MR

1 6 8 5 6

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI[®]

NOTE TO USERS

This reproduction is the best copy available.

UMI[®]

**GEOLOGY OF THE SOUTHERN CAMPBELL RANGE,
SOUTHEASTERN YUKON:
IMPLICATIONS FOR THE TECTONIC EVOLUTION OF
YUKON-TANANA TERRANE**

by

FIONNUALA DEVINE , B.Sc.

**A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of
Master of Science**

**Ottawa-Carleton Geoscience Centre and
Department of Earth Sciences**

Carleton University

Ottawa, Ontario

March, 2005

© 2005 Fionnuala Devine

Library and
Archives Canada

Bibliothèque et
Archives Canada

Published Heritage
Branch

Direction du
Patrimoine de l'édition

0-494-06856-6

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file *Votre référence*

ISBN:

Our file *Notre référence*

ISBN:

NOTICE:

The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protègent cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

FRONTISPIECE

Campbell Range, Yukon

A clear, broad, Yukon-view looking north along the ridges of the Campbell Range in southeastern Yukon. To the east is the Frances River Valley, which is underlain by remnants of the Late Paleozoic Slide Mountain Ocean basin and rocks of the Ancient North American continental margin. The green vegetation-free slopes in the centre of the photo are directly below the King Arctic jade mine and are underlain by serpentinite, an important geological component of the structural evolution of the southern Campbell Range.

ABSTRACT

The southern Campbell Range in southeastern Yukon is underlain by rocks of Yukon-Tanana terrane, a Middle to Late Paleozoic volcanic arc terrane formed along and outboard of the margin of the western North American continental margin. The newly defined Klatsa metamorphic complex is a significant component of the southern Campbell Range and includes rocks that locally preserve the only evidence of Early Mississippian eclogite facies metamorphism within Yukon-Tanana terrane. Understanding the metamorphic and structural history of the region provides insight into the oldest subduction zone metamorphism in the terrane and the subsequent tectonic evolution of this part of the terrane.

Yukon-Tanana terrane in the southern Campbell Range consists of thrust-imbricated Upper Mississippian to Lower Permian metasedimentary rocks and Early Mississippian-metamorphosed Klatsa metamorphic complex.

Mississippian to Lower Permian prehnite-pumpellyite to greenschist facies metasedimentary rocks in the southern Campbell Range comprise three formations. Stratigraphically lowest White Lake formation chert and limestone are unconformably overlain by the King Arctic formation basal pebble to cobble conglomerate, lithic arenite and wacke. Money Creek formation carbonaceous phyllite, chert pebble conglomerate, and wacke unconformably overlie the two lower formations.

The Klatsa metamorphic complex comprises a mafic-ultramafic member which includes serpentinized ultramafic rocks and co-magmatic leucogabbro, a layered schist member composed of quartz-muscovite schist and interfoliated metabasite lenses, blocks of amphibolite contained within serpentinite, and lesser phyllite-matrix mélange including orthoquartzite and chert. U-Pb SHRIMP and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology, and trace element geochemistry on units from the Klatsa metamorphic complex reveal: 1) metasedimentary protoliths with detrital ages ranging from 0.47 Ga to 2.8 Ga, related to the basement of Yukon-Tanana terrane; 2) metabasite with N-MORB and crustally contaminated arc basalt geochemistry, 3) mafic unit protoliths, with a 368 ± 10 Ma magmatic age, coeval with the oldest arc magmatism in Yukon-Tanana terrane; 3) eclogite facies metamorphism at 353.0 ± 3.7 Ma, and 4) rapid exhumation following high-pressure metamorphism (353.4 ± 0.80 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ on muscovite).

The Klatsa metamorphic complex was metamorphosed in an Early Mississippian subduction zone along the western margin of Yukon-Tanana terrane and was rapidly exhumed in the frontal arc to forearc region. In the Early Permian, the complex, along with part of the frontal arc, was transported eastwards along the Cleaver Lake and underlying thrust faults. Poorly age constrained D1-D3 folding affected both the hanging wall and footwall of the Cleaver Lake fault, and were followed by D4 imbricate faulting which has reactivated most Cleaver Lake fault contacts. Nephrite jade at the King Arctic Jade Mine formed in metasomatic reaction zones along D4 faults, during fault displacement.

ACKNOWLEDGEMENTS

This project was made possible by a research grant from the National Science and Engineering Research Council (NSERC) to Don Murphy, field support and funding from the Yukon Geological Survey, and by scholarships and research grants to F. Devine from NSERC, Carleton University, and the Geological Society of America (GSA).

To my supervisors, Don Murphy and Sharon Carr, thanks for all the support, and academic freedom! Thanks Don, for hours spent explaining Yukon-Tanana terrane Finlayson Lake belt geology, a great introduction and passing of knowledge. Thanks Sharon, for the consistent input of new ideas and progressive thinking. I have learned so much from both of you.

Bill Davis explained details of U-Pb zircon geochronology. Rob Berman was a enthusiastic support in understanding the world of metamorphic petrology. Thanks to Mike Villeneuve and Steve Smith for the introduction to Ar geochronology. In the SHRIMP lab at the GSC, thanks to Tom Pestaj and Nicole Rayner for technical support, Mike Orchard provided corroborating conodont fossil age dates. Thanks to Peter Jones and Pat Hunt for microprobe analyses and imaging, to Mike Jackson for technical support at Carleton, and to John Blenkinsop for last minute logistical help.

My time spent working in the Yukon has been a fantastic experience. Thanks to Amy Tizzard and Reid Kennedy for great company and friendship in the field, always ready for a laugh and for a good time in Watson Lake. The Yukon is beautiful country. I feel very fortunate to have had such a great introduction to the geology, and to company of so many great people. So many shared their enthusiasm for geology and their understanding of the Cordillera. Many also shared their homes, great meals, bottles of wine, their friendship. Many, many thanks to you all. I hope you will be a part of future adventures!

At Carleton, thanks to Kumari Karunaratne for an understanding ear, and to Alana Hinchey for great office company.

And from where support has always come, and continues to grow, thanks to my family.

ORIGINAL CONTRIBUTIONS

The project began with an introduction to the field area while looking at eclogites in Yukon-Tanana Terrane in September 2002 with Maurice Colpron, Don Murphy, and Lee Pigage of the Yukon Geological Survey (YGS). A January 2003 start was followed by 3 months of field work in the southern Campbell Range beginning in June, 2003. I worked for the Yukon Geological Survey and independently mapped the geology and structure of southwestern 105H/3 at 1:20 000, locally at 1:10 000 scale, and investigated the occurrence of nephrite jade at the King Arctic Jade Mine in the southern Campbell Range. While in the field I visited parts of the central Finlayson region to the north of the field area with Don Murphy, and visited sites along the Robert Campbell Highway. A progress report summarizing the findings of this seasons work was published in Yukon Exploration and Geology 2003.

The 1:20 000 scale map of the southern Campbell Range is an original work and provides some of the first detailed structural mapping along the eastern margin of Yukon-Tanana terrane in the Finlayson Lake belt. I handled all aspects of cartography and map production. This work, along with a structural analysis and cross sections provides the base for all structural and tectonic interpretations presented herein. Petrographic analysis of the Klatsa metamorphic complex and nephrite jade at the King Arctic Mine provided important petrogenetic constraints.

For the geochronologic component of the project I analyzed three samples for U/Pb zircon and two for $^{40}\text{Ar}/^{39}\text{Ar}$. I performed all stages of mineral separation and grain selection. The U/Pb zircon analyses using the SHRIMP at the Geological Survey of Canada (GSC) in Ottawa were completed under the guidance of Bill Davis, Nicole Rayner, and Tom Pestaj. The U/Pb zircon TIMS analyses were completed at the Pacific Centre for Isotope and Geochronology Research at the University for British Columbia. $^{40}\text{Ar}/^{39}\text{Ar}$ of muscovite was analyzed by Steve Smith and technicians in the geochronology lab at the GSC. Some SEM imaging was performed by technicians at the GSC although I handled all imaging done at Carleton University. Microprobe analyses were also completed by technicians at the GSC and Carleton University. Geochemistry analyses were obtained on contract from Actlabs.

METHOD OF PRESENTATION

This thesis is presented as three papers, each with a different focus to highlight themes and topics in the research.

Chapter 1 describes the geology of the southern Campbell Range and summarizes the structural history of the area. The Klatsa metamorphic complex is placed into geological context. The data presented in Chapter 1 is based on geological mapping undertaken during the summer of 2003. Maps 1 and 2 (back pocket) are hard copy versions of the southern Campbell Range maps.

Chapter 2 focuses on the Klatsa metamorphic complex and investigates the evidence for, and tectonic implications of this unit having been at eclogite facies in the mid-Paleozoic. Geochronological and geochemical data are presented and tectonic models build on the structural setting of the rocks described in detail in Chapter 1.

Chapter 3 describes the nephrite jade occurrences at the King Arctic jade mine and focuses on relatively young structures in the region involved in nephrite genesis.

Chapter 4 provides a summary of conclusions.

All field data was entered into a Microsoft Access database used in production of the digital map. This data is provided in digital form on CD (Appendix IV), along with the program GeoFIELD which is a Microsoft Access application created and developed at the Yukon Geological Survey for digital data entry in the field and map production (Open File 2003-8(D): GeoFIELD v.2.2). GeoFIELD is provided for free to the public. Also included on the CD are .PDF files of this thesis including all figures and maps.

TABLE OF CONTENTS

FRONTISPICE	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
ORIGINAL CONTRIBUTION	v
METHOD OF PRESENTATION	vi
TABLE OF CONTENTS	vii
LIST OF MAPS AND FIGURES	x
LIST OF TABLES	xiii
LIST OF APPENDICES	xiii

CHAPTER 1:

Yukon-Tanana terrane in the southern Campbell Range, Finlayson Lake belt, southeastern Yukon: the geological setting of retrogressed eclogite of the Klatsa metamorphic complex

ABSTRACT	1
INTRODUCTION	2
REGIONAL GEOLOGIC SETTING: THE FINLAYSON LAKE BELT	2
GEOLOGY OF THE SOUTHERN CAMPBELL RANGE	4
Yukon-Tanana terrane	4
<i>Klatsa metamorphic complex</i>	<i>5</i>
<i>Layered schists</i>	<i>5</i>
<i>Mafic-ultramafic rocks</i>	<i>7</i>
<i>Amphibolite</i>	<i>8</i>
<i>Mississippian to Permian metasedimentary rocks</i>	<i>8</i>
<i>White Lake formation</i>	<i>9</i>
<i>King Arctic formation</i>	<i>11</i>
<i>Un-named "upper" limestone</i>	<i>13</i>
<i>Money Creek formation</i>	<i>13</i>
<i>Undifferentiated Waters Creek group and Simpson</i>	
<i>Range Plutonic Suite.....</i>	<i>14</i>
Slide Mountain terrane and Simpson Lake group	15
<i>Paleozoic and Triassic metasedimentary rocks</i>	
<i>Fortin Creek group</i>	<i>15</i>
<i>Flow-banded rhyolite</i>	<i>15</i>
<i>Simpson Lake group</i>	<i>16</i>
STRUCTURE	16
Devono-Mississippian structures in the Klatsa metamorphic	
complex	17
Regional Deformation	18
<i>Klatsa metamorphic complex bounding faults</i>	<i>18</i>
<i>D1 and D2 folding: F1, F2, S2, L2</i>	<i>18</i>
<i>D3 folding: F3</i>	<i>20</i>

<i>D4 faulting: S4</i>	20
<i>D5 faulting</i>	22
DISCUSSION	23
Devono-Mississippian amalgamation and exhumation of the Klatsa metamorphic complex	23
Pennsylvanian to Early Permian siliciclastic and carbonate deposition	24
Early Permian(?) thrust faulting - emplacement of the Klatsa metamorphic complex	24
Middle to Late Triassic (?) D1-2 northeast-vergent folding	25
Jurassic D4 faulting	26
SUMMARY OF CONCLUSIONS	26

CHAPTER 2:

**Geochronology and geochemistry constraints on the origin of the Klatsa
metamorphic complex: Implications for the Late Paleozoic tectonic development of
Yukon-Tanana terrane**

ABSTRACT	43
INTRODUCTION	44
REGIONAL GEOLOGY	45
SOUTHERN CAMPBELL RANGE GEOLOGY	47
KLATSA METAMORPHIC COMPLEX	48
Layered schists	49
Mafic-ultramafic rocks	50
Amphibolite	51
GEOCHEMISTRY	51
Geochemistry results	52
GEOCHRONOLOGY	52
U-Pb samples and results	53
<i>Quartz-muscovite schist: sample 03FD056-2</i>	53
<i>Metabasite: sample 03FD039-2</i>	55
<i>Leucogabbro: sample 03FD231-1</i>	57
⁴⁰ Ar/ ³⁹ Ar samples and results	59
<i>Metabasite: sample 03FD039-2</i>	59
<i>Quartz-muscovite schist: sample 03FD056-2</i>	59
DISCUSSION	
Klatsa metamorphic complex protoliths	60
<i>Quartz-muscovite schist (layered schists unit)</i>	61
<i>Metabasite (layered schists unit)</i>	62
<i>Leucogabbro (mafic-ultramafic unit)</i>	64
<i>Relationships</i>	65
Timing of high-pressure metamorphism	65

Timing and location of exhumation	67
Structural emplacement	68
SUMMARY OF CONCLUSIONS	69
 CHAPTER 3:	
Structurally controlled nephrite jade formation at the King Arctic Jade Mine, southern Campbell Range, southeastern Yukon	
ABSTRACT	93
INTRODUCTION	94
GEOLOGICAL SETTING OF THE SOUTHERN CAMPBELL RANGE	95
KING ARCTIC JADE MINE	97
GEOLOGICAL SETTING OF NEPHRITE JADE AT KING ARCTIC	97
NEPHRITE DEPOSITS	98
Working Face	98
Upper Quarry	99
Other nephrite occurrences	100
DISCUSSION	
Nephrite formation: structural and fluid controls	100
Nephrite protolith	102
Future nephrite discoveries in Yukon	103
CONCLUSIONS	103
 CHAPTER 4:	
Summary of Conclusions	113
 REFERENCES	116
 APPENDIX I	
U-Pb zircon TIMS data from rhyolite associated with the Fortin Creek group	127
APPENDIX II	
Analytical methods	128
APPENDIX III	
Microprobe data.....	131
APPENDIX IV	
Compilation of data and thesis files (CD-ROM).....	back pocket

LIST OF MAPS AND FIGURES

MAPS

Map 1	Geology of the southern Campbell Range	back pocket
Map 2	Station Location Map, southern Campbell Range	back pocket

FIGURES

Figure 1-1	Location map of the southern Campbell Range	28
Figure 1-2	Stratigraphy of Yukon-Tanana terrane within the Finlayson Lake belt, southeastern Yukon	29
Figure 1-3	Simplified southern Campbell Range geology map with vertical and profile sections	30
Figure 1-4	Representative rock and thin section photos of the Klatsa metamorphic complex	32
Figure 1-5	Schematic stratigraphy of metasedimentary rocks in the southern Campbell Range	33
Figure 1-6	Representative rock photographs of the White Lake formation	34
Figure 1-7	Representative rock photographs of the King Arctic formation	36
Figure 1-8	Representative rock photographs of the Money Creek formation	37
Figure 1-9	Photographs of F2 folds in White Lake formation	38
Figure 1-10	Photograph of D4-bound structural panels of serpentinite and metasedimentary units	39
Figure 1-11	Stereogram plots from D4 fault slices in the southern Campbell Range	40
Figure 1-12	Structural evolution of the southern Campbell Range	42
Figure 2-1	Southern Campbell Range location map	71
Figure 2-2	Simplified stratigraphy and structural relationships of Yukon-Tanana terrane, Slide Mountain terrane, and rocks of the ancient North American continental margin in the Finlayson Lake region	72

Figure 2-3	Simplified southern Campbell Range geology	73
Figure 2-4	Representative photomicrographs from the Klatsa metamorphic complex	74
Figure 2-5	Geochemistry: multielement plots of metabasite suites from the Klatsa metamorphic complex layered schists	77
Figure 2-6	Geochemistry: Multielement diagram and Th/Yb vs. Nb/Yb diagram illustrating the possible effects of crustal contamination on mafic suites of the Klatsa metamorphic complex	78
Figure 2-7	Garnet zoning profiles from the Klatsa metamorphic complex metabasite	82
Figure 2-8	Layered schists, quartz muscovite schist 03FD056-2: Cathodoluminescence and back-scatter electron images of zircon and titanite mantled rutile	83
Figure 2-9	Layered schists, metabasite 03FD039-2: Cathodoluminescence and back-scatter electron images of zircon and rutile	84
Figure 2-10	Leucogabbro 03FDF231-1: Cathodoluminescence and back-scatter electron images of zircon and titanite mantled rutile	85
Figure 2-11	U-Pb diagrams: Concordia diagrams, Tera-Wasserburg diagrams, and cumulative probability diagram	86
Figure 2-12	$^{40}\text{Ar}/^{39}\text{Ar}$ age spectra and inverse isochron plots	91
Figure 2-13	Schematic cross sections illustrating proposed structural relationships across the southern Finlayson Lake belt and the Stewart Lake klippe	92
Figure 3-1	Location map of the King Arctic Jade Mine	105
Figure 3-2	Geology of the King Arctic Jade Mine and surrounding region	106
Figure 3-3	Schematic stratigraphy of the southern Campbell Range metasedimentary rocks	107
Figure 3-4	Photograph of the nephrite-serpentinite-metasedimentary contacts at the King Arctic Working Face	108
Figure 3-5	Photograph D4 fault contacts south of the King Arctic Working Face	108
Figure 3-6	Photomicrographs of nephrite and rodingite	109

Figure 3-7	Photographs of the nephrite-metasedimentary contact at the King Arctic Upper Quarry	110
Figure 3-8	Photograph of a rodingite pod with serpentinite	111

LIST OF TABLES

Table 2-1	Geochemical data from metabasite lenses within the Klatsa metamorphic complex	76
Table 2-2	U-Pb SHRIMP analytical data for the Klatsa metamorphic complex and leucogabbro	79
Table 2-3	^{40}Ar - ^{39}Ar data for the Klatsa metamorphic complex	89

LIST OF APPENDICES

Appendix I	U/Pb TIMS data for rhyolite associated with the Fortin Creek group	127
Appendix II	Analytical Methods	128
Appendix III	Microprobe data from the Klatsa metamorphic complex	131
Appendix IV	Data CD: Field data and .pdf files of thesis documents	back pocket

CHAPTER 1

Yukon-Tanana terrane in the southern Campbell Range, Finlayson Lake belt, southeastern Yukon: the geological setting of retrogressed eclogite of the Klatsa metamorphic complex

ABSTRACT

Yukon-Tanana terrane in the southern Campbell Range is composed of rocks that have different metamorphic, exhumation, and structural histories and formed in disparate parts of the Paleozoic Yukon-Tanana volcanic arc. The geological relationships in the southern Campbell Range reveal the tectonic and structural origin of the Klatsa metamorphic complex, comprising the first recognized remnants of an early Mississippian subduction zone beneath the Yukon-Tanana arc. The Klatsa metamorphic complex comprises foliated to massive serpentinite with relict cumulate texture; leucogabbro, interpreted to be cogenetic with the ultramafic rocks; amphibolite; and retrogressed eclogitic quartz-muscovite schist with lenses of metabasite. It was structurally juxtaposed with Upper Mississippian to Lower Permian metasedimentary rocks: chert and limestone of the White Lake formation, conglomerate, lithic arenite and wacke of the King Arctic formation, and heterolithic metasedimentary rocks of the Money Creek formation. Regional and local structural and stratigraphic relationships suggest that the Klatsa metamorphic complex is part of the Cleaver Lake thrust sheet, the structurally highest thrust sheet in a north- to northeast-vergent thrust belt that deformed the Yukon-Tanana terrane during the Early Permian. Restoration of the displacement on the Cleaver Lake and underlying thrust faults places the Klatsa metamorphic complex on the western margin of Yukon-Tanana terrane. Late Devonian to Early Mississippian subduction is thought to have occurred along this margin based on previous paleogeographic reconstructions. Generally north to northeast vergent D1 to D3 folds deformed the hanging wall and footwall of the Cleaver Lake thrust fault. Jurassic(?) D4 imbricate thrust faulting has, in part, reactivated the Cleaver Lake thrust fault contacts and imbricated the Klatsa metamorphic complex with metasedimentary rocks in fault panels that are repeated at a scale of 10 to 100s of metres.

INTRODUCTION

Yukon-Tanana and Slide Mountain terranes in the northern Canadian Cordillera preserve Devonian-Mississippian volcanic arc and related backarc rocks. Predictions of Devonian-Mississippian arc polarity based on geochemistry (Mortensen, 1992a; Piercey et al., 2004) suggest that an east-dipping subduction zone existed on the west-southwest side of Yukon-Tanana terrane. However, subsequent events have obscured the Mississippian paleogeography and direct geological evidence of a Mississippian subduction zone along the western side of Yukon-Tanana terrane has not been found. Two occurrences of retrogressed high-P rocks with evidence for Mississippian metamorphism and cooling occur in the Yukon-Tanana terrane lying northeast of the Tintina fault; these are the Simpson Range and Stewart Lake occurrences of Erdmer et al. (1998; Figure 1-1). This position near the eastern side of Yukon-Tanana terrane is contrary to what simple paleogeographic reconstructions suggest for the relative location of Mississippian subduction-zone - related rocks, as per the classic fore-arc exhumation models for eclogite exhumation (Platt, 1986).

In this paper we describe the geological setting of the herein-defined Klatsa metamorphic complex, which includes rocks with retrogressed high-P mineralogy, originally described by Erdmer et al. (1998) as the Simpson Range eclogite. These rocks occur in the southern Campbell Range in the Finlayson Lake belt of Yukon-Tanana terrane in southeastern Yukon (Figure 1-1). We describe the stratigraphy and structure of the southern Campbell Range, show the relationship of the Klatsa metamorphic complex retrogressed eclogite to the surrounding rocks, and discuss the geological evolution of the area to explain the enigmatic location of these high-grade rocks.

REGIONAL GEOLOGIC SETTING: THE FINLAYSON LAKE BELT

In southeastern Yukon northeast of the Tintina Fault, a sheet of Yukon-Tanana and Slide Mountain terranes, herein called the Finlayson Lake belt, structurally overlies

Upper Triassic rocks of the North American continental margin (Figure 1-1). In the Finlayson Lake belt, Yukon-Tanana terrane metavolcanic and metasedimentary volcanic arc-derived rocks are separated from Slide Mountain terrane metasedimentary rocks along the Jules Creek fault (Murphy et al., 2005). Yukon-Tanana terrane and Slide Mountain terrane together overlie North America continental margin rocks along the west-dipping Inconnu thrust fault (Murphy et al., 2005). The Finlayson Lake belt comprises a part of Yukon Tanana terrane that was displaced southward during post-Late Cretaceous dextral displacement along the Tintina fault (Figure 1-1; Murphy and Mortensen, 2003).

In the Finlayson Lake belt, Yukon-Tanana terrane rocks occur in three Early Permian thrust sheets comprising pre-Upper Devonian to Lower Permian rocks that formed in different environments within the evolving Yukon-Tanana arc (Figure 1-2). The structurally lowest Big Campbell thrust sheet contains rift-related mafic and felsic volcanic rocks and basinal sedimentary rocks with a backarc lithological and geochemical character locally built on a pre-Late Devonian basement (Murphy et al., 2005; Piercey et al., 2004). The middle Money Creek thrust sheet contains Devonian to Mississippian arc volcanic and plutonic rocks and pre-Upper Devonian metaclastic rocks (Murphy et al., 2005; Piercey et al., 2004) and Upper Mississippian to Lower Permian limestone, chert and clastic rocks (Murphy et al., 2005; this paper). The upper Cleaver Lake thrust sheet contains mafic volcanic rocks as well as lesser felsic volcanic and mafic to ultramafic intrusive arc rocks (Grant, 1997; Murphy et al., 2005; Piercey et al., 2004). The thrust faulting event ended in the Early Permian as evidenced by the basalt of the Lower Permian Campbell Range formation that was unconformably deposited on all three thrust sheets.

Slide Mountain terrane rocks occur east of the Jules Creek fault. They include the Fortin Creek group carbonaceous clastic rocks, chert, and rift-related mafic volcanic rocks deposited in an ocean basin setting (Murphy et al., 2005).

Yukon-Tanana terrane and Slide Mountain terrane were juxtaposed along the Jules Creek fault, a possible mid-Permian to Triassic strike-slip fault that has been re-activated as a Mesozoic thrust fault (Murphy et al., 2005; this study). Together, the Yukon-Tanana and Slide Mountain terranes were thrust over upper Triassic strata of the North American continental margin, possibly in the Jurassic, along the Inconnu thrust fault (Murphy et al., 2005).

GEOLOGY OF THE SOUTHERN CAMPBELL RANGE

The southern Campbell Range lies along the boundary between Yukon-Tanana and Slide Mountain terranes along the southeastern margin of the Finlayson Lake belt of southeastern Yukon. These two tectonic elements were juxtaposed along the Jules Creek fault which trends NNW along the eastern side of the southern Campbell Range study area (Figure 1-3).

Rock units of Yukon-Tanana and Slide Mountain terranes are described in the following section. Metamorphic grade in the region ranges from prehnite-pumpellyite to greenschist facies, with the exception of blocks within the Klatsa metamorphic complex that contain variably retrogressed amphibolite and eclogite facies assemblages. As primary textures are widely preserved in low grade rocks, metasedimentary units are referred to and described using sedimentary terminology. Also, informal stratigraphic nomenclature is used throughout the paper with “formation” used to refer to mappable units, locally with defined members. These divisions are not formalized according to the North American Stratigraphic Code. Structurally, the rocks range from undeformed to highly transposed; structures are described in the following section.

Yukon-Tanana terrane

In the southern Campbell Range three packages of Yukon-Tanana terrane rocks from temporally and tectonically distinct parts of the Yukon-Tanana arc are

present. Layered upper Mississippian to Permian metasedimentary rocks are structurally imbricated with retrogressed Mississippian high-grade metamorphic rocks of the Klatsa metamorphic complex throughout the central part of the field area. To the west, Devonian volcanic and plutonic rocks from the older part of the Yukon-Tanana arc occur across a high angle fault.

Klatsa metamorphic complex

The Klatsa metamorphic complex consists of: 1) retrogressed eclogitic layered schists, 2) amphibolite, 3) serpentinitized mafic-ultramafic rocks, and 4) locally occurring phyllite-matrix *mélange*. Serpentinitized ultramafic rocks in the region occur as both massive bodies and highly foliated serpentinite *mélange*. The serpentinite *mélange* contains a variety of blocks including blocks of leucogabbro, interpreted to be the mafic component of the mafic-ultramafic unit; amphibolite; polydeformed amphibolite blocks; and locally, retrogressed eclogite facies layered schists. Phyllite-matrix *mélange* occurs locally, spatially associated with serpentinite, and is host to a variety of metasedimentary rocks including orthoquartzite and chert not found locally. Blocks and slivers of Mississippian to Permian metasedimentary rocks are also present within serpentinite *mélange*. They were structurally incorporated during the subsequent Jurassic(?) assembly of the region.

Erdmer et al. (1998) were the first to describe the layered schists of the Klatsa metamorphic complex, referring to them as the Simpson Range eclogite. We include the layered schists in the Klatsa metamorphic complex; a newly defined complex based on new age data (Chapter 2) which indicate a common metamorphic age for the layered schists and associated rocks.

Layered schists

The layered schists occur in two regions of the southern Campbell Range. The

rocks are best exposed as a fault-bounded block at the western end of a southwest-trending ridge in the southwestern corner of the study area (Figure 1-3) but also occur approximately 1 kilometre north across a high-angle D5 fault as poorly exposed approximately 30 metre elongate blocks within a serpentinite and phyllite-matrix *mélange*.

The layered schist unit comprises primarily coarse-grained quartz-muscovite schist interfoliated with 1 to 10 metre-thick lenses of metabasite. Textural and compositional evidence supports eclogite facies paragenesis for the schists, although they are commonly retrogressed to greenschist facies (Erdmer et al., 1998, Chapter 2).

Coarse-grained quartz-muscovite schist is well foliated and displays compositional variation on the cm- to m-scale (Figure 1-4a). Muscovite layers < 0.5 cm thick and local carbonate-rich lenses less than 50 cm thick occur within a quartz-rich matrix. Irregular to augen-shaped domains of green chlorite < 1 cm in diameter occupy < 50% volume of the schist and are inferred to be retrogressed garnet porphyroblasts. Titanite and titanite-mantled rutile are locally concentrated in the chlorite-domains, but also occur as trails parallel to foliation within the schist. Inclusions trails within the retrogressed garnet domains outline the trace of a foliation that is at a high angle to the matrix fabric.

Metabasite occurs as < 10 metre thick foliation-concordant lenses of dense fine to medium-grained greenstone within the quartz-muscovite schist (Figure 1-4b). Contacts are poorly exposed but have been observed to be sharp, and overgrown by muscovite. Highly fractured garnet porphyroblasts < 1 cm diameter are partly to completely replaced by chlorite, epidote, and clinozoisite. The matrix comprises epidote, chlorite and actinolite, locally as symplectite of actinolite, epidote and muscovite. The symplectitic matrix appears to overgrow an early medium-grained actinolite phase in the matrix which is locally preserved as euhedral, prismatic crystals with symplectite rims. Coarse-grained muscovite occurs in variable amounts within the metabasite lenses.

The protolith of the layered schists of the Klatsa metamorphic complex is interpreted to be a series of mafic dykes, transposed sills, or basalt flows within a quartz-rich metasedimentary sequence. Geochronological studies show Early Mississippian eclogite facies metamorphism was followed by rapid exhumation and cooling (Erdmer et al., 1998, Chapter 2). Metamorphic zircons from both the quartz muscovite schist and the metabasite are 352.6 ± 2.3 Ma (SHRIMP U-Pb zircon; Chapter 2) and are interpreted to have grown during eclogite facies metamorphic conditions. The unit cooled through 350°C by 353.4 ± 0.79 Ma (^{40}Ar - ^{39}Ar age from muscovite, plateau date).

Mafic-ultramafic rocks

The mafic-ultramafic rocks of the Klatsa metamorphic complex comprise serpentinite and leucogabbro. Dark green massive to well-foliated serpentinite lenses and layers occur throughout the field area in north-trending fault-bounded domains. Blocks of leucogabbro and layered schist are included within serpentinite.

Serpentinite is commonly well foliated and dark green with smooth, greasy surfaces, especially in close proximity to bounding faults. Massive, blocky, and resistant weathering domains are up to 100 metres thick. Massive serpentinite has microscopic mesh texture and contains <40%, <1cm diameter bastite locally with relict clinopyroxene cores. The serpentinite bodies range in thickness from 200 metres to several centimeters thick along D4 faults. Serpentinite contacts are ubiquitously faulted and are commonly marked by talc-schist zones < 50 cm wide.

Leucogabbro blocks within serpentinite range up to 200 metres in diameter. Fine- to medium-grained, varitextured leucogabbro consists of amphibole that is surrounded by sausseritized plagioclase. A primary magmatic relationship between the leucogabbro and host serpentinite is inferred due to a common spatial occurrence and the suggestion of a magmatic origin for the ultramafic rocks based on the presence of clinopyroxene phenocrysts.

New U-Pb age data from magmatic zircons show that the leucogabbro is Late Devonian (Chapter 2). These data affirm correlation of mafic and ultramafic rocks of the Klatsa metamorphic complex with mafic and ultramafic rocks of the Big Campbell and Cleaver Lake thrust sheets (see Discussion), rather than with the Early to Middle Permian mafic and ultramafic metaplutonic rocks thought to be comagmatic with basalt of the Campbell Range formation (Murphy et al., 2005). Metamorphic zircon from leucogabbro has an age of 351 ± 12 Ma, interpreted to be coeval with metamorphic zircon from the layered schist unit (Chapter 2).

Amphibolite

Blocks of garnet amphibolite and plagioclase-amphibole schist occur within foliated serpentinite in the southern Campbell Range. Garnet amphibolite blocks > 10 to 20 metres in diameter are poorly to moderately foliated and locally contain < 50%, 1 to 5 mm diameter fractured idioblastic garnet porphyroblasts rimmed by blebby plagioclase in a matrix of medium-grained, elongate actinolitic amphibole with edenite cores. Garnet domains concentrate < 1 mm-sized titanite-mantled rutile grains while titanite up to 2 mm diameter occurs abundantly throughout the matrix. Plagioclase-amphibole-quartz schist and plagioclase-amphibole schist are well foliated with domains < 1 cm in diameter of clinozoisite-chlorite-plagioclase inferred to be pseudomorphs after garnet porphyroblasts. The high-grade metamorphic history of the amphibolites and their structural association with serpentinite links them to the other members of the Klatsa metamorphic complex; however, no age data are available for these rocks.

Mississippian to Permian metasedimentary rocks

Mississippian to Early Permian polydeformed metasedimentary rocks occur as 100 metre-thick, kilometre-long structural slices interleaved with serpentinite of the Klatsa metamorphic complex. They are all part of the Money Creek thrust sheet,

the middle thrust sheet extending throughout much of the Finlayson Lake belt. The metasedimentary rocks have been divided into four stratigraphic units separated by unconformities (Figure 1-5). The stratigraphically lowest rocks are chert and limestone of the newly defined White Lake formation. The White Lake formation is unconformably overlain by metaconglomerate, lithic-arenite, and lithic wacke of the newly defined King Arctic formation. The newly recognized “upper” limestone unconformably overlies the White Lake formation and is inferred to also overlie the King Arctic formation, although stratigraphic relationships along this unconformity are not well constrained. These three lower units are unconformably overlain by the heterolithic Money Creek formation.

White Lake formation

Chert and limestone of the White Lake formation are the oldest layered metasedimentary rocks in the area. The formation comprises three members, which are, from top to bottom: 1) a lower limestone member, and 2) a unit of pink and green chert interbedded with limestone which passes gradationally upwards into 3) an upper unit of banded green chert with fine-grained clastic interlayers. Cherts of the lower and upper units are most abundant on the eastern side of the southern Campbell Range while structurally thickened limestone caps the hilltops in the central to northern field area, most spectacularly above the King Arctic Jade Mine.

