure 4.9). Despite the apparent wide spread in the data, which could suggest chemical mobility due to alteration, the K20-SiO2 plot shows some obvious trends. Montana Mountain (*s.l.*) samples are divisible into steep clusters of intermediate, medium-K volcanics and felsic, high-K volcanics which correspond to rocks of the Montana Mountain (*s.s.*) and Windy Arm/Dail Peak areas respectively. Wheaton River volcanics show two flat trends of intermediate medium-K and high-K volcanics that correspond to rocks from the Follé Mountain and Grey Ridge areas.

TABLE 4.1 Whole rock and trace element determinations for Cretaceous volcanic rocks described in this report

Sample	Y88-37A	Y88-38	91CH Kva	P88-19	P88-75	Y88-4	Y88-5B	P88-18	P88-57	P88-59
	CH	CH	CH	MM	MM	MM	MM	MM	MM	MM
Locality	Carbon Hill	Carbon Hill	Carbon Hill	Dail Peak	Ramshorn Creek	Windy Arm	Montana Mountain	Dail Peak	Dail Peak	Dail Peak
Rock Type	andesite flow	rhyolite dyke	andesite flow	dacite flow	rhyolite dyke	rhyolite flow	dacite tuff	dacite flow	andesite plug	andesite flow
SiO2	61.09	69.17	60.73	66.79	73.03	67.38	61.31	67.42	65.24	62.78
TiO2	0.92	0.35	0.71	0.80	0.34	0.51	1.02	0.78	0.74	0.88
Al2O3	16.53	14.92	17.54	15.97	15.36	15.51	15.56	15.35	15.12	15.78
Fe2O3	8.37	4.96	5.53	4.65	2.08	5.51	8.99	5.13	5.10	5.63
MnO	0.13	0.07	0.12	0.07	0.03	0.10	0.12	0.07	0.08	0.08
MgO	1.64	1.02	3.19	1.18	0.92	0.60	1.54	1.52	2.90	2.98
CaO	3.18	2.53	4.92	2.76	1.93	2.04	3.19	3.66	2.76	5.74
Na2O	3.97	3.41	3.66	4.27	4.02	4.39	3.60	2.63	4.68	3.78
K2O	3.91	3.46	3.39	3.25	2.18	3.84	4.33	3.15	3.09	2.03
P2O5	0.25	0.11	0.20	0.26	0.11	0.13	0.33	0.28	0.28	0.31
LOI	0.10	0.84	2.56	2.90	2.70	3.96	1.75	4.90	2.40	5.30
SUM	99.59	99.50	99.77	99.87	99.98	99.65	99.60	99.72	99.68	99.73
Mg #	27.93	29.03	53.30	33.41	46.60	17.64	25.36	37.03	52.97	51.22
Cr	nd	nd	nd	0.01	0.01	nd	nd	0.01	0.01	0.01
Rb	96.8	128	95.2	nd	nd	113	104	nd	nd	nd
Sr	647	365	550	nd	nd	286	404	nd	nd	nd
Ba	nd	nd	nd	1529	1626	nd	nd	1622	1829	1567
Zr	nd	nd	nd	191	138	nd	nd	179	166	159
Lab	C	C	C	A	A	C	C	A	A	A

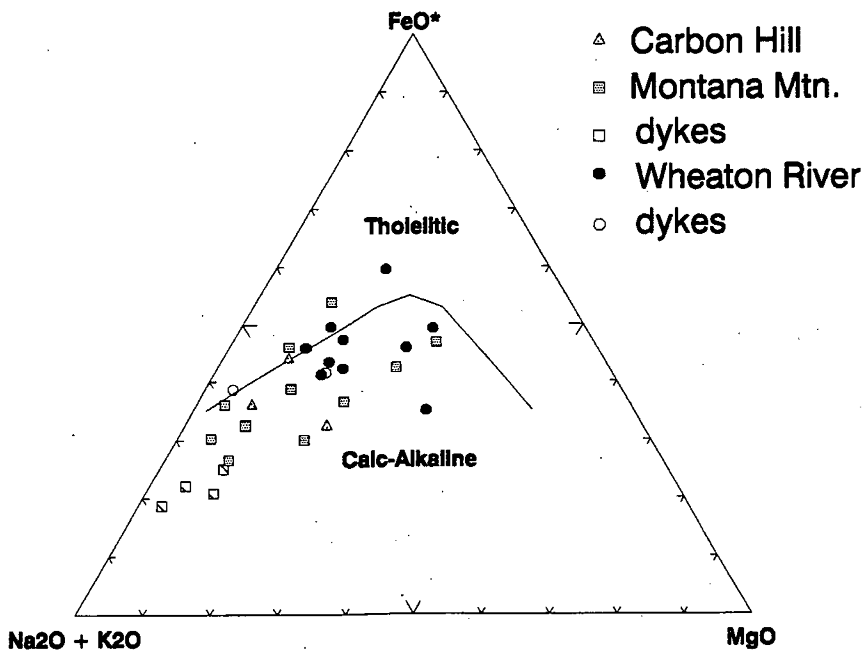
Sample	88CH 4-9	88CH 5-5	P88-50	P88-51	MM 33-2	CH 56-3	P88-49	CH 57-1	88 GR1	P88-46
	MM	MM	MM	MM	MM	MM	MM	MM	WR	WR
Locality	Ramshorn Creek	Escarpment Mountain	Montana Mountain	Montana Mountain	Mount Conrad	Uranus	Montana Mountain	Montana Mountain	Grey Ridge	Grey Ridge
Rock Type	rhyolite dyke	rhyolite dyke	andesite tuff	andesite flow	rhyolite dyke	dacite flow	rhyolite flow	andesite plug	andesite flow	andesite flow
SiO2	75.26	71.83	62.83	59.48	74.12	70.03	73.56	62.26	64.68	62.61
TiO2	0.22	0.25	0.65	0.85	0.28	0.45	0.57	0.91	1.19	0.75
Al2O3	14.26	15.34	16.73	15.68	13.61	14.50	13.62	15.25	9.08	16.55
Fe2O3	2.20	2.01	8.25	8.00	2.53	3.51	3.18	6.66	8.92	6.49
MnO	0.02	0.02	0.13	0.15	0.05	0.07	0.06	0.11	0.08	0.14
MgO	0.76	0.34	1.52	4.63	0.55	1.15	0.49	3.73	4.56	2.56
CaO	2.08	2.61	4.83	7.37	1.34	2.55	2.25	6.32	6.20	5.25
Na2O	4.08	5.23	3.57	2.70	3.50	3.66	4.52	2.98	3.89	4.30
K2O	1.08	2.25	1.24	0.86	3.94	3.93	1.58	1.44	1.02	1.12
P2O5	0.05	0.11	0.25	0.28	0.09	0.16	0.18	0.33	0.37	0.24
LOI	3.20	3.50	1.70	1.80	1.80	5.20	3.20	2.10	4.20	2.60
SUM	99.79	99.55	99.84	99.83	99.78	99.69	99.94	99.93	99.84	99.83
Mg #	40.54	25.39	26.75	53.40	30.21	39.25	23.27	52.58	50.30	43.80
Cr	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.02	0.01	0.01
Rb	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sr	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Ba	336	1858	1191	845	1008	1337	466	1241	743	1527
Zr	nd	nd0	109	103	159	159	205	167	184	109
Lab	A	A	A	A	A	A	A	A	A	A

Sample	Y88-27A WR	Y88-23 WR	Y88-15 WR	Y88-13 WR	A9-2 WR	CH 33-6 WR	CH 5-12 WR	CH 5-10 WR	CH 6-8 WR	P88-27 WR
Locality	Idaho Hill	Carcross Road	Folle Mountain	Wheaton Mountain	Perkins Peak	Bush Mountain	Wheaton Mountain	Wheaton Mountain	Folle Mountain	Grey Ridge
Rock Type	rhyolite dyke	basalt flow	basalt flow	dacite dyke	andesite flow	andesite flow	andesite flow	andesite flow	andesite flow	andesite flow
SiO2	61.91	54.91	52.37	66.18	55.42	60.27	52.96	63.45	54.73	57.91
TiO2	0.51	1.22	1.58	0.26	1.69	1.43	1.52	0.77	1.53	1.06
Al2O3	17.53	18.47	18.97	16.98	17.99	17.35	19.71	18.04	20.98	15.51
Fe2O3	6.95	10.47	12.01	5.61	8.76	7.15	9.89	5.85	9.78	7.01
MnO	0.10	0.18	0.13	0.10	0.16	0.09	0.19	0.11	0.20	0.11
MgO	2.46	3.18	2.95	0.54	1.93	2.35	2.33	2.03	5.04	6.21
CaO	4.03	4.03	7.14	2.77	5.78	4.77	6.20	4.21	3.03	6.24
Na2O	4.38	5.99	3.07	4.84	4.51	3.66	4.37	3.00	1.44	4.30
K2O	1.96	1.29	1.33	2.62	2.83	2.36	2.30	2.49	2.55	1.22
P2O5	0.17	0.26	0.44	0.09	0.93	0.56	0.52	0.03	0.72	0.41
LOI	3.22	5.16	2.28	0.34	0.70	2.90	0.70	0.90	3.70	3.90
SUM	99.28	99.77	99.68	99.67	99.61	99.37	100.08	98.42	99.08	99.87
Mg #	41.16	37.56	32.70	16.11	30.40	39.45	31.85	40.71	50.52	63.72
Cr	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.04
Rb	80.4	32.3	37.5	72.6	nd	nd	nd	nd	nd	nd
Sr	1450	806	598	481	nd	nd	nd	nd	nd	nd
Ba	nd	nd	nd	nd	nd	nd	nd	nd	nd	795
Zr	nd	nd	nd	nd	nd	nd	nd	nd	nd	146
Lab	C	C	C	C	B	B	B	B	B	A

NOTES. All sample numbers are followed by a two letter abbreviation indicating their rock suite: CH=Carbon Hill; MM=Montana Mountain; WR=Wheaton River. Samples were collected by C.J.R. Hart, R.L. Armstrong, D.K. Ghosh, K.S. Pelletier and R.A. Doherty. Rock type was assigned by the collector in the field. Concentrations of major elements are given in weight percent, and have been recalculated from the analytical values to 100% on a volatile-free basis (i.e. anhydrous). Total iron reported as Fe2O3. LOI (Loss on Ignition) refers to the total volatile component in weight percent as reported in the original analyses. SUM is the total of the major oxides plus LOI as determined in the original analyses. Mg# is the magnesium number, calculated as:

$$Mg\# = 100*(MgO/MgOMW)/((FeO^*/FeO^*MW)+(MgO/MgOMW))$$

using NewPet (1993). Analyses were performed at: (A) Acme Analytical Labs (Vancouver, B.C.) - major oxides by ICP. Duplicate analyses showed less than 10% within-run sample deviation; (B) Bondar-Clegg Co. Ltd., (Vancouver, B.C.) - total digestion/DCP, fusion/ICP and specific techniques; (C) British Columbia Geological Survey Branch (Victoria, B.C.) - XRF on fused discs. Analyses of standards showed less than 10% deviation from standard values. Trace elements are given in ppm. Ba and Zr by ICP at Acme Analytical, Rb and Sr by XRF on pressed pellets at UBC and are the same values reported in Table 4.4. nd= not determined.



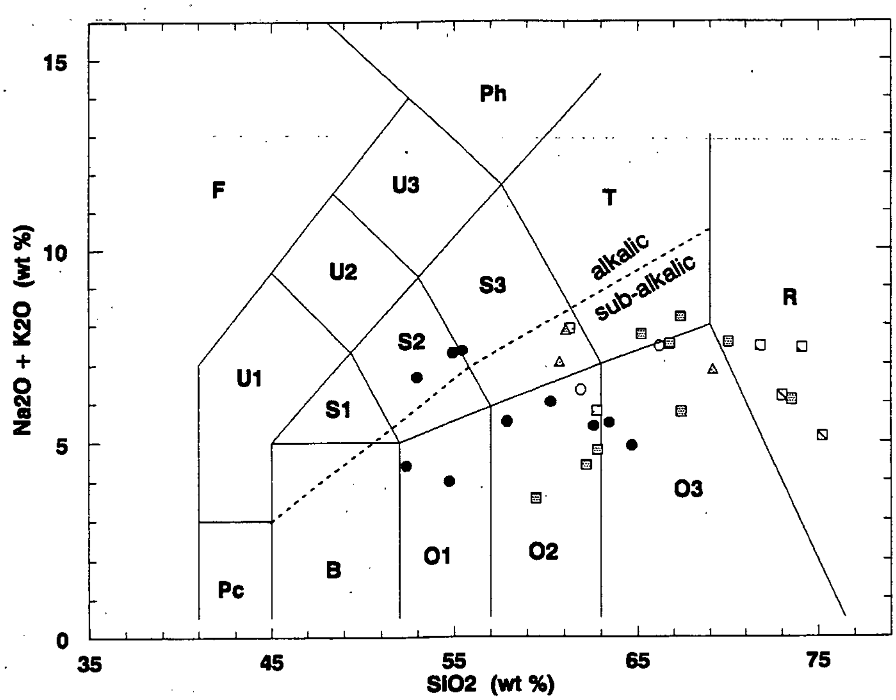


Figure 4.8a. AFM plot of Carbon Hill, Montana Mountain and Wheaton River volcanics. Plot is after Irving and Baragar (1971).

Figure 4.8b. Akalis-SiO_2 plot of Carbon Hill, Montana Mountain and Wheaton River volcanics. Plot is after LeMaitre (1989). Abbreviations: F=foidite, Pc=picrobasalt, B=basalt, O1=basaltic andesite, O2=andesite, O3=dacite, S1=trachybasalt, S2=basaltic trachyandesite, S3=trachydacite, T=trachyte, R=rhyolite, U1=tephrite, U2=phonotephrite, U3=tephriphonolite, Ph=phonolite.

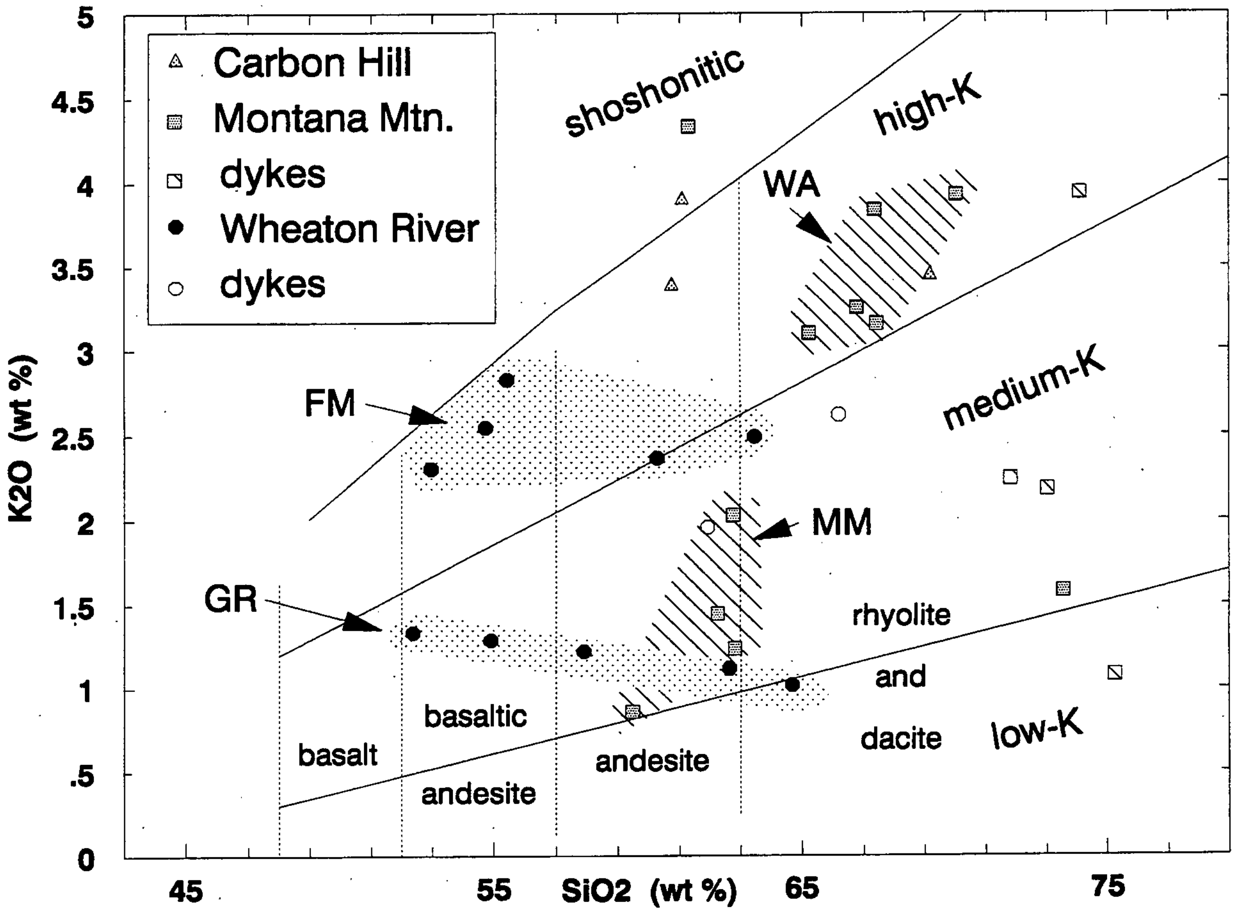


Figure 4.9. K_2O-SiO_2 plot of Carbon Hill, Montana Mountain and Wheaton River volcanics using fields from Le Maitre (1989).

The Montana Mountain (*s.l.*) data are indicative to two geochemically distinct magmas since the felsic Windy Arm rocks could not be generated by simple fractionation from the intermediate Montana Mountain (*s.s.*) magma. The Windy Arm lavas are stratigraphically high in the section and are likely the youngest rocks in the complex. Similarly, but for different reasons, the Wheaton River data are also indicative of two different magma sources. In this case, the Follé Mountain magmas have more than twice the potassium of the Grey Ridge lavas, but, aside from minor lithological differences, no geological evidence is available to suggest the relative ages of the two lava batches. Carbon Hill volcanics are all high-K but the limited number of samples precludes any further interpretation.

The classification of the all three volcanic complexes as medium to high-K volcanics is similar to limited geochemical analyses of Late Cretaceous volcanic rocks in southern Yukon Territory by Grond *et al.* (1984, interpreted by de Rosen-Spense and Sinclair 1987), Payne *et al.* (1987); and Carlson (1987). They suggested that volcanic rocks, then considered part of the Mount Nansen Group, were calc-alkaline and high in potassium. Coeval Carmacks Group rocks were deemed to be alkalic, high potassium shoshonites. Geochemical analyses of *ca.* 78 Ma volcanic rocks at Freegold Mountain (McInnes *et al.* 1988), indicated that the least altered rhyolites there, were of the high-K series.

GEOCHRONOLOGY

Two U-Pb zircon (Table 4.2) and ten K-Ar dates (Table 4.3) define four distinct volcanic episodes within the three volcanic suites. The isotopic dates range from mid- to Late Cretaceous, 106 to 65 Ma. Sample locations are shown in Figure 4.10. Errors are all reported at two sigma.

<u>Carbon Hill volcanics</u> yielded two mid-Cretaceous K-Ar dates. Biotite from an east-trending dacite dyke intruding the Carbon Hill pluton gave a date of 106±4 Ma. A whole rock date from an andesite flow returned a similar age of 105±4 Ma. The ages suggest that Carbon Hill volcanic rocks are among the oldest reported for Cretaceous volcanic rocks in southern Yukon Territory and constrain the age of underlying Tantalus Formation clastic rocks to mid-Albian and older (using timescale of Harland *et al.* 1990). Cross-cutting epigenetic quartz-sulphide veins and porphyry style mineralization at Carbon Hill must be younger than 105 Ma.

TABLE 4.2 U-Pb zircon geochronometric data for Montana Mountain volcanic rock samples[a]

Fraction[b]	Wt. (mg)	U (ppm)	Radiogenic Pb (ppm)	$^{206}Pb/^{204}Pb^c$ Measured	Common Pb^c (pg)	$\%^{208}Pb^d$	Isotopic Ratios ± $2\sigma^d$ (Dates in Ma ± 2σ) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
	Y88-4		Windy Arm rhyolite flow (60°00.0'N, 135°35.8'W)						
a NM2.0A/1° +74μ	1.1	498	6.51	289	158	11.3	0.01284±0.29 (82.3±0.5)	0.08713±0.67 (84.8±1.1)	0.04920±0.51 (157.4±24)
b NM1.5A/3° M2.0A/1° All sizes	0.2	461	5.96	486	150	12.1	0.01260±0.36 (80.7±0.6)	0.08278±2.44 (80.8±3.8)	0.04765±2.22 (81.7±109)
c M1.0A/5° All sizes	0.2	550	7.28	339	275	10.2	0.01318±0.27 (84.4±0.5)	0.08670±0.88 (84.4±1.4)	0.047713±0.71 (85.0±34)
	Y88-5A		Montana Mountain dacite tuff (60°01.8'N, 134°41.5'W)						
a NM2.0A/1° -74μ+44μ	0.9	1027	15.2	1408	592	10.9	0.01465±0.31 (93.8±0.6)	0.09693±0.38 (93.9±0.7)	0.047987±0.13 (98.6±6.2)
b NM2.0A/1° -44μ	0.5	1415	21.7	1782	364	12.3	0.01492±0.38 (95.4±0.7)	0.09861±0.40 (95.5±0.7)	0.04795±0.10 (96.7±4.9)

[a] Analyses by D.K. Ghosh at The University of British Columbia. Sample preparation and analytical procedures are as outlined in Armstrong et al. (1991). U and Pb concentrations and isotopic ratios are corrected for fractionation, spike and blank Pb. Isotopic composition of UBC blank is 206:207:208:204 = 17.0±5.0%:15.0±3.0%:37.3±3.0%. Total procedural blanks contain approximately 0.03 nanograms of both U and Pb.

[b] Split abbreviations: μ-microns, M-magnetic, NM-non-magnetic. The magnet current (Amperes) and backward tilt of the magnetic separator (in degrees) are given. All splits are hand-picked.

[c] Corrected for spike and Pb fractionation of 0.46%±0.21% amu^{-1} for Daly, and of 0.12%±0.25% amu^{-1} for Faraday collectors.

[d] Common Pb isotopic compositions are corrected using Stacy and Kramers (1975) model Pb composition at 200 Ma. Errors are 1σ standard errors of the mean in percent for ratios and 2σ standard errors of the mean for ages. Estimation of errors follows numerical error propagation method of Roddick (1987). IUGS conventional decay constants are used in age calculations: $\lambda^{238}U = 1.55125 \times 10^{-10} a^{-1}$, $\lambda^{235}U = 9.8485 \times 10^{-10} a^{-1}$ (Steiger and Jäger 1977)

TABLE 4.3 New K-Ar data and dates for Cretaceous volcanic rocks described in this report

Sample	Rock Type	Latitude °N	Longitude °W	Material Analysed	[a]K (%)	[b]^{40}Ar cc/gm	^{40}Ar (%)	[c]Date $\pm 2\sigma$	Interpretation
CARBON HILL VOLCANIC SUITE									
Y88-38	dacite dyke	60°11.5'	135°16.3'	biotite	4.55	19.383	95.7	106±4	
Y88-37A	andesite porphyry flow	60°11.0'	135°16.6'	whole rock	3.01	12.590	80.5	105±4	
MONTANA MOUNTAIN VOLCANIC SUITE									
Y88-5A	dacite tuff	60°01.8'	134°41.5'	whole rock	3.49	8.907	85.1	64.5±1.8	reset from 96 Ma
Y88-5B	dacite tuff	60°01.8'	134°41.4'	whole rock	3.48	8.959	94.1	65.1±2.3	reset from 96 Ma
WHEATON RIVER VOLCANIC SUITE									
Y88-23	andesite flow	60°23.7'	135°48.9'	whole rock	1.07	3.436	92.3	80.8±2.8	
Y88-15	andesite porphyry flow	60°17.8'	135°04.1'	feldspar	0.57	1.761	87.3	78.3±3.6	
CH88 75-2	andesite porphry plug	60°03.4'	134°52.8'	whole rock	2.38	6.691	87.0	70.9±2.5	
Y88-27A	rhyolite dyke	60°18.9'	135°01.7'	feldspar	1.48	4.108	91.6	70.1±3.3	minimum
89CH 34-1	andesite dyke	60°19.0'	135°11.5'	whole rock	1.80	4.651	84.5	65.3±2.3	minimum
89CH 49-6	rhyolite dyke	60°18.5'	134°54.5'	whole rock	3.27	8.222	76.6	63.6±2.2	minimum
Y88-13	dacite dyke	60°15.9'	135°01.1'	feldspar	2.31	5.634	87.3	61.7±2.2	minimum

NOTES: K analyses are by D. Ghosh and D. Runkle, and Ar analyses are by J. Harakal, Geochronometry Laboratory, The University of British Columbia.

[a] Potassium was determined in duplicate by atomic absorption using a Techtron AA4 spectrophotometer on dilute sulphate solutions buffered by Na and Li nitrates. K (%) is average of at least two determinations.

[b] Argon was determined by isotope dilution using an AEI MS-10 mass spectrometer with Carey Model 10 vibrating reed electrometer, high purity ^{38}Ar spike, and conventional gas extraction and purification procedures as described by White et al. (1967).

[c] The errors reported, based on multiple analyses for K, are estimated two standard deviations as related to the calculated date. IUGS conventional decay constants (Steiger and Jäger, 1977) are $^{40}K/b = 4.962 \times 10^{-10} a^{-1}$, $^{40}K/e = 0.581 \times 10^{-10} a^{-1}$, and $^{40}K/K = 0.0001167$ atom ratio.

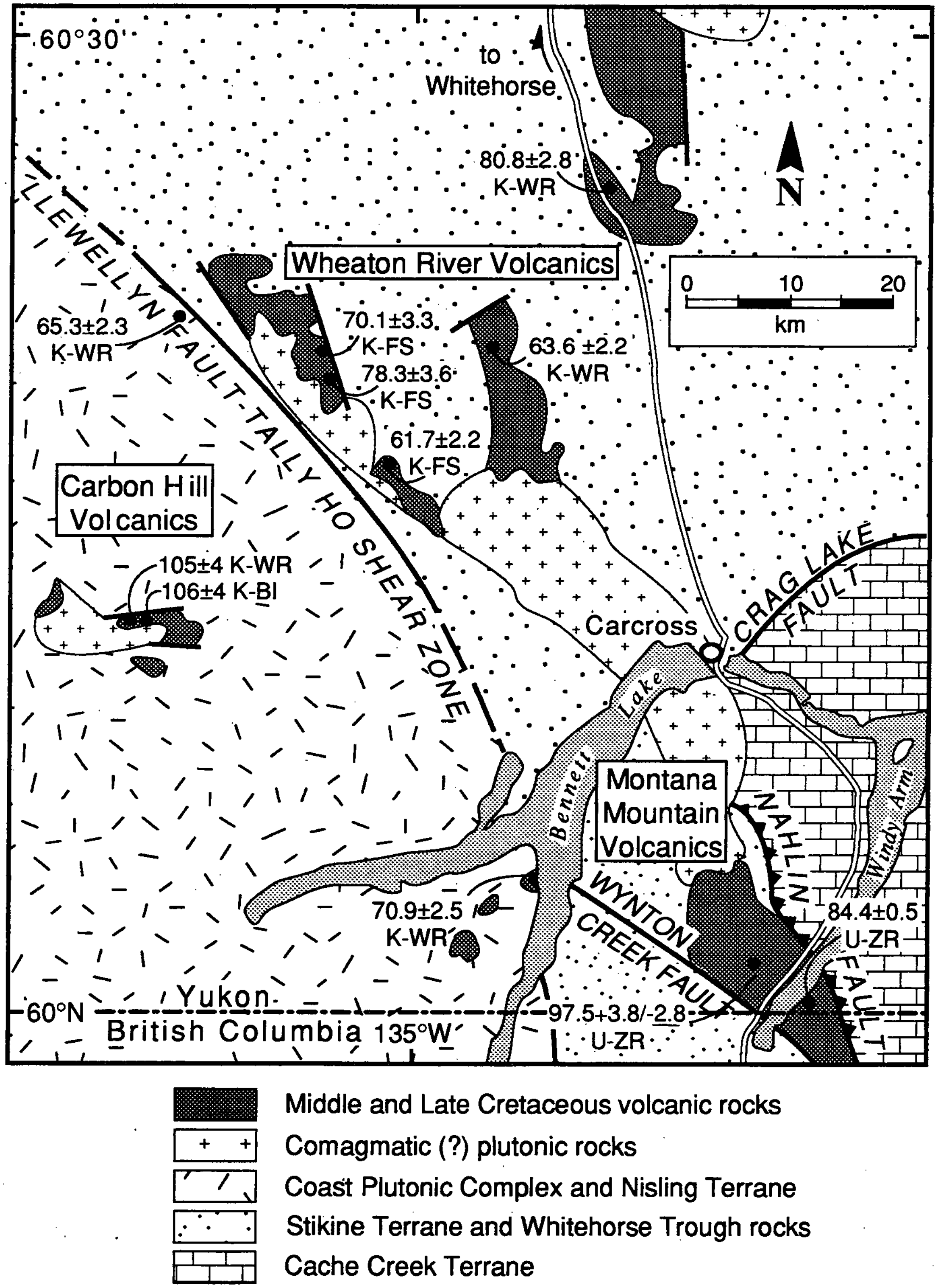


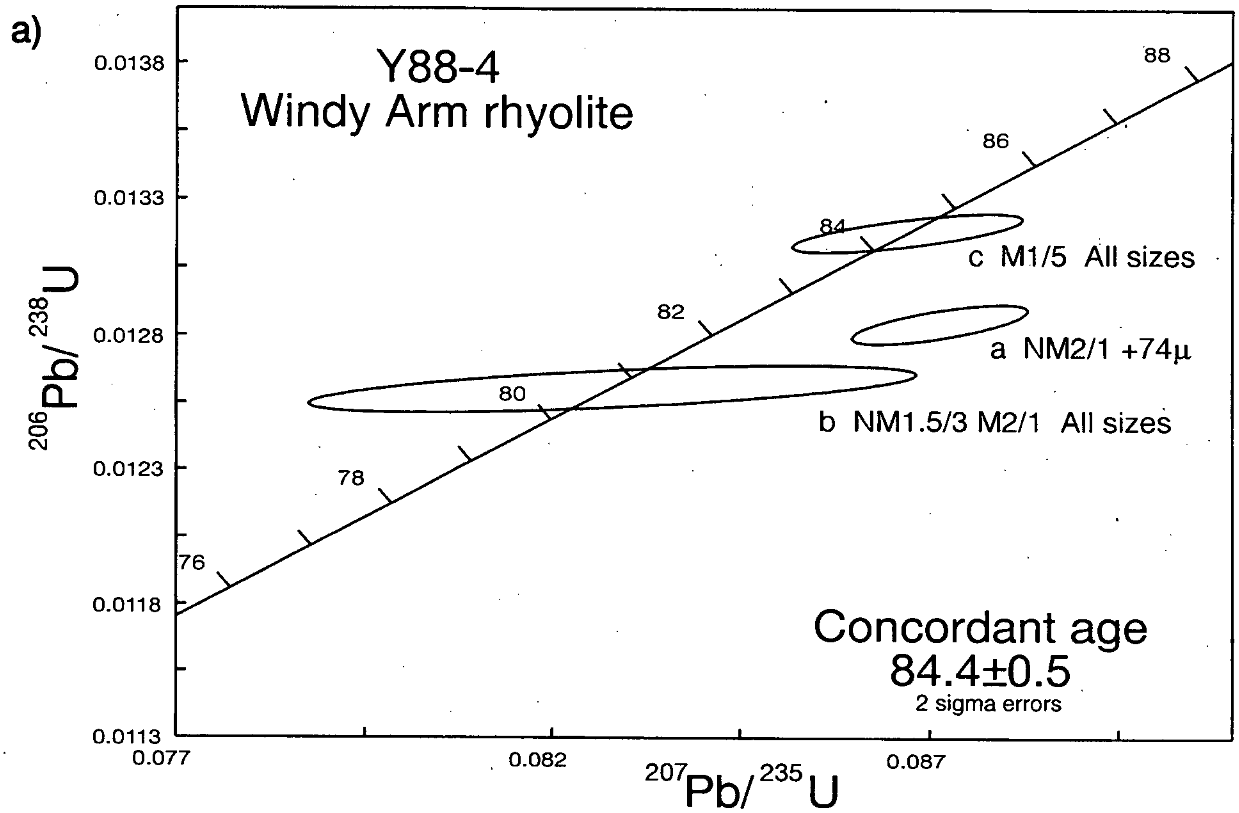
Figure 4.10. Locations and dates of samples from the Carbon Hill, Montana Mountain and Wheaton River volcanics. Dating method: K = K-Ar; U = U-Pb. Material dated: WR=whole rock; FS=feldspar; BI=biotite; ZR=zircon.

