



This document was produced
by scanning the original publication.

Ce document est le produit d'une
numérisation par balayage
de la publication originale.

GEOLOGICAL SURVEY OF CANADA
BULLETIN 441

MESOZOIC STRATIGRAPHY AND JURASSIC PALEONTOLOGY WEST OF HARRISON LAKE, SOUTHWESTERN BRITISH COLUMBIA

Andrew J. Arthur, Paul L. Smith, James W.H. Monger,
and Howard W. Tipper



1993



Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

Canada

THE ENERGY OF OUR RESOURCES

THE POWER OF OUR IDEAS

GEOLOGICAL SURVEY OF CANADA
BULLETIN 441

**MESOZOIC STRATIGRAPHY AND JURASSIC
PALEONTOLOGY WEST OF HARRISON LAKE,
SOUTHWESTERN BRITISH COLUMBIA**

Andrew J. Arthur, Paul L. Smith, James W.H. Monger,
and Howard W. Tipper

1993

©Minister of Supply and Services Canada 1993

Available in Canada through authorized
bookstore agents and other bookstores

or by mail from

Canada Communication Group — Publishing
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W.,
Calgary, Alberta T2L 2A7

100 West Pender Street
Vancouver, B.C. V6B 1R8

A deposit copy of this publication is also available for
reference in public libraries across Canada

Cat. No. M42-441E
ISBN 0-660-14680-0

Price subject to change without notice

Cover description

View looking southeast across Harrison Lake. Brokenback Hill is located on the western shore with Long Island immediately to the east. In the distance are Cascade Peninsula and Echo Island. The Cascade Mountains form the skyline. (GSC 1992-186A)

Authors' addresses

Andrew J. Arthur
BP Resources Canada Limited
#2100, 855-2nd Street S.W.
Calgary, Alberta CANADA
T2P 4J9

Paul L. Smith
Department of Geological Sciences
University of British Columbia
6339 Stores Road
Vancouver, B.C. CANADA
V6T 1Z4

James W.H. Monger
Howard W. Tipper
Sedimentary and Cordilleran Geoscience Branch
Geological Survey of Canada
100 West Pender Street
Vancouver, B.C. CANADA
V6B 1R8

Original manuscript received: 1989 – 12

Final version approved for publication: 1992 – 06

Preface

The Mesozoic sequence west of Harrison Lake is the most complete and best understood section of Middle Triassic (Ladinian) to Lower Cretaceous (Albian) rocks of the western part of the Coast Belt in British Columbia. They are intruded by Middle Jurassic to mid-Cretaceous plutonic rocks of the Coast Plutonic Complex. This detailed study of the lithostratigraphy and biostratigraphy of the strata permits a reconstruction of much of the history of sedimentation, volcanism, plutonism, uplift and erosion during Mesozoic time in the Coast Mountains, an area commonly devoid of stratigraphic sections with reliable fossil control. In this bulletin several fossil groups are used to date the various lithological units that can be traced into the plutonic complex.

The studies on which this report is based were carried out during a three month period in 1985 and serve to update and refine the pioneering studies of C.H. Crickmay in 1924 and 1926 and additional work by many workers subsequently. The area has been the focus of mineral exploration from time to time and this report will provide a geological framework in which the mineral deposits may be considered. The report offers much data that confirm or refute many concepts of Cordilleran tectonic evolution.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

La séquence mésozoïque observée sur la rive ouest du lac Harrison constitue la coupe la plus complète et la mieux comprise couvrant l'intervalle du Trias moyen (Ladinien) au Crétacé inférieur (Albien) dans la partie occidentale de la Chaîne côtière, en Colombie-Britannique. Elle est traversée par des intrusions du Complexe plutonique côtier s'échelonnant du Jurassique moyen au Crétacé moyen. Cette étude détaillée de la lithostratigraphie et de la biostratigraphie des strates permet de reconstituer en grande partie les épisodes de sédimentation, de volcanisme, de plutonisme, de soulèvement et d'érosion survenus au cours du Mésozoïque dans la région de la Chaîne côtière, qui est généralement dépourvue de coupes stratigraphiques où des fossiles fiables permettent un contrôle. Dans le présent bulletin, plusieurs groupes de fossiles sont utilisés pour dater les diverses unités lithologiques identifiées dans le complexe plutonique.

Les études sur lesquelles est basé ce texte ont été réalisées au cours d'une période de trois mois en 1985; elles servent tant à mettre à jour qu'à affiner les études pionnières de C.H. Crickmay, faites en 1924 et 1926, et les travaux complémentaires effectués ensuite par de nombreux chercheurs. Étant donné que la région a été à diverses époques le point focal de travaux d'exploration minière, le bulletin fournira un contexte géologique dans lequel les gîtes minéraux pourront être étudiés. Il présente une grande quantité de données qui permettent de confirmer ou de réfuter de nombreux concepts relatifs à l'évolution tectonique de la Cordillère.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

CONTENTS

| | |
|----|---|
| 1 | Abstract/Résumé |
| 2 | Summary/Sommaire |
| 3 | Introduction |
| 3 | Acknowledgments |
| 4 | Previous work |
| 4 | Regional geology and metamorphism |
| 5 | Local structure |
| 5 | Stratigraphy |
| 5 | Camp Cove Formation |
| 8 | Harrison Lake Formation |
| 9 | Celia Cove Member |
| 10 | Francis Lake Member |
| 11 | Weaver Lake Member |
| 13 | Echo Island Member |
| 13 | Mysterious Creek Formation |
| 16 | Billhook Creek Formation |
| 19 | Kent Formation |
| 20 | Peninsula Formation |
| 25 | Brokenback Hill Formation |
| 27 | Plutonic rocks |
| 27 | Regional tectonics |
| 29 | Systematic Paleontology |
| 29 | Dactylioceratidae |
| 29 | <i>Dactylioceras?</i> |
| 31 | Hildoceratidae |
| 31 | <i>Harpoceras?</i> |
| 31 | <i>Dumortieria</i> |
| 34 | Phymatoceratidae |
| 34 | <i>Phymatoceras</i> |
| 35 | Hammatoceratidae |
| 35 | <i>Erycitoides?</i> |
| 35 | Sphaeroceratidae |
| 35 | <i>Lilloettia</i> |
| 39 | Cardioceratidae |
| 39 | <i>Cadoceras</i> |
| 44 | <i>Cardioceras</i> |
| 46 | References |
| 51 | Appendix 1. Fossil localities |
| 7 | Table 1. Table of Formations |
| | Figures |
| 4 | 1. Index map |
| | 2. Topography of the Harrison Lake area (<i>in pocket</i>) |
| | 3. Geology of west half of the Hope map area (<i>in pocket</i>) |

| | |
|----|---|
| 6 | 4. Geology of west side of Harrison Lake (<i>in pocket</i>) |
| 10 | 5. Schematic stratigraphic column of map area showing general lithology and ages |
| 12 | 6. Bryozoans and crinoid ossicles are from limestone clasts of the Celia Cove Member |
| 14 | 7. Schematic correlation chart for selected Mesozoic sections (<i>in pocket</i>) |
| 15 | 8. Columnar jointing in flows of the Weaver Lake Member |
| 16 | 9. Glass shards in tuffaceous sandstone of the Mysterious Creek Formation |
| 17 | 10. Early Callovian faunal succession for the Cordilleran region |
| 18 | 11. Measured stratigraphic sections for the Mysterious Creek, Billhook Creek and Peninsula formations |
| 18 | 12. Volcaniclastic rocks of the Billhook Creek Formation |
| 19 | 13. Gradational contact between Mysterious Creek Formation and Billhook Creek Formation |
| 20 | 14. Early Oxfordian faunal successions for the Western Interior and Cordilleran regions |
| 21 | 15. Paleobiogeographic map of western North America for Oxfordian time |
| 21 | 16. Peninsula Formation lying unconformably on Billhook Creek Formation |
| 22 | 17. Basal conglomerate of the Peninsula Formation |
| 22 | 18. Thin conglomerate beds in sandstones of Peninsula Formation |
| 22 | 19. <i>Buchia coquina</i> in sandstones of Peninsula Formation |
| 23 | 20. Belemnite coquina in sandstone of Peninsula Formation |
| 25 | 21. Jurassic-Cretaceous unconformity on southwest shore of Cascade Peninsula |
| 26 | 22. Canadian zonation for the Late Jurassic and Early Cretaceous |
| 30 | 23. Volcanic conglomerate from Brokenback Hill Formation |
| 32 | 24. Volcanic conglomerate of Brokenback Hill Formation |
| 38 | 25. Locality chart by formation listing faunas |
| | 26. Ornamentation and volution plots for data from <i>D. cf. insignisimilis</i> and <i>D. cf. levesquei</i> |
| | 27. Whorl shapes and suture patterns noted on Callovian ammonites from localities 17 and 17A |

Plates

| | |
|----|---------|
| 33 | Plate 1 |
| 34 | Plate 2 |
| 37 | Plate 3 |
| 39 | Plate 4 |
| 41 | Plate 5 |
| 43 | Plate 6 |

MESOZOIC STRATIGRAPHY AND JURASSIC PALEONTOLOGY WEST OF HARRISON LAKE, SOUTHWESTERN BRITISH COLUMBIA

Abstract

One of the best preserved Mesozoic stratigraphic sections in the Coast Mountains occurs along the west side of Harrison Lake, southwestern British Columbia. The study of this area involves re-evaluation of the stratigraphic nomenclature for this section, together with lithological descriptions of the units, and age determinations based on fossils collected.

The oldest unit, the Middle Triassic Camp Cove Formation, comprises conglomeratic sandstone, siltstone and minor volcanic rock. Unconformably overlying it is the Toarcian to Lower Bajocian(?) Harrison Lake Formation, which is here divided into four members: Celia Cove (basal conglomerate), Francis Lake (siltstone, shale), Weaver Lake (flows, pyroclastic rocks, minor sediments), and Echo Island (interbedded tuff, siltstone, sandstone). The total thickness of this formation is estimated at 3000 m. A hiatus probably separates this unit from overlying shale, siltstone and sandstone of the Lower Callovian Mysterious Creek Formation, which is 700 m thick. Conformably above this are 230 m of volcanoclastic sandstone and breccias of the Lower Oxfordian Billhook Creek Formation whose type section is designated herein. Lower Jurassic(?) fluvial conglomerate, sandstone and siltstone of the Kent Formation, perhaps 1000 m thick south of Harrison River, unconformably(?) overlie the previous two units mentioned. Berriasian to Valanginian conglomerate and sandstone (218 m thick) of the Peninsula Formation overlie the Billhook Creek Formation with slight angular unconformity. The Peninsula Formation is conformably overlain by tuffaceous sandstone, volcanic conglomerate, crystal tuff and flows of the Valanginian to Middle Albian Brokenback Hill Formation which is several kilometres thick.

Résumé

Dans la Chaîne côtière, l'une des coupes stratigraphiques du Mésozoïque les mieux conservées s'observe sur la rive ouest du lac Harrison, dans le sud-ouest de la Colombie-Britannique. L'étude de cette région comprend une réévaluation de la nomenclature stratigraphique de cette coupe, de même qu'une description lithologique des unités identifiées et les résultats de datation de fossiles recueillis.

L'unité la plus ancienne, la Formation de Camp Cove (Trias moyen), se compose de grès conglomératique, de siltstone et d'un peu de volcanite. La Formation de Harrison Lake, qui s'échelonne du Toarcien au Bajocien inférieur ?, repose en discordance sur l'unité susmentionnée et se laisse subdiviser en quatre membres, soit ceux de Celia Cove (conglomérat basal), de Francis Lake (siltstone, shale), de Weaver Lake (coulées, roches pyroclastiques, quantités mineures de sédiments) et d'Echo Island (tuf interlité, siltstone, grès). L'épaisseur totale de cette formation est estimée à 3 000 m. Un hiatus la sépare probablement du shale, du siltstone et du grès sus-jacents de la Formation de Mysterious Creek (Callovien inférieur), qui a 700 m d'épaisseur. Sur celle-ci reposent en concordance les 230 m de grès et de brèches volcanoclastiques de la Formation de Billhook Creek (Oxfordien inférieur), dont le stratotype est défini dans le présent bulletin. Le conglomérat fluvial, le grès et le siltstone de la Formation de Kent (Jurassique inférieur ?), qui atteignent peut-être 1 000 m d'épaisseur au sud de la rivière Harrison River, recouvrent en discordance (?) les deux dernières unités décrites. Le conglomérat et le grès de la Formation de Peninsula, mesurant 218 m d'épaisseur et s'échelonnant du Berriasien au Valanginien, sont en légère discordance angulaire sur la Formation de Billhook Creek. La Formation de Peninsula est recouverte en concordance par le grès tufacé, le conglomérat volcanique, le tuf à cristaux et les coulées de la Formation de Brokenback Hill, qui couvre l'intervalle du Valanginien à l'Albien moyen et mesure plusieurs kilomètres d'épaisseur.

SUMMARY

The rocks along the west shore of Harrison Lake represent one of the most complete and well preserved Mesozoic sections in the Coast Mountains. The object of this study was to revise and determine the lithostratigraphy, biostratigraphy, age, nomenclature and possible environmental setting of the rocks on the west side of Harrison Lake and to re-map an area which has not been regionally mapped since Crickmay (1925). Regional correlations with other rock units are suggested and possible paleogeographic settings discussed.

The oldest rock unit in this section is the Camp Cove Formation, which has now been accurately dated as Middle Triassic by means of both radiolaria and conodonts. A regionally extensive unconformity separates this formation from the overlying Harrison Lake Formation of Toarcian to Early Bajocian(?) age. The formation is divided into four members and includes Crickmay's (1925) previously described Echo Island Formation. The four members are the Celia Cove Member (Early(?) Toarcian), Francis Lake Member (Middle Toarcian to mid-Aalenian), and the Weaver Lake and Echo Island members (Aalenian to Early Bajocian(?)).

A regionally extensive hiatus of probable Late Bajocian to Bathonian age separates the Harrison Lake Formation from the Lower Callovian Mysterious Creek Formation and conformably overlying Lower Oxfordian Billhook Creek Formation. Locally, the Upper Jurassic Kent Formation overlies the Mysterious Creek Formation. A third regionally extensive unconformity separates the Billhook Creek Formation from the Lower Berriasian to Lower Valanginian Peninsula Formation and the conformably overlying Upper Valanginian to Middle Albian Brokenback Hill Formation.

All these formations contain fossils, predominantly ammonites and bivalves. Nine ammonite genera of Jurassic age were identified and many specimens could be identified to specific level despite the generally poor preservation. Ammonite genera and species newly reported in the Harrison Lake area include, *Harpoceras?* sp., *Phymatoceras?* sp., *Dumortieria* cf. *levesquei*, *Dumortieria* cf. *insignisimilis*, *Erycitoides?* sp., *Cadoceras comma*, *Cadoceras (Paracadoceras) tonniense*, *Cardioceras (Scarburgiceras) martini*, *Cardioceras (Cardioceras) hyatti* and *Ammonoceratites* sp.

Currently there is no independent zonation for Toarcian faunas of North America, but Callomon (1984) has proposed faunal assemblage zones for some Middle and Late Jurassic Stages and the Early Callovian and Early Oxfordian faunas of the Harrison Lake area correlate well with the faunal successions of his Cordilleran Region. The faunas in the Mysterious Creek and Billhook Creek formations are similar to

SOMMAIRE

Les roches qui bordent la rive ouest du lac Harrison constituent l'une des coupes les plus complètes et les mieux conservées de la Chaîne côtière. Le but de cette étude était de réviser et de déterminer la lithostratigraphie, la biostratigraphie, l'âge, la nomenclature et le contexte environnemental possible des roches observées du côté ouest du lac Harrison, mais aussi de cartographier à nouveau un secteur qui ne l'avait pas été (à l'échelle régionale) depuis les travaux de Crickmay, en 1925. Des corrélations régionales avec d'autres unités lithostratigraphiques sont suggérées et des possibilités de cadre paléogéographique, examinées.

La plus ancienne unité lithostratigraphique de cette coupe est la Formation de Camp Cove, maintenant précisément datée du Trias moyen à l'aide de radiolaires et de conodontes. Une discordance d'importance régionale sépare ces roches de la formation sus-jacente de Harrison Lake (Toarcien-Bajocien précoce?). Cette formation se laisse subdiviser en quatre membres et comprend la Formation d'Echo Island anciennement décrite par Crickmay (1925). Les quatre membres sont ceux de Celia Cove (Toarcien précoce?), de Francis Lake (Toarcien moyen-Aalénien moyen), ainsi que de Weaver Lake et d'Echo Island (Aalénien-Bajocien précoce?).

Un hiatus d'envergure régionale, qui probablement s'échelonne du Bajocien tardif au Bathonien, sépare la Formation de Harrison Lake de la Formation de Mysterious Creek (Callovien inférieur) et de la Formation de Billhook Creek (Oxfordien inférieur), cette dernière reposant en concordance sur la précédente. Localement, la Formation de Kent (Jurassique supérieur) recouvre la Formation de Mysterious Creek. Une troisième discordance régionale sépare la Formation de Billhook Creek de la Formation de Peninsula (Berriasien inférieur-Valanginien inférieur) et de la Formation de Brokenback Hill (Valanginien supérieur à Albien moyen), les deux dernières unités étant séparées par un contact concordant.

Toutes ces formations sont fossilifères, avec surtout des ammonites et des bivalves. Neuf genres d'ammonites du Jurassique ont été reconnus et de nombreux spécimens ont pu être identifiés jusqu'au niveau de l'espèce, malgré leur état de conservation généralement médiocre. Les genres et les espèces d'ammonites récemment découverts dans la région du lac Harrison comprennent *Harpoceras?* sp., *Phymatoceras?* sp., *Dumortieria* cf. *levesquei*, *Dumortieria* cf. *insignisimilis*, *Erycitoides?* sp., *Cadoceras comma*, *Cadoceras (Paracadoceras) tonniense*, *Cardioceras (Scarburgiceras) martini*, *Cardioceras (Cardioceras) hyatti* et *Ammonoceratites* sp.