A massive, grey weathering, locally crinoidal and sandy limestone at least 30 metres thick is exposed in fault bounded panels and locally at the base of fault-sole stratigraphy in the western part of the study area. Data constraining the stratigraphic position of these massive limestone units are limited; however, local and regional geological relationships suggest a massive limestone is overlain by interbedded limestone and chert. The chert-limestone unit is over 150 metres thick. Limestone layers within chert range from 5 cm to 10 metres-thick and are grey weathered, pale grey fresh, locally crinoidal and/or sand-rich (Figure 1-6e,f). Limestone is locally stained rusty orange,

especially where interlayered with silver-green phyllite on a cm-scale. Where thickened by folding, limestone is a striped black and white mylonitic marble, and silicified layers are boudinaged. Chert of the lower chert-limestone unit is green to white ribbon chert, locally varicoloured pink and green at the handsample scale, with conformable domains of bright pink chert > 30 m thick (Figure 1-6c,d). Beds range from 2 to 10 cm thick with pale green muscovite-chlorite-epidote phyllite interlayers from 1 mm to 1 cm thick. Phyllite locally contains feldspar grains up to 1 mm in size, and flattened chlorite patches up to 1 cm diameter that are inferred to have replaced amphibole crystals.

The upper banded chert member is over 40 metres thick and overlies the lower chert-limestone sequence over a metre-scale gradational transition. It is composed of thinly bedded to finely laminated green chert (Figure 1-6a,b). Black, bright epidote-green, and white layers of translucent to opaque chert are interlayered with fine-grained green chlorite-epidote-quartz silt laminae on a mm to sub-mm scale. Magnetite porphyroblasts up to 0.5 mm diameter are common throughout this unit.

A Late Mississippian to Early Pennsylvanian age is inferred for the White Lake formation based on its correlation with lithologically similar rocks from which fossils have been extracted near Whitefish Lake north and west of the study area. The lower massive limestone unit and overlying limestone chert units in the study area resemble outcrops of the Whitefish limestone and overlying chert-limestone unit, respectively, that occur extensively to the north and northwest of the study area. Near Whitefish Lake, limestone in the lower part of the limestone-chert unit has a Serpukhovian conodont age and directly overlying chert has a Pennsylvanian radiolarian age (Murphy et al., 2005). In the east-central part of the study area, a Serpukhovian conodont has been extracted from a block of limestone within serpentinite (F7 in Murphy et al., 2005; Poulton et al., 2003; Orchard, 2005); although its relationship with the nearby rocks of the White Lake formation is unclear. A Moscovian upper age limit is provided by a massive limestone in the upper part of the section (the “upper” limestone) with Moscovian to Early Permian

conodont ages (Murphy et al., 2005; Orchard, 2005).

Rocks of the White Lake formation were previously included within the volcanic Tutchitua River formation lying beneath the regionally extensive Whitefish limestone (Murphy et al., 2002, 2005 and Devine et al. 2004). However, the new observations presented in this paper show that the rocks of the White Lake formation lie above the Whitefish limestone and below the Upper Pennsylvanian to Lower Permian “upper” limestone.

King Arctic formation

Approximately 300 metres of clastic rocks of the King Arctic formation unconformably overlie the White Lake formation. A basal green chert pebble conglomerate is overlain by lithic-arenite and granule to pebble conglomerate which grades upwards into dark grey, fine grained quartz-wacke. The basal unconformity is well exposed along the resistant limestone-capped hills above and to the southwest of the King Arctic Jade Mine.

The basal conglomerate is < 15 metres thick and contains sub-angular to well-rounded, granule to pebble-sized clasts of green chert and subordinate white limestone derived from the underlying White Lake formation (Figure 1-7b). Normally graded beds of green siltstone to angular granule conglomerate 1 to 3 cm thick as well as fine-grained arenite to siltstone with pale to dark green mm- to cm-scale banding are interlayered with conglomeratic beds. The matrix of the conglomerate is commonly calcareous where it rests upon limestone, and clasts of chert dominate where it rests upon White Lake formation chert. The basal unconformity is sharp but irregular, and conglomerate thickness and clast content above the unconformity vary along strike. Fine-grained siltstone clasts with composition and texture similar to beds within the unit occur locally within the conglomerate and intraformational unconformities may be present.

Approximately 150 metres of fine to medium grained, green lithic arenite and

lithic wacke overlies the basal conglomerate (Figure 1-7a). A distinctive cm-scale mottled texture on weathered surfaces is characteristic of the unit. Clasts are commonly quartz (chert?) with < 10% plagioclase; locally there are fine-grained, angular white lithic clasts < 3mm in diameter and angular argillaceous clasts < 1 cm occupying < 10% volume. The upper 50 metres consist of dark grey fine-grained lithic-wacke. The transition from green arenite and wacke to dark grey fine-grained wacke is gradational with metre-scale interbedding of units. Dark grey argillite that is locally a chloritic phyllite, gradationally caps the wacke and is locally interbedded with argillaceous chert on the metre-scale and fine grained green lithic-arenite on mm-scale.

The King Arctic formation is indirectly constrained to be Pennsylvanian in age by the ages of underlying and overlying rocks. In the field area, it overlies the Upper Mississippian to Pennsylvanian White Lake formation. Regionally, to the north and west, a unit of limestone pebble to cobble conglomerate with minor green phyllite and chert-clast granule conglomerate resembling the King Arctic formation immediately underlies limestone from which Moscovian conodonts have been extracted (F. Devine field observations; Murphy et al., 2005; Orchard, 2005). The upwardly increasing clastic content of the White Lake formation and the similarity of the fine grained clastic units in the banded chert of the White Lake formation and the King Arctic formation may indicate deposition of these units through progressive sedimentation into a basin across a short time-span unconformity at the base of the King Arctic formation.

The King Arctic formation was previously undefined and was mapped as part of the Tuchitua succession and Tuchitua River formation of Murphy et al. (2002, 2005). This correlation is no longer viable as the Tuchitua River formation underlies the Whitefish limestone and the King Arctic formation overlies the White Lake formation, which is younger than the Whitefish limestone.

“upper” limestone

A north trending discontinuous ridge of limestone with poorly exposed contacts lies along the western side of the field area (Figure 1-3a). Structural relationships suggest that the “upper” limestone is preserved in the antiformal hinge of a parasitic fold along the western side of a regional north-trending anticline. It overlies White Lake formation chert above an unexposed contact and is overlain by Money Creek formation conglomerate to the west.

The limestone is locally crinoidal, pale grey weathering, and grey on fresh surfaces. It is dominantly massive with buff coloured recrystallized patches. The base of the upper limestone is inferred to be an unconformity as it overlies different rock units in different places. In the study area, massive limestone overlies the White Lake formation. Regionally, a similar massive and locally conglomeratic limestone overlies rocks correlated with the White Lake formation near White Lake (F. Devine, field observations).

The “upper” limestone is constrained by conodont collections to be Pennsylvanian to Early Permian in age. A Pennsylvanian conodont age was extracted from the limestone in the field area (Orchard, 2005). Regional conodont collections from lithologically similar units in a similar stratigraphic position range in age from Pennsylvanian to Lower Permian (Figure 1-2; Murphy et al., 2005).

The “upper” limestone was previously included with the Whitefish limestone (Murphy et al., 2002, 2005). However, new regional mapping and the observations presented in this paper require that a new, younger limestone unit be defined.

Money Creek formation

Dark-coloured, fine to coarse metaclastic rocks of the Money Creek formation (Murphy et al., 2005) overlie the White Lake formation, King Arctic formation and the “upper” limestone. Although exposed in fault slices throughout the field area, rocks of

the Money Creek formation are more extensive to the north of the study area and underlie much of the region directly north of the King Arctic Jade Mine.

The Money Creek formation contains a wide variety of dark-coloured, generally phyllitic metasedimentary rocks. These include dark grey to black, sub-angular to rounded chert-pebble conglomerate (Figure 1-8b); dark argillaceous chert; black carbonaceous phyllite; angular, sand to granule conglomeratic lithic wacke commonly with glassy blue quartz granules; and minor green to brown lithic arenite. Distinctive black and white diamictite with irregularly shaped white quartzite clasts < 2 cm in diameter in a black phyllitic matrix is found locally (Figure 1-8a). Although these lithologies are interbedded at outcrop-scale, they are not laterally continuous. Blocks of grey ribbon chert and crinoidal limestone up to 30 m long are found locally within medium to fine-grained lithic units and the limestone blocks commonly occur in restricted linear domains.

The basal unconformity is exposed in the central field area where it cuts primary layering in chert of the White Lake formation. Blocks of chert up to 20 cm in diameter are included in heterolithic phyllite-matrix conglomerate immediately above the irregular basal contact (Figure 1-8c).

The age of the formation is constrained to be Early Permian based on fossil age dates reported for overlying and underlying rocks in the Finlayson Lake belt. The youngest unit below the unconformity at the base of the Money Creek formation is the “upper” limestone (Murphy et al., 2005; this paper) while the overlying Campbell Range formation basalt is interlayered with radiolarian chert that yields Early Permian ages (Murphy et al., 2005; Pigage, 2001; Plint and Gordon, 1997).

Undifferentiated Waters Creek formation and Simpson Range Plutonic Suite

Along the western side of the map area poorly exposed metamorphosed intrusive and extrusive rocks are in presumed fault contact with Money Creek formation rocks

to the east. Metaintrusive rocks comprise moderately foliated, fine- to medium-grained chloritized muscovite-amphibole granodiorite and chloritized, foliated, coarse-grained quartz-phyric amphibole granodiorite. Foliated quartz-phyric chlorite-muscovite schist of presumed metavolcanic origin is exposed in one locality. These rocks resemble, and are correlated with, the Devonian Waters Creek formation and Simpson Range plutonic suite found in other parts of the Finlayson Lake area (Mortensen and Jilson, 1985; Murphy et al., 2004).

Slide Mountain terrane Permian rhyolite and Simpson Lake group

Rocks belonging to Slide Mountain terrane and Simpson Lake group occur east of the Jules Creek fault in the poorly exposed eastern side of the study area.

Paleozoic and Triassic metasedimentary rocks

Fortin Creek group

Rocks of the Fortin Creek group include: grey to black chert pebble conglomerate, rusty weathering medium-grained quartz arenite and aphanitic rhyolite. Rocks commonly display open quartz-lined vugs < 2 cm diameter and sub-mm, black silica spiderweb-like veining. Regional fossil ages (summarized in Murphy et al., 2005) suggest a Mississippian to Early Permian age for the Fortin Creek group.

Flow-banded rhyolite

Pale cream coloured quartz-phyric rhyolite with mm-scale flow banding occurs in isolated outcrops, spatially associated with the Fortin Creek group east of the Jules Creek fault. The crystallization age of the rhyolite is dated by U-Pb zircon methods as 259.6 ± 1.2 Ma (Appendix I). Although contacts with the Fortin Creek group metasedimentary rocks are not exposed, the rhyolite must unconformably overlie the Fortin Creek group,

and may correlate with Middle to Late Permian volcanic and magmatic rocks, regionally known as the Klondike Schist (Murphy et al., 2005).

Simpson Lake group

Heterolithic conglomerate of the Simpson Lake group locally overlies the Fortin Creek group immediately adjacent to the Jules Creek fault in the northern part of the field area (Figure 1-3). The conglomerate is more extensively exposed directly north of the field area near the road to the King Arctic mine and along the Robert Campbell Highway to the north and south of the area.

In the study area, the moderately foliated, green conglomerate varies from clast to matrix supported and is poorly sorted with subrounded granule- to pebble-sized clasts of chert, green quartz-arenite and serpentinite, reflecting local sources. Regionally, the unit includes interbedded siltstone and sandstone and contains a variety of clasts derived from Yukon-Tanana terrane (Mortensen et al., 1997; Mortensen et al., 1999; Murphy et al., 2002, 2005)

A Late Triassic age is inferred from isotopic age dates and fossil ages on clasts (Murphy et al., 2005 and references therein; Mortensen et al., 1997) and from fossil ages on interbedded shale in correlative rocks near Faro (Mortensen and Jilson, 1985; Pigage, 2004; Pigage, 2001; Tempelman-Kluit, 1979). The unit is an overlap assemblage on Yukon-Tanana and Slide Mountain terranes (Murphy et al., 2005).

STRUCTURE

Three structural domains are recognized in the southern Campbell Range: the western and central domains lie west of the Jules Creek fault and the eastern domain is east of the Jules Creek fault. This paper focuses on the central domain, which is bound to the east by the Jules Creek fault and to the west by the faulted contact of central domain rocks with metavolcanic and metaintrusive rocks of the Waters Creek group and

the Simpson Range plutonic suite (Figure 1-3a). Five generations of structures affected the metasedimentary rocks of the central domain; the latter two are also preserved in the Klatsa metamorphic complex. The layered schists of the Klatsa metamorphic complex also preserve an older structural history not seen elsewhere in the region. The following section describes structures from oldest to youngest.

Devono-Mississippian structures in the Klatsa metamorphic complex

Two generations of structure which pre-dated regional structures are preserved in the layered schists of the Klatsa metamorphic complex: Sm1 and Sm2. Sm1 is a well-developed foliation in the quartz-muscovite schist of the Klatsa metamorphic complex layered schist member. Sm1 strikes northwest and dips moderately to the southwest. It is defined by compositional variation within quartz-muscovite schist and outlined by layers of muscovite and quartz in hand sample (Figure 1-4). Metabasite lenses are parallel to Sm1; the lenses are foliated along the margins but only rarely display minor foliation internally. Muscovite is commonly undeformed within metabasite. Retrogressed garnet domains within the quartz-muscovite schist locally display a foliation outlined by included accessory minerals, which may correspond to Sm1 or be an older fabric overprinted by Sm1 (see also Figure 2-4, Chapter 2).

Discrete shear fractures (Sm2) < 2 cm thick and >10 cm long cut Sm1 at a low angle (see Figure 2-4, Chapter 2). Cataclastic domains display local grain-size reduction of quartz, and preferential deformation of muscovite oriented at a high-angle to the fractures. At the southern occurrence of the layered schist unit, the bounding faults appear to cut the metamorphic assemblage fabrics at a low angle.

Isotopic ages partly constrain the age of Sm1 and Sm2. Sm1 is considered to be older than ca. 353 Ma based on ^{40}Ar - ^{39}Ar ages from undeformed muscovite in the metabasite lenses; the muscovite is interpreted to be the same generation as muscovite outlining Sm1 in the quartz-muscovite schist. Sm2 is constrained to be younger than ca.

353 Ma as it deforms the ca.353 Ma generation muscovite in the quartz-muscovite schist (Chapter 2). Sm1 deformation may be linked to metamorphism and exhumation of the Klatsa metamorphic complex layered schist unit in the Early Mississippian. Sm2 may correlate with D4 faulting.

Regional Deformation

The earliest structure in the southern Campbell Range is a cryptic thrust fault, interpreted to be the Cleaver Lake fault (see Discussion), responsible for juxtaposition of rocks of the Klatsa metamorphic complex with greenschist facies metasedimentary rocks of the Money Creek thrust sheet. Five regional deformation events, affect all the map units in the southern Campbell Range, therefore post-dating the thrust emplacement of the Klatsa metamorphic complex. These include three generations of folding (F1, F2 and F3) followed by D4 and D5 faulting. The D4 faults interleave panels of the deformed metasedimentary sequence with sheets of Klatsa metamorphic complex. Steep brittle faults of D5 trend E-NE across the region cut all earlier structures.

Bounding faults of the Klatsa metamorphic complex

The juxtaposition of Klatsa metamorphic complex with southern Campbell Range metasedimentary rocks requires a major fault, based on the significantly different peak metamorphic grades in each package. Although the boundaries of the Klatsa metamorphic complex are exposed as D4 faults, D4 displacements are too small to result in the observed metamorphic juxtaposition. The initial juxtaposition is, therefore, interpreted as an early, pre-D1 fault that has been modified by younger structural events.

D1 and D2 folding: F1, F2, S2, L2

F1 folding is suggested by a possible fold interference pattern in the central field area. A 100-m amplitude, isoclinal, originally west-vergent fold pair was refolded by a

highly attenuated F2 fold (Figure 1-3b). The hinge zone of the F1 fold contains tightly folded chert and limestone of the White Lake formation cut by tightly folded 5-10 cm thick bull-quartz veins. Phyllite of the Money Creek formation is demonstrably folded around the hinge zone across the White Lake group-Money Creek unconformity (Figure 1-8c). Contact relationships and fold orientations indicate original west-vergence for this F1 fold; however, using the folded unconformity as the basis for fold style and geometry may be misleading as folding of a highly irregular surface will produce unpredictable fold geometry. No other structures that can conclusively be assigned to F1 were observed in outcrop or thin section. Either F1 was an early structural phase of a progressive F2 event and the fold in the central field area is a relict of an irregular unconformity, F1 is progressive to F2, and/or all earlier D1 structures are concordant with D2 and undifferentiable from D2 structures.

The structural geometry of the field area is dominated by F2 folds. F2 folds were mapped at 1:20 000 scale. Folds generally plunge to the west and northwest, are overturned and verge to the north and northeast; however, D4 faulting has resulted in some reorientation of F1 to F3 structures (Figure 1-11). Contacts between folded metasedimentary units are not well exposed but cleavage-bedding relationships, observed fold asymmetry, and the map pattern define regional fold orientations. Microscopic mm-scale to 10 metre-scale amplitude folds, visible in outcrop, are inferred to be parasitic on higher order folds.

Bedding in chert and limestone of the White Lake formation is folded into tight to close, subangular to subrounded asymmetric folds that are locally disharmonic in the hinge zones. Fold style varies from limbs to hinge zones. On limbs, parasitic folds have highly attenuated limbs and thickened hinges (Figure 1-9), whereas in F2 hinge zones, folds are close to open with shorter limbs and similar bed thickness (Figure 1-3b,c, f). A poorly- to well-developed cleavage (S2) is axial planar to F2 folds and clast- and mineral-elongation lineations (L2) are parallel or nearly parallel to F2 fold axes. Transposed

bedding in chert and alignment of platy minerals in ribbon chert interlayers defines the S2 cleavage in the White Lake formation. Rocks of the King Arctic formation have poorly developed 5-10 cm spaced cleavage with chlorite-lined foliation planes in fine to medium-grained sandstone and stretched pebble conglomerate. In rocks of the Money Creek formation, coarse continuous foliation in phyllites with clast-elongation lineation varies to a well-developed L- and L-S tectonite defined by clast- and mineral-elongation.

F1-2 folds in the study area are constrained to be younger than the folded Lower Permian Money Creek formation. To the north, folds with a similar style deform the Early Permian Campbell Range basalt (Plint and Gordon, 1997) which overlies the Money Creek formation (Murphy et al., 2005), suggesting that these folds are even younger. The minimum age of F2 folding is unconstrained.

D3 folding: F3

D3 folds are km-scale open, upright, generally east-west trending and deform the S2 cleavage (Figure 1-3f). F3 axial planes are at a high angle to F2 axial planes. The orientation of the F3 fold axes is roughly parallel to F2 fold axes, although their orientation is not well constrained. F3 folds were not observed at outcrop scale but their presence is required based on the change in orientation of S0 and S2 cleavages across the area (Figure 1-3f).

D4 faulting: S4

Southeast striking, moderately to steeply west-dipping D4 faults imbricate the folded metasedimentary sequence with sheets of serpentinite and the Klatsa metamorphic complex (Figure 1-10). D4 faults form an anastomosing system with the trace of individual fault strands extending from 10 metres to 5 kilometres along strike. Vertical cross sections (Figure 1-3b,c,d) show D4 faults to be curvilinear with dips varying from 30 to 80 degrees to the southwest, and dip changing over strike lengths of 100's of metres

along a single fault plane. Metasedimentary rocks bounded by D4 faults occur in slices that range from several metres thick to >200 metres thick. Limestone in the immediate hanging wall of D4 faults shows highly strained mm-scale banding (S4). Rare cm-scale, generally north-trending kink folds deform the D3 cleavage within the metasedimentary units and have NW-trending fold axes; they may be related to the D4 faulting event.

Although locally absent, massive to foliated serpentinite bodies ranging from a few centimetres to several hundred metres thick occur along D4 faults (Figure 1-10). Alteration and metasomatic replacement zones are concentrated along the boundaries between serpentinite bodies and adjacent metasedimentary units; talc schist zones, 10 cm to 1 metre thick, are developed along faults, and limestone slices adjacent to and within serpentinite show tremolite alteration and concentrations of magnetite porphyroblasts. In the vicinity of the King Arctic Jade Mine, nephrite jade formed through metasomatic replacement of serpentinite in areas where D4 faults juxtapose limestone of the White Lake formation and conglomerate of the King Arctic formation with serpentinite. Nephrite occurs as lenses up to 3 metres thick along D4 faults (Devine et al., 2004; Devine, 2005).

D4 faults are inferred to be low- and high-angle reverse faults based on consistent repetition of metasedimentary stratigraphy and older-over-younger faulted relationships. Devonian mafic and ultramafic rocks were thrust over Pennsylvanian to Permian rocks (Figure 1-3b,c,d). Maximum displacement along D4 faults is poorly constrained; however, the consistency of metasedimentary stratigraphy and structural style of the different fault panels imply maximum offsets in the range of 2 km. F2 folds can locally be restored across D4 faults with < 20 m displacement. Serpentinite along the Jules Creek fault, likely correlative with the other serpentinite in the region, indicates that it was reactivation during D4 deformation.

Metasedimentary fault slices were offset and rotated with respect to each other across D4 faults. D1-3 structures are consistent in orientation within fault slices but

are misoriented from slice to slice (Figure 1-11). F2 structures in the panel along the east flank of the southern Campbell Range (stereograms C and D; Figure 1-11) show moderately inclined west-trending folds plunging 30 degrees while folds in the westernmost panel (stereogram H) are upright and plunge 15 degrees to the north-northwest. Structural domains from different fault slices throughout the field area show structural variation between these two orientations.

F2, F3 and D4 are considered separate structural events. Some evidence suggests that D4 faulting may be progressive from earlier F1-2 fold deformation: D4 faults are located along F2 fold hinges in the King Arctic area with < 100 metres of offset along the fault. However, D4 faults cut all earlier structures in metasedimentary rocks, including the open D3 folds, and there are many D4 faults that are not localized along F2 hinge zones.

D4 faults in the southern Campbell Range are constrained to be post-Early Permian, and likely post-Late Triassic in age. They deform the Lower Permian Money Creek formation and have reactivated the Jules Creek fault which cuts the Upper Triassic Simpson Lake group immediately north of the field area (D.C. Murphy, pers.comm., 2004). D4 faulting may coincide with displacement on the Inconnu thrust which is constrained to be post-Late Triassic based on the age of overthrust Upper Triassic North American continental margin strata (Mortensen, 1992b; Murphy et al., 2005).

D5 faulting

Northeast-southwest to north-south striking, nearly vertical high-angle brittle faults offset all earlier structures. Offset of geological contacts across D5 structures constrains the throw on these faults to at least 20 metres; however, the offset is locally > 200 metres. Where exposed, the fault zones are < 10 m wide and filled with hematitic silicified fault gouge.

Slickenlines are developed locally along discrete fractures and joints in

metasedimentary rocks along the east side of the map area. Asperity truncations along these slickensides show normal west-dipping fault motion. There are no age constraints on D5 faults other than that they cut D4 structures interpreted to be post-Late Triassic.

DISCUSSION

The following discussion chronologically describes the stratigraphic and structural evolution of Yukon-Tanana terrane in the southern Campbell Range, from oldest to youngest. The structural origin of the Klatsa metamorphic complex is addressed.

Devono-Mississippian amalgamation and exhumation of the Klatsa metamorphic complex

The Klatsa metamorphic complex comprises the oldest rocks in the southern Campbell Range; the complex was metamorphosed and exhumed in the Devonian to Mississippian. Protolith ages vary for different members of the unit. The mafic-ultramafic member (serpentinite and leucogabbro) has a magmatic age of 368 ± 12 Ma (U-Pb zircon on leucogabbro, Chapter 2). This age correlates with the earliest volcanism and magmatism in Yukon-Tanana terrane in the Finlayson Lake belt (Murphy et al., 2005; Piercey et al., 2004). The other dominant member of the Klatsa metamorphic complex, the layered schists, contains zircon cores with inherited detrital zircons as old as Proterozoic; the schist is interpreted to be part of, or derived from, the continentally-derived basement to Yukon-Tanana terrane (Chapter 2).

Amalgamation of the complex occurred prior to or during metamorphism at ~ 353 Ma (U-Pb age of metamorphic zircon; Chapter 2). Microscopic structures within metamorphic minerals record deformation during metamorphism or early exhumation of the unit. Similar, and possibly correlative, mid-Paleozoic deformation is recorded elsewhere in the Finlayson Lake belt (Mortensen, 1992b; Murphy et al., 2005), and in other parts of Yukon-Tanana terrane. The oldest arc stratigraphy of Yukon-Tanana

terrane in the Finlayson Lake region was deformed during a poorly understood intra-arc tectonism prior to the earliest Mississippian (Murphy et al., 2005). Basement units to Yukon-Tanana terrane also show evidence for old deformation, for example in the Snowcap Complex in the Glenlyon area (Colpron et al., 2003), the Dorsey Complex in northern British Columbia and southern Yukon (Nelson and Friedman, 2004; Roots et al., 2000), and metasedimentary rocks in the Stewart River area of western Yukon (Ryan et al., 2003).

Pennsylvanian to Early Permian siliciclastic and carbonate deposition

The Pennsylvanian to Early Permian metasedimentary rocks in the region represent a period of siliciclastic and carbonate deposition within the Yukon-Tanana arc. A change in tectonic regime from platformal carbonate and chert sedimentation to flysch-style, syn-tectonic sedimentation is recorded by the transition into the Money Creek formation.

Regional correlation with other rocks in the Finlayson Lake region constrain these units to be from the arc proper, as opposed to the backarc region represented by basinal rocks in other parts of the Finlayson Lake belt (Murphy et al., 2005).

Early Permian(?) thrust faulting: structural origin of the Klatsa metamorphic complex

Early Permian shortening and thrust faulting of the Yukon-Tanana arc is responsible for structural stacking of rocks from different parts of the arc. The Money Creek and Cleaver Lake thrusts carry thrust sheets that extend the length of the Finlayson Lake belt. Regional mapping and correlation show that the Pennsylvanian to Early Permian metasedimentary rocks in the southern Campbell Range are part of the Money Creek thrust sheet (Figure 1-2).

Structural relationships in the southern Campbell Range indicate that the Klatsa

metamorphic complex is in the hanging wall of the Cleaver Lake thrust fault and structurally overlies the metasedimentary rocks in the footwall. Regionally, the Cleaver Lake thrust fault occurs in the same structural position, structurally overlying the Money Creek formation. The Klatsa metamorphic complex is interpreted to occupy the core of a synform involving Money Creek formation, with limbs modified by D4 faults. At the southern occurrence of the layered schists, metasedimentary stratigraphy across the bounding faults tops inwards, indicating a synform cored by the layered schists (Figs. 3b and 12).

The structural position of the Klatsa metamorphic complex in the hanging wall of the Cleaver Lake fault is important to understanding the “enigmatic” inboard location of the eclogitic rocks along the eastern side of Yukon-Tanana terrane. Transport of the Klatsa metamorphic complex by the Cleaver Lake thrust sheet implies an initial frontal arc position for exhumation of the metamorphic complex prior to Early Permian thrust faulting based on westward restoration of the Cleaver Lake fault (Murphy et al., 2005). The Klatsa metamorphic complex was exhumed in the frontal arc region in Mississippian time, prior to Early Permian east-directed thrust faulting.

Middle to Late Triassic (?) D1-2 northeast-vergent folding

The timing of D1-2 shallowly northwest-plunging, northeast vergent folding, and possibly D3 folding, is constrained by geological relationships in the southern Campbell Range to be younger than the folded Lower Permian Money Creek formation.

Post-mid Permian penetrative ductile deformation is recorded regionally in other parts of Yukon-Tanana terrane. The timing of deformation is not always well constrained locally; however, two broadly defined tectonic events are recognized regionally: 1) Post-Mid-Permian, pre-Late Triassic east-directed thrust faulting and folding (Mortensen, 1992b; Nelson and Friedman, 2004), and 2) Early to Middle Jurassic northeast-directed (in southcentral Yukon) deformation (Colpron et al., 2003; Hansen, 1989). The

geological relationships in the southern Campbell Range favour correlation of D1-2 folding with Middle Triassic deformation as they pre-date D4 faults which are tentatively correlated with Jurassic deformation.

Jurassic D4 faulting

The dominant structures in the southern Campbell Range are the imbricate high-angle to steeply southeast-dipping thrust faults which juxtaposed panels of serpentinite (the Klatsa metamorphic complex) with polydeformed metasedimentary rocks. Brittle thrust faults which juxtapose Yukon-Tanana terrane, Slide Mountain terrane, and Triassic North American rocks are recognized in a > 20 km wide belt along the entire eastern side of the Finlayson Lake belt. The Inconnu thrust fault carried Yukon-Tanana and Slide Mountain terrane rocks eastwards over fault-imbricated Upper Triassic North American continental margin strata with > 60 km of displacement (Gordey and Murphy, 2003). We correlate D4 in the southern Campbell Range with the post-Late Triassic Inconnu event and suggest that the brittle D4 faults involving serpentinite are the local manifestation of this thrust belt.

Regional ductile, and locally brittle, Jurassic deformation affected many different parts of Yukon-Tanana terrane in Yukon and Alaska (eg. Colpron et al., 2003; de Keijzer et al., 1999; Hansen and Dusel-Bacon, 1998). Also to the south, in northern British Columbia, the equivalent of the Inconnu thrust soles the Sylvester allochthon, where Slide Mountain and Yukon-Tanana terranes were structurally emplaced onto rocks of the North American margin (Nelson and Friedman, 2004).

SUMMARY OF CONCLUSIONS

The geology, geological relationships, and structural history of the southern Campbell Range, including the Klatsa metamorphic complex is summarized as follows:

- 1) Metasedimentary rocks in the southern Campbell Range can be divided into four

separate units. From oldest to youngest these are: the Serpukovian White Lake formation chert and limestone, unconformably overlying King Arctic formation conglomerate, Pennsylvanian limestone and Early Permian heterolithic Money Creek formation.

- 2) The Klatsa metamorphic complex comprises, in order of decreasing abundance: 1) a mafic-ultramafic member which includes serpentized ultramafic rocks and co-magmatic leucogabbro, 2) a layered schist member composed of quartz-muscovite schist and interfoliated metabasite lenses, 3) blocks of amphibolite, 4) phyllite-matrix *mélange*, and 5) blocks of orthoquartzite and chert.
- 3) The Klatsa metamorphic complex was formed and exhumed along the western side of the Yukon-Tanana arc in Early Mississippian time. Shortening within Yukon-Tanana terrane, including transport along the Early Permian Cleaver Lake thrust fault, is responsible for eastward transport of Mississippian eclogitic rocks towards the Yukon-Tanana terrane backarc.
- 4) Five regional structural events, following structural juxtaposition of the Klatsa metamorphic complex and Campbell Range metasedimentary rocks, are recognized in the southern Campbell Range: 1,2) northeast-vergent tight, overturned F1?/ F2 folding, 3) broad east-west-trending F3 folding, 4) low to high-angle reverse D4 faulting, imbricating all units, and 5) high angle, low displacement D5 faulting. D4 faults control the regional map pattern.

Figure 1-1. Map of the Finlayson Lake belt showing major geological units, thrust sheets, and major faults. The southern Campbell Range region and Figure 1-3 are delineated by the box in the centre of the map. 1:250 000 map sheet boundaries are labelled. The Stewart Lake klippe is soled by the Inconnu fault in the southeastern corner of the map. The inset map of Yukon and northern British Columbia outlines the distribution of Yukon-Tanana and Slide Mountain terranes in the Territory. Modified after Murphy et al., 2005; Stewart Lake klippe contacts modified from J. Mortensen, unpublished data.

Figure 1-2. Simplified stratigraphic relationships in fault bounded domains of Yukon-Tanana Terrane (YTT), Slide Mountain Terrane (SMT), and rocks of the North American miogeocline north of the Tintina fault. The age range of upper Mississippian to lower Pennsylvanian for the White Lake formation to the "upper" limestone is based on regional fossil data (M. Orchard, 2005, Murphy et al., 2005) and one conodont sample from the western study area (in yellow); F = conodont, R = radiolarian. Modified after Murphy et al., 2005.

Figure 1-3. a) Simplified geological map of the southern Campbell Range. Black diamonds mark the Upper Quarry (left) and the Working Face (right) at the King Arctic Jade Mine b, c, d) Vertical cross sections A, B, and C drawn at 1.5 times the map scale. e) Isometric diagram interpreting the profile section orientation. f) Profile section D drawn at 1.5X map scale. The profile plane is drawn at a right angle to the plunge and trend of F2 fold axes.

Figure 1-4. Representative rock photographs from the layered schist member of the Klatsa metamorphic complex: **a)** quartz-muscovite schist with chlorite-clinozoisite-epidote pseudomorphs after garnet porphyroblasts, **b)** retrogressed eclogite with chlorite-epidote-clinozoisite pseudomorphs after garnet in an amphibole-epidote matrix, overgrown by coarse-grained white mica.

Figure 1-5. Schematic stratigraphy of the southern Campbell Range. Unit thicknesses are not to scale, and ages are based on regional constraints and correlations with dated units elsewhere in the Finlayson region (age data in Murphy et al., 2005; Orchard, 2005; this paper Figure 1-2).

Figure 1-6. Representative rock photographs of the White Lake formation, from stratigraphic top to bottom: (a,b) Banded to laminated magnetite-bearing green chert, scale is in cm; (c) Pink ribbon chert. (continued)

Figure 1-6 (concluded). Representative rock photographs of the White Lake formation: (d) green ribbon chert with calcareous and tuffaceous mm-scale interlayers; (e) Limestone with interbedded quartz sand-rich layers; (f) Well-foliated marble along the margin of a D4 thrust sheet, possibly correlative with the Whitefish limestone.

Figure 1-7. Representative rock photographs of the King Arctic formation: **a)** graded siltstone and lithic arenite, **b)** basal green chert-clast conglomerate containing clasts possibly derived from underlying White Lake group. Scale is in cm.

Figure 1-8. Representative rock photographs of the Money Creek formation: **a)** diamictite with white quartz-rich clasts within a phyllite matrix (scale is in cm), **b)** black and grey chert pebble conglomerate, and **c)** the unconformity along the limb of an overturned F_1 fold with the Money Creek formation unconformably overlying chert of the White Lake formation.

Figure 1-9. F2 folds in banded chert of the White Lake formation.

Figure 1-10. Southward view of the southeastern field area of an oblique section through the fault-stacked sequence of metasedimentary rocks and serpentinite. All contacts are D4 faults, cut by a high-angle D5 fault. The fault plane above the uppermost eastern serpentinite sheet in the photo dips to the south-southwest. PMC = Money Creek formation, PPKAcl = King Arctic formation, Serp = serpentinite.