Montana Mountain volcanic complex dacite tuff and breccia gave a nearly concordant U-Pb zircon date of 97.5+3.8/-2.8 Ma (Figure 4.11b). The two fractions are nearly concordant and give similar 207/206 ages suggesting very slight Pb-loss. The regressed upper intercept age (forced through the origin) of 97.5±3.8 Ma defines the maximum age and includes both 207/206 ages within its error. Fraction **b**, with concordant 206/208 and 207/235 ages of 95.5±0.7 Ma defines the minimum age for this rock. The stratigraphically highest volcanic unit, a flow-banded rhyolite near Windy Arm, yielded a concordant U-Pb zircon date of 84.4±0.5 Ma (Figure 4.11a). Out of the three fractions analysed, two are very close to concordia. The most concordant, fraction **c** with only 0.8% discordance, is nearly identical to the upper intercept age determined by the regression of fractions **b** and **c** forced through the origin (84.7±31 Ma). As a result, fraction **c** defines the age of these rocks. A small amount of Pb-loss accounts for the position of fraction **b**. Fraction **a** likely contains an inherited, pre-Middle Jurassic component, which corresponds to the age of the enclosing country rocks.

Two K-Ar whole rock dates on dacite tuff (from the same locality as the 98 Ma zircon date) returned much younger dates of 65.1±2.3 and 64.5±1.8 Ma. These dates are similar to K-Ar biotite ages of the nearby Carcross pluton (64 Ma in Morrison *et al.* 1979; 68 Ma, Chapter 3 this thesis) and likely reflects thermal resetting by the pluton. The *circa* 98 Ma rocks are proximal to the Montana Mountain quartz monzonite which yielded a U-Pb date of 106.5 Ma. These rocks are considered to be co-magmatic, but their U-Pb dates are 10 Ma apart suggesting either that they are not co-magmatic or that there is a problem with one of the age dates. The preferred explanation is that the 98 Ma dates are apparent and that they represent *circa* 106 Ma fractions with some Pb-loss. This could be determined by analysing abraded, low-U fractions. A further complication is the 13 million year difference in the ages of the dacite tuff and the rhyolite flows. This too may be settled with additional analyses.

The Nahlin and Wynton Creek faults cut the rhyolite flows and the last motion on them must be younger than 84 Ma. The Nahlin fault is a crustal-scale structure that probably channeled magmas and focused eruptions and intrusions along it -- including those that formed the MMVC and nearby plutons. Polymetallic mesothermal gold veins in the Montana Mountain volcanic complex are the same age or younger than the 84 Ma felsic volcanic rocks in which they are hosted.

a)



b)

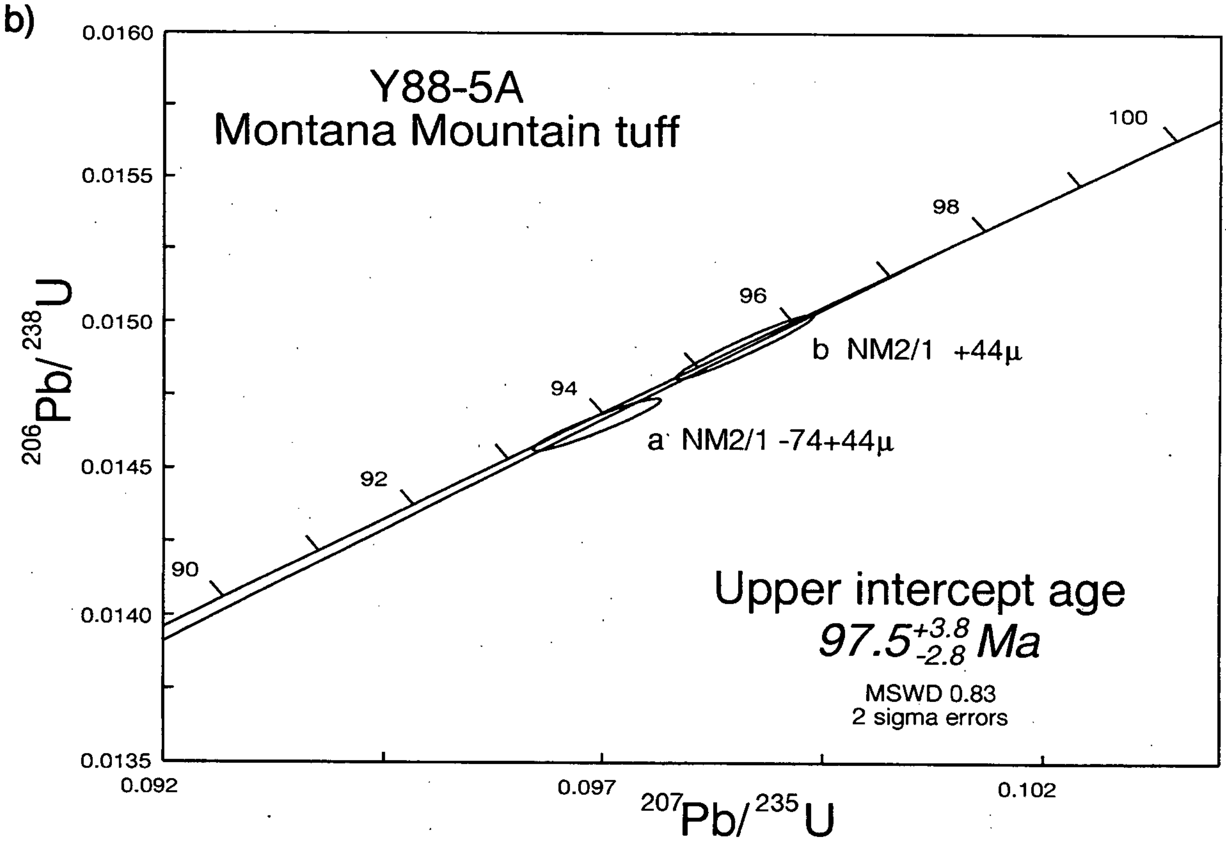


Figure 4.11a. U-Pb concordia diagram for sample Y88-4 of rhyolite from near Windy Arm, Montana Mountain volcanic complex.

Figure 11b. U-Pb concordia diagram for sample Y88-5 of siliceous tuff from Montana Mountain volcanic complex. Data for both samples are in Table 4.2.

Wheaton River volcanics andesitic flows gave two nearly concordant K-Ar dates of 78.3±3.6 and 80.8±2.8 Ma from feldspar and whole rock samples from different parts of the complex. Rhyolite dykes cut much of the Wheaton River suite and provide minimum ages for those flows, tuffs and epigenetic mineralization that they host. The dykes yielded younger K-Ar dates from the rhyolite dykes of 70.1±3.3 Ma and 63.6±2.0 Ma from whole rock and feldspar respectively. A porphyritic andesite dyke gave a K-Ar whole rock age of 65.3±2.3 Ma. A slightly altered, andesite porphyry plug from a shoreline exposure near Bennett Lake gave a whole-rock K-Ar date of 70.9±2.5 Ma.

Late Cretaceous dates of 81-78 Ma for the succession of andesite flows that comprise most of the Wheaton River volcanics likely reflect the timing of the dominant volcanic episode. The integrity of these dates is supported by two 78 Ma U-Pb zircon dates from the nearby, and possibly comagmatic Follé Mountain and Wheaton River plutons (Hart and Radloff 1990; Chapter 3 this thesis), which intrude the complex. Further support for this age of volcanism is supported by a U-Pb date of 81.3±0.3 Ma from the Table Mountain volcanics in northern British Columbia (Mihalynuk *et al.* 1992). K-Ar dates from rhyolite dykes are approximately contemporaneous with the intrusion of the Late Cretaceous Carcross pluton (*ca.* 68 Ma, Morrison *et al.* 1979; Chapter 3 this thesis). The variability of the dates on rhyolite dykes likely results from partial Ar loss during glass devitrification.

The age of the Wheaton River volcanics which overlie Tantalus Formation strata and constrains the sediments' age to pre-mid-Campanian. This is consistent with a Santonian palynological age for the Tantalus Formation (G.E. Rouse, written comm. 1990). Mineralization in, and associated with Wheaton River volcanic rocks are synchronous with the emplacement of younger rhyolite dykes at *ca.* 70-64 Ma.

Rb-Sr isochrons for each of the three suites give unreasonably old and meaningless ages (Figure 4.12). Cretaceous volcanics elsewhere in the Yukon also gave Rb-Sr isochrons that are too old (Wood and Armstrong 1982; Grond *et al.* 1984). The Carbon Hill isochron, the oldest at *ca.* 173 Ma likely results from contamination by adjacent Nisling Terrane rocks. The Montana Mountain isochron is calculated from rocks of two ages(98 and 84 Ma), which do not represent a comagmatic suite and thus give a meaningless isochron. Similarly, K-Ar dating indicates that the Wheaton River suite is composed of non-comagmatic *ca.* 80 Ma volcanics and a younger suite of rhyolite dykes - again giving a meaningless isochron.

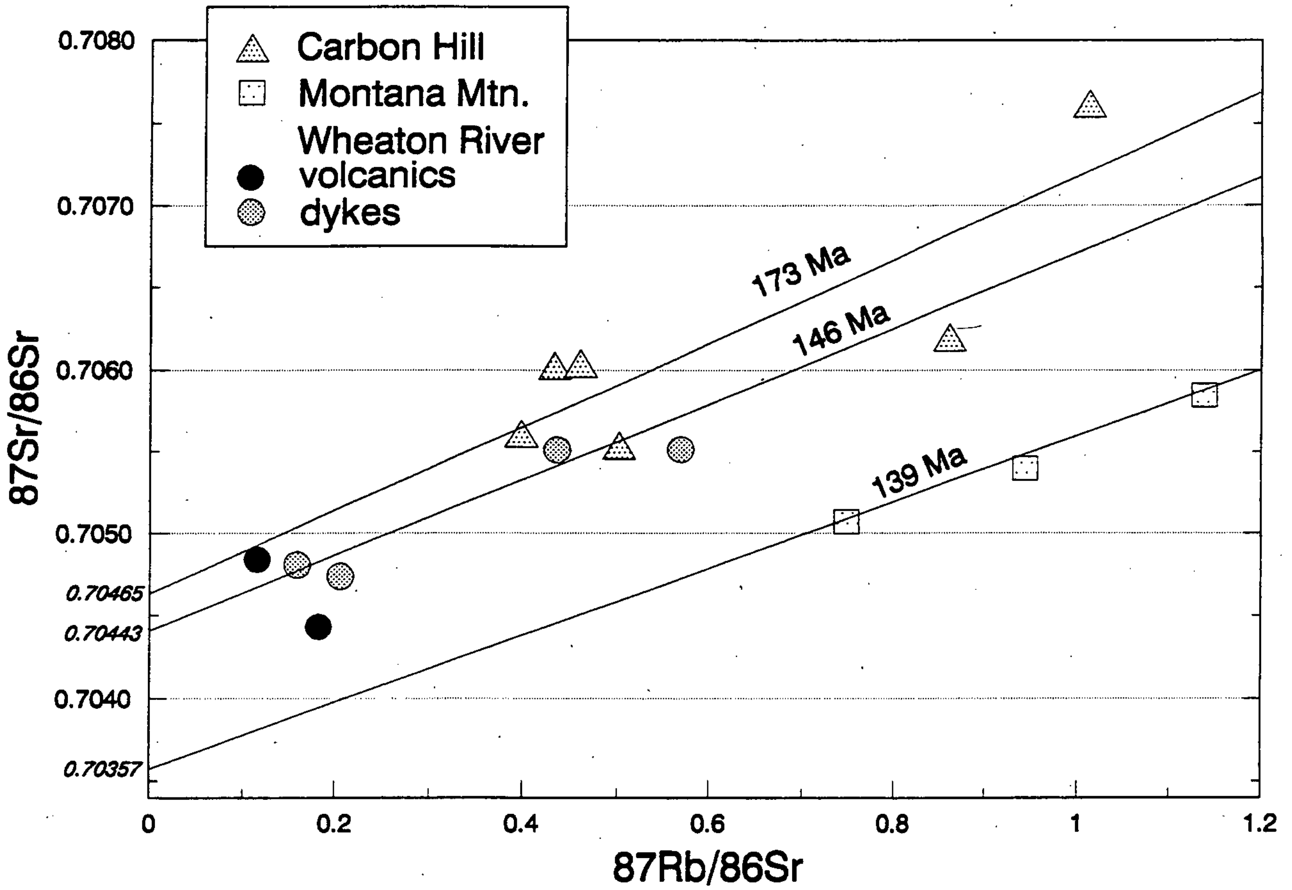


Figure 4.12. Rb-Sr isochrons for (from top to bottom) Carbon Hill, Wheaton River (dykes only), and Montana Mountain suites. The isochrons are all older than the K-Ar and U-Pb ages and reflect likely hydrothermal alteration and Rb contamination from wallrock (see text for discussion).

The dating indicates that volcanic events occurred at *ca.* 106, 98, 84 and 81-78 Ma with a period of rhyolite dyke emplacement at 70-64 Ma. The Wheaton River volcanic K-Ar dates are close to the 84 Ma U-Pb zircon date on rhyolite flows from the Montana Mountain volcanic complex and together are interpreted to represent a single volcanic epoch between 84 and 78 Ma.

INITIAL STRONTIUM RATIOS

The isotopic composition of strontium in volcanic rocks provides information about the sources from which magmas originated and about the processes which modify their chemical and isotopic compositions. Consequently, initial strontium ratios $[(^{87}Sr/^{86}Sr)_i]$ of volcanic rocks may be used to interpret the nature of magmagenic processes which may be associated with particular tectonic environments.

Fifteen whole rock samples from the three volcanic suites were analysed. Initial strontium ratios are between 0.70406 and 0.70606. When corrected for the time lapsed since crystallization (as determined by K-Ar or U-Pb dates; Table 4.4). The six samples of Carbon Hill volcanics occupy the widest range and have the highest mean value (0.70522). Montana Mountain volcanic complex samples occupy a narrow range with the lowest mean value (0.70422). The Wheaton River volcanics span a moderate range with an intermediate mean value (0.70469). Initial strontium ratios from five samples of Late Cretaceous volcanic rocks elsewhere in the southern Yukon Territory give a narrow range between 0.7046-0.7050 (Grond *et al.* 1984). The Late Cretaceous Table Mountain volcanics in northern British Columbia give slightly higher ratios of *circa* 0.7042 (Mihalynuk *et al.* 1992).

The higher initial strontium ratios from the Carbon Hill volcanics probably reflects shallow crustal contamination from the underlying, radiogenic metasedimentary rocks of the Nisling Terrane. The initial Sr ratio for these metamorphic rocks in Cretaceous time was greater than 0.710 (Armstrong, unpublished data); even small percentages of contamination could yield the determined values. The mean values of the Montana Mountain and Wheaton River volcanic rocks are similar to the mean value of modern island arcs (0.70437; Faure 1986) whose magmas were derived from the mantle. The implication is that the magmas which formed the Montana Mountain and Wheaton River volcanics were mantle derived and essentially uncontaminated by continental crust.

Cretaceous volcanic rocks between 98 and 60 Ma in the southern Yukon show a systematic increase in initial strontium values from 0.70406 to 0.70513 with decreasing

TABLE 4.4 Whole rock Rb - Sr data for Cretaceous volcanic rocks described in this report

Sample	Rock Type	Location	Latitude °N	Longitude °W	[a]Sr (ppm)	[a]Rb (ppm)	[b]$^{87}Rb/^{86}Sr$	[c]$^{87}Sr/^{86}Sr$ observed	[d]$^{87}Sr/^{86}Sr$ initial ±2σ	Age (Ma)
				CARBON HILL SUITE						
Y88-38	dacite dyke	Carbon Hill	60°11.5'	135°16.3'	365	128	1.011	0.70759	0.70606±10	106
Y88-37A	andesite porphyry flow	Carbon Hill	60°11.0'	135°16.6'	647	96.8	0.433	0.70600	0.70535±4	105
Y88-37C	andesite flow	Carbon Hill	60°11.0'	135°16.6'	482	74.4	0.459	0.70601	0.70532±10	106e
Kva	andesite flow	Carbon Hill	60°11.0'	135°16.6'	550	95.2	0.501	0.70551	0.70475±18	106e
Kvr	rhyolite tuff	Carbon Hill	60°11.0'	135°16.6'	398	119	0.863	0.70618	0.70488±3	106e
PGP-2	dacite tuff	Carbon Hill	60°10.8'	135°15.5'	529	72.6	0.397	0.70558	0.70498±4	106e
mean±2σ					*495*	*98*	*0.611±0.237*		*0.70522±43*	
				MONTANA MOUNTAIN SUITE						
Y88-5B	dacite tuff	Montana Mtn.	60°01.8'	134°41.5'	428	140	0.944	0.70539	0.70409±6	97e
Y88-5C	andesite tuff	Montana Mtn.	60°01.8'	134°41.5'	404	104	0.747	0.70507	0.70404±4	97
Y88-4	rhyolite flow	Montana Mtn.	60°00.0'	135°35.8'	286	113	1.137	0.70584	0.70447±8	85
mean±2σ					*373*	*119*	*0.943±0.159*		*0.70420±19*	
				WHEATON RIVER SUITE						
Y88-23	basalt flow	Carcross Road	60°23.7'	135°48.9'	806	32.3	0.115	0.70484	0.70470±6	81
Y88-15	basalt porphyry flow	Folle Mountain	60°17.8'	135°04.1'	598	37.5	0.182	0.70443	0.70422±4	78
CH88 75-2	andesite porphyry plug	Bennett Lake	60°03.4'	134°52.8'	504	99.3	0.570	0.70550	0.70492±6	71
Y88-27A	rhyolite dyke	Idaho Hill	60°18.9'	135°01.7'	1450	80.4	0.159	0.70480	0.70464±4	70
89CH 49-6	rhyolite dyke	Grey Ridge	60°18.5'	134°54.5'	871	62.1	0.206	0.70474	0.70455±6	64
Y88-13	dacite dyke	Mt. Wheaton	60°15.9'	135°01.1'	481	72.6	0.436	0.70551	0.70512±4	62
mean±2σ					*785*	*64.0*	*0.278±0.160*		*0.70469±28*	

NOTES. Analyses by D.K. Ghosh, R.L. Armstrong, C.J.R. Hart and D. Runkle at The University of British Columbia.

a Sr and Rb concentrations were determined by duplicate analyses of pressed-powder pellets using X-ray fluorescence. Mass absorption coefficients were obtained from Mo Kα Compton scatter measurements. Rb and Sr concentrations have $\pm 1\sigma$ errors of 5%.

b $^{87}Rb/^{86}Sr$ ratios by XRF have $\pm 1\sigma$ error values of 2% for samples with both concentrations over 50 ppm; for samples with concentrations below 50 ppm, the $\pm 1\sigma$ error value approximates the $^{87}Rb/^{86}Sr$ divided by the lowest concentration (effectively ±1 ppm on concentration uncertainty).

c Sr isotopic composition was measured on unspiked samples prepared using standard ion exchange techniques. Sr isotopic measurements were made on a Vacuum Generators Isomass 54R mass spectrometer (with upgraded source, focus and detector electronics) linked with a Hewlett-Packard HP-85 computer. Blanks contain approximately 0.8 and 6 ng of Rb and Sr respectively. Measured Sr isotope analyses are normalized, assuming $^{86}Sr/^{88}Sr$ ratio of 0.1194, and further adjusted so the Eimer and Amend standard gives a $^{87}Sr/^{86}Sr$ ratio of 0.70800±0.00002 and the NBS Sr standard $SrCO_3$ (SRM 987) gives a ratio of 0.71019±0.00002. The IUGS decay constant for Rb of $\lambda = 1.42 \times 10^{-11}\ a^{-1}$ (Steiger and Jäger, 1977) was used in calculations.

d Initial $^{87}Sr/^{86}Sr$ ratios are calculated using U-Pb and K-Ar dates determined elsewhere in this report or estimated dates (e).

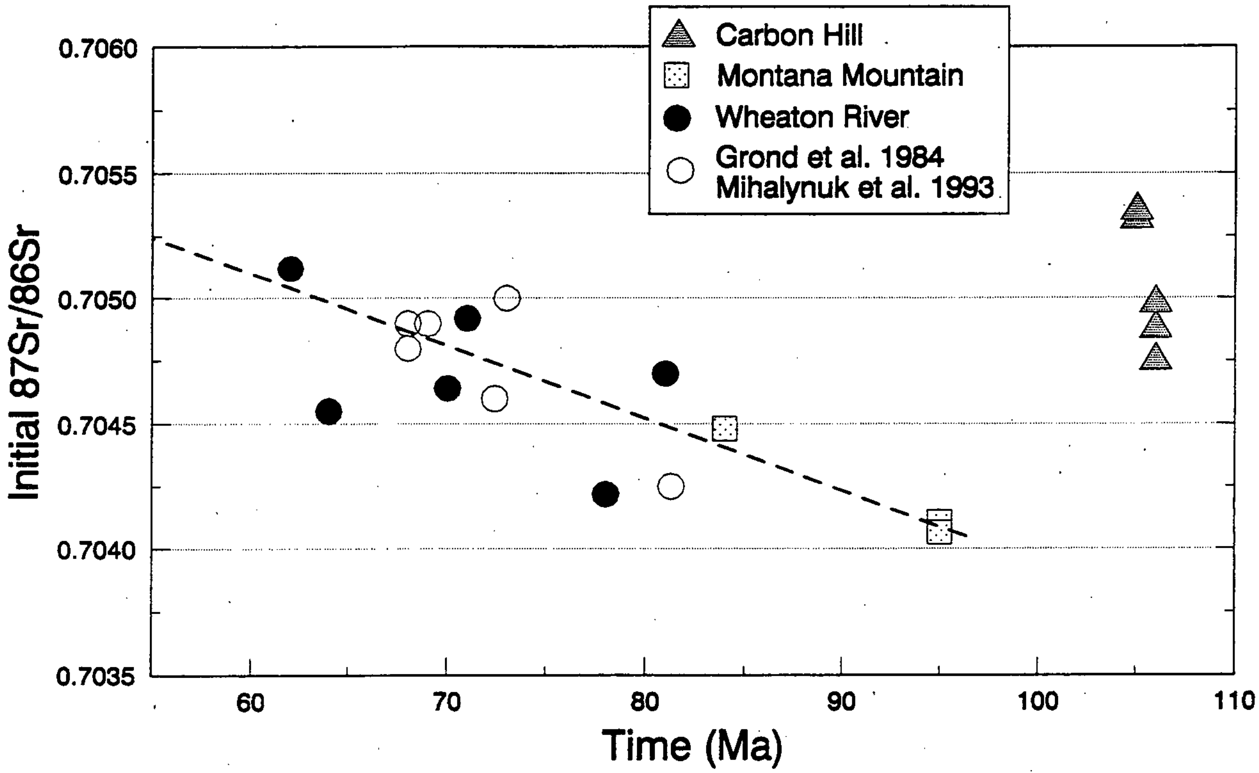


Figure 4.13. Plot of strontium initial strontium ratios versus age using data from this report and Grond *et al.* (1984). For samples younger than 100 Ma, the data show a systematic increase of 2.76×10^5 $(^{87}Sr/^{86}Sr)_i$/Ma with decreasing age. A best fit line has a correlation coefficient of 0.806 and indicates an increasing continental crustal contribution to the volcanic magmas with decreasing age. Carbon Hill samples are interpreted to be heavily contaminated by proximal ancient crustal material of the Nisling Terrane.

age (Figure 13: slope, m=2.76x10^5 i/Ma; correlation coefficient=0.806). This trend requires that continental contamination of volcanogenic magmas increased throughout that time span. This may result from an increasing geothermal gradient which allowed progressively greater contributions from crust. The geothermal gradient may have increased as a result of increasing amounts of magma in the crust or crustal thinning. Similar systematic trends in initial $^{87}Sr/^{86}Sr$ with age have been reported in igneous rocks in similar tectonic settings in California (Kistler and Peterman 1973), and the Andes (McNutt *et al.* 1975).

Distribution of all published data for mid- and Late Cretaceous volcanic rocks in Yukon show a slight westward increase in initial strontium values – a 0.705 isopleth crudely approximates the contact between the Stikinia and Nisling terranes and is similar to the location shown by Armstrong (1988; Figure 4.14). The lowest values are from rocks adjacent or on top of Cache Creek Terrane. The correlation between initial Sr values and terrane affinity suggests that the basement rocks contributed to the isotopic character of the Cretaceous volcanic magmas.

DISCUSSION

Three volcanic events have been determined for post-orogenic volcanic rocks in southwestern Yukon Territory at *ca.* 106, 98, 84-78 Ma. Age determinations from other mid- and Late Cretaceous volcanic rocks in the northern Cordillera are combined with the dates presented here and displayed in Table 4.5 and Figure 4.15. Note that: 1) the data set is dominated by K-Ar dates; 2) The whole rock and feldspar dates are particularly susceptible to Ar loss and should be regarded as minimum ages; 3) The 12 Ma discordance between the K-Ar biotite and hornblende dates of sample GSC 81-50 and 51 indicates that a Late Cretaceous thermal gradient was locally high enough to reset biotite (250°C in Harrison *et al.* 1985); and 4) Many of the dates are from dykes and should be interpreted as minimum ages for the volcanic strata that they cut.

The data set in Table 4.5 and Figure 4.15 makes several themes apparent: 1) there were two apparent episodes of volcanism, at mid- and Late Cretaceous time; 2) the Late Cretaceous dates suggest that volcanism was initiated at circa 84 Ma and protracted and continuous with Paleocene volcanism; 3) mid-Cretaceous volcanism is less well pronounced and ceased at 105 Ma; 4) evidence of volcanism between 105 and 84 Ma is rare. 5) whole rock K-Ar dates younger than 68 Ma are largely from younger felsic dykes or may have been reset; 6) dates close to 60 Ma are supported by

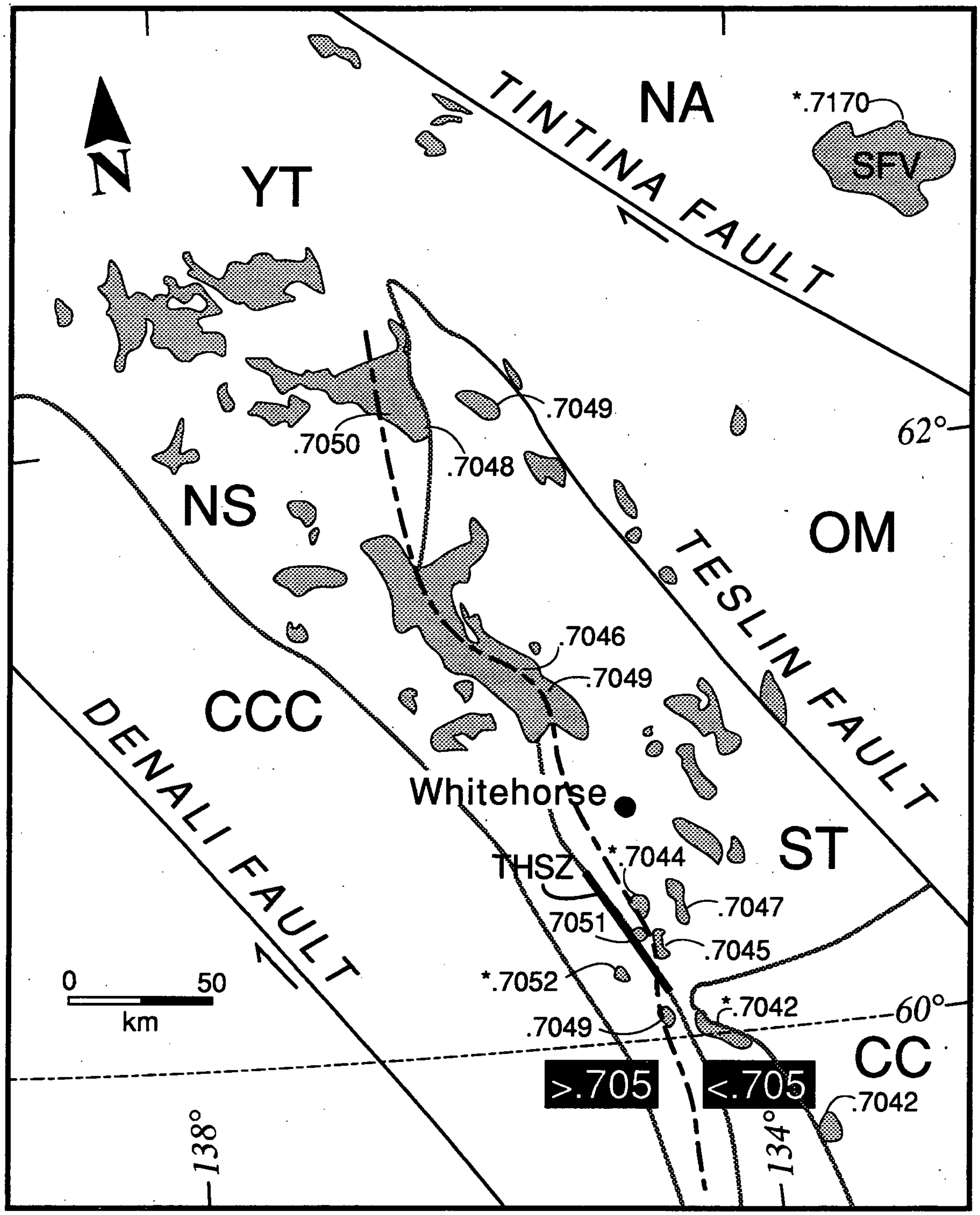


Figure 4.14. Distribution of mid- and Late Cretaceous volcanic rocks and their initial strontium ratios in southern Yukon Territory. Terrane boundaries and abbreviations are the same as in Figure 1. Note the concordance of the 0.705 isopleth with the contact between Stikine Terrane and the Coast Crystalline Belt (which includes Nisling Terrane). The values reported are from this report, Grond *et al.* (1984) and Mihalynuk *et al.* (1993). Initial strontium value for South Fork Volcanics (SFV) is the average from Wood and Armstrong (1982). *=average value.