Pour l'instant, il n'existe aucune zonation indépendante des faunes du Toarcien en Amérique du Nord; toutefois, Callomon (1984) a proposé des zones d'assemblages fauniques pour quelques étages du Jurassique moyen et tardif, et les faunes du Callovien précoce et de l'Oxfordien précoce de la région du lac Harrison présentent une bonne corrélation avec les successions fauniques de sa région cordillérienne. Les faunes des formations de Mysterious Creek et de Billhook Creek sont semblables à celles rencontrées

those found farther north and south in the Cordillera, including southern Alaska, north-central British Columbia (Bowser Basin), Oregon and California. The Lower Cretaceous Peninsula and Brokenback Hill formations contain faunas similar to some of those in the correlative Gambier and Fire Lake groups and together these units appear to represent an overlap assemblage which links Wrangellia to Jurassic and older rocks of the Harrison Lake assemblage by Early Cretaceous time.

The Harrison Lake area represents a possible western margin and the Coquihalla area the eastern margin of a Triassic-Jurassic oceanic basin which is represented in its axial region by the Bridge River-Hozomeen assemblage. Closure of this basin may have started in Middle Jurassic time, the shrinking basin becoming the locus for Callovian to Albian marine sedimentation in the Tyaughton and Methow troughs. By the end of the Albian, the trough ceased to be a marine basin due to infilling, uplift and regression. Rocks of the Tyaughton and Methow troughs and surrounding region were subsequently disrupted by transpressional faulting in post-Albian to pre-Eocene time and by Late Eocene transtensional faulting.

plus au nord et plus au sud dans la Cordillère, notamment dans le sud de l'Alaska, dans le centre nord de la Colombie-Britannique (bassin de Bowser), en Oregon et en Californie. Les formations de Peninsula et de Brokenback Hill (Crétacé inférieur) contiennent des faunes semblables à certaines décrites dans les groupes corrélatifs de Gambier et de Fire Lake; l'ensemble de ces unités représente un assemblage de recouvrement qui lie la Wrangellie aux roches jurassiques et plus anciennes de l'assemblage de Harrison Lake dès le Crétacé précoce.

La région du lac Harrison constitue peut-être la marge occidentale d'un bassin océanique triasique-jurassique, la région de Coquihalla en étant la marge orientale; la zone axiale du bassin est représentée par l'assemblage de Bridge River-Hozomeen. La fermeture du bassin a peut-être débuté au Jurassique moyen; en voie de rétrécissement, ce bassin est devenu le point focal de la sédimentation marine du Callovien à l'Albien dans les cuvettes de Tyaughton et de Methow. À la fin de l'Albien, la dépression n'était plus un bassin marin en raison de son comblement, de son soulèvement et d'une régression. Les roches des cuvettes de Tyaughton et de Methow ainsi que de la région environnante ont ensuite été affectées par des failles de transpression (au cours de l'intervalle post-albien à pré-éocène) et de transtension (à l'Éocène tardif).

INTRODUCTION

The study area is located in southwest British Columbia, about 100 km east of Vancouver and lies west of Harrison Lake, a 55 km long and 1 to 7 km wide lake which contains Echo Island, Long Island and Cascade Peninsula (Fig. 1). Chehalis River valley forms the western limit at the contact with igneous rocks of the Coast Belt. The area extends from south of Harrison River, near Mount Woodside (Fig. 2, in pocket), northward to Doctors Point. It lies within the southern Coast Mountains of British Columbia. To the north and west, Cretaceous and Tertiary granodiorite, quartz diorite and diorite of the Coast Plutonic Belt predominate; metamorphosed roof pendants of Lower Cretaceous Gambier and Fire Lake and Jurassic Harrison Lake strata are relatively common (Roddick, 1965). The region has several rock assemblages that differ in lithology and metamorphic grade (Fig. 3, in pocket).

Access to the area is from the Morris Lake road and the Forest Service road along the west side of the lake. The turn-off to these roads from Highway 7 is at Harrison Mills, about 1 km north of the Harrison River bridge (Fig. 4, in pocket). Access to the shoreline geology was by boat.

Acknowledgments

This report is based on a Master of Science thesis undertaken at the University of British Columbia by A.J. Arthur and supported by the Geological Survey of Canada and an N.S.E.R.C. operational grant to P.L. Smith.

We would also like to acknowledge the work of the late J.A. Jeletzky (Cretaceous faunas), M.J. Orchard (Triassic conodonts), E.S. (Beth) Carter and Fabrice Cordey (Triassic radiolaria) and W.R. Danner (Permian fusulinids) for identifying some of the fossils collected during this study. D. Beder (UBC) and D. Rotherham (Kookaburra Gold Corp., Vancouver) each donated a specimen from the Hale Creek area which we figure on plates 4 and 2, respectively. Drafting was done by C. Davis and T. Oliveric. Ammonite photography was by K. Gordanier-Smith. We appreciate the helpful reviews of John Callomon (University College London) and Greg Lynch (GSC, Quebec Geoscience Centre, Sainte-Foy, Quebec). B. Vanlier was of great assistance in preliminary editing and preparation of the manuscript.

PREVIOUS WORK

The geology around Harrison Lake was first mentioned in the Geological Survey of Canada's Director's Report for 1888 (Selwyn, 1888) which stated that older Cretaceous rocks were extensively developed in the area. The following year Whiteaves (1889) confirmed this, identifying Cretaceous *Aucella* (now *Buchia*) from several collections made in 1882 by A. Bowman of the Geological Survey of Canada (see Crickmay, 1925 for more details).

Work started in 1896 on the Providence Group of mining claims along the west shore of Harrison Lake, about 5 km southeast of Doctors Point and a small amount of ore was shipped; the mine proved to be unsuccessful (see Ray et al., 1985 for a more detailed discussion).

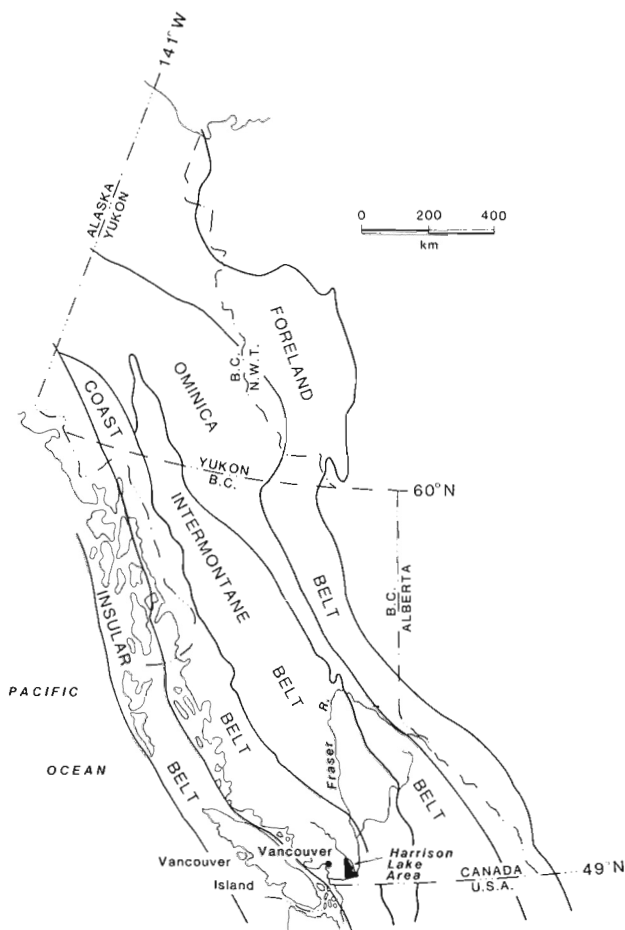


Figure 1. Location of the Harrison Lake area in British Columbia and the five morphological belts in the Canadian Cordillera.

A doctoral study by Crickmay (1925) was the first detailed work on the geology of the Harrison Lake area, resulting in the compilation of a geological map and report in which he described the stratigraphy and lithology of the rocks and erected formational names, most of which are still used. His paleontological studies resulted in the description of many new species and several new genera (*Lilloettia*, *Homolsomites*). Crickmay provided the first interpretations of the paleogeography and structure of the region and his studies led to the recognition of two major unconformities.

The area west of Harrison Lake received little attention between 1930 and 1960. W.E. Snow collected *Buchia* from several localities in 1939 (see Appendix 1). Cairnes (1944) compiled a geological map of the Hope area and Hans Frebold of the Geological Survey of Canada collected fossils from several localities in the Harrison Lake Formation during the summers of 1955 and 1956. Interest in the area was renewed after 1960, especially in the southwest part between Chehalis River and Harrison Lake where hydrothermal alteration and vein development is common (Thompson, 1972; Pearson, 1973). Monger (1970) re-compiled the geology of the west half of the Hope map area and Brookfield (1973) discussed the Lower Oxfordian sediments around Harrison Lake and

their implications with respect to the tectonic history of the area. This study is part of the re-mapping of the Hope map area by the Geological Survey of Canada under the direction of J.W.H. Monger (1989a); field work for this study was undertaken during the summer of 1985.

REGIONAL GEOLOGY AND METAMORPHISM

The Mesozoic assemblage west of Harrison Lake is separated from the Triassic(?) Slollicum assemblage (Fig. 3) to the east, by the Harrison Fault which runs through the neck of Cascade Peninsula and along the western edge of Long Island and continues north following the lake (Fig. 4). The Slollicum assemblage is composed of schistose, basic to intermediate flows and volcanoclastic rocks interbedded with dark grey to black pelites and local conglomerates (Monger, 1986). The metamorphic grade of the Slollicum rocks increases eastward from greenschist facies near Harrison Lake to low amphibolite (ga, bi) facies. East and north of this are kyanite and sillimanite schists and gneiss of the Breakenridge, Cogburn and Settler assemblages (Fig. 3). These rocks probably represent the northern extension of the high grade metamorphic core of the Cascade Belt in Washington (Monger, 1986; Brown, 1987).

By comparison, Mesozoic rocks west of Harrison Lake are typically subgreenschist grade (prehnite to pumpellyite) and penetrative deformation is noted only near the Harrison Fault. Beaty (1974) noted laumontite, montmorillonite, prehnite, pumpellyite, epidote and other metamorphic minerals in amygdules and veinlets in volcanic rocks of the Harrison Lake Formation; hydrothermal alteration is common. Higher in the section, the high pressure, low temperature metamorphic mineral lawsonite is noted in sandstone of the Billhook Creek Formation (M. Brandon, pers. comm., 1987). This high pressure mineral occurs in the Chilliwack Group and Cultus Formation south of Fraser River and is widely distributed in the western Cascades and San Juan Islands of Washington State (Monger, 1966; Beaty, 1974; Brown, 1987). Prehnite and pumpellyite are present in most thin sections of Lower Cretaceous Peninsula and Brokenback Hill strata, but no lawsonite was found.

South of Fraser River is the Devonian to Jurassic Chilliwack-Cultus assemblage (Fig. 3). The Devonian, Carboniferous and Permian Chilliwack Group (Monger, 1970) consists of pelite, sandstone, limestone, basic volcanic and pyroclastic rock and minor chert. Rocks of the Triassic to Lower Jurassic Cultus Formation include pelite, sandstone and rare flows (Monger, 1970). A sliver of Chilliwack Group, composed mainly of argillite and sandstone, lies north of Fraser River, at the southeast end of Harrison Lake on Bear Mountain (Fig. 2) (Crickmay, 1930a) and contains a crinoidal limestone from which mid-Carboniferous conodonts have been extracted (Monger, 1986).

South of Fraser River the Chilliwack-Cultus assemblage has undergone two phases of deformation. The first produced major thrust faults and related tight northeast trending recumbent folds which are overturned to the northwest

(Monger, 1970). The second phase of deformation formed the common northeasterly plunge of the earlier folds and produced chevron folds and reverse faults, which trend northwest with a southwest vergence. Metamorphic grade of the Chilliwack-Cultus assemblage, like the Harrison Lake assemblage, is typically subgreenschist.

LOCAL STRUCTURE

The Mesozoic section west of Harrison Lake is notable for its simple structure and low metamorphic grade compared with those of surrounding areas. East of it lies a zone up to 5 km wide of highly sheared rocks (first noted by Crickmay, 1925) which are bounded on the east by the probably post-Albian, pre-Eocene Harrison Fault (Fig. 4). Within this zone, cleavage is well developed on the northwest shore of Harrison Lake, most of Long Island, the neck of Cascade Peninsula and the eastern shore of Cascade Bay. This cleavage strikes about 340° and dips consistently to the east about 50° to 70° (Monger, 1986). No linear fabric is noted in the western part of the zone but strongly developed stretching lineations are developed in the eastern part, in an interval 1 km wide. Here, conglomerate clasts and bivalve shells (*Buchia*) are highly elongated (up to 12:1) in this zone (Crickmay, 1962; Lowes, 1972; Monger, 1986) and lineations plunge mainly 10° to 30° towards 340°. This strong subhorizontal stretching lineation in the Cretaceous rocks may indicate strike-slip movement along the Harrison Fault (Monger, 1986).

West of the shear zone there is little or no cleavage. A broad northeast plunging anticline and syncline (Fig. 4) in the central part of the map area involves beds as young as Early Cretaceous. Numerous minor thrust faults, which offset these beds, are also present (Fig. 4). The trend orientation of both the folds and thrust faults suggest that these structures may have been formed in association with movement along the Harrison Fault.

The folded and faulted beds occur immediately west of the hinge in Harrison Lake where it changes from a north-northwest to a northwest linear feature. This directional change is possibly due to a bend in the Harrison Fault. Strike-slip movement along the fault would have led to increased strain in rocks located on the west side of this hinge point, resulting in folding and minor thrusting of these rocks. This implies that these structures formed in post-Albian, pre-Eocene time.

The near vertical, normal Sakwi Creek and Camp Cove faults west of Camp Cove strike northwest. Rocks between them are the oldest in the study area and are uplifted between the faults (Fig. 4). The Camp Cove Fault cuts off the northwest limb of an anticline involving both Camp Cove Formation and the lower part of the Harrison Lake Formation.

STRATIGRAPHY

Mesozoic strata of the Harrison Lake area range in age from Middle Triassic to Middle Albian (Fig. 5 and Table 1: Table of Formations; Arthur, 1986) and are characterized by both micro- and macrofossils. The oldest unit is the Middle Triassic Camp

Cove Formation. Lying unconformably above it is the thick Harrison Lake Formation, which is divided into four members: Celia Cove Member (conglomerate), Francis Lake Member (shale, siltstone), Weaver Lake Member (volcanic flows, pyroclastic rock) and Echo Island Member (tuff, siltstone and volcanic derived sandstone). Above the Echo Island Member, possibly unconformably, is Middle Jurassic siltstone and shale of the Mysterious Creek Formation, which in turn is overlain by Upper Jurassic sandstone and volcanoclastic rock of the Billhook Creek Formation. A marked unconformity separates this formation from Lower Cretaceous conglomerate and sandstone of the Peninsula Formation. Conformably above the Peninsula Formation are volcanic conglomerates, crystal tuffs, tuffaceous sandstones and flows of the Brokenback Hill Formation. South of Harrison River, conglomerate, sandstone and pelite of the Upper Jurassic Kent Formation overlies rock of the Mysterious Creek Formation.

Camp Cove Formation

Nomenclature and distribution

This formation was first described as the Camp Cove Series by Crickmay (1925). The type area lies between the Forest Service road and the lakeshore about 3 km south of Camp Cove (lat. 49°20'50"N; long. 121°49'53"W).

Camp Cove Formation is exposed along the shore from Camp Cove south to a point about 1 km north of Celia Cove and in roadcuts to the west (Fig. 4). Bedding is variable in attitude but generally strikes to the southeast and dips 20° to 40° southwest. The formation is cut off at the north end by the Camp Cove normal fault (Fig. 4). The base of the formation is not exposed.

Crickmay (1925) reported Triassic fossils (*Juvavites*, *Atractites* cf. *elegans* Smith) from a locality along the east shore of Long Island 6 km south of the northernmost point, but he did not figure the specimens. The sediments at this locality are within the Harrison Fault Zone and have a well developed cleavage; they could belong to the Camp Cove Formation or possibly the Triassic(?) Slollicum assemblage east of the lake (Fig. 3).

Lithology

The formation comprises andesitic or basaltic(?) volcanic flows, siliceous siltstone and medium- to coarse-grained sandstone. The flows are found at the base of the exposed section in Camp Cove and are dark grey with calcite-filled vesicles and are commonly veined. The siliceous siltstone is grey to black and finely bedded (2-3 cm thick beds). Sandstones are green or grey, fine to medium grained, and are volcanogenic with abundant plagioclase grains. Along the lakeshore are conglomeratic sandstones with pebbles up to 0.5 cm of indurated siltstone, mudstone and possibly volcanic flow rock. The sandstones are generally medium to thick bedded but interbedded siltstone and sandstone with fine laminae show convoluted bedding at several localities. The sediments are more abundant than volcanics and the total thickness is estimated at 300 m.

Depositional environment

Radiolaria in the siliceous siltstone (locality 9) indicate deposition in marine waters although water depth is uncertain. Spumellarian radiolaria, which in modern environments predominate on the inner shelf in relatively

shallow water are abundant, whereas the deeper water nassellarians are absent. Convolute bedding may have formed because of disturbance of sediments by wave action, by seismic activity causing slumping, or dewatering, and perhaps the sediments represent turbidity deposits.