Figure 1-11. Map showing structural domains in D4 fault-bounded panels. Stereograms A to H show the orientations of S0, F1-2 fold axes, S2, and L2 in metasedimentary rocks from selected structural domains within the D4 fault panels. Bedding (S0) is folded by generally northeast vergent, west-plunging F1-2 folds; S2 axial planar cleavage and L2 clast and mineral elongations formed during D2. The spread of S2 along great circles is interpreted to reflect gentle, upright D3 folding that reoriented F1-2 structures. D4 thrust faulting intercalated the metasedimentary sequence with serpentinite; the rigid blocks of metasedimentary rock were shuffled and rotated with respect to one another leading to variation in the orientation of D1, D2, and D3 structures between blocks. Although orientation of D1-3 structures varies across D4 faults, the relationships within blocks is consistent.

Figure 1-12. Summary diagram of the structural emplacement of the Klatsa metamorphic complex into thrust-stacked Yukon-Tanana terrane.

CHAPTER 2

Geochronology and geochemistry constraints on the origin of the Klatsa metamorphic complex: Implications for the Late Paleozoic tectonic development of Yukon-Tanana Terrane

ABSTRACT

The newly defined Klatsa metamorphic complex, one of the last vestiges of Early Mississippian subduction zone rocks in Yukon-Tanana terrane, occurs in the southern Campbell Range near the southeastern margin of Yukon-Tanana terrane in the Finlayson Lake belt, southeastern Yukon. It comprises primarily massive to well-foliated serpentinite; leucogabbro; amphibolite; polydeformed retrogressed eclogitic layered schists; and, lesser phyllite-matrix *mélange*. Detailed SHRIMP U-Th-Pb geochronology studies of zircon, $^{40}\text{Ar}/^{39}\text{Ar}$ dating of muscovite and trace element geochemistry provide age constraints on protoliths, provenance, and timing of high-pressure metamorphism and exhumation: 1) The metasedimentary protolith of the layered schists has zircons with detrital cores that have ages ranging from 2.8 Ga Ma to 0.47 Ga; 2) metabasite lenses in the layered schists have NMORB and arc basalt protoliths 3) the mafic components of the ultramafic unit have a 368 ± 10 Ma magmatic age, coeval with the oldest arc magmatism in Yukon-Tanana terrane; 4) Early Mississippian eclogite facies metamorphism of the layered schists occurred at 353.0 ± 3.7 Ma, constrained by cogenetic mineral inclusions of garnet and omphacite in zircon; and 5) rapid exhumation of the complex occurred at 353.3 ± 0.8 Ma on the basis of $^{40}\text{Ar}/^{39}\text{Ar}$ dates from muscovite from the layered schists. The Klatsa metamorphic complex is interpreted to be an Early Mississippian subduction-related *mélange*, host to sedimentary rocks of, or derived from, Yukon-Tanana terrane basement and early Yukon-Tanana arc rocks. The complex was metamorphosed, locally at eclogite facies, rapidly exhumed in the western frontal arc region of Yukon-Tanana arc, and subsequently thrust eastwards along the Cleaver Lake fault during Early Permian shortening within Yukon-Tanana terrane. The Stewart Lake klippe is a structurally isolated klippe of rocks correlative with the Klatsa metamorphic complex.

INTRODUCTION

The volcano-sedimentary Yukon-Tanana terrane extends from Alaska, through Yukon and into British Columbia, forming an integral part of the autochthonous and allochthonous terranes that make up the northern Canadian Cordillera (Figure 1). Arc and arc-rift – related volcanic and plutonic rocks, as well as associated metasedimentary units, range in age from Late Devonian to Late Permian and were built upon a pre-Late Devonian basement with ties to the North American continental margin (Mortensen, 1992; Nelson et al., 2002). Current models for YTT development favour initial arc development along the extended North American continental margin which evolved to backarc spreading and separate arc evolution (Nelson et al., 2002). Geological complexity within Yukon-Tanana terrane is the result of intra-arc deformation and metamorphism in the Devono-Mississippian and Permian, as well as during Jurassic (?) obduction, which was followed by post obduction deformation and margin-parallel displacement.

Two generations of eclogitic rocks occur within the Yukon-Tanana terrane, preserving evidence of two paleosubduction and deep exhumation events at different times within and/or alongside the Paleozoic Yukon-Tanana arc. Well-preserved Late Permian eclogites and blueschists lie along the eastern boundary of Yukon-Tanana terrane (Erdmer, 1987, 1992; Erdmer et al., 1998; Erdmer and Helmstaedt, 1983; Pigage, 2004). They mark the tectonic position of the Late Permian west-dipping subduction zone, active during closure of the Slide Mountain ocean basin that separated Yukon-Tanana terrane from North America. Poorly preserved exposures of an older generation of eclogites, Mississippian in age, also occur near the eastern boundary of Yukon-Tanana terrane. However, the explanation for their current position is somewhat enigmatic based on the classic Franciscan model for forearc-related eclogite exhumation, given that polarity of the Devono-Mississippian subduction zone was east-dipping along the western side of the Yukon-Tanana arc (Mortensen, 1992; Piercey et al., 2004a). A more complex structural

history, as well as alternative mechanisms of eclogite exhumation with the Yukon-Tanana arc, must be considered to explain the metamorphic and exhumation history of the Mississippian eclogitic rocks in YTT.

An Early Mississippian metamorphic complex that locally includes retrogressed eclogitic rocks is exposed in two localities in southeastern Yukon. In the southern Campbell Range, highly retrogressed eclogitic rocks, serpentinite and gabbro form the Klatsa metamorphic complex (Chapter 1). Near Stewart Lake amphibole-eclogites, ultramafic rocks, and gabbroic rocks, interpreted to be correlative with the Klatsa metamorphic complex, are preserved in a klippe structurally overlying North American rocks and soled by the Jurassic(?) Inconnu thrust fault (Figure 1; Erdmer et al., 1998). Erdmer et al. (1998) reported $^{40}\text{Ar}/^{39}\text{Ar}$ ages of ~344 Ma from white mica within retrogressed eclogites from both localities, and interpreted the ages to date Early Mississippian cooling of the rocks. Broad P-T constraints from eclogites in the Stewart Lake klippe record minimum pressures of 14 kb (Erdmer et al., 1998).

This paper examines the protolith, petrology, metamorphic evolution and deformation history of the Klatsa metamorphic complex, part of which was previously referred to as the Simpson Range eclogite by Erdmer et al. (1998). We use petrochemical data to investigate the protolith of some units within the complex, SHRIMP geochronology data to place timing constraints on high-P metamorphic petrogenesis, and $^{40}\text{Ar}/^{39}\text{Ar}$ data to date the exhumation of the complex. We then extend the discussion to comment on possible Klatsa metamorphic complex correlatives within Yukon-Tanana terrane, and summarize the implications of these new data for the earliest tectonic history of the Yukon-Tanana arc.

REGIONAL GEOLOGY

In southeastern Yukon, the Finlayson Lake belt comprises a sheet of Yukon-Tanana terrane and Slide Mountain terrane, offset from the rest of Yukon-Tanana terrane

during post-Late Cretaceous dextral displacement along the Tintina fault (Figure 1; Murphy and Mortensen, 2003). Within the Finlayson Lake belt, Yukon-Tanana terrane metavolcanic and metasedimentary volcanic arc-derived rocks were juxtaposed with basinal metasedimentary rocks of Slide Mountain terrane along the Jules Creek fault, a possible mid-Permian to Triassic strike-slip fault that was thrust re-activated in the Mesozoic (Murphy et al., 2005; this study). Amalgamated Yukon-Tanana terrane and Slide Mountain terrane were juxtaposed against Upper Triassic rocks of the North American continental margin along the arcuate, west-dipping Inconnu thrust fault (Figure 1).

Yukon-Tanana terrane in the Finlayson Lake belt is made up of three thrust sheets which comprise Upper Devonian to Lower Permian rocks formed at different times and in different environments within the evolving Yukon-Tanana arc. Thrusting occurred in the Early Permian (Murphy et al., 2005; Figure 2). The structurally lowest Big Campbell thrust sheet contains rift-related mafic volcanic rocks and basinal sedimentary rocks with backarc lithological and geochemical character (Murphy et al., 2005; Piercey et al., 2004b). The middle Money Creek thrust sheet contains Devonian to Mississippian arc volcanic and plutonic rocks (Murphy et al., 2005; Piercey et al., 2004b) and Upper Mississippian to Lower Permian limestone, chert and clastic rocks (Murphy et al., 2005; this paper). The uppermost Cleaver Lake thrust sheet also contains mafic and lesser felsic volcanic and mafic to ultramafic intrusive arc rocks, exposed regionally in the Money and North klippen (Figure 1; Grant, 1997; Murphy et al., 2005; Piercey et al., 2004b). The thrust faulting event ended in the Early Permian as evidenced by the unconformable deposition of basalt of the Lower Permian Campbell Range formation onto different thrust sheets.

Slide Mountain terrane rocks occur east of the Jules Creek fault. They include the Fortin Creek group carbonaceous clastic rocks, chert, and rift-related mafic volcanic rocks deposited in an ocean basin setting (Murphy et al., 2005).

The Devonian to Mississippian rocks in Yukon-Tanana terrane record east-dipping subduction along the extended North American continental margin, concurrent with opening of the Slide Mountain ocean basin, in a back-arc position relative to the mid-Paleozoic arc (Mortensen, 1992; Murphy et al., 2005; Nelson, 1993; Piercey et al., 2004b). Regions of the arc were locally, but not everywhere, built upon basement with continental character, and sedimentary units within the arc locally show continental influence (Creaser et al., 1997; Piercey et al., 2003). Throughout the development of YTT, extensional tectonics and backarc formation were punctuated by episodes of deformation (Colpron et al., 2000; Murphy et al., 2005). Middle Mississippian to Pennsylvanian carbonate and chert sedimentation was concurrent with ongoing volcanism in disparate parts of YTT. This was followed in the Middle Permian by a switch in subduction polarity from east- to west-dipping under the Yukon-Tanana arc resulting in closure of the Slide Mountain Ocean basin which lay in a back-arc position relative to YTT. Final amalgamation of YTT, Slide Mountain terrane and emplacement onto North America occurred post Late Triassic time, likely in the Jurassic (Murphy et al., 2005, Nelson and Friedman, 2004).

SOUTHERN CAMPBELL RANGE GEOLOGY

The southern Campbell Range is underlain by polydeformed rocks of Yukon-Tanana terrane. The trace of the steeply west-dipping Jules Creek fault along the eastern base of the Range separates the Yukon-Tanana terrane domain from chert and argillite of the Fortin Creek group of Slide Mountain terrane to the east (Figure 3).

Yukon-Tanana terrane in the southern Campbell Range comprises Carboniferous to Early Permian metasedimentary rocks that are interleaved with the Klatsa metamorphic complex along imbricate thrust faults (Figure 3; Chapter 2). The metasedimentary succession of limestone, chert and metaclastic rocks of the White Lake, King Arctic and Money Creek formations is folded by 100 metre amplitude tight, northeast-vergent,

overturned folds (D1,2) and broad, generally east-west-trending open D3 folds (Figure 3). Panels of the metasedimentary sequence 10 to 100's of metres thick are imbricated by ENE-vergent Jurassic(?) thrust to high-angle reverse faults (D4) and interleaved with sheets of foliated to massive serpentinite of the Klatsa metamorphic complex. Younger high-angle, low-displacement faults (D5) cut all earlier structures.

The Klatsa metamorphic complex in the southern Campbell Range consists of serpentinite, layered schists, amphibolite, and leucogabbro; most units occur as blocks within serpentinite. The layered schists locally occur as an isolated D4-fault bounded block. Evidence for metamorphism and exhumation of the entire Klatsa metamorphic complex in the Early Mississippian, some of which affected rocks at eclogite facies, is presented in this paper.

A pre-D1 regional structure is responsible for initial juxtaposition of the Klatsa metamorphic complex rocks with the Pennsylvanian to Early Permian metasedimentary rocks. Structural relationships in the southern Campbell Range suggest that the Klatsa metamorphic complex is part of the regionally recognized Cleaver Lake thrust sheet, the upper sheet of the Finlayson Lake thrust belt (Figure 1, 2; Chapter 2). However, geochemically similar rocks also occur in the lowermost Big Campbell thrust sheet. All contacts related to original structural emplacement of the Klatsa metamorphic complex have been modified by D4 faults.

THE KLATSA METAMORPHIC COMPLEX

The Klatsa metamorphic complex consists of: 1) quartz muscovite schist and metabasite (layered schists), 2) mafic-ultramafic rocks, 3) amphibolite, and 4) locally occurring phyllite-matrix mélange. In the southern Campbell Range, serpentinitized ultramafic rocks dominate, and occur as both massive bodies and highly foliated serpentinite mélange. The serpentinite mélange contains a variety of blocks including leucogabbro, amphibolite, and retrogressed eclogitic layered schists. Phyllite-matrix

mélange occurs locally, spatially associated with serpentinite, and is host to a variety of metasedimentary rocks including orthoquartzite and chert. Blocks and slivers of the Upper Mississippian to Lower Permian metasedimentary rocks are also present within serpentinite mélange, structurally incorporated during the subsequent Jurassic(?) assembly of the region.

Some units within the Klatsa metamorphic complex preserve evidence of eclogite facies metamorphism; although all rocks in the southern Campbell Range have been metamorphosed to amphibolite and greenschist facies (Erdmer et al., 1998; this paper). The layered schists contain zircons with microscopic inclusions of garnet, omphacite, and rutile, indicating eclogite facies metamorphic paragenesis for the metamorphic zircon (presented herein). Similar preservation of peak metamorphic mineral assemblages in resistant mineral phases is known from other high-grade terrains (Katayama et al., 2002), and allows for dated metamorphism to be directly tied to metamorphic conditions (Rubatto and Hermann, 2003). Further evidence for eclogite facies metamorphism of parts of the Klatsa metamorphic complex comes from rocks in the Stewart Lake klippe, correlative with the Klatsa metamorphic complex, which locally preserve amphibole-eclogite facies mineral assemblages that have survived retrogression (Erdmer et al., 1998)

Layered schist (quartz-muscovite schist and metabasite)

The layered schists are exposed along two southwest trending ridges in the southwestern study area (Figure 3). The southern occurrence is exposed at the end of the ridge as a 2 km-long fault-bounded block surrounded by greenschist facies metasedimentary rocks of the Money Creek formation. The northern occurrence consists of two 50 to 100 metre-long elongate blocks of the Klatsa metamorphic complex layered schists surrounded by serpentinite and phyllite-matrix mélange. Money Creek formation rocks bound the serpentinite mélange on both sides across high angle D4 faults.

The layered schists of the Klatsa metamorphic complex are characterized by

greenschist-facies well-foliated, coarse-grained quartz-muscovite schist containing lenses of metabasite. The schist generally contains 70-80 modal % quartz with minor albite. Round to irregularly shaped domains of chlorite-epidote-clinozoisite symplectite < 1 cm diameter are interpreted to represent retrogressed garnet porphyroblasts (Figure 4C,D). Coarse-grained muscovite, locally chloritized, occurs throughout the schist. The quartz-muscovite schist is well foliated and contains cm-scale to microscopic cataclasite domains (Sm2) which are commonly concordant with, but locally cross-cutting, the main foliation (Sm1; Figure 4D). Approximately 10 % of the layered schist unit consists of lenses of dark green, dense, medium-grained metabasite that are concordant with the foliation in the schist. The metabasite lenses are up to 10's of metres long and range from 1 to 10 metres thick with a spacing of > 5 metres. Relict garnet porphyroblasts < 1 cm in diameter are highly fractured and variably altered to epidote and chlorite (Figure 4A,B). The matrix contains granoblastic to prismatic actinolitic amphibole and granular epidote. An early generation of amphibole is locally altered to symplectitic intergrowths of amphibole, epidote, and chlorite, overgrown by muscovite. Paragenetically late muscovite occurs within some metabasite lenses. Metabasite lenses have foliated margins, but have massive and undeformed cores.

Mafic-ultramafic rocks

The mafic-ultramafic rocks of the Klatsa metamorphic complex comprise serpentinite and leucogabbro. Serpentinite is foliated to massive; where massive, cumulate textures are preserved by serpentized pyroxene crystals, locally with diopside cores. There are no indications of a mantle origin for the ultramafic rocks and they may represent crustal differentiated intrusions; however, all are highly serpentized and foliated with original textures and composition poorly preserved. Leucogabbro blocks up to 200 metres in diameter commonly occur within serpentinite; contacts are faulted. Serpentinite and leucogabbro are interpreted to be parts of a dismembered cogenetic

mafic-ultramafic unit, based on the ubiquitous occurrence of leucogabbro associated with serpentinite.

Amphibolite

Amphibolite of the Klatsa metamorphic complex occurs as blocks up to 30 metres in diameter within serpentinite. The amphibolites are fine to medium grained, poorly to well foliated, and locally schistose. Fractured idoblastic garnet porphyroblasts range from < 1 mm to 0.5 cm in diameter and are surrounded by thin rims of blebby albite in a matrix of fine to medium-grained ferroactinolite replacing magnesiohornblende and edenite (Figure 4E). Titanite-rimmed rutile grains < 1mm in diameter are concentrated within garnet. Titanite grains up to 2 mm in diameter occur throughout the matrix, locally with small rutile cores. Other amphibolite facies blocks include plagioclase-ferroactinolite-quartz schist and plagioclase-ferroactinolite schist, both well foliated, with garnet porphyroblasts that are variably altered to a clinozoisite-epidote-chlorite assemblage.

GEOCHEMISTRY

Six samples were collected from metabasite within the Klatsa metamorphic complex for major and trace element analysis in order to define its origin. All new analyses from the southern Campbell Range are from fine- to medium-grained, dense metabasite with variably preserved garnet porphyroblasts. Samples 03FD050-1, 03FD052-1, and 03FD054-1 were taken from a ~ 50 metre wide zone of metabasite and were sampled along strike at >250 metre intervals. All other samples are from metabasite lenses at the north and southern end of the southern occurrence of the Klatsa metamorphic complex layered schists, and are all from demonstrably separate lenses within quartz-muscovite schist.

The degree of metamorphism and retrogression of these rocks precludes use of

alkalis and other mobile elements in geochemical analysis. However, many elements have been shown to be immobile under metamorphic conditions up to eclogite facies (Bernard-Griffiths et al., 1985; Spandler et al., 2004; Tribuzio et al., 1996). The elements chosen for use in discrimination diagrams and presentation in multielement plots are those shown to be relatively immobile up to high-P/T conditions. Creaser et al. (1999) provide a summary of the mobility of trace elements at eclogite facies P-T conditions.

Geochemistry Results

All samples have compositions of basalt to basaltic andesite, although major element chemistry may have been affected by metamorphism. Two suites of samples are recognized based on trace element patterns on multielement plots (Figure 5A,B): Suite 1 has relatively flat HREE patterns and depleted LREE, Th, Ta and Nb contents. Suite 2 has relatively enriched HREE patterns and variable LREE enrichment with Ta and Nb depletion relative to Th. To investigate the degree of crustal contamination, particularly in the samples with elevated LREE contents, Th/Yb vs. Nb/Yb was plotted for all metabasite samples (Figure 6B). The diagram illustrates the relative Th enrichment due either to crustal contamination or subduction zone processes. A sample of quartz-muscovite schist was also plotted as a representative of the possible contaminant. Suite 2 shows Th enrichment relative to Suite 1, along a rough trend towards the quartz-muscovite schist composition.

GEOCHRONOLOGY

An Early Mississippian metamorphic history for the layered schists of the Klatsa metamorphic complex was previously interpreted on the basis of a single $^{40}\text{Ar}/^{39}\text{Ar}$ white mica age of 344 ± 1 Ma, interpreted to be the cooling age of the unit through approximately 300°C (plateau age; Erdmer et al., 1998). New U-Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations broadly agree with the previous data, and also place constraints on the

earlier high-P metamorphic history for the Klatsa metamorphic complex. Furthermore, U-Pb zircon data allows for a more broad definition of the Klatsa metamorphic complex and provide insight into the protoliths and origins of the comprised units.

U-Pb samples and results

Three samples from the Klatsa metamorphic complex were analyzed by SHRIMP U-Pb methods. Two samples were collected from the layered schists, one from quartz-muscovite schist and a second from a metabasite lens, to constrain the age of protoliths as well as the timing and paragenesis of zircon-forming metamorphic events. A sample from a block of leucogabbro was collected to determine a magmatic age for the dismembered mafic-ultramafic unit, and to test the metamorphic relationship between the different lithological members of the Klatsa metamorphic complex

(A) Quartz-muscovite schist: sample 03FD056-2 (Figures 2-8 and 2-11a,b,c)

The quartz-muscovite schist is best exposed on the end of an east-west-trending ridge in the southeastern corner of the field area. Well-foliated quartz and muscovite surround elongate, irregular to augen-shaped chlorite-epidote domains interpreted to be retrogressed garnet porphyroblasts. Coarse-grained muscovite is partly altered to chlorite and grain orientations generally outline a foliation in the schist (Sm1). Shear fractures are nearly parallel to the foliation in the schist and form cm-scale to microscopic cataclastic domains which deform all minerals, including muscovite (Sm2; Figure 4C,D). Fine-grained rutile included within retrogressed garnet domains outlines the trace of an early foliation at a high angle to the external matrix foliation. Rutile in the matrix is < 1 mm in diameter and mantled by titanite. Accumulations of rutile grains outline the boundaries of the retrogressed garnet domains. Zircon was identified in thin section in both the garnet domains and in the matrix.

Zircon grains range in size up to 150 μm , with most being < 74 μm in length.

Morphology ranges from clear, multi-faceted, well-formed prisms to subrounded, metamict crystals with pitted surfaces. Round, dark coloured cores with clear overgrowths are common.

Two domains in the zircons are characterized by different chemical zoning patterns, highlighted in cathodoluminescence (CL) images and correspond with different age domains (Figure 7). Core domains are surrounded by new zircon growth in almost all zircons imaged. Round to irregularly shaped cores display a range of internal textures, including fine or broad oscillatory zoning, sector zoning, and homogenous texture. Th/U contents vary from 0.3 to 1.5 in the core domains from one crystal to another. Petal-textured zircon mantles cores outside of highly irregular boundaries commonly marked by very non-luminescent zircon and inclusions of quartz, muscovite, and omphacite (Figure 7B). This main phase of zircon crystallization has Y contents ranging from 17 to 108 ppm and Th/U ratios ranging from 0.003 to 0.009. Rutile inclusions occur within the zircon, presumably of the same generation as titanite-mantled rutile within the matrix of the schist and metabasite, which itself includes <10 μ m-sized zircon grains of undetermined age (Figure 2-7h). Morphologically distinct domains in the zircon overgrowths can be correlated from grain to grain (domains 2 to 5 on Figure 7B). The boundary between cores and rims are highly irregular, locally with small embayments into the cores, and are marked by mineral inclusions (Figure 7). Domain 2 is a highly luminescent domain immediately adjacent to the cores. Domains 3-5 are moderately luminescent in CL.

Zircon cores yield ages ranging from 2.8 to 0.47 Ga (Figure 11A,B), and are interpreted to be inherited from the detrital protolith of the schist. Six clusters of ages are recognized: 2.8-2.6 Ga, 2.4 Ga, 2.0 - 1.8 Ga, and 1.0 Ga ($^{207}\text{Pb}/^{206}\text{Pb}$ ages); 0.68 – 0.62 Ga, 0.52 Ga, and 0.47 Ga ($^{206}\text{Pb}/^{238}\text{U}$ ages). $^{206}\text{Pb}/^{238}\text{U}$ ages are quoted for the post 1.0 Ga grains due to low ^{207}Pb . Figure 11A shows a plot of all 55 spot analyses on a concordia diagram. Thirty seven analyses that are >90% concordant are shown on a cumulative

probability diagram in Figure 11B. One sample was not included due to a high common Pb value.

The main phase of zircon crystallization yields a combined age of 353.0 ± 3.7 Ma (Figure 11C). All twelve analyses were combined on a Tera-Wasserburg diagram (Figure 11C). Most analyses show low common Pb and cluster along concordia. The age determination is based on the lower concordia intercept of an inverse isochron anchored at the $^{207}\text{Pb}/^{206}\text{Pb}$ common Pb value (surface $^{207}\text{Pb}/^{206}\text{Pb} = 0.895 \pm 0.01$). The error was determined by quadratically combining the intercept error with the mount calibration error (standard error of the mean 0.5%) to a total of ± 3.7 Ma. The same method for age determination is used for subsequent samples.

The main phase of zircon crystallization is interpreted to be new sub-solidus metamorphic zircon, identified by its occurrence as overgrowths, its character in cathodoluminescence images (patchy, fir-tree zoned, homogeneous), internal crosscutting domains (Corfu et al., 2003), and Th/U ratios which are consistently much lower (<0.001) than dominantly igneous inherited core zircon domains (Hoskin and Schaltegger, 2003; Möller et al., 2003; Williams et al., 1996). Separate ages of metamorphic zircon domains are not resolved, within error, although they display internal cross-cutting relationships and highly variable luminescence (domains 2 to 6 in the schist and un-numbered variable CL domains in the metabasite, Figures 7 and 8). All metamorphic zircon is interpreted to have formed during the same metamorphic event. Textural differences are interpreted to reflect variations in trace element availability during the zircon growth.

(B) Metabasite: sample 03FD039-2 (Figures 2-9 and 2-11d)

A sample of metabasite was collected from the middle of a 5 m thick and > 10 m long lens of metabasite hosted within quartz-muscovite schist, and located approximately 200 m along strike 03FD056-2. Contacts of the lens with quartz-muscovite schist are sharp, occurring over < 2 cm. The medium-grained metabasite contains up to 20 volume

% fractured garnet porphyroblasts, partly replaced by epidote and chlorite, in a matrix of actinolite-epidote-muscovite symplectite and coarse-grained prismatic actinolite with Ca-rich rims (Figure 4A,B). Garnet is compositionally zoned with Mn decreasing and Mg/Fe+Mg increasing from core to rim, indicative of prograde garnet growth (Figure 2-10). Apatite and albite are minor phases in the matrix. Titanite-mantled rutile occurs throughout the matrix.

Several hundred zircon were separated from ~15 kg of rock. The majority of grains are < 74 μm , but they range up to > 150 μm in length. Grains are clear to brown, stubby to elongate, and range in shaped from well-faceted to irregular to subrounded.

Cathodoluminescence images of the zircon grains reveal rare cores overgrown by multiple domains. Two zircon grains containing cores with high Th/U ratios (> 0.05) and relatively high Y-contents (>388 ppm) are compositionally banded and display oscillatory zoning truncated across irregular boundaries by successive zircon growth domains (Figure 8F). Most zircon is characterized by broad concentric zonation with regions of sector zoning with fir-tree intersections between section domains and regions of overlapping petal-texture (Figure 8A-D). Variable CL character highlights internal domains and truncations within the main-phase zircon. All zircon, discluding cores, has low Th/U contents (all <0.02, most < 0.008) and Y contents that are generally < 80 ppm with three analyses >100 ppm. Inclusions of rutile and garnet are rare, but present, (Figure 9C), and titanite-mantled rutile in the matrix includes zircon (Figure 8G).

The two cores analyzed have $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 2379 ± 49 Ma and 1161 ± 14 Ma, respectively. Drift of the common Pb value during the SHRIMP analysis precludes accurate use of a $^{207}\text{Pb}/^{206}\text{Pb}$ vs $^{238}\text{U}/^{206}\text{Pb}$ plot. However, we assume concordancy and use the $^{206}\text{Pb}/^{238}\text{U}$ ages, corrected for standard surface ^{207}Pb (Figure 11D). The cores are interpreted to be xenocrystic zircon, incorporated from the host quartz-muscovite schist, based on the Proterozoic ages, relatively high Th/U ratios, and angular internal textural relationships with mantling zircon.

Metamorphic zircons yield a combined age of 353.1 ± 2.4 Ma. Fourteen of 15 analyses from the main-phase zircon are plotted on a Tera-Wasserburg (Figure 11D). Point 132.1 has an anomalously low age; highly luminescent zones may represent recrystallization which has caused Pb-loss in this grain. All analyses have very low common Pb and plot near concordia. The zircon is interpreted to be sub-solidus metamorphic zircon, coeval with the metamorphic zircon in the quartz-muscovite schist described above, based on the same textural and chemical arguments.

(C) Leucogabbro: sample 03FD231-1 (Figures 2-10 and 2-11e,f)

A sample of leucogabbro was collected from a resistant 20 metre-diameter block, surrounded by recessive weathering, well-foliated serpentinite. The leucogabbro is fine- to medium-grained with grain size varying from the cm to metre scale. Approximately 50 modal % is euhedral to subhedral amphibole surrounded by domains of sausseritized plagioclase, which contain round, cloud-structure symplectic masses of epidote, chlorite, and sericite.

All zircons are $< 105 \mu\text{m}$ and are generally stubby and sub-rounded with clear or brown colour and very rough surfaces. Grains imaged in CL reveal dark cores with broad to fine oscillatory zoning. The cores are commonly fractured and locally contain many inclusions (Figure 9). They are interpreted to be magmatic in origin based on fine oscillatory and sector zoning, consistently high Y contents (193 – 2058 ppm), and Th/U ratios of > 0.80 . Very bright, extremely low-U zircon (≥ 0.11 ppm U) surrounds the cores on the exterior of smooth but irregular boundaries. These bright zones are located at crystal pyramidal terminations and have amoeboid embayments and lobes which extend into the cores (Figure 9C,D,F). The low-U zircon also occurs along fractures cutting the core domains (Figure 9E) and as patches internal to the cores, which locally are concordant with oscillatory zones. Zircon grain shapes around the low-U domains often correspond to the orientation of oscillatory zoning in the primary cores (Figure 9A).

The cores to the leucogabbro zircons have a combined inverse isochron age of 368 ± 10 Ma (Figure 11F). Five analyses from the cores cluster along concordia; one spot (7.1) has an anomalous $^{206}\text{Pb}/^{238}\text{U}$ age which may be due to matrix effects on the Pb and U calibration as a result of the high U, as well as Th and Y content, of the grain. The weighted average of $^{206}\text{Pb}/^{238}\text{U}$ ages of the same five analyses is 370 ± 8 Ma. The cores are interpreted to be primary magmatic zircon based on the fine oscillatory and sector zoning and zoning concordant with grain boundaries.

The low-U rims have a combined age of 351 ± 12 Ma (Figure 11E). Two analyses with very low U are not included in the isochron age calculation. One other analysis (spot 34.1) is excluded as the spot encompasses a highly luminescent region, and has an anomalously low age, possibly due to Pb-loss. The low-U zircon rims and fracture-fillings are interpreted to be metamorphically recrystallized magmatic zircon. Textural evidence, such as grain shapes inherited by the recrystallized zircon and cathodoluminescence textures continuous across recrystallization fronts (Figures 9) indicate that metamorphic zircon formed along transgressive recrystallization fronts through solid state recrystallization of the magmatic zircon cores, as opposed to being dissolved and reprecipitated zircon (see Hoskin and Black, 2000; Hoskin and Schaltegger, 2003; Pidgeon, 1992). This is supported by the extremely low trace element contents of the recrystallized zircon, the result of cation expulsion during solid-state lattice reorganization. Conversely, a melt related origin for the metamorphic zircon, involving partial dissolution or late stage magmatic crystallization, would likely result in elevated REE contents (Hoskin and Black, 2000). Rare zircon grains consisting of a single domain of low-U zircon may be completely recrystallized grains (Figure 9G,H). The presence of fluids during zircon alteration is suggested by recrystallization extending along zircon fractures. While the magmatic and metamorphic ages from the leucogabbro do overlap within error, the correlation of the leucogabbro metamorphic recrystallization event with the more tightly constrained metamorphism in the layered schists, as well as

obvious textural differences between the two domains, allows for confident separation of the two generations of zircon.

⁴⁰Ar/³⁹Ar Samples and Results

Muscovite from two samples from the layered schists of the Klatsa metamorphic complex was analyzed for ⁴⁰Ar/³⁹Ar to place constraints on the cooling history and to test the relative cooling ages of the different lithological components of the layered schists. One sample is from a massive metabasite lens and two are from the well-foliated quartz-muscovite schist that dominates the unit.

(A) Metabasite: sample 03FD039-2

Muscovite was separated from the same metabasite sample as was dated using U-Pb techniques described above. The massive, unfoliated metabasite contains < 5 modal % medium-grained muscovite platelettes.

Data from the two aliquots analyzed show one good plateau with an age of 353.3 ± 0.79 Ma and another partial plateau with an age of 349.9 ± 1.1 Ma (Figure 12A). The reason for the difference in ages between aliquots 1 and 2 is uncertain but may be due to sampling different parts of individual muscovite crystals. The plateau from aliquot 1 is calculated over 7 consecutive steps which contained 99% of the total ³⁹Ar collected and is considered to be the most accurate age, while the partial plateau for aliquot 2 was calculated over 3 steps containing 38% of the total ³⁹Ar collected. The steps used in plateau calculations are highlighted in Table 3. Early steps in each aliquot have young apparent ages, due to Ar-loss, and are shown in Figure 12 but are not included in the plateau age calculation. The high MSWD of the inverse isochron plot is mainly the result of clustering of points along the ³⁹Ar/⁴⁰Ar axis, indicating very little component of trapped Ar.

(B) Quartz-muscovite schist: samples 03FD063-1 & 03FD056-1

Muscovite was separated from the quartz-muscovite schist (U-Pb sample 03FD056-1). An additional sample of quartz-muscovite schist was collected from the same unit immediately adjacent to the metabasite (U-Pb sample 03FD039-2), approximately 10 metres along strike from the metabasite sample locality. Both samples contain garnet porphyroblasts retrogressed to chlorite-epidote-clinozoisite, locally overgrown by muscovite, surrounded by a well-foliated matrix composed of a 40:60 mix of coarse-grained muscovite:quartz. Muscovite is concordant with an early foliation (Sm1) but cut by nearly foliation-parallel late shear fractures (Sm2). Sm2 is macroscopically visible as 2-5 mm wide cataclasite zones with > 5 cm spacing, but is also variably developed microscopically as grain-size reduction of quartz, brittle deformation of mica, and cataclasite domains with mm- to cm-scale spacing.