TABLE 4.5 Compilation of published dates for mid and Late Cretaceous volcanic rocks in southern Yukon and northern British Columbia

	Sample	Location	Rock Type	Material & Method	Date ±2σ (Ma)	Reference	Note	Latitude °N	Longitude °W
1.	GSC 90-81	Mount Nansen	biotite-feldspar porphyry dyke	wr K-Ar	61.2±1.2	Hunt and Roddick 1991	altered dyke	62°05'	137°16'
2.	Y88-13	Wheaton River	andesite feldspar porphyry dyke	fs K-Ar	61.7±2.2	This Report		60°15.9'	135°01.1'
3.	GSC 78-100	Granite Canyon	basalt/ands	bi K-Ar	63.5±3.1	Wanless *et al.* 1979		62°43'30"	136°13'
4.	MMI89 53-6-2	Tagish Lake		zr U-Pb	62.3±2.2	Mihalynuk (in prep)			
5.	89CH 49-6	Wheaton River	rhyolite dyke	wr K-Ar	63.6±2.2	This Report		60°17.5'	124°54.5'
6.	GSC 81-46	Twin Lakes	andesite	wr K-Ar	64.0±2.1	Stevens *et al.* 1982		61°40'00"	135°58'00"
7.	14-01	Indian River	andesite sill	wr K-Ar	64.8±1.7	Lowey *et al.* 1986		63°39'50"	139°10'30"
8.	13-01	Indian River	andesite sill	wr K-Ar	65.2±1.7	Lowey *et al.* 1986		63°42'30"	139°08'30"
9.	89CH 34-1	Wheaton River	andesite flow	wr K-Ar	65.3±2.3	This Report		60°19.0'	135°11.5'
10.	GSC 92-42	Glenlyon	quartz-feldspar porphyry	hb K-Ar	67.7±3.3	Hunt and Roddick 1992		62°12'04"	135°04'54"
11.	15-1e	Carmacks	andesite flow	wr K-Ar	67.9±2.3	Grond *et al.* 1984		61°58'05"	136°13'30"
12.	14	Carmacks	trachybasalt	bi K-Ar	68.0±2.2	Grond *et al.* 1984		62°04'07"	135°56'48"
13.	21-01	Indian River	andesite sill	wr K-Ar	69.0±1.7	Lowey *et al.* 1986		63°42'10"	139°07'50"
14.	GSC 90-82	Mount Nansen	quartz-feldspar porphyry dyke	wr K-Ar	69.0±1.7	Hunt and Roddick 1991	altered dyke	62°03'	137°07'
15.	23-3	Miners Range	andesite flow	fs K-Ar	69.1±2.6	Grond *et al.* 1984		61°09'08"	135°37'03"
16.	GSC 90-80	Mount Nansen	quartz-feldspar porphyry dyke	wr K-Ar	69.7±1.4	Hunt and Roddick 1991	altered dyke	62°05'	137°27'
17.	Y88-27A	Wheaton River	rhyolite dyke	fs K-Ar	70.1±3.3	This Report		60°18.9'	135°01.7'
18.	GSC 81-37	Mt. Nansen	biotite-feldspar porphyry (core)	bi K-Ar	70.5±2.2	Stevens *et al.* 1982		62°04'26"	137°15'19"
19.	CH88 75-2	Bennett Lake	andesite stock	wr K-Ar	70.9±2.5	This Report		60°03.4'	134°52.8'
20.	22-00	Miners Range	andesite flow	wr K-Ar	72.4±2.5	Grond *et al.* 1984		61°10'09"	135°38'01"
21.	12-2d	Carmacks	alkali basalt	wr K-Ar	73.1±2.5	Grond *et al.* 1984		62°04'12"	136°24'30"
22.	GSC 92-41	Glenlyon	basalt flow	wr K-Ar	73.4±1.3	Hunt and Roddick 1992		62°04'49"	135°28'22"
23.	GSC 81-49	Macmillan Range	porphyry	hb K-Ar	74.4±3.0	Stevens *et al.* 1982		62°56'00"	136°11'30"
24.	F85-33B	Mt. Freegold	rhyolite dike	wr K-Ar	77.5±6.2*	McInnes *et al.* 1988	altered, large error		
25.	Y88-15	Wheaton River	trachyte flow	fs K-Ar	78.3±3.6	This Report		60°17.8'	135°04.1'

TABLE 4.5 Compilation of published dates for mid and Late Cretaceous volcanic rocks in southern Yukon and northern British Columbia (continued)

	Sample	Location	Rock Type	Material & Method	Date ±2σ (Ma)	Reference	Note	Latitude °N	Longitude °W
26a.	GSC 81-51	Mt. Pitts	basalt plug	hb K-Ar	78.4±3.2	Stevens *et al.* 1982		62°28'30"	137°38'00"
26b.	GSC 81-50	Mt. Pitts	basalt plug	bi K-Ar	65.8±1.6	Stevens *et al.* 1982	reset from 78 Ma (see GSC 81-51)	62°28'30"	137°38'00"
27.	GSC 90-92	Klondike area	basalt dyke	wr K-Ar	79.4±1.1	Hunt and Roddick 1991		64°16.4'	139°40.0'
28.	GSC 81-43	Boswell Mtns.	dacite flow	wr K-Ar	80.0±2.3	Stevens *et al.* 1982	Open Creek volcanics	61°07'00"	134°06'00"
29.	Y88-23	Carcross Road	andesite flow	wr K-Ar	80.8±2.8	This Report		60°23.7'	134°48.9'
30.	NWI89-17-5	Graham Creek/ Table Mtn., B.C.	rhyolite ash flow	zr U-Pb	81.3±0.3	Mihalynuk *et al.* 1993		59°40'41"	134°00'56"
31.	T75 305-8	various Yukon & Table Mtn., B.C.	various/rhyolite	wr Rb-Sr n=5	72.4±2.1*	Grond *et al.* 1984	U-Pb date of 81.3 Ma (NWI89 17-5)	59°38'	133°57'
32.	GSC 81-42	Hootalinqua	feldspar-biotite flow	wr K-Ar	83.4±2.1	Stevens *et al.* 1982	Open Creek volcanics	61°36'30"	134°54'00"
33.	Y88-4	Windy Arm	rhyolite flow	zr U-Pb	84.4±0.5	This Report		60°00.0'	135°35.8'
34.	GSC 90-85	Mount Nansen	trachyte flow	wr K-Ar	93.7±1.5	Hunt and Roddick 1991		62°07'	137°20'
35a.	Y88-5A	Montana Mtn.	dacite tuff	zr U-Pb	$97.5^{+3.8}/_{-2.8}$	This Report		60°01.8'	134°41.5'
35b.	Y88-5A	Montana Mtn.	dacite tuff	wr K-Ar	64.5±1.8	This Report	reset from 98 Ma	60°01.8'	134°41.5'
35c.	Y88-5B	Montana Mtn.	dacite tuff	wr K-Ar	65.1±2.3*	This Report	reset from 98 Ma	60°01.8'	134°41.4'
36.	Y88-37A	Carbon Hill	andesite flow	wr K-Ar	105.0±4.0	This Report		60°11.0'	135°16.6'
37.	Y88-38	Carbon Hill	rhyolite dyke	bi K-Ar	106.0±4.0	This Report		60°11.5'	135°16.3'
38.	GSC 90-84	Bow Creek	feldspar-hornblende porphyry dyke	hb K-Ar	107.9±1.6	Hunt and Roddick 1991		62°14'	137°21'
39.	GSC 81-57	Klaza Mountain	felsite	wr K-Ar	109±3	Stevens *et al.* 1982		62°16'30"	137°30'
40.	GSC 81-48	Packers Mtn.	flow banded rhyolite	wr K-Ar	116±3	Stevens *et al.* 1982	possible excess Ar	61°50'00"	135°32'00"

NOTES: * These dates have not been included in Figure 4.15 since they have a large error or the same rock package has been superseded by better analyses.
Abbreviations: wr=whole rock, fs=feldspar, bi=biotite, hb=hornblende, zr=zircon

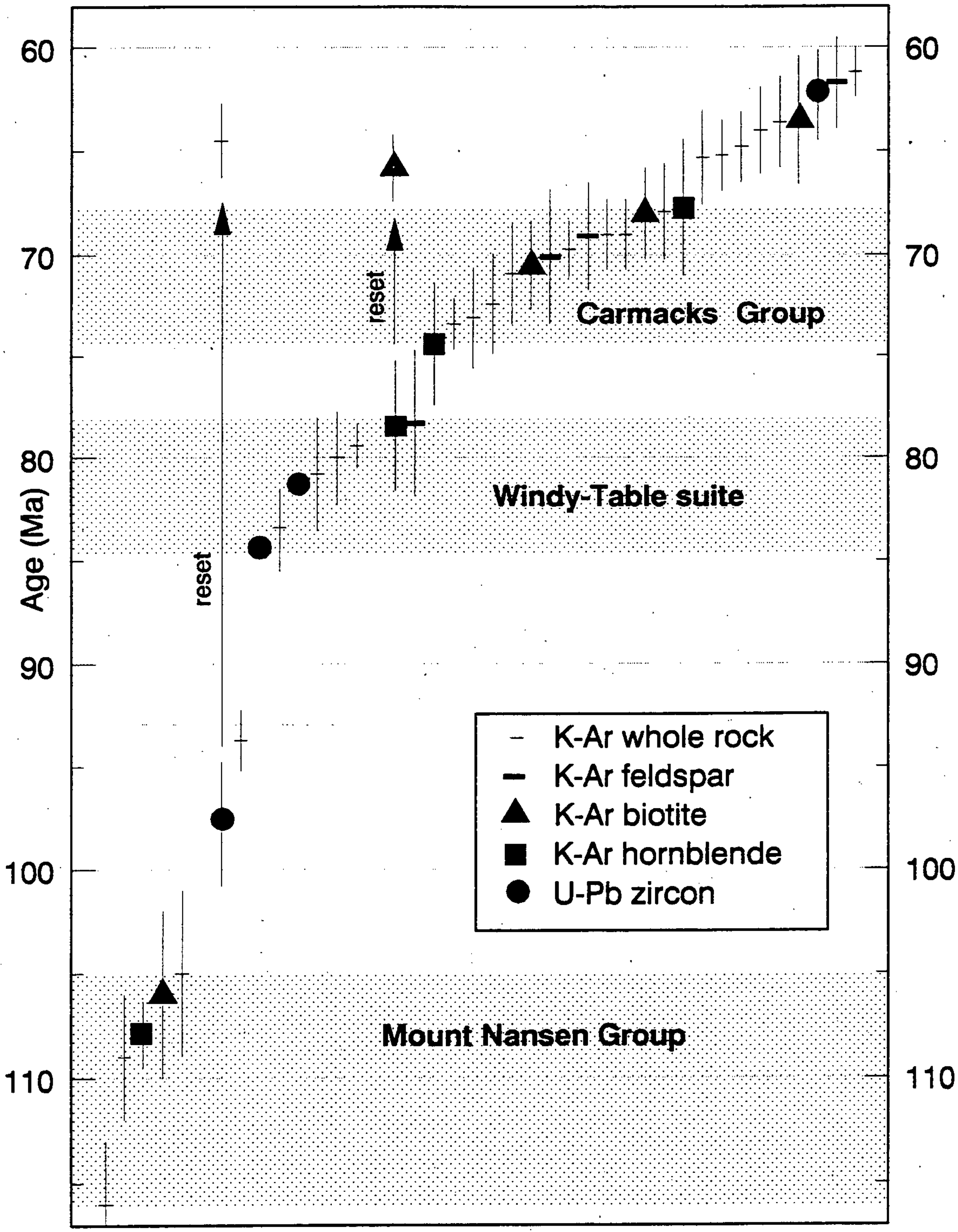


Figure 4.15. Isotopic dates for mid- and Late Cretaceous volcanic rocks on accreted terranes in Yukon Territory and northernmost British Columbia as compiled from Table 4.5. The vertical bars incorporate the two sigma errors of the sample. The dates indicate a poorly pronounced Mount Nansen episode at *ca.* 106 and 98 Ma followed by a pronounced Carmacks volcanic episode between 84 and 68 Ma. However, most Carmacks Group dates are K-Ar whole rock determinations that have likely suffered Ar loss due to devitrification. The Windy-Table suite is well defined by two U-Pb zircon and a hornblende K-Ar dates at between 84 and 78 Ma.

a zircon date and may belong to the Paleocene Skukum Group; 7) dates older than 80 Ma are from volcanic successions dominated by felsic flows and tuff.

The rocks yielding the mid-Cretaceous dates are all assigned to the Mount Nansen Group (although definitive mid-Cretaceous dates have not been obtained from the type area). Closer examination of the better quality Late Cretaceous dates indicates that there may have been two, at 84-78 and 74-68 Ma. Although the apparent hiatus between 78-74 Ma may reflect inadequate sampling, geological evidence supports two distinct volcanic suites. The older suite is dominated by felsic flows and pyroclastics of the Windy Arm, Table Mountain, Wheaton River and Open Creek areas (all south of 62°N latitude), and here named the Windy-Table volcanic suite (see also Mihalynuk in prep.). These rocks are lithologically and spatially distinct from typical Carmacks Group volcanics

Most localities of Mount Nansen and Carmacks groups as they are presently mapped, are not sufficiently lithologically diagnostic as to permit confident assignment without age constraints. However, in light of the information presented in this paper, and by Tempelman-Kluit (in Stevens *et al.* 1982, p. 20-21) and Souther (1991, p. 477-479), the following descriptions are offered.

Mount Nansen Group is characterized by small exposures (essentially localized remnants) of intermediate to felsic, explosive volcanic rocks that are less areally extensive than Carmacks Group volcanic rocks. The dominance of coarsely fragmental, heterolithic breccias and welded tuff represents the preferential preservation of facies proximal volcanics in block-faulted grabens and caulderas. Mount Nansen Group volcanics have been eroded to a lower level; the successions are often represented by several, proximal, fault-bounded erosional remnants adjacent to their comagmatic pluton. The pluton is typically areally larger than the volcanic rocks which are generally altered as a result of the comagmatic intrusions. Mount Nansen Group rocks typically have steeper dips than Carmacks Group rocks. Locally the flows are pillowed. The more explosive style of volcanism tends to favour fault hosted, mesothermal and epithermal vein deposits.

Mount Nansen Group volcanics are unlike South Fork volcanics (Wood and Armstrong 1982; Gordey 1988) and rhyolitic calderas described in eastern Alaska (Bacon *et al.* 1990). Although similar in age (*ca.* 100 and 93 Ma respectively) – the

Alaskan rhyolitic calderas and South Fork volcanics are dominated by large (50-200 km^2) caldera complexes filled with thick successions of crystal-rich welded tuff.

Carmacks Group is defined by more subdued, more mafic and more areally extensive subaerial lava flows. Successions typically cover hundreds of square kilometres, are better layered than Mount Nansen Group rocks and rarely dip greater than 20°. Originally they may have formed as numerous coalescing shield volcanoes that capped much of the region. Exposed comagmatic plutons are small, hypabyssal, potassic and rare. Portions of the successions are highly vessiculated and locally columnar jointed. The accumulation of extensive and thick successions of lava flows prevents the escape of volatiles and encouraged the development of large scale, sub-volcanic hydrothermal alteration and the formation of porphyry deposits. Carmacks Group may be represented by several units or suites, including much of what is presently mapped as Mount Nansen Group in central Yukon. North of Whitehorse and in the Dawson Range, Carmacks Group locally has a felsic lower unit (previously called Mount Nansen Groups by Tempelman-Kluit (1974, 1978) and Grond *et al.* (1984)) that is overlain by numerous, thick basalt flows.

The Windy-Table suite, in southern Yukon and northern British Columbia, has a pronounced felsic and pyroclastic component with flow banded, extrusive rhyolite flows. This suite of rocks occurs south of 61°N latitude which seems to be the southern limit of Carmacks Group. The Windy-Table suite is 84-78 Ma which is notably older than "type" Carmacks Group and defines a discreet volcanic event.

Both Mount Nansen and Carmacks group successions locally overlie clastic strata of the Tantalus Formation. The volcanic activity, and preservation of the volcanic strata, may be related to the formation of pull-apart basins that initiated deposition of the Tantalus Formation. The basins and the volcanics probably formed due to transtension of the amalgamated terranes during their northward migration along the western edge of North America.

CONCLUSIONS

Three successions of post-orogenic volcanic rocks, previously mapped as Hutshi Group, yield U-Pb and K-Ar ages indicating episodic volcanic activity through mid- and Late Cretaceous time. Carbon Hill volcanics comprise mostly felsic pyroclastics that were erupted at *ca.* 106 Ma. Montana Mountain volcanic complex is composed of phyllically altered andesitic and dacitic breccias and pyroclastics that are 98 Ma. This package is overlain by rhyolite flows that are 84 Ma. Wheaton River volcanics consist of thicker, more extensive and subdued effusions of basaltic andesite and andesite of 81-78 Ma that are cut by 70 to 62 Ma rhyolite dykes. All three volcanic packages were derived from calc-alkaline, medium to high-K, sub-alkalic magmas. Each volcanic succession has a diagnostic range of initial Sr values that reflect the isotopic signature of the basement rocks at each site and indicates modification of the primative arc magmas. The Carbon Hill suite, in particular, shows evidence of contamination from an ancient crustal source with initial Sr ratios as high as 0.70606. Despite the range in geologic setting, lithologies, ages and isotopic signatures, all the suites have associated epigenetic precious metal deposits suggesting a potential link between the mineralization and these high-K volcanics.

The dates presented here provide constraints for the maximum age of formation of mineral deposits hosted by the volcanic rocks. In addition, clastic strata of the Tantalus Formation locally preserved under the Carbon Hill and Wheaton River volcanic successions are assigned Albian and Campanian-Santonian ages respectively.

Mid and Late Cretaceous medium to high-K volcanic successions were deposited as part of a post-accretionary, continental arc that formed a north-northwesterly trending zone across amalgamated terranes in the northern Canadian Cordillera. Preservation in down-faulted blocks, often stratigraphically on top of clastic sediments, suggests that the medium to high-K volcanism may have been associated with localized basin formation during a transtensional tectonic regime. Mid-Cretaceous volcanism of the Mount Nansen Group was sparse (or is poorly preserved) throughout southern Yukon with short-lived episodes of intermediate to felsic pyroclastics at *ca.* 106 and 98 Ma. Late Cretaceous volcanism of the Carmacks Group was widespread, volumetrically significant, dominantly mafic to intermediate, and occurred over a protracted period between 84 and 68 Ma. The Windy-Table suite was deposited during 84-78 Ma and is recognized as a distinct volcanic event prior to the deposition of Carmacks Group.

Chapter V

Provenance constraints for Whitehorse Trough conglomerate: U-Pb zircon dates and initial Sr ratios of granitic clasts in Jurassic Laberge Group

INTRODUCTION

Much of the Canadian Cordillera is composed of suspect terranes whose spatial and temporal relations to one another remain controversial. Exotic or distinctive detritus in basinal conglomerate has the potential for identifying "point" sources useful in paleogeographic terrane reconstructions. Recently this concept has been applied to terrane analysis to identify overlap successions and provenance linkages between disparate crustal fragments. The Whitehorse Trough, a marine basin in the northern Canadian Cordillera (Figure 5.1), records an Early Mesozoic depositional history synchronous with terrane amalgamation. Examination of it's detritus may yield clues about the tectonic setting of the Whitehorse Trough and it's source regions.

A 3 km thick succession of Lower Jurassic conglomerate of the Laberge Group constitutes about half of the Whitehorse Trough fill. The variety and abundance of igneous clasts in the conglomerate suggest that the clasts were derived from a lithologically diverse, volcano-plutonic source terrane (or terranes) of earliest Jurassic or older age. Petrologic similarities between some granitic clasts and a suite of "Late Triassic-Early Jurassic" batholiths which flank the northern and western margins of the basin led previous workers to postulate that these batholiths were the source of the basin fill (Figure 5.2; Bultman 1979; Tempelman-Kluit 1974; 1979; Dickie 1989; Woodsworth *et al.* 1991; Wheeler and McFeely 1991).

Published K-Ar dates of granitic clasts failed to define reliable ages for the source plutons as they are younger than the rock's stratigraphic age, had large uncertainties or assumed 100% radiogenic argon (Table 5.1). More precise U-Pb crystallization ages of the granitic clasts are necessary to confidently assess potential source units and to clarify tectonic relationships between the Whitehorse Trough and adjacent terranes. This paper presents the first U-Pb zircon dates from four Laberge Group clasts. The dates, plus initial $^{87}Sr/^{86}Sr$ data from six granitic cobbles and four interbedded shale samples, together with sedimentologic data indicate a Late Triassic and earliest Jurassic magmatic arc provenance for the Laberge Group conglomerate.

TECTONIC FRAMEWORK

The northern Canadian Cordillera consists of numerous tectonic terranes accreted to the western margin of the North American craton during Mesozoic time (Monger *et al.* 1991). The northern portion of Stikinia, the largest of the accreted terranes, is composed of the Whitehorse Trough and the Late Triassic Lewes River arc

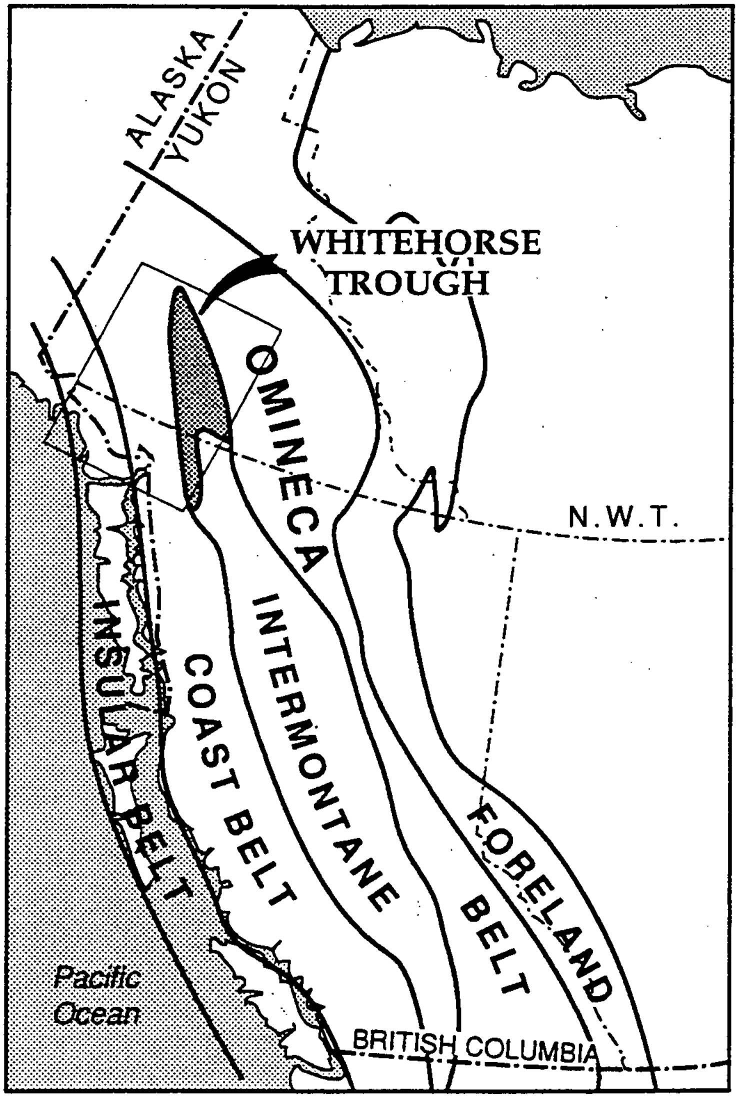


Figure 5.1 The location and setting of the Whitehorse Trough with respect to the physiographic belts of the Canadian Cordillera. Whitehorse Trough rocks form part of Northern Stikinia, which underlies most of the Intermontane Belt.

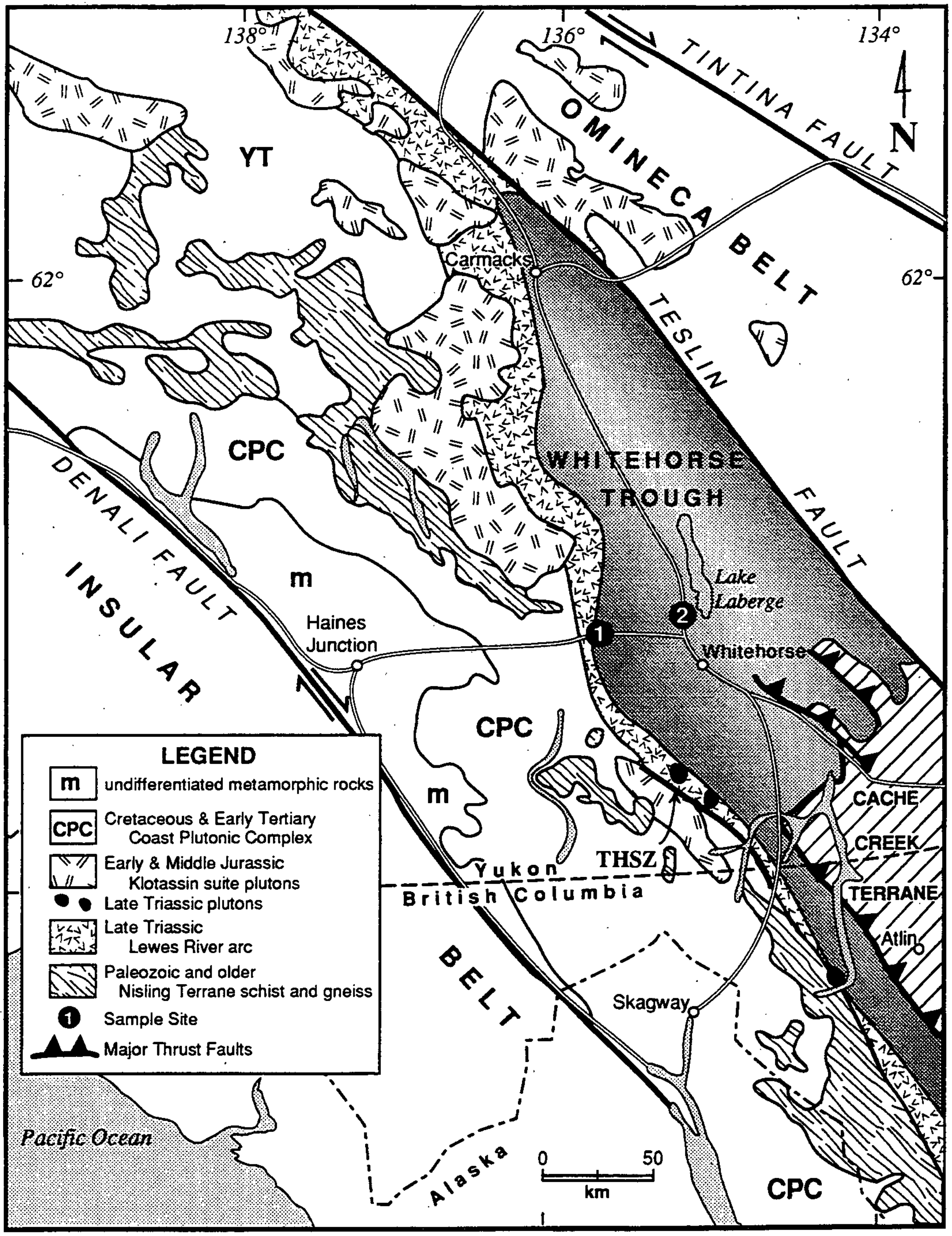


Figure 5.2 Generalized tectonic map of south-central Yukon Territory showing the relationship of the Whitehorse Trough to the Lewes River arc, Late Triassic and Early Jurassic plutons and Nisling Terrane. The Lewes River arc and Whitehorse Trough combine to form northern Stikinia. Klotassin suite batholiths have traditionally been assumed to be the source region for granitic clastic material in the Whitehorse Trough. Abbreviations are: CPC = Coast Plutonic Complex; m = undifferentiated metamorphic rocks: THSZ = Tally Ho shear zone, YT = Yukon Tanana Terrane. Sample sites are: 1) Alaska Highway and 2) Horse Creek.

TABLE 5.1 Compilation of K-Ar determinations on igneous clasts from Jurassic Laberge Group conglomerate

Rock Type	Material Dated	Date ±2σ	Reference	Comment
granodiorite	chloritic biotite	231*	Lowden 1963	assumed 100% radiogenic Ar
granodiorite	chloritic biotite	210*	Lowden 1963	assumed 100% radiogenic Ar
granodiorite	hornblende	179±8*	Tempelman-Kluit and Wanless 1975	too young
granodiorite	hornblende	199±34	Tempelman-Kluit and Wanless 1975	large error
granodiorite	hornblende	144±5	Morrison *et al.* 1979	too young
granodiorite	hornblende	185±5*	Bultman 1979	
granite	hornblende	142±2	Hunt and Roddick 1990	too young
andesite hornblende porphyry	hornblende	163±6	R.L. Armstrong, unpub.	too young

Note: *Recalculated using constant of Steiger and Jäger (1977)

(Figure 5.2). Northern Stikinia and is bounded to the west by pericratonic metamorphic rocks of the Nisling and Yukon-Tanana Terranes and plutons of the Coast Plutonic Complex. An understanding of the spatial and temporal relationships between these various tectonic entities is important in deducing provenance and tectonic relations of the Whitehorse Trough.

Nisling (and Yukon-Tanana) Terrane

Nisling Terrane, a para-autochthonous metamorphosed continental margin assemblage, forms a northwest-trending belt of Cambrian and older, quartz-rich metasedimentary rocks and marble west of Northern Stikinia (Wheeler and McFeely 1991). Recent work suggests that Nisling Terrane may be basement to deformed Paleozoic sedimentary and volcanic rocks of the adjacent Yukon-Tanana Terrane (Mortensen 1992; Gehrels *et al.* 1990; 1991). Together the Nisling and Yukon-Tanana terranes constitute a very large assemblage of Paleozoic and older, siliceous metasedimentary and felsic metaigneous rocks.

Northern Stikinia

Stikinia consists of Paleozoic volcanic and marine sedimentary assemblages overlain by Triassic and younger arc volcanic rocks and associated sedimentary successions (Brown *et al.* 1991). North of 59°N latitude however, the Paleozoic basement is apparently absent, and Stikinia is represented entirely by Late Triassic arc volcanics (Lewes River arc), coeval plutons and the marginal basin sedimentary rocks of the Whitehorse Trough. "Northern" Stikinia is used herein to distinguish the dominantly Mesozoic rocks in the north from Stikinia with Paleozoic basement.

Lewes River arc

This Late Triassic calc-alkaline, island arc assemblage is dominated by submarine and subaerial augite and plagioclase-phyric basaltic andesite flows, autoclastic breccia, agglomerate and lahar. The arc has a present-day strike length of >700 km, includes the volcanic portions of the Lewes River (Povoas Formation) and Stuhini groups and forms the western margin of most of Northern Stikinia. Coeval, Late Triassic plutons that form the roots to the volcanic arc are typical of the northwestern part of Stikinia in British Columbia (Woodsworth *et al.* 1991) but are not well exposed in the Yukon.

Whitehorse Trough

The Whitehorse Trough is a 500 km long, early Mesozoic marine basin whose lithologically diverse sedimentary strata recorded evidence of a tectonically active source region (Wheeler 1961; Souther 1971; Eisbacher 1974; Dickie 1989). Late Triassic to Middle Jurassic strata of the Whitehorse Trough in southern Yukon form four distinct assemblages: (1) a Carnian and Norian arc-marginal coarse-fragmental volcanogenic succession of laharic flows, agglomerate, conglomerate, tuff and greywacke in depositional contact with volcanic rocks of the Lewes River arc; (2) upper Norian bioclastic limestone and limey fine-grained clastics; (3) Sinemurian to Toarcian shale, sandstone and interbedded sandstone-mudstone rhythmites; and (4) Sinemurian to Bajocian, coarse-grained, clast-supported, cobble and boulder marine conglomerate (Figure 5.3). Assemblages 1 and 2 comprise the Aksala Formation of the Lewes River Group and are constrained by macrofossil and conodont ages (Tozer 1958; Wheeler 1961; Tempelman-Kluit 1984; Hart and Radloff 1990; M. Orchard written comm. 1990; Orchard 1991). Assemblages 3 and 4 comprise the Richthofen and Conglomerate Formations of the Laberge Group (Tempelman-Kluit 1984). They are correlated with the Takwahoni and Inklin Formations respectively in British Columbia, and are constrained largely by ammonite biochronozones (Smith *et al.* 1988; H. Tipper, pers. comm. 1989 1993; Poulton and Tipper 1991; Johannson 1993). The basin fill exceeds 6000 m in thickness of which the Laberge Group accounts for at least 2500 m (Cockfield and Bell 1944; Wheeler 1961; Dickie 1989; Hart and Radloff 1990). Dramatic easterly thickening of the clastic portion of the Whitehorse Trough has been documented by Wheeler (1961) and Dickie (1989).

The Lewes River and Laberge groups are separated by a laterally discontinuous erosional unconformity along the western basin margin, yet are conformable along the basin axis (Wheeler 1961; Dickie 1989). This disconformity marks a sea-level lowstand in the basin, reflecting either uplift of the basin margin, a major eustatic sea-level fall during Rhaetian and Hettangian time (Haq *et al.* 1987) or both (Dickie and Hein 1992). The Lewes River-Laberge Group contact is variably assigned to the top of the upper Lewes River limestone unit or the bottom of the lower Laberge Group conglomerate (Tozer 1958; Hart and Radloff 1990).