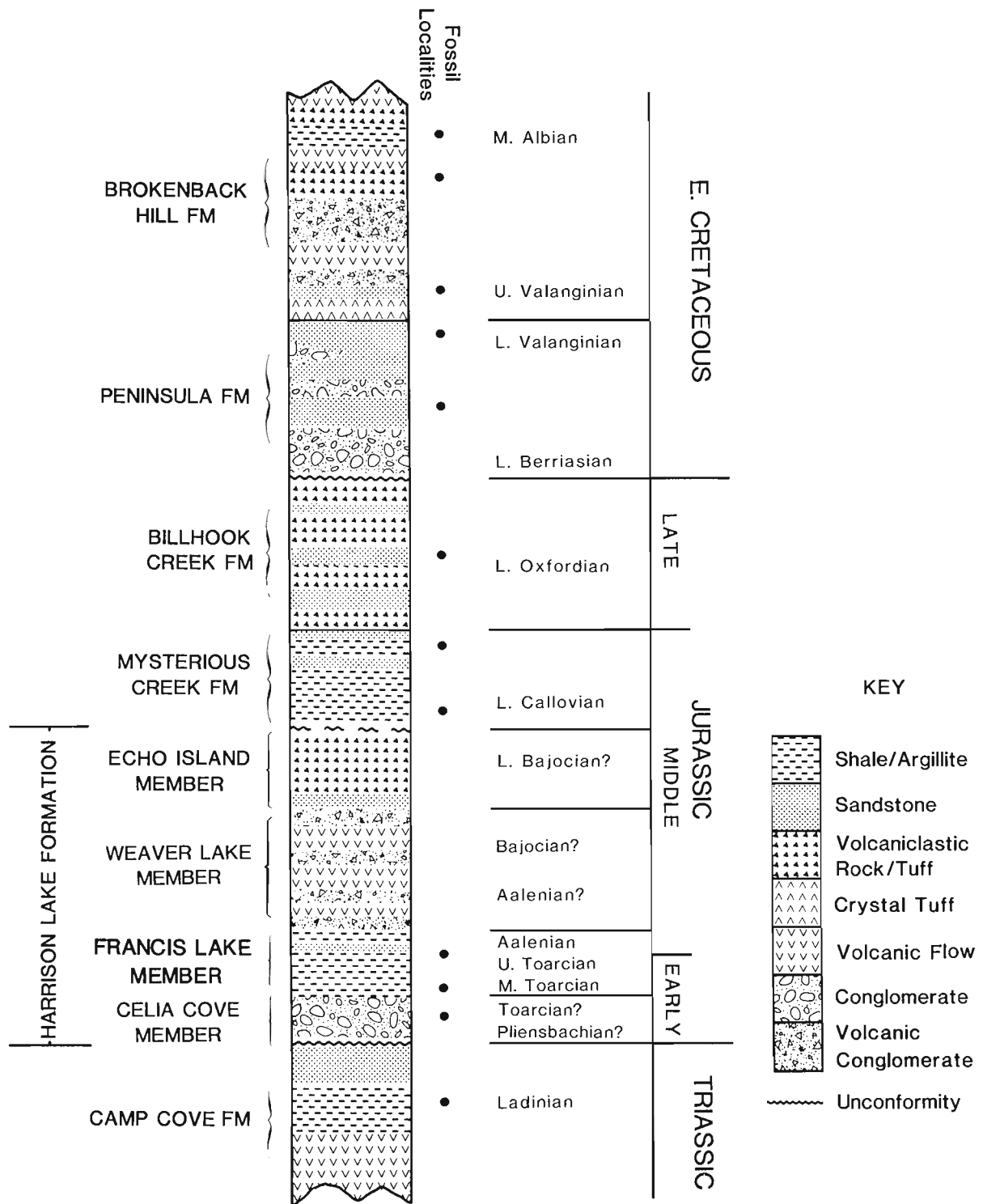


Figure 5. Schematic stratigraphic column of map area showing general lithology and ages.

Table 1. Table of Formations

| ERA | PERIOD | AGE/EPOCH | MAP UNIT | MAP UNIT SYMBOL | THICK-NESS | LITHOLOGY | DEPOSITIONAL ENVIRONMENT | CONTAINED FAUNA |
|----------|--|--|----------------------------|-----------------|-------------------------|---|--|---|
| CENOZOIC | PALEOGENE | Oligocene 25 Ma | CHILLIWACK SUITE | Tgd | | granodiorite | | |
| | | INTRUSIVE CONTACT - plutons equivalent to Chilliwack Batholith found at Doctors Point and on Mount Agassiz | | | | | | |
| MESOZOIC | CRETACEOUS | Late Valanginian to Middle Albian | BROKENBACK HILL FORMATION | LKbh | 2000-3000m | Tuffaceous sandstone, crystal tuff, volcanic conglomerate, andesite to dacite flows, volcanic breccia, siltstone, shale. | Island arc, nearshore to offshore marine | <i>Buchia crassicolis</i> , <i>B. keyserlingi</i> , <i>Homalosomes quatsinoensis</i> , <i>H. packardii</i> , <i>Inoceramus paraketzovi</i> , <i>Cleoniceras perezianum</i> , <i>Pleuromya</i> , belemnites |
| | | Early Berriasian to Early Valanginian | PENINSULA FORMATION | LKp | 218m | Sandstone, conglomerate | Nonmarine (?) and shallow marine. | <i>Buchia uncioides</i> , <i>B. okensis</i> , <i>B. pacifica</i> , <i>B. tolmatschowi</i> , <i>B. keyserlingi</i> , belemnites |
| | ANGULAR UNCONFORMITY - CKp overlies UJbc on Cascade Peninsula and west of Long Island. | | | | | | | |
| | JURASSIC | Oxfordian to Tithonian (?) | KENT FORMATION | UJk | 1000m | Conglomerate, siltstone, sandstone. | Fluvial (?) | plant debris |
| | | UNCONFORMITY - UJk overlies MJmc and possibly UJbc on Mount Agassiz. | | | | | | |
| | | 160 ± 2Ma | | UJgd | | granodiorite | | |
| | | INTRUSIVE CONTACT - plutons intrude Harrison Lake formation northwest of Weaver Lake. | | | | | | |
| | | Early Oxfordian | BILLHOOK CREEK FORMATION | UJbc | 230m | Volcaniclastic, breccia, sandstone. | Nearshore to offshore marine waters. | <i>Cardioceras martini</i> , <i>C. hyatti</i> , <i>C. lilloetensis</i> , bivalves (including <i>Oxytoma</i> , <i>Pinna</i>), belemnites. |
| | | Early Cretaceous | MYSTERIOUS CREEK FORMATION | MJmc | 700m | Shale, siltstone, sandstone. | Nearshore to offshore marine waters. | <i>Cadoceras comma</i> , <i>C. cf. catostoma</i> , <i>C. (Paracadoceras) cf. tonniense</i> , <i>Pseudocadoceras grewingki</i> , <i>Lilloettia lilloetensis</i> , <i>L. stantoni</i> belemnites, bivalves. |
| | | POSSIBLE UNCONFORMITY | | | | | | |
| | | Middle Toarcian to mid-Aalenian | Echo Island Member | MJcf | 750m | Well stratified tuff, siltstone, sandstone and rare volcaniclastic rock plus andesite flows. | Marine waters near volcanic source. | <i>Trigonia</i> sp., belemnites |
| | | | Weaver Lake Member | MJwl | 2000m | Acidic to intermediate flows, lapilli tuff, volcanic breccia, volcanic conglomerate, crystal tuff, minor sandstone and shale. | Island arc, sub aerial and submarine. | Belemnites, bivalves. |
| | | | Francis Lake Member | LJfl | 200m | Calcareous siltstone, shale, sandstone. | Marine oxygen deficient waters. | <i>Erycitoides</i> ? sp., <i>Dumortieria cf. levesquei</i> , <i>Dumortieria cf. insignisimilis</i> , belemnites, bivalves <i>Dactyloceras</i> , <i>Harpoceras</i> , <i>Phymatoceras Pentacrinus</i> . |
| | | | Celia Cove Member | LJcc | 30-50m | Clast supported conglomerate, sandstone | Submarine channel fill (?). | Limestone clasts (<i>Parafusulina</i> , crinoid ossicles, bryozoa, corals, brachiopods - indicate Early Permian age) Chert clasts (<i>Tripocyclia acanthus</i> , <i>Pseudostylosphaera</i> aff. <i>compacta</i> , <i>Triassocampe</i> sp. <i>Parasertispongia</i> ? sp. indicate Ladinian - Early Carnian age.) |
| | | UNCONFORMITY | | | | | | |
| | TRIASSIC | LADINIAN | CAMP COVE FORMATION | MTcc | 300m (base not exposed) | Sandstone, siltstone, andesitic flows. | Inner marine shelf possibly turbidity flows. | Conodonts (<i>Neogondolella</i> cf. <i>constricta</i>) Radiolaria (<i>Emiluvia</i> ? sp., <i>Tripocyclia</i> ? sp.). |

Biostratigraphy and age

Abundant radiolaria and rare conodonts were extracted from indurated siltstones at locality 9. The samples yielded radiolarians indicating a Middle Triassic (possibly Ladinian) age (E.S. Carter, pers. comm.). The few conodont specimens were identified as *Neogondolella* cf. *N. constricta* (Mosher and Clark) which indicate a Middle Triassic age (M.J. Orchard, pers. comm., 1987). No macrofossils were found within this unit.

Correlations

Monger (1970) tentatively correlated this formation in part with Upper Triassic to Lower Jurassic siltstones, shales and volcanic arenites of the Cultus Formation lying to the south (Misch, 1966; Monger, 1986). The new Middle Triassic age for the Camp Cove Formation makes this correlation questionable but it may be equivalent to an as yet undated older section of the Cultus Formation or a younger part of the Chilliwack Group that has been removed by erosion. The formation is roughly age equivalent to basalt and turbidite flows (siltstone, sandstone, conglomerate) of the Triassic Cadwallader Group (Rusmore, 1985), lying 180 km to the north-northwest; Monger (1986) speculatively correlated the Slollicum assemblage (Fig. 3) east of Harrison Lake with the Cadwallader Group based on general lithological similarities.

To the east, in the Coquihalla area, the Lower to Middle(?) Triassic Spider Peak Formation, composed of greenstone, gabbro plus minor tuff, siltstone and sandstone, outcrops locally along the Hozameen Fault (Ray, 1986). It is partly age equivalent to the Camp Cove Formation. These two formations can be correlated in part with Permian to Middle Jurassic chert, siltstone, basalt, ultramafics and minor carbonates of the Bridge River-Hozameen assemblage (see Fig. 7, in pocket) which is believed to represent former oceanic crust and overlying sediments (Potter, 1983).

Harrison Lake Formation

Introduction

Crickmay (1925) first named and described this formation, placing it in the Porphyrite Series together with the Echo Island and Mysterious Creek formations. He described the type section along the west shore of Harrison Lake from Camp Cove north to Walian Creek (then Eagle Creek). Total thickness was 2820 m (9240 ft) of pyroclastic rocks, tuffs, flows, agglomerates and siltstones, although Crickmay (1925) stated that all sections measured were cut by small faults. He indicated a probable Middle Jurassic age for the formation on the basis of the few fossil fragments found.

More recent work (Thompson, 1972; Pearson, 1973) and the discovery of better preserved fossils (Frebold, unpublished data; Brookfield, 1973) resulted in a clearer understanding of its age and stratigraphic succession. Here the formation is divided into four members. The Celia Cove Member is a basal conglomerate conformably overlain by

siltstone and shale of the Francis Lake Member. The volcanic member of Harrison Lake Formation, here named the Weaver Lake Member, lies conformably above. Next are interbedded tuff, siltstone, volcanogenic sandstone and rare flows of the Echo Island Member which represent the end of Middle Jurassic volcanism.

Correlations

A regional unconformity at the Triassic-Jurassic boundary is present over much of British Columbia (Frebold and Tipper, 1970) including the Coquihalla area (Anderson, 1976; O'Brien, 1986) and Harrison Lake area (Fig. 7, in pocket). In the Taseko Lakes area, the Tyaughton Group is as young as uppermost Triassic, but Early and Middle(?) Hettangian (Early Jurassic) age fossils have not been found in the overlying unnamed Lower Jurassic unit indicating a hiatus at the Triassic-Jurassic boundary. The flysch-like sediments of the Cultus Formation (Misch, 1966; Monger, 1966) contain Late Triassic (Norian) and Early Jurassic (Sinemurian and Pliensbachian) fossils, but a continuous section across the Triassic-Jurassic boundary is not proven. The same argument is true for oceanic sediments of the Bridge River and Hozameen groups which contain Middle Norian and Pliensbachian, Sinemurian, and possibly Aalenian to Bajocian (Haugerud, 1985) radiolaria (Potter, 1983).

The Francis Lake Member is lithologically similar and age equivalent to Toarcian shales of the unnamed unit above the Tyaughton Group, Taseko Lakes area (Fig. 7). It can be correlated with Upper Toarcian shales of the Ladner Group, Manning Park area. The overlying flows, tuffs, pyroclastic rocks and minor sediments of the Weaver Lake and Echo Island members are markedly similar lithologically and of the same age as andesite to dacite flows, breccias and intercalated sediments of the Wells Creek volcanics in Washington (Danner, 1960; Misch, 1966). They are also age equivalent to Toarcian(?) to Lower Bajocian (O'Brien, 1986) tuffaceous sediments, breccias and andesitic flows of the Dewdney Creek Formation lying along the east side of the Tyaughton and Methow troughs in the Coquihalla area. Spatially (and temporally) between these two units (Weaver Lake Member and Dewdney Creek Formation) are oceanic sediments of the Bridge River and Hozameen groups.

Celia Cove Member

Nomenclature and distribution

Celia Cove Member, first described here, is named after a small cove lying 1 km south of the shoreline outcrop of the member, southwest of Echo Island. The type area lies about 2.5 km south of Camp Cove, 100 m along a turn-off from the Forest Service road (lat. 49°20'44"N; long. 121°49'52"W).

Outcrops of the Celia Cove Member are found mainly in roadcuts and along the lakeshore. South of Camp Cove the unit is fairly well exposed and can readily be mapped. Outcrop west of Camp Cove is sporadic. The conglomerate at localities 8 and 10 (Fig. 4) is an extension of the conglomerate

outcropping along the shoreline to the south. The member is cut off to the north by the Camp Cove Fault, a normal fault with the north side downthrown.

Lithology

The member consists mainly of clast supported conglomerate with a medium- to coarse-grained calcareous sandy matrix of poorly sorted feldspar, quartz and lithic grains (Arthur, 1986). The unit is generally massively bedded but rare lenses of medium- to coarse-grained sandstone occur. Clasts weather out easily, are fairly well rounded and up to 25 cm in diameter. They consist predominantly of volcanic flow rock, chert and limestone. The volcanic clasts are mainly green aphanitic andesite and average 13 cm in diameter. The limestone clasts are light to dark grey and generally smaller, averaging 7 cm in diameter. Along the lakeshore the limestone clasts are well preserved, but in vegetation covered outcrops they are deeply weathered with much or all of the carbonate removed. The chert clasts are pale green and usually only 1 to 3 cm in diameter, rarely reaching 6 cm. Both the limestone clasts and the chert clasts contain fossils. Total thickness is 30 to 50 m.

Depositional environment

Sedimentary structures are lacking in this unit and the matrix has not yielded fossils. The poor sorting of both the matrix and clasts, and the member's position beneath anoxic marine shales and siltstones may suggest an environment of deposition in a submarine channel.

Structural relations

The Jurassic Celia Cove Member lies disconformably on the Middle Triassic Camp Cove Formation with little or no angular discordance. A marked disconformity or hiatus usually exists at the Triassic-Jurassic boundary in British Columbia as it does in much of the world. This disconformity in the Harrison Lake region possibly extends from the Middle Triassic to Middle Toarcian.

Biostratigraphy and age

The Celia Cove Member conformably underlies the Toarcian Francis Lake Member (Fig. 5). Fossils have not been recovered from its matrix, but based on the age of bounding units the member could be as young as Middle Toarcian or as old as Middle Triassic, and is most probably Toarcian as the conglomerate grades upwards into Middle Toarcian shales.

Chert and limestone clasts from this member yielded several fossil groups at locality 8. The chert clasts contain abundant sponge spicules and poorly preserved radiolaria which were studied by E.S. Carter (written comm.). A Middle to early Late Triassic (Ladinian-Early Carnian) age was suggested based on the presence of *Pseudostylosphaera* aff. *compacta* (Nakaseko and Nishimura), *Paraoertlispongus?* sp., *Triassocampe* sp. B? (Yao, Matsuoka and Nakatani) and *Tripocyelia* cf. *acanthus* De Wever. Rare conodonts extracted

from the chert clasts were identified as *Neohindeodella* sp. indicating a Middle to Late Triassic age (M.J. Orchard, pers. comm., 1987).

The weathered limestone clasts contain abundant external molds of crinoid ossicles and bryozoans (Fig. 6) together with rare fusulinids and brachiopods (Arthur, 1986; Monger, 1986). The clasts were impregnated with resin to produce external casts of the crinoid ossicles and bryozoans which could then be photographed. The detail of the specimens is excellent considering they are resin casts. The bryozoa in Figure 6a belongs to the Order Cryptostomata (Family Fenestellidae) which ranged from the Ordovician to Permian, with their peak of development in the Devonian and Mississippian. The specimen in Figure 6b also belongs to the Order Cryptostomata and shows well developed pores. Thin sections of fusulinid-bearing clasts were studied by Arthur and by W.R. Danner of the University of British Columbia. The fusulinids most closely resemble *Parafusulina* of Early Permian age.

Clast provenance

Provenance of the Lower Permian limestone clasts is probably the Pennsylvanian to Permian Chilliwack Group, as faunas in the clasts (*Parafusulina*, bryozoans, crinoid ossicles, corals, brachiopods) are forms commonly found in that group (Monger, 1966). Presence of these clasts in the Celia Cove Member suggests that a stratigraphic linkage existed between the Harrison Lake assemblage and Chilliwack-Cultus assemblage by Early Toarcian time (Monger, 1986).

Provenance of the pale green chert clasts of Middle Triassic age based on radiolaria and conodonts is difficult to determine. The Bridge River Group lying to the east represents deposits of a possible ocean basin that existed at least until the Middle Jurassic, as indicated by radiolaria of this age recovered from chert (Potter, 1983). It is unlikely that this unit could be the source for the chert clasts because it was not uplifted until mid-Cretaceous time (Coates, 1974). Pale green chert (silicified tuff) of Permian age is known from the Chilliwack Group (Monger, 1966); perhaps undated beds as young as Triassic are present or were present prior to erosion(?) of this unit.

Francis Lake Member

Nomenclature and distribution

The member is named after Francis Lake which is situated about 1.5 km east of Weaver Lake. The type area lies along the British Columbia Forest Service road east of Francis Lake (lat. 49°20'37"N; long. 121°49'52"W).

The Francis Lake Member outcrops from just north of Celia Cove northwest to the Camp Cove Fault beyond which it is faulted out (Fig. 4). It is best exposed along the Forest Service road. Siltstones and shales predominate in the lower part of the section. The upper part of the section is poorly exposed but shale seems to predominate; there are local sandstone beds.