Both samples produce highly disturbed age spectra (Figure 12C and E) with no plateaus, a reflection of the higher degree of deformation in muscovite from the quartz-muscovite schist. Apparent ages lie between 265 and 364 Ma. Linear regression of the data on inverse isochron plots (Figure 12D and F) clearly shows the effect of excess Ar on both samples with very low (relative to atmospheric Ar) intercepts on the $^{36}\text{Ar}/^{40}\text{Ar}$ axis. The inverse isochron plots yield poorly constrained ages of 334.2 ± 8.9 Ma and 329.0 ± 3.8 Ma. The MSWD on isochron lines is 7.63 for sample 03FD063-1, which is high, but not unreasonable. For sample 03FD039-1 the MSWD is 0.61, suggesting that the scatter is from analytical uncertainty.

DISCUSSION**Klatsa metamorphic complex protoliths**

The Klatsa metamorphic complex is a composite metamorphic assemblage comprising units with different protoliths that were juxtaposed and subsequently metamorphosed at ~353 Ma. The quartz-muscovite schist and metabasite of the layered

schist unit were related prior to metamorphism, either through intrusion of the metabasite protolith or synsedimentary basalt flows. The mafic-ultramafic unit has a different geological history prior to metamorphism and juxtaposition with other units of the Klatsa metamorphic complex.

Quartz-muscovite schist (layered schist unit)

The sedimentary protolith of the quartz-muscovite schist incorporated detritus from a variety of source terranes, potentially through multiple cycles of sedimentation within the Yukon-Tanana Mississippian forearc. U-Pb analysis of zircon cores yielded an abundance of Late Archean and Proterozoic ages, as well as two grains with Early Cambrian and Early Ordovician ages (Figure 11A,B).

The detrital zircon age pattern shows a signature very similar to detrital zircon populations from younger (Pennsylvanian to Jurassic) sedimentary rocks of the North American miogeocline, with North American and Cordilleran sources (Gehrels and Ross, 1998). Archean and Proterozoic sources of matching age are all represented in the North American continental basement and are common in rocks of the western North American miogeocline (Ross et al., 1989; Villeneuve et al., 1993). There are also Late Proterozoic detrital zircons (650 Ma) reported from metamorphosed North American related supracrustal rocks in the Monashee complex in southern British Columbia (Parrish et al., 1989). The 1037 Ma population is not represented in the western North American basement; however, zircon grains of this age are known in western Canada, either recycled from sediments derived from the Grenville orogen in eastern Canada (Rainbird et al., 1992; Rainbird et al., 1997), or from plutons along the Cordilleran margin (Gehrels and Ross, 1998, Parrish and Reichenbach, 1991)

The Early Cambrian (524 Ma) and Early Ordovician (473 Ma) ages are more rarely seen in North American miogeoclinal rocks; however these grains may be derived from discrete Early Paleozoic plutons present along the North American continental

margin (eg. Okulitch, 1985, Erdmer et al., 2001). Another potential source is the Early Paleozoic arc plutonic suites in terranes along the Alaskan-Canadian margin (Gehrels and Ross, 1998). However, these terranes are considered allochthonous to North America (Gehrels et al., 1996), and significantly outboard of the Yukon-Tanana terrane during the Early Mississippian.

The Klatsa quartz-muscovite schist may be a metamorphosed fragment of the basement to Yukon-Tanana terrane, or be a second-cycle sedimentary rock derived therefrom. Gehrels and Kapp (1998) illustrate the similarity of Yukon-Tanana terrane basement in the Coast Mountains to the northwestern North American miogeocline. The Klatsa quartz-muscovite schist has a very similar detrital pattern to the Coast Mountains and North American miogeocline. No detailed detrital zircon studies have been conducted on the basement to Yukon-Tanana terrane in the Finlayson Lake belt; however, indications of underlying old crustal basement come from inherited Proterozoic zircons in arc plutonic rocks (Grant, 1997; Mortensen, 1992), and isotopic and geochemical data for crustal contamination of arc volcanic rocks (Grant, 1997; Piercey, 2001; Piercey et al., 2004b). Proterozoic inheritance has also been found in Yukon-Tanana terrane arc intrusive rocks elsewhere in Yukon (Gordey et al., 1998; Heaman and Erdmer, 1996; Mortensen, 1990). Current tectonic models for Yukon-Tanana terrane development involve arc development on top of rifted blocks from the extended North American continental margin (Nelson et al., 2002).

Metabasite (layered schist unit)

The metabasite lenses are interpreted to be either mafic sills or dykes that intruded the quartz-muscovite schist sedimentary sequence, or syn-sedimentary basalt flows. Thin lenses occur regularly throughout the layered schist unit, with no observed strain gradient at contacts with the quartz-muscovite schist. The metabasites are constrained to be younger than 473 Ma, the age of the youngest detrital zircon in the quartz-muscovite

schist, and older than 353 Ma, the common metamorphic age for the entire layered schist unit.

Geochemistry of the metabasite lenses reveals two basalt suites: Suite 1 with NMORB trace element signatures, and Suite 2 LREE-enriched basalts with trace element signatures similar to oceanic arc calc-alkaline basalt (Figure 5A,B). The two suites are indistinguishable petrographically and both are basalts with high Mg. Compatible elements V, Ti, and Cr are also high in both suites, indicating a relatively unevolved parental magma.

The LREE enrichment of Suite 2 may be, at least in part, due to crustal contamination. Suite 2 may be the crustally contaminated product of temporally equivalent Suite 1 N-MORB, or may be arc-related basalt (calc-alkaline basalt or arc tholeiite) with or without crustal contamination. A lens of Suite 2 metabasite (U-Pb sample 03FD039-2) contains zircons with xenocrystic detrital cores, evidence of at least minor assimilation of the quartz-muscovite schist host rock. Crustal contamination increases LREE contents in mafic rocks in a similar fashion to subduction zone LREE enrichment (Pearce, 1983; Pearce et al., 1995; Piercey et al., 2002). The two processes are difficult to distinguish, and are not exclusive of each other. Figure 6B illustrates that Suite 2 rocks experienced Th enrichment relative to Nb through either subduction zone addition of LREEs to mafic source rocks and, or possibly also, addition through continental contamination by bulk assimilation.

Evidence of crustal contamination of Yukon-Tanana terrane arc volcanic and magmatic rocks is reported from other parts of Yukon-Tanana terrane in the Finlayson Lake Belt (Piercey, 2001; Piercey, 2004a). In the Fire Lake unit and Cleaver Lake formation in the Finlayson Lake belt, arc-related mafic rocks show geochemical and isotopic evidence for crustal contamination (Piercey et al., 2004; Piercey, 2002). Samples from the Cleaver Lake formation are plotted on Figure 6A and b and show similar trace element patterns and Th/Nb ratio to the Klatsa metabasite, possibly indicating similar

processes of subduction zone generation and crustal contamination.

An arc tholeiite protolith for Suite 2 is suggested by the trends in LREE content illustrated in Figure 6. No obvious mixing line exists between Suite 2 and Suite 1 N-MORB; rather, Suite 2 lies along a rough trend, possibly a mixing line, between Stewart Lake arc tholeiites and Klatsa quartz-muscovite schist, the possible contaminant. The Stewart Lake eclogites are correlative with the Klatsa metamorphic complex and have arc tholeiite trace element signatures (Figure 6a) and have high ϵ_{Nd} values, indicating a primitive source with no crustal influence (Creaser et al., 1999). Similarly, earliest Yukon-Tanana mafic arc rocks from the Cleaver Lake formation have similar trace element pattern to the Klatsa Suite 2 metabasites (Figure 5), and show potential crustal contamination along the same trend (Figure 6), possibly from mixing of a similar arc protolith and crustal contaminant.

Leucogabbro (mafic-ultramafic unit)

Leucogabbro blocks within serpentinite may be a mafic phase of a differentiated mafic-ultramafic intrusion, or alternatively, crustal blocks sampled by a serpentinite subduction mélange. A U-Pb sample yielded zircon with 368 ± 10 Ma magmatic cores, dating leucogabbro formation. This age corresponds to some of the oldest magmatic and volcanic rocks in the Finlayson Lake belt, which also have lithological similarities to the Klatsa mafic-ultramafic rocks. The ~365-360 Ma Fire Lake formation mafic volcanic rocks (Big Campbell thrust sheet) are host to variably serpentinized layer-parallel bodies of ultramafic rocks, interpreted to be synvolcanic intrusions (Murphy et al., 2005; Piercey et al., 2004b). The Cleaver Lake formation in the Cleaver Lake thrust sheet also contains similar mafic-ultramafic rocks that are poorly constrained to be ~360-356 Ma based on few ages of inferred synvolcanic intrusions (Murphy et al., 2005). The Fire Lake and Cleaver Lake formations are broadly temporally correlative but formed in different parts of the Yukon-Tanana arc, in the backarc and more frontal portions of the arc, respectively.

Relationships

All components of the Klatsa metamorphic complex were juxtaposed prior to, or during, metamorphism at 353 Ma. The relationships between units within the Klatsa metamorphic complex prior to metamorphism are difficult to establish conclusively; however, the discussion above potentially relates both the metabasite in the layered schist unit and the mafic-ultramafic unit to the earliest mafic volcanism in the Yukon-Tanana arc.

Timing of high-pressure metamorphism

Microscale mineral inclusions in zircon preserve a high-pressure eclogite facies mineral assemblage in the layered schists in the Klatsa metamorphic complex. Peak metamorphism occurred at, or prior to, 353.0 ± 3.7 Ma, based on the age of metamorphic zircon hosting the inclusions. Other units in the complex may have also experienced high-pressure metamorphic conditions; however, retrogression of all units is to amphibolite and greenschist facies.

Rare inclusions in metamorphic zircon from the layered schists include: quartz, rutile, and omphacite in the quartz muscovite schist zircons; and garnet and rutile in the metabasite zircons (Figures 7 and 8). While the garnet and omphacite inclusions, key indicators of an eclogite facies mineral assemblage, were found in zircons from different units within the layered schists, all zircon formed during the same metamorphic event at 353 Ma. The garnet inclusions have the same chemical composition as the rims of normally Fe/Mg zoned garnet porphyroblasts in the matrix, linking metamorphic zircon growth to the final stages of prograde metamorphism. The omphacite inclusions, found in one zircon in the quartz-muscovite schist, are key to the determination of eclogite facies peak metamorphic conditions. Although omphacite would not be a major mineral

phase of a felsic rock at eclogite facies metamorphic conditions, it may be present as a minor phase (Carswell, 1990). The omphacite inclusions occur along the metamorphic zircon interface with an inherited Proterozoic core (Figure 7B). They are determined to be trapped inclusions in new-growth metamorphic zircon, and not inherited through recrystallization of the older core. The core zircon has a relatively high Th/U ratio (0.390), not consistent with metamorphic genesis; and there are no indications of recrystallization of inherited cores in any of the other schist zircons.

The trace element content of metamorphic zircon also supports formation under garnet-present P-T conditions, consistent with eclogite facies paragenesis. The yttrium (Y) content of zircon was measured as a proxy for HREE abundance and is used as a general indicator of HREE enrichment or depletion. One cause of HREE depletion in zircons is competition with co-genetic garnet (Rubatto, 2002). All metamorphic zircon from both the schist and eclogite display low Y contents of 16.7 to 469.6 ppm and generally < 100 ppm, which is low relative to inherited detrital cores with magmatic textures. These data support the interpretation that metamorphic zircon grew under garnet-present conditions, as inferred from the presence of rare garnet inclusions in metamorphic zircon.

Not all parts of the Klatsa metamorphic complex preserve evidence of high-pressure metamorphism. Although leucogabbro blocks share a common metamorphic age with the layered schists they preserve igneous homeoblastic textures, with no garnet growth and amphiboles are edenite rimmed by actinolite. Metamorphic zircon in leucogabbro formed as recrystallized protolith zircon, not as new-growth zircon, likely under conditions of high fluid flow and deformation.

Metamorphism and assembly of the Klatsa metamorphic complex occurred along a subduction zone, as indicated by the relict evidence of eclogite facies mineral assemblages. Interestingly, eclogitic rocks in the Sanbagawa metamorphic belt along the southwestern Japan arc contain zircon with similar inherited Proterozoic detrital

cores surrounded by high-pressure metamorphic zircon, interpreted to be eclogite facies metamorphosed forearc sedimentary rocks. The schists of the Klatsa metamorphic complex may have a similar origin and metamorphic history.

Timing and location of exhumation

Parts of the Klatsa metamorphic complex were rapidly exhumed following eclogite facies metamorphism. $^{40}\text{Ar}/^{39}\text{Ar}$ ages on white mica from the layered schists, interpreted to date cooling of the rocks through 350°C (Hames and Bowring, 1994), are the same, within error, as U-Pb ages of zircon interpreted to have formed under eclogite facies P-T conditions. Eclogite exhumation may follow various P-T paths, over different time scales (Duchene et al., 1997); however, relatively rapid exhumation is required to preserve high-pressure mineral assemblages. Ultra-high pressure, collision-related eclogite in the Alps records exhumation of up to 3.5 cm/yr (34 km/Ma) along part of the retrograde P-T path (Rubatto and Hermann, 2001). Oceanic-related high-pressure terrains also record rapid exhumation; for example in the French Range of British Columbia, blueschists record high-pressure metamorphic assemblages cross-cut by emplacement-related fabrics in <2.5 Ma (Mihalynuk et al., 2004).

The Klatsa metamorphic complex is interpreted to have been exhumed in the arc to forearc region of the Yukon-Tanana arc, based on its structural position in the uppermost, regionally recognized Cleaver Lake thrust sheet (Chapter 2). The Cleaver Lake thrust sheet also carries early YTT volcanic rocks with arc geochemical signatures and restores to a western frontal-arc position within the Yukon-Tanana arc (Murphy et al., 2005).

Eclogites exhumed in subduction-accretion complexes in forearc regions are commonly associated with blueschist terrains, for example in the Franciscan complex of California (Ernst, 1984; Wakabayashi, 1992). Exhumation models generally involve exhumation through blueschist facies followed by extensional processes in the forearc

(Platt, 1986). Alternatively, supra-subduction zone extension unrelated to extension in the fore-arc wedge may also exhume eclogites intra-arc. A modern example of suprasubduction zone eclogite exhumation unrelated to immediate forearc processes is in the D'Entrecasteaux islands, Papua New Guinea, where eclogites are currently being exhumed in metamorphic core complexes where the active Woodlark basin spreading centre has intersected the Papuan continental crust (Baldwin and Ireland, 1995; Davies and Warren, 1988).

Determination of the location and mechanism of exhumation of the Klatsa metamorphic complex requires more information from Mississippian subduction-related rocks. Other schist units in Yukon-Tanana terrane, previously thought to be stable Yukon-Tanana terrane basement, should be examined for evidence of previous high-pressure metamorphism. Remnants of fore-arc, accretionary wedge-metamorphosed sedimentary rocks may be more widespread in Yukon-Tanana terrane than previously realized and provide further insight into the composition, extent, and exhumation history of the Early Mississippian high-pressure rocks.

Structural emplacement

Structural juxtaposition of the Klatsa metamorphic complex with other Yukon-Tanana terrane rocks, post-exhumation, is related to Early Permian thrust faulting in the Finlayson Lake belt of Yukon-Tanana terrane (Chapter 2). The contrast in peak metamorphic grade in Yukon-Tanana terrane rocks in the southern Campbell Range requires an early emplacement structure. Early Mississippian retrogressed eclogite facies rocks of the Klatsa metamorphic complex are juxtaposed against greenschist-facies Upper Mississippian to Lower Permian metasedimentary rocks of the Money Creek thrust sheet, the middle thrust sheet of Yukon-Tanana terrane in the Finlayson Lake belt.

We suggest that the Klatsa metamorphic complex was carried along the upper-level Cleaver Lake thrust fault (Figure 13). Where the Cleaver Lake thrust fault occurs

elsewhere in the Finlayson Lake belt, it also structurally overlies the Money Creek formation. Structural relationships in the southern Campbell Range suggest emplacement of the Klatsa metamorphic complex in an upper-level thrust sheet. Multiple regional folding events (D1 - D3) were followed by a second thrust faulting event (D4) that imbricated the Klatsa metamorphic complex with underlying metasedimentary rocks in the footwall of the Cleaver Lake fault.

The Inconnu fault structurally underlies the Stewart Lake klippe, host to the Stewart Lake eclogites, which are correlative with the Klatsa metamorphic rocks. The Stewart Lake klippe is a structurally orphaned thrust slice of the Klatsa metamorphic complex. The Inconnu fault transected the Early Permian Yukon-Tanana terrane thrust sheets and carried the Stewart Lake rocks over the North American miogeoclinal rocks (Figure 13).

SUMMARY OF CONCLUSIONS

New geochronological and geochemical data are used to define the Klatsa metamorphic complex within Yukon-Tanana terrane in southeastern Yukon and constrain its geological history. Protoliths of the complex are tentatively tied to Devonian early arc magmatism in the Yukon-Tanana arc. Eclogite facies metamorphism of the Klatsa metamorphic complex was immediately followed by rapid Early Mississippian exhumation. The definition of the Klatsa metamorphic complex and new insights into its metamorphic and structural history are as follows:

- 1) The Klatsa metamorphic complex comprises: 1) mafic-ultramafic rocks (leucogabbro and serpentinite), 2) highly retrogressed eclogitic layered schists, 3) amphibolite, and 4) phyllite-matrix mélange. In the southern Campbell Range, serpentinitized ultramafic rocks dominate, and are host to blocks of leucogabbro, layered schists and amphibolite.
- 2) The protolith of the mafic-ultramafic unit is a ca. 368 Ma mafic-ultramafic

- assemblage, coeval with earliest arc volcanism in Yukon-Tanana terrane. The metasedimentary protolith of the layered schist unit contains detrital zircons that indicate a cratonic source, possibly the North American continent. The schists may be Yukon-Tanana terrane basement or second-cycle metasedimentary rocks derived therefrom. Metabasite lenses within the metasedimentary sequence are mafic intrusions or basalt flows. Constrained to be younger than 473 Ma, the metabasite lenses may be related to early extensional arc magmatism.
- 3) The layered schists unit of the Klatsa metamorphic complex contains metamorphic zircon that crystallized at ~353 Ma as part of an eclogite facies mineral assemblage. The mafic-ultramafic rocks may have been metamorphosed at different P-T conditions but were subsequently juxtaposed during exhumation.
 - 4) Rapid exhumation of the Klatsa metamorphic complex immediately followed eclogite-facies metamorphism. The layered schists cooled through ~350°C by 353 Ma, immediately following metamorphic zircon growth at eclogite-facies conditions.
 - 5) Structural emplacement of the Klatsa metamorphic complex occurred along the Cleaver Lake thrust fault, during Early Permian shortening of Yukon-Tanana terrane in the Finlayson Lake belt. The structural relationships of the complex were further modified by Jurassic? imbricate faults.

Figure 2-1. Map of the Finlayson Lake belt showing major geological units, thrust sheets, and faults. The southern Campbell Range region is enclosed by the box in the centre of the map delineating Figure 2-3. The Stewart Lake klippe is soled by the Inconju fault in the southeastern corner of the map. Cross section lines C and D are located here; cross sections are displayed in Figure 2-13. The inset map of Yukon and northern British Columbia outlines the distribution of Yukon-Tanana and Slide Mountain terranes. Modified after Murphy et al. (2005), with Stewart Lake klippe contacts modified from J. Mortensen (unpublished data, 2005).

Figure 2-2. Simplified stratigraphic relationships in fault bounded domains of Yukon-Tanana Terrane (YTT), Slide Mountain Terrane (SMT), and rocks of the North American miogeocline in the Finlayson Lake belt. Stratigraphy in the upper Mississippian to Lower Permian portion of the hanging wall of the Money Creek thrust fault comprises the metasedimentary rocks found in the southern Campbell Range. Modified after Murphy et al.(2005).

Figure 2-3. Simplified geology of the southern Campbell Range with cross sections through the northern and southern occurrences of the Klatsa metamorphic complex layered schists.

Klatsa metamorphic complex

Figure 2-4. Photomicrographs of the Klatsa metamorphic complex in plane polarized light and with crossed polars. Abbreviations: gar=garnet, act=actinolite, ms=muscovite, hbl=magnesiohornblende (also edenite), ab=albite, q=quartz, pl=plagioclase, chl=chlorite, ep=epidote, clz=clinozoisite, r=titanite-rimmed rutile, ti=titanite, sym=symplectite of actinolite-chlorite-epidote-muscovite replacing matrix amphibole, catal=cataclase, Sm1/Sm2=first/second structural generations within the layered schists member.

Sample	03FD039-1	03FD048-1	03FD048-3	03FD050-1	03FD052-1	03FD054-1	03FD065-1	03FD64-1
Latitude	61°02'06"	61°02'34"	62°02'34"	61°02'28"	61°02'24"	61°02'20"	61°02'05"	6°02'11"
Longitude	129°25'20"	129°26'10"	130°26'10"	129°26'03"	129°25'57"	129°25'49"	129°25'24"	130°34'37"
	Suite 2	Suite 2	duplicate Suite 2	Suite 1	Suite 1	Suite 1	Suite 1	Qmschist
	LREE -enr.	LREE-enr.	LREE-enr.	N-MORB	N-MORB	N-MORB	N-MORB	
SiO ₂ (wt %)	43.61	45.25	45.40	43.50	45.63	49.08	52.21	52.21
TiO ₂	1.46	1.45	1.56	1.53	1.09	1.18	1.23	1.23
Al ₂ O ₃	14.43	12.02	12.13	15.61	15.01	14.53	12.82	12.82
Fe ₂ O ₃	13.38	12.75	12.70	12.03	10.35	11.10	7.94	7.94
MnO	0.23	0.24	0.24	0.18	0.16	0.17	0.16	0.16
MgO	8.67	9.98	9.91	7.54	5.50	6.74	4.35	4.35
CaO	11.64	12.60	12.75	11.39	14.22	9.02	8.61	8.61
Na ₂ O	0.68	1.26	1.25	2.48	1.47	2.26	1.41	1.41
K ₂ O	1.49	0.24	0.15	0.17	0.05	0.40	2.02	2.02
P ₂ O ₅	0.10	0.15	0.15	0.17	0.11	0.11	0.26	0.26
LOI	2.88	2.63	2.63	3.99	5.33	4.01	8.94	8.94
Total %	98.56	98.57	98.87	98.57	98.92	98.60	99.94	99.94
V (ppm)	347	299	315	348	296	294	352	127
Cr	324	309	319	234	357	217	314	163
Co	48.4	42.3	42.7	37.5	35.0	31.0	46.9	24.7
Ni	86	63	65	66	87	55	81	84
Cu	68	31	30	203	63	91	76	31
Zn	169	151	159	94	91	108	134	94
Ga	18.3	10.3	10.9	19.4	17.2	14.3	16.3	16.5
Ge	2.0	1.8	1.7	1.7	1.6	1.7	2.0	0.9
As	8.6	DL	DL	17.8	18.1	15.7	12.4	DL
Rb	45.8	5.2	5.2	4.7	1.2	9.9	15.3	64.5
Sr	238	286	301	354	260	234	320	168
Y	31.57	22.40	23.42	33.72	25.80	26.81	28.32	19.52
Zr	80.62	91.17	99.68	90.96	56.71	66.92	68.43	159.88
Nb	4.0	4.7	5.3	3.3	1.6	1.7	2.9	20.8
Sn	5	6	5	4	4	4	5	5
Sb	1.2	0.8	0.9	0.6	0.7	0.9	1.0	0.3
Cs	3.55	0.20	0.18	0.21	DL	0.33	0.54	1.55
Ba	597	72	73	116	48	204	247	610
La	5.90	11.15	12.36	4.23	2.25	2.49	1.73	38.44
Ce	13.01	25.36	27.66	11.58	6.32	7.41	4.98	71.26
Pr	1.80	3.42	3.70	1.86	1.09	1.31	0.86	8.29
Nd	8.99	15.58	17.28	10.69	6.55	7.67	5.30	32.55
Sm	2.91	4.04	4.49	3.71	2.37	2.85	2.04	6.35
Eu	0.97	1.20	1.34	1.44	0.92	1.08	0.84	1.59
Gd	4.51	3.87	4.11	5.26	3.59	4.15	3.42	5.57
Tb	0.85	0.51	0.54	0.94	0.69	0.75	0.71	0.78
Dy	5.81	3.32	3.39	6.42	4.52	4.92	4.87	4.42
Ho	1.19	0.85	0.85	1.28	0.92	0.98	1.03	0.77
Er	3.96	3.44	3.48	4.17	3.08	3.23	3.36	2.25
Tm	0.62	0.58	0.61	0.65	0.49	0.51	0.53	0.30
Yb	3.59	3.50	3.57	3.70	2.68	2.95	2.96	1.72
Lu	0.55	0.56	0.59	0.58	0.43	0.45	0.47	0.26
Hf	2.03	2.21	2.49	2.34	1.44	1.68	1.74	3.57
Ta	0.17	0.26	0.27	0.16	0.05	0.07	0.07	1.53
W	DL	DL	DL	DL	DL	DL	DL	DL
Ti	0.62	0.06	0.05	DL	DL	0.11	0.16	0.62
Pb	DL	DL	DL	DL	DL	DL	DL	DL
Bi	0.1	DL	DL	0.1	DL	DL	0.1	DL
Th	1.05	2.09	2.31	0.27	0.11	0.13	0.14	10.06
U	0.59	1.12	1.22	0.13	0.05	0.13	0.19	1.64

Note: Major elements: fused disc XRF, Actlabs, Ancaster, Ontario. Trace elements: (x) indicates pressed pellet XRF, Actlabs; all others analyzed by ICP-MS, Actlabs.

Suite 1 and 2 are N-MORB and LREE-enriched basalts, respectively. DL = below detection limit

Table 2-1. Major and trace element abundances for the Klatsa metamorphic complex layered schists. Suite 1 and 2 are metabasites, QMschist is one sample from the quartz muscovite schist.

Figure 2-5. Multielement diagrams defining geochemistry of the two suites of metabasite in the Klatsa metamorphic complex layered schists. **(a)** Suite 1 has an N-MORB trace element signature. **(b)** Suite 2 LREE enriched basalts may be N-MORB or arc tholeiites contaminated by continental crust.

Figure 2-6. (a) Multi-element diagram illustrating the LREE contents of mafic units from the Klatsa metamorphic complex, the Stewart Lake eclogite, and the Cleaver Lake formation, as well as the Klatsa quartz-muscovite schist, a possible contaminant. **(b)** Th/Yb vs. Nb/Yb diagram that illustrates the input of Th from either subduction zone enrichment (SZ) or crustal contamination (CC) in early YTT mafic rocks listed above. WPE = within plate enrichment. Diagram from Stern et al. (1995) and Piercey et al. (2004), after Pearce (1983). N-MORB, E-MORB, and OIB from Sun and McDonough (1989).

Table 2-2a. SHRIMP U-Th-Pb data for inherited cores in zircon from the Klatsa metamorphic complex layered schists (metabasite and quartz-muscovite schist).

Spots ^a	U (ppm)	Th (ppm)	Y ^b (ppm)	Th U	Pb ^c (ppm)	²⁰⁴ Pb (ppb)	²⁰⁶ Pb ²⁰⁴ Pb	²⁰⁸ Pb ^{d,e} ²³² Th	²⁰⁷ Pb ^{d,e} ²³⁵ U	²⁰⁶ Pb ^{d,e} ²³⁸ U
03FD056-2 Quartz-muscovite schist - layered schists, Klatsa metamorphic complex										
UTM NAD 83, Zone 9 476825E, 6767113N										
<i>ZIRCON CORES - Inherited detrital grains with variable luminescence and zoning patterns</i>										
8213-03.1	160	129	n/a	0.833	62	5	1475	0.096 ± 0.004	5.23 ± 0.11	0.3296 ± 0.0056
8213-04.1	180	99	n/a	0.569	87	4	5512	0.124 ± 0.004	9.66 ± 0.18	0.4175 ± 0.0066
8213-06.1	94	69	n/a	0.759	48	5	16327	0.128 ± 0.004	10.58 ± 0.37	0.4230 ± 0.0077
8213-07.1	143	94	n/a	0.679	54	8	3722	0.099 ± 0.005	5.11 ± 0.28	0.3320 ± 0.0108
8213-08.1	62	31	n/a	0.522	22	6	1272	0.091 ± 0.003	5.08 ± 0.12	0.3278 ± 0.0064
8213-10.1	415	131	n/a	0.325	146	9	567	0.097 ± 0.004	5.61 ± 0.09	0.3360 ± 0.0052
8213-12.1	98	57	n/a	0.600	11	15	1133	0.031 ± 0.002	0.76 ± 0.06	0.1016 ± 0.0018
8213-15.1	42	37	n/a	0.907	16	7	5106	0.093 ± 0.004	4.79 ± 0.13	0.3125 ± 0.0055
8213-16.1	88	40	n/a	0.474	16	5	2869	0.054 ± 0.002	1.79 ± 0.07	0.1746 ± 0.0033
8213-17.1	209	74	n/a	0.365	108	4	2472	0.133 ± 0.004	11.12 ± 0.18	0.4694 ± 0.0073
8213-19.1	408	124	n/a	0.313	160	9	893	0.109 ± 0.005	7.57 ± 0.37	0.3675 ± 0.0098
8213-20.1	145	130	n/a	0.923	50	7	9372	0.090 ± 0.003	4.40 ± 0.09	0.2843 ± 0.0050
8213-21.1	42	60	n/a	1.471	25	11	1487	0.128 ± 0.005	9.21 ± 0.24	0.4303 ± 0.0075
8213-23.1	312	116	n/a	0.383	138	11	10223	0.116 ± 0.005	8.70 ± 0.16	0.4062 ± 0.0068
8213-24.1	295	140	n/a	0.490	112	9	6697	0.101 ± 0.003	5.81 ± 0.13	0.3474 ± 0.0064
8213-25.1	102	67	n/a	0.679	13	9	2254	0.035 ± 0.001	0.95 ± 0.04	0.1120 ± 0.0018
8213-26.1	128	82	n/a	0.661	45	6	1531	0.093 ± 0.003	4.88 ± 0.11	0.3131 ± 0.0053
8213-28.1	96	108	n/a	1.164	13	10	22691	0.033 ± 0.002	0.96 ± 0.07	0.1111 ± 0.0020
8213-29.1	163	72	n/a	0.453	83	12	9184	0.128 ± 0.004	10.72 ± 0.31	0.4574 ± 0.0075
8213-30.1	132	77	n/a	0.603	74	8	1442	0.141 ± 0.004	11.38 ± 0.23	0.4775 ± 0.0080
8213-31.1	77	52	n/a	0.700	26	3	4695	0.089 ± 0.003	4.66 ± 0.14	0.2952 ± 0.0048
8213-32.1	142	71	n/a	0.518	51	5	2874	0.095 ± 0.004	5.50 ± 0.11	0.3274 ± 0.0058
8213-32.1	137	99	n/a	0.750	64	6	4254	0.117 ± 0.004	8.42 ± 0.42	0.3987 ± 0.0066
8213-34.1	375	138	n/a	0.379	111	2	4288	0.083 ± 0.002	4.28 ± 0.08	0.2817 ± 0.0047
8213-35.1	95	34	n/a	0.369	56	5	1096	0.149 ± 0.006	14.43 ± 0.44	0.5236 ± 0.0127
8213-36.1	177	74	n/a	0.434	55	3	5421	0.086 ± 0.003	4.48 ± 0.09	0.2897 ± 0.0049
8213-37.1	41	13	n/a	0.320	22	4	2857	0.137 ± 0.007	12.75 ± 0.34	0.4954 ± 0.0107
8213-38.1	90	125	n/a	1.431	37	8	1638	0.092 ± 0.003	4.86 ± 0.12	0.3135 ± 0.0064
8213-40.1	255	90	n/a	0.365	88	8	13537	0.095 ± 0.003	5.64 ± 0.11	0.3269 ± 0.0059
8213-41.2	21	26	n/a	1.257	8	10	3033	0.095 ± 0.005	4.73 ± 0.26	0.3068 ± 0.0066
8213-42.1	198	75	n/a	0.390	55	4	4143	0.081 ± 0.003	4.38 ± 0.09	0.2580 ± 0.0048
8213-44.1	104	82	n/a	0.818	39	10	603	0.094 ± 0.003	5.11 ± 0.12	0.3210 ± 0.0060
8213-46.1	62	24	n/a	0.397	31	6	518	0.129 ± 0.005	10.56 ± 0.27	0.4565 ± 0.0091
8213-47.1	219	119	n/a	0.562	76	9	12657	0.092 ± 0.003	4.98 ± 0.11	0.3127 ± 0.0058
8213-49.1	133	56	n/a	0.432	41	9	6290	0.095 ± 0.004	4.69 ± 0.11	0.2781 ± 0.0053
8213-49.1.2	125	49	n/a	0.408	38	6	586	0.094 ± 0.003	4.73 ± 0.13	0.2771 ± 0.0070
8213-50.1	28	15	n/a	0.542	16	3	2575	0.150 ± 0.007	12.86 ± 0.41	0.4966 ± 0.0119
8213-52.1	181	49	n/a	0.282	61	11	8315	0.097 ± 0.004	5.54 ± 0.15	0.3224 ± 0.0079
8213-53.1	176	62	n/a	0.364	58	6	9869	0.089 ± 0.004	5.14 ± 0.14	0.3112 ± 0.0079
8213-54.1	227	120	n/a	0.545	73	5	7321	0.086 ± 0.004	4.40 ± 0.18	0.2934 ± 0.0087
8213-55.1	171	102	n/a	0.614	71	6	9179	0.109 ± 0.003	7.60 ± 0.17	0.3594 ± 0.0068
8213-56.1.2	66	57	n/a	0.902	40	17	13454	0.142 ± 0.005	12.44 ± 0.29	0.4881 ± 0.0105
8213-57.1	132	90	n/a	0.706	73	17	8244	0.130 ± 0.004	11.11 ± 0.21	0.4640 ± 0.0083
8213-58.1	140	63	n/a	0.465	11	18	6426	0.024 ± 0.002	0.60 ± 0.05	0.0761 ± 0.0021
8213-59.1	48	31	n/a	0.666	16	16	4655	0.102 ± 0.005	4.88 ± 0.18	0.2943 ± 0.0081
8213-60.1	108	60	n/a	0.571	60	17	58106	0.133 ± 0.005	12.48 ± 0.46	0.4791 ± 0.0111
8213-61.1	264	44	n/a	0.172	41	27	5089	0.045 ± 0.003	2.59 ± 0.09	0.1519 ± 0.0040
8213-62.1	76	37	n/a	0.504	43	30	193	0.141 ± 0.008	12.71 ± 0.36	0.4944 ± 0.0097
8213-63.1	74	25	n/a	0.353	24	34	14795	0.087 ± 0.006	4.83 ± 0.21	0.3076 ± 0.0104
8213-64.1	68	72	n/a	1.107	7	28	6881	0.026 ± 0.002	0.70 ± 0.37	0.0848 ± 0.0021
8213-65.1	170	135	n/a	0.817	70	12	1527	0.103 ± 0.004	6.07 ± 0.15	0.3495 ± 0.0068
8213-66.1	76	43	n/a	0.588	38	18	787	0.132 ± 0.011	10.62 ± 0.27	0.4237 ± 0.0082
8213-69.1	88	68	n/a	0.805	35	17	8195	0.103 ± 0.004	5.59 ± 0.14	0.3412 ± 0.0064
8213-70.1	105	63	n/a	0.625	37	20	4849	0.097 ± 0.004	4.94 ± 0.18	0.3170 ± 0.0105
8213-71.1	194	67	n/a	0.356	71	26	9979	0.100 ± 0.016	5.77 ± 0.77	0.3456 ± 0.0318
03FD039-2 Metabasite - layered schists, Klatsa metamorphic complex										
UTM NAD 83, Zone 9 477191E, 6766748N										
<i>ZIRCON CORES - Oscillatory zoned, xenocrystic detrital grains</i>										
8212-46.1	68	51	633.3	0.777	41	0	230415	0.144 ± 0.003	14.56 ± 0.32	0.4881 ± 0.0090
8212-136.1	88	50	388.0	0.586	21	0	35689	0.077 ± 0.003	2.99 ± 0.04	0.2042 ± 0.0025