<u>Relations between Tectonic Elements</u>

Lower Mesozoic Whitehorse Trough strata are thought to have been deposited in a forearc basin lying above a southwest-dipping subduction zone, northeast of the Lewes River arc (Tempelman-Kluit 1979; Morrison 1981; Figure 5.4). The Lewes River

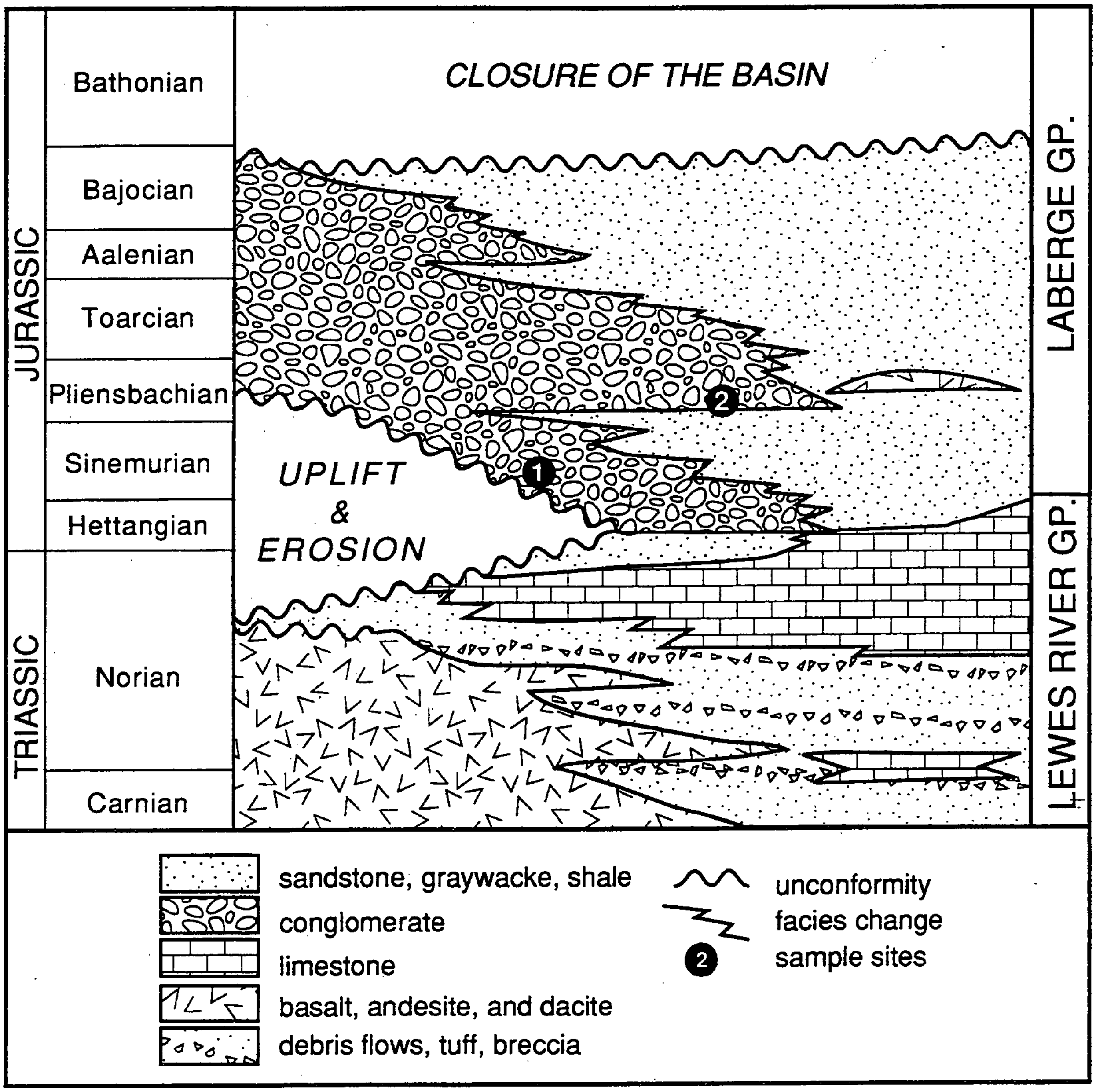
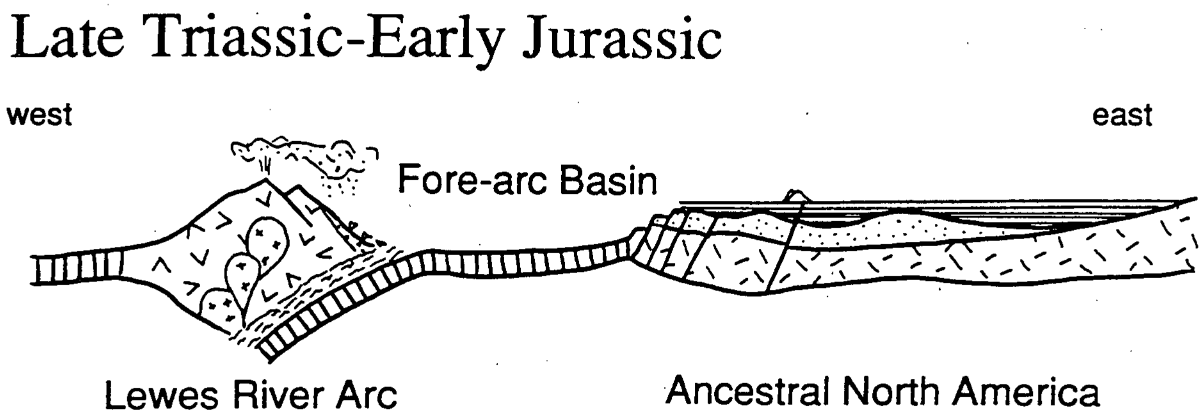


Figure 5.3 Generalized stratigraphy of Whitehorse Trough strata near Whitehorse (modified from Hart and Radloff 1990). The basin represents two phases of accumulation spanning Carnian to Bajocian time. The first (Late Triassic) is dominated by volcaniclastic debris flows of the Lewes River Group and the second (Early-Middle Jurassic) is characterized by progradation of submarine fans of the Laberge Group. The contact between the two groups is generally marked by a disconformity, the upper carbonate unit of the Lewes River Group or the first appearance of granite clast conglomerate. At Site 1 these markers are absent and the strata there may represent a transition between Lewes River and Laberge groups. As a result the strata may be Hettangian or Sinemurian in age.

a)



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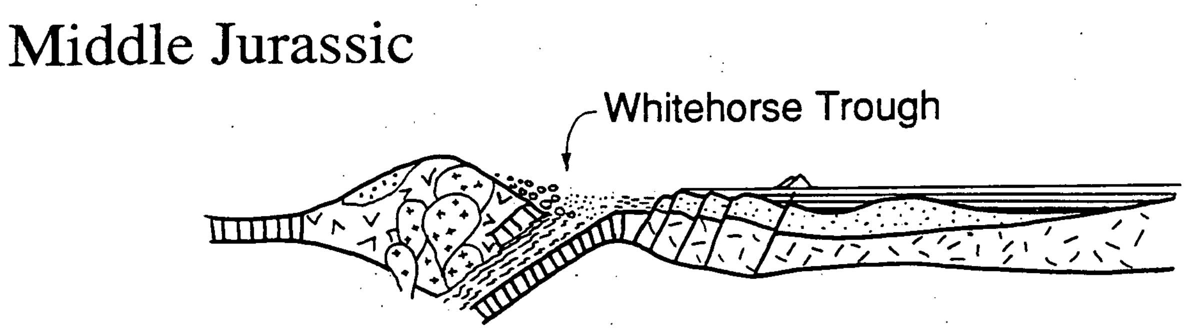

Figure 5.4 Tectonic cross-section of Whitehorse Trough and adjacent crustal units in southern Yukon during Late Triassic time (modified from Tempelman-Kluit 1979). Note that the Whitehorse Trough is represented as a forearc basin above a southwest-dipping subduction zone. Tempelman-Kluit showed the Lewes River arc constructed upon continental crust (Nisling Terrane) however isotopic signatures in the arc suggest it was built upon a primitive or transitional crust as indicated in this figure.

arc in Northern Stikinia was thought to have developed upon the leading(?) edge of metasedimentary rocks currently assigned to the Nisling and Yukon-Tanana terranes (Tempelman-Kluit 1979). A linear array of quartz-diorite to granite plutons and batholiths of the Klotassin suite which intrude the pericratonic metamorphic rocks, were presumed to be co-magmatic equivalents to the Late Triassic arc volcanic rocks and lie parallel to the trend of the volcanic arc (Tempelman-Kluit 1979).

Nisling Terrane and Northern Stikinia in the southern Yukon are separated by the 1 to 4 km wide Tally Ho shear zone (THSZ; Figure 5.2). The THSZ is a complex, northwest-trending zone of steeply dipping L-S tectonite with shallowly plunging lineations and sinistral kinematic indicators (Hart and Radloff 1990; Radloff *et al.* 1990; Hansen *et al.* 1990). Displacement across the zone probably occurred during Late Triassic and Early Jurassic time (Hart and Radloff 1990). The deformed zone is in Lewes River arc rocks at the westernmost limit of northern Stikinia. Immediately west of the shear zone, Nisling Terrane rocks are exposed as pendants in the Coast Plutonic Complex but the thick Whitehorse Trough clastic package is absent (Hart and Radloff 1990). Although the THSZ records dominantly strike-slip motion, it is likely that a component of vertical motion along the structure played a role in the development of the western margin of the Whitehorse Trough.

The nature and timing of the juxtaposition of Nisling and Northern Stikinia is the subject of much debate (Doherty and Hart 1988; Hart and Radloff 1990; Jackson *et al.* 1991; Currie and Parrish 1993; Johnston 1993; Johnston and Erdmer, 1995). Most workers would agree that Nisling was structurally juxtaposed with Northern Stikinia and could have provided material to the Whitehorse Trough by *ca.* 180 Ma.

LABERGE CONGLOMERATE

The Laberge Group is dominated by polymictic, clast- and matrix-supported cobble- and boulder-rich conglomerate whose well-rounded clasts are locally up to 2 metres in size (Figure 5.5). The conglomerates are debris flow, sheet flood and bar deposits of fan deltas which prograded basinward in response to basin subsidence and uplift of the source region throughout the Early Jurassic (Figure 5.6; Dickie 1989; Dickie and Hein, in press). Paleoflow indicators along the western margin of the trough reveal essentially east-directed sediment transport (Bultman 1979; Dickie 1989).

Volcanic and plutonic clasts dominate over sedimentary clasts in the heterogeneous clast population (Figure 5.7). Volcanic clasts consist of aphyric or

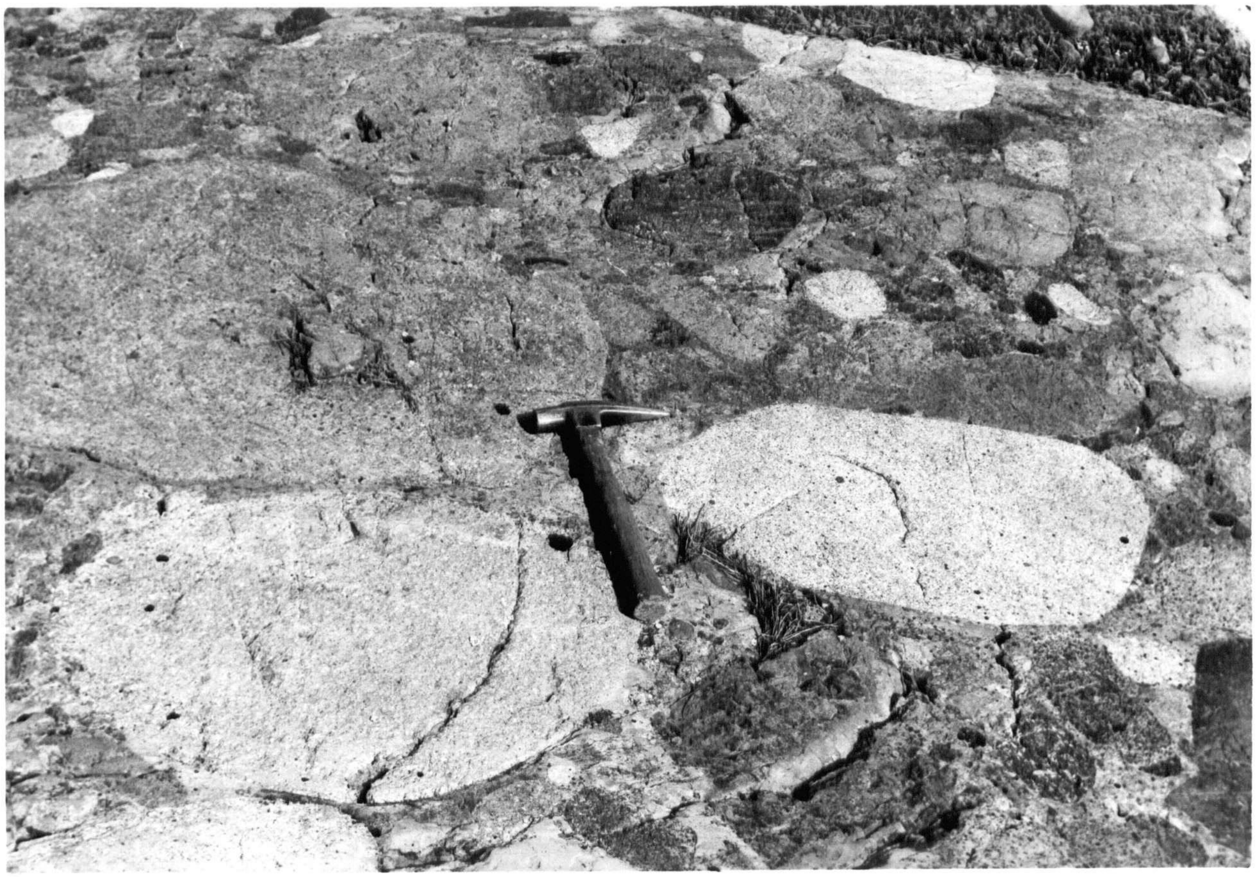

Figure 5.5a Laberge Group conglomerate at Site 1 on the Alaska Highway, showing typical poorly-sorted, polymictic, well-rounded and coarse-grained nature of the clasts. Clasts are dominantly volcanic and plutonic in origin.

Figure 5.5b Extremely large boulders such as this among smaller clasts are not atypical in proximal Laberge Group fan deltas. These boulders are evidence of deposition of already rounded clasts in gravitational debris flows.

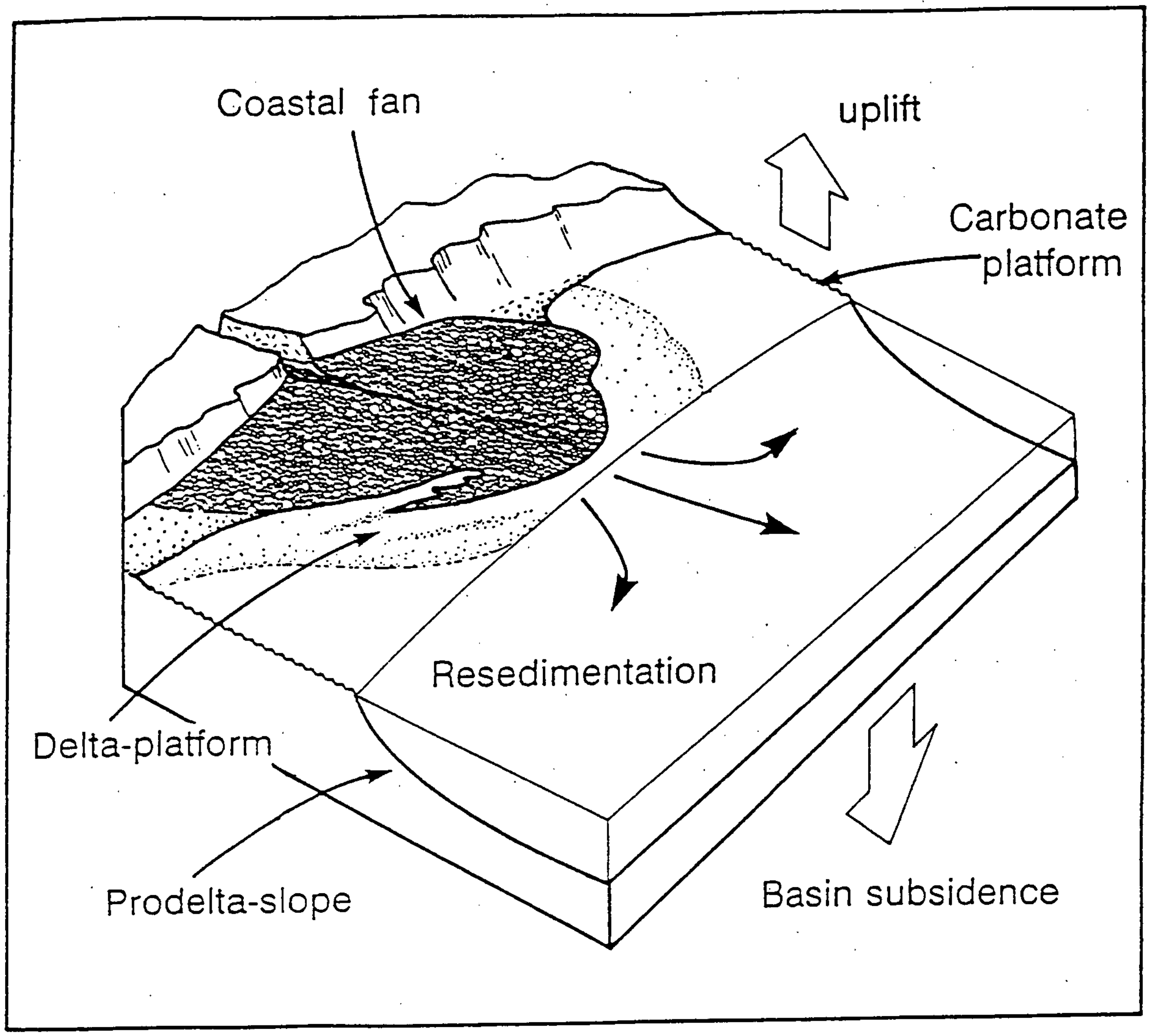

Figure 5.6 Model for the deposition of fan deltas and submarine fans associated with uplift and regional subsidence of the arc margin. Site 1 represents a proximal coastal fan setting whereas Site 2 represents a marginal coastal fan setting (modified from Dickie and Hein, in press).

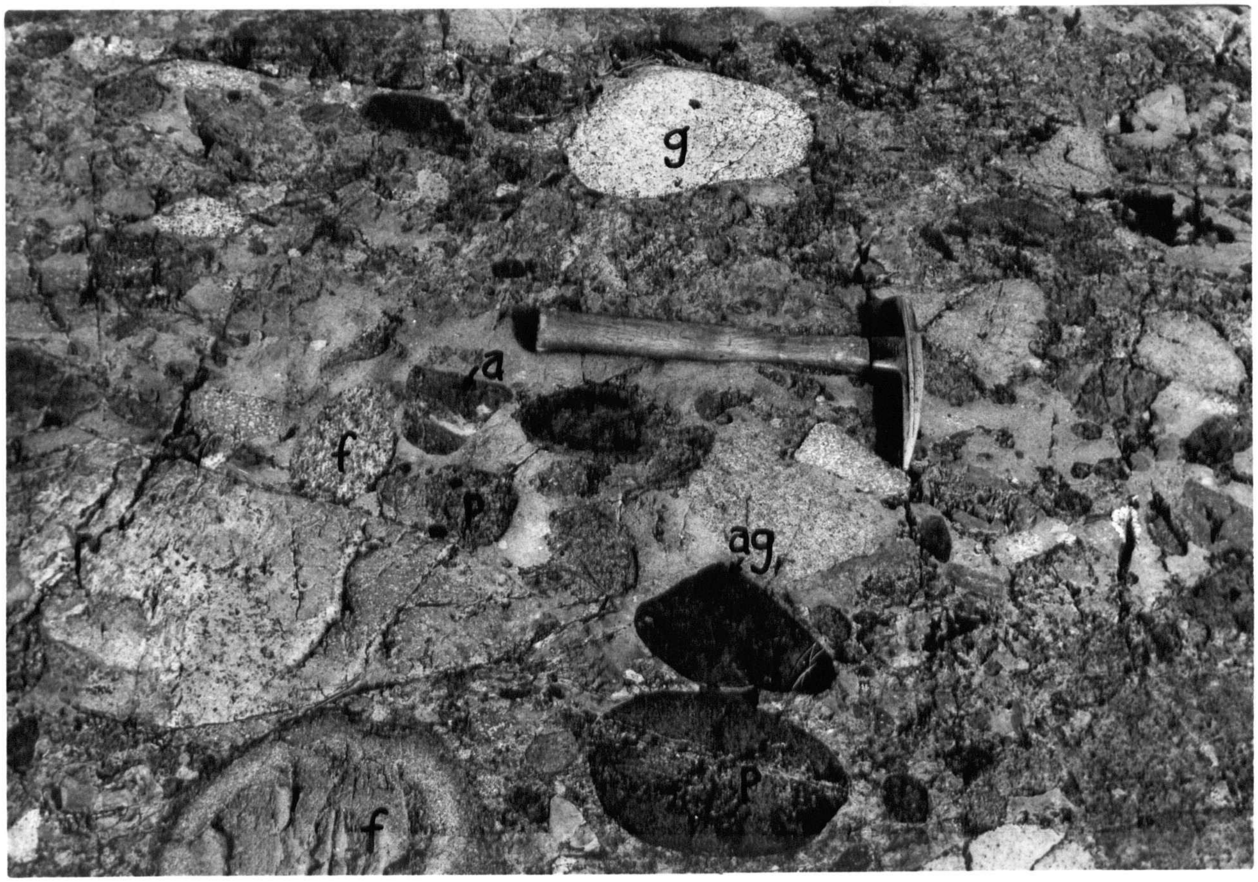

Figure 5.7 Polymict, clast-supported cobble-boulder Laberge Group conglomerate at Site 1. Clast lithologies include: **a**-aphanitic basaltic andesite; **ag**-agglomerate; **p**-augite-phyric basalt; **f**-feldspar porphyritic andesite; and **g**-hornblende-biotite granite.

plagioclase and augite-phyric basaltic andesite porphyries, propyllitically altered andesite, unwelded tuff and volcanic conglomerate. Plutonic clasts include alkali feldspar megacrystic and equigranular biotite-hornblende granite and granodiorite, slightly foliated hornblende quartz diorite, fine-grained potassium feldspar-hornblende granophyric granodiorite, and pink potassium feldspar granophyric granite. Alkali feldspar syenite and granitic clasts containing disseminated copper mineralization are rare but distinctive. Sedimentary clasts include black to grey shale, red shale, volcanogenic sandstone, limestone, and finely interbedded sandstone-black mudstone couplets. A minor, though important clast suite is a metamorphic population composed of foliated quartzite, quartz-mica schist, chlorite schist, orthogneiss, marble and quartz siltite.

A ternary plot of clast data, recalculated from 45 000 clasts in terms of sedimentary, volcanic and plutonic end members, demonstrates the temporal evolution of the clast population throughout the deposition of the Laberge Group conglomerate (Figure 5.8). Volcanic and sedimentary clasts predominate in older strata (uppermost and transitional Lewes River Group) and basal Laberge Group. The proportion of granitic clasts in Laberge Group strata increases upsection until they constitute 67% of the total clast population by Aalenian-Bajocian time. The temporal shift from sedimentary to volcanic to plutonic clast domination represents progressive erosion of the arc marginal shelf, the volcanic arc and the arc plutons respectively (Dickie 1989).

Clast Provenance

Sedimentary clasts are entirely intrabasinal, originating from Lewes River Group sandstone, shale and limestone. They are correlated on the basis of petrography, *in situ* intraclastic channel fill and side-wall collapse blocks, and the presence of Late Norian conodonts in limestone clasts (M. J. Orchard written comm. 1990). Sedimentary clasts were produced during the development of the erosional unconformity on the western margin of the Whitehorse Trough during earliest Jurassic time.

Distinctive volcanic clast lithologies, specifically augite, and augite-feldspar-phyric basaltic andesite, are confidently correlated to the Povoas Formation which forms the volcanic part of the Lewes River Group. Rhyolitic and dacitic clasts are locally common but have no known correlatable source. Felsic volcanic rocks may have been locally deposited late in the arc-building process, and were among the first rocks to have been eroded, thus preventing preservation.

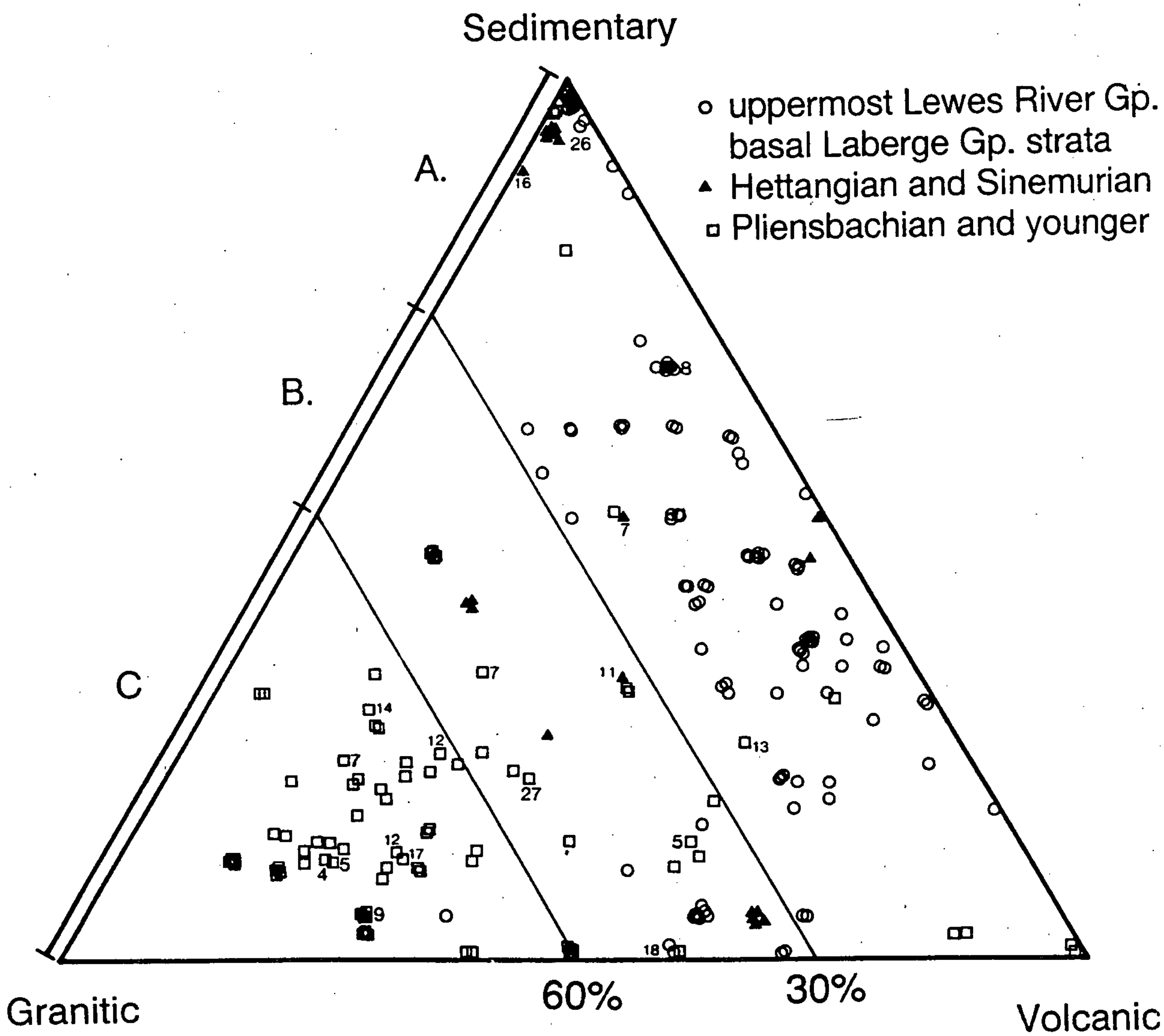

Figure 5.8 Temporal Clast Trend diagram depicts the evolution of conglomerate clast abundance over time in the Whitehorse Trough (after Dickie 1989; Dickie and Hein, in press). overall trend (A to C) reflects an initial phase of coastal uplift (A) and incision of fan deltas and shelf channels with abundant arc volcanics and coastal sedimentary lithic clasts, evolving into a dissected arc (C) phase dominated by arc-pluton derived material. The numbers represent the number of beds with identical or very similar clast tallies. Each tally is based on 100 or 50 clasts per bed for 440 beds.

Plutonic clasts are lithologically diverse and difficult to confidently correlate with specific source plutons. Petrographic similarities between distinctive plutonic clast types and potential source plutons west of the basin were noted by Wheeler (1961), Tempelman-Kluit (1974, 1979), Bultman (1979), Mihalynuk and Mountjoy (1990), Jackson *et al.* (1991) and Hart and Brent (1993). However, most of the potential source plutons so far dated have returned reliable U-Pb zircon dates younger than 190 Ma (Hart and Radloff 1990; Johnston 1993; Currie 1992) thus indicating that they are too young to have provided clasts to Pliensbachian and older strata. Distinctive alkali feldspar megacrystic, hornblende granodiorite clasts in Whitehorse Trough strata (Figure 5.9) have been variably attributed to the Little River and Bennett batholiths, the pink quartz monzonite (of Tempelman-Kluit 1974) in the Yukon, and the Willison pluton in British Columbia. However only the Willison pluton has yielded reliable pre-Jurassic dates (*ca.* 220 Ma; Bultman 1979; Mihalynuk, pers. comm. 1992). Clasts attributed to this pluton are in Norian strata (Mihalynuk and Mountjoy 1990; Jackson *et al.* 1991), and extrapolation of this as a detrital source pluton to the Early Jurassic Laberge Group seems probable.

Some coarsely crystalline quartz-rich granite clasts contain augite-phyric basalt xenoliths (Figure 5.10). This suggests that at least some of the granite plutons which eroded to form clasts in the Laberge Group were intrusive into the augite-phyric volcanics typical of the Lewes River Group. Potential pre-Laberge plutonic sources for syenitic and copper-bearing clasts are unknown in the Yukon but plentiful in northern British Columbia.

Metamorphic clasts rarely exceed 1-2% of the Laberge Group total clast tallies but have been observed locally in western Whitehorse Trough strata (Wheeler 1961; Bultman 1979; Dickie 1989; Hart and Pelletier 1989). West of Whitehorse the metamorphic clasts are in strata of probable Middle Jurassic age, but west of Atlin, British Columbia metamorphic clasts are found in conglomerate of Norian age (Mihalynuk and Mountjoy 1990; Jackson *et al.* 1991). The metamorphic clasts show a remarkable similarity to rocks of the Nisling Terrane and have been interpreted as a stratigraphic linkage with that terrane (Jackson *et al.* 1991). However, Currie and Parish (1993) suggest that the metasedimentary clasts have an origin in the Paleozoic part of Stikinia and that Nisling Terrane could not have supplied detritus until Middle Jurassic time.