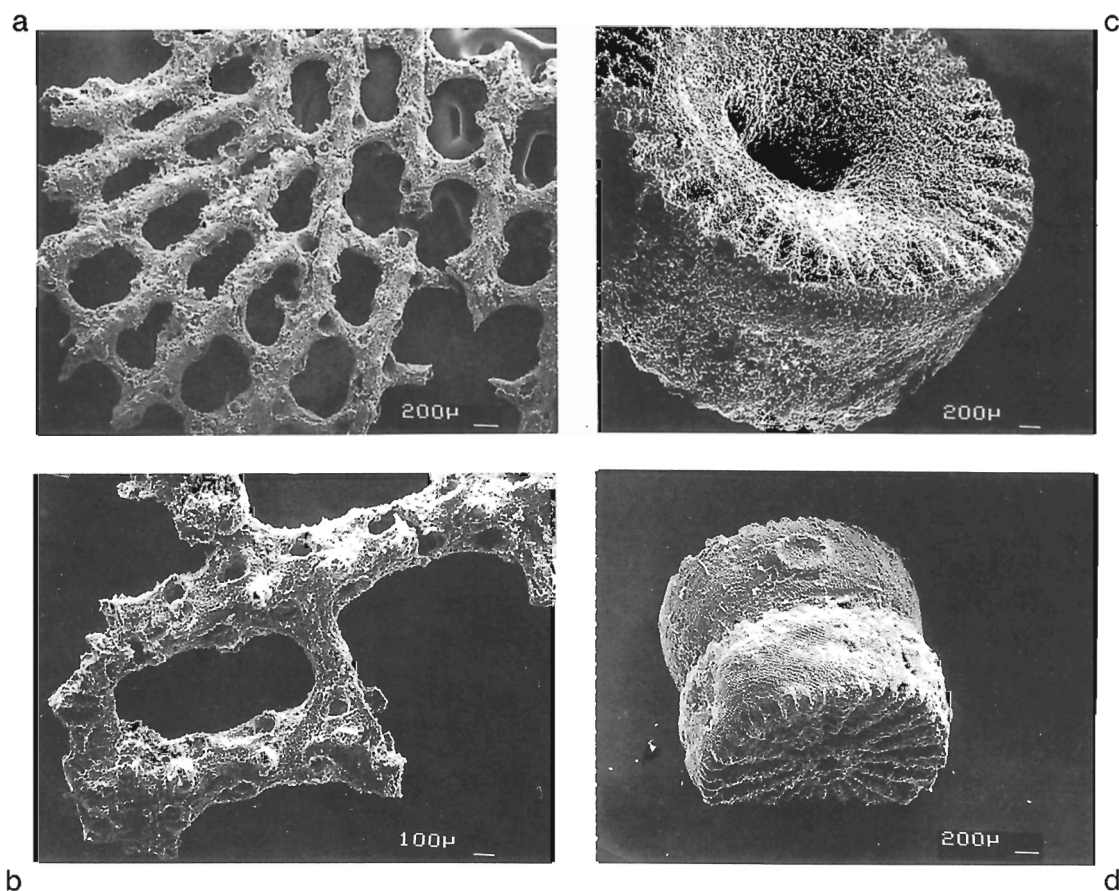


Figure 6. Bryozoans (a,b) and crinoid ossicles (c,d) are reworked fossils from limestone clasts of the Celia Cove Member. Natural weathering removed all carbonate from the clast leaving external molds of the fossils. Clasts were impregnated with resin to produce external casts. GSC type specimens: a) 91624, b) 91625, c) 91626, d) 91627. GSC 1992-186B

Lithology

The Francis Lake Member is mainly calcareous siltstone, shale and local sandstone beds. The rocks are commonly fractured; pyrite and calcite veins are common. Siltstone beds vary in thickness and are usually well indurated. Thin bedded sequences (1-5 cm) consist of alternating light and dark grey beds. More massive beds are generally light grey, up to 15 cm thick and have a blocky to sub-conchoidal fracture pattern. Shales are light grey to brown, rarely calcareous, friable and commonly part along laminae less than 1 cm apart. Manganese(?) staining is common in the shales and both shales and siltstones have abundant disseminated pyrite cubes. Sandstone is fine to medium grained, volcanogenic, generally green in colour, may contain disseminated pyrite, generally massively bedded, and found locally in the upper part of the section. Thickness of the member is estimated at 150 to 200 m.

Depositional environment

The upward gradational change from possible deltaic conglomerates to probable quiet marine waters may have been the result of transgression in the Toarcian. Crinoid debris found in the lower part of the section may have been

broken up and transported to the site of deposition as only individual ossicles are noted. The presence of ammonites, disseminated pyrite and rare fish skeletons (locality 7) may indicate an offshore setting in oxygen minimum marine waters; preservation of fish skeletons usually requires a very low energy, low oxygen environment. The sandstone beds near the top of the member may indicate submarine channels or a shallowing of marine waters prior to onset of mid-Jurassic volcanism.

Structural relations

The contact between the Celia Cove Member and Francis Lake Member is poorly exposed in the type area but the underlying conglomerate appears to grade conformably into siltstone and shale.

Biostratigraphy and age

In the Francis Lake Member of the Harrison Lake Formation at locality 7, about 10 m stratigraphically above the contact with the Celia Cove Member, the ammonite genera *Dactyloceras*, *Harpoceras* and *Phymatoceras* were tentatively identified indicating a Toarcian age. In Europe

Dactylioceras ranges from the Tenuicostatum to Bifrons Zone, *Harpoceras* ranges from the Falcifer to Bifrons Zone and *Phymatoceras* ranges from the Bifrons to the Variabilis Zone (Dean et al., 1961; Donovan et al., 1981). Identification to species level is simply not possible due to their poor preservation in the calcareous siltstone, but the association of genera would clearly indicate a Middle Toarcian age, approximately equivalent to the Bifrons Zone.

These miserably preserved ammonites show some resemblance to the Pliensbachian genera *Aveyroniceras*, *Lioceratoides* and *Fuciniceras*. As discussed in the systematic section, however, the resemblance is equivocal and the association of these genera at a single locality would be unusual since elsewhere in North America they characterize different parts of the Pliensbachian. We therefore favour an assignment to Toarcian genera.

Immediately beneath locality 7 are less indurated grey calcareous shales and siltstones containing molds of star-shaped crinoid ossicles. Rocks of the same lithology containing star-shaped crinoid ossicles are found at locality 6 to the south and on the roadcut 800 m northwest of locality 10 (Fig. 4). These star-shaped crinoid ossicles are characteristic of the Jurassic (Nelson, 1979, p. 506) and belong to the genus *Pentacrinus*. In Alaska, they are strongly indicative of Early Jurassic and this seems to be true for the Harrison Lake area, as they were not found in younger strata. The crinoid ossicles are found only near the base of the Francis Lake Member which conformably overlies conglomerate of the Celia Cove Member.

Middle Toarcian rocks are widely distributed in British Columbia, including the Queen Charlotte Islands (Cameron and Tipper, 1985) and the Rocky Mountains (Frebold, 1957, 1976; Hall, 1987). Recently, Toarcian rocks bearing *Dactylioceras* have been found in the Spatsizi area (Smith et al., 1984; Thomson, 1985; Thomson et al., 1986) and unpublished occurrences are known in many areas of central and northern British Columbia and the southern Yukon.

The first report of Toarcian ammonites in the Harrison Lake area was by Brookfield (1973) who recorded *Dactylioceras* supposedly in the Camp Cove Formation. It is now known that the Camp Cove Formation is Triassic in age and the calcareous siltstones in which Brookfield found *Dactylioceras* are presumably part of the Harrison Lake Formation (locality 7 of the Francis Lake Member). The presence of *Harpoceras?* and *Phymatoceras?* in the Harrison Lake area is here recorded for the first time. Along the shoreline of Harrison Lake in Celia Cove, belemnites are commonly found in siltstones of the Francis Lake Member together with rare bivalves. It is from this area that Crickmay (1930a) identified and described *Cylindroteuthis themis* Crickmay and *Entolium vulcanicum* Crickmay suggesting a Middle Jurassic age.

At locality 5 the Late Toarcian ammonites *Dumortieria* cf. *levesquei* d'Orbigny and *Dumortieria* cf. *insignisimilis* (Brauns) were collected from folded and intruded brown to grey siltstones and shales. Rare, small, thin-shelled pectinid bivalves are associated with the ammonites. A single very poorly preserved ammonite resembling *Dumortieria* was found

at locality 2 associated with belemnites. In Europe *Dumortieria* ranges from the Levesquei Subzone to the Moorei Subzone of the Late Toarcian (Dean et al., 1961; Donovan et al., 1981). Frebold collected specimens of this genus from the Harrison Lake area but he mis-identified them as the Early Bajocian genus *Fontannesia* (see Monger, 1970; Brookfield, 1973). Upper Toarcian beds are widely distributed from Oregon to Alaska (Imlay, 1968; Frebold and Tipper, 1970) and the genus *Dumortieria* has been recorded from Oregon (Imlay, 1968; Smith, 1976), Queen Charlotte Islands (Cameron and Tipper, 1985), Spatsizi (Thomson et al., 1986), Hazelton area (Tipper and Richards, 1976), Yukon (Cockfield and Bell, 1926, p. 21) and Harrison Lake (this report).

Between localities 2 and 5 on the northeast slope of an unnamed mountain, belemnites, pectinid bivalves and a single ammonite specimen were found at locality 3 at the top of the Francis Lake Member. The ammonite is not well preserved but most closely resembles *Erycitoides?* sp. of probable mid-Aalenian age. The age of the member therefore ranges from Middle Toarcian to mid-Aalenian. Localities: 2, 3, 5, 6, 7.

Weaver Lake Member

Nomenclature and distribution

Crickmay (1925) described and measured approximately 2820 m of predominantly volcanic rock along the western shore of Harrison Lake between Camp Cove and Walian Creek (Fig. 2) as the type section of the Harrison Lake Formation. As the formation is here divided into four members, Crickmay's section is now considered the type section of the volcanic Weaver Lake Member.

The member consists of a volcanic sequence covering an area stretching 20 km north from Harrison River almost to Hale Creek and 10 km from Harrison Lake to Chehalis River (Fig. 4). It outcrops over much of Mount Woodside immediately south of Harrison River and on the northern half of Echo Island (Fig. 4). Exposure is excellent in roadcuts between Mount Downing and Walian Creek but the internal stratigraphy of the member is uncertain due to lack of continuous outcrop, discontinuous units, poor bedding and the presence of numerous small faults and fractures with much hydrothermal alteration.

Lithology

The member is lithologically varied but acidic to intermediate volcanic flows and pyroclastic rocks are most common (Monger, 1970). Flows include dacite, light grey to tan (on fresh surface) rhyolite and dark green, locally amygdaloidal, plagioclase andesite porphyry. They are generally thick, massive and may be columnar jointed (Fig. 8). Well developed flow banding in a grey rhyolite can be seen on the northern shore of Camp Cove. Pyroclastic rocks are more abundant than flow rocks, as stated by Monger (1970), and include lapilli tuff, volcanic breccia and volcanic conglomerate. Also noted were crystal lithic tuff, crystal tuff and minor sandstone and shale beds. Pearson (1973) recorded the presence of waterlain tuffs with load casts and convolute

laminae, pillowed andesites and pillow breccias. Intrusive feldspar porphyry dykes commonly cut across strata, are columnar jointed and usually shallowly dipping.

Thompson (1972) used refractive index determinations of fused glass beads from 196 volcanic rock samples to determine rock compositions of the Weaver Lake Member. A histogram plot of his data (Thompson, 1972, Fig. 6) is skewed towards the rhyolite-dacite compositional field, illustrating the high degree of felsic volcanism. He also selected 6 representative samples for complete silicate analysis which showed a positive correlation with the calc-alkaline Cascade trend on a chemical variation diagram (Thompson, 1972; Church, 1973).

Depositional environment

Rocks of the Weaver Lake Member may have been deposited in a volcanic island arc setting based on chemistry which indicates a calc-alkaline Cascade trend. The presence of waterlain tuffs, pillowed andesites and pillowed breccias suggest submarine volcanism. Isolated localities of marine fossils (bivalves, belemnites) in shales and sandstones also indicate marine conditions. Rare columnar joints in some flows (Fig. 8) suggest some subaerial volcanism, possibly on emergent volcanic islands.

Structural relations

The contact with the underlying Francis Lake Member is placed at the top of the sediments and base of the volcanic rocks. No unconformity was noted although a hiatus can not be ruled out. The contact is best exposed near locality 3 (Fig. 4) where andesitic flows rest on mid-Aalenian shales.

Biostratigraphy and age

Few fossils have been found in the Weaver Lake Member. Belemnites collected from locality 4 and belemnites and bivalves from locality 11 collected by D.E. Pearson of the

British Columbia Department of Mines (Pearson, 1973) cannot be used to date the member precisely. Belemnites from locality 4 of the member only indicate an age of post-Early Toarcian to mid-Early Cretaceous. At locality 11, pectinid bivalves and belemnites indicate marine conditions but an age is not determinable. Fossils younger than Aalenian have not been recovered from the Harrison Lake Formation, but the great thickness of section (most of the Weaver Lake Member and all of the Echo Island Member) lying above these fossil localities and below the Early Callovian Mysterious Creek Formation suggest a significant time span during which these strata were deposited. The age of the Weaver Lake Member probably ranges from mid-Aalenian to Early Bajocian(?), possibly younger.

Echo Island Member

Nomenclature and distribution

The type section first described and named by Crickmay (1925) is found on the southeastern tip of Echo Island, after which the unit is named. It is closely related to the Weaver Lake Member in that the contact is gradational and the member simply represents the final stages of the Middle Jurassic volcanic episode. For this reason the unit has been redescribed as the Echo Island Member of the Harrison Lake Formation (Arthur, 1986) instead of the Echo Island Formation (lat. 49°20'40"N; long. 121°46'24"W).

The Echo Island Member is found on the southeast corner of Echo Island, the north and south shore of Harrison River west of Sakwi Creek Fault and east and north of Mount McRae (Fig. 4). Crickmay (1925) measured 355 m (1170 ft) of stratified tuff, argillite and sandstone at the type section on Echo Island but the top of the section is absent there. On the south shore of Harrison River Crickmay measured a 365 m (1200 ft) section which included the top of the unit. He concluded there was perhaps 120 m (400 ft) of section missing between the top of the Echo Island section and the base of the Harrison River section and from this he computed a total thickness of 843 m (2770 ft). The actual thickness



Figure 8.

Columnar jointing in flows of the Weaver Lake Member near Mount McRae. GSC 1992-186C

missing between these two sections cannot be ascertained, but Crickmay's estimate is probably close. The thickness of the member is variable. It is not seen in outcrop along the west shore of Harrison Lake, although this may be partly due to faulting. East of Mount McRae the thickness increases dramatically, perhaps up to 1000 m. An average thickness is estimated at 750 m.

Lithology

Characteristically this member is well stratified and consists mainly of interbedded tuff, siltstone and sandstone. The siltstone is dark grey to black and the tuff is usually light grey with individual beds averaging about 2.5 cm in thickness, giving a banded pattern to the outcrop. The sandstones are volcanogenic, light grey or green, and fine to medium grained with beds to 25 cm thick. Graded bedding, load casts and soft sediment deformation structures occur locally. Rare beds of grey to green, massive volcanoclastic rock are found, especially in the type section. Volcanic flows have not been seen in the Echo Island Member along Harrison River or on Echo Island (Crickmay, 1925) but southeast and north of Mount McRae several plagioclase porphyry flows up to 10 m thick are found within the interbedded tuff, sandstone and shale. The flows are green, resembling the green andesitic flows of the Weaver Lake Member, and have plagioclase phenocrysts up to 5 mm long. The member is well layered and folding is common with broad open folds east of Mount McRae and a tighter anticline on the east shore of Echo Island. This folding may be a result of minor local deformation following deposition of this unit and prior to deposition of the Lower Callovian Mysterious Creek Formation as similar folds are not noted in Callovian or younger deposits.

Depositional environment

The presence of tuff, siltstone and volcanogenic sandstone and the decrease in volcanic flows compared with the Weaver Lake Member marks the waning and end of Middle Jurassic volcanism in the area. The well developed stratification of the sediments probably resulted from successive episodes of volcanic activity which laid down a bed of ash, followed by marine sedimentation. The uniform thickness of beds suggests that volcanism occurred regularly. Extensive flows are rare.

Trigoniid bivalves, typical of shallow marine waters, and belemnites are found locally in the member, suggesting a probable nearshore marine setting. Soft sediment deformational structures probably resulted from disturbance of the slope sediments by volcanic or seismic activity.

Structural relations

The lower contact is well exposed near the southern tip of Echo Island at the type section. The contact is conformable (Crickmay, 1925, p. 34) with well bedded tuff, sandstone and siltstone resting on massive flows and tuffs of the Weaver Lake Member.

Biostratigraphy and age

The Echo Island Member has yielded belemnites and trigoniid bivalves which are long ranging and cannot be used to date the unit precisely. The member lies between Aalenian (Weaver Lake Member) and Early Callovian (Mysterious Creek Formation). For reasons discussed later (see Mysterious Creek Formation – Structural Relations) its age is believed to be Early Bajocian(?).

Mysterious Creek Formation

Nomenclature and distribution

Crickmay (1925) first described this formation and named it after Mysterious Creek, which has since been renamed Mystery Creek. The type area, 2 km west of the mouth of Hale Creek and northwest to Mystery Creek valley, has many isolated outcrops (lat. 49°30'20"N; long. 121°55'30"W).

The main exposure of the Mysterious Creek Formation lies in the type area but it also outcrops along the southern shore of Harrison River where it underlies the Kent Formation and, probably, a thin section of Billhook Creek Formation (Crickmay, 1962). On the southeast shore of Harrison Lake, 3.5 km northeast of Harrison Hot Springs (Fig. 2), metamorphosed and deformed siltstones outcrop and are doubtfully assigned to Mysterious Creek Formation.

Lithology

The Mysterious Creek Formation comprises dark grey to black shale and siltstone and fine grained green to grey sandstone. Along much of Hale Creek the shale and siltstone is sheared by faulting and intruded by dacitic(?) dykes. Calcite veins and fault gouge are common in the valley 2 to 3 km west of the creek mouth. In Mystery Creek valley the shale is thinly bedded to laminated and commonly manganese stained. Siltstones are in beds 10 to 30 cm thick, commonly fractured and contain disseminated pyrite.

The fine grained sandstone may be tuffaceous and is generally near the top of the formation (e.g. localities 18, 19, 21, 26, 41) and in the area southwest of locality 26 (section 1) (Fig. 4). It is usually medium to thick bedded (0.2-2.0 m) and non-calcareous. A thin section of tuffaceous sandstone from 400 m east of locality 18 contains abundant volcanic glass shards (Fig. 9). The shards do not appear to be reworked because of their sharp outline suggesting that there was Early Callovian volcanic activity. Thickness of the Mysterious Creek Formation is about 700 m.