^aIon probe spot labels include: Sample number - Grain number.Spot number, some grains with second spot in same location as first (ex 49.1^bYttrium normalized to 230ppm in zircon standard BR6266; n/a - not analyzed^cRadiogenic Pb^d03FD056-2 Corrected for common Pb according to procedure outlined by Stern and Berman (2000), uncertainties are reported at 1 error and are calculated by numerical propagation of all known sources of error.^e03FD039-2 Uncorrected for common Pb^fDiscordance = 100 x [(²⁰⁶Pb/²³⁸U age)/(²⁰⁷Pb/²⁰⁶Pb age)]

Table 2-2a. (concluded)

Spots ^a	$\frac{^{207}\text{Pb}^{d,e}}{^{206}\text{Pb}}$	$\frac{^{206}\text{Pb}^{d,e}}{^{232}\text{Th}}$ (Ma)	$\frac{^{206}\text{Pb}^{d,e}}{^{238}\text{U}}$ (Ma)	$\frac{^{207}\text{Pb}^{d,e}}{^{235}\text{U}}$ (Ma)	$\frac{^{207}\text{Pb}^{d,e}}{^{206}\text{Pb}}$ (Ma)	% DISC ^f
03FD056-2 Quartz-muscovite schist - layered schists, Klatsa metamorphic complex						
UTM NAD 83, Zone 9 476825E, 6767113N						
<i>ZIRCON CORES - Inherited detrital grains with variable luminescence and zoning patterns</i>						
8213-03.1	0.1150 ± 0.0013	1849 ± 69	1837 ± 27	1857 ± 18	1880 ± 20	2.3
8213-04.1	0.1678 ± 0.0014	2367 ± 66	2249 ± 30	2403 ± 18	2536 ± 14	11.3
8213-06.1	0.1815 ± 0.0050	2438 ± 78	2274 ± 35	2487 ± 33	2666 ± 46	14.7
8213-07.1	0.1117 ± 0.0044	1908 ± 89	1848 ± 52	1838 ± 47	1827 ± 73	1.1
8213-08.1	0.1124 ± 0.0012	1767 ± 62	1828 ± 31	1833 ± 20	1838 ± 20	0.6
8213-10.1	0.1210 ± 0.0005	1876 ± 65	1867 ± 25	1917 ± 14	1971 ± 8	5.3
8213-12.1	0.0541 ± 0.0043	612 ± 48	624 ± 10	573 ± 37	377 ± 189	65.5
8213-15.1	0.1111 ± 0.0020	1788 ± 69	1753 ± 27	1783 ± 22	1817 ± 32	3.5
8213-16.1	0.0742 ± 0.0025	1054 ± 46	1037 ± 18	1041 ± 27	1048 ± 69	1.0
8213-17.1	0.1718 ± 0.0007	2525 ± 79	2481 ± 32	2533 ± 16	2575 ± 7	3.7
8213-19.1	0.1495 ± 0.0057	2092 ± 89	2018 ± 46	2182 ± 45	2340 ± 67	13.8
8213-20.1	0.1123 ± 0.0012	1733 ± 49	1613 ± 25	1713 ± 18	1837 ± 19	12.2
8213-21.1	0.1553 ± 0.0028	2436 ± 83	2307 ± 34	2359 ± 25	2405 ± 31	4.1
8213-23.1	0.1553 ± 0.0010	2218 ± 82	2198 ± 31	2307 ± 17	2406 ± 11	8.6
8213-24.1	0.1213 ± 0.0012	1946 ± 63	1922 ± 30	1947 ± 19	1975 ± 18	2.7
8213-25.1	0.0617 ± 0.0021	700 ± 26	685 ± 11	680 ± 20	665 ± 76	3.0
8213-26.1	0.1129 ± 0.0015	1794 ± 62	1756 ± 26	1798 ± 19	1847 ± 24	4.9
8213-28.1	0.0625 ± 0.0046	653 ± 33	679 ± 12	682 ± 39	692 ± 164	1.9
8213-29.1	0.1700 ± 0.0038	2437 ± 74	2428 ± 33	2499 ± 28	2558 ± 38	5.1
8213-30.1	0.1729 ± 0.0015	2662 ± 74	2516 ± 35	2555 ± 19	2586 ± 15	2.7
8213-31.1	0.1145 ± 0.0026	1716 ± 62	1668 ± 24	1760 ± 25	1872 ± 42	10.9
8213-32.1	0.1219 ± 0.0011	1836 ± 66	1826 ± 28	1901 ± 18	1984 ± 16	8.0
8213-32.1	0.1532 ± 0.0068	2237 ± 81	2163 ± 30	2278 ± 46	2382 ± 78	9.2
8213-34.1	0.1103 ± 0.0009	1608 ± 45	1600 ± 24	1690 ± 16	1805 ± 16	11.4
8213-35.1	0.1999 ± 0.0031	2808 ± 107	2715 ± 54	2779 ± 29	2826 ± 25	3.9
8213-36.1	0.1122 ± 0.0011	1660 ± 51	1640 ± 25	1728 ± 17	1835 ± 17	10.6
8213-37.1	0.1866 ± 0.0025	2590 ± 122	2594 ± 46	2661 ± 25	2713 ± 22	4.4
8213-38.1	0.1124 ± 0.0011	1776 ± 52	1758 ± 31	1795 ± 20	1838 ± 18	4.4
8213-40.1	0.1252 ± 0.0007	1831 ± 58	1823 ± 29	1922 ± 17	2031 ± 10	10.2
8213-41.2	0.1117 ± 0.0054	1830 ± 99	1725 ± 33	1772 ± 47	1828 ± 90	5.6
8213-42.1	0.1232 ± 0.0014	1571 ± 48	1480 ± 25	1709 ± 19	2004 ± 21	26.2
8213-44.1	0.1154 ± 0.0014	1823 ± 58	1795 ± 29	1837 ± 20	1886 ± 22	4.9
8213-46.1	0.1678 ± 0.0022	2447 ± 96	2424 ± 41	2485 ± 24	2536 ± 22	4.4
8213-47.1	0.1156 ± 0.0010	1782 ± 55	1754 ± 28	1816 ± 18	1889 ± 15	7.1
8213-49.1	0.1222 ± 0.0012	1840 ± 70	1582 ± 27	1765 ± 19	1989 ± 18	20.5
8213-49.1.2	0.1238 ± 0.0011	1816 ± 63	1577 ± 35	1773 ± 23	2012 ± 16	21.6
8213-50.1	0.1878 ± 0.0033	2826 ± 118	2599 ± 52	2669 ± 30	2723 ± 29	4.5
8213-52.1	0.1247 ± 0.0009	1866 ± 67	1802 ± 39	1908 ± 23	2025 ± 13	11.0
8213-53.1	0.1199 ± 0.0010	1727 ± 66	1747 ± 39	1844 ± 24	1955 ± 15	10.6
8213-54.1	0.1088 ± 0.0028	1660 ± 73	1659 ± 43	1713 ± 35	1780 ± 48	6.8
8213-55.1	0.1533 ± 0.0015	2094 ± 63	1979 ± 32	2185 ± 20	2384 ± 17	17.0
8213-56.1.2	0.1848 ± 0.0013	2692 ± 87	2562 ± 46	2638 ± 22	2696 ± 12	5.0
8213-57.1	0.1737 ± 0.0009	2477 ± 73	2457 ± 36	2533 ± 18	2594 ± 9	5.3
8213-58.1	0.0572 ± 0.0040	470 ± 36	473 ± 13	478 ± 30	501 ± 163	5.6
8213-59.1	0.1202 ± 0.0025	1970 ± 86	1663 ± 40	1799 ± 31	1960 ± 38	15.1
8213-60.1	0.1889 ± 0.0049	2531 ± 92	2523 ± 49	2641 ± 35	2733 ± 43	7.7
8213-61.1	0.1237 ± 0.0025	886 ± 55	911 ± 23	1298 ± 26	2010 ± 36	54.7
8213-62.1	0.1864 ± 0.0034	2661 ± 149	2590 ± 42	2658 ± 27	2711 ± 30	4.5
8213-63.1	0.1138 ± 0.0025	1694 ± 120	1729 ± 51	1789 ± 37	1861 ± 41	7.1
8213-64.1	0.0599 ± 0.0065	527 ± 31	524 ± 13	539 ± 49	600 ± 253	12.6
8213-65.1	0.1261 ± 0.0015	1983 ± 73	1932 ± 33	1987 ± 21	2044 ± 22	5.5
8213-66.1	0.1818 ± 0.0027	2509 ± 196	2277 ± 37	2491 ± 24	2670 ± 25	14.7
8213-69.1	0.1189 ± 0.0018	1984 ± 69	1893 ± 31	1915 ± 22	1940 ± 27	2.4
8213-70.1	0.1129 ± 0.0015	1874 ± 80	1775 ± 52	1808 ± 32	1847 ± 24	3.9
8213-71.1	0.1210 ± 0.0105	1928 ± 292	1913 ± 154	1941 ± 123	1972 ± 164	3.0
03FD039-2 Metabasite - layered schists, Klatsa metamorphic complex						
UTM NAD 83, Zone 9 477191E, 6766748N						
<i>ZIRCON CORES - Oscillatory zoned, xenocrystic detrital grains</i>						
8212-46.1	0.2164 ± 0.0022	2714 ± 87	2562 ± 39	2787 ± 21	2954 ± 16	13.3
8212-136.1	0.1061 ± 0.0007	1492 ± 49	1198 ± 13	1404 ± 11	1733 ± 12	30.9

Table 2-2b. SHRIMP U-Th-Pb data for metamorphic and magmatic zircon from the Klatsa metamorphic complex layered schists and leucogabbro in the southern Campbell Range.

Spots ^a	U (ppm)	Th (ppm)	Y ^b (ppm)	Th U	Pb ^c (ppm)	²⁰⁴ Pb (ppb)	²⁰⁶ Pb ²⁰⁴ Pb	²⁰⁷ Pb ^d ²⁰⁶ Pb	²³⁸ U ^d ²⁰⁶ Pb	²⁰⁷ Pb ^d ²⁰⁶ Pb	AGE (Ma)	²⁰⁶ Pb ^a ²³⁸ U AGE (Ma)
03FD056-2 Quartz-muscovite schist - layered schists, Klatsa metamorphic complex												
UTM NAD 83, Zone 9 476825E, 6767113N												
RIMS (METAMORPHIC) - Overgrowths on detrital cores; with patchy zoning and internal domain truncations												
8213-18.1	590	4	40	0.007	30	0	171233	0.0559 ± 0.0008	17.89 ± 0.29	450 ± 33	349.7 ± 5.5	
8213-27.1	1062	9	168	0.009	55	0	100000	0.0550 ± 0.0009	17.64 ± 0.43	414 ± 38	354.8 ± 8.6	
8213-41.1	481	4	70	0.009	25	0	100000	0.0567 ± 0.0005	17.73 ± 0.34	480 ± 18	352.3 ± 6.6	
8213-88.1	1093	7	183	0.006	58	0	100000	0.0535 ± 0.0003	17.13 ± 0.23	350 ± 13	365.9 ± 4.8	
8213-101.1	228	1	80	0.007	12	0	100000	0.0603 ± 0.0012	17.66 ± 0.26	614 ± 42	352.3 ± 5.2	
8213-106.1	394	2	108	0.006	20	0	100000	0.0570 ± 0.0006	17.78 ± 0.37	492 ± 25	351.3 ± 7.2	
8213-110.1	307	2	76	0.005	16	0	100000	0.0563 ± 0.0013	17.89 ± 0.57	464 ± 51	349.4 ± 11.0	
8213-119.1	130	1	28	0.005	7	0	100000	0.0641 ± 0.0011	17.81 ± 0.30	745 ± 36	347.8 ± 5.8	
8213-121.1	198	1	45	0.005	11	0	100000	0.0606 ± 0.0010	17.53 ± 0.25	625 ± 36	354.7 ± 5.0	
8213-134.1	41	0	17	0.007	2	0	100000	0.0892 ± 0.0019	17.47 ± 0.33	1408 ± 41	344.0 ± 6.4	
8213-144.1	285	1	52	0.003	15	0	100000	0.0581 ± 0.0010	17.72 ± 0.27	534 ± 39	351.9 ± 5.2	
8213-153.1	204	1	38	0.006	11	0	100000	0.0657 ± 0.0010	17.71 ± 0.28	795 ± 32	349.2 ± 5.4	
03FD039-2 Metabasite - layered schists, Klatsa metamorphic complex												
UTM NAD 83, Zone 9 477191E, 6766748N												
MAIN PHASE (METAMORPHIC) - Variable cathodoluminescence and multiple internal domains												
8212-5.1	89	1	17	0.011	5	0	100000	0.0585 ± 0.0012	17.54 ± 0.21	547 ± 46	355.5 ± 4.3	
8212-5.2	229	2	76	0.007	12	0	100000	0.0587 ± 0.0011	17.61 ± 0.35	558 ± 42	354.0 ± 6.9	
8212-11.1	235	1	46	0.006	12	0	100000	0.0578 ± 0.0007	17.49 ± 0.20	522 ± 27	356.7 ± 4.0	
8212-11.2	69	0	54	0.007	4	0	6836	0.0771 ± 0.0021	17.40 ± 0.22	1124 ± 56	350.5 ± 4.5	
8212-42.1	199	4	455	0.021	10	0	100000	0.0558 ± 0.0009	17.81 ± 0.27	446 ± 37	351.2 ± 5.2	
8212-43.1	327	6	470	0.019	17	0	100000	0.0566 ± 0.0009	17.79 ± 0.23	478 ± 34	351.3 ± 4.4	
8212-45.1	212	2	70	0.008	11	0	100000	0.0582 ± 0.0006	17.67 ± 0.20	538 ± 21	352.9 ± 3.9	
8212-46.2	52	0	110	0.006	3	0	100000	0.0685 ± 0.0022	17.69 ± 0.27	882 ± 66	348.4 ± 5.3	
8212-59.1	314	2	45	0.007	16	0	100000	0.0548 ± 0.0008	17.56 ± 0.23	404 ± 31	356.6 ± 4.6	
8212-74.1	257	2	69	0.008	13	0	100000	0.0565 ± 0.0007	17.65 ± 0.23	470 ± 26	354.2 ± 4.6	
8212-129.1	230	1	57	0.007	12	0	100000	0.0558 ± 0.0010	17.85 ± 0.22	443 ± 40	350.5 ± 4.3	
8212-132.1	153	1	56	0.005	8	0	100000	0.0605 ± 0.0012	18.04 ± 0.24	623 ± 45	345.0 ± 4.4	
8212-140.1	193	1	36	0.004	10	0	100000	0.0574 ± 0.0009	17.77 ± 0.21	505 ± 36	351.3 ± 4.2	
8212-141.1	194	3	57	0.017	10	0	100000	0.0585 ± 0.0010	17.73 ± 0.26	550 ± 39	351.6 ± 5.0	
8212-155.1	269	1	25	0.004	14	0	100000	0.0563 ± 0.0006	17.60 ± 0.20	463 ± 22	355.2 ± 4.1	
03FD231-1 Leucogabbro - Klatsa metamorphic complex												
UTM NAD 83, Zone 9 476278E, 6769322N												
CORES (MAGMATIC) - Dark in CL, fine oscillatory and sector zoning												
8214-5.1	318	302	1721	0.982	22	0	100000	0.0549 ± 0.0005	17.27 ± 0.20	406 ± 21	362.3 ± 4.2	
8214-7.1	598	2059	6178	3.554	66	0	100000	0.0551 ± 0.0006	16.50 ± 0.20	417 ± 23	378.8 ± 4.6	
8214-30.1	887	990	2384	1.152	64	0	100000	0.0560 ± 0.0007	16.97 ± 0.23	453 ± 27	368.1 ± 5.0	
8214-40.1	248	194	2018	0.807	17	0	100000	0.0599 ± 0.0010	17.13 ± 0.23	598 ± 36	363.3 ± 4.8	
8214-54.1	419	759	3158	1.872	35	0	100000	0.0551 ± 0.0007	16.79 ± 0.24	415 ± 27	372.4 ± 5.3	
8214-62.1	471	588	3116	1.288	34	0	100000	0.0561 ± 0.0008	17.37 ± 0.21	457 ± 33	359.7 ± 4.3	
RIMS (RECRYSTALLIZED METAMORPHIC) - Moderate to very bright in CL												
8214-34.1	45	11	84	0.262	3	0	100000	0.1270 ± 0.0023	17.41 ± 0.26	2057 ± 32	329.1 ± 4.9	
8214-36.1	11	0	529	0.005	1	0	100000	0.2685 ± 0.0078	13.63 ± 0.36	3297 ± 46	342.8 ± 10.0	
8214-44.1	1	0	2	0.170	0	0	100000	0.5889 ± 0.0492	7.93 ± 0.22	4481 ± 127	288.7 ± 46.6	
8214-45.1	0	0	112	0.466	0	0	100000	0.9710 ± 0.0435	0.96 ± 0.12			
8214-46.1	74	39	659	0.544	5	0	100000	0.0787 ± 0.0009	16.89 ± 0.49	1166 ± 24	360.2 ± 10.3	
8214-47.1	72	19	232	0.265	5	0	100000	0.0896 ± 0.0016	17.00 ± 0.77	1417 ± 34	353.1 ± 15.6	
8214-51.1	3	0	204	0.008	1	0	100000	0.3912 ± 0.0273	10.57 ± 0.38	3875 ± 109	355.4 ± 22.7	
8214-53.1	0	0	26	0.264	0	0	231	0.9001 ± 0.0350	1.06 ± 0.10			

^aIon probe spot labels include: Sample number - Grain number, Spot number, some grains with second spot in same location as first (ex 49.1.2)

^bYttrium normalized to 230ppm in zircon standard BR6266; n/a - not analyzed

^cRadiogenic Pb

Klatsa metamorphic complex
QUARTZ MUSCOVITE SCHIST: 03FD056-2

Figure 2-7. Cathodoluminescence images of zircon from the Klatsa metamorphic complex quartz-muscovite schist. Locations of SHRIMP analyses are shown as dashed oval outlines. Inclusions in zircon are labelled. Metamorphic zircon contains inclusions of omphacite and rutile. Muscovite and quartz occur along the boundaries of xenocrystic cores with overgrown metamorphic zircon.

Klatsa metamorphic complex
METABASITE: 03FD039-2

Figure 2-8. Cathodoluminescence images of zircon from the Klatsa metamorphic complex metabasite. Locations of SHRIMP analyses are shown as dashed oval outlines. Xenocrystic Proterozoic cores are overgrown by metamorphic zircon. Inclusions are rare in the metamorphic zircon, but where present they are quartz and rutile with plagioclase and biotite occurring along fractures.

Klatsa metamorphic complex
LEUCOGABBRO: 03FD231-1

Figure 2-9. Cathodoluminescence images of zircon from Klatsa metamorphic complex leucogabbro. Magmatic zircon (dark in CL) is recrystallized and/or altered to metamorphic zircon with extremely low U content (<0.11 ppm). Locations of SHRIMP analyses are shown as dashed oval outlines.

Figure 2-10. (a) Backscatter scanning electron microscope image of a partly chlorite-epidote altered garnet from Klatsa metamorphic complex metabasite. The line across the garnet shows the transect path of microprobe analyses. (b) Element zoning profiles across the garnet transect shown in (a).

**Quartz-muscovite schist (layered schists, Klatsa metamorphic complex
Sample 03FD056-2**

Figure 2-11. (a,b) U-Pb concordia diagram for zircon cores from the Klatsa metamorphic complex quartz-muscovite schist (sample 03FD056-2) and a cumulative probability diagram screened to 10% discordance including data from 38 of the grains. Representative cathodoluminescence images show locations of SHRIMP spot analyses.

(c) Quartz-muscovite schist (layered schists, Klatsa metamorphic complex)
Sample 03FD056-2

(d) Metabasite (layered schists, Klatsa metamorphic complex)

Sample 03FD039-2

Figure 2-11. (c,d) U-Pb inverse concordia diagram for zircon cores from the Klatsa metamorphic complex quartz-muscovite schist (sample 03FD056-2) and metabasite (sample 03FD039-2), including SHRIMP data and cathodoluminescence images of representative zircon grains with SHRIMP analysis spot locations.

Leucogabbro (Klatsa metamorphic complex)
Sample 03FD231-1

METAMORPHIC RECRYSTALLIZATION

Figure 2-11. (e,f) U-Pb inverse concordia diagrams for zircon cores and recrystallized metamorphic rims from leucogabbro within serpentinite, part of the mafic-ultramafic unit of the Klatsa metamorphic complex, (sample 03FD231-1). Representative cathodoluminescence images locations of SHRIMP spot analyses.

Power ^a	Volume ³⁹ Ar x10 ⁻¹¹ cc	³⁶ Ar/ ³⁹ Ar	³⁷ Ar/ ³⁹ Ar	³⁸ Ar/ ³⁹ Ar	⁴⁰ Ar/ ³⁹ Ar	% ⁴⁰ Ar ATM	⁴⁰ Ar/ ³⁹ Ar	f _g ^b (%)	Apparent Age Ma ^c
03FD039-1 Muscovite; J=.00286190 (Z8122; 477191E, 6766748N UTM NAD 83, Zone 9)									
<i>Aliquot: A</i>									
2.4	0.0257	0.1567±0.1014	0.126±0.181	-0.013±-0.064	76.134±11.137	66.8	25.250±15.362	0	125.87±73.98
2.8	0.0454	0.0272±0.0646	0.320±0.180	0.036±0.032	70.835±5.657	11.9	62.398±11.077	0.1	296.42±48.53
3	0.0744	0.0105±0.0432	0.121±0.104	-0.004±-0.032	74.830±5.752	2.1	73.270±8.159	0.1	343.43±34.84
3.5	0.2989	0.1609±0.0119	0.034±0.026	-0.016±-0.012	121.246±3.354	38.9	74.069±2.479	0.3	346.84±10.56
3.9	1.2727	0.0046±0.0027	0.001±0.003	0.000±0.011	76.196±0.601	1	75.418±0.667	1.4	352.58±2.83
4.2	41.3009	0.0003±0.0005	0.000±0.001	0.002±0.011	75.846±0.251	0.2	75.684±0.253	45.4	353.71±1.07
4.6	0.2475	0.0011±0.0150	0.008±0.026	-0.008±-0.012	76.708±1.539	1.1	75.895±2.028	0.3	354.60±8.60
5	0.112	0.0012±0.0236	0.015±0.069	-0.005±-0.017	75.521±2.970	2.1	73.918±4.072	0.1	346.20±17.36
13	5.5759	0.0003±0.0006	0.000±0.001	0.002±0.011	75.561±0.293	0	75.526±0.301	6.1	353.04±1.28
<i>Aliquot: B</i>									
2.4	0.0725	0.0717±0.0089	0.042±0.136	0.060±0.027	84.845±4.745	25	63.651±6.405	0.1	301.90±27.98
2.8	0.151	0.004±0.0034	0.041±0.067	0.020±0.015	62.910±1.768	1.9	61.736±2.681	0.2	293.52±11.77
3	4.5312	0.0005±0.0001	0.001±0.002	0.002±0.011	75.073±0.295	0.2	74.930±0.306	5	350.50±1.30
3.5	7.186	0.0007±0.0001	0.001±0.002	0.002±0.011	75.115±0.318	0.3	74.896±0.326	7.9	350.36±1.39
3.9	23.1418	0.0007±0.0001	0.008±0.001	0.004±0.011	74.782±0.275	0.3	74.586±0.278	25.4	349.04±1.19
4.2	1.2255	0.0004±0.0006	0.004±0.009	0.003±0.011	71.368±0.524	0.2	71.260±0.632	1.4	334.83±2.71
5	0.2166	0.0032±0.002	0.075±0.058	0.002±0.013	73.950±1.175	1.3	73.012±1.643	0.2	342.33±7.02
18	5.5619	0.0001±0.0001	0.005±0.002	0.002±0.011	73.880±0.251	0	73.848±0.257	6.1	345.90±1.10
03FD063-1 Muscovite; J=.00287200 (Z8123; 477167E, 6766738N, UTM NAD83, Zone 9)									
<i>Aliquot: A</i>									
2.4	0.068	0.0526±0.0129	0.602±0.165	0.090±0.026	77.562±4.585	13.8	66.893±5.659	0.1	317.03±24.60
2.8	0.4599	0.0065±0.0026	0.242±0.029	0.003±0.011	72.127±1.034	1.3	71.215±1.246	0.6	335.72±5.36
3	6.5198	0.0016±0.0002	0.008±0.002	0.002±0.011	78.232±0.439	0.5	77.841±0.441	8.8	364.00±1.87
3.5	20.0883	0.0016±0.0004	0.015±0.004	0.004±0.011	78.338±0.528	0.6	77.882±0.537	27.1	364.17±2.27
3.9	11.5846	0.0007±0.0002	0.005±0.001	0.002±0.011	71.975±0.294	0.2	71.804±0.296	15.7	338.25±1.27
4.2	0.9431	0.0023±0.0011	0.061±0.018	0.007±0.011	72.146±0.756	0.2	72.028±0.838	1.3	339.21±3.60
5	0.2646	0.0129±0.0037	0.135±0.037	0.021±0.013	72.335±1.545	3.2	70.055±1.683	0.4	330.72±7.26
18	8.6588	0.0004±0.0001	0.009±0.001	0.002±0.011	72.519±0.369	0	72.491±0.371	11.7	341.20±1.59
<i>Aliquot: B</i>									
2.4	0.0674	0.0242±0.0064	0.469±0.105	0.018±0.020	70.114±3.501	10.2	62.969±5.020	0.1	299.89±22.03
2.8	0.4638	0.0033±0.001	0.134±0.012	0.007±0.011	66.982±0.930	1.5	66.010±1.096	0.6	313.19±4.78
3	5.5383	0.001±0.0001	0.006±0.001	0.002±0.011	76.803±0.316	0.4	76.522±0.326	7.5	358.40±1.38
3.5	12.0521	0.0002±0.0001	0.004±0.001	0.002±0.011	74.081±0.156	0.1	74.009±0.161	16.3	347.70±0.69
3.9	1.9383	0.0002±0.0003	0.006±0.005	0.001±0.011	71.682±0.441	0.1	71.616±0.478	2.6	337.44±2.06
4.2	0.1566	0.0007±0.0029	0.024±0.084	-0.010±-0.013	73.401±2.267	0.3	73.189±2.838	0.2	344.19±12.15
5	0.8766	0.0027±0.0004	0.007±0.013	0.004±0.011	71.430±0.954	1.1	70.644±0.973	1.2	333.26±4.19
15	4.3353	0.0001±0.0001	0.005±0.001	0.002±0.011	72.039±0.301	0	72.022±0.311	5.9	339.19±1.34
03FD056-1 Muscovite; J=.00289730 (Z8124; 476825E, 6767113N, UTM NAD83, Zone 9)									
<i>Aliquot: A</i>									
2.4	0.1081	0.0928±0.0317	0.065±0.067	0.028±0.019	78.736±2.952	29.7	55.371±6.159	0.2	268.42±27.75
2.8	0.5092	0.0072±0.0067	0.036±0.014	0.007±0.011	75.479±0.955	2.3	73.734±1.391	0.9	349.30±5.99
3	10.0209	0.0018±0.0004	0.002±0.001	0.003±0.011	76.616±0.311	0.6	76.148±0.319	16.8	359.67±1.37
3.5	6.209	0.0005±0.0006	0.003±0.001	0.002±0.011	72.671±0.300	0.3	72.462±0.314	10.4	343.81±1.36
3.9	1.9342	0.0007±0.0019	0.006±0.004	0.001±0.011	71.372±0.472	0.3	71.168±0.525	3.2	338.21±2.28
4.2	0.3461	0.0050±0.0098	0.031±0.024	0.015±0.011	71.828±1.241	0.8	71.220±1.887	0.6	338.44±8.18
4.6	0.3204	0.0045±0.0108	0.024±0.020	0.021±0.012	69.646±1.087	0.7	69.145±1.784	0.5	329.42±7.77
5.5	2.1155	0.0006±0.0017	0.009±0.003	0.004±0.011	71.216±0.387	0.1	71.178±0.473	3.5	338.25±2.05
14	2.2042	0.0010±0.0016	0.010±0.002	0.006±0.011	71.456±0.358	0.4	71.171±0.441	3.7	338.23±1.91

Continued...

Table 2-3. ⁴⁰Ar/³⁹Ar analytical data for samples from the layered schists of the Klatsa metamorphic complex.

Table 2-3 concluded.

Power ^a	Volume ³⁹ Ar x10 ⁻¹¹ cc	³⁶ Ar/ ³⁹ Ar	³⁷ Ar/ ³⁹ Ar	³⁸ Ar/ ³⁹ Ar	⁴⁰ Ar/ ³⁹ Ar	% ⁴⁰ Ar ATM	* ⁴⁰ Ar/ ³⁹ Ar	f ₃₉ ^b (%)	Apparent Age Ma ^c
03FD056-1 Muscovite; J=.00289730 (Z8124; 476825E, 6767113N, UTM NAD83, Zone 9)									
<i>Aliquot: B</i>									
2.4	0.1114	0.0558±0.005	0.112±0.094	0.042±0.017	68.648±3.068	20.4	54.663±4.073	0.2	265.23±18.38
2.8	0.6236	0.0122±0.0011	0.003±0.018	0.004±0.011	80.418±0.896	3.9	77.267±1.123	1	364.45±4.80
3	8.5832	0.0011±0.0001	0.005±0.001	0.002±0.011	74.534±0.283	0.4	74.242±0.287	14.4	351.48±1.23
3.5	12.2292	0.0011±0.0001	0.001±0.001	0.002±0.011	74.620±0.166	0.4	74.325±0.169	20.5	351.84±0.73
3.9	6.1013	0.0002±0.0001	0.001±0.002	0.001±0.011	68.996±0.201	0	68.993±0.208	10.2	328.76±0.91
4.2	0.4983	0.0004±0.0008	0.006±0.020	0.002±0.011	69.919±0.936	0.4	69.651±1.035	0.8	331.63±4.50
5	1.7689	0.0002±0.0004	0.012±0.007	0.001±0.011	68.937±0.498	0.1	68.859±0.541	3	328.18±2.35
6.5	2.6997	0.0001±0.0002	0.007±0.004	0.001±0.011	70.265±0.302	0	70.231±0.322	4.5	334.15±1.40
18	3.4163	0.0001±0.0002	0.007±0.003	0.003±0.011	70.223±0.471	0.1	70.181±0.479	5.7	333.93±2.08

a: As measured by laser in % of full nominal power (10W)

b: Fraction ³⁹Ar as percent of total run

c: Errors are analytical only and do not reflect error in irradiation parameter J

(a) Metabasite

(b)

(c) Quartz-muscovite schist

(d)

(e) Quartz-muscovite schist

(f)

Figure 2-12. $^{40}\text{Ar}/^{39}\text{Ar}$ age spectra and inverse isochron plots for three samples from the layered schists of the Klatsa metamorphic complex (see text for interpretation).

★ Klatsa metamorphic complex and Stewart Lake eclogite

High-P rocks carried along the Early Permian Cleaver Lake thrust, in the Cleaver Lake thrust sheet

Figure 2-13. Schematic cross sections illustrating proposed structural relationships across the southern Finlayson Lake belt and the Stewart Lake klippe. Section lines are located on Figure 2-1.

CHAPTER 3

Fault-controlled nephrite jade formation at the King Arctic Jade Mine, southern Campbell Range, southeastern Yukon

ABSTRACT

Nephrite at the King Arctic Jade Mine in the southern Campbell Range, Yukon occurs along imbricate faults (D4) that juxtapose metasedimentary rocks with serpentinitized ultramafic rocks. Nephrite is spatially associated with Ca-metasomatism (rodingitization) of metasedimentary rocks. Exposed sections through metasomatic reaction zones along the D4 faults show increasing rodingitization of metasedimentary rocks towards D4 faults. Nephrite occurs adjacent to metasedimentary rocks across a sheared contact, and is interpreted to have formed through silica addition to an ultramafic protolith. Foliated nephrite and structurally disrupted alteration zones attest to syn-faulting nephrite formation.

INTRODUCTION

Nephrite, also known as amphibole jade, is microcrystalline tremolite with a randomly oriented, felted, sheaf-like habit (Leaming, 1978). Nephrite occurrences are of two genetic varieties (Harlow and Sorensen, 2001): “Metasomatic” nephrite forms at reaction zones along fault-bounded serpentinitized ultramafic bodies juxtaposed with siliceous intrusive rocks or, more commonly, metasedimentary rocks. “Metamorphic” nephrite forms within metamorphosed metasedimentary rocks, associated with dolomitic marble and calc-silicate rocks.

Nephrite in the Canadian Cordillera is almost exclusively metasomatic in origin, associated with serpentinitized ultramafic rocks of the Cache Creek and Slide Mountain terranes (Leaming, 1978; Simandl et al., 2001; Simandl et al., 2000). Well known nephrite producing regions in British Columbia include the Cassiar, Cry Lake, Kutcho areas in the northwest; Mt. Ogden in central British Columbia, and in the Pinchi Lake area in south-central British Columbia (Leaming, 1978; Simandl et al., 2000). All major British Columbia nephrite jade deposits are associated with faulted contacts of serpentinite with metasedimentary or felsic igneous rocks (Simandl et al., 2001). In jade-producing regions, nephrite boulders are commonly found in valley bottoms, and can locally be traced back to in-situ occurrences.