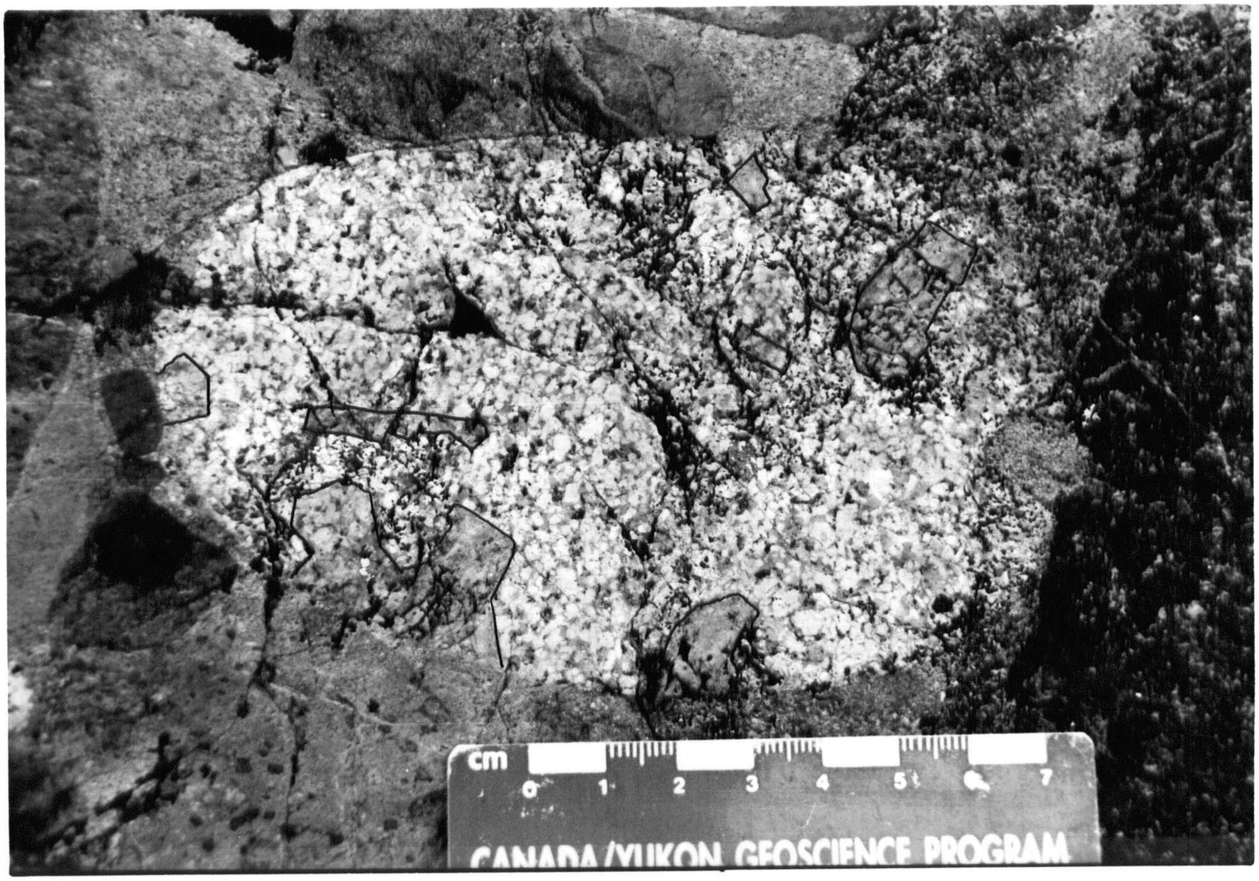

Figure 5.9 Clast of alkali feldspar megacrystic granite from Site 1. These clasts are common throughout Laberge Group conglomerate and have been attributed to the petrologically similar Bennett Batholith and pink quartz monzonite (Long Lake suite) in southern Yukon or Willison pluton in northern British Columbia. The Willison pluton is Late Triassic in age, the others are late Early Jurassic. The alkali feldspar megacrysts are outlined in black to make them apparent.

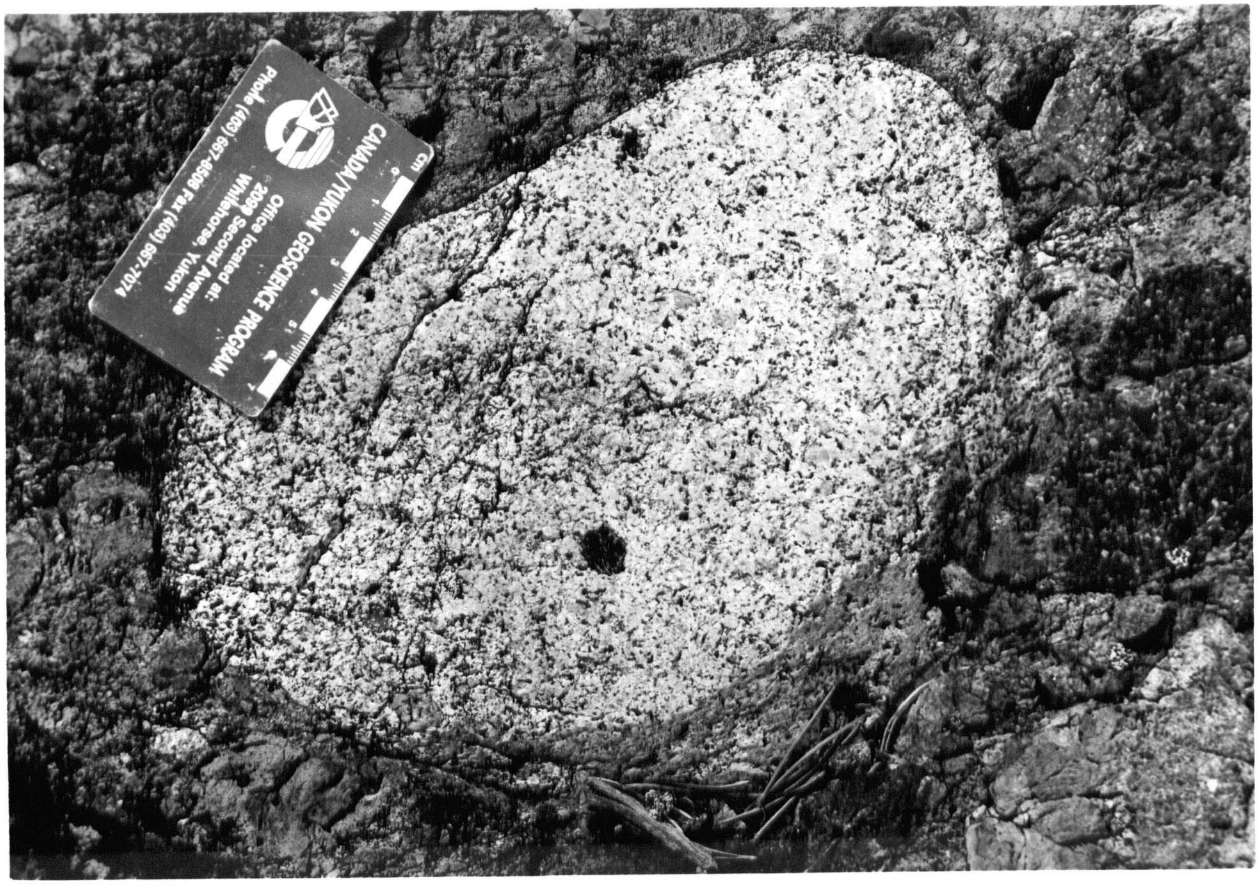

Figure 5.10 Coarse-grained, biotite granite clast containing a dark grey augite-phyric basalt xenolith typical of the Lewes River Group volcanic rocks. These relationships, as well as the clasts low initial strontium value (0.70414), suggests that the source granite pluton intruded the Late Triassic volcanic arc and not metasedimentary rocks of the Nisling Terrane.

GEOCHRONOMETRY

Sample Locations and Sedimentology

Lithologically diverse granitic clasts were collected from two conglomerate exposures at different stratigraphic levels. Sample locations and descriptions are given in Table 5.2. Site 1 (samples Y-1A to Y-1E) is part of a section exposed in a roadcut on the south side of the Alaska Highway at kilometre 1505 (Figure 5.11).

The age of the conglomerate at Site 1 is not directly known. The strata have characteristics of both the Lewes River and Laberge Group, yet the section lacks the typical disconformity or carbonate unit which represents the contact between the two units. As such, these rocks are considered to be a transitional unit between the two groups, deposited during Late Carnian to Sinemurian time. Similar clast tallies, exotic clast types, progradation and transgressional sequences allow correlation of the conglomerate with similar rocks seven kilometres to the north. Those rocks are in stratigraphic contact with a Late Norian limestone, thus suggesting a Hettangian and younger age for the conglomerate. Most conglomeratic units in the Whitehorse Trough that have biostratigraphic age determinations are Toarcian and older (H. Tipper pers. comm. 1989; Johannson 1993, Palfy and Hart 1995). In addition the Alaska Highway conglomerate is interbedded with distinctive Nordenskiold tuff which are elsewhere dated as Upper Pliensbachian (Palfy and Hart 1995; Hart and Mortensen unpublished data). Although the application of layer-cake stratigraphy to the facies dominated Laberge Group is inappropriate, correlation of the sample site to like-strata with age constraints leads us to suggest that the strata of the Alaska Highway section is an areally and volumetrically restricted alluvial and coastal fan deposit of Hettangian to Pliensbachian age.

Distinctive boulder beds with clasts over a metre in size, are interbedded with thin sandstones containing heavy mineral laminae and shoreface bar-swash stratification. The abundance of very coarse-grained strata with debris-flow characteristics, or beds containing single large clasts suggests extreme paleotopographic gradients. This outcrop has been interpreted as a source-proximal, steep-sided lobe of a multilobe fan-delta (Dickie 1989). Various paleocurrent indicators, some bi-directional but biased by unidirectional in-channel features and the location of basin fill, indicate general eastward paleoflow (Figure 5.12a).

TABLE 5.2 Location and descriptions of granitic clasts and shale samples

Sample	Latitude Longitude	Locality	Description and Notes
Y-1A	60°51.3N 135°26.0W	Alaska Highway km 1505, Site 1	medium-grained, slightly foliated, sphene-rich hornblende>biotite granodiorite with small and sparse pink alkali feldspar
Y-1B	60°51.3N 135°26.0W	Alaska Highway km 1505, Site 1	green-grey, granophyric plagioclase-hornblende dacite-granodiorite porphyry
Y-1C	60°51.3N 135°26.0W	Alaska Highway km 1505, Site 1	fine-grained hornblende monzodiorite with alkali feldspar megacrysts and biotite clots
Y-1D	60°51.3N 135°26.0W	Alaska Highway km 1505, Site 1	fine to medium grained, pyroxene-phyric andesite
Y-1E	60°51.3N 135°26.0W	Alaska Highway km 1505, Site 1	medium-grained, hornblende>biotite, quartz monzonite with alkali feldspar megacrysts
Y-2A	60°58.5N 135°11.0W	Horse Creek, Site 2	coarsely-crystalline, grey alkali feldspar syenite with medium grained hornblende
Y-2B	60°58.5N 135°11.0W	Horse Creek, Site 2	dark grey, medium-grained, plagioclase-hornblende granophyric granodiorite
WHA 11	60°51.3N 135°26.0W	Alaska Highway km 1505, Site 1	hornblende granodiorite, collected by G.W. Morrison 1979.

Y-2C	60°58.5N 135°11.0W	Horse Creek, Site 2	Laberge Group shale (Pliensbachian?).
T75 107-6	59°19N 134°02W	Torres Channel	Laberge Group siltstone-shale turbidite, (Early Pliensbachian), collected by T. Bultman.
T74 202-2	59°32N 134°17W	Taku Arm	Calcareous siltstone, (Pliensbachian?), collected by T. Bultman.
A-8-2-2	59°19.5N 133°53.7W	Teresa Island	Laberge Group greywacke (Early Sinemurian), collected by L. Werner.
T74 109-1	59°17.2N 134°01.9W	Copper Island	Lewes River Group sandstone (Norian?) collected by T. Bultman

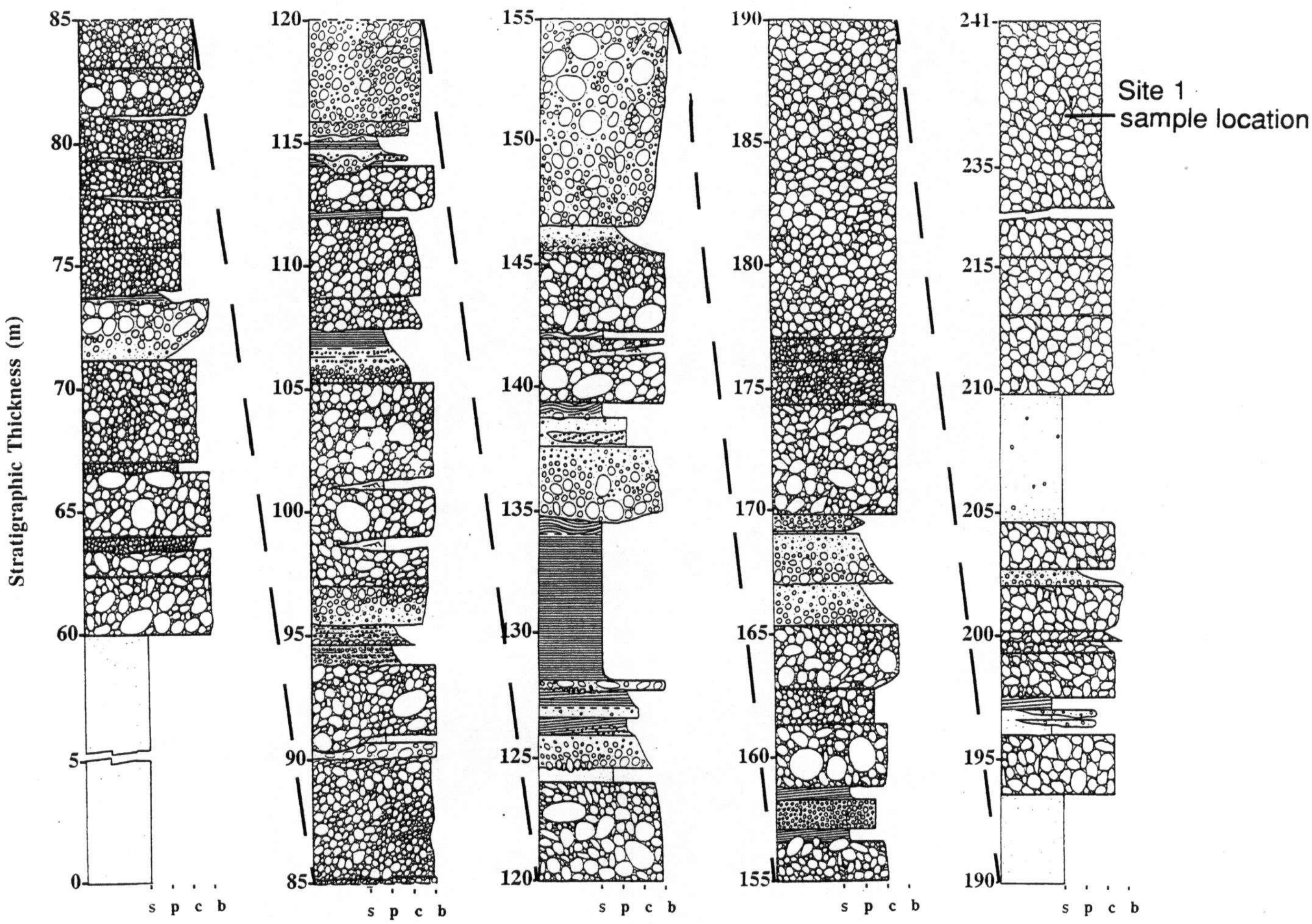

Figure 5.11 Stratigraphic section including the Site 1 sample location at km 1505 on the Alaska Highway. Most conglomerate beds are boulder conglomerate (clasts >23 cm). Outsized boulder flows (clasts >50 cm to a maximum of 240 cm) are depicted graphically. The section represents a coastal fan sequence containing stacked beachface to mid-shoreface deposits broken by thick successions of debris flow boulder conglomerate. This section is indicative of relative sea-level rise coupled with fan progradation. S,P,C, and B = sand, pebble, cobble and boulder clast sizes.

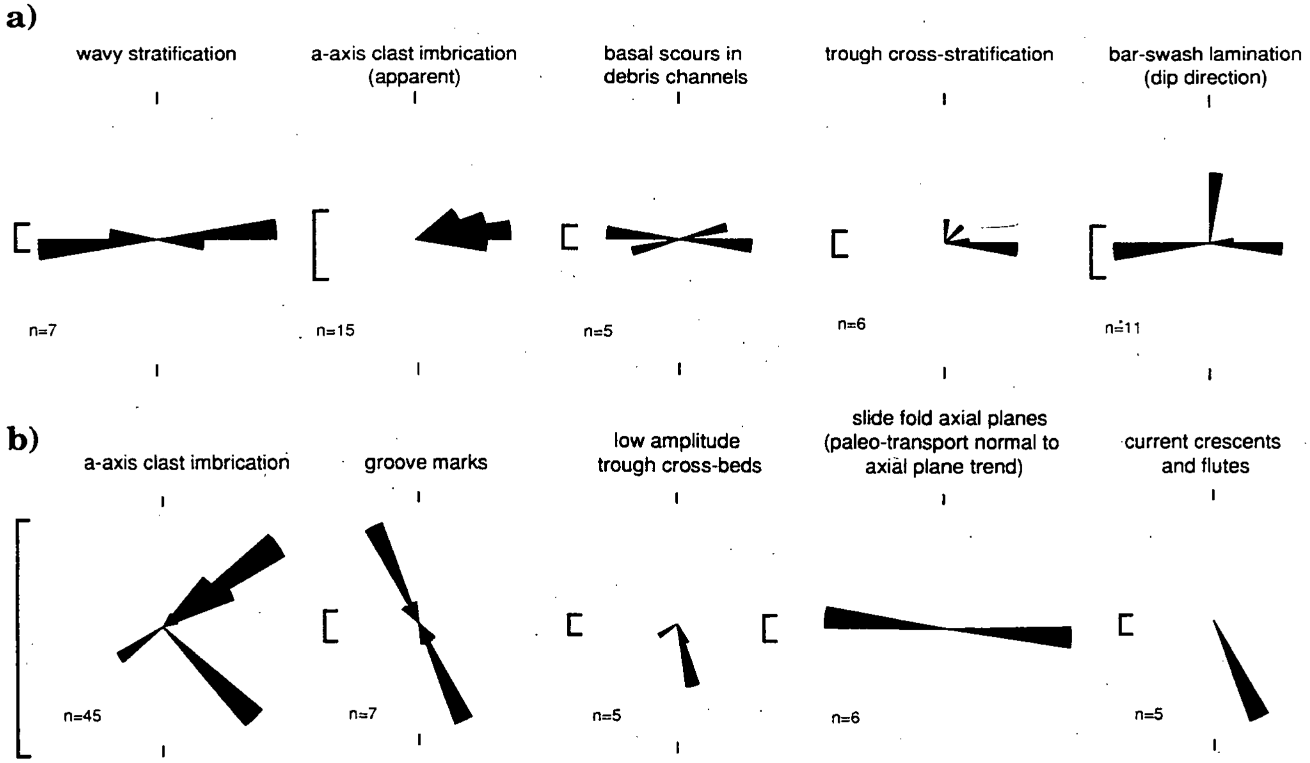

Figure 5.12 Paleocurrent plots for various sedimentary structures indicating general east-directed sediment transport. The number at the bottom left is the number of data and the bar scale represents 20 percent of the readings. **a)** Alaska Highway section of Figure 11. Wavy-stratified sandstone suggests wave encroachment from the east since imbricated clasts in the thick debris flow conglomerate and channel base scours point to east-directed sediment transport. Heavy mineral rhythmites of nearshore sand-shoal deposits record stoss- and lee-side swash processes and along-shore currents. **b)** Horse Creek section of Figure Sole marks indicate that bottom-hugging currents flowed in a southeast-direction. Slide-fold axial planes oriented normal to sole marks support a southeasterly down-slope direction. Variations in apparent transport directions at this site are probably the result of a lateral fan lobe shift and abandonment.

Site 2 (samples Y-2A and Y-2B) is a well exposed outcrop of boulder-rich conglomerate with minor interbeds of sandstone and black shale on the Klondike Highway near the south end of Lake Laberge at Horse Creek (Figure 5.13). Conglomerate at this site is dominated by granitic clasts and depositionally overlies mudstone containing Sinemurian ammonites (G. Johannson pers. comm. 1993). Consequently rocks at this site are interpreted to be Pliensbachian in age. Prodeltaic shale, recumbent slump-folds and boulder-bed fan toesets interbedded with deep water shale (Dickie 1989) reflect a deep water origin which contrasts sharply with the coastal fan setting of the Alaska Highway section. The Horse Creek section represents a submarine fan lobe which changed course and flooded prodeltaic muds with conglomerate. Paleocurrents are well developed at this locality and include channel scours, nested flute casts, grooves, superbly preserved crescents, minor cross-stratification and imbricated clasts. Paleoflow is to the southeast and northeast, reflecting a fan lobe migration through the section. Radial paleoflow is typical of fans and the degree of variance at this site probably reflects deposition in a more distal setting, but are interpreted to reflect dominantly eastward sediment transport (Figure 5.12b).

Results

U-Pb analyses were performed on two samples from each of the two sites (Table 5.3). All dates are reported with two sigma errors. None of the samples gave unequivocally concordant dates. All regressions were performed using the method of York (1969). The interpreted dates have been rounded from their analytical result to the nearest integer and their errors have been rounded up to the next integer.

Sample Y-1A yielded a clear, transparent, sub- to euhedral prismatic zircon population. Two fractions were analysed (Figure 5.14a). Fraction **a** is concordant at 206.2±2.5 but fraction **b** is slightly discordant with lower $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages, but its $^{207}Pb/^{206}Pb$ age is similar to that of fraction **a**. Fraction **b** is interpreted to have suffered Pb loss. Assuming modern day Pb loss, a discordia fit to the fractions yields an age of 207.5±10.0. Since the sample cannot be younger than the minimum $^{206}Pb/^{238}U$ age of fraction **a**, 204.4 Ma, the lower error limit on the 207.5 Ma date is about 3 Ma. As a result, the interpreted age of this rock is 208+10/-3 Ma.

Sample Y-1E gave clear, transparent, long, prismatic zircons which yielded three slightly discordant analyses that plot in a linear array reflecting Pb-loss (Figure 5.14b).

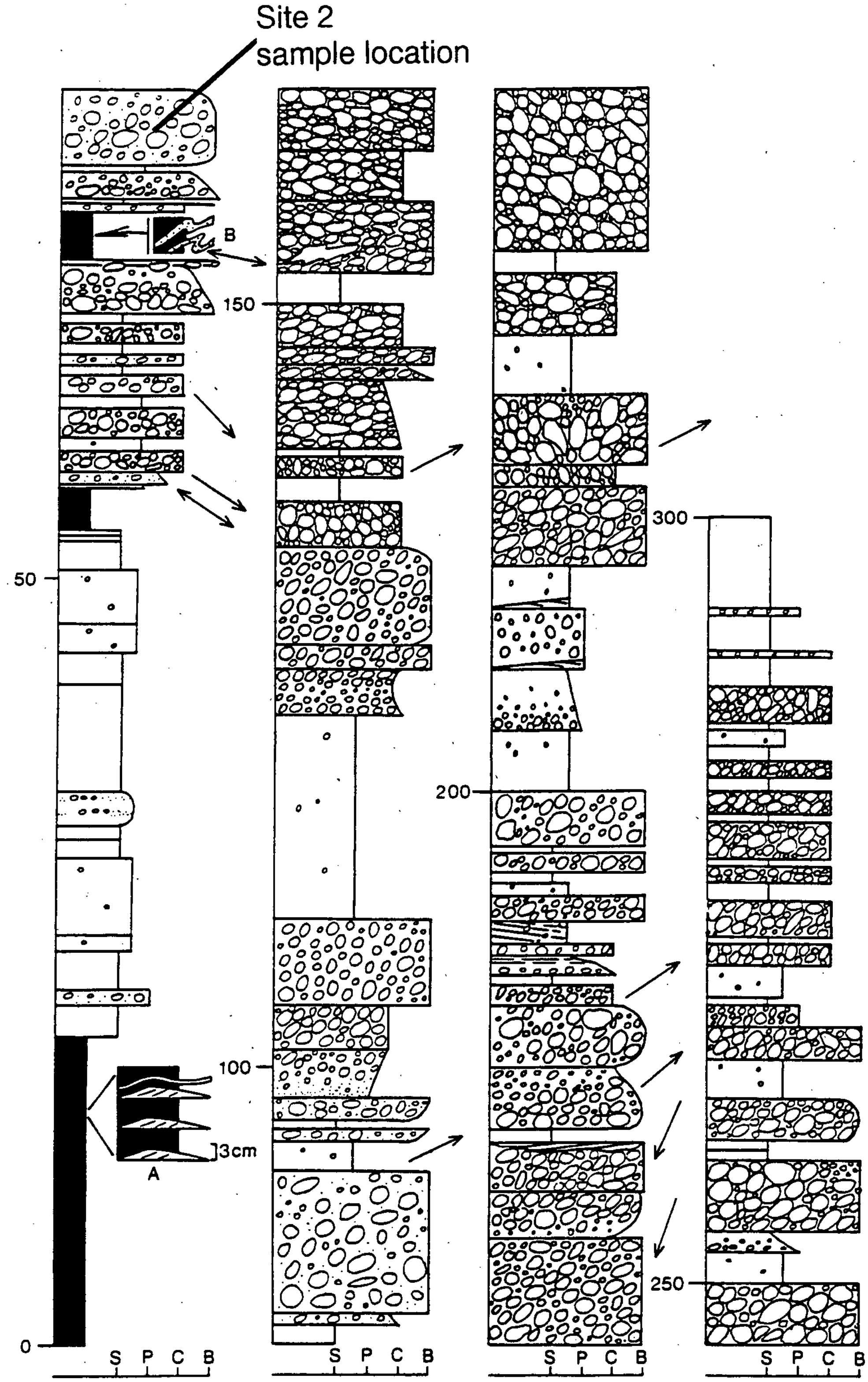

Figure 5.13 Stratigraphic section including the Site 2 sample location at Horse Creek. Arrows indicate locations of uni and bidirectional paleocurrent indicators. Inset A is of non-graded, ripple cross-laminated sand and shale couplets typical of the shale dominated strata. Inset B is of slide folds. Of particular interest is the very thick (15m) boulder conglomerate between 235-250 m which contains a large proportion of rafted shale blocks up to 4m long. s,p,b and c = sand, pebble, cobble and boulder clast sizes.

TABLE 5.3. U-Pb ZIRCON ANALYTICAL DATA OF SAMPLES FROM LABERGE GROUP GRANITIC COBBLES*

Fraction†	Wt. (mg)	U (ppm)	Radiogenic Pb (ppm)	$^{206}Pb/^{204}Pb$§ Measured	Common§ Pb (pg)	$^{208}Pb/^{206}Pb$**	$^{206}Pb/^{238}U$ (Isotopic Ratios ± 2σ**; Dates in Ma ± 2σ)	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
Y88-1A (UBC lab number Y88-31A)									
a, NM2/1° +74μ	0.3	203.6	6.56	802	154	0.1019	0.03250±0.43 (206.2±1.8)	0.22518±0.66 (206.2±2.5)	0.05025±0.39 (206.7±18.2)
b, M1.0/5° -44μ	0.2	289.2	9.00	1306	86	0.1008	0.03146±0.43 (199.7±1.7)	0.21811±0.57 (200.3±2.1)	0.05027±0.27 (207.9±12.4)
Y88-1E (UBC lab number Y88-31E)									
a, NM2/1° +74μ	0.5	441.8	14.04	2646	163	0.1041	0.03199±0.15 (203.0±0.6)	0.22263±0.18 (204.1±0.7)	0.05047±0.06 (216.7±3.0)
b, NM1.5/3° M2/1°, 74+44μ	0.3	1187.6	35.91	2771	239	0.1073	0.03037±0.11 (192.9±0.4)	0.21082±0.21 (194.2±0.8)	0.05034±0.16 (210.8±7.4)
c, M1.0/5° -44μ	0.1	874.6	25.52	1063	148	0.1145	0.02912±0.12 (185.0±0.5)	0.20219±0.23 (187.0±0.8)	0.05035±0.16 (211.6±7.4)
Y88-2A (UBC lab number Y88-44A)									
a, NM2/1° +74μ	0.4	303.4	9.29	403	582	0.1193	0.03045±0.32 (193.4±1.2)	0.21081±1.42 (194.2±5.0)	0.05021±1.25 (204.9±58.1)
b, NM1.5/3° M2/1, 74+44μ	0.2	384.1	11.89	571	257	0.1327	0.03041±0.22 (193.1±0.8)	0.21196±0.49 (195.2±1.8)	0.05054±0.34 (220.0±15.8)
c, M1.0/5° -44μ	0.1	797.3	24.66	2190	66	0.1593	0.02971±0.21 (188.8±0.8)	0.20588±0.32 (190.1±1.1)	0.05025±0.18 (206.6±8.5)
Y88-44B (UBC lab number Y88-44B)									
a, NM2/1° +74μ	0.6	202.1	6.76	2569	94	0.1335	0.03286±0.19 (208.5±0.8)	0.22793±0.29 (208.5±1.1)	0.05030±0.14 (208.9±6.8)
b, NM1.5/3° M2/1, -74+44μ	0.4	265.0	8.51	417	506	0.1395	0.03138±0.22 (199.2±0.9)	0.21892±0.60 (201.0±2.2)	0.05059±0.44 (222.2±20.4)
c, M1.0/5° -44μ	0.6	74.3	2.40	631	137	0.1617	0.03096±0.19 (196.6±0.8)	0.21485±0.53 (197.6±1.9)	0.05032±0.40 (209.8±18.8)

* Analyses by D.K. Ghosh at The University of British Columbia. Sample preparation and analytical procedures are as outlined in Armstrong et al. (1991). U and Pb concentrations and isotopic ratios are corrected for fractionation, spike and blank Pb. Isotopic composition of UBC blank is 206:207:208:204 = 17.0±2.6%:15.0±0.9%:37.3±0.5%. Total procedural blanks contain approximately 0.03 nanograms of both U and Pb.

† Split abbreviations: μ-microns, M-magnetic, NM-non-magnetic. The magnet current (Amperes) and backward tilt of the magnetic separator (in degrees) are given. All splits are hand-picked.

§ Corrected for spike and Pb fractionation of 0.46%±0.21% amu^{-1} for Daly, and of 0.12%±0.25% amu^{-1} for Faraday collectors.

** Common Pb isotopic compositions are corrected using Stacy and Kramers (1975) model Pb composition at 200 Ma. Errors are 1σ standard errors of the mean in percent for ratios and 2σ standard errors of the mean for ages. Estimation of errors follows numerical error propagation method of Roddick (1987). IUGS conventional decay constants are used in age calculations: $\lambda^{238}U = 1.55125 \times 10^{-10} a^{-1}$, $\lambda^{235}U = 9.8485 \times 10^{-10} a^{-1}$ (Steiger and Jäger 1977)

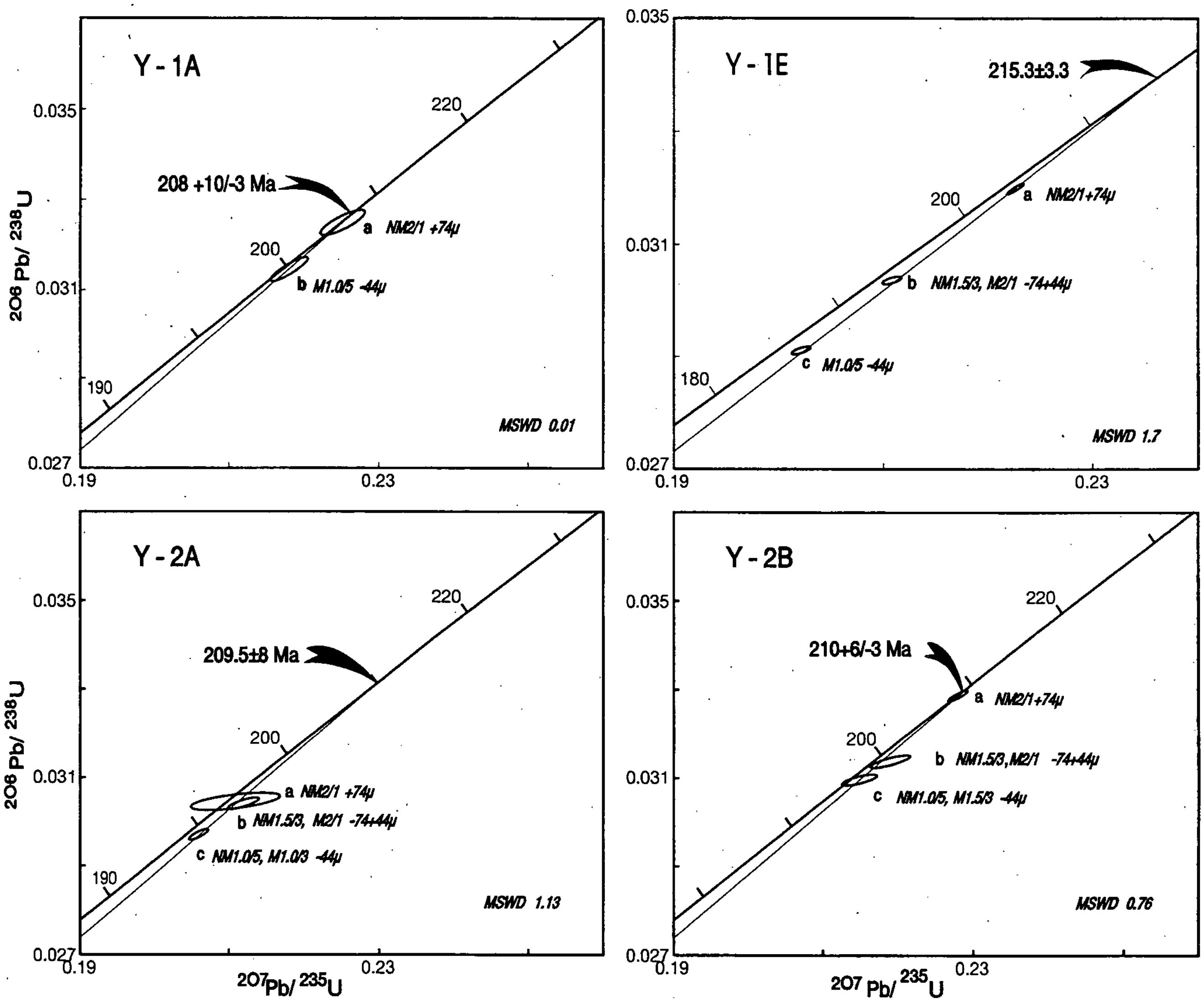

Figure 5.14 U-Pb concordia diagrams for Laberge Group cobbles. Samples Y1-A and Y1-E are from Site 1 on the Alaska Highway; Y-2A and Y-2B are from the Horse Creek section at Site 2. Concordia intercepts are based on York (1969) regression and Ludwig (1980) error algorithms. Error ellipses are 2 sigma. See text for explanation.