Depositional environment

Taylor (1982) proposed a series of paleocommunities based on the relative abundance of several environmentally controlled faunas, including ammonites, bivalves, brachiopods and belemnites. These paleocommunities are depth related and Taylor (1982) proposed the term Composite Assemblage to describe these faunal associations.

Localities 17 and 17A (Fig. 4) of the Mysterious Creek Formation contain an abundance of ammonites in grey to black, rarely laminated, non-calcareous shale and siltstone. Shallow marine bivalves are absent but a large, thin shelled pectinid bivalve was found. The inferred environment is offshore marine approximately equivalent to Composite Assemblage D; probably D(2) as belemnites are extremely rare (Taylor, 1982).

About 2 km to the northwest at section 1 (locality 26, Fig. 4) are fine grained sandstones which are age equivalent to the sediments at localities 17 and 17A, based on ammonites. Trigoniid bivalves and belemnites are most common. Ammonites are present locally and rare brachiopods were noted. This fauna, particularly the trigoniids, and the enclosing sediments suggest shallow marine waters equivalent to Composite Assemblage B of Taylor (1982). Localities 18, 19, 21 and 41 may belong to this assemblage but fossils are rare at these localities. The differing composite assemblages of age equivalent localities suggest rapid facies changes within the Mysterious Creek Formation.

Structural relations

The contact between the Echo Island Member of Harrison Lake Formation and the Mysterious Creek Formation has not been seen in outcrop. East and north of Mount McRae (Fig. 4), small scale folding of rocks in the Echo Island Member is common but in the stratigraphically higher Callovian Mysterious Creek Formation no similar small scale folding is seen and the beds consistently dip to the north and northeast. This and the lack of Bathonian fossils in collections from this area and the general absence of Upper Bajocian and Lower Bathonian rocks throughout British Columbia (Frebold and Tipper, 1967, p. 8; 1970, p. 12; Fig. 7, in pocket) suggest a possible hiatus between the Harrison Lake Formation (Echo Island Member) and the overlying Mysterious Creek Formation, from Late(?) Bajocian to Late Bathonian time.

Biostratigraphy and age

Callomon (1984) has proposed a biostratigraphic zonation for the post-Early Bajocian Jurassic ammonites of northern and western North America (Fig. 10). The Harrison Lake area belongs in Callomon's Region B – North American Cordillera. The oldest Callovian locality in the Harrison Lake area is found in the Mysterious Creek Formation about 1 km west of the mouth of Hale Creek at locality 17A (Fig. 4). At this locality *Lilloettia lilloetensis* was collected from steeply dipping sheared siltstone. Locality 35 and section 1 (locality 26) yielded specimens assigned to *L. lilloetensis*. Locality 17A belongs in the *Cadoceras comma* Fauna B8 (Fig. 10) of Callomon (1984) which is approximately equivalent to Imlay's (1975) *Cadoceras catostoma* zone now abandoned for reasons discussed by Callomon (1984, p. 159). Fauna B8 is further divided into sub-faunas and locality 17A is assigned to the *Lilloettia lilloetensis* Fauna B8c of Callomon (1984, p. 161).

About 10 m stratigraphically above locality 17A, still within the Mysterious Creek Formation, locality 17 yielded a large collection of fragmented or complete ammonites and rare bivalves. Fragments of *Cadoceras* macroconchs are most abundant but identification of these to species level is impossible. Six fairly complete specimens of *Cadoceras comma* Imlay have been collected from this locality and four specimens described as *Cadoceras* (*Paracadoceras*) *tonniense* Imlay. Some 20 specimens of the microconch *Cadoceras* (*Pseudocadoceras*) *grewingki* Pompeckj were collected; their smaller size resulted in better preservation. A single specimen of *Lilloettia tipperi* Frebold was also collected from this locality. Locality 17 can be referred to Callomon's (1984) *Cadoceras comma* Fauna B8 and is placed in the *Cadoceras wosnessenskii* Fauna B8e (Fig. 10). Also placed in this Fauna B8(e) by Callomon (1984) are the species *C. catostoma* Pompeckj, *C. glabrum* Imlay and *C. comma* Imlay.

The three species at locality 17 (*C. comma*, *C. (P.) grewingki*, *C. (P.) tonniense*) occur together in localities within the lower part of the Chinitna Formation, Alaska

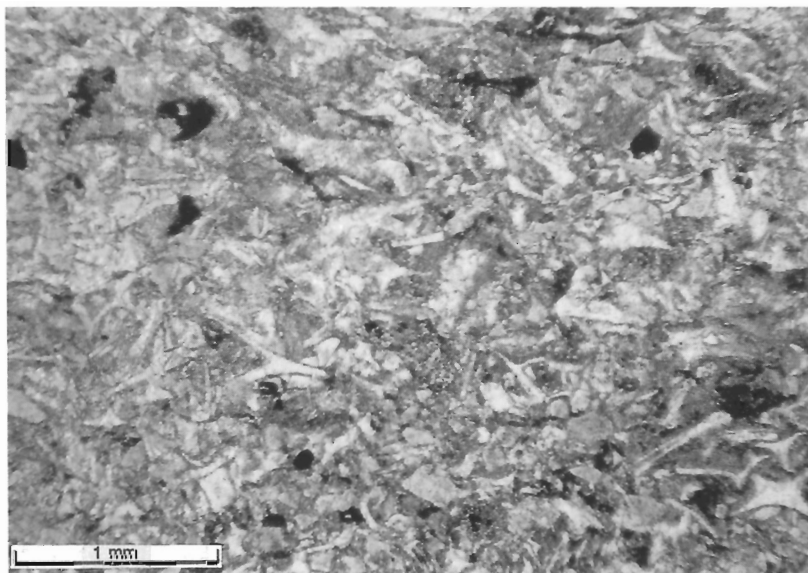


Figure 9.

Glass shards in tuffaceous sandstone of the Mysterious Creek Formation indicating possible Early Callovian volcanic activity. Thin section taken in plane polarized light. Magnification x42. GSC 1992-186-D

| | | REGION B-CORDILLERA | |
|------------|---|--|--|
| | | U.S.-B.C. | S. ALASKA |
| CALLOCVIAN | MIDDLE | | B9 <i>Stenocadoceras stenoloboide</i> |
| | <i>Kosmoceras jason</i> <i>Sigaloceras calloviense</i> + <i>Cadoceras sublaeue</i> | | |
| LOWER | <i>Macrocephalites macrocephalus</i> + <i>Cadoceras elatmae</i> <i>Paracadoceras breue</i> + <i>Keplerites kepleri</i> | <i>Cadoceras comma</i> B8d <i>Lilloettia tipperi</i> B8c <i>Lilloettia lilloetensis</i> B8b <i>Paracadoceras tonniense</i> B8a <i>Keplerites loganians</i> | B8g <i>Lilloettia stantoni</i> B8f <i>Keplerites abruptus</i> B8e <i>Cadoceras wosnessenskii</i> |

Figure 10. Early Callovian faunal successions for the Cordilleran region together with equivalent European faunal successions (modified from Callomon, 1984).

(Imlay, 1953b, 1975), but the problem of relative stratigraphic position of species is greatest during the time period of the *C. comma* Fauna B8 assemblage (Callomon, 1984). Overlapping age ranges for many of the species is common and Fauna B8 is divided into subfaunas based on the relative abundances of particular species. For example, *C. (P.) tonniense* is generally most common in Fauna B8b (Fig. 10), but it can range through other faunal assemblages such as Fauna B8e (locality 17). Callomon (1984, p. 161) stated that these two faunas (B8b and B8e) are similar and the time-gap between the two must have been short.

Cadoceras (Pseudocadoceras) growingki, which occurs at localities 17 and 30, is not discussed with respect to its zonal affinity by Imlay (1975) or Callomon (1984). The similar species *C. (Pseudocadoceras) petelini* Pompeckj, however, is placed in the *Cadoceras (Stenocadoceras) stenoloboide* Fauna B9 (Fig. 11) by Callomon (1984) which is equivalent to the *C. (S.) stenoloboide* zone of Imlay (1975). The age of Fauna B9 is assumed to be Middle Callovian, although definite proof is lacking (Callomon, 1984, p. 162). *C. (P.) growingki* and *C. (P.) petelini* are found together at localities within the Shelikof Formation, Alaska (Imlay, 1953b, 1975) and possibly the Taseko Lakes region of British Columbia (Frebold and Tipper, 1967) implying that *C. (P.) growingki* may belong to Fauna B9.

C. (P.) growingki is associated with *C. comma* of Fauna B8(e), which is middle Early Callovian, and *C. (P.) petelini* of Fauna B9, which is Middle Callovian. Therefore, *C. (P.) growingki* may well range through the time

period between Fauna B8 and Fauna B9 (Fig. 10). Another possibility is that Fauna B9 is somewhat older, perhaps late Early Callovian.

About 10 to 15 m stratigraphically above locality 17 is locality 18 (Fig. 4) which yielded 10 poorly preserved *Cadoceras* fragments, one bivalve and several belemnites. One ammonite specimen resembles *Cadoceras catostoma*, belonging to the *C. wosnessenskii* Fauna B8e of Callomon (1984). Locality 18 is therefore assigned to the same faunal assemblage as locality 17.

South of Harrison River at locality 1, *Lilloettia* cf. *stantoni* and *Xenocephalites* cf. *vicarius* were collected. Imlay (1975, p. 7) placed all species of *Lilloettia* into his *Cadoceras catostoma* zone (Callomon's (1984) Fauna B8 assemblage) except for *L. stantoni*. Callomon (1984, p. 162) felt there was consistent evidence of a higher *Lilloettia* assemblage that differed from his older *L. lilloetensis* Fauna B8c. This higher assemblage is described by Callomon (1984) as the *Lilloettia stantoni* Fauna B8g and placed at the top of the *C. comma* Fauna B8 assemblage (Fig. 10). Locality 1 may therefore be younger than the other Callovian localities west of Harrison Lake, although it is still Early Callovian (Macrocephalus Zone), or it may be of the same age. Localities: 17, 17A, 18, 19, 21, 26, 29, 30, 35, 36, 38, 41.

Crickmay (1930a) identified several bivalve species from the Mysterious Creek Formation, including *Entolium hertleini* Crickmay, *Haidaia billhookensis* Crickmay, *H. packardi* Crickmay, *H. statluensis* Crickmay, *Anomia columbiana* Crickmay and *Astarte harrisonensis* Crickmay.

Paleobiogeography

The Early Callovian ammonite succession from the Mysterious Creek Formation west of Harrison Lake bears marked similarities with other locations along the Northeast Pacific Coast. Such localities include southern Alaska (Imlay, 1953b, 1975), southwestern British Columbia (Frebold and Tipper, 1967), Oregon (Imlay, 1964) and possibly California (Imlay, 1961). Alaska is faunally by far the richest area, with taxa of both the Boreal Realm (*Cadoceras*, *C. (Paracadoceras)*, *C. (Stenocadoceras)*, *Pseudocadoceras*, *Keplerites*) and East Pacific Realm (*Lilloettia*, *Xenocephalites*) along its southern coast. The Harrison Lake area yields fewer Early Callovian ammonite species than southern Alaska but all species found in the Mysterious Creek Formation are present in Alaska (Chinitna Formation) with the exception of *L. tipperi* and the taxa from Mysterious Creek Formation also represent both the Boreal and East Pacific Realms. Successions from Mexico lack any Boreal taxa but contain the East Pacific genera *Lilloettia* and *Xenocephalites* (Callomon, 1984; Sandoval et al., 1990).

The Western Interior Region was the site of an Early Callovian regression (Callomon, 1984) and faunas from this region once described as Early Callovian (Imlay, 1953a), are now considered to be Bathonian (Callomon, 1984). The Arctic Region has so far yielded few Early Callovian ammonites and

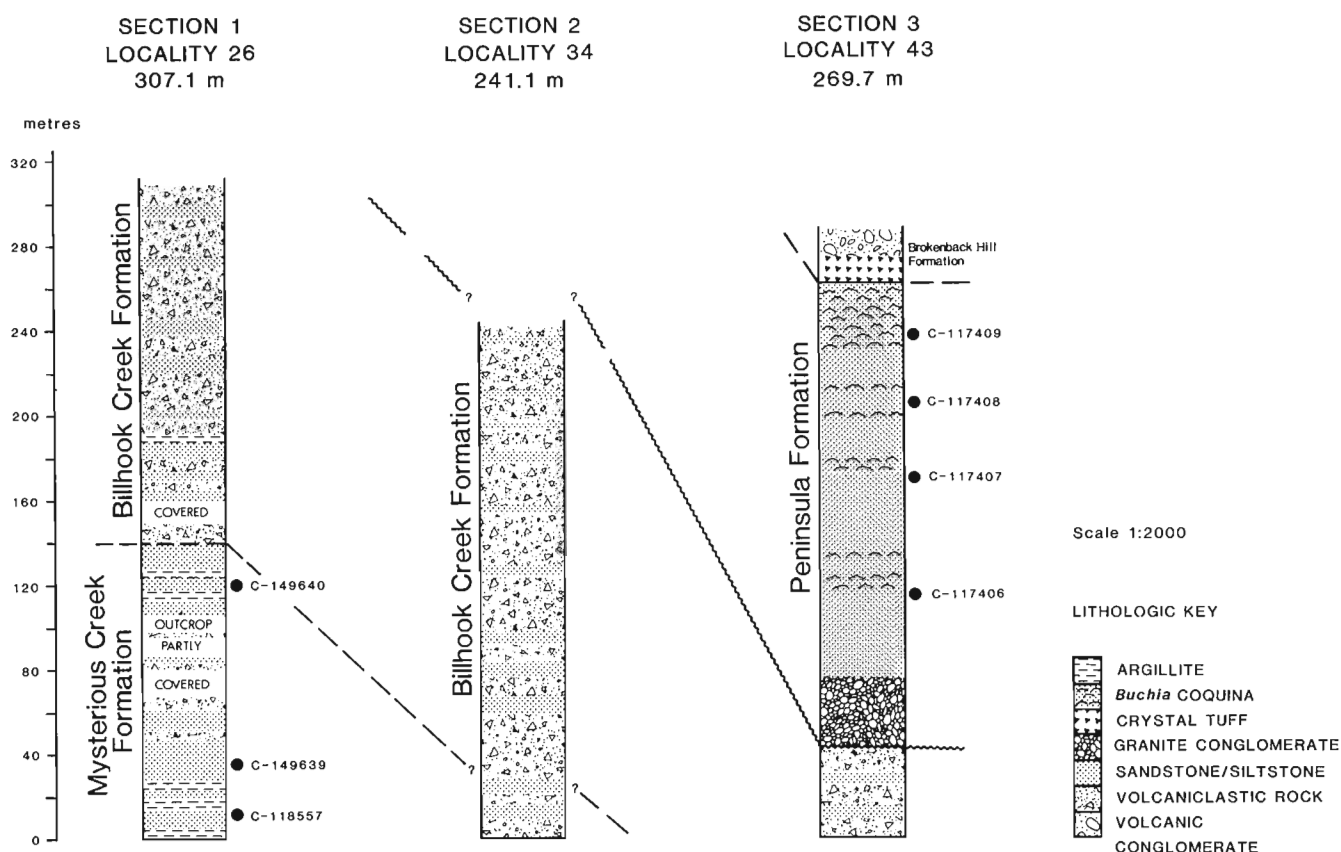


Figure 11. Measured stratigraphic sections for the Mysterious Creek, Billhook Creek and Peninsula formations. Locations for these sections and information on the fossil localities can be found in Figure 4 and Appendix 1.

those known are not closely similar to the faunas from the Cordilleran Region (Imlay, 1953b), but the major features of the ammonite fauna from the Arctic region are almost identical with those from East Greenland (Callomon, 1984) suggesting deposition in the same broad Arctic basin.

Correlations

Between the Harrison Lake and Mysterious Creek formations is a significant faunal gap spanning Late Bajocian and Bathonian time (Fig. 7) which is regionally extensive (Frebold and Tipper, 1970). The Early Callovian Mysterious Creek Formation is lithologically similar to siltstones and shales in the basal part of the Relay Mountain Group, Taseko Lakes (Jeletzky and Tipper, 1968). Other units of the same age are shown in Figure 7.

Billhook Creek Formation

Nomenclature and distribution

This formation was named by Crickmay (1930b), although he described no type section. It is well exposed 3 km southwest of the mouth of Mystery Creek on a small hill. Section 2 (Fig. 11) which crosses the southeast side of this hill along a roadcut, is here designated the type section (lat. 49°30'27"N; long. 121°54'56"W).

Originally, Crickmay (1925, p. 42) included rocks of the present Billhook Creek Formation west of Long Island within the Kent Formation; the two sequences are at about the same stratigraphic level but are lithologically dissimilar. Later he divided the two sequences into separate formations (Crickmay, 1930b, 1962), naming the tuffaceous sequence west of Long Island the Billhook Formation, and stated that a sliver of this formation may be present between Mysterious Creek Formation and Kent Formation south of Harrison River (Crickmay, 1962, p. 4). The Billhook Creek Formation also outcrops along the western shore of Cascade Peninsula.

Lithology

Volcaniclastic breccias predominate in the Billhook Creek Formation. They are light to dark green on fresh surfaces (Fig. 12) and weather reddish brown. Beds are commonly thick, massive and separated by thin- to medium-bedded volcanogenic sandstones. Clasts are angular, less than 3 cm in diameter and composed entirely of plagioclase-rich volcanic material. Plagioclase crystals are acicular to equant, and supported in a fine grained groundmass; rare clasts contain abundant spherulites. The matrix is probably ash, commonly with calcite alteration. Lesser amounts of chlorite and epidote are present and the high pressure/low temperature metamorphic mineral lawsonite was noted by

M. Brandon (pers. comm., 1987), although it was not seen in the three thin sections cut during our study. Quartz filled microfractures are present.

The volcanogenic sandstone interbeds are fine to medium grained, thin to medium bedded, green to dark grey and rarely contain fossils. Crossbedding was reported at one locality by Brookfield (1973, p. 1688) but was not seen by the writers. An offshore facies of the Billhook Creek Formation consisting of dark grey, non-calcareous to slightly calcareous shale and tuffaceous siltstone is present on the western shore of Cascade Peninsula (Fig. 4).

At the type section (locality 34, Fig. 4) a 215 m section was measured; total thickness of the formation is slightly greater, possibly 230 m.

Depositional environment

West of Long Island, sediments of the Billhook Creek Formation were probably deposited in shallow marine and fluvial environments. Carbonized wood debris is abundant in the sandstones and several beds contain carbonized logs.