The Yukon is also prospective for nephrite jade. While the ultramafic rocks of the Cache Creek terrane are not widespread in Yukon, Slide Mountain terrane ultramafic rocks occur locally, and ultramafic rocks also occur within Yukon-Tanana terrane, which underlies much of the southern Yukon Territory. Also, the structural history and geological relationships of ultramafic rocks are more important for forming nephrite than their tectonic origin. Many ultramafic bodies in Yukon have experienced significant structural transposition juxtaposing them with siliceous units, and are thus favorable for hosting nephrite jade.

In situ nephrite in Yukon occurs in the Campbell Range in southeastern Yukon

at the southern end of the Finlayson Lake belt, north of Watson Lake (Figure 3-1). The deposits are associated with serpentinite and metasedimentary rocks of Yukon-Tanana terrane. The previously mined King Arctic and Tuchtua deposits are located in the southern and central Campbell Range, respectively. They occur within the same belt of rocks, separated by approximately 50 km along strike. Understanding of the geology and structural history of the southern Campbell Range has been advanced through recent regional geological mapping (Chapter 1). Here we document the geology of nephrite occurrences at the King Arctic Jade Mine that were visited during the course of regional mapping, and present insights into the genesis of these occurrences in light of the structural history of the region.

GEOLOGICAL SETTING OF THE SOUTHERN CAMPBELL RANGE

The Finlayson Lake belt in southeastern Yukon includes the Paleozoic volcano-sedimentary Yukon-Tanana and basinal Slide Mountain terrane rocks north of the Tintina fault. Amalgamated Yukon-Tanana and Slide Mountain terranes were thrust over rocks of the North American continental margin along the Inconnu thrust fault post-Late Triassic, and subsequently displaced from the rest of Yukon-Tanana terrane during post-Late Cretaceous offset along the Tintina fault (Mortensen, 1992; Mortensen and Jilson, 1985; Murphy et al., 2005).

The southern Campbell Range lies along the Jules Creek fault, the boundary between Yukon-Tanana terrane and Slide Mountain terrane in the Finlayson Lake belt (Figure 3-2). To the east of the Jules Creek fault, the Slide Mountain terrane is represented by the Fortin Creek group basinal clastic rocks. The Triassic Simpson Lake conglomerate locally overlies the Fortin Creek group. To the west of the Jules Creek fault, polydeformed Yukon-Tanana terrane rocks underlie the well-exposed hills around the King Arctic Jade Mine.

Yukon-Tanana terrane in the southern Campbell Range includes Mississippian

to Permian metasedimentary rocks structurally imbricated with rocks of the Klatsa metamorphic complex. The metasedimentary rocks include three unconformity-bound formations (Figure 3-3). From bottom to top they are: 1) the White Lake formation, which comprises Upper Mississippian chert and limestone, 2) the King Arctic formation chert and limestone pebble conglomerate, lithic arenite and wacke, and 3) the Money Creek formation with heterolithic conglomerate, dark chert, carbonaceous phyllite, and lithic wacke. The Klatsa metamorphic complex is dominated by well foliated to massive, cumulate-texture serpentinite, leucogabbro, variably retrogressed Early Mississippian eclogitic rocks.

The oldest structures in the region are associated with the structural emplacement of the Klatsa metamorphic complex along the regionally recognized Cleaver Lake fault. The Early Mississippian high-pressure metamorphism, and subsequent exhumation of the Klatsa metamorphic complex are interpreted to have occurred in the frontal arc region west of the Mississippian Yukon-Tanana arc, associated with Devonian-Mississippian east-dipping subduction. Early Permian shortening of the YTT resulted in thrust emplacement of the Klatsa metamorphic complex above the Mississippian to Early Permian metasedimentary rocks (Chapter 1).

Three generations of folding affect the metasedimentary rocks, following the thrust emplacement of the Klatsa metamorphic complex. D1-2 folds are up to 100-metre amplitude, tight, overturned, northeast vergent and northwest-plunging. D3 folds generally trend east-west, are broad and open, and warp the D2 axial planar cleavage (S2).

D4 northeast-vergent faults imbricate 1 to 100 metre thick slices of the polydeformed metasedimentary sequence with the Klatsa metamorphic complex (Figure 3-2). The D4 thrust to high-angle reverse faults have curvilinear surfaces and generally shallow to the east, towards the Jules Creek fault. The Jules Creek fault locally bounds serpentinite along the eastern base of the southern Campbell Range and is itself

interpreted to have been reactivated during D4 faulting. Serpentine along the D4 faults is well foliated and commonly in contact with metasedimentary panels across a <20 cm thick zone of talc-schist. Metasedimentary rocks in the hanging wall of D4 faults are locally well foliated; limestone is locally altered and deformed to mylonitic marble.

D5 faults are high angle, low displacement and cut all earlier structures. The faults are commonly near vertical and generally trend northeast-southwest. Hematitic fault breccia zones up to 10 metres wide locally mark the D5 faults.

KING ARCTIC JADE MINE

King Arctic Jade Mine lies immediately west of the Robert Campbell Highway approximately 25 km north of the Nahanni Range Road junction, and south of Frances Lake (Figure 3-1). The deposits occur along an east-facing slope overlooking the Frances River Valley.

First staked in 1964, the claims around King Arctic were explored through the 1970's and then mined from 1988 to 1994 (MINFILE 105H 014; Deklerk and Traynor, 2004). Over 100 tonnes of jade was removed from the site. There is no current jade production from the region.

GEOLOGICAL SETTING OF NEPHRITE JADE AT KING ARCTIC

In the immediate vicinity of the King Arctic Jade Mine, D4 faults bound a 3 km² region of serpentinite structural mélange (Figure 3-2). At the southern end of the region, immediately south of the major nephrite occurrences, a high-angle northeast-trending fault transects a southeast-dipping D4 fault panel of metasedimentary rocks of the King Arctic and Money Creek formations. The fault is well-exposed in the cliff-face immediately south of the King Arctic working face, and terminates against the overlying metasedimentary fault panel to the west.

The King Arctic region serpentinite mélange is well foliated and is host to blocks

and lenses of the Mississippian to Lower Permian chert, limestone, and metaclastic rocks which occur as rounded blocks 1 metre to 100 metre in diameter and also as lenses down to 1 metre width and 10's of metres long. Limestone lenses are twisted and boudinaged, chert and metaclastic rocks are rounded to subangular. Mélange formation occurred during D4 faulting. Metasedimentary rocks are similarly incorporated into D4 serpentinite fault panels regionally.

NEPHRITE DEPOSITS

The King Arctic nephrite jade deposits occur along D4 faults that juxtapose serpentinite with metasedimentary rocks of the White Lake and King Arctic formations. Nephrite lenses are closely spatially associated with calc-silicate alteration (rodingitization) and are interpreted to have formed during D4 faulting.

Nephrite and its structural relationships to adjacent rocks are best exposed at two localities: the 'Working Face' and the 'Upper Quarry', described below. Most nephrite was mined from the Working Face.

Working Face

The nephrite lenses in the King Arctic working face area occur along D4 faults that juxtapose King Arctic metasedimentary rocks with serpentinite (Figure 3-4). The King Arctic formation rocks are generally conglomerates and bedded lithic arenites, interpreted to represent the lower part of the King Arctic formation. The most significant lens occurs along a D4 fault with metasedimentary rocks in the hanging wall and serpentinite in the footwall. It is up to 3 metres in width and continuous for at least 10 metres in length and occurs over a strike length of ~100 metres along the D4 fault.

More broad exposure at the Working Face reveals significant structural disruption of serpentinite and alteration products along the D4 faults. White rodingite lenses are incorporated into sheared serpentinite along the fault contacts with metasedimentary

rocks (Figure 3-5).

Nephrite at the working face includes poor-quality white to green semi-nephrite (including coarse, prismatic tremolite), well-foliated nephrite, to high-quality translucent apple to dark green true nephrite (fine-grained tremolite with felted texture). Inclusions of picotite (Cr-spinel) are common within nephrite (Figure 3-6a).

Upper Quarry

The upper quarry is located at the highest point in the region, above the King Arctic mine working face (Figure 3-2). In August of 2003, the test pit was approximately 8 x 5 metres and 2 metres deep and located along a shallowly west-dipping D4 fault that separates serpentinite in the footwall from White Lake and King Arctic formation metasedimentary rocks in the hanging wall. The pit lies along the eastern side of the resistant metasedimentary hanging wall and exposes a 2 metre wide transition across the Ca-metasomatically altered zone in the immediate hanging wall of the underlying D4 fault.

The hanging wall metasedimentary rocks are folded by shallowly west-dipping, north-vergent tight, recumbent D2 folds, and the rocks are moderately foliated by D2-related deformation. The exposed Ca-metasomatised zone occurs above the D4 fault where it cuts King Arctic green chert pebble conglomerate overlying White Lake formation limestone. The conglomerate occupies the core of a synform that folds the King Arctic basal unconformity.

The section in the quarry pit wall shows increasing Ca-metasomatism downwards towards the D4 fault (Figure 3-7). Unaltered King Arctic formation chert-pebble conglomerate transitionally changes into rodingite-altered conglomerate. Coarse-grained, prismatic tremolite-rock and nephrite occur across a well-foliated rodingite domain. Serpentinite is not exposed but underlies the nephrite at the base of the pit.

Rodingitized metasedimentary rocks occur over an interval of approximately 1

metre and preserve primary conglomeratic texture (Figure 3-6b). Clasts are preferentially replaced by different Ca-minerals; by symplectic pseudomorphs of fine grained masses of clinozoisite or tremolite with hydrogarnet as anhedral patches within tremolite domains, as well as domains of coarse-grained tremolite and wollastonite (Figure 3-7).

The Ca-metasomatised conglomerate is bounded below by a strain zone in the Ca-altered rocks. Rodingite is well foliated and highly strained with black and white-striped < mm-scale mylonitic bands which correspond to varying concentrations of fine-grained tremolite and epidote/clinozoisite. The foliation is cut by <mm-scale veinlets that are undeformed but host the same mineral assemblage.

Below the strain zone, milky white tremolite rocks with relatively coarse, prismatic tremolite are mingled with translucent green nephrite to semi-nephrite (Figure 3-7).

Other nephrite occurrences

Rodingite-altered rocks and semi-nephrite are locally found in other parts of the King Arctic region. Rodingite alteration is found along the margins of some metasedimentary rocks within serpentinite. Some mélange blocks are completely rodingitized (Figure 3-8). Occurrences outside of the King Arctic region mélange are few. However, a rodingite lens 5 metres long, with talc and tremolite-rock along its boundaries was found to the south of the King Arctic region, in a different serpentinite sheet. Contacts of the alteration zone around the lens are gradational with serpentinite over several centimeters.

DISCUSSION

Nephrite formation: structural and fluid controls

The association of nephrite, rodingite alteration, and deformation and

serpentinization of ultramafic rocks is known from other metasomatic nephrite deposits (Leaming, 1978; O'Hanley, 1996; Prokhor, 1991; Simandl et al., 2000). Fluid circulation along major structures aids the metasomatic chemical transfer of silica from wall rock metasedimentary or igneous rocks, and Ca from serpentinized ultramafic rocks (Karpov et al., 1987). Rodingitization is the result of silica removal and calcium addition to wall rocks adjacent to faulted contacts with serpentinized ultramafic rocks. Nephrite forms locally in this metasomatic environment, generally thought to be the product of silica addition to ultramafic rocks with Ca liberated from clinopyroxene during serpentinization (Prokhor, 1991).

Nephrite and associated rodingite alteration in the King Arctic region fit well within this genetic model for metasomatic nephrite formation. Structural relationships and textures demonstrate that nephrite formed synchronously with, and as a result of imbricate D4 faulting. All nephrite occurrences lie directly along D4 faulted contacts between metasedimentary rocks and serpentinite, and nephrite itself is locally foliated by a D4-related fabric. Given the strength of nephrite, relative to adjacent serpentinite, the foliation of nephrite implies formation during D4 faulting. Also, at the Upper Quarry, sheared rodingite is cross-cut by undeformed veinlets containing the same Ca-silicate mineral assemblage, evidence of deformation accompanied by alteration.

The metasomatic reaction domains hosting rodingite and nephrite in the King Arctic region are the product of metasomatic exchange along D4 faults. The relationships at the Upper Quarry show a transition from wall rock to rodingite-altered wallrock to nephrite to serpentinite (Figure 3-6). Similar lithological and structural relationships are found around other metasomatic nephrite deposits; for example in many of the nephrite deposits in British Columbia (Leaming, 1978; Simandl et al., 2000), as well as in East Sayan, Russia (Prokhor, 1991).

Significant in the relationships demonstrated at the Upper Quarry is the presence of a shear zone between the rodingitized hanging wall rocks and nephrite (Figure 3-6).

The D4 fault is mapped below the nephrite lens, within serpentinite; however, shearing may have first occurred along the rodingite shear zone and subsequently been transferred downwards into the serpentinite following nephrite formation.

Nephrite protolith

A serpentinite protolith for nephrite has been demonstrated in other metasomatic nephrite occurrences, based on stable isotope characteristics (Yui and Yeh, 1988), chemical composition (Leaming, 1978), and gradational contacts of nephrite and serpentinite (Simandl et al., 2000). The diagnostic felted texture of nephrite is also interpreted by some authors to reflect original serpentinite textures (O'Hanley, 1996). Similarly, nephrite in the King Arctic region preserves evidence of an ultramafic protolith. Relict picotite (Cr-spinel) grains in nephrite and the high Ti-content of nephrite (Leaming, 1978) are likely inherited from an ultramafic precursor. Also, the structural relationships at the Upper Quarry also indicate an early fault contact between the nephrite protolith and hanging wall rocks; possibly an early D4 fault juxtaposing footwall ultramafic rocks and hanging wall metasedimentary rocks.

The silica and calcium sources for King Arctic nephrite formation may have been the wall rock metasedimentary rocks, and the serpentinitized ultramafic rocks, respectively. Another possible calcium source in the King Arctic region is limestone of the White Lake formation. Nephrite occurrences are spatially associated with White Lake formation limestone and the lower King Arctic formation metaclastic rocks stratigraphically immediately above the White Lake formation. However, the importance and role, if any, of White Lake formation limestone to nephrite genesis is uncertain. The spatial relationship may simply be coincidental as many serpentinite-metasedimentary contacts in the King Arctic region that transect limestone do not host nephrite.

Future nephrite discoveries in Yukon

The Campbell Range is prospective for future nephrite discoveries. D4 fault-bound bodies of serpentinite of the Klatsa metamorphic complex extend to the north. The Tuchitua nephrite deposits occur approximately 50 km to the north, in a similar structural position as the King Arctic occurrences, in fault contact with possible White Lake formation correlative rocks (F. Devine, field observations). Nephrite is also reported from the Simpson Lake region, approximately 50 km south and along strike of the Campbell Range (McIsaac, 2000).

Other parts of the Finlayson Lake belt are also prospective for nephrite. The Lady Lee occurrence in the western Finlayson Lake belt (MINFILE 105G 114; Deklerk and Traynor, 2004) is associated with a different package of ultramafic rocks, part of the Cleaver Lake formation. It should be reiterated that nephrite formation is a function of structurally dynamic metasomatic processes and is not necessarily tied to specific ultramafic units. Other ultramafic-bearing terranes in Yukon are therefore also prospective for nephrite.

CONCLUSIONS

Nephrite jade at the King Arctic Jade Mine formed during fault-controlled alteration of serpentinite along D4 faulted contacts with White Lake group and King Arctic formation metasedimentary rocks. Key geological relationships and conclusions related to the origin of nephrite are as follows:

- 1) Major nephrite lenses in the King Arctic region lie along D4 faults separating footwall serpentinite from hanging wall King Arctic formation metasedimentary rocks.
- 2) Exposed contacts show a metasomatic progression from unaltered metasedimentary rocks to rodingite separated from nephrite across a shear zone in rodingite. Serpentinite underlies the nephrite.

- 3) Nephrite formed syn-D4 faulting; nephrite and rodingite are foliated and occur exclusively along D4 faults.
- 4) The protolith of nephrite is inferred to be ultramafic rock, based on picotite inclusions in nephrite, and the sheared relationship between rodingitized hanging wall metasedimentary rocks and nephrite.

Figure 3-1. Location map of the King Arctic Jade Mine in the southern Campbell Range, southeastern Finlayson Lake belt, southeastern Yukon.

Figure 3-2. Geological map and cross section of the King Arctic Jade Mine region. Cross section is 1.5x map scale.

Figure 3-3. Schematic stratigraphy of the southern Campbell Range metasedimentary rocks. Unit thicknesses are not to scale, and ages are based on regional constraints and correlations with dated units elsewhere in the Finlayson region (age data in Murphy et al., 2005, Chapter 1). From Chapter 1.

Figure 3-4. Jade contacts near the Working Face at the King Arctic mine. Jade (nephrite) occurs along the D4 faulted contact between serpentinite (below) and King Arctic formation clastic rocks (above).

Figure 3-5. Serpentinite-King Arctic formation faulted contact immediately south of the King Arctic Working Face. The Working Face nephrite lenses occur along the upper (left in this photo) side of this serpentinite sheet. In this photo, foliated serpentinite is host to syn-D4 blocks of rodingite (tremolitite) along the fault.

Figure 3-6. Photomicrographs of a) semi-nephrite and b) rodingitized King Arctic formation conglomerate.

King Arctic Uppery Quarry Nephrite contacts

Figure 3-7. In-situ nephrite at the King Arctic Upper Quarry. The upper photo is taken approximately 1 metre above the lower photo at the same outcrop. **a)** Rodingitized King Arctic formation green chert pebble conglomerate, **b)** Nephrite lies below the rodingite altered zone across a highly attenuated rodingite zone. The D₄ fault may have originally separated serpentinite and metasedimentary rocks but moved progressively downwards during nephrite formation. Serpentinite lies below nephrite, in the footwall of the present D₄ fault.

Figure 3-8. Rodingite pod within serpentinite south of the King Arctic Jade Mine, near location 3 on Figure 3-2. Reid Kennedy for scale.

CHAPTER 4

Summary of Conclusions

Yukon-Tanana terrane rocks in the southern Campbell Range display a wide variation in metamorphic and geological histories, the result of formation in disparate parts of the Yukon-Tanana terrane arc during different phases of arc development and deformation. Relict high-pressure eclogite facies metamorphic mineral assemblages are preserved in rocks of the Klatsa metamorphic complex; these are interpreted to have formed and been exhumed along the western margin of Yukon-Tanana terrane in the Early Mississippian. Upper Mississippian to Lower Permian metasedimentary rocks have mineral assemblages reflecting at most lower greenschist facies metamorphism. The definitions, metamorphic history and structural amalgamation of Yukon-Tanana terrane rocks in the southern Campbell Range are summarized chronologically below.

- 1) Upper Mississippian to Lower Permian metasedimentary rocks in the southern Campbell Range can be divided into four separate units. From oldest to youngest these are: the Serpukovian White Lake formation chert and limestone, unconformably overlying King Arctic formation conglomerate, Pennsylvanian limestone; and Early Permian heterolithic Money Creek formation.
- 2) The Klatsa metamorphic complex comprises, in order of decreasing abundance: 1) a mafic-ultramafic member which includes serpentized ultramafic rocks and co-magmatic leucogabbro, 2) a layered schist member composed of quartz-muscovite schist and interfoliated metabasite lenses, 3) blocks of amphibolite contained within serpentinite, 4) phyllite-matrix mélange including orthoquartzite and chert.
- 3) The protolith of the mafic-ultramafic unit is a ca. 368 Ma mafic-ultramafic intrusive assemblage, coeval with earliest arc volcanism in Yukon-Tanana terrane. The protolith of the layered schist member is an Early Paleozoic succession of sandstone or siltstone with mafic flows or intrusions. The former contains zircons

with detrital cores that indicate a cratonic source, possibly the North American continent. Constrained to be younger than ca. 473 Ma, the metabasite lenses may be related to early extensional arc magmatism. Trace element geochemistry reveals two geochemical suites within the metabasites: Suite 1 with N-MORB character, and Suite 2 with an inferred arc basalt protolith that has been affected by crustal contamination. The schists may be a block of Yukon-Tanana terrane basement or second-cycle sedimentary rocks derived therefrom.

- 4) The layered schists unit of the Klatsa metamorphic complex grew metamorphic zircon at ~353Ma, syngenetic with an eclogite facies mineral assemblage.
- 5) Rapid exhumation of the Klatsa metamorphic complex immediately followed eclogite-facies metamorphism. The layered schists cooled through 350°C by 353 Ma, immediately following eclogite- facies metamorphic zircon formation.
- 6) The Klatsa metamorphic complex was thrust over the Money Creek formation along the Cleaver Lake thrust fault, during Early Permian shortening of Yukon-Tanana terrane in the Finlayson Lake belt. The Cleaver Lake thrust fault restores to a frontal arc position within the Mississippian Yukon-Tanana arc. Association of the Klatsa metamorphic complex with the Cleaver Lake thrust sheet implies formation and exhumation of the complex along the western margin of the arc, prior to eastward structural transport in the Early Permian.
- 7) Five regional structural events, post Klatsa metamorphic complex emplacement, are recognized in the southern Campbell Range: D1, D2) northeast-vergent tight, overturned folding, D3) broad east-west-trending folding, D4) thrust to high-angle reverse faulting, imbricating all units, and D5) north- to northeast-striking high angle, low displacement faulting.
- 8) Nephrite jade at the King Arctic Jade Mine formed from a serpentinite protolith through metasomatic exchange with metasedimentary rocks along D4 faults during fault displacement.

The Klatsa metamorphic complex, defined in the southern Campbell Range, is interpreted to correlate with other Mississippian eclogite-bearing rocks in the Stewart Lake klippe. Together these two occurrences are the only currently recognized evidence of a Mississippian subduction zone in Yukon-Tanana terrane. However, future studies should examine schists previously thought to be stable basement in Yukon-Tanana terrane for evidence of high-pressure metamorphism. The extent of the Klatsa metamorphic complex may be much greater than previously recognized.

REFERENCES

- Baldwin, S. L., and Ireland, T. R., 1995, A tale of two eras: Pliocene-Pleistocene unroofing of Cenozoic and late Archean zircons from active metamorphic core complexes, Solomom Sea, Papua New Guinea: *Geology*, v. 23, no. 11, p. 1023-1026.
- Bernard-Griffiths, J., Peucat, J. J., Cornichet, J., Iglesias Ponce de Leon, M., and Iberguchi, J. I. G., 1985, U-Pb, Nd isotope and REE geochemistry in eclogites from the Cabo Ortegal complex, Galicia, Spain: an example of REE immobility conserving MORB-like patterns during high-grade metamorphism: *Chemical Geology*, v. 52, p. 217-225.
- Carswell, D. A., 1990, Eclogites and the eclogite facies: definitions and classifications, *in* Carswell, D. A., ed., *Eclogite Facies Rocks*: New York, Chapman and Hall, p. 1-13.
- Colpron, M., Murphy, D. C., and Mortensen, J. K., 2000, Mid-Paleozoic tectonism in Yukon-Tanana Terrane, northern Canadian Cordillera: record of intra-arc deformation: *Geological Society of America, Program with Abstracts*, v. 32, no. 6, A-7.
- Colpron, M., Murphy, D. C., Nelson, J. L., Roots, C. F., Gladwin, K., Gordey, S. P., and Abbott, J. G., 2003, Yukon Targeted Geoscience Initiative, Part 1: Results of accelerated bedrock mapping in Glenlyon (105L/1-7,11-14) and northeast Carmacks (115L/9,16) areas, central Yukon, *in* Emond, D. S., and Lewis, L. L., eds., *Yukon Exploration and Geology 2002*: Whitehorse, YT, Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 85-108.
- Corfu, F., Hanchar, J. M., Hoskin, P. W. O., and Kinny, P., 2003, Atlas of zircon textures, *in* Hanchar, J. M., and Hoskin, P. W. O., eds., *Zircon: Reviews in Mineralogy and Geochemistry*: Washington D.C., Mineralogical Society of America, p. 469-500.

- Creaser, R., Goodwin-Bell, J. S., and Erdmer, P., 1999, Geochemical and Nd isotopic constraints for the origin of eclogite protoliths, northern Cordillera: implications for the Paleozoic tectonic evolution of the Yukon-Tanana terrane: *Canadian Journal of Earth Sciences*, v. 36, p. 1697-1709.
- Creaser, R. A., Erdmer, P., Stevens, R. A., and Grant, S. L., 1997, Tectonic affinity of Nisutlin and Anvil assemblage strata from the Teslin tectonic zone, northern Canadian Cordillera: Constraints from neodymium isotope and geochemical evidence: *Tectonics*, v. 16, p. 107-121.
- Dazé, A., Lee, J.K.W., Villeneuve, M.E., 2003, An intercalibration study of the Fish Canyon sanidine and biotite $^{40}\text{Ar}/^{39}\text{Ar}$ standards and some comments on the age of the Fish Canyon Tuff: *Chemical geology*, v. 199, no.1-2, p. 111-127.
- Davies, H. L., and Warren, R. G., 1988, Eclogites of the D'Entrecasteaux Islands: *Contributions to Mineralogy and Petrology*, v. 112, p. 463-474.
- de Keijzer, M., Williams, P. F., and Brown, R. L., 1999, Kilometre-scale folding in the Teslin zone, northern Canadian Cordillera, and its tectonic implications for the accretion of the Yukon-Tanana terrane to North America: *Canadian Journal of Earth Sciences*, v. 39, p. 479-494.
- Deklerk, R., and Traynor, S., 2004, Yukon MINFILE - A database of mineral occurrences, v. Yukon Geological Survey, CD-ROM.
- Devine, F., Murphy, D. C., Kennedy, R., Tizzard, A., and Carr, S. D., 2004, Geological setting of retrogressed eclogite and jade in the southern Campbell Range: Preliminary structure and stratigraphy, Frances Lake area (NTS 105H), southeastern Yukon: *Yukon Exploration and Geology* 2003.
- Devine, F., Murphy, D. C., Carr, S. D., Kennedy, R., and Tizzard, A. M., 2005, Geological map of the southern Campbell Range (NTS 105H/3 SW), southeastern Yukon (1:20 000), *Geoscience Map* 2005-1, Yukon Geological Survey.
- Duchene, S., Lardeaux, J.-M., and Albarede, F., 1997, Exhumation of eclogites; insights

- from depth-time path analysis: *Tectonophysics*, v. 280, no. 1-2, p. 125-140.
- Erdmer, P., 1987, Blueschist and eclogite in mylonitic allochthons, Ross River and Watson Lake areas, southeastern Yukon: *Canadian Journal of Earth Sciences*, v. 24, p. 1439-1449.
- Erdmer, P., 1992, Eclogitic rocks in the St. Cyr klippe, Yukon, and their tectonic significance: *Canadian Journal of Earth Sciences*, v. 29, p. 1296-1304.
- Erdmer, P., Ghent, E. D., Archibald, D. A., and Stout, M. Z., 1998, Paleozoic and Mesozoic high-pressure metamorphism at the margin of ancestral North America in central Yukon: *Geological Society of America Bulletin*, v. 110, p. 615-629.
- Erdmer, P., Heaman, L., Creaser, R. A., Thompson, R. I., and Daughtry, K. L., 2001, Eocambrian granite clasts in southern British Columbia shed light on Cordilleran hinterland crust: *Canadian Journal of Earth Sciences*, v. 38, p. 1007-1016.
- Erdmer, P., and Helmstaedt, H., 1983, Eclogite from central Yukon: a record of subduction at the western margin of ancient North America: *Canadian Journal of Earth Sciences*, v. 20, p. 1389-1408.
- Ernst, W. G., 1984, Californian blueschists, subduction, and the significance of tectonostratigraphic terranes: *Geology*, v. 12, p. 436-440.
- Gehrels, G. E., Butler, R. F., and Bazard, D. R., 1996, Detrital zircon geochronology of the Alexander terrane, southeastern Alaska: *Geological Society of America Bulletin*, v. 108, no. 6, p. 722-734.
- Gehrels, G. E., and Kapp, P. A., 1998, Detrital zircon geochronology and regional correlation of metasedimentary rocks in the Coast Mountains, southeastern Alaska: *Canadian Journal of Earth Sciences*, v. 35, p. 269-279.
- Gehrels, G. E., and Ross, G. M., 1998, Detrital zircon geochronology of Neoproterozoic to Permian miogeoclinal strata in British Columbia and Alberta: *Canadian Journal of Earth Sciences*, v. 35, p. 1380-1401.
- Gordey, S. P., and Murphy, D. C., 2003, Yukon-Tanana Terrane its relationship to North

- America, *In* Geological Association of Canada - Mineralogical Association of Canada - Society of Economic Geologists Joint annual Meeting, Vol. 28.
- Gordey, S. P., McNicholl, V. J., and Mortensen, J. K., 1998, New U-Pb ages from the Teslin area, southern Yukon, and their bearing on terrane evolution in the northern Cordillera: Geological Survey of Canada, Current Research 1998-F.
- Grant, S. L., 1997, Geochemical, radiogenic tracer isotopic and U-Pb geochronological studies of Yukon Tanana terrane rocks from the Money klippe, southeastern Yukon, Canada [M.Sc. thesis]: University of Alberta, 174 p.
- Hames, W. E., and Bowring, S. A., 1994, An empirical evaluation of the argon diffusion geometry in muscovite: *Earth and Planetary Science Letters*, v. 124, p. 161-167.
- Hansen, V. L., 1989, Structural and kinematic evolution of the Teslin suture zone, Yukon: Record of an ancient transpressional margin: *Journal of Structural Geology*, v. 11, p. 717-733.
- Hansen, V. L., and Dusel-Bacon, C., 1998, Structural and kinematic evolution of the Yukon-Tanana upland tectonites, east-central Alaska: A record of late Paleozoic to Mesozoic crustal assembly: *Geological Society of America Bulletin*, v. 110, p. 211-230.
- Harlow, G. E., and Sorensen, S. S., 2001, Jade: Occurrence and metasomatic origin: *The Australian Gemmologist*, v. 21, p. 7-10.
- Heaman, L. M., and Erdmer, R., 1996, Detrital Zircon U-Pb constraints on the Evolution of the Teslin Tectonic Zone, Yukon: Lithoprobe SNORCLE Transect meeting, University of Calgary, p. 54-57.
- Hoskin, P. W. O., and Black, L. P., 2000, Metamorphic zircon formation by solid-state recrystallization of protolith igneous zircon: *Journal of Metamorphic Geology*, v. 18, p. 423-439.
- Hoskin, P. W. O., and Schaltegger, U., 2003, The composition of zircon and igneous and metamorphic petrogenesis, *in* Hanchar, J. M., and Hoskin, P. W. O., eds., *Zircon*:

- Reviews in Mineralogy and Geochemistry: Washington D.C., Mineralogical Society of America, p. 29-62.
- Karpov, I. K., Chudnenko, K. V., and Suturin, A. N., 1987, Physicochemical Modeling of Processes of Contact-Infiltration Metasomatism: Transactions (Doklady) of the U.S.S.R. Academy of Sciences: Earth Science Section, v. 297, p. 189-192.
- Katayama, I., Zayachkovsky, A. A., and Maruyama, S., 2002, Mineral inclusions in zircon from the Kokchetav Massif; an excellent container of UHP minerals, *in* Parkinson, C. D., Katayama, I., Liou, J. G., and Maruyama, S., eds., The diamond-bearing Kokchetav Massif, Kazakhstan; petrochemistry and tectonic evolution of an unique ultrahigh-pressure metamorphic terrane: Frontiers Science Series: Tokyo, Japan, Universal Academy, p. 147-156.
- Krogh, T.E., 1982, Improved accuracy of U Pb zircon ages by the creation of more concordant systems using an air abrasion technique: *Geochimica et Cosmochimica Acta*, v. 46, p. 637-649.
- Leaming, S. F., 1978, Jade in Canada: Geological Survey of Canada, Paper 78-19, 78-19.
- McIsaac, D., 2000, Botryoidal Jade: Rarest of the Rare Jades: *Canadian Rockhound*, v. 4, no. 2.
- Mihalynuk, M. G., Erdmer, P., Ghent, E. D., Cordey, F., Archibald, D. A., Friedman, R. M., and Johansson, G. G., 2004, Coherent French Range blueschist: Subduction to exhumation in < 2.5 m.y.?: *Geological Society of America Bulletin*, v. 116, no. 7/8, p. 910-922.
- Möller, A., O'Brien, P. J., Kennedy, A., and Kröner, A., 2003, Linking growth episodes of zircon and metamorphic textures to zircon chemistry: an example from the ultrahigh-temperature granulites of Rogaland (SW Norway), *in* Vance, D., Müller, W., and Villa, I. M., eds., *Geochronology: Linking the Isotopic Record with Petrology and Textures: Special Publications*, London, Geological Society, v. 220 p. 65-81.

- Mortensen, J. K., 1990, Significance of U-Pb ages for inherited and detrital zircons from Yukon-Tanana terrane, Yukon and Alaska: Geological Association of Canada - Abstracts with Programs, v. A91.
- Mortensen, J. K., 1992a, New U-Pb ages for the Slide Mountain Terrane in southeastern Yukon Territory, Radiogenic Age and Isotopic Studies: Report 5. Geological Survey of Canada, Paper 91-2: Ottawa, ON, Canada, Geological Survey of Canada, p. 167-173.
- Mortensen, 1992b, Pre-mid-Mesozoic tectonic evolution of the Yukon-Tanana Terrane, Yukon and Alaska: Tectonics, v. 11, p. 836-853.
- Mortensen, J.K., Ghosh, D., and Ferri, F., 1995, U-Pb age constraints of intrusive rocks associated with Copper-Gold porphyry deposits in the Canadian Cordillera, in Schroeter, T.G., ed., Porphyry deposits of the northwestern Cordillera of North America: Canadian Institute of Mining and Metallurgy, Special Volume 46.
- Mortensen, J. K., Erdmer, P., and Ghent, E. D., 1997, Westerly-derived Upper Triassic clastic sedimentary rocks in southeastern Yukon: evidence for Early Mesozoic terrane interaction with the western margin of ancestral North America, *in* Slave - Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting, Abstracts, p. 76.
- Mortensen, J. K., Erdmer, P., Piercey, S. J., and Ghent, E. D., 1999, Evidence for Late Triassic terrane accretion in the northern Canadian Cordillera in southeastern Yukon, *in* Terrane Paths 99, Circum-Pacific Terrane Conference, Okanagan Valley, B.C., Canada, p. 55.
- Mortensen, J. K., and Jilson, G. A., 1985, Evolution of the Yukon-Tanana terrane: evidence from southeastern Yukon Territory: Geology, v. 13, p. 806-810.
- Murphy, D. C., Colpron, M., Roots, C. F., Gordey, S. P., and Abbott, J. G. 2002. Finlayson Lake Targeted Geoscience Initiative (southeastern Yukon), Part 1: Bedrock geology. *In* Yukon Exploration and Geology 2001. *Edited by* D. S.