Assuming recent Pb-loss, a discordia gives an upper intercept at 215±4 Ma. The intercept is largely controlled by the $^{207}Pb/^{206}Pb$ age of the most precise fraction.

Sample Y-2A gave a population of short, stubby, brownish, euhedral zircon whose three fractions plot to form a short linear array just under concordia (Figure 5.14c). The large $^{207}Pb/^{235}U$ error on fraction **a** makes it overlap concordia near 194 Ma but its older $^{207}Pb/^{206}Pb$ age suggests probable Pb-loss. Assuming the Pb-loss is recent, the weighted mean $^{207}Pb/^{206}Pb$ age of the three fractions is 210±8 Ma.

Sample Y-2B yielded three fractions of clear, light brown, long, prismatic, transparent zircon. Fraction **a** is concordant at 208.5±1.0 Ma (Figure 5.14d). The other fractions nearly intersect concordia and appear to have suffered minor Pb-loss. A discordia fit through all fractions gives an upper intercept of 210±6 Ma, if recent Pb-loss is assumed. However the date cannot be less than the minimum $^{206}Pb/^{238}U$ age (207.7 Ma) of the concordant fraction. As a result, the interpreted age of this clast is 210+6/-3 Ma.

U-Pb determinations of four Laberge Group clasts indicate that Late Triassic plutons were important sources for the Whitehorse Trough clastic fill. The range of interpreted crystallization ages for the four clasts spans 215 to 208 Ma. Errors from the three youngest samples overlap between 216 and 207 Ma. There does not appear to be a difference in the age of the source plutons between the two sites, although the sample size is small. In addition, despite the varying lithologies of the analysed clasts, there are no notable differences in their ages. The proximity of the four dates and overlap of errors suggest that the clasts probably represent a single magmatic event. No obvious component of inherited zircon was observed in any of the analysed fractions.

WHOLE ROCK STRONTIUM VALUES

Strontium isotopic whole rock analyses for six Laberge Group granitic clast yielded initial strontium values between 0.70416 and 0.70498 (average 0.7045; Table 5.4). The values are consistent with the average value for island arc magmas (0.70437; Faure 1986) and suggest magma generation from Phanerozoic oceanic crust with negligible contributions from continental crust. The data approximate values from *in situ* Late Triassic plutons along the western margin of Northern Stikinia (0.70384-0.70439, av. 0.70417; Armstrong, Hart and Mihalynuk, unpub. data; Jackson *et al.* 1991).

TABLE 5.4 Whole rock strontium data for Laberge Group plutonic clasts and fine-grained clastic rocks in southern Yukon and northern British Columbia

Sample	Rock Type	Locality	Sr[a] (ppm)	Rb[a] (ppm)	$^{87}Rb/^{86}Sr$[b]	$^{87}Sr/^{86}Sr$[c] observed	Age[d] (Ma)	$^{87}Sr/^{86}Sr$[d] initial ±2σ
PLUTONIC CLASTS								
Y-1A	granodiorite	Alaska Highway	640	61.3	0.208	0.70479	208	0.70417±8
Y-1B	dacite	Alaska Highway	693	83.8	0.350	0.70565	~210	0.70460±4
Y-1C	granodiorite	Alaska Highway	687	73.9	0.311	0.70518	~210	0.70424±6
Y-1E	monzodiorite	Alaska Highway	680	78.3	0.333	0.70518	215	0.70416±6
Y-2A	syenite	Horse Creek	735	89.2	0.351	0.70590	210	0.70485±6
Y-2B	granodiorite	Horse Creek	875	70.5	0.233	0.70568	210	0.70498±10
WHA 11[e]	granodiorite	Alaska Highway	801	63.7	0.229	0.7055	~210	0.7048
FINE-GRAINED CLASTIC ROCKS								
Y-2C	shale	Horse Creek	409	111	0.787	0.70688	~190	0.70475±6
T75 107-6[f]	siltstone	Torres Channel	490	96.1	0.567	0.7066	~190	0.7051
T74 202-2[f]	calc-shale	Taku Arm	903	19.8	0.063	0.7054	~190	0.7052
T74 109-1[f]	sandstone	Copper Island	352	128	1.051	0.7096	~210	0.7065
A-8-2-2[g]	greywacke	Teresa Island	443	46.4	0.303	0.7056	~200	0.7047

NOTES: Analyses by D.K. Ghosh, R.L. Armstrong and C.J.R. Hart at The University of British Columbia.

[a] Sr and Rb concentrations were determined by duplicate analyses of pressed-powder pellets using X-ray fluorescence. Mass absorption coefficients were obtained from Mo Kα Compton scatter measurements. Rb and Sr concentrations have $\pm 1\sigma$ errors of 5%.

[b] $^{87}Rb/^{86}Sr$ ratios by XRF have $\pm 1\sigma$ error values of 2% for samples with both concentrations over 50 ppm and $^{87}Rb/^{86}Sr$ divided by the lowest concentration for samples with concentrations below 50 ppm (effectively ±1 ppm lower limit on concentration uncertainty).

[c] Sr isotopic composition was measured on unspiked samples prepared using standard ion exchange techniques. $^{87}Sr/^{86}Sr$ isotopic analyses reported to four decimals were determined prior to 1982. Sr isotopic measurements were made on a National Bureau of Standard (NBS) type 30 cm radius, 60° sector mass spectrometer designed and constructed by H. Faul and automated by R. L. Armstrong with a Nova 1210 computer. The $\pm 2\sigma$ errors for $^{87}Sr/^{86}Sr$ are 0.0002 for values with four decimal figures.

After 1982, Sr isotopic measurements were made on a Vacuum Generators Isomass 54R mass spectrometer (with upgraded source, focus and detector electronics) linked with a Hewlett-Packard HP-85 computer. Errors for values with five decimal figures are reported individually. Blanks contain approximately 0.8 and 6 ng of Rb and Sr respectively. Meaured Sr isotope analyses are normalized, assuming $^{86}Sr/^{88}Sr$ ratio of 0.1194, and further adjusted so the Eimer and Amend standard gives a $^{87}Sr/^{86}Sr$ ratio of 0.70800±0.00002 and the NBS Sr standard $SrCO_3$ (SRM 987) gives a ratio of 0.71019±0.00002. $\lambda = 1.42 \times 10^{-11}\ a^{-1}$ (Steiger and Jäger 1977).

[d] Initial $^{87}Sr/^{86}Sr$ ratios are calculated using U-Pb and presumed dates for granitic clasts and biostratigraphic ages (as determined by G. Johannson and H.W. Tipper, pers. comm. 1993) and assigned numerical ages using Harland et al. (1990) for the fine-grained clastic rocks.

[e] Sample of Morrison *et al.* (1979) recalculated with approximate date of 210 Ma.

[f] Sample of Bultman (1979) from UBC collection.

[g] Sample of L. Werner from UBC collection.

A single shale sample was analysed and is listed with three previously unpublished values from the Laberge Group and one from the Lewes River Group in northern British Columbia (Table 5.4). Assigning absolute ages to biostratigraphic ages determined from ammonite collections (using timescale of Harland *et al.* 1989), Laberge Group shale samples give calculated initial strontium values from 0.7047 to 0.7052 (average 0.7049). These values occupy a much narrower range than that determined for other Early Jurassic sedimentary rocks in Stikinia (0.70355-0.70547 by Samson *et al.* (1989). The Late Triassic Lewes River sandstone gives an elevated initial strontium value of 0.7065.

The $^{87}Sr/^{86}Sr$ values of the sedimentary rocks are slightly higher than those obtained for the granitic clasts, and for the Lewes River Group volcanics (Jackson *et al.* 1991; Armstrong, unpub. data data). This may be the result of: (1) contamination by radiogenic detritus from the adjacent metamorphic terrane; (2) chemical weathering of the detritus (which preferentially leaches out ^{86}Sr); (3) alteration of the detritus by pore seawater (which had $^{87}Sr/^{86}Sr$ values *ca.* 0.7075 during the Early Jurassic (Burke *et al.* 1982)); (4) allogenic or autogenic carbonate contamination (which contains seawater-equivalent $^{87}Sr/^{86}Sr$ values). Large quantities of smectite, kaolinite and calcite as alteration products of volcanic lithic grains, clinopyroxene and plagioclase in marine Laberge Group volcanogenic sandstone indicate that sediment-seawater interactions were pronounced. It is unlikely, however, that diagenentic interactions with interstitial pore-water can account for the magnitude of radiogenic strontium enrichment recorded by the Late Triassic sandstone sample. Contamination from a more radiogenic source terrain is likely and supported by the presence of metamorphic clasts in Whitehorse Trough conglomerate. Further evidence is supplied by additional isotopic studies of Samson *et al.* (1989) and Jackson *et al.* (1991).

The *ca.* 0.7049 values indicate that Laberge Group sediments were chiefly derived from a primative source terrane which was not significantly older than their stratigraphic age. However, despite the plethora of primitive, arc-derived sediment, a component of continentally derived detritus occurs in both the Laberge and Lewes River groups. Although the source of the continental detritus is uncertain, both Nisling Terrane and the Paleozoic portion of Stikinia have been suggested as sources. However, isotopically evolved rocks of Stikinia are not known to be present north of 59°N latitude suggesting that Nisling (or Yukon-Tanana) Terrane is the preferred source.

DISCUSSION

Plutonic clasts from Laberge Group conglomerate were derived from a Late Triassic plutonic-arc source which crystallized, at least in part, at *circa* 215 to 208 Ma west of the Whitehorse Trough . The belt of Klotassin suite batholiths west of the trough, suggested to be "Late Triassic-Early Jurassic" in age (Wheeler and McFeely 1991; Woodsworth *et al.* 1991) is the most obvious source for the clasts. However, despite paleocurrent data and apparent clast-pluton similarities which support this source region, reliable isotopic dates so far determined for these bodies are between 192 and 174 Ma (Tempelman-Kluit and Wanless 1980; Stevens *et al.* 1982; Hart and Radloff 1990; Currie 1992; J. Mortensen pers. comm. 1990 1993; Johnston 1993). These dated plutons are too young to have been the source for Sinemurian and Pliensbachian sediments and do not correlate with dated clasts from the conglomerate.

Furthermore, since Klotassin suite plutons intrude isotopically evolved, Paleozoic and older Nisling and Yukon-Tanana Terrane metasedimentary rocks, they have elevated initial strontium values (>0.706; LeCouteur and Tempelman-Kluit 1976; Morrison *et al.* 1979; R.L. Armstrong, unpub. data 1988) and a marked Proterozoic or Archean inherited zircon component (Baadsgaard in Hart and Radloff 1990; Johnston 1993; Mortensen 1992). The isotopic characteristics of these plutons are dissimilar from the Laberge Group plutonic clasts analysed in this study which indicate a lack of a crustal component in their parent magma and suggest intrusion into primitive country rocks.

Late Triassic ages (*ca.* 228-201 Ma) have been determined for a few plutons in southern Yukon and northernmost British Columbia (Bultman 1979; Stevens *et al.* 1982; Hart and Radloff 1990; M. Mihalynuk, pers. comm. 1990, 1993). These plutons are typically small, intrude Lewes River volcanic rocks (not Nisling Terrane), have primitive initial strontium ratios and U-Pb systematics which do not indicate an inherited zircon component. This suite of plutons is the probable origin for the Laberge Group clasts and is supported by a petrologic and geochronometric correlation between the 211 Ma Friday Creek biotite-hornblende quartz diorite and samples Y88-1A and Y88-1E. However, the present day areal exposure of this suite is meager and inadequate to explain the significant volume of granitic clasts in nearly three verticle kilometres of Laberge Group strata. In addition, sources for Late Triassic alkalic and copper-bearing clasts are not known in the Yukon. The Late Triassic plutonic suite must have been more areally extensive during Early Jurassic time than today. The discrepancy may be acounted for due to: 1) burial of the plutons by Whitehorse Trough sediments; 2) removal of the plutons by uplift and erosion; or 3) Laberge Group was sourced from another region and is now separated from it by large faults.

The sudden and dramatic change in depositional style from marine carbonate and lagoonal facies in the Late Triassic, to extremely coarse-grained, alluvial mass-flow facies in the earliest Jurassic required the rapid initiation of a high-energy transport system associated with steep topographic gradients. Uplift modified the western margin of the Jurassic Whitehorse Trough such that a disconformity marks the Triassic-Jurassic boundary. Arc uplift and subsidence of the adjacent Whitehorse Trough maintained steep basin margin gradients which resulted in the basinward progradation of the conglomeratic wedge (Dickie 1989). The increase in the volume of coarse Laberge Group granitic detritus, with time, indicates that exhumation of the plutonic source area was extensive in Sinemurian time and increased through to Middle Jurassic time.

The cause of this uplift is unknown but the magnitude of its results require a tectonic explanation. Regional scale structures on the western margin of the Whitehorse Trough, like the Tally Ho shear zone, may have been responsible for accommodating initially rapid, and eventually protracted, uplift and basin subsidence. Since some Laberge Group conglomerate is Sinemurian or older, uplift was likely initiated in the Hettangian. Protracted and episodic uplift correspond with prograding successions of conglomerate deposited throughout most of the later part of the Early Jurassic until Bajocian time when the Whitehorse Trough seaway closed. Metamorphic clasts and contaminated isotopic signatures require that an evolved source terrane locally supplied detritus during at least Norian, and Middle Jurassic times.

CONCLUSIONS

The Laberge Group conglomerate is composed of well-rounded, lithologically diverse, dominantly igneous boulders and cobbles derived primarily from a volcano-plutonic arc. U-Pb zircon ages of four Laberge Group granitic cobbles from two sites at different stratigraphic levels indicate that Late Triassic (*ca.* 215 to 208 Ma) plutons were present in the source terrain. Plutons intruding Nisling Terrane pericratonic rocks west of the Whitehorse Trough have traditionally been the inferred source. Paleocurrent data and petrologic similarities with those plutons support this source region. However none of the dated representatives of these bodies are old enough to be a source for Pliensbachian and older strata, and the isotopic signatures of these plutons are unlike those determined for Laberge Group granitic clasts.

A sparsely distributed suite of small, Late Triassic and earliest Jurassic plutons which intrude the Lewes River arc have similar dates and isotopic character to the clasts and support a westerly source derivation. This suite is the interpreted source for the Pliensbachian and older Whitehorse Trough granitic detritus. A lack of crustal contamination, as indicated by low initial strontium values and a lack of older zircon in the igneous clasts, suggests that the source plutons were derived from an arc constructed on oceanic or transitional crust and not the pericratonic Nisling Terrane.

The volume of granitic clasts in Laberge Group strata infers that exposures of this suite were previously much more extensive than at present. The presence of metamorphic clasts and elevated initial Sr values in Whitehorse Trough clastics indicate that a continental source terrane, probably Nisling or Yukon-Tanana Terrane, also supplied detritus to the trough.

Chapter VI

CONCLUSIONS

The Intermontane Superterrane and Coast Plutonic Complex in southern Yukon Territory host the products of numerous magmatic events. Geological mapping, geochronometry, whole rock and Sr isotopic geochemistry defines four magmatic episodes -- Late Triassic to Early Jurassic Klotassin Episode (220-175 Ma), mid-Cretaceous Whitehorse Episode (115-106 Ma), Late Cretaceous Carmacks Episode (85-68 Ma) and Early Tertiary Skukum Episode (58-54 Ma). There was a pronounced magmatic lull between 175-115 Ma. Twenty -one U-Pb dates are presented with 25 K-Ar dates and greater than 60 strontium isotopic analyses from plutonic and volcanic rocks across the study area to define the timing and nature of magmatic and tectonic events.

Each magmatic episode is composed of two or more plutonic suites. The Klotassin episode is composed of the pre-accretionary Stikine and Red Ridge suites, the syn-accretionary Aishihik and Long Lake suites and the post-accretionary Bennett and Fourth of July suites. The Stikine suite is the plutonic equivalent to Lewes River Group volcanism whereas Long Lake granites are comagmatic with Nordenskiold dacite. The Whitehorse episode is composed of the Teslin, Whitehorse and the potassic Mount McIntyre suite that is comagmatic with Mount Nansen Group volcanism. The Carmacks episode is composed of felsic and mafic phases of the Wheaton River suite as well as the Carcross suite, both are plutonic roots to Carmacks Group volcanism. Skukum episode magmatism includes Nisling and Bennett plutonic suites as well as the high level rhyolite plugs that are all associated with Skukum Group volcanism.

Rocks of the Klotassin Episode have experienced a thermal event greater than the K-Ar closure temperature of hornblende (~530°C) as they return Early Cretaceous cooling dates coincident with the magmatic lull. K-Ar dates from other episodes are generally reliable and only locally affected by younger thermal influences and low temperature hydrothermal alteration.

Zircon dates are mostly concordant to mildly discordant with minor amounts of Pb-loss. U-Pb data indicating a significantly older inherited component are rare and mild except for the Early Jurassic Bennett suite that locally has a Proterozoic component. Initial $^{87}Sr/^{86}Sr$ ratios within all plutonic suites are largely transitional (av. 0.7045) and range from 0.7035 to 0.7066. The variation reflects slight to moderate contamination. The higher values occur in the Coast Crystalline Complex adjacent to exposures of Nisling Terrane rocks. All suites have generally low $^{87}Rb/^{86}Sr$ ratios (>1.0) except plutons of the Skukum episode which are up to 100.

All plutonic suites have characteristics of calc-alkaline, magnetite-series, I-type subduction-related granitoids except the Skukum episode. Skukum magmatism has characteristics more typical of A-type magmatism and occurred coincidentally during upper crustal extension.

Successions of post-accretionary volcanic rocks in southwestern Yukon Territory indicate that episodic volcanism occurred during mid to Late Cretaceous time at 106, 98, 84 and 81-78 Ma. Hypabyssal dikes and plugs yield dates between 70 and 62 Ma. The mid-Cretaceous (106 Ma) Carbon Hill volcanics are composed of a few small occurrences of intermediate to felsic pyroclastic centred around a comagmatic pluton. The Montana Mountain volcanics form a fault-bounded complex comprising 95 Ma intermediate flows and pyroclastics overlain by felsic flows that are 10 Ma younger. Late Cretaceous Wheaton River volcanics (81-78 Ma) consist of a thick and extensive succession of basic to intermediate lava flows cut by 70-62 Ma rhyolite dykes. The ages of these volcanic successions provide maximum age constraints for the numerous epigenetic precious metal deposits hosted in the volcanics, and minimum ages for the underlying coal-bearing strata of the Tantalus Formation.

Whole rock, major element geochemistry indicates that all three suites were formed from sub-alkalic, medium to high-K, calc-alkaline magmas. Initial strontium ratios vary considerably between the suites from 0.7041 to 0.7061 and reflect the isotopic nature of the basement terrane at each site. Low ratios in the Wheaton River and Montana Mountain suites indicate derivation from primitive, mantle-derived magmas. Elevated initial strontium ratios in the Carbon Hill suite suggests contamination from ancient continental material -- probably from Nisling Terrane metasedimentary rocks.

The volcanic successions were deposited as part of a continental margin volcanic arc across amalgamated terranes in the mid to Late Cretaceous. Available geochronometric data indicate that mid-Cretaceous activity, attributable to the Mount Nansen Group, was sparse and episodic at 106 and 95 Ma. Late Cretaceous volcanism was much more voluminous and extensive, and peaked through 84 to 78 Ma. Although initially allied with the Carmacks Group, these rocks are like those at Table Mountain in British Columbia and together comprise the Windy-Table Formation.

U-Pb zircon dating of granitic cobbles in Lower Jurassic Laberge Group conglomerate of the Mesozoic Whitehorse Trough suggests clast derivation from a source terrane containing Late Triassic (*ca.* 215 to 208 Ma) granitic plutons. Initial strontium ratios are primitive and paleocurrent data show that detritus comprising Laberge Group conglomerate was westerly derived. A string of small, isotopically unevolved plutons of Late Triassic to earliest Jurassic age intrude the Lewes River volcanic arc rocks along the western margin of the Whitehorse Trough and are interpreted as the probable western source for the clasts. The age dates, the lack of zircon inheritance, and the primative initial strontium values of the clasts rule out previous suggestions that the clasts were derived from the Early Jurassic Klotassin suite batholiths which intrude Nisling Terrane rocks. Instead the source pluton's isotopic character suggests intrusion into oceanic or transitional crust.

The deposition of extremely coarse Early Jurassic boulder conglomerate on top of Late Triassic carbonate facies represents a dramatic change in depositional style. Sudden uplift incised a Lower Jurassic erosional disconformity into arc and arc-flanking shelf deposits along the western margin of the Whitehorse Trough. Episodic uplift periodically maintained extreme paleotopographic relief in the arc, sufficient to prograde coarse-grained debris flows into the basin and erode the plutonic roots of the arc throughout Early and early Middle Jurassic time. Metamorphic clasts in Laberge Group conglomerate are presumed to be sourced from the Nisling Terrane, confirming that Nisling and Stikinia were linked by Middle Jurassic time.

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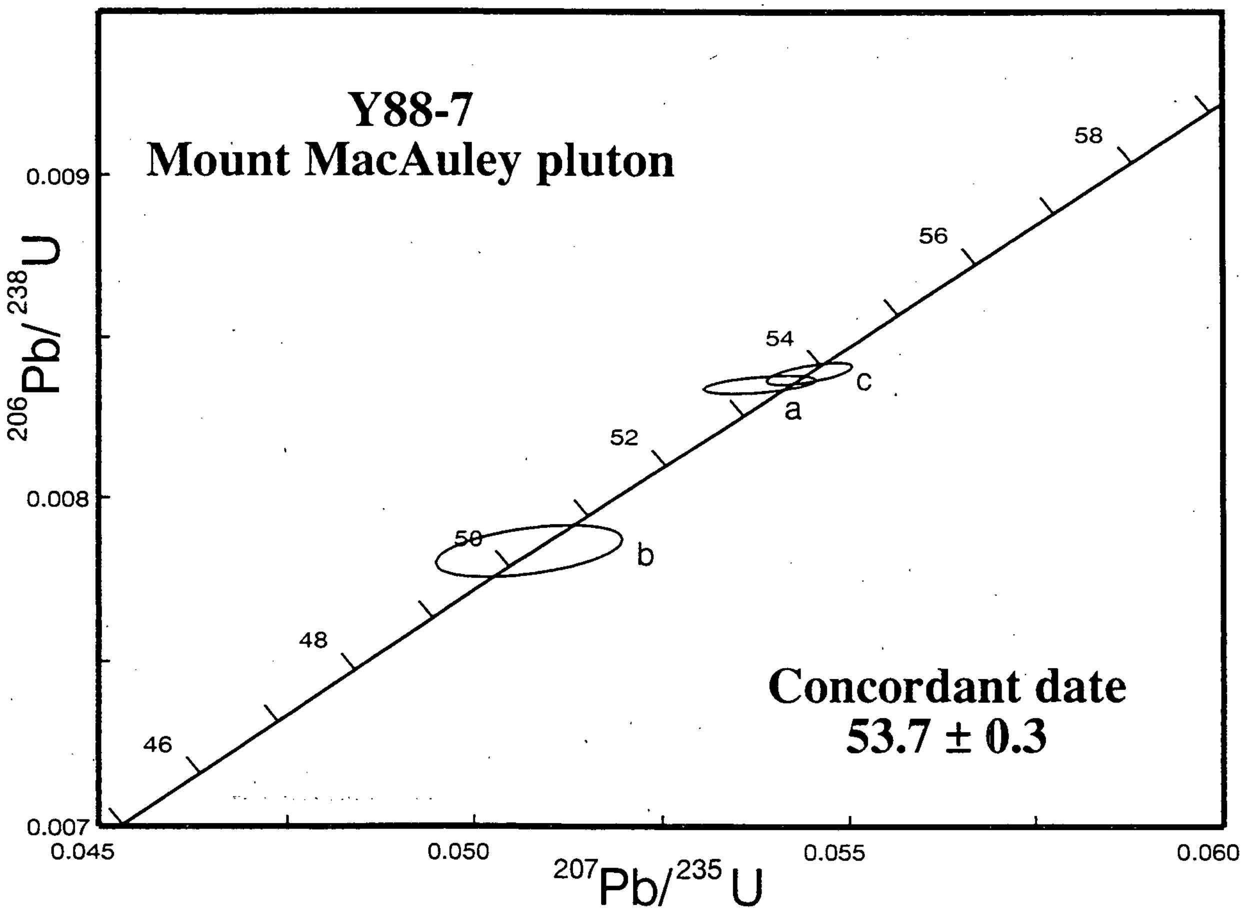
Appendix

U-Pb zircon analytical results of plutonic rocks from Chapter III.

All samples were analysed in the Geochronology Lab at UBC during 1988-1990 using method described in Armstrong *et al.* 1991 and Tables 4.2 and 5.3. Analytical data are recalculated using weighted means and input into HTB-based software program of J. Roddick. Results are calculated using a Pb 206:207:208:204 blank of 17±5%:15±3%:37.3±3%.

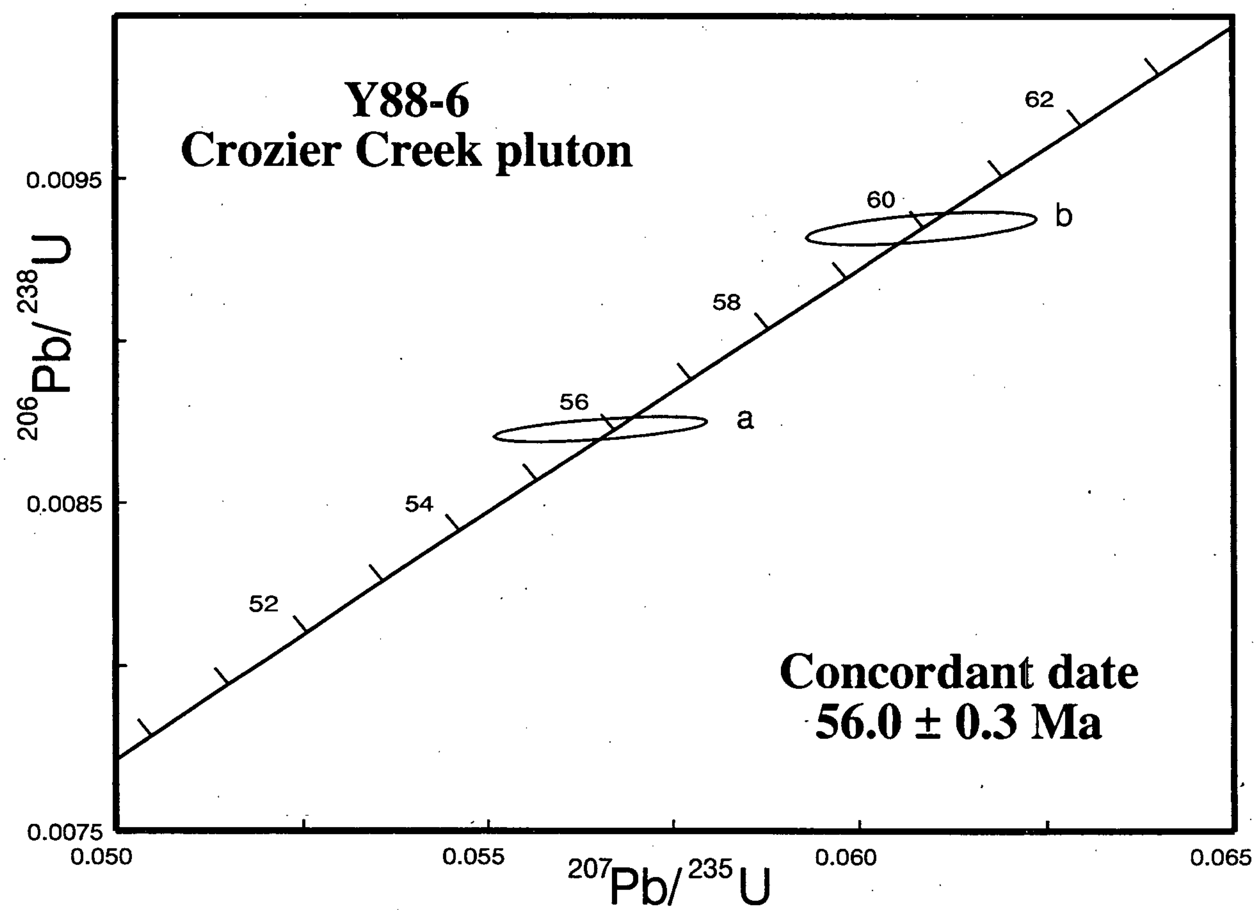
Y88-7	Mount McAuley						60° 01.5'	135° 30.9'	
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U \pm \%1\sigma$	$^{207}Pb/^{235}U \pm \%1\sigma$	$^{207}Pb/^{206}Pb \pm \%1\sigma$
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.2	1835	15.6	1379	137	11.5	0.00835±0.17	0.05380±0.70	0.04672±0.63
+74μ							53.6±0.2	53.2±0.7	34.8±30
b									
NM1.5/3,M2/1	0.3	2638	28.9	2810	135	35.5	0.00783±0.51	0.050724±1.2	0.046958±1.1
-74+44μ							50.3±0.5	50.2±1.2	47.1±52
c									
NM0.5/5,M1/5	0.3	1720	14.7	1101	243	11.4	0.00839±0.20	0.05447±0.53	0.04710±0.42
-44μ							53.8±0.2	53.8±0.2	54.3±20.1



Y88-7

Two fractions (a and c) are nearly concordant and the date is defined by the combined 206/238 ages of those fractions. Fraction b has experienced some Pb loss due to its high U content.