Figure 12. Characteristic volcaniclastic rocks of the Billhook Creek Formation which forms much of the section west of Long Island. Clasts are subangular, plagioclase-rich, set in a fine grained commonly calcite replaced matrix and average 1 cm diameter. GSC 1992-186E

Belemnites occur in some sandstone beds but ammonites were found only at locality 20 (Fig. 4) in a medium grained sandstone, associated with bivalves (including the bivalve *Pinna*) and belemnites. On the west side of Cascade Peninsula (locality 15) the shale, siltstone and the faunas they contain indicate a deeper water facies equivalent of the sandstones and volcaniclastic strata west of Long Island.

Locality 20 yields mainly bivalves, including *Pinna*. The approximate parallel orientation of the less common belemnites and the fragmented remains of ammonites suggest moderate wave action in shallow marine waters. Locality 20 fits best into Taylor's (1982) Composite Assemblage B. At locality 15, which on the basis of ammonites is roughly time equivalent with locality 20, ammonites are the most common fossils, although they are low in diversity. Thin shelled bivalves, including *Oxytoma* are also abundant (see Brookfield, 1973, p. 1689). This locality is tentatively placed into Composite Assemblage D(2) of Taylor (1982). Brookfield (1973) stated and the writers concur that the faunas present at locality 15 suggest a relatively deep shelf environment. The close proximity of localities 15 and 20, which differ in depositional environment, indicate rapid facies changes, possibly near volcanic islands.

Structural relations

The contact between Mysterious Creek Formation and Billhook Creek Formation is upwardly gradational, with siltstone and green sandstone in the upper part of Mysterious Creek Formation clearly grading into volcaniclastic rocks of Billhook Creek Formation (Fig. 13) in section 1 (Fig. 11).

Biostratigraphy and age

The faunas of the Harrison Lake area correlate well with the ammonite zonation for the Oxfordian of North America (Fig. 14) worked out by Callomon (1984). There are three Oxfordian fossil localities in the Billhook Creek Formation and only two (localities 15 and 20) yield identifiable specimens. Locality 15, which is situated on the southwest shore of Cascade Peninsula (Fig. 4), yielded mainly ammonites (*Cardioceras*) and several bivalves including an *Oxytoma* sp. Brookfield (1973) recovered mainly *Cardioceras* and *Oxytoma* from this locality and rare *Lingula* sp., *Entolium* sp., *Grammatodon* sp., *Astarte* sp. and ?*Phylloceras* sp. The ammonite *Phylloceras columbianum* Crickmay and the bivalve *Parallelodon cardiocerotatum* Crickmay were found at this locality by Crickmay (1930a).

Cardioceras (*Scarburgiceras*) *martini* Reeside is the most common ammonite species from locality 15 and is placed in Callomon's (1984) *Cardioceras martini* Fauna B12 of the Cordilleran Region (Fig. 14). This Fauna B12 according to Callomon (1984) is close to if not identical with the *C. reesidei* Fauna A13a of the Western Interior Region. Locality 15, which is assigned to Fauna B12 (Fig. 14) is therefore Early Oxfordian in age (Bukowskii Subzone).

Associated with *C. (S.) martini* at locality 15 are two specimens of *Cardioceras* (*Cardioceras*) cf. *hyatti* Reeside. Although rare at this locality, *C. (C.)* cf. *hyatti* is common at



Figure 13.

Gradational contact between siltstones and sandstones of Mysterious Creek Formation and volcaniclastic rock of Billhook Creek Formation. Photograph taken at section 1. GSC 1992-186F

| | EUROPE | WESTERN INTERIOR | CORDILLERA | |
|-----------------|-----------------------------|-------------------------------|-----------------------------------|---------------------------|
| | | | U.S.-B.C. | S. ALASKA |
| LOWER OXFORDIAN | <i>Cardioceras cordatum</i> | A 14b <i>C. distans</i> | | |
| | <i>C. costicardia</i> | A 14a <i>C. hyatti</i> | | B 13 <i>C. spiniferum</i> |
| | | A 13cc <i>mathiaspeakense</i> | | |
| | <i>C. bukowskii</i> | A 13b <i>C. mountjoyi</i> | | B 12 <i>C. martini</i> |
| | | A 13a <i>C. reesidei</i> | | |
| | <i>C. praecordatum</i> | | B 11b <i>C. praecordatum</i> | |
| | <i>C. scarburgense</i> | A 12 <i>C. cordiforme</i> | B 11a <i>C. aff. scarburgense</i> | |
| | | | | |

Figure 14. Early Oxfordian faunal successions for the Western Interior and Cordilleran regions together with equivalent European faunal subzones (modified from Callomon, 1984).

locality 20 west of Long Island (Fig. 4). Callomon (1984, p. 156) placed *C. (C.) cf. hyatti* into his Western Interior *Cardioceras distans* Fauna A14, which is further divided into the *C. hyatti* Fauna A14a and *C. distans* Fauna A14b (Fig. 14). Fauna A14a lies in the Early Oxfordian Cordatum Zone of Europe; Costicardia Subzone. It appears to be roughly equivalent to Callomon's (1984) Cordilleran *Cardioceras spiniferum* Fauna B13, which is found in the upper Bukowskii to lower Costicardia subzones (Fig. 14). Also present at locality 20 are abundant shallow marine bivalves (including *Pinna*), belemnites and *Cardioceras (Cardioceras) lillooetense* Reeside. This ammonite species belongs in the *C. spiniferum* Fauna B13 and its presence with *C. (C.) cf. hyatti* implies a position for locality 20 in the Early Oxfordian Cordatum Zone and probably the lower Costicardia Subzone (Fig. 14).

The ammonites at the two localities show that the beds at locality 15 (Bukowskii Subzone) are slightly older than those at locality 20 (lower Costicardia Subzone). The two specimens of *C. (C.) hyatti* collected from locality 15 may roughly mark the first appearance of this species, suggesting that locality 15 may lie in the upper part of the Bukowskii Subzone.

Paleobiogeography

Cardioceratids spread southwards as marine waters transgressed once again into the Western Interior Region in Late Callovian and Early Oxfordian time. This led to faunal similarities between the Cordilleran and the Western Interior regions by Early Oxfordian (Imlay, 1982). The genus *Cardioceras* is common in both regions and although some species appear to be confined to one region, many are found in both (Imlay, 1964, 1981, 1982). The Early Oxfordian ammonites of the Western Interior Region lived in a shallow sea extending as far inland as Wyoming and parts of adjoining states (Imlay, 1947, 1982) and possibly included Colorado and northern New Mexico (Hallam, 1975). This shallow sea was called the Logan Sea by Schuchert (1923) (now called the Sundance Sea) who believed it to have been separated from the open ocean to the west by mountains which joined the craton to the south. This bordering landmass to the west was called "Jurozephyria" by Crickmay (1931). It extended from southeastern Arizona through Nevada and western Idaho and along the Omineca Belt in British Columbia. Neither hypothesis can be excluded. Faunal similarities and differences between the two regions could be attributed to physical and climatic barriers. The Early Oxfordian of southern Alaska, the Bowser Basin and Harrison Lake contain the probable pelagic genus *Phylloceras* (Fig. 15) together with the other ammonite forms, but this genus is notably absent in the Western Interior Region (Imlay, 1982). The presence of *Phylloceras* probably indicates access to the open ocean (Callomon, 1984; Taylor et al., 1984, p. 125) and its absence in the shallow epeiric and shelf seas (Imlay, 1953b) of the Western Interior Region may therefore be due to ecological factors.

Correlations

The Lower Oxfordian volcaniclastic breccias and sandstones of the Billhook Creek Formation are age equivalent to siltstones and shales of the Relay Mountain Group (Jeletzky and Tipper, 1968), but volcanic material of this age is uncommon in British Columbia. The Oxfordian Netalzul volcanics are known in the Smithers area (Tipper and Richards, 1976) and Upper Jurassic

tuff beds are present in the Mount Waddington area (Tipper, 1969) but the ages of these units probably do not overlap with the Billhook Creek Formation.

Kent Formation

Nomenclature and distribution

The Kent Formation is exposed south of Harrison River and was named by Crickmay (1925) after the municipality of Kent. Its type locality is on Mount Agassiz (lat. 49°16'34"N; long. 121°50'29"W) where Crickmay (1925) measured 930 m of strata. Other outcrops are on the west side of Cemetery Hill 4 km south of Mount Agassiz. Crickmay described Kent Formation west of Long Island and on Cascade Peninsula but the beds at the former belong to the Billhook Creek Formation (Crickmay, 1930b) and those at the latter are included here in the Peninsula Formation.

Lithology

The Kent Formation is mainly clast supported conglomerate. Clasts are rounded to subrounded, poorly sorted, ranging from less than 1 cm up to 8 cm in diameter and include indurated black shale, chert, interbedded tuffs and volcanic flow rock. The volcanic clasts resemble rock types of the Weaver Lake Member

of Harrison Lake Formation in lithology and colour. Interbedded tuff clasts may be from the Echo Island Member and indurated shale clasts from the Mysterious Creek Formation. Granitic clasts are absent in contrast to the younger Peninsula Formation, which contains abundant granitic clasts. Interbeds of siltstone and sandstone are common in the conglomerate. The siltstone is dark grey, locally contains plant remains and commonly shows a fairly well developed cleavage. Sandstones are medium grained, commonly massive or contain conglomerate beds up to 15 cm thick. The sediments become hornfelsed east of Mount Agassiz near a Tertiary granite pluton, an apophysis of the Chilliwack Batholith (Fig. 4). Thickness is estimated at about 1000 m.

Depositional environment

Clasts within the Kent Formation commonly show a vague orientation suggesting imbrication. Their poor sorting and close spacing may indicate deposition in braided streams as Brookfield (1973) suggested. The depositional environment was possibly fluvial and perhaps deltaic, because plant remains are noted in the black siltstones and no marine fossils were found in the formation.

Structural relations

The basal contact of the Kent Formation is not well exposed but lies on the north slope of Mount Agassiz. Conglomerate, typical of the Kent Formation was noted at one locality, and 200 m to the north, shales and siltstones of the Mysterious Creek Formation outcrop. Crickmay (1962) noted a thin outcrop of the Billhook Creek Formation between Mysterious Creek and Kent formations on Mount Agassiz but this was not seen by the writers.

About 2 km south of Mount Agassiz highly deformed and mineralized shale and siltstone outcrop on the flanks of two hills. The name Agassiz Prairie Formation was assigned to these sediments by Crickmay (1925). He described them as conformably overlying the Kent Formation on the west side of Cemetery Hill and found a single crushed ammonite of probable Late Jurassic age (Crickmay, 1925, p. 46). Brookfield (1973) found that based on a fauna collected by him which included *Lilloettia* sp., the sediments are in fact beneath the Kent Formation. If the shales and siltstones overlie the Kent Formation they would be better described still as a member of the Kent Formation as little is known of their stratigraphy or exact age. If they are stratigraphically beneath the conglomerate, they almost certainly belong to the Mysterious Creek Formation (Brookfield, 1973).

Biostratigraphy and age

Fossils have not been found in the Kent Formation but on the basis of superjacent and subjacent stratigraphic units, it may be as old as Early Oxfordian and as young as Early Berriasian. Brookfield (1973) concluded, and the writers agree, that the age is between Early Oxfordian and Tithonian.

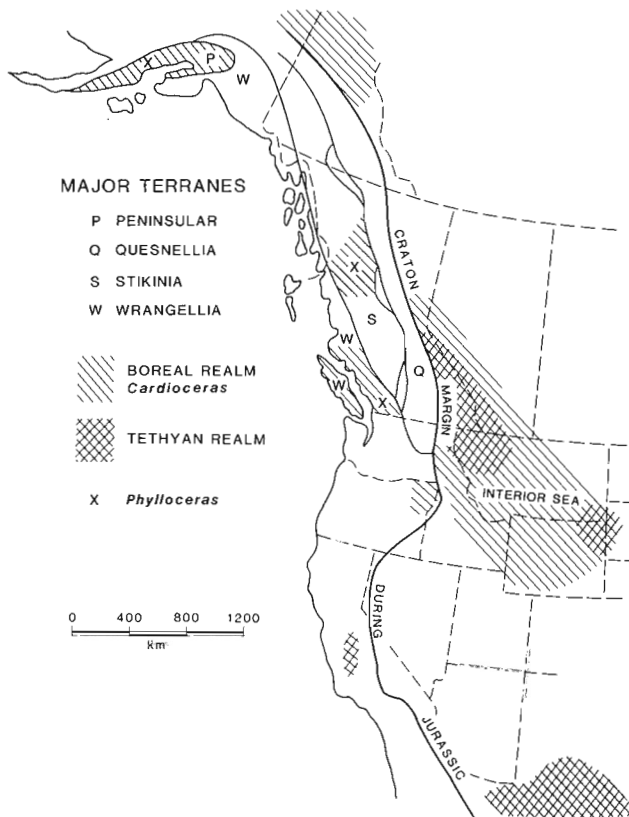


Figure 15. Paleobiogeographic map of western North America for Oxfordian time (modified from Taylor et al., 1984).

Peninsula Formation

Nomenclature and distribution

The Peninsula Formation was named by Crickmay (1925) after Cascade Peninsula on which it outcrops. The type section is west of Long Island near the lakeshore south of Brokenback Hill. A better exposed section (section 3, Fig. 11), described in this report, outcrops along a roadcut 3 km due west of the mouth of Mystery Creek (lat. 49°28'54"N, long. 121°51'50"W) (Fig. 16). The formation extends westward from Harrison Lake at least as far as the Chehalis Valley.

Crickmay (1925) measured 384 m (1260 ft) of sandstone at the type section near the lakeshore north of Hale Creek. The section measured by the writer at locality 43 (Fig. 4) is 218 m thick (Fig. 11), displays a more complete section of the basal conglomerate, and has better fossil control than the type section.

Lithology

The Peninsula Formation consists of basal conglomerate (Fig. 17) which grades upward into sandstone. Clasts of the conglomerate are predominantly intrusive rock with lesser volcanic clasts and rare sedimentary (shale, siltstone, sandstone) clasts. The conglomerate is usually clast supported, and clasts locally range up to 50 cm in diameter and are set in a medium- to coarse-grained sandstone matrix. Higher in the section medium and coarse grained sandstone is richly fossiliferous and has thin (5-10 cm) interbedded conglomerate beds (Fig. 18). It is light grey to green, calcareous, and usually in beds 10 to 20 cm thick. The light grey sandstone has a "salt and pepper" appearance due to the presence of plagioclase, quartz and hornblende grains. Some sandstone found in the upper part of the section is green due to alteration of a tuffaceous component.

As stated previously, clasts of the basal conglomerate are up to 50 cm in diameter but such clasts have been found only in the Chehalis Valley. At locality 43 clasts are at most 20 to

30 cm in diameter and average 10 cm. This decrease in clast size continues to the type section near the lakeshore where matrix supported intrusive clasts 2 to 3 cm in diameter and chert pebble lenses were noted. This marked decrease in clast size indicates provenance from the west for the intrusive igneous clasts (Arthur, 1986).

A thin section of medium grained sandstone from the Peninsula Formation contains quartz, hornblende, plagioclase and mica grains. Volcanic rock fragments make up about 15% of the grains, are plagioclase-rich and commonly chloritized. Grains are subangular to subrounded, poorly sorted, and are set in a fine matrix which forms about 10% of the rock. Chlorite is the main cement. Shell fragments were seen in the thin section.

Depositional environment

In the Chehalis Valley sediments of the Peninsula Formation were deposited in a probable nonmarine environment where 50 cm clasts are found in conglomerates and fossils are lacking. On Cascade Peninsula to the east a shallow marine environment existed. Coarse conglomerate is present west of Harrison Lake but clast size decreases eastward as does the thickness of the basal conglomerate. In the area immediately west and south of Brokenback Hill, sediments of the formation were probably deposited in a beach environment. Wood debris is common as is the shallow marine bivalve *Buchia* which form coquinas up to 9 m thick (Fig. 19). Belemnites are abundant but coquinas (Fig. 20) were found only in float blocks, making it impossible to determine current direction. The sandstone is usually well sorted and medium to coarse grained, also indicating a probable shallow marine environment. Green tuffaceous sandstone becomes common near the top of the section, marking the initiation of the second major regional volcanic episode (Brokenback Hill Formation) (Arthur, 1986).

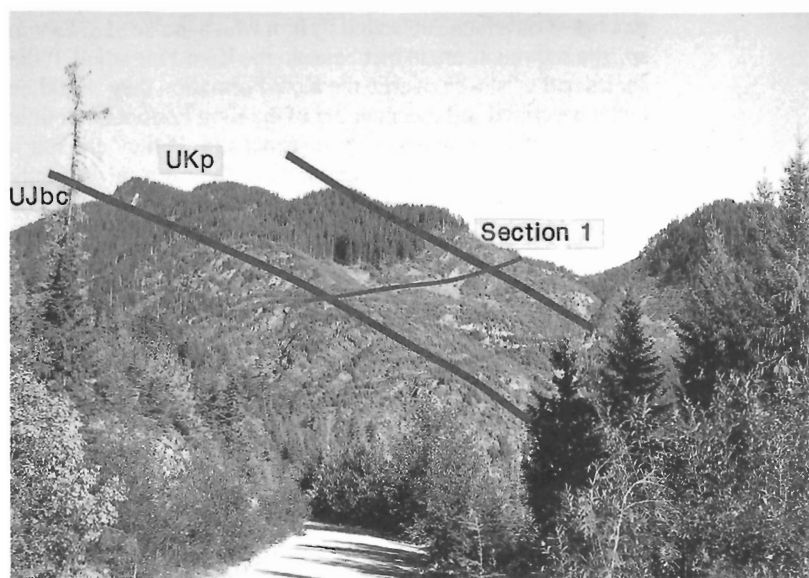


Figure 16.

Location of section 3 showing Peninsula Formation (UKp) lying unconformably on Billhook Creek Formation (UJbc). View looking to northwest. GSC 1992-186G



Figure 17.

Basal conglomerate of the Peninsula Formation showing abundance of granitic clasts; about 65%. Photograph taken 2 km northwest of mouth of Hale Creek. GSC 1992-186H



Figure 18.

Thin conglomerate beds in sandstones of Peninsula Formation. GSC 1992-186I

Structural relations

Between the Billhook Creek and Peninsula formations west of Long Island is an unconformity spanning the interval from Early Oxfordian to Early Berriasian. This unconformity is important because it marks a time of significant uplift and erosion which unroofed plutons within a volcanic arc to supply granitic material to the Lower Berriasian basal conglomerate of the Peninsula Formation (Arthur, 1986).