- Emond, L.H. Weston, and L.L. Lewis. Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, pp. 189-207.
- Murphy, D. C., and Mortensen, J. K., 2003, Late Paleozoic and Mesozoic Features Constrain Displacement on Tintina Fault and Limit Large-Scale Orogen-Parallel Displacement in the Northern Cordillera. *In* Geological Association of Canada - Mineralogical Association of Canada - Society of Economic Geologists Joint annual Meeting, Vol. 28, p. 151.
- Murphy, D. C., Mortensen, J. K., Piercey, S. J., Orchard, M. J., and Gehrels, G. E., 2005, Mid- to late Paleozoic tectonostratigraphic evolution of the northeasternmost part of Yukon-Tanana Terrane and adjacent parts of Slide Mountain Terrane, Finlayson Lake massive sulphide district, southeastern Yukon. Geological Association of Canada Special Volume, p. in press.
- Nelson, J. L., 1993, The Sylvester allochthon: Upper Paleozoic marginal-basin and island-arc terranes in northern British Columbia: Canadian Journal of Earth Sciences, v. 30, p. 631-643.
- Nelson, J. L., Paradis, S., Christensen, J., and Gabites, J., 2002, Canadian Cordilleran Mississippi Valley-Type Deposits: A Case for Devonian-Mississippian Back-Arc Hydrothermal Origin: Economic Geology, v. 97, p. 1013-1036.
- Nelson, J., and Friedman, R. M., 2004, Superimposed Quesnel (late Paleozoic-Jurassic) and Yukon-Tanana (Devonian-Mississippian) arc assemblages, Cassiar Mountains, northern British Columbia: field, U-Pb, and igneous petrochemical evidence: Canadian Journal of Earth Sciences, v. 41, p. 1201-1235.
- O'Hanley, D. S., 1996, Serpentinites: Records of Tectonic and Petrological History: New York, Oxford University Press, 277 p.
- Orchard, M. J., 2005, Carboniferous to Triassic conodont biostratigraphy of the Yukon-Tanana terrane and adjacent areas of Yukon Territory and northern British Columbia, *in* Colpron, M., Nelson, J. L., and Thompson, R. I., eds., Paleozoic

- evolution and metallogeny of pericratonic terranes at the ancient Pacific margin of North America, Canadian and Alaskan Cordillera, Geological Association of Canada, p. in press.
- Parrish, R., Roddick, J.C., Loveridge, W.D. and Sullivan, R.W., 1987. Uranium lead analytical techniques at the geochronology laboratory, Geological Survey of Canada, in Radiogenic age and isotopic studies, Report 1: Geological Survey of Canada Paper 87 2, p. 3-7.
- Parrish, R. R., Ross, G., Carr, S. D., Coleman, V., and Journeay, J. M., 1989, Single grain U-Pb provenance ages of detrital zircons from metaquartzites of the southern Omenica belt, British Columbia: Geological Society of America, Abstracts with Programs, v. 21, p. 127-128.
- Pearce, J. A., 1983, Role of the Sub-continental Lithosphere in Magma Genesis at Active Continental Margins, *in* Hawkesworth, C. J., and Norry, M. J., eds., Continental basalts and mantle xenoliths, Nantwich, UK, Shivan, p. 230-249.
- Pearce, J. A., Baker, P. E., Harvey, P. K., and Luff, I. W., 1995, Geochemical Evidence for Subduction Fluxes, Mantle Melting and Fractional Crystallization Beneath the South Sandwich Island Arc: *Journal of Petrology*, v. 36, p. 1073-1109.
- Pidgeon, R. T., 1992, Recrystallization of oscillatory zoned zircon: some geochronological and petrological implications: *Contributions to Mineralogy and Petrology*, v. 110, p. 463-472.
- Piercey, S. J., 2001, Petrology and Tectonic Setting of Mafic and Felsic Volcanic and Intrusive Rocks in the Finlayson Lake Volcanic-Hosted Massive Sulphide (VHMS) District, Yukon, Canada: A Record of Mid-Paleozoic Arc and Back-Arc Magmatism and Metallogeny [Ph.D. thesis]: University of British Columbia, 305 p.
- Piercey, S. J., Colpron, M., Nelson, J., Dusel-Bacon, C., Simard, R.-L., and Roots, C. F., 2005, Paleozoic Magmatic, Tectonic, and Crustal Growth History of the Ancient

- Pacific Margin of North America: Geochemical Constraints from the Yukon-Tanana Terrane in British Columbia, Yukon, and Alaska, Geological Association of Canada Special Paper, in review.
- Piercey, S. J., Murphy, D. C., Mortensen, J. K., and Creaser, R., 2004, The Mid-Paleozoic Initiation of the Northern Cordilleran Marginal Back-Arc Basin: Geological, Geochemical and Neodymium Isotopic Evidence from the Oldest Mafic Magmatic Rocks in Yukon-Tanana Terrane, Finlayson Lake district, Southeast Yukon, Canada: Geological Society of America Bulletin, v. 119, no. 9/10, p.1087-1106.
- Piercey, S. J., Mortensen, J. K., and Creaser, R. A., 2003, Neodymium isotope geochemistry of felsic volcanic and intrusive rocks from the Yukon-Tanana Terrane in the Finlayson Lake region, Yukon, Canada: Canadian Journal of Earth Sciences, v. 40, p. 77-97.
- Piercey, S. J., Murphy, D. C., Mortensen, J. K., and Creaser, R., 2004b, The Mid-Paleozoic Initiation of the Northern Cordilleran Marginal Back-ArcBasin: Geological, Geochemical and Neodymium Isotopic Evidence from the Oldest Mafic Magmatic Rocks in Yukon-Tanana Terrane, Finlayson Lake district, Southeast Yukon, Canada: Geological Society of America Bulletin, v. 116, p. 1087-1106.
- Pigage, L., 2004, Bedrock geology compilation of the Anvil District (parts of NTS 105K/2,3,5,6,7 and 11), central Yukon, Yukon Geological Survey, 103 p.
- Pigage, L. C., 2001, Geological map of Anvil District (NTS 105K/2, 3, 5, 6, 7, 11), Central Yukon (1:100 000 scale): Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Open File 2001-31, scale 1:100 000.
- Platt, J. P., 1986, Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks: Geological Society of America Bulletin, v. 97, p. 1037-1053.

- Plint, H. E., and Gordon, T. M., 1997, The Slide Mountain Terrane and the structural evolution of the Finlayson Lake Fault Zone, southeastern Yukon: *Canadian Journal of Earth Sciences*, v. 34, p. 105-126.
- Poulton, T., Orchard, M. J., Gordey, S. P., and Davenport, P., 2003, Selected Yukon fossil determinations, *in* Gordey, S. P., and Makepeace, A. J., eds., *Yukon digital geology*.
- Prokhor, S. A., 1991, The genesis of nephrite and the emplacement of the nephrite-bearing ultramafic complexes of East Sayan: *International Geology Review*, v. 33, p. 290-300.
- Rainbird, R. H., Heaman, L. M., and Young, G. M., 1992, Sampling Laurentia: Detrital zircon geochronology offers evidence for an extensive Neoproterozoic river system originating from the Grenville orogen: *Geology*, v. 20, p. 351-354.
- Rainbird, R. H., McNicholl, V. J., Theriault, R. J., Heaman, L. M., Abbott, J. G., Long, D. G. F., and Thorkelson, D. J., 1997, Pan-continental river system draining Grenville orogen recorded by U-Pb and Sm-Nd geochronology of Neoproterozoic quartz arenites and mudrocks, northwestern Canada: *Journal of Geology*, v. 105, p. 1-17.
- Roddick, J.C., Cliff, R.A., Rex, D.C., 1980, The evolution of excess argon in alpine biotites - a ^{40}Ar - ^{39}Ar analysis: *Earth and Planetary Science Letters*, v. 48, p. 185-208.
- Roddick, J.C., 1987, Generalized numerical error analysis with application to geochronology and thermodynamics: *Geochimica et Cosmochimica Acta*, v. 51, p. 2129-2135.
- Roots, C. F., deKeijzer, M., and Nelson, J., 2000, Wolf Lake Project: Revision mapping of Dorsey Terrane assemblages in the upper Swift River area, southern Yukon and northern B.C., *in* Emond, D. S., and Weston, L. H., eds., *Yukon Exploration and Geology 1999*, Exploration and Geological Services Division, Yukon, Indian and

- Northern Affairs Canada, p. 115-125.
- Ross, G. M., McMechan, M. E., and Hein, F. J., 1989, Proterozoic History: The birth of the miogeocline, *in* Ricketts, B. D., ed., Western Canada sedimentary basin: A case history: Calgary, Alta., Phoenix Press, p. 79-104.
- Rubatto, D., 2002, Zircon trace element geochemistry: partitioning with garnet and the link between U-Pb ages and metamorphism: *Chemical Geology*, v. 184, p. 123-138.
- Rubatto, D., and Hermann, J., 2001, Exhumation as fast as subduction?: *Geology*, v. 29, no. 1, p. 3-6.
- Rubatto, D., and Hermann, J., 2003, Zircon formation during fluid circulation in eclogites (Monviso, Western Alps); implications for Zr and Hf budget in subduction zones: *Geochimica et Cosmochimica Acta*, v. 67, no. 12, p. 2173-2187.
- Ryan, J. J., Gordey, S. P., Villeneuve, M. E., and Piercey, S. J., 2003, Schists and gneisses of the Yukon-Tanana Terrane in the Stewart River area, western Yukon: composition, protolith and paleotectonic setting, *in* Geological Association of Canada, Vancouver, B.C., p. CD-ROM.
- Simandl, G. J., Paradis, S., and Nelson, J. L., 2001, Jade and rhodonite deposits, British Columbia, Canada, *in* Intermountain West forum; 35th forum on the Geology of industrial minerals, Salt Lake City, UT, p. 163-171.
- Simandl, G. J., Riveros, C. P., and Schiarizza, P., 2000, Nephrite (Jade) Deposits, Mount Ogden Area, Central British Columbia (NTS 093N 13W), Geological Fieldwork 1999, B.C. Ministry of Employment and Investment, Geological Survey Branch, p. 339-347.
- Spandler, C., Hermann, J., Arculus, R., and Mavrogenes, J., 2004, Geochemical heterogeneity and element mobility in deeply subducted oceanic crust; insights from high-pressure mafic rocks from New Caledonia: *Chemical Geology*, v. 206, p. 21-42.

- Stacey, J.S. and Kramer, J.D., 1975, Approximation of terrestrial lead isotope evolution by a two stage model: *Earth and Planetary Science Letters*, v. 26, p. 207-221.
- Steiger, R.H. and Jäger, E., 1977, Subcommittee on geochronology: convention on the use of decay constants in geo- and cosmochemistry: *Earth and Planetary Science Letters*, v. 36, p. 359-362.
- Sturm, R. 2002. PX-NOM: an interactive spreadsheet program for the computation of pyroxene analyses derived from the electron microprobe. *Computers & Geosciences*, v. 28, issue 4, p. 473-483.
- Tempelman-Kluit, D. J., 1979, Transported cataclasite, ophiolite and granodiorite in Yukon, and evidence of arc-continent collision: Geological Survey of Canada, Paper 79-14.
- Tribuzio, R., Messiga, B., Vannucci, R., and Bottazzi, P., 1996, Rare earth element redistribution during high-pressure - low-temperature metamorphism in ophiolitic Fe-gabbros (Liguria, northwestern Italy): Implications for light REE mobility in subduction zones: *Geology*, v. 24, no. 8, p. 711-714.
- Villeneuve, M. E., Ross, G. M., Theriault, R. J., Miles, W., Parrish, R. R., and Broome, J., 1993, Tectonic Subdivision and U-Pb Geochronology of the Crystalline Basement of the Alberta Basin, Western Canada: Bulletin 447, Geological Survey of Canada.
- Wakabayashi, J., 1992, Nappes, Tectonics of Oblique Plate Convergence, and Metamorphic Evolution Related to 140 Million Years of Continuous Subduction, Franciscan Complex, California: *Journal of Geology*, v. 100, p. 19-40.
- Williams, I. S., Buick, I. S., and Cartwright, I., 1996, An extended episode of early Mesoproterozoic metamorphic fluid flow in the Reynolds Range, central Australia: *Journal of Metamorphic Geology*, v. 14, p. 29-47.
- Yui, T.-F., and Yeh, H.-W., 1988, Stable isotope studies of nephrite deposits from Fengtien, Taiwan: *Geochimica et Cosmochimica Acta*, v. 52, p. 593-602.

APPENDIX I

U-Pb geochronology of rhyolite east of the Jules Creek fault

Table A1. U-Pb analytical data.

Sample Description ¹	Wt (mg)	U (ppm)	Pb ² (ppm)	²⁰⁶ Pb/ ²⁰⁸ Pb (meas.) ³	total common Pb (pg)	% ²⁰⁸ Pb ²	²⁰⁶ Pb/ ²³⁸ U ⁴ (± % 1σ)	²⁰⁷ Pb/ ²³⁵ U ⁴ (± % 1σ)	²⁰⁷ Pb/ ²⁰⁶ Pb ⁴ (± % 1σ)	²⁰⁶ Pb/ ²³⁸ U age (Ma; ± % 2σ)	²⁰⁷ Pb/ ²³⁵ U age (Ma; ± % 2σ)
Sample 03FD388-1 UTM NAD83 Zone 9 479801E, 6773793N											
A: N5,+134,1	0.008	399	16.9	1462	5	13.5	0.04033(0.13)	0.2885(0.34)	0.05189(0.28)	254.9(0.7)	280.6(12.6)
B: N5,104-134,1	0.003	1303	55.5	398	26	12.7	0.04106(0.19)	0.2895(0.59)	0.05114(0.48)	259.4(1.0)	247.2(22.0)
C: N5,92-104,7	0.02	371	15.6	1482	13	12.5	0.04061(0.19)	0.2915(0.35)	0.05206(0.27)	256.6(1.0)	288.0(12.4)
D: N5,74-92,12	0.016	681	29	2423	11	12.6	0.04109(0.16)	0.2917(0.25)	0.05149(0.15)	259.6(0.8)	262.7(7.1)
E: N5,74-92,14	0.017	643	27	263	111	12.2	0.04064(0.24)	0.2899(0.81)	0.05174(0.66)	256.8(1.2)	273.9(30.1)
F: N5,74-92,10	0.018	746	31.4	2791	12	11.6	0.04115(0.16)	0.2931(0.23)	0.05166(0.12)	260.0(0.8)	270.3(5.7)

¹ NS = non-magnetic at 5 degrees side slope on Frantz magnetic separator; grain size given in microns; number of grains in each fraction listed.

² radiogenic Pb; corrected for blank, initial common Pb, and spike

³ corrected for spike and fractionation

⁴ corrected for blank Pb and U, and common Pb.

Figure A1. U-Pb concordia diagram.

Flow-banded quartz-phyric rhyolite which is spatially associated with the Fortin Creek group was sampled for U-Pb zircon TIMS analysis, conducted at the Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the University of British Columbia. Analytical methods are described in Appendix II. The contacts of the rhyolite with the Fortin Creek group metasedimentary rocks are not exposed; however, the rhyolite must unconformably overlie the Fortin Creek group metasedimentary rocks which have an upper age limit of Middle Permian (Murphy, NATMAP).

Only a small amount of zircon was recovered from the sample. It comprised square, stubby, prismatic grains with simple terminations. The grains were clear and colorless and contained scattered clear, bubble-shaped inclusions but no evidence of inherited cores. All grains >74 microns in diameter were picked, abraded together, and then split into six fractions prior to dissolution. Two of the coarsest grains remaining were analyzed as single grains, and the others were separated on the basis of grain size. All six fractions fall on or near the concordia curve (Figure A1). Three of the fractions (B, D and F) yield overlapping concordant analyses with a total range of ²⁰⁶Pb/²³⁸U ages of 259.6 ± 1.2 Ma, which is interpreted to be the crystallization age of the sample. The remaining three fractions give slightly younger ²⁰⁶Pb/²³⁸U ages and are interpreted to have suffered minor post-crystallization Pb-loss effects that were not completely eliminated by the abrasion.

A Late Permian U-Pb age supports correlation of the rhyolite with Middle to Late Permian volcanic and magmatic rocks described regionally within the Finlayson Lake region and in western Yukon called the Klondike schist (Murphy et al., 2005).

APPENDIX II

Analytical Methods

Geochemistry analytical methods

Samples were trimmed to remove weathered edges and large areas of alteration and quartz-carbonate veining, and were pulverized using a steel jaw crusher and steel mill. Analysis for major, minor and trace elements was completed by Actlabs in Ancaster, Ontario. Major and minor elements were determined from fused disks on a Philips PW-2400 sequential X-ray fluorescence spectrometer following the technique of Norrish and Hutton (1969). Prior to fusion, the loss on ignition (LOI) was determined by baking of the sample at 1050°C for 2 hours. The fusion disk was made using 0.5 g equivalent of baked sample mixed with 5.0 g of a mixture of lithium metaborate and lithium tetraborate. The samples were fused in a Pt crucible, with lithium bromide as a releasing agent. The detection limit of all oxides was approximately 0.01wt%. Precision and accuracy, controlled by submitted and in-house pulp duplicates and standards was generally better than 1 and 1.4 % for all oxides, except K₂O which was as high as 15% and 18.3, respectively, and Na₂O at 5.6% and 5.3, respectively. Rare earth elements and other trace elements in sample splits were analyzed on a Perkin Elmer SCIEX ELAN 6000 ICP-MS following lithium metaborate/tetraborate fusion. The precision and accuracy of analyses was calculated with respect to duplicate analyses and reference standards, respectively, and was better than 10% for elements not near detection limits. Exceptions are Cu, Zn, Ge, Sn, La, Ce, Pr, Hf, Ta, Tl and Pb which generally had better than 20% accuracy and precision, but up to 40 and 55% accuracy for Nb and Sb, respectively.

U-Pb SHRIMP analytical methods

Five to 15 kg samples for U-Pb zircon analysis were prepared at Carleton University, Ottawa, Canada. Heavy minerals from ground samples were concentrated using a Rogers table™ followed by heavy mineral separation using methylene iodide. The washed and dried heavy mineral concentrate was further separated into multiple magnetic fractions using a Frantz™ isodynamic magnetic separator.

Selected, representative zircon grains from each sample were picked from all magnetic fractions and cast in an epoxy grain mount (IP326) along with fragments of GSC laboratory zircon standard z6266 which, has a ²⁰⁶Pb/²³⁸U age of 559 Ma, standard Temora (z6449) with an age of 416.8 Ma, and Fish Canyon tuff (z5567) with an age of 28.4 Ma. Grinding and polishing with 9, 6, and 1 μm diamond compound revealed sections through the grain centres. The mount was carbon coated and imaged with a Cambridge Instruments scanning electron microscope with a cathodoluminescence detector at the Geological Survey of Canada, Ottawa, in order to characterize zircon textures and identify internal growth zones within zircon. Potentially different growth domains in zircon were identified and grouped pre-analysis based on relative luminescence, internal

zoning patterns, and boundary characteristics between domains. Age, Th/U ratios, and Y content of individual domains provided a post-analysis check on the group assignments. The grain mount was then coated with approximately 10 nm of high purity Au in preparation for SHRIMP analysis. Transmitted and reflected light photos of the grain mount were used for navigation during SHRIMP analysis and to identify fractures and inclusions within grains. Inclusions in zircon were identified on the GSC Cambridge Instruments scanning electron microscope and the Camebax MBX electron microprobe at Carleton University.

U-Pb analyses were carried out using the GSC sensitive high-resolution ion microprobe (SHRIMP II). A $^{16}\text{O}^-$ primary beam transmitted through a 120 μm aperture created an ellipse approximately 23 μm in long dimension on zircon grain surfaces. Count rates of eleven isotopes of Zr^+ , U^+ , Th^+ , Pb^+ and Y^{3+} in zircon were sequentially measured over 5 scans with a single electron multiplier and a pulse counting system. Analytical and data reduction procedures follow those described in Stern (1997). Isotopic Pb/U ratios were corrected by reference to the standard zircon (Z6266) and isotopic ratios reported in Table 2-2 incorporate a $\pm 1.1\%$ error in calibrating the standard zircon (see Stern and Amelin, 2003). Common Pb correction used the ^{207}Pb method. Isoplot v. 3 was used to calculate weighted means.

U-Pb TIMS analytical methods

Zircon was separated from a ~15 kg sample using conventional crushing, grinding, Wilfley table, heavy liquids and Frantz magnetic separator techniques. U-Pb analyses were done at the Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the University of British Columbia. The methodology for zircon grain selection, abrasion, dissolution, geochemical preparation and mass spectrometry are described by Mortensen et al. (1995). All fractions were air abraded (Krogh, 1982) prior to dissolution to minimize the effects of post-crystallization Pb-loss. Procedural blanks were 2 pg for Pb and 1 pg for U. U-Pb data are plotted on a conventional U-Pb concordia diagram in Figure A1 of Appendix I. Errors attached to individual analyses were calculated using the numerical error propagation method of Roddick (1987). Decay constants used are those recommended by Steiger and Jäger (1975). Compositions for initial common Pb were taken from the model of Stacey and Kramer (1975). All errors are given at the 2 sigma level.

Only a small amount of zircon was recovered from the sample. It comprised square, stubby, prismatic grains with simple terminations. The grains were clear and colorless and contained scattered clear, bubble-shaped inclusions but no evidence of inherited cores. All grains >74 microns in diameter were picked, abraded together, and then split into six fractions prior to dissolution. Two of the coarsest grains remaining were analyzed as single grains, and the others were separated on the basis of grain size. All six fractions fall on or near the concordia curve (Figure A1, Appendix I). Three of the fractions (B, D and F) yield overlapping concordant analyses with a total range of $^{206}\text{Pb}/^{238}\text{U}$ ages of 259.6 ± 1.2 Ma, which is interpreted to be the crystallization age of

the sample. The remaining three fractions give slightly younger $^{206}\text{Pb}/^{238}\text{U}$ ages and are interpreted to have suffered minor post-crystallization Pb-loss effects that were not completely eliminated by the abrasion.

$^{40}\text{Ar}/^{39}\text{Ar}$ analytical methods

Laser $^{40}\text{Ar}/^{39}\text{Ar}$ analysis of samples from the Klatsa metamorphic complex was carried out at the Geological Survey of Canada laboratories in Ottawa, Canada. Crushed samples were sieved, rinsed and dried. Hand-picked white mica separates from the three samples were packed in aluminum foil for irradiation at the McMaster University reactor, Canada, using the Fish Canyon Tuff sanidine as a flux monitor (apparent age of 28.03 ± 0.1 Ma; (Renne, 1994). These packets were placed, along with other samples bearing FCT-SAN, into six tubes arranged radially around an aluminium can 40 mm×19 mm in diameter. Samples were irradiated in central core position 5C with a resulting J-factor ranging from 0.00260 to 0.00290. Variation in J-factor is corrected for by utilising the approximately 10 packets per tube to interpolate along the length of the can.

Following irradiation, samples were split into two aliquots and loaded into individual holes in a copper planchet where they were heated and analysed separately. Step-heating was carried out with a 10W *New Wave Research* CO₂-laser with a ca. 200 m flat field lens. The beam was panned across grains to maintain even heating. Following gas extraction, argon was purified for 7 minutes using a *SAES AP 10* getter, operated at 400°C. Isotopic analysis was carried out using a VG3600 noble gas mass spectrometer with a secondary electron multiplier detector. The mass spectrometer scanned peaks at masses 36, 37, 38, 39 and 40, and measured background values. Peaks were measured twelve times at each step, and peak intensities were extrapolated back to the inlet time by linear regression. Blank levels were determined by running the system in the same way as for a sample analysis but without operating the laser. Blank corrections were made by averaging the values obtained during each day of analysis. Average blank levels were $^{40}\text{Ar} = 7 \times 10^{-12}\text{cc}$, $^{39}\text{Ar} = 1 \times 10^{-14}\text{cc}$, $^{36}\text{Ar} = 1 \times 10^{-13}\text{cc}$. Complete analytical results are presented in Table 2-3.

Data from both aliquots of each sample are plotted on a single step-heating gas-release plot, normalized to the total volume of ^{39}Ar for both aliquots (Figure 2-12). This plot displays the heating profiles produced, as well as a rough measure of sample size for each aliquot, and permits the visual comparison of the plateaus from aliquots of the same sample. The data are also combined onto correlation plots (Roddick et al., 1980) for presentation because of the presence of excess ^{40}Ar in some samples. Error in J-factor ($\pm 0.60\%$, 2), as conservatively estimated from replicate analysis and cross-calibration of FCT-SAN (Dazé et al., 2003), is applied to the final age determination, but uncertainty in the age of the monitor is not. In calculating ages for plateaus for each aliquot and for determining the fit on the inverse isochron plot for each aliquot, low gas volume steps at the beginning and end of the run were omitted when they displayed large volumes of excess Ar or did not lie on the plateau.

APPENDIX III

Selected mineral analyses from units in the southern Campbell Range

KLATSA METAMORPHIC COMPLEX

LAYERED SCHISTS

GARNET - Transect 1 (Figure xx.)															
Sample (03FD):	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3
Analysis No.:	393-1	393-2	393-3	393-4	393-5	393-6	393-7	393-8	393-9	393-10	393-11	393-12	393-13	393-14	393-15
Comment:	RIM						CORE								RIM
SiO ₂	38.44	38.74	37.79	37.94	39.64	38.49	37.82	37.73	38.00	38.06	38.05	38.46	38.56	38.73	38.88
Al ₂ O ₃	21.78	21.75	21.47	21.58	22.50	21.71	21.47	21.21	21.24	21.50	21.57	21.53	21.56	21.94	21.94
TiO ₂	0.16	0.02	0.04	0.08	0.09	0.08	0.11	0.15	0.14	0.10	0.12	0.15	0.14	0.08	0.08
Cr ₂ O ₃	0.27	0.17	0.19	0.19	0.19	0.21	0.09	0.10	0.06	0.06	0.03	0.11	0.06	0.10	0.03
FeO	22.23	22.52	25.03	23.92	24.25	24.51	25.57	25.44	25.64	25.81	26.23	23.88	23.46	22.90	23.70
MnO	0.60	0.74	1.04	1.20	1.10	1.39	1.53	1.47	1.31	1.37	1.17	0.82	0.62	0.41	0.36
MgO	5.13	5.02	3.16	3.81	4.51	3.59	2.39	3.12	2.83	2.74	2.73	4.31	4.88	5.72	6.11
CaO	12.38	11.67	11.96	11.85	11.54	11.72	11.96	11.50	12.00	11.89	11.79	12.12	12.12	11.36	10.20
Na ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
TOTAL	100.99	100.63	100.68	100.57	103.82	101.70	100.94	100.72	101.22	101.53	101.69	101.38	101.40	101.24	101.33
Fe/(Fe+Mg)	0.81	0.82	0.89	0.86	0.84	0.87	0.91	0.89	0.90	0.90	0.91	0.85	0.83	0.80	0.80

NOTES:
Incl.Met. = garnet inclusion
within metamorphic zircon

GARNET - Transect 2 (Figure xx.)										Inclusions in zircon	
Sample (03FD):	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-2	039-2
Analysis No.:	393-26	393-26	393-26	393-26	393-26	393-26	393-26	393-26	393-26	392-62	392-64
Comment:	CORE									RIM	Incl.Met.
SiO ₂	38.24	37.79	37.41	37.37	38.03	38.08	37.94	38.41	39.00	39.14	
Al ₂ O ₃	21.00	20.45	20.83	21.16	21.33	20.85	21.17	21.26	23.02	21.88	
TiO ₂	0.10	0.10	0.14	0.12	0.08	0.10	0.08	0.05	0.08	0.08	
Cr ₂ O ₃	0.06	0.08	0.03	0.05	0.00	0.01	0.03	0.05	0.00	0.07	
FeO	24.82	24.98	24.63	24.29	24.91	25.11	24.73	23.02	24.35	23.84	
MnO	2.20	2.32	2.35	1.89	1.69	1.23	0.97	0.79	0.55	0.43	
MgO	2.20	2.12	2.09	2.70	2.89	3.40	3.43	4.58	4.22	4.80	
CaO	12.41	11.95	11.95	11.49	11.80	11.35	11.91	12.23	9.26	10.43	
Na ₂ O	0.03	0.05	0.07	0.05	0.04	0.03	0.03	0.02			
TOTAL	101.06	99.84	99.50	99.12	100.77	100.16	100.29	100.41	100.48	100.67	
Fe/(Fe+Mg)	0.92	0.92	0.92	0.90	0.90	0.88	0.88	0.83	0.85	0.83	

Scanning electron
microscope (SEM)
backscatter images of
garnets in metabasite

Metabasite Garnet 1 (03FD039-3)

Metabasite Garnet 2 (03FD039-3)

Element zoning
profiles along
garnet transects
1 and 2

KLATSA METAMORPHIC COMPLEX LAYERED SCHISTS

AMPHIBOLE										
Sample (03FD):	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	039-3	048-1b
Analysis No.:	393-16	393-17	393-20	393-21	393-22	393-23	391-1	391-2	393-55	481-61
Comment:	CM	CM	M	M	CM	S	CM	RCM	M	S
Classification:	actinolite	actinolite	actinolite	actinolite	actinolite	actinolite	Mg-hbl	actinolite	actinolite	actinolite
SiO ₂	53.94	54.60	54.33	53.44	55.15	54.14	52.55	52.18	53.99	51.80
Al ₂ O ₃	4.26	4.60	4.55	6.04	1.81	4.17	6.17	5.11	2.39	3.61
TiO ₂	0.08	0.06	0.07	0.22	0.00	0.07	0.09	0.08	0.03	0.04
Cr ₂ O ₃	0.06	0.03	0.05	0.05	0.00	0.06	0.05	0.06	0.04	0.06
FeO	5.92	6.35	8.19	7.57	10.72	11.42	7.16	13.30	15.05	15.27
MnO	0.02	0.05	0.07	0.04	0.21	0.26	0.03	0.27	0.22	0.48
MgO	18.84	18.62	17.81	17.17	16.37	14.85	17.54	13.73	13.67	13.34
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K ₂ O	0.43	0.53	0.27	0.29	0.07	0.28	0.42	0.17	0.12	0.14
CaO	11.31	11.22	11.48	10.41	12.98	12.72	11.28	12.88	12.60	12.62
Na ₂ O	1.56	1.78	1.49	1.99	0.17	0.37	1.86	0.59	0.31	0.43
Cl	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.01	0.00	0.01
F	0.51	0.40	0.14	0.19	0.00	0.06	0.25	0.03	0.04	0.00
TOTAL	96.93	98.24	98.46	97.41	97.48	98.40	97.42	98.41	98.46	97.80

EPIDOTE				FELDSPAR				CHLORITE				
Sample(03FD):	039-3	039-3	048-1b	Sample (03FD):	039-1	039-3	048-1	Sample (03FD):	039-3	039-3	044-1	056-1
Analysis No.:	393-18	393-35	481-59	Analysis No.:	391-4	393-56	481-60	Analysis No.:	393-34	393-55	411-4	561-74
Comment:	M	winGar	M	Comment:	albite - vein	K-spar	albite	Comment:	winGar	ChlvM	ChlvM	ChlvM
SiO2	38.58	38.58	39.04	SiO2	68.57	65.59	67.47	SiO2	25.46	26.48	25.74	26.02
Al2O3	25.98	26.73	27.25	Al2O3	19.77	18.56	20.31	Al2O3	19.85	20.05	20.12	21.26
TiO2	0.35	0.12	0.05	Fe2O3	0.06	0.05	0.31	TiO2	0.07	0.04	0.04	0.24
Cr2O3	0.04	0.02	0.07	K2O	0.11	16.34	0.05	Cr2O3	0.03	0.03	0.00	0.27
Fe2O3	10.23	9.40	9.18	CaO	0.81	0	0.15	FeO	28.35	27.78	29.40	26.00
MnO	0.12	0.38	0.15	Na2O	11.35	0.07	11.77	MnO	0.63	0.60	0.30	0.63
MgO	0.00	0.00	0.00	BaO	0	0.27	0.12	MgO	12.78	12.25	13.33	14.30
NiO	0.00	0.00	0.00	TOTAL	100.67	100.88	100.18	K2O	0.09	0.35	0.02	0.10
K2O	0.02	0.02	0.01					CaO	0.15	0.05	0.03	0.10
CaO	23.98	23.73	23.74					NiO	0.00	0.00	0.00	0.00
Na2O	0.01	0.04	0.00					Cl	0.04	0.01	0.02	0.05
Cl	0.00	0.00	0.02					F	0.01	0.00	0.00	0.13
F	0.00	0.00	0.00					TOTAL	87.46	87.64	89.00	89.10
TOTAL	99.31	99.02	99.51									

MUSCOVITE														
Sample (03FD):	039-3	039-3	039-3	039-3	039-3	039-1	041-1	041-1	041-1	056-1	056-1	056-1	056-2	056-2
Analysis No.:	393-19	393-24	393-25	391-3193-54	391-58	411-1	411-2	411-3	561-1	561-2	561-72	561-75	562-65	562-66
Comment:	M	S	CM	CM	CM	MwChl	AlIG	AlIG	CM	CM	MwChl	CM	Zr Incl.	Zr Incl.
Classification:														
SiO ₂	50.71	49.64	51.18	50.81	50.84	49.56	49.44	50.40	50.14	50.14	50.87	48.60	49.47	55.36
Al ₂ O ₃	27.60	29.16	26.35	26.70	26.12	26.91	25.14	26.50	26.24	28.74	29.19	29.23	29.34	29.95
TiO ₂	0.29	0.17	1.02	0.86	0.89	1.10	1.31	0.92	0.41	0.84	0.56	1.19	0.79	0.47
Cr ₂ O ₃	0.01	0.07	0.05	0.06	0.05	0.05	0.00	0.00	0.02	0.00	0.02	0.01	0.00	0.01
FeO	1.81	2.68	1.51	1.52	1.86	1.71	3.26	2.48	3.03	1.99	1.95	1.97	1.85	2.20
MgO	3.87	3.00	4.68	4.56	4.65	4.51	4.19	4.33	3.55	2.79	2.78	2.56	2.59	2.99
MnO	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.01	0.00
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K ₂ O	10.56	10.82	10.58	10.37	10.13	10.46	10.68	10.32	10.05	9.59	9.99	9.89	10.29	3.18
CaO	0.07	0.06	0.01	0.00	0.03	0.00	0.02	0.06	0.01	0.01	0.00	0.01	0.00	0.00
Na ₂ O	0.33	0.16	0.39	0.35	0.31	0.38	0.37	0.41	0.17	0.63	0.70	*	*	0.31
BaO	0.44	0.45	0.46	0.56	0.53	0.48	0.37	0.28	0.41	0.34	0.35	*	*	0.00
F	0.08	0.03	0.11	0.06	0.01	0.04	0.16	0.17	0.11	0.04	0.10	0.02	0.06	0.13
Cl	0.00	0.04	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.01
TOTAL	95.77	96.28	96.39	95.88	95.42	95.20	94.94	95.92	94.14	95.12	96.53	93.49	94.40	94.61