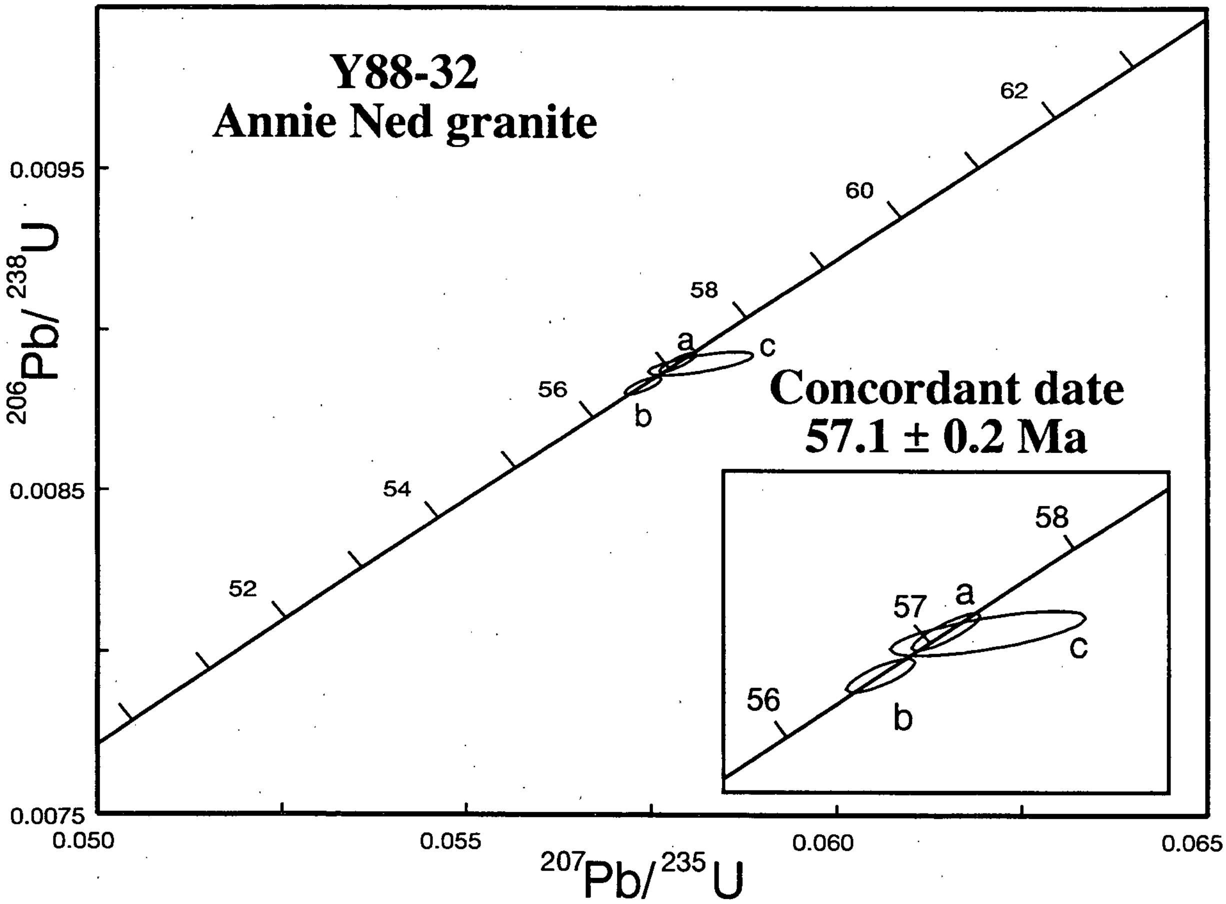
Y88-6	Crozier Creek quartz monzonite						60° 02.9'	135° 11.1'	
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U \pm \%1\sigma$	$^{207}Pb/^{235}U \pm \%1\sigma$	$^{207}Pb/^{206}Pb \pm \%1\sigma$
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.3	1763	15.7	921	310	11.8	0.00873±0.23	0.05653±1.3	0.04697±1.2
+149μ							56.0±0.3	55.8±1.4	47.8±55
b									
NM2/1	0.7	1660	15.9	756	893	12.0	0.00935±0.27	0.060835±1.27	0.047194±1.1
-74+44μ							60.0±0.3	60.0±1.5	59.1±55



Y88-6

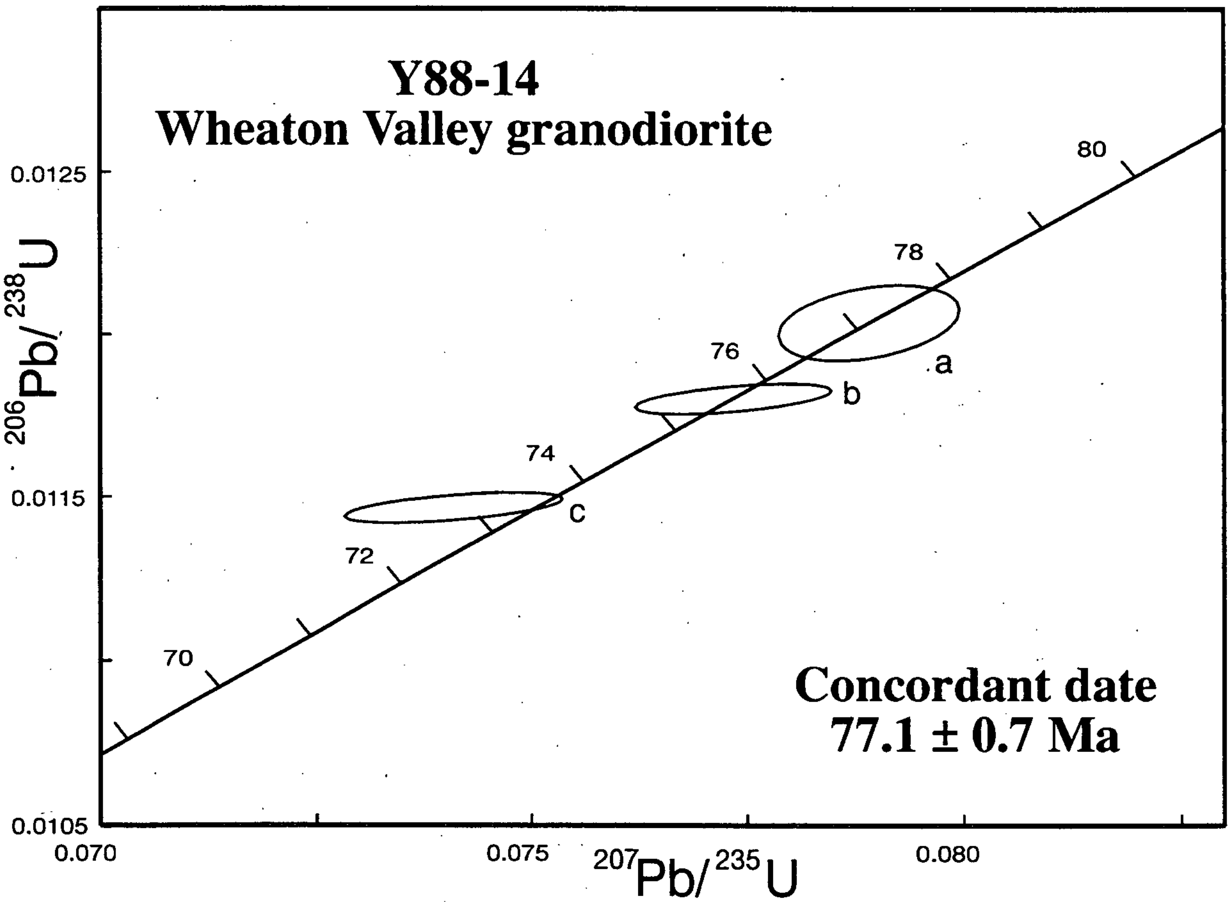
Both fractions are nearly concordant, but the age of this rock is defined by the 206/238 age of fraction a. Fraction b is interpreted to give an older age as a result of contamination. Although inherited cores were not recognized in either of the clear prismatic zircon fractions, an abraded portion of fraction b plotted even further up concordia near 80 Ma. This is also apparent in the high value of common Pb in this fraction. An small inherited component is not unexpected since this pluton since it intrudes Nisling Terrane metasedimentary rocks.

Y88-32	*Annie Ned granitè*						*60° 48.4'*	*135° 58.5'*	
			Radiogenic		Common				
Fraction	**Wt.**	**U**	**Pb***	**$^{206}Pb/^{204}Pb$**	**Pb**	**$\%^{208}Pb$**	**$^{206}Pb/^{238}U \pm \%1\sigma$**	**$^{207}Pb/^{235}U \pm \%1\sigma$**	**$^{207}Pb/^{206}Pb \pm \%1\sigma$**
Size	**(mg)**	**(ppm)**	**(ppm)**	**measured**	**(pg)**		**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**
a									
NM2/1	0.8	874	7.7	2535	150	9.00	0.00890±0.17	0.05786±0.21	0.04716±0.11
+149μ							57.1±0.2	57.1±0.2	57.3±5.2
b									
NM1.5/3, M2/1	0.2	1657	14.6	2535	71	9.77	0.00883±0.16	0.05738±0.22	0.04716±0.13
-74+44μ							56.6±0.2	57.7±0.2	57.1±6.3
c									
NM1/5, M1.5/3	0.1	1176	10.4	523	126	9.20	0.00890±0.21	0.05816±0.61	0.04742±0.49
-44μ							57.1±0.2	57.4±0.7	70.4±23



Y88-32
Three concordant fractions defined by the 206/238 ages of the two oldest, most concordant and overlapping fractions.

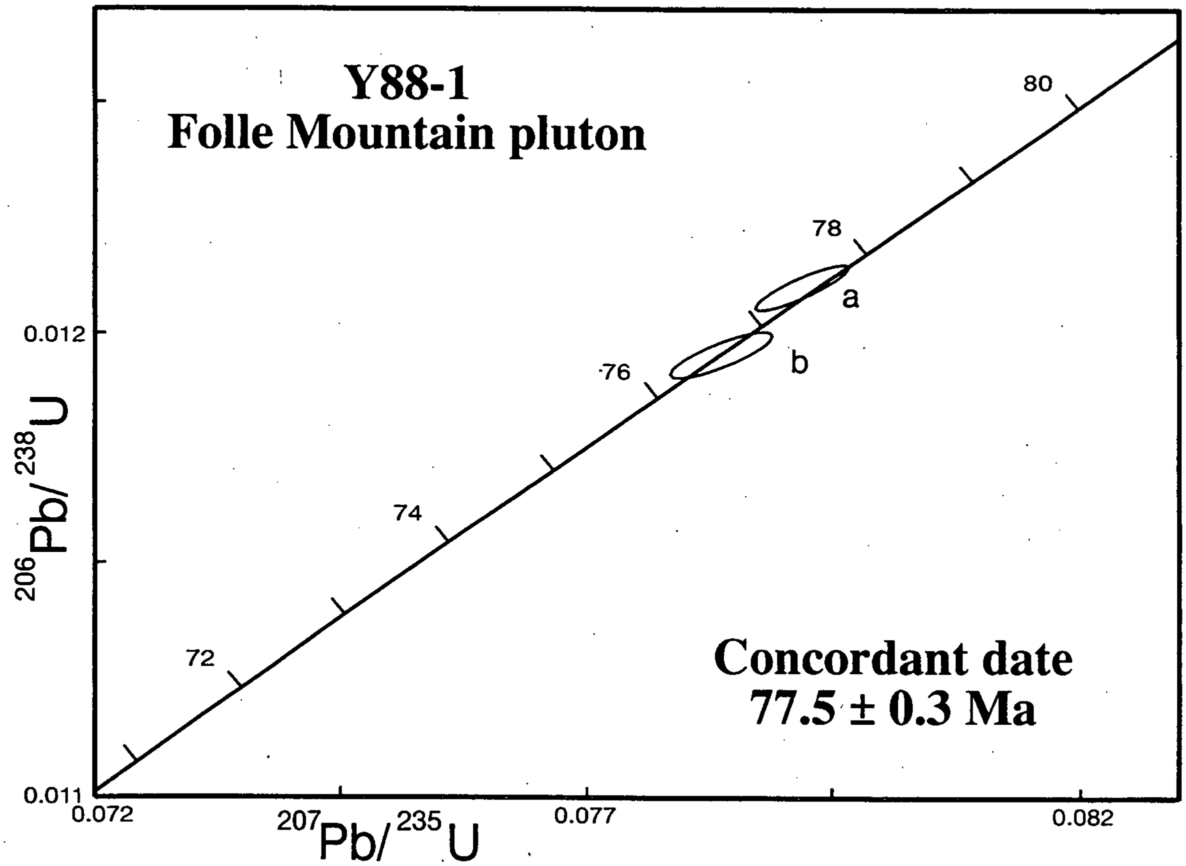
Y88-14	*Wheaton Valley granodiorite*						*60° 15.4'*	*135° 02.2'*	
			Radiogenic		Common				
Fraction	**Wt.**	**U**	**Pb***	**$^{206}Pb/^{204}Pb$**	**Pb**	**$\%^{208}Pb$**	**$^{206}Pb/^{238}U \pm \%1\sigma$**	**$^{207}Pb/^{235}U \pm \%1\sigma$**	**$^{207}Pb/^{206}Pb \pm \%1\sigma$**
Size	**(mg)**	**(ppm)**	**(ppm)**	**measured**	**(pg)**		**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**
a									
NM2/1	1.3	460	5.45	916	496	8.75	0.01204±0.49	0.07891±0.66	0.04755±0.67
+149μ							77.1±0.7	77.1±1.0	76.7±32
b									
NM1.5/3, M2/1	0.2	1413	16.4	1886	108	8.28	0.01180±0.20	0.07734±0.74	0.04753±0.65
-74+44μ							75.6±0.3	75.6±1.1	76.1±31
c									
NM1/4	0.1	3481	39.0	1005	246	7.84	0.01147±0.21	0.07393±0.86	0.04677±0.76
-44μ							73.5±0.3	72.4±1.2	37.4±37



Y88-14

Three nearly concordant fractions of long prismatic clear and brownish zircon give ages between 73 and 78 Ma. The high U content has encouraged minor Pb-loss in fractions b and c. The date of this pluton is defined by the 206/238 age of fraction a.

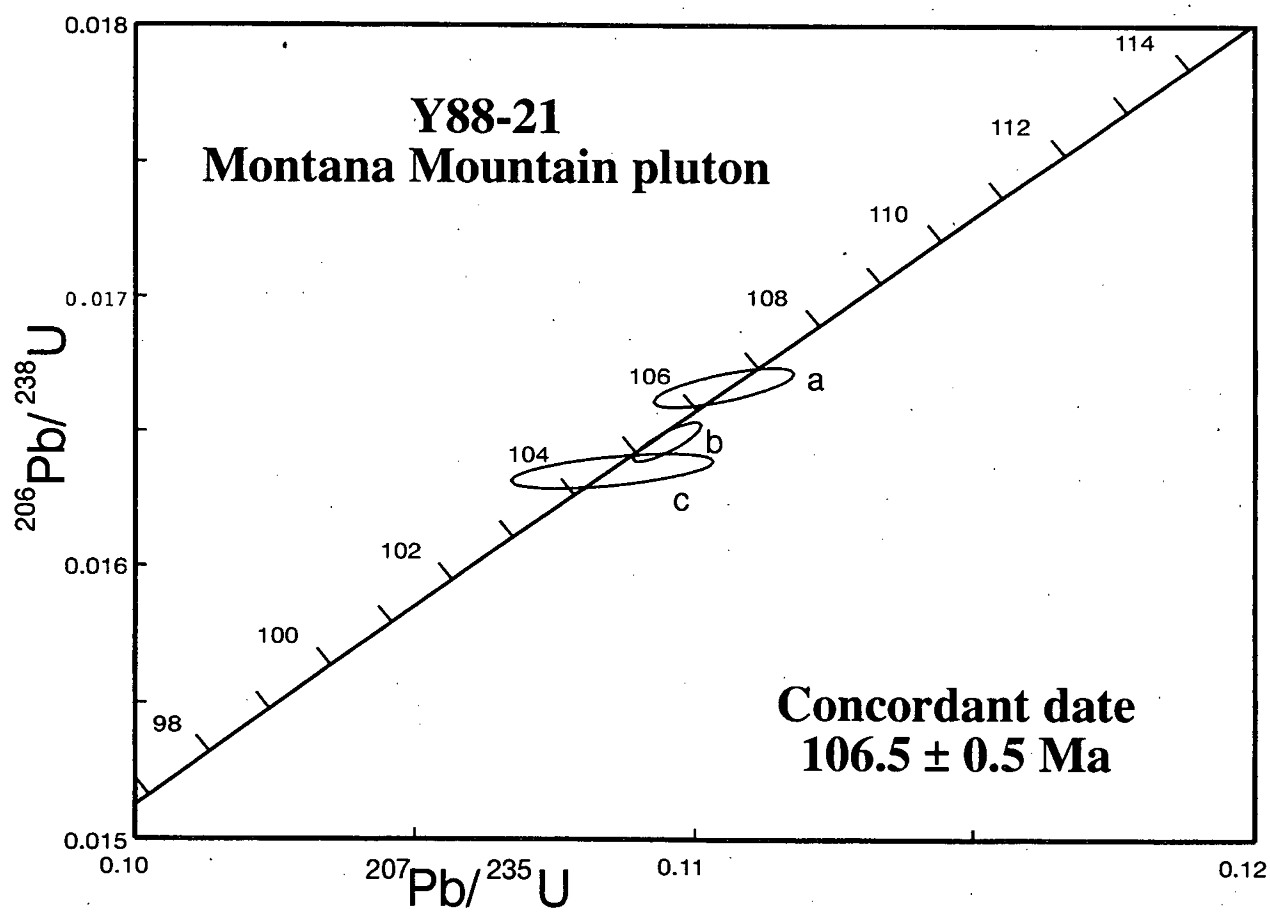
Y88-1	*Folle Mountain*			*60° 17.4'*	*135° 0.7'*				
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U$ ± %1σ	$^{207}Pb/^{235}U$± %1σ	$^{207}Pb/^{206}Pb$ ± %1σ
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.7	1206	14.5	3313	192	9.19	0.01210±0.21	0.07914±0.30	0.04744±0.15
+74μ							77.5±0.3	77.3±0.4	71.3±7.2
b									
NM0.5/5	0.4	1294	15.3	2981	127	9.16	0.01195±0.21	0.07837±0.33	0.04755±0.19
-149+74μ							76.6±0.3	76.6±0.5	77.0±9.2



Y88-1

The date is defined by 206/238 age of the concordant fraction a. The high U content of both fractions of short prismatic and whitish zircons encourages Pb-loss, but is only apparent in the smaller b fraction.

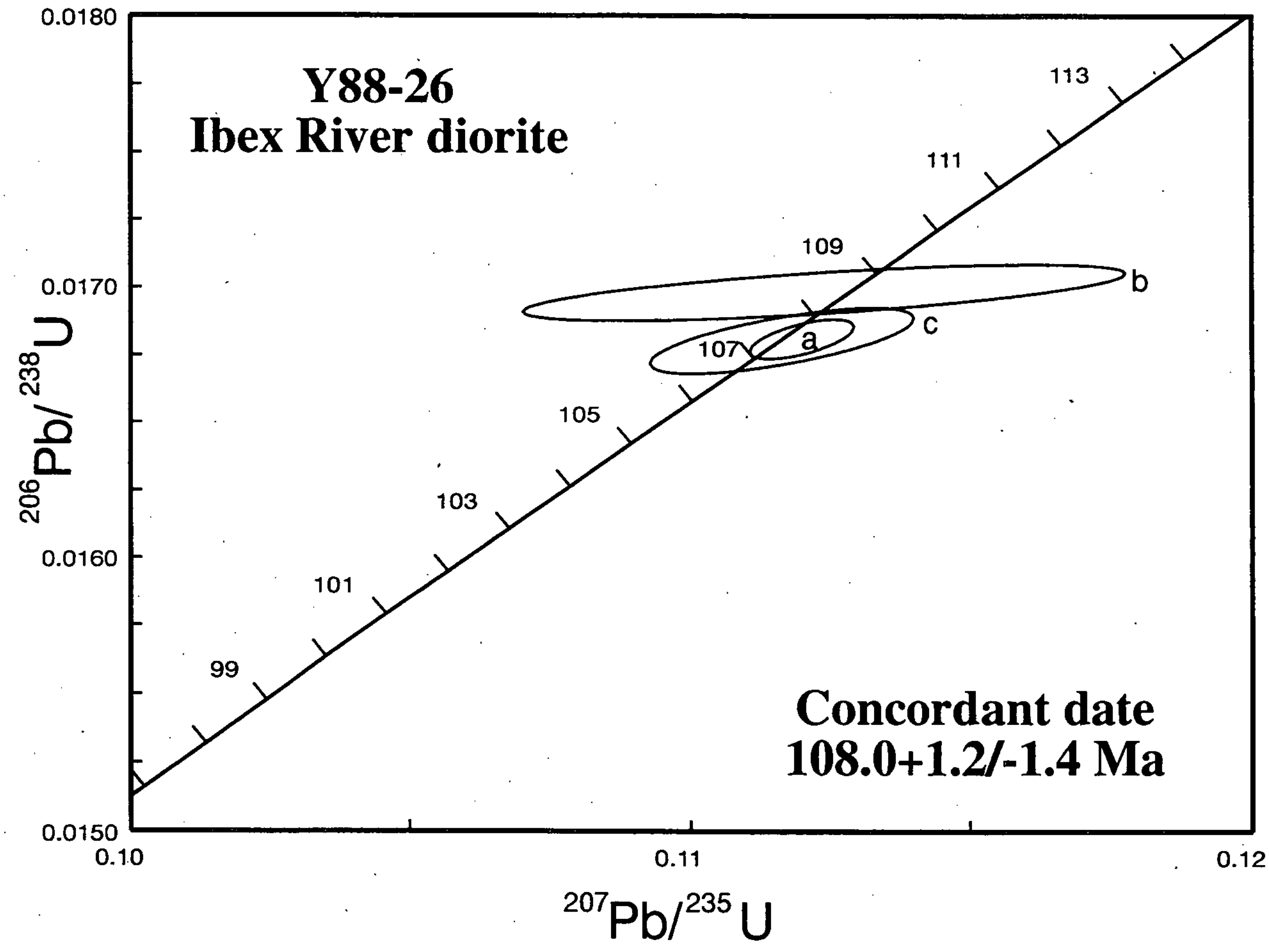
Y88-21	*Montana Mountain pluton*						*60° 05.7'*	*134° 42.0'*	
			Radiogenic		Common				
Fraction	**Wt.**	**U**	**Pb***	**$^{206}Pb/^{204}Pb$**	**Pb**	**$\%^{208}Pb$**	**$^{206}Pb/^{238}U \pm \%1\sigma$**	**$^{207}Pb/^{235}U \pm \%1\sigma$**	**$^{207}Pb/^{206}Pb \pm \%1\sigma$**
Size	**(mg)**	**(ppm)**	**(ppm)**	**measured**	**(pg)**		**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**
a									
NM2/1	0.5	352	6.36	597	308	16.8	0.01666±0.22	0.11023±0.57	0.048143±0.49
+74μ							106.5±0.5	106.5±1.2	106.3±23
b									
NM1.5/3	0.2	1181	21.7	2044	117	19.0	0.01646±0.22	0.10950±0.28	0.04824±.15
-74+44μ							105.3±0.5	105.5±0.6	111.2±7.0
c									
NM1/5	0.1	1009	18.5	1040	98	19.4	0.01635±0.20	0.10853±0.83	0.04813±0.73
-44μ							104.6±0.4	104.6±1.6	105.8±35



Y88-21

Three nearly concordant fractions indicate a mid-Cretaceous age that is defined by fraction the 206/238 age of the concordant fraction a. Fractions b and c have high U contents that likely resulted in minor Pb-loss.

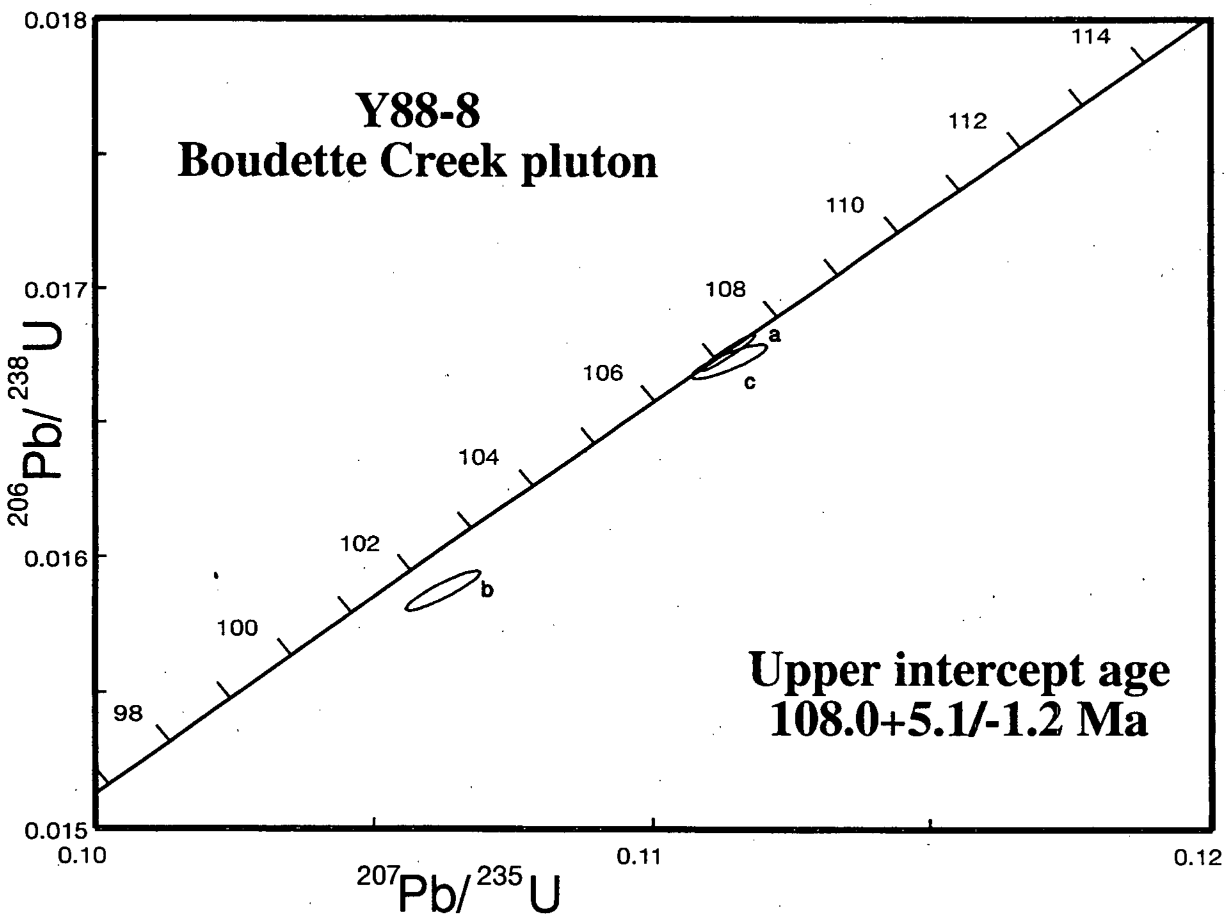
Y88-26	*Ibex River*						*60° 35.5'*	*135° 25.6'*	
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U \pm \%1\sigma$	$^{207}Pb/^{235}U \pm \%1\sigma$	$^{207}Pb/^{206}Pb \pm \%1\sigma$
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.4	178	3.22	886	84	16.4	0.01681±0.22	0.11199±0.42	0.04832±0.33
+74μ							107.5±0.5	107.8±0.9	114.8±0.9
b									
NM2/1	0.2	69	1.26	452	33	15.9	0.01698±0.31	0.11239±2.4	0.04800±2.2
+74μ, long							108.5±0.7	108.1±4.9	99.4±100
c									
NM2/1	0.2	418	7.57	189	502	16.3	0.01680±0.36	0.11163±1.06	0.04819±0.85
-74μ							107.4±0.8	107.5±2.2	108.3±40



Y88-26

Three nearly concordant fractions indicate a mid-Cretaceous age whose date includes all three 206/238 ages and their error limits. There is a possibility that this pluton could be as old as the 207/206 age of the fraction (a) - the fraction with the least analytical error.

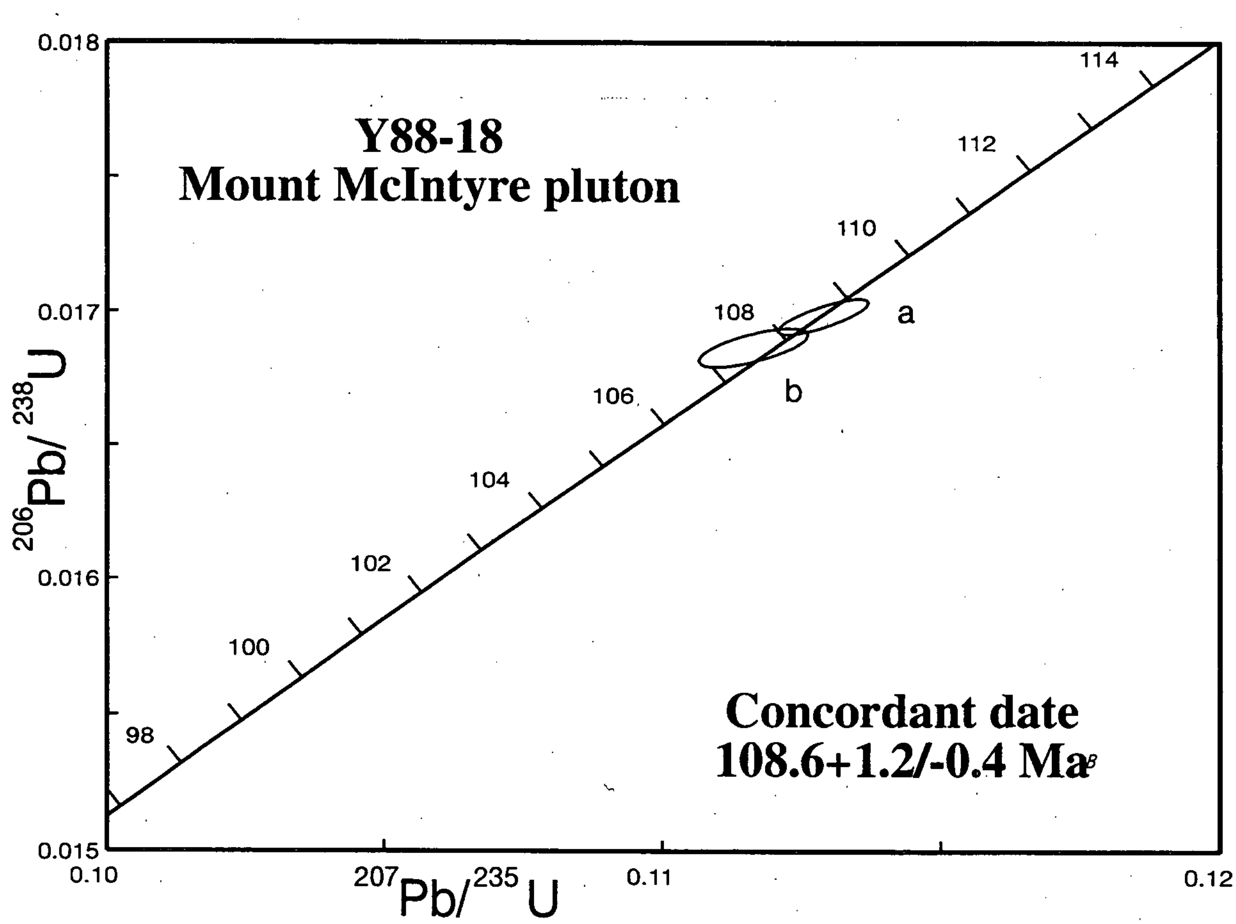
Y88-8	*Boudette Creek (Morisson et al. 1979 locality)*						*60° 05.4'*	*135° 24.9'*	
			Radiogenic		Common				
Fraction	**Wt.**	**U**	**Pb***	**$^{206}Pb/^{204}Pb$**	**Pb**	**$\%^{208}Pb$**	**$^{206}Pb/^{238}U \pm \%1\sigma$**	**$^{207}Pb/^{235}U \pm \%1\sigma$**	**$^{207}Pb/^{206}Pb \pm \%1\sigma$**
Size	**(mg)**	**(ppm)**	**(ppm)**	**measured**	**(pg)**		**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**
a									
NM2/1	1.6	648	10.7	3388	313	8.22	0.01676±0.20	0.11135±0.22	0.048178±0.06
+149μ							107.2±0.4	107.2±0.4	108.0±2.8
b									
NM2/1	1.0	800	12.5	4073	190	8.30	0.01588±0.24	0.10625±0.31	0.04855±0.14
-149+74μ							101.5±0.5	102.5±0.6	126.0±6.5
c									
NM2/1	0.3	898	14.7	2581	107	7.98	0.01673±0.19	0.11137±0.30	0.04828±0.17
-44μ							107.0±0.4	107.2±0.6	113.1±8.0



Y88-8

Two fractions (a and c) are nearly concordant and a date of 107.1±0.5 Ma is defined. However all fractions are long and needle shaped with higher 207/206 ages suggesting Pb-loss -- particularly fraction b. As a result, the 207/206 age of the most concordant fraction (a) is the probable crystallization age of this pluton. The date cannot however, be younger than the youngest possible 206/238 age of that fraction and that is reflected in the lower error limit. The upper error limit is increased to include the 207/206 age of fraction c which is equivalent to the hornblende K-Ar from this pluton.