During an earlier uplift, in Late Jurassic time, conglomerates of the Kent Formation which lack granitic clasts were deposited. Crickmay (1931, p. 46) thought the conglomerate of the Kent Formation represented a period of regional orogenic deformation which he called the Agassiz Orogeny. Brookfield (1973, p. 1691) believed the conglomerate simply indicated uplift and not necessarily orogenic deformation. However, on the southwest shore of Cascade Peninsula, argillaceous sediments of the Billhook Creek Formation have a well

developed cleavage (Fig. 21) whereas calcareous rocks of the overlying Peninsula Formation, which is lithologically similar, lacks this cleavage; it is not clear whether this is due to compositional differences between the units or to a deformational event in the lower unit. The same relationship was noted along the northwest shore of Cascade Peninsula. This lends some credibility to Crickmay's Agassiz Orogeny, although the orogenic event may have been relatively minor. The uplift during this time interval is comparable to the inferred Late Oxfordian to Early Kimmeridgian uplift of the Taseko Lakes region situated to the north (Jeletzky and Tipper, 1968; Brookfield, 1973).

Biostratigraphy and age

Faunas of the Late Jurassic and Early Cretaceous of Canada have been exhaustively studied by Jeletzky (1965, 1984) who described a zonal scheme for western and Arctic Canada



Figure 19.

Buchia coquina in sandstones of Peninsula Formation. From section 3. GSC 1992-186J

Figure 20.

Belemnite coquina in sandstone of Peninsula Formation west of Brokenback Hill on Forest Service road. GSC 1992-186K

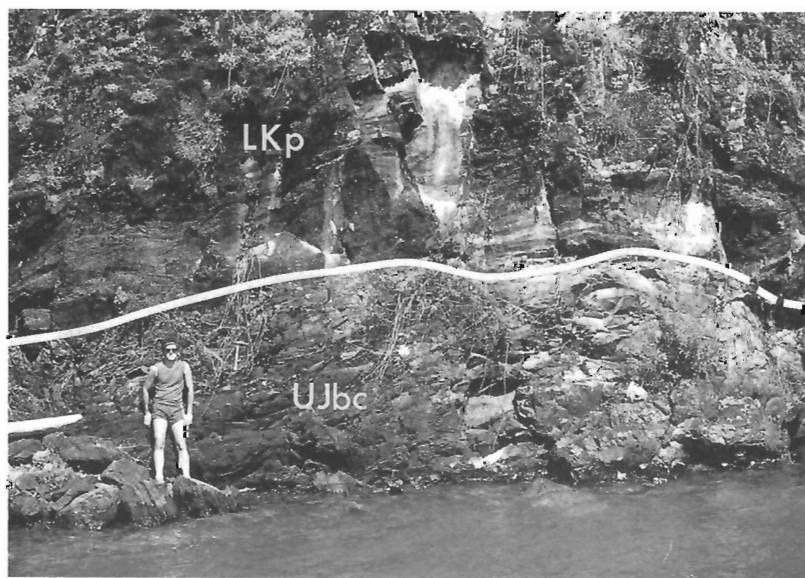
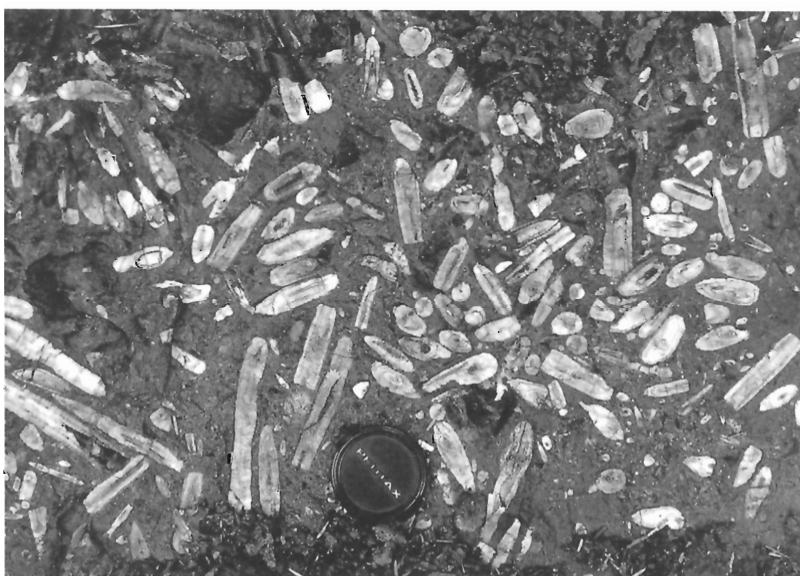


Figure 21.

Jurassic-Cretaceous unconformity on southwest shore of Cascade Peninsula where cleaved siltstones of the Billhook Creek Formation (UJbc) underlie the Peninsula Formation (LKp) that comprises calcareous siltstones and sandstones which lack this cleavage and contain granite and limestone clasts. GSC 1992-186L

(Jeletzky, 1984, Fig. 10), and a simplified version of this is shown in Figure 22. Cretaceous fossils from both Peninsula and Brokenback Hill formations were sent to J.A. Jeletzky for identification. The names and ages for Cretaceous fossils discussed in this report have been obtained from Jeletzky's unpublished Report Km-1-1986-JAJ, unless otherwise stated.

Buchia collected by Crickmay (1925, 1930a) have been synonymized by Jeletzky (1984). Crickmay also identified and described several other species of bivalves and belemnites, including *Mclearnia mclearnii* Crickmay, *Yaadia lewisagassizi* Crickmay, *Quoiechia aliciae* Crickmay, *Entolium aucellarum* Crickmay, *Astarte barbara* Crickmay, *Cylindroteuthis baculus* Crickmay and *Pachyteuthis eocretacicus* Crickmay.

| | | | |
|------------------|---------------------|--|----------|
| EARLY CRETACEOUS | ALBIAN | <i>Desmoceras (Pseudohiligella) dawsoni</i> | 97.5 Ma. |
| | | <i>Cleoniceras (Grycia?) perezianum</i> | |
| | | <i>Breweriaceras hulenense</i> | |
| | | <i>Breweriaceras (Leconteites) lecontei</i> subsp. <i>whiteavesi</i> | 113 Ma |
| | APTIAN | UNZONED | |
| | BARREMIAN | UNZONED | 119 Ma |
| | HAUTERIVIAN | <i>Simbirskites cf. broadi</i> | 124 Ma |
| | | UNZONED | |
| | | <i>Inoceramus colonicus</i> | |
| | | <i>Simbirskites (Hollisites) lucasi</i> & <i>Speetoniaceras cf. agnessense</i> | |
| | | <i>Homolomites (Wellsia) packardii</i> | |
| | VALANGINIAN | <i>Homolomites (Wellsia) oregonensis</i> | 131 Ma |
| | | <i>Buchia crassicolis</i> s. str. | |
| | BERRIASIAN | <i>Buchia pacifica</i> | |
| | | <i>Buchia tolmatschowi</i> s. lato | 138 Ma |
| | | <i>Buchia uncitoides</i> s. lato | |
| | TITHONIAN (in part) | <i>Buchia okensis</i> s. str. | 144 Ma |
| | | <i>Buchia terebratuloides</i> s. lato | |
| | | <i>Buchia fischeriana</i> s. lato | |
| | | <i>Buchia piochii</i> s. str. | |
| | | <i>Buchia cf. blanfordiana</i> | |

Figure 22. Canadian zonation for the Late Jurassic and Early Cretaceous (modified from Imlay, 1960; Jeletzky and Tipper, 1968; Jeletzky, 1984).

It appears, as discussed, that an episode of uplift, erosion and probable deformation (Crickmay's (1931) Agassiz Orogeny) followed deposition of the Lower Oxfordian Billhook Creek Formation. During this time the Kent Formation was probably deposited. Uplift and erosion of plutons supplied granitic material to the Peninsula Formation. The basal conglomerate of this formation has not been dated, but immediately above are sandstones full of *Buchia*. Section 3 (locality 43 in Fig. 4) shows a complete section of the Peninsula Formation (Fig. 11) and four fossil collections were studied by Jeletzky. The lowest in the section (C-117406) yielded exclusively *Buchia uncitoides* s. lato (Pavlow) var. *acutistriata* Crickmay from a massive coquina. Its age is Middle Berriasian. However, stratigraphically above C-117406 is C-117407 (Fig. 12) with *Buchia okensis* s. str. (Pavlow) and rare *B. uncitoides*, which are assigned to the upper part of the *Buchia okensis* Zone (Fig. 22) of the Early Berriasian according to (Jeletzky, 1965, 1984).

Locality C-117408 of section 3 is 37 m stratigraphically above C-117407 (Fig. 12) and contains *B. okensis* (normal and giant forms are common) and *B. uncitoides*, including *B. uncitoides* var. *spasskensis* Crickmay and *B. uncitoides* var. *acutistriata* Crickmay. These faunas indicate an age in the uppermost part of the *B. okensis* Zone (Early Berriasian) which is consistent with its recorded stratigraphic position slightly above C-117407. The highest collection of *Buchia* made at section 3 was from C-117409. This locality is dominated by large forms of *B. uncitoides* var. *spasskensis*. Rare forms of *B. uncitoides* var. *acutistriata* and *B. okensis* were also noted. The fauna represents the lower part of the *Buchia uncitoides* Zone of Middle Berriasian age (Fig. 22).

This possible Middle Berriasian age for C-117406 presents a problem because faunas of Early Berriasian age (C-117407, C-117408) overlie it. There is no evidence for faulting or overturning of this section. The most probable reason for the discrepancy in age for C-117406 is a failure in collecting. Ages based on *Buchia* are obtained by comparing the relative abundances of particular variants or "species" and it is possible that this collection did not give a representative view of the *Buchia* population at this locality. The remainder of the localities along section 3 appear to conform well to the zonal scheme of Jeletzky (1965, 1984).

Buchia faunas were also collected from isolated localities within the Peninsula Formation. Localities 32 and 40 yielded *Buchia* of Early Berriasian (*B. okensis* Zone) age. Locality 40 yielded *Buchia* of the same species as that from C-117408 in section 3 and was probably derived from the same bed (J.A. Jeletzky, written comm.). *B. okensis*, a large pectinid (*Mclearnia* (= *Boreionectes*)? sp.) and an indeterminate belemnite were collected from locality 32.

Faunas of Middle Berriasian age (*B. uncitoides* Zone) were collected from localities 14, 22, 25, 27, 31, 33, 37 and 39. The first two localities (14 and 22) are equivalent to C-117409 (lower *B. uncitoides* Zone) and contain the same three *Buchia* species as C-117409. Locality 22 yielded a solitary specimen of *Buchia keyserlingi* (Lahusen) var. *visiginensis* (Sokolov) and the belemnite *Cylindroteuthis* (*Artctoteuthis*) cf. *baculus* (Crickmay). The other localities

are younger than 14 and 22 but are still within the *B. uncitoides* Zone. All contain abundant specimens of *B. uncitoides* var. *acutistriata* and collections from localities 27 and 39 are exclusively this species. Localities 31 and 33 also yielded *B. uncitoides* var. *spasskenoides*. The genus *Buchia* *uncitoides* var. *catamorpha* (Crickmay) was found in large numbers at locality 25 and rare specimens were recovered from localities 33 and 37.

The youngest fossils found in the Peninsula Formation were collected from beneath a powerline tower, 350 m southwest of the fire lookout on Brokenback Hill at locality 28 (Fig. 4). Two collections were made at this locality about 3 m apart stratigraphically. C-118588 yielded *Buchia* *tolmatschowi* (Sokolov), *B. tolmatshowi* var. *americana* (Sokolov) and early forms of *Buchia* *pacifica* Jeletzky. This collection was placed in the topmost part of the *Buchia* *tolmatschowi* Zone (Fig. 22) which is in the uppermost Berriasian (Jeletzky, 1965, 1984). The collection from the overlying locality C-118587 contains predominately *B. pacifica* and less commonly *B. tolmatshowi* var. *americana*. Jeletzky placed this fauna in the basal part of the *Buchia* *pacifica* Zone of Early Valanginian age. *B. pacifica* has not been previously recorded from the Peninsula Formation or Brokenback Hill Formation, but it is found to the west in the correlative Fire Lake Group (J.A. Jeletzky, written comm., 1986).

In Long Island Bay along the west shore of Long Island, strongly deformed *Buchia* shells were collected from locality 23. Jeletzky identified them as either *B. tolmatshowi*, *B. pacifica* or *Buchia* *crassicolis* (Keyserling). The age accordingly can range from Late Berriasian to Late Valanginian. The rocks along the southwest side of Long Island including locality 23, have been assigned to Brokenback Hill Formation. Locality 24, on a small island in Long Island Bay, yielded strongly deformed *Buchia* from a phyllite. Unlike locality 23, several specimens could be assigned to *B. pacifica*. This locality is therefore assigned to some part of the *B. pacifica* Zone (Early Valanginian).

Correlations and paleobiogeography

The bivalve *Buchia* is a widespread facies-tolerant genus found over much of northwestern North America and USSR (see Jeletzky, 1965, 1984) and is confined mainly to the Boreal Realm. Berriasian *Buchia* faunas of the Taseko Lakes, western Vancouver Island and Harrison Lake areas are the same (Jeletzky, 1984) and faunal similarities exist between the Harrison Lake area and the Nooksack area, Washington (Jeletzky, 1965). The Harrison Lake section lacks Late Jurassic *Buchia* (Fig. 22), probably a result of erosion prior to deposition of the Peninsula Formation or a period of non-deposition spanning most of Late Jurassic time in the Harrison Lake region.

The *B. okensis* Zone is the oldest Cretaceous zone in the Harrison Lake area and is dominated by the species *B. okensis*. This fauna is widely distributed in Russia, East Greenland, the Sverdrup Basin of Arctic Canada, western British Columbia, Washington and rarely in northwest California. Crickmay's *Buchia* descriptions (1925, 1930a) were re-examined by Jeletzky (1965) who felt that "*Aucella*"

canadiana Crickmay and "*Aucella*" *cascadensis* Crickmay are conspecific with *B. okensis*; "*A.*" *canadiana* is merely an extreme morphological variant of the North American geographical subspecies *B. okensis* (Jeletzky, 1984).

The overlying zone in the Harrison Lake section is rich with *B. uncitoides* after which the zone is named. *B. uncitoides* is more restricted in distribution than *B. okensis*, being found in parts of Russia, in the Richardson Mountains in Yukon, in southwest British Columbia and in California. Its abundance in California and the scarcity of *B. okensis* in this area was believed to result from the gradual southward increase in water temperature of the Berriasian Pacific Slope seas of North America (Jeletzky, 1984, p. 209). Faunas of the *B. uncitoides* Zone have also been found in metamorphosed rocks of the Fire Lake Group northwest of Harrison Lake which more precisely delimits the western margin of the Tyaughton Trough in that area (Roddick, 1965, p. 41, 42; Jeletzky, 1984, p. 211).

Crickmay's (1925, 1930a) three "species" of *Buchia* ("*Aucella*") *acutistriata*, *catamorpha*, and *spasskenoides* were considered to be variants of *B. uncitoides* by Jeletzky (1965). They are all found in the Harrison Lake area, although *B. uncitoides* var. *acutistriata* is the most common.

The youngest rocks of the Peninsula Formation are found at locality 28 and represent the upper *B. tolmatshowi* Zone and lower *B. pacifica* Zone. The *B. tolmatshowi* Zone is restricted to southwest British Columbia and California, perhaps because of paleozoogeographical reasons (Jeletzky, 1965, p. 36). The overlying *B. pacifica* Zone (Early Valanginian), however, is widespread in the western Cordilleran belt from Alaska to California. Areas in the Canadian Cordillera where the *B. pacifica* Zone is represented include the west coast of Vancouver Island, the Lillooet area, the Bridge River area, the Harrison Lake area and southwestern Yukon. It is doubtfully represented in the Nooksack area of Washington (Jeletzky, 1965, p. 44).

Locality 24 was also tentatively placed in the *B. pacifica* Zone by J.A. Jeletzky (written comm.). The rocks of this locality are highly deformed and it can be said only that they belong to the Peninsula or Brokenback Hill formations. If the rocks do in fact belong to the Peninsula Formation, then they have been thrust over Brokenback Hill Formation which lies along the southwest shore of Long Island (Fig. 4). If they belong to Brokenback Hill Formation the contact between Peninsula Formation and Brokenback Hill Formation must lie within the *B. pacifica* Zone.

Brokenback Hill Formation

Nomenclature and distribution

The formation was named after Brokenback Hill by Crickmay (1925). The type section is immediately south of Long Island Bay on Long Island and along the west shore of Harrison Lake below Brokenback Hill. Exposure is good in roadcuts near the headwaters of Twenty Mile and Kirkland creeks (lat. 49°28'48"N; long. 121°50'32"W).

The formation covers a broad area (Fig. 4) along the eastern shore of Cascade Peninsula, the southwest side of Long Island, Brokenback Hill and the area north to Doctors Point and 6 to 8 km west to the contact with the Coast Plutonic Complex. Stratigraphic correlations and thickness measurements are

difficult due to the lack of continuous outcrops and poor bedding, especially in the upper part of the section. Faults are common and the section may be repeated. Some stratigraphic control for the lower part of the section is possible using fossils collected from the tuffaceous sandstone.

Lithology

The lithology of the Brokenback Hill Formation is variable. The lower part of the section around Twenty Mile Creek comprises mainly green crystal tuff, volcanic conglomerate (Fig. 23), and tuffaceous sandstone. The conglomerate is commonly matrix supported and clasts range in size from boulders as much as 1 m diameter along the shore east of Brokenback Hill and up to 2 m in diameter (Fig. 24) on the ridge just north of the headwaters of Kirkland Creek; average clast size is about 15 cm. The tuffaceous sandstone is fossiliferous, dark to light grey in colour and moderately well bedded. Minor sandstone and siltstone beds were noted in the lower part of the section.

Higher in the section near Doctors Point, volcanic and volcaniclastic rocks predominate. Also present are siliceous graded siltstones and siliceous black shales. The volcanic rocks are both porphyritic and non-porphyritic, generally highly altered andesite to dacite (Ray et al., 1985). Geochemistry of altered andesites from Doctors Point shows them to have arc affinities (G.E. Ray, written comm., 1988). The volcaniclastic rocks include siliceous crystal lithic tuffs, volcanic breccias and possible waterlain tuffs. Fossils are rare in the upper part of the section. The thickness is estimated to be several thousand metres.