Composition expressed as wt. % oxides

- ☐ Analyses of minerals from metabasite (Campbell Range metamorphic assemblage)
- ☐ Analyses of minerals from quartz-muscovite schist (Campbell Range metamorphic assemblage)
- ☐ Analyses of minerals included in metamorphic zircon Campbell Range schist/metabasite

COMMENT ABBREVIATIONS:

CM = coarse matrix

M = matrix

S = symplectite

RCM = rim to coarse matrix amphibole

MwChl = muscovite intergrown with chlorite

ChlwM = chlorite intergrown muscovite

AlIG = within altered garnet domains

winGar = within garnet

ZrIncl. = mineral included in zircon

* not analysed

PYROXENE		
Sample No. (03FD):	056-2	056-2
Analysis Number:	562-67	562-68
Comment:	Zr Incl.	Zr Incl.
Classification:	omphacite	omphacite
SiO ₂	56.89	56.83
Al ₂ O ₃	14.74	14.8
TiO ₂	0.13	0.12
Cr ₂ O ₃	0.04	0.02
FeO	4.61	4.61
MnO	0.04	0.01
MgO	5.36	5.34
CaO	9.74	9.92
Na ₂ O	9.03	8.96
TOTAL	100.58	100.61
jadeite	60.27	60.08
aegirine	1.21	0.97
Ca-Mg-Fe	38.52	38.95

KLATSA METAMORPHIC COMPLEX

AMPHIBOLITE

GARNET				
Sample (03FD):	506-2	506-2	506-2	506-2
Analysis No.:	506-2105	506-2109	506-2110	506-2111
Comment:	M	Rim	Rim	Core
SiO ₂	38.73	37.54	38.27	37.80
Al ₂ O ₃	22.22	21.69	22.07	21.76
TiO ₂	0.10	0.04	0.03	0.14
Cr ₂ O ₃	0.00	0.03	0.00	0.01
FeO	26.56	27.10	25.58	26.48
MnO	0.78	0.93	0.52	0.90
MgO	4.66	4.08	4.96	3.71
CaO	9.24	9.25	9.39	10.47
TOTAL	102.29	100.66	100.82	101.27
Fe/(Fe+Mg)	0.85	0.87	0.84	0.88

AMPHIBOLE								
Sample (03FD):	506-2	506-2	506-2	506-2	506-2	506-2	507-2	507-2
Analysis No.:	506-2104	506-2106	506-2107	506-2112	506-2113	506-2114	507-2115	507-2116
Comment:	CM	CM	CM	CM	CM	CM	CM	CM
Classification:	magnesian-hornblende	edenite	edenite	magnesian-hornblende	ferro-actinolite	edenite	ferro-actinolite	ferro-actinolite
SiO ₂	45.43	45.1	45.09	48.06	53.7	44.56	53.31	52.72
Al ₂ O ₃	11.34	11.69	11.72	8.99	0.4	12.39	0.57	0.72
TiO ₂	0.77	0.73	0.73	0.58	0.04	0.85	0	0.04
Cr ₂ O ₃	0.02	0.01	0.01	0.03	0.01	0.05	0	0
FeO	15.46	15.83	15.19	14.58	20.07	15.3	20.46	20.29
MnO	0.17	0.13	0.15	0.17	0.37	0.14	0.59	0.53
MgO	10.95	10.96	11.15	12.7	10.9	10.77	10.75	11.1
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K ₂ O	0.71	0.58	0.66	0.39	0.04	0.66	0.09	0.08
CaO	11.03	11.14	11.25	11.01	12.7	11.29	12.27	12.5
Na ₂ O	1.58	1.85	1.61	1.38	0.06	1.84	0.11	0.15
Cl	0.02	0	0.01	0.01	0	0.01	0	0.02
F	0.13	0.1	0.05	0.01	0.05	0.12	0.01	0
TOTAL	97.61	98.12	97.62	97.91	98.34	97.98	98.16	98.15

SERPENTINITE

PYROXENE				
Sample (03FD):	517-2	517-2	517-2	517-2
Analysis No.:	517-2100	517-2101	517-2102	517-2103
Comment:	Core	Core	Core	Core
Classification:	aluminian chromian wollastonite	aluminian chromian diopside	aluminian chromian diopside	aluminian chromian diopside
SiO ₂	51.22	51.38	52.09	52.06
Al ₂ O ₃	6.8	6.97	6.82	6.19
TiO ₂	0.47	0.54	0.42	0.45
Cr ₂ O ₃	0.93	0.94	0.94	0.99
FeO	1.92	2.05	2.12	2.31
MnO	0.1	0.07	0.08	0.1
MgO	14.62	15.64	14.9	15.08
CaO	22.33	20.69	21.41	21.41
Na ₂ O	1.17	1.31	1.24	1.27
TOTAL	99.56	99.59	100.02	99.82
enstatite	45.97	49.34	47.27	47.39
ferrosillite	3.57	3.75	3.92	4.25
wollastonite	50.46	46.91	48.81	48.36

COMMENT ABBREVIATIONS:

CM = coarse matrix
M = matrix
Core = core of crystal
Rim = rim of crystal

* not analysed

Composition expressed as wt. % oxides

NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI

VERTICAL CROSS SECTIONS

View north along the Campbell Highway

LATE DEVONIAN TO EARLY CRETACEOUS

Klatsa metamorphic complex

serpentinite:
surfaces; < 5%
massive cumulus
replacement of

leucogabbro:
white saussurite

amphibolite:
and plagioclase
greenschist facies

layered schists:
lenses of medium
metabasite containing
epidote-clinopyroxene
peak metamorphism

Ottawa-Carleton
Geoscience Centre

MAP 1

To accompany F. Devine M.Sc. thesis, 2005

GEOLOGICAL MAP OF THE SOUTHERN CAMPBELL RANGE (NTS 105H/3 SW) southeastern Yukon (1:20 000 scale)

THIS
M.Sc.
2005
149
149

LEGEND

***Dark shades of unit colours indicate regions of outcrop*

Yukon-Tanana Terrane

MONEY CREEK THRUST SHEET

LATE DEVONIAN TO EARLY MISSISSIPPIAN

Klatsa metamorphic complex

serpentinite: bright green weathering on vegetation-free slopes, dark green and smooth on fresh surfaces; < 5 % relict pyroxene phenocrysts up to 0.5 cm diameter are found locally, where massive cumulate texture is preserved. Green colour represents regions of metasomatic replacement of serpentinite to nephrite jade.

leucogabbro: grey, moderately foliated, medium- to locally coarse-grained; dark amphibole and white saussuritized plagioclase; blocks up to 300 m in diameter occur within serpentinite bodies

amphibolite: fine- to medium-grained, moderately to well foliated amphibolite, garnet amphibolite, and plagioclase amphibole schist are found as blocks within serpentinite variably retrogressed to greenschist facies.

layered schist: coarse-grained heterogenous **quartz-muscovite schist** with local carbonate and lenses of medium-grained chlorite-epidote-amphibole-garnet **metabasite** up to 5 m thick. The metabasite contains chloritized garnet porphyroblasts up to 1.5 cm in diameter within an amphibole-epidote-clinzoisite matrix with accessory titanite-rimmed rutile. Amphibolite and eclogite facies peak metamorphic mineral assemblages are retrogressed to amphibolite and greenschist facies.

PROFILE SECTIONS - Geology projected to an inclined plane at right angles to F₂ fold

F₂ fold profile - view towards 270°N, plunging 30°

F₂ fold profile - View towards 230°N, plunging 40°

F₂ fold profile - View towards 278°N, plunging 35°

angles to F_2 fold axes

F_2 fold profile - View towards 340°N , plunging 19°

- geological contact (defined, approximate)
- fault, displacement unit (defined, approximate)
- thrust fault (D_4) (defined, approximate)
- fault - Cleaver Lake fault (approximate, teeth on)
- axial surface trace (F_1)
- axial surface trace (F_2) sections, overturned s

NOTES

- ① Schematic fold style, interpreted from fold geometry in outcrop and in thin section, rather than mapped structures.
- ② Jules Creek fault - possibly an Early Permian strike-slip fault (Murphy, 2004) reactivated with east-directed thrust motion in the Jurassic (Inconnu-age).
- ③ King Arctic Upper Quarry. Metasomatic replacement of chert granule to pebble conglomerate by tremolite is visible in outcrop over an interval of 5 metres. The lithologies across the contact from bottom to top are: serpentinite, nephrite, semi-nephrite, partly-replaced conglomerate, and nonmetasomatized metaconglomerate. Nephrite formation resulted from metasomatic replacement of metasedimentary rocks (King Arctic formation green chert pebble conglomerate and lithic arenite and White Lake group Whitefish limestone) and/or serpentinite by serpentinite-derived fluids along D3 thrust faults interpreted to have Early Jurassic motion.

SYMBOL LEGEND

geological contact
(defined, approximate, inferred).....

fault, displacement unknown
(defined, approximate, inferred).....

thrust fault (D₄)
(defined, approximate, inferred; teeth on hanging wall).....

fault - Cleaver Lake fault? or D₄?
(approximate, teeth on hanging wall).....

axial surface trace (F₁) - antiform and synform

axial surface trace (F₂) - overturned anticline on map and cross sections, overturned syncline on map and cross sections

lenses of metabasite of epidote-clinopyroxene peak metamorphism

phyllite-mylonite and grey ribbon

undifferentiated Waters

muscovite and quartz-phyllosilicate muscovite schist

LOWER PERMIAN

Money Creek formation

carbonaceous material consistent with interlayered volcanic and lithic fragments. Pebble metaconglomerates occur locally, found within a

PENNSYLVANIAN TO LOWER PERMIAN

"upper" limestone

limestone: recrystallized scale interbedded

PENNSYLVANIAN

King Arctic formation

lithic-arenite dominated by sandstones and wackes. Includes metaarenite, respectively

chert-pebble conglomerate chert with submillimetric thickness varying from granule conglomerate to dark green micaceous to 5 cm thick, calcareous. @

UPPER MISSISSIPPIAN

White Lake formation

laminated chert of translucent green quartz-s

lenses of medium-grained chlorite-epidote-amphibole-garnet **metabasite** up to 5 m thick. The metabasite contains chloritized garnet porphyroblasts up to 1.5 cm in diameter within an amphibole-epidote-clinozoisite matrix with accessory titanite-rimmed rutile. Amphibolite and eclogite facies peak metamorphic mineral assemblages are retrogressed to amphibolite and greenschist facies.

phyllite-matrix mélange: dark grey to black carbonaceous phyllite hosts blocks of orthoquartzite, grey ribbon chert and ODls unit up to 30 m diameter

undifferentiated Waters Creek group and Simpson Lake Plutonic Suite

muscovite amphibole granodiorite and chlorite muscovite schist: fine- to medium-grained, quartz-phyric, epidote- and chlorite-altered granodiorite; moderately foliated, quartz-phyric muscovite schist

CLEAVER LAKE THRUST

Yukon-Tanana Terrane

MONEY CREEK THRUST SHEET

LOWER PERMIAN

Money Creek formation

carbonaceous phyllite, lithic metawacke, and chert-pebble metaconglomerate: no consistent internal stratigraphy. Well foliated dark grey phyllite (L-, L-S-, and S-tectonite fabrics) is interlayered with variable amounts of fine sand to granule-sized wacke that contains chert, quartz, and lithic fragments; most distinctive are smoky-blue, glassy quartz granules. Grey to black chert-pebble metaconglomerate with angular to well-rounded, white, dark grey and black chert clasts occur locally. Blocks of grey crinoidal limestone and grey ribbon chert up to 50 m long are locally found within a mixed, mélange-style matrix of wacke and phyllite.

UNCONFORMITY

PENNSYLVANIAN TO LOWER PERMIAN

"upper" limestone

limestone: pale grey weathering, grey on fresh surfaces; dominantly massive with patches of recrystallization and minor crinoid accumulations; locally sandy with rust staining and millimetre-scale interbeds of pale green phyllite.

UNCONFORMITY

PENNSYLVANIAN

King Arctic formation

lithic-arenite and quartz-wacke: green to pale grey, fine- to medium-grained, lithic arenite dominated by green chert clasts grades upwards into dark grey fine-grained quartz-wacke. Arenite passes transitionally upward into fine-grained quartz-wacke with metre-scale interbedding of arenite and wacke over 10's of metres. Dark grey argillite and chloritic phyllite overlie the wacke and includes metre-scale and millimetre-scale interbeds of argillaceous chert and fine-grained lithic arenite, respectively.

chert-pebble conglomerate: green, sub-angular to well rounded, granule to pebble-sized green chert with subordinate white limestone and argillite clasts. Conglomerate clast size and unit thickness varies along the basal unconformity; normally graded beds of green siltstone to angular granule conglomerate 1 to 3 cm thick as well as fine-grained lithic arenite to siltstone with pale to dark green millimetre- to centimetre-scale banding are interlayered with conglomerate lenses down to 5 cm thick. Where overlying limestone, limestone clasts are dominant and the matrix is calcareous. Clasts are flattened to 20% of original thickness where the rocks are highly deformed.

UNCONFORMITY

UPPER MISSISSIPPIAN TO PENNSYLVANIAN

White Lake formation

laminated chert, fine-grained lithic wacke, and siltstone: Black, bright green, and white layers of translucent to opaque chert are interlayered on a millimetre- to sub-millimetre scale; fine-grained

G

F₂ fold profile - View towards 230°N, plunging 40° F₂ fold profile - View towards 278°N, plunging 35°

Location Map

a)

c)

Kir
Ja
MINF

F₂ fold profile - View towards 340°N, plunging 19°

Profile Section Interpretation:
Isometric diagram showing the geometric relationship between the profile plane, map plane, and F₂ fold axes

King Arctic
Jade Mine
MINFILE 105H 014

- geological contact
(defined, approximate, inferred)
- fault, displacement unknown
(defined, approximate, inferred)
- thrust fault (D₄)
(defined, approximate, inferred)
- fault - Cleaver Lake fault? or D₄
(approximate, teeth on hanging wall)
- axial surface trace (F₁) - antiform
- axial surface trace (F₂) - overthrust
sections, overturned syncline of
- axial surface trace (F₃) - anticline
- axial surface trace (F₄) - anticline
- bedding, upright
- bedding, overturned
- foliation (cleavage in sedimentary rocks)
- lineation (elongate clasts)
- fold hinge
- lines of section:
vertical cross section
- profile section (box encloses)
profile plane, dotted line
arrow shows plunge and direction
- U-Pb zircon sample location
- U-Pb zircon and ⁴⁰Ar/³⁹Ar sample location
- fossil
- nephrite jade occurrence
- KING ARCTIC - MINFILE 105H 014
- road, minor road or track
- VERTICAL AND PROFILE SECTION**
Linework as above, additional symbols
- unconformity - base of Money Crystalline
- base of King Arctic Crystalline
- base of "upper" In situ
- form lines:
bedding
- foliation (in serpentinite and
measured F₂ foliation projected)
- stratigraphic facing direction (first
apparent sense of transport on

Symbol Sample

SYMBOL LEGEND

geological contact (defined, approximate, inferred).....	
fault, displacement unknown (defined, approximate, inferred).....	
thrust fault (D ₄) (defined, approximate, inferred; teeth on hanging wall).....	
fault - Cleaver Lake fault? or D ₄ ? (approximate, teeth on hanging wall).....	
axial surface trace (F ₁) - antiform and synform	
axial surface trace (F ₂) - overturned anticline on map and cross sections, overturned syncline on map and cross sections	
axial surface trace (F ₃) - anticline and syncline.....	
axial surface trace (F ₄) - anticline and syncline	
bedding, upright	
bedding, overturned	
foliation (cleavage in sedimentary rocks and serpentinite).....	
lineation (elongate clasts)	
fold hinge	
lines of section:	
vertical cross section	
profile section (box encloses the projected outline of the profile plane, dotted line shows the limit of projected data), arrow shows plunge and plunge direction	
U-Pb zircon sample location	
U-Pb zircon and ⁴⁰ Ar/ ³⁹ Ar sample location	
fossil	
nephrite jade occurrence	
KING ARCTIC - MINFILE 105H 014	
road, minor road or track	

VERTICAL AND PROFILE SECTIONS:

Linework as above, additional symbols below:

unconformity - base of Money Creek formation	
- base of King Arctic formation	
- base of "upper" limestone	
form lines:	
bedding	
foliation (in serpentinite and metasedimentary rocks)	
measured F ₂ foliation projected to plane of section	
stratigraphic facing direction (fining upwards sequences in lithic arenite)	
apparent sense of transport on thrust fault	

69

68

6767000m. N.

61°02'

DMWC

eriated White Lake
g Arctic formations

PKAd

lithic-arenite and quartz-wacke: green to pale grey, fine- to medium-grained, lithic arenite dominated by green chert clasts grades upwards into dark grey fine-grained quartz-wacke. Arenite passes transitionally upward into fine-grained quartz-wacke with metre-scale interbedding of arenite and wacke over 10's of metres. Dark grey argillite and chloritic phyllite overlie the wacke and includes metre-scale and millimetre-scale interbeds of argillaceous chert and fine-grained lithic arenite, respectively.

PKAcM

chert-pebble conglomerate: green, sub-angular to well rounded, granule to pebble-sized green chert with subordinate white limestone and argillite clasts. Conglomerate clast size and unit thickness varies along the basal unconformity; normally graded beds of green siltstone to angular granule conglomerate 1 to 3 cm thick as well as fine-grained lithic arenite to siltstone with pale to dark green millimetre- to centimetre-scale banding are interlayered with conglomerate lenses down to 5 cm thick. Where overlying limestone, limestone clasts are dominant and the matrix is calcareous. Clasts are flattened to 20% of original thickness where the rocks are highly deformed.

UNCONFORMITY

UPPER MISSISSIPPIAN TO PENNSYLVANIAN

White Lake formation

MPWic

laminated chert, fine-grained lithic wacke, and siltstone: Black, bright green, and white layers of translucent to opaque chert are interlayered on a millimetre- to sub-millimetre scale; fine-grained green quartz-silt layers are locally present as thin laminations; <5% magnetite porphyroblasts up to 0.5 mm diameter

MPWc

green-pink chert and Interbedded limestone: green ribbon chert with pale-green to silver micaceous partings, locally contains plagioclase granules and pyrite boxwork; sections of bright rose to pink ribbon chert <20 metres thick is locally present. The unit locally contains green and pink chert layers mingled at handsample scale, concentrations of magnetite porphyroblasts up to 1 mm diameter; and interbeds of fine- to medium-grained quartz wacke. Interbedded limestone lenses <10 cm thick are included within this unit, but broken out as unit PPWU when > 10 m thick.

MPWl

limestone: white to grey, locally sandy and crinoidal, interlayered with chert. Layers range from 5 centimetre-thick lenses to 30 m thick massive limestone. Where interlayered with chert on the metre-scale, limestone contacts with silvery-green phyllite are gradational over 0.5 cm intervals. Local patchy rusty discolouration creates a striking colour juxtaposition of bright orange limestone with green phyllite. Where strongly deformed the limestone may be mylonitic and striped black-white with boudinaged silicified layers.

MPW

limestone (sandy): brown weathering, carbonate-matrix quartz-arenite with <50% sand-sized quartz grains. Centimetre-scale beds are enhanced on weathered surfaces by variable sand content.

JULES CREEK FAULT

TRIASSIC

Simpson Lake group

TSL

heterolithic conglomerate: clast or matrix supported, poorly sorted with sub-rounded granule- to pebble-sized clasts of chert, green quartz-arenite and serpentinite, reflecting local sources.

UNCONFORMITY

PERMIAN

Pr

rhyolite: Quartz-phyric rhyolite with <5 mm clear quartz phenocrysts; local mm-scale flow banding. Rhyolite was not broken out from the Fortin Creek group.

UNCONFORMITY

Slide Mountain Terrane

LOWER MISSISSIPPIAN TO LOWER PERMIAN

Fortin Creek group

MPFC

chert pebble conglomerate, quartz wacke and rhyolite: dark grey to black chert-pebble conglomerate; rusty weathering, medium-grained quartz wacke. Units are spatially related but have poorly exposed contacts. Metasedimentary rocks are locally silicified and display open quartz-lined vugs up to 2 cm diameter.

a) Map of Yukon showing major faults and the distribution of pre-Late Devonian to Permian Yukon-Tanana and Slide Mountain terranes. The dashed outline shows the location of inset map (b). **b)** Location map of Yukon-Tanana and Slide Mountain terranes in east-central Yukon showing eclogite localities and the locations of relevant regional geological compilations. The dark outline shows the location of the Frances Lake area shown in inset map (c). **c)** Location map of the Frances Lake area showing the southern Campbell Range field area (this map) in the shaded region.

King
Jack
MINFI

profile section (bottom)
profile plane, dotted
arrow shows plunge

U-Pb zircon sample local

U-Pb zircon and $^{40}\text{Ar}/^{39}\text{Ar}$

fossil

nephrite jade occurrence
KING ARCTIC - MINFILE

road, minor road or track

VERTICAL AND PROFILE
Linework as above, addit

unconformity - base of M
- base of Ki
- base of "u

form lines:

bedding

foliation (in serpent

measured F_2 foliation

stratigraphic facing direct

apparent sense of transp

Symbol	Sample
39-2	03FD039-2
56-2	03FD056-2
231-1	03FD231-1
388-1	03FD388-1

Symbol	Sample
F	03FD292-1
F	00DM324/C203149

MINE	
Yukon MINFIL	
105H 014	◆ K

Shaded digital elevation model of the Southern Campbell Range region;
red lines show roads and tracks; yellow lines are fault traces (see adjacent
map).

profile section (box encloses the projected outline of the profile plane, dotted line shows the limit of projected data), arrow shows plunge and plunge direction

U-Pb zircon sample location
 U-Pb zircon and $^{40}\text{Ar}/^{39}\text{Ar}$ sample location
 fossil
 nephrite jade occurrence
 KING ARCTIC - MINFILE 105H 014
 road, minor road or track

VERTICAL AND PROFILE SECTIONS:

Linework as above, additional symbols below:

unconformity - base of Money Creek formation
 - base of King Arctic formation
 - base of "upper" limestone
 form lines:
 bedding
 foliation (in serpentinite and metasedimentary rocks)
 measured F_2 foliation projected to plane of section
 stratigraphic facing direction (fining upwards sequences in lithic arenite)
 apparent sense of transport on thrust fault

ISOTOPIC AGE DATES (Devine, 2005)

Sample	Unit	Date	System	Mineral	
03FD039-2	ODIs (metabasite)	353.1 $\pm$ 2.4 Ma 2379 $\pm$ 49 Ma & 1161 $\pm$ 14 Ma 350.0 $\pm$ 2.9 Ma	U-Pb (SHRIMP) U-Pb (SHRIMP) $^{40}\text{Ar}-^{39}\text{Ar}$	zircon (metamorphic) zircon (xenocrystic) muscovite	high xen coo
03FD056-2	ODIs (schist)	353.0 $\pm$ 3.7 Ma 2825 $\pm$ 25Ma to 473 $\pm$ 13Ma no age	U-Pb (SHRIMP) U-Pb (SHRIMP) $^{40}\text{Ar}-^{39}\text{Ar}$	zircon (metamorphic) zircon (inherited) muscovite	high inhe dist
03FD231-1	Dig (leucogabbro)	352 $\pm$ 22 Ma 368 $\pm$ 10 Ma	U-Pb (SHRIMP) U-Pb (SHRIMP)	zircon (metamorphic) zircon (magmatic)	high crys
03FD388-1	Pr	259.6 $\pm$ 1.2 Ma	U-Pb (TIMS)	zircon (igneous)	crys J. M

FOSSIL AGES

Sample	Material	Age range	Reference
03FD292-1	Conodont	Pennsylvanian	Orchard, 2005
00DM324/C203149	Conodont	Carboniferous, Serpukhovian	Orchard, 2005

MINERAL OCCURRENCES

Yukon MINFILE (Deklerk and Traynor, 2004)

KING ARCTIC/LIND open pit producer (inactive)

Mineral	Comments
metamorphic)	high-P/retrograde metamorphism
enocrystic)	xenocrystic cores
e	cooling age; inverse isochron age
metamorphic)	high-P/retrograde metamorphism
herited)	inherited detrital cores
e	disturbed systematics, no age
metamorphic)	high-grade metamorphism
agmatic)	crystallization age
neous)	crystallization age
	J. Mortensen, pers. comm. 2005

Topographic base produced by
SURVEYS AND MAPPING BRANCH
DEPARTMENT OF ENERGY, MINES
AND RESOURCES

Copyright Her Majesty the Queen
in Right of Canada

ONE THOUSAND METRE
Universal Transverse Mercator Grid
ZONE 9

SOUTHERN CAMPBELL RANGE
105H/3 SW
YUKON
SCALE 1:20 000

metres 1000 0 1000 2000 metres

Contour interval 20 metres
Elevations in feet above Mean Sea Level
North American Datum 1983
Transverse Mercator Projection

MP

TRIASSIC

Simpson

TSU

PERMIAN

Pr

LOWER

Fortin

MPF

Dekker

Devine

Murphy

Bond, J

Orchard

Pigage

Devine

This map

Digital

Copies

Records

E-mail g

Keep th

quartz grains. Centimetre-scale beds are enhanced on weathered surfaces by variable sand content.

JULES CREEK FAULT

TRIASSIC

Simpson Lake group

TSL

heterolithic conglomerate: clast or matrix supported, poorly sorted with sub-rounded granule- to pebble-sized clasts of chert, green quartz-arenite and serpentinite, reflecting local sources.

PERMIAN

Pr

rhyolite: Quartz-phyric rhyolite with <5 mm clear quartz phenocrysts; local mm-scale flow banding. Rhyolite was not broken out from the Fortin Creek group.

Slide Mountain Terrane

LOWER MISSISSIPPIAN TO LOWER PERMIAN

Fortin Creek group

MPFC

chert pebble conglomerate, quartz wacke and rhyolite: dark grey to black chert-pebble conglomerate; rusty weathering, medium-grained quartz wacke. Units are spatially related but have poorly exposed contacts. Metasedimentary rocks are locally silicified and display open quartz-lined vugs up to 2 cm diameter.

REFERENCES

- Deklerk, R. and Traynor, S. (compilers), 2004. Yukon MINFILE - A database of mineral occurrences. Yukon Geological Survey, CD-ROM.
- Devine, F., 2005. Geology of the southern Campbell Range, southeastern Yukon: Implications for the tectonic evolution of Yukon-Tanana terrane. Unpublished M.Sc. thesis, Carleton University, Ottawa, Ontario.
- Murphy, D. C., 2000. Preliminary geological map of part of the Klatsa River Area (105 H/3), southeastern Yukon (1:50 000 scale). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Open File 2000-15.
- Bond, J.D., Murphy, D. C., Colpron, M., Gordey, S.P., Plouffe, A., Roots, C.F., Lipovsky, P.S., Stronghill, G., Abbott, J.G., 2002. Digital compilation of bedrock geology and till geochemistry, northern Finlayson Lake map area, southeastern Yukon (105G). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, File 2002-7(D), CD-ROM.
- Orchard, M. J. 2005. Carboniferous to Triassic conodont biostratigraphy of the Yukon-Tanana terrane and adjacent areas of Yukon Territory and northern British Columbia. In Paleozoic evolution and metallogeny of pericratonic terranes at the ancient Pacific margin of North America, Canadian and Alaskan Cordillera. Edited by M. Colpron, J.L. Nelson, and R.I. Thompson. Geological Association of Canada, Special Paper, in press.
- Pigage, L. C., 2001. Geological map of Anvil District (NTS 105K/2, 3, 5, 6, 7, 11), central Yukon (1:100 000 scale). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Open File 2001-31.

RECOMMENDED CITATION

Devine, F., Murphy, D.C., Carr, S.D., Kennedy, R. and Tizzard, A., 2005. Geological map of the southern Campbell Range (105H/3 SW), southeastern Yukon (1:20 000 scale). Yukon Geological Survey, Geoscience Map 2005-1.

This map is published as part of an M.Sc. thesis project by F. Devine (2005), see above.

Digital cartography and drafting by F. Devine.

Copies of this map and Yukon MINFILE may be purchased from the Geoscience Information and Sales, c/o Whitehorse Mining Recorder, P.O. Box 2703 (K 102), Whitehorse, Yukon, Y1A 2C6. Phone 867-667-5200, Fax 867-667-5150, E-mail geosales@gov.yk.ca.

Keep this map in a dark area to keep colours from fading

66

65

64

6763000m. N.
61° 00'

NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI[®]

483000 483500

Ottawa-Carleton
Geoscience Centre

MAP 2

To accompany F. Devine M.Sc. thesis, 2005

STATION LOCATION MAP SOUTHERN CAMPBELL RANGE (NTS 105H/3 SW) Southeastern Yukon (1:20 000 scale)

7445
1144
1045
1044
1044
1044

LEGEND

Geological contact
(defined, approximate, inferred).....

Fault, displacement unknown
(defined, approximate, inferred).....

Thrust fault (D4)
(defined, approximate, inferred; teeth on hanging wall).....

Fault - Cleaver Lake Fault? or D4?
(approximate, teeth on hanging wall).....

Axial surface trace (F1) - antiform and synform

Axial surface trace (F2) - overturned anticline on map and cross sections, overturned syncline on map and cross sections

Axial surface trace (F3) - anticline and syncline.....

Axial surface trace (F4) - anticline and syncline

Road, minor road or track

Traverse station - all with prefix 03FD + station number

-533

Road, minor road or track

Traverse station - all with prefix 03FD + station number

-533

Geology:

Yukon-Tanana Terrane

LATE DEVONIAN TO EARLY MISSISSIPPIAN

Klatsa metamorphic complex

DS Serpentinite

Dlg Leucogabbro

D?a Amphibolite

ODls Layered schists

Mm Phyllite-matrix mélange

undifferentiated Waters Creek group and Simpson Lake Plutonic Suite

DMwc Muscovite amphibole granodiorite and chlorite muscovite schist

CLEAVE LAKE THRUST

Yukon-Tanana Terrane

MONEY CREEK THRUST SHEET

LOWER PERMIAN

Money Creek formation

PMC Dark grey carbonaceous phyllite, lithic metawacke, and dark grey chert-pebble metaconglomerate

UNCONFORMITY

PENNSYLVANIAN

PPMI "upper" limestone

UNCONFORMITY

UPPER MISSISSIPPIAN TO LOWER PERMIAN

King Arctic formation

PKAcI Green lithic-arenite and grey quartz-wacke

PKAcm Green chert-pebble conglomerate

UNCONFORMITY

UPPER MISSISSIPPIAN TO LOWER PERMIAN

White Lake formation

MPwic Laminated chert, fine-grained lithic wacke, and siltstone

MPwc Green-pink chert and interbedded limestone

MPwi Limestone

MPWc

PKAq

MPWc

385

MPFG

MPWc

PKAcm

PENNSYLVANIAN

PPMI "upper" limestone

UNCONFORMITY

UPPER MISSISSIPPIAN TO LOWER PERMIAN

King Arctic formation

PKAcI Green lithic-arenite and grey quartz-wacke

PKAcm Green chert-pebble conglomerate

UNCONFORMITY

UPPER MISSISSIPPIAN TO LOWER PERMIAN

White Lake formation

MPWlc Laminated chert, fine-grained lithic wacke, and siltstone

MPWb Green-pink chert and interbedded limestone

MPwi Limestone

JULES CREEK FAULT

TRIASSIC

Simpson Lake group

TSL Heterolithic conglomerate

UNCONFORMITY

PERMIAN

rhyolite

Pr Quartz-phyric rhyolite with <5 mm clear quartz phenocrysts; local mm-scale flow banding. Rhyolite was not broken out from the Fortin Creek group.

UNCONFORMITY

Slide Mountain Terrane

LOWER MISSISSIPPIAN TO LOWER PERMIAN

Fortin Creek group

MPFc Grey to black chert pebble conglomerate, rusty weathering medium-grained quartz wacke and aphanitic rhyolite

Topographic base produced by
 DEPARTMENT OF ENERGY, MINES
 AND RESOURCES
 SURVEYS AND MAPPING BRANCH
 Copyright Her Majesty the Queen
 in Right of Canada

ONE THOUSAND METRE
 Universal Transverse Mercator Grid
 ZONE 9

Miles 1

Mc

SOUTHERN CAMPBELL RANGE
105H/3 SW
YUKON TERRITORY
SCALE 1:20 000

CONTOUR INTERVAL 20 METRES
Elevations in feet above Mean Sea Level
North American Datum 1983
Transverse Mercator Projection

479500 480000 480500 481000 481500 482000 482500 483000

2 Miles

2000 Mètres

Use diagram to obtain numerical values
APPROXIMATE MEAN DECLINATION 2000
FOR CENTRE OF 105H/3 1:50 000 MAP
Annual change decreasing 5.1'

105 H/5	105 H/6	105 H/7
105 H/4	105 H/3	105 H/2
105 A/13	105 A/14	105 A/15

TSL Heterolithic conglomerate

UNCONFORMITY

PERMIAN

rhyolite

Pr

Quartz-phyric rhyolite with <5 mm clear quartz phenocrysts; local mm-scale flow banding. Rhyolite was not broken out from the Fortin Creek group.

UNCONFORMITY

Slide Mountain Terrane

LOWER MISSISSIPPIAN TO LOWER PERMIAN

Fortin Creek group

MPFC

Grey to black chert pebble conglomerate, rusty weathering medium-grained quartz wacke and aphanitic rhyolite

105 H/6	105 H/7
105 H/3	105 H/2
105 A/14	105 A/15