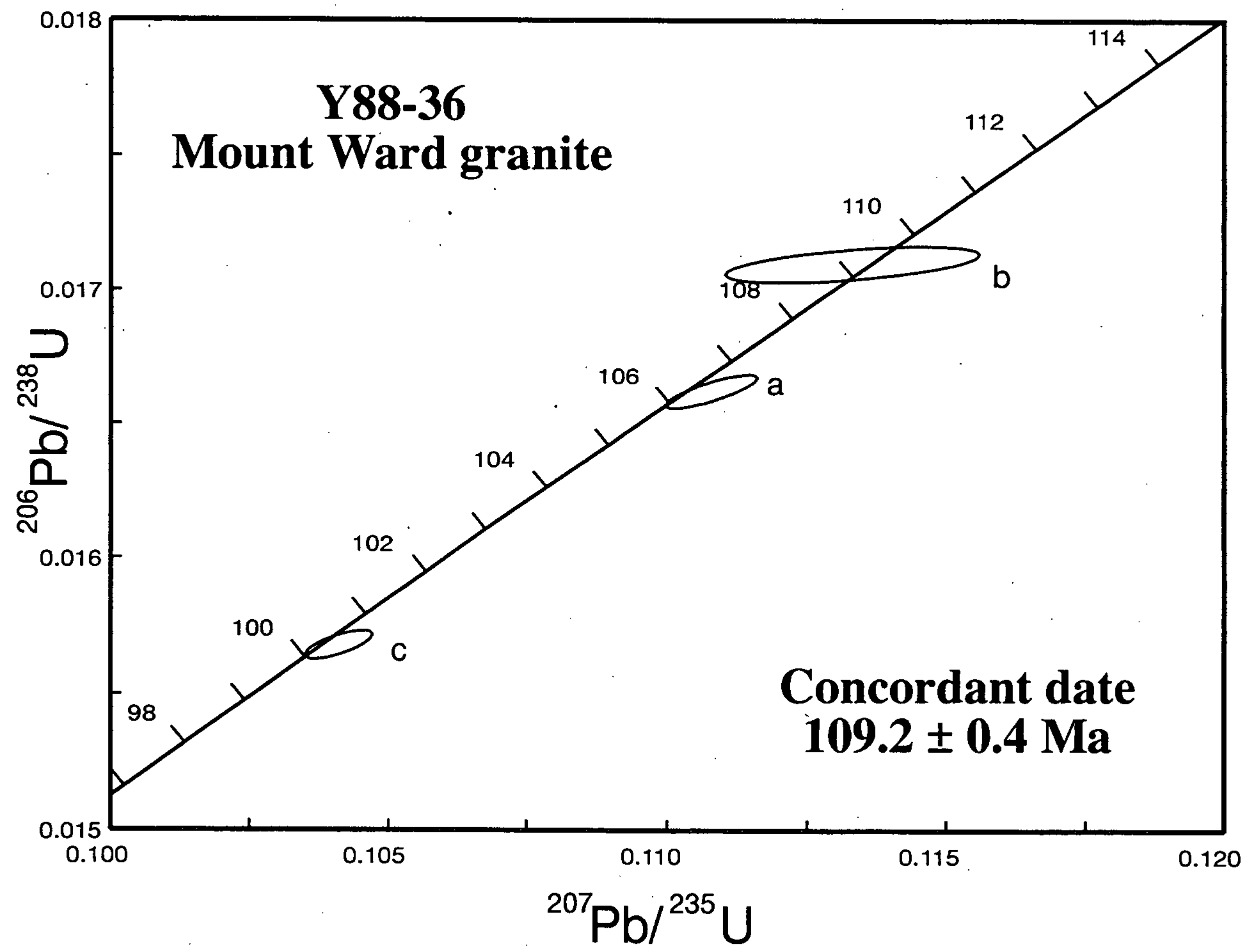
Y88-18	Mount McIntyre						60° 38.7'	135° 11.2'	
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U \pm \%1\sigma$	$^{207}Pb/^{235}U \pm \%1\sigma$	$^{207}Pb/^{206}Pb \pm \%1\sigma$
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.1	2473	45	1308	201	15.8	0.01698±0.20	0.11289±0.36	0.04821±0.23
+74μ							108.6±0.4	108.6±0.7	109.8±11
b									
NM2/1	0.1	3822	68.3	2930	134	14.9	0.01687±0.21	0.11164±0.47	0.04800±.33
+149μ							107.8±0.5	107.5±0.9	99.4±16



Y88-18

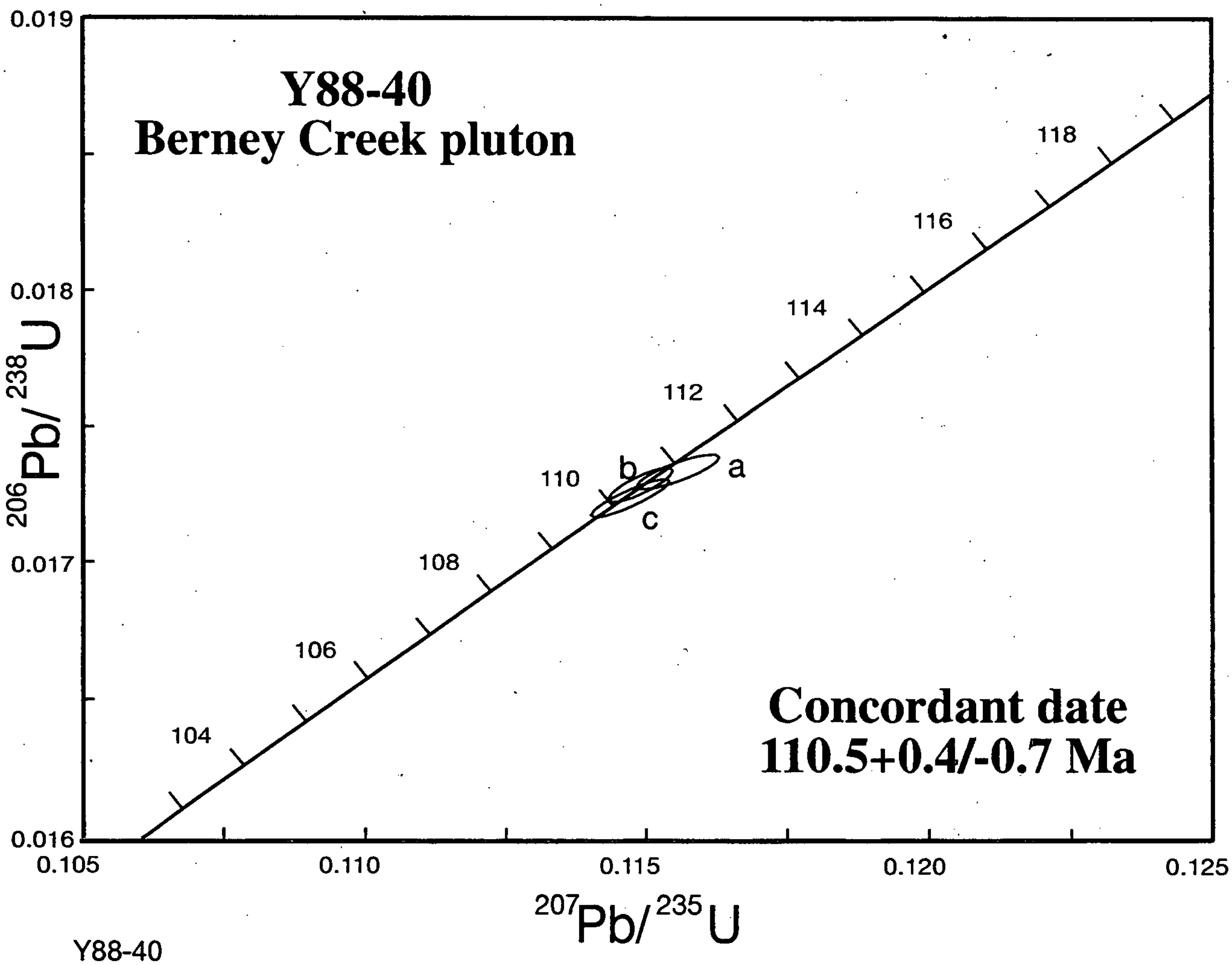
Two fractions give results indicating a mid-Cretaceous date defined by concordant fraction a. The upper error limit includes the possibility of minor Pb-loss suggested by the slightly older 207/206 age of fraction a.

Y88-36	Mount Ward pluton						60° 08.9'	135° 20.3'	
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U \pm \%1\sigma$	$^{207}Pb/^{235}U \pm \%1\sigma$	$^{207}Pb/^{206}Pb \pm \%1\sigma$
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.7	497	8.93	1036	351	16.6	0.01662±0.19	0.11078±0.37	0.04833±0.24
+74µ							106.3±0.4	106.7±0.7	115.7±11
b									
M2/1, NM1.5/3	0.2	828	15.3	539	330	16.8	0.01707±0.20	0.11346±1.01	0.048185±0.91
-74+44µ							109.2±0.4	109.1±2.1	108.2±43
c									
M2/1, NM1.5/3	0.1	2721	46.9	848	313	17.9	0.01568±0.17	0.10410±0.29	0.04816±0.20
-44µ							100.3±0.3	100.6±0.6	107.0±9.6



Y88-36
The age of this pluton is defined by the 206/238 age of the concordant fraction b and is similar to an upper intercept regression age. Fractions a and c have suffered minor Pb-loss.

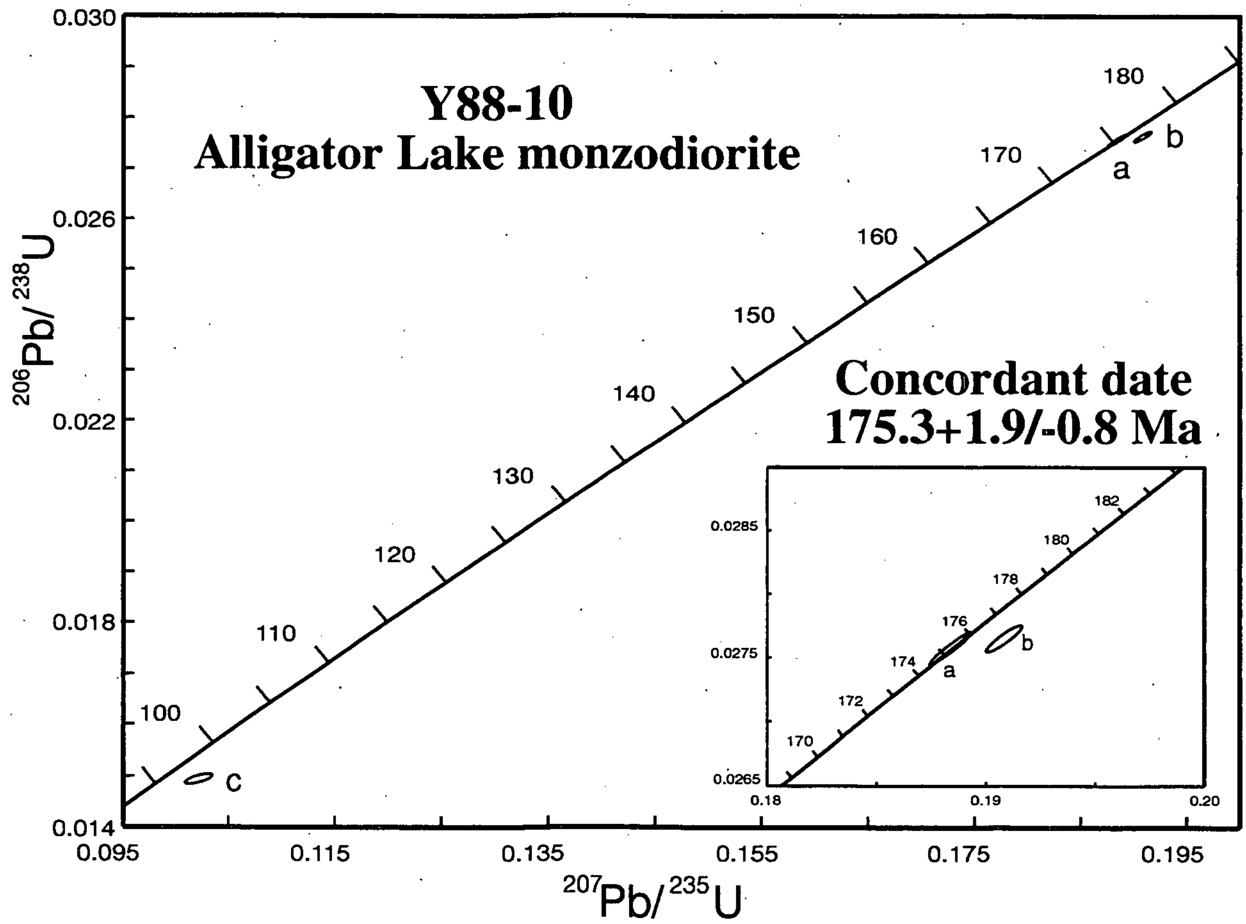
Y88-40	*Berney Creek pluton*						*60° 10.1'*	*135° 24.0'*	
			Radiogenic		Common				
Fraction	**Wt.**	**U**	**Pb***	**$^{206}Pb/^{204}Pb$**	**Pb**	**$\%^{208}Pb$**	**$^{206}Pb/^{238}U \pm \%1\sigma$**	**$^{207}Pb/^{235}U \pm \%1\sigma$**	**$^{207}Pb/^{206}Pb \pm \%1\sigma$**
Size	**(mg)**	**(ppm)**	**(ppm)**	**measured**	**(pg)**		**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**
a									
M0.5/5	0.1	1359	24.8	2434	59	14.3	0.01734±0.17	0.11568±0.31	0.04839±0.23
-44μ							110.8±0.4	111.2±0.7	118.5±10.8
b									
NM2/1	0.7	688	12.3	2328	219	12.9	0.01729±0.18	0.11491±0.25	0.04821±0.14
+74μ							110.5±0.4	110.4±0.5	109.6±6.5
c									
NM1.5/3, M2/1	0.3	1311	23.6	2544	163	13.7	0.01724±0.20	0.11473±0.30	0.04827±0.15
-74+44μ							110.2±0.4	110.3±0.6	112.3±7.2



Y88-40

Three overlapping concordant fractions define that includes the 206/238 errors limits of all three fractions. The 207/206 ages of the U-rich fractions (a and c) suggest that this pluton may be slightly older.

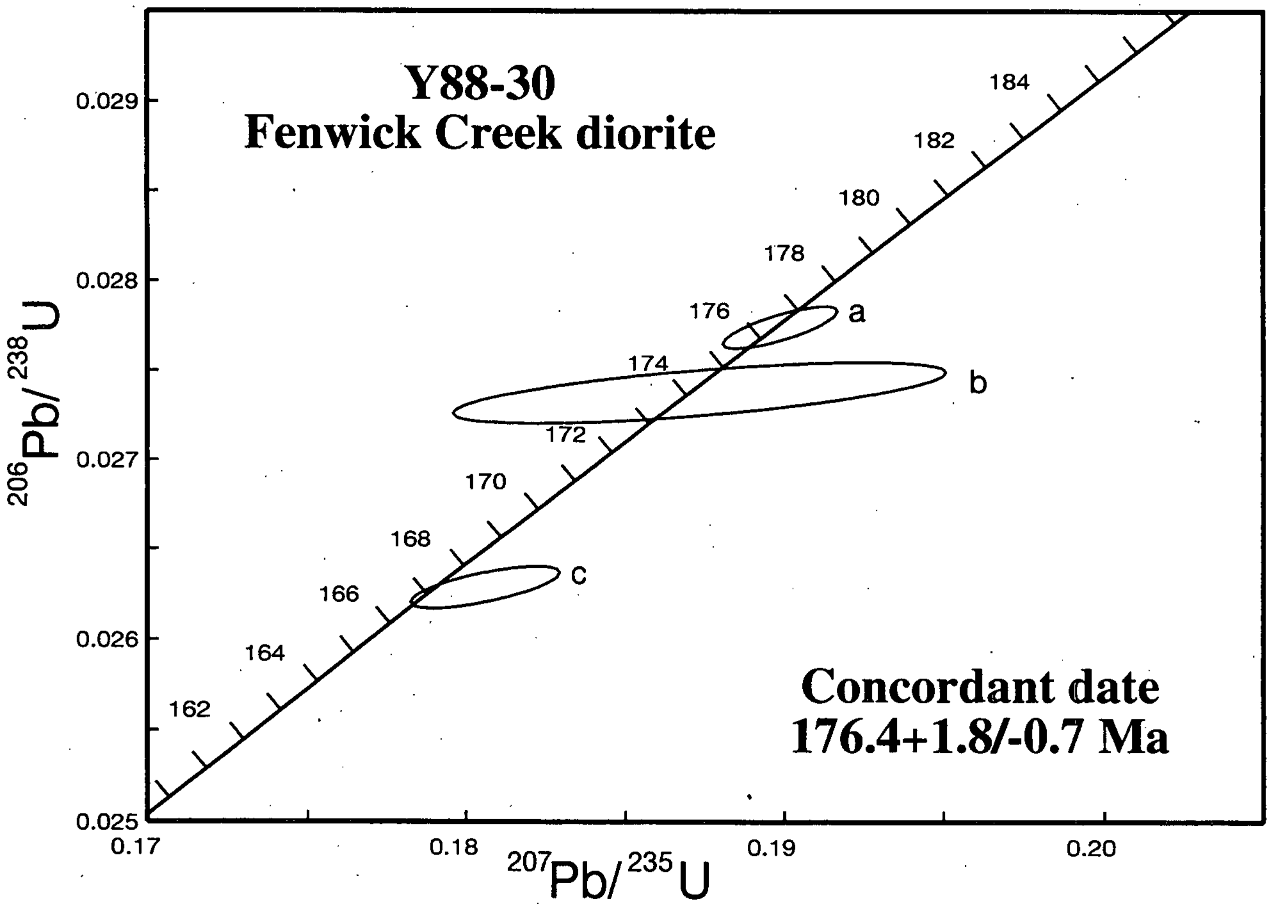
Y88-10	*Alligator Lake*						*60° 21.7*	*135° 27.5*	
			Radiogenic		**Common**				
Fraction	**Wt.**	**U**	**Pb***	**^{206}Pb/^{204}Pb**	**Pb**	**%^{208}Pb**	**^{206}Pb/^{238}U ± %1σ**	**^{207}Pb/^{235}U± %1σ**	**^{207}Pb/^{206}Pb ± %1σ**
Size	**(mg)**	**(ppm)**	**(ppm)**	**measured**	**(pg)**		**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**
a									
NM2/1	2.2	183	5.08	3130	220	10.4	0.02757±0.23	0.18839±0.25	0.04955±0.07
+74μ							175.3±0.8	175.3±0.8	174.0±3.2
b									
NM1.5/3, M2/1	0.8	302	8.37	2544	161	9.74	0.02765±0.19	0.19081±0.22	0.05006±0.09
-74+44μ							175.8±0.7	177.3±0.7	197.7±4.0
c									
M1/5	0.2	753	10.9	645	218	7.03	0.01494±0.33	0.10217±0.64	0.04959±0.47
-44μ							95.6±0.6	98.8±1.2	175.7±22



Y88-10

The date is defined by the concordant fraction a. The upper error limit includes the 207/206 ages of fractions a and c. The U-rich, clear, needle-like fraction of small zircon (c) has endured some Pb-loss but gives a 206/207 age (albeit with large error) that is within the error of 206/238 age of fraction a. The white oval zircon of fraction b contains a small inherited component.

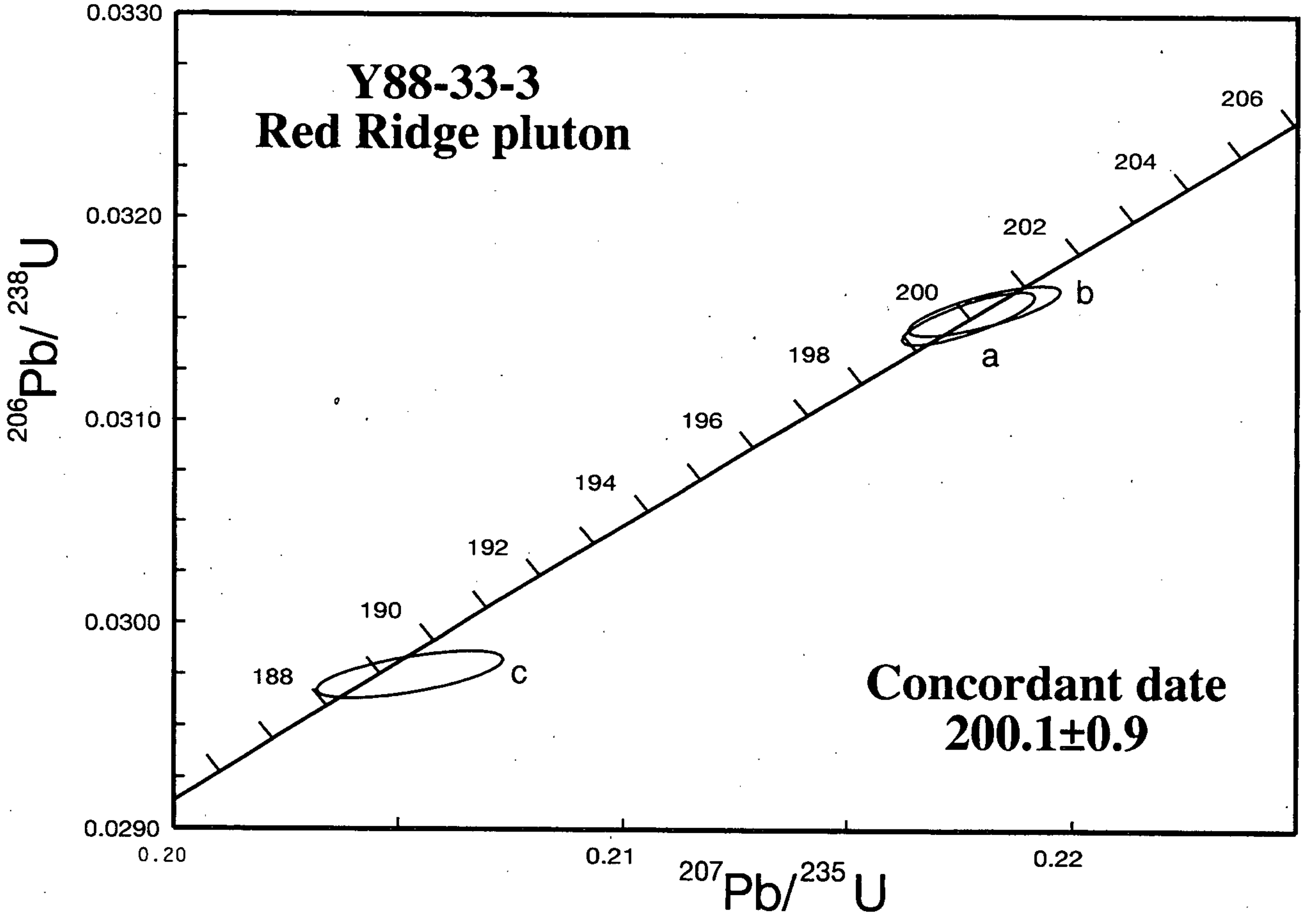
Y88-30	*Fenwick Creek*						*60° 08.4'*	*135° 12.4'*	
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U \pm \%1\sigma$	$^{207}Pb/^{235}U \pm \%1\sigma$	$^{207}Pb/^{206}Pb \pm \%1\sigma$
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.4	389	11.2	625	440	12.7	0.02774±0.21	0.18987±0.47	0.04964±0.34
+149μ							176.4±0.7	176.5±1.5	178.2±16
b									
NM1.5/3, M2/1	0.2	190	5.40	226	303	13.0	0.02737±0.32	0.1873±2.1	0.04964±1.87
-74+44μ							174.1±1.1	174.1±6.6	177.7±89
c									
NM1.0/5, M1.5/3	0.3	200	5.84	452	221	18.7	0.02638±.22	0.18060±0.65	0.049835±0.51
-44μ							167.2±0.7	168.6±2.0	187.3±24



Y88-30

The age of this pluton is defined by the 206/238 age of concordant fraction a. The upper error limit has been increased to include the 207/206 date of this fraction and fraction b.

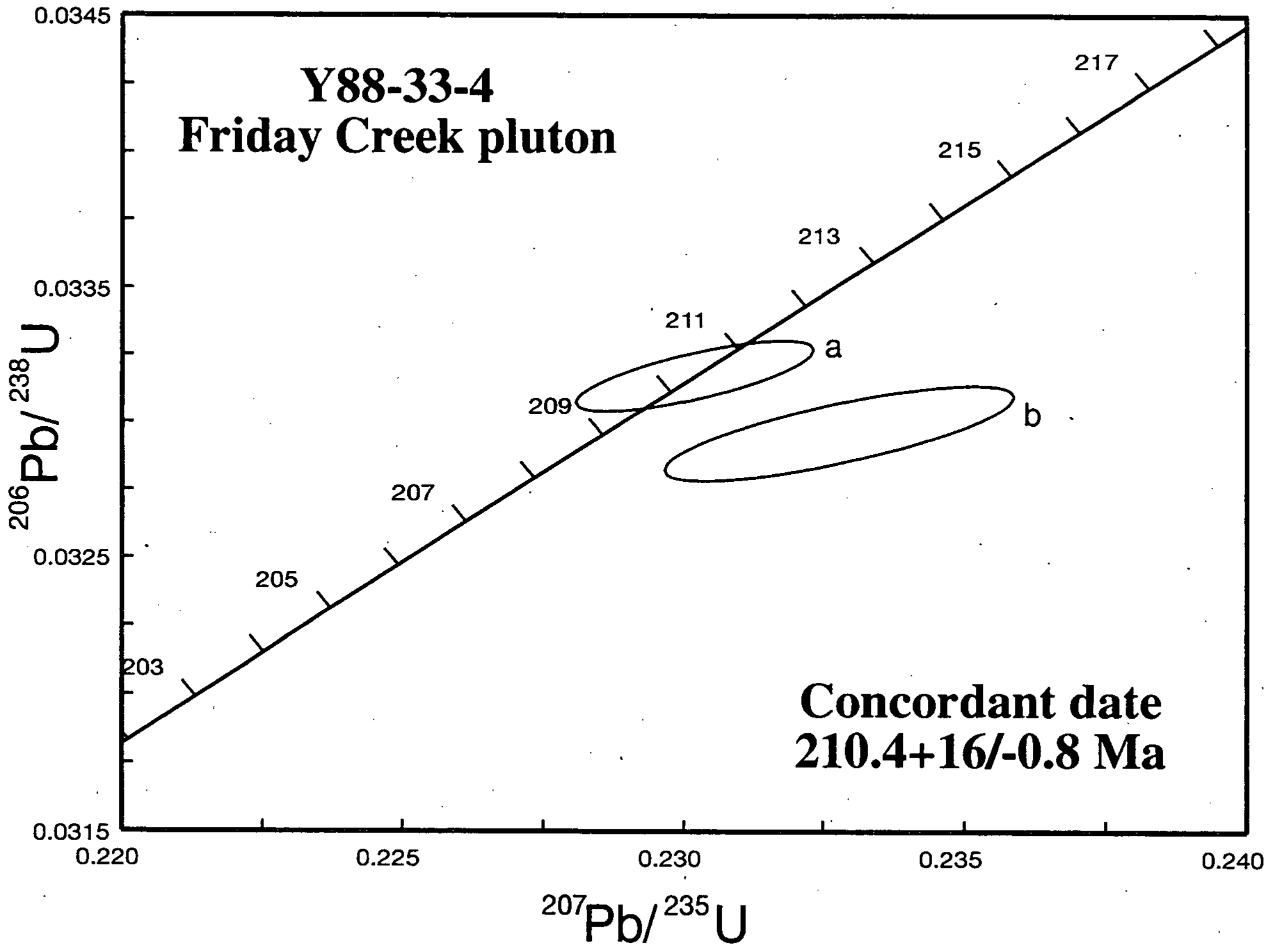
Y88-33-3	*Red Ridge pluton*						*60° 21.6'*	*135° 04.2'*	
			Radiogenic		Common				
Fraction	**Wt.**	**U**	**Pb***	**$^{206}Pb/^{204}Pb$**	**Pb**	**$\%^{208}Pb$**	**$^{206}Pb/^{238}U \pm \%1\sigma$**	**$^{207}Pb/^{235}U \pm \%1\sigma$**	**$^{207}Pb/^{206}Pb \pm \%1\sigma$**
Size	**(mg)**	**(ppm)**	**(ppm)**	**measured**	**(pg)**		**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**	**Age ± 2σ (Ma)**
a									
NM2/1	0.8	457	14.8	3706	190	11.8	0.03151±0.21	0.21767±0.34	0.05010±0.21
+74µ							200.0±0.8	200.0±1.2	199.4±9.7
b									
NM1.5/3, M2/1	0.2	695	23.1	1164	233	14.1	0.03155±0.19	0.21802±0.39	0.05012±0.264
-74+44µ							200.2±0.8	200.3±1.4	200.4±12
c									
NM1/5, M1.5/3	0.2	734	23.5	1611	167	16.1	0.02975±0.20	0.20527±0.51	0.05005±0.41
-44µ							189.0±0.7	189.6±1.8	197.1±19



Y88-33-3

Two concordant and overlapping fractions (a and b) combine to define the date and error limits of this pluton. The smallest U-rich fraction (c) has some Pb-loss.

Y88-33-4	*Friday Creek pluton*						*60° 27.3'*	*135° 16.6'*	
			Radiogenic		Common				
Fraction	Wt.	U	Pb*	$^{206}Pb/^{204}Pb$	Pb	$\%^{208}Pb$	$^{206}Pb/^{238}U \pm \%1\sigma$	$^{207}Pb/^{235}U \pm \%1\sigma$	$^{207}Pb/^{206}Pb \pm \%1\sigma$
Size	(mg)	(ppm)	(ppm)	measured	(pg)		Age ± 2σ (Ma)	Age ± 2σ (Ma)	Age ± 2σ (Ma)
a									
NM2/1	0.8	165	5.36	727	374	8.01	0.03317±0.20	0.23020±0.46	0.05033±0.34
+74μ							210.4±0.8	210.4±1.8	210.3±16
b									
NM1/5, M1.5/3	0.1	747	23.9	394	396	7.14	0.03284±0.25	0.22931±0.54	0.50645±0.40
-44μ							208.3±1.0	209.6±2.1	224.7±18



Y88-33-4

Fraction a is concordant at 210.4±0.8 Ma but has a 207/206 age whose error allows for an age as old as 226 Ma. Fraction b is well off of concordia and likely indicates a small inherited component, but alternatively since it is the small U-rich fraction, it's position may result from Pb-loss from a 206/207 age of approx. 225 Ma.

Fraction size	Wt. mg	U ppm	Pb* ppm	$^{206}Pb/^{204}Pb$	Pb pg	^{208}Pb %	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	Corr. Coeff.	$^{207}Pb/^{206}Pb$	207/206 Age (Ma)
ZR4-2											
A +200M ABR	2.0	39	1	1014	161	12.3	0.0337 ± 0.16%	0.2334 ± 0.36%	0.80	0.05023 ± 0.26%	205.8 +11.9/-12.0
B -200M ABR	3.0	47	2	659	481	9.8	0.03589 ± 0.39%	0.3434 ± 0.74%	0.76	0.06941 ± 0.51%	910.9 +21.0/-21.3

Errors are 1 std. error of mean in % except 207/206 age errors which are 2 std. errors in Ma;
* = Radiogenic Pb
a = Include sample weight error of ± 0.001 mg in concentration uncertainty;
c = Total Common Pb in analysis

-analysis by J. Gabites