A thin section from an andesite flow near the mouth of Kirkland Creek contains prehnite and pumpellyite as well as chlorite, epidote and zoisite (P. Read, pers. comm., 1987). The pumpellyite is commonly found within plagioclase grains. Crystal tuff from the shoreline southeast of Brokenback Hill contains blebs of prehnite about 5 cm in diameter which form a bumpy pattern on the weathered surface.



Figure 23. Volcanic conglomerate from Brokenback Hill Formation. Photograph taken at top of section 3. GSC 1992-186M

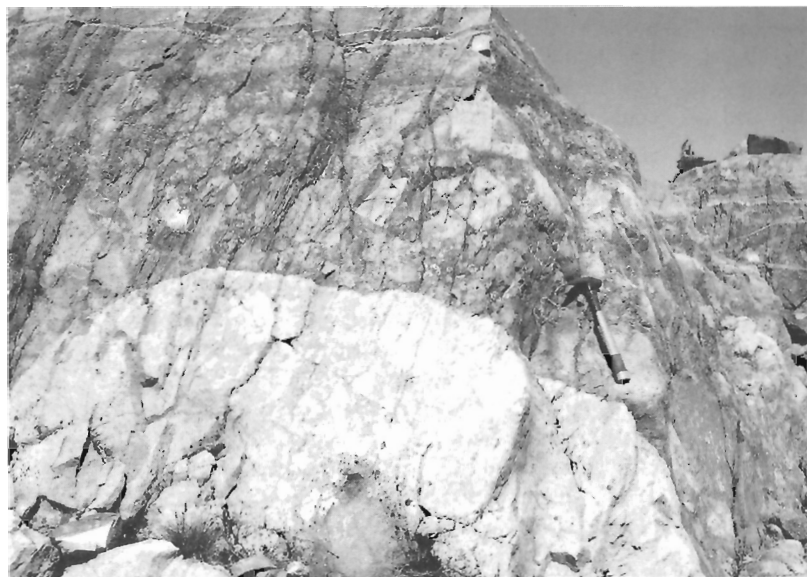


Figure 24.

Volcanic conglomerate of Brokenback Hill Formation containing a clast 2 m across of dacitic(?) volcanic flow rock. Photograph taken just north of Kirkland Creek headwaters. GSC 1992-186N

Depositional environment

Buchia are prevalent in the lowermost part of the section, in crystal tuff and tuffaceous sandstone overlying the Peninsula Formation. Rare ammonites are found here as well (locality 12, Fig. 4). Higher in the section *Inoceramus* and belemnites are common and ammonites are found locally. This may suggest deeper marine conditions as *Inoceramus* typically lived in quiet water settings on soft substrate. Many of these bivalves reached large sizes; a specimen from locality 46 measured 35 cm. Tuff beds are commonly undisturbed in this part of the section suggesting little wave action, but ripple marks were noted at one locality together with a feeding trace. The large size of the clasts in the volcanic conglomerate may indicate proximity to a volcanic vent, although flows are not noted in the lower part of the formation.

The upper part of the section consists mainly of volcanic and pyroclastic rock which may have been deposited in an island arc setting. A single ammonite has been found in intercalated sediments indicating marine conditions.

Structural relations

The contact between the Brokenback Hill and Peninsula formations is conformable. It is best exposed at the top of section 3 (Fig. 11), where *Buchia*-rich tuffaceous sandstone of the Peninsula Formation rapidly grades upwards into green crystal tuff and volcanic conglomerate of Brokenback Hill Formation.

Biostratigraphy and age

Zonal schemes for Cordilleran faunas of this age proposed by Imlay (1960) and Jeletzky and Tipper (1968) have been incorporated into Figure 22 in a simplified version. The oldest locality within the Brokenback Hill Formation (excluding the possible locality 24) occurs on the southeast shore of Cascade Peninsula at localities 12 and 13. Locality 13 yielded *Buchia crassicolis* (Keyserling) var. *solida* (Lahusen). This species is abundant in collections from locality 12, together with rare *Buchia keyserlingi* (Lahusen) var. *gigas* (Crickmay), *Pleuromya* cf. *uniformis* (Sowerby) and *Pleuromya* ex gr. *uralensis* (d'Orbigny). The ammonite *Homolomites quatsinoensis* (Whiteaves) is found at locality 12. Crickmay (1930a) collected *Pleuromya harrisonensis* Crickmay and *Homolomites poecilochotomus* Crickmay from this locality as well as several species of *Buchia* which are now synonymized with species listed above (Jeletzky, 1984). Faunas at localities 12 and 13 are Late Valanginian, lower part of the *Buchia crassicolis* Zone (Fig. 22).

Fossil localities within Brokenback Hill Formation west of Harrison Lake are rare and isolated. *Inoceramus paraketzovi* Efomova subsp. *latus* Pochialainen and Terekhova was recovered from locality 44 and *Inoceramus paraketzovi* cf. subsp. *acutus* Pochialainen and Terekhova from locality 46. This species was recently described from northeastern Siberia, where it is confined to Upper Hauterivian rocks, but it ranges into Lower Hauterivian rocks in the Taseko Lakes area (J.A. Jeletzky, written comm., 1987). Therefore, these two localities can only be dated as of a

general Hauterivian age. At locality 47 two specimens of *Homolomites* (*Wellsia*) cf. *packardi* Imlay were collected. Jeletzky believed these belong to some part of the *Homolomites packardi* Zone of Early Hauterivian age (Fig. 22).

A single ammonite from locally derived float at locality 55 near Doctors Point was submitted by G.E. Ray of the British Columbia Ministry of Energy, Mines and Petroleum Resources was identified as *Cleoniceras* (*Grycia*?) *perezianum* (Whiteaves) of Middle Albian age by Jeletzky (Report No. Km-11-1985-JAJ). The only other locality in Brokenback Hill Formation which yielded identifiable fossils is locality 49 where an ammonite identified by Arthur (1987) as *Ammonoceras* sp. was found. It closely resembles the specimen figured in McLearn (1972, pl. 1, Fig. 5) from the Queen Charlotte Islands which was associated with a Middle Albian fauna; Wright (in Arkell et al., 1957) preferred a more general Late Aptian to Cenomanian age for *Ammonoceras*. The remaining localities not discussed (45, 48, 50-54) yielded belemnites or ammonites too poorly preserved for identification.

Correlations and paleobiogeography

The *B. crassicolis* Zone is widespread in the western Cordillera and *B. crassicolis* s. str. is the youngest *Buchia* species known from this region (Jeletzky, 1965), except for the undocumented record of *Buchia teutoburgensis* (Weerth) from the presumably Hauterivian beds of the Harrison Lake area (Crickmay, 1930a, p. 49; 1962, p. 9). On the west coast of Vancouver Island the *B. crassicolis* Zone is unknown as the section ends in the *B. pacifica* Zone, but in the Quatsino Sound area rocks of the *B. crassicolis* Zone transgressively overlap Middle Jurassic intrusive rocks (Jeletzky, 1965, p. 65, Fig. 4). This zone is the oldest Cretaceous zone known from the San Juan Islands (Spieden Island) and *Homolomites quatsinoensis* is found in both areas.

In the Harrison Lake and Nooksack areas the *B. crassicolis* Zone is present and overlies older *Buchia* zones in apparent conformity (Jeletzky, 1965). To the north, isolated localities belonging in the *B. crassicolis* Zone are known from other parts of British Columbia, southwestern Yukon and Alaska (Jeletzky, 1965). In California a possible hiatus appears to cut out the *B. crassicolis* Zone, although the uppermost *Buchia*-bearing beds could reach into the basal part of this zone.

The Hauterivian *Inoceramus paraketzovi* from localities 44 and 46 are not common in the western Cordillera but they are known from the Taseko Lakes area as stated earlier. *Inoceramus* species similar to *I. paraketzovi* have also been found west of Harrison Lake in the Fire Lake Group (J.A. Jeletzky, written comm.). The Early Hauterivian *Homolomites packardi* Zone, to which locality 47 belongs, was first described from Oregon (Imlay, 1960, p. 176). This zone and the next older *Homolomites* (*Wellsia*) *oregonensis* Zone are little known in British Columbia and to date have only been found in the Taseko Lakes (Jeletzky and Tipper, 1968), Quatsino Sound (Jeletzky, 1976), Mount Waddington (Tipper, 1969) and now Harrison Lake areas.

The discovery of *Cleoniceras* (*Grycia*?) *perezianum* at locality 55 is paleogeographically and stratigraphically important. Rocks of the Gambier Group were previously thought to be restricted to the poorly understood mid-Cretaceous Gambier Basin (see Jeletzky, 1977a). The *C. (G.) perezianum* Zone is the only Albian zone known from the Georgia Basin. It is also present in the Queen Charlotte Islands, the Tyaughton Trough and Bowser Basin (Jeletzky, 1977a, Fig. 2). The presence of *C. (G.) perezianum* at Harrison Lake therefore now documents the eastward extension into this area of marine rocks correlative with the Gambier Group (Ray et al., 1985; Jeletzky, Internal report No. Km-11-1985-JAJ).

The age of the presumably stratigraphically older *Ammonoceratites* sp. from locality 49 cannot be determined with certainty. It could be as old as Late Aptian but is probably Albian as it occurs in the Queen Charlotte Islands first in the Middle Albian *C. (G.) perezianum* Zone (McLearn, 1972, p. 17).

The wide extent of the *C. (G.) perezianum* Zone in western British Columbia indicates a strong mid-Albian transgression over the region (Jeletzky, 1977a, p. 112). Marine sediments continued to be deposited in the Tyaughton and Methow troughs until the end of the Albian. This marked the end of marine sedimentation in the Harrison Lake area.

PLUTONIC ROCKS

West of Chehalis Valley and the Mesozoic section described here, are mid-Jurassic to Tertiary plutons of the Coast Belt. Several small igneous bodies, part of the Coast Belt, are exposed within the Weaver Lake Member near Mount Keenan (Fig. 4). A sample from one of these igneous bodies has yielded a U-Pb date of 160 ± 2 Ma (P. van der Heyden, pers. comm., 1987), which is coeval with the volcanoclastic rocks of the Billhook Creek Formation. These early Late Jurassic plutons may have been unroofed by earliest Cretaceous time to supply granitic material to the basal conglomerate of the Peninsula Formation.

Andesitic feeder dykes to the Weaver Lake Member are commonly noted along the lakeshore, cutting across the Camp Cove Formation, and one dyke slightly displaces the Camp Cove Formation-Celia Cove Member contact west of Echo Island along the Forest Service road. Feldspar porphyry bodies on the east side of Mount Keenan and along parts of the Hemlock Valley road have well developed columnar jointing; Pearson (1973) considered these to be dykes. To the north, intrusions into Mysterious Creek Formation are noted along a probable fault where the Forest Service road crosses Hale Creek.

The Doctors Point pluton on the northwest shore of Harrison Lake has a preliminary date (K-Ar on biotite) of 25 Ma by J. Harakal (Ray et al., 1985); and 24.63 ± 0.82 Ma in its extension east of Harrison Lake (Monger, 1989b). This is contemporaneous with the Chilliwack Batholith southeast of Harrison Lake (Fig. 3) and a probable extension of the Chilliwack Batholith cuts across the Harrison River just west of Harrison Hot Springs (Fig. 4).

REGIONAL TECTONICS

The North American Cordillera consists of a collage of fault-bounded terranes, each with a stratigraphy and/or lithological association which differs from those of neighbouring terranes and from sequences deposited along and on the North American craton (Coney et al., 1980; Monger et al., 1982). Most terranes consist of late Paleozoic and early Mesozoic volcanic and sedimentary rocks, although both older and younger strata are represented in places. The petrology of most of these terranes suggests that they formed in intraoceanic settings, as ocean floor and overlying deposits, or island arcs or perhaps as oceanic plateaus. Terranes typically contain faunal associations and/or paleomagnetic records which differ from one another and from those now at the same latitude on the craton (e.g. Davis et al., 1978; Monger, 1984; Irving et al., 1985). The implication is that the terranes formed in positions other than those they presently occupy, mainly independently of one another, on the western North American continental margin. Later, mainly in Jurassic and Cretaceous times, they were emplaced by convergent and transcurrent plate motions in the positions they now occupy within the continental margin. The geology of the area west of Harrison Lake is reviewed below in this context.

In the western Canadian Cordillera, there are four large terranes with distinctive stratigraphic sequences that evolved mainly as magmatic arcs and related deposits. These are, from east to west, Quesnellia, Stikinia, Alexander and Wrangellia. Separating these are linear belts of highly disrupted strata and mafic/ultramafic bodies that probably represent deposits and basement of oceanic and marginal basins. In the east, between the ancient craton and Quesnellia, is the Slide Mountain Terrane; between Quesnellia and Stikinia, is the Cache Creek Terrane; in southwest British Columbia between Stikinia and Wrangellia are Cache Creek and Bridge River terranes. The latter contain fossils as young as Middle Jurassic in pelagic or hemipelagic sediments (e.g. Haugerud, 1985; Cordey et al., 1987), which strongly suggest that large ocean basins existed as late as the time represented by the collage of terranes comprising the western Cordillera.

The area west of Harrison Lake presently lies between Bridge River Terrane on the east and Wrangellia on the west. For the earlier part of its history, it apparently was separated by an ocean basin (represented by the Bridge River Terrane) from Quesnellia, which was accreted to the ancient cratonic margin in Early to Middle Jurassic time. Magmatic rocks as old as 170 Ma extend across the southwest Coast Belt from Harrison Lake, where they intrude the Harrison Lake sequence, to tidewater, where they intrude Wrangellian strata (Friedman et al., 1990; Monger, 1991b). Stratified rocks (Gambier Group) may correlate with Peninsula and Brokenback Hill formations (Roddick, 1965) thus linking the region west of Harrison Lake with the Howe Sound area by early Cretaceous time (Monger, 1991b).

There is at present considerable discussion of when and how the Middle Jurassic and older Jurassic basin to the east closed. Closure was clearly post-Middle Jurassic, as shown by the age of the youngest oceanic sediments, and pre-early

Late Cretaceous, when the region east of Harrison Lake underwent thrust faulting, metamorphism to high grades, and emplacement of granitic intrusions in mid-Cretaceous to early Late Cretaceous time (about 92-96 Ma: Monger, 1991b; M. Journeay, pers. comm., 1991). On strike to the south of the region of high-grade metamorphism, in the western North Cascades south of latitude 49°, are the latest Jurassic-Early Cretaceous (149-130 Ma) Shuksan blueschists in a metabasalt/clastic sequence (Monger, 1991a). As blueschist metamorphism is associated with subduction of oceanic crust, it is reasonable to assume that closure of the ocean basin, accompanied by high-pressure, low-temperature metamorphism, was occurring at this time, with final closure (collision) by mid-Cretaceous-early Late Cretaceous time, when the terrane west of Harrison Lake, a western superterrane, including Harrison Lake and Wrangellia was brought against terranes to the east. The contact region is the area east of Harrison Lake where the high-grade metamorphic rocks are present.

However this scenario considers only orthogonal plate movement in the region. There is evidence, from the magnetic patterns of the Pacific Ocean floor and from plate positions relative to hot spots, of vigorous northward movements of the Kula or Farallon plates during Cretaceous-Tertiary interval dextrally across the "bow" of the westward-moving North American Plate (Engelbreton et al., 1985). Paleomagnetic data support this view (e.g. Irving et al., 1985), as does field evidence in the region. Major structures such as the Harrison Fault are post-Early Cretaceous and pre-Eocene, and cut slightly earlier "collisional" structures (Monger, 1986). Brown (1987) argued strongly that the entire process of accretion as reflected in western North Cascades structures was due to oblique subduction, with a strong dextral component. The paleogeographic reconstructions for this region in the Cretaceous, let alone earlier, must necessarily remain highly tentative.

Stratigraphic constraints provided by rocks in the Harrison Lake area are presented in the following discussion.

The base of the Mesozoic section west of Harrison Lake is represented by the Middle Triassic Camp Cove Formation. A conservative paleogeographic reconstruction is that this unit formed the western margin of a Triassic ocean basin, represented by the Bridge River-Hozomeen assemblage, and the Spider Peak Formation formed the eastern margin. This site later became the locus of the Tyaughton and Methow troughs in the Jurassic. The high grade metamorphic rocks between Harrison Lake and Fraser River represent the northern extension of the Cascade Metamorphic Core (Monger, 1986; Brown, 1987) and are perhaps in part the metamorphosed equivalents of the ocean basin's basement (Cogburn assemblage = (?) Bridge River-Hozomeen) and overlying sediments (Settler Schist = (?) Ladner and Spider Peak groups) of the Tyaughton and Methow troughs, or Darrington phyllite, Shuksan greenschist of the northwest Cascade Mountains.

A Middle Jurassic (Aalenian to Early Bajocian) volcanic arc along the western margin of this ocean basin is represented by the Harrison Lake Formation and the probably correlative Wells Creek volcanics of Washington, and perhaps by the Bowen Island Group farther west near Vancouver. A possibly coeval arc may have been situated along the eastern margin of the ocean basin as suggested by the presence of Lower and Middle Jurassic volcanic rocks of the Dewdney Creek Formation. How these arcs formed is not known, but one possibility would be both western and eastern subduction of the oceanic crust (Bridge River-Hozomeen assemblage) followed by final closure of the basin, perhaps in a way similar to that postulated by Monger (1984, Fig. 8). Shuksan blueschists, however, give metamorphic ages of latest Jurassic-Early Cretaceous age (Brown, 1987), too young for subduction to have been related to these volcanics (see also discussion by Thorkelson and Smith, 1989).

A regionally extensive hiatus above the rocks of these volcanic arcs spans Late Bajocian and Bathonian time (Frebold and Tipper, 1970). This is about the same time as the beginning of the opening of the North Atlantic Ocean and the hiatus may reflect a change in motions of the North American Plate relative to plates flooring the Pacific Ocean (Monger and Price, 1979).

Sedimentation following this hiatus began again in Callovian to Oxfordian time (Fig. 7, in pocket) but was discontinuous over much of the region. Unconformities spanning the Jura-Cretaceous boundary are common, but in the Relay Mountain area the section is uninterrupted across this boundary probably because of its location in the axial part of the Tyaughton Trough (Fig. 7; Jeletzky and Tipper, 1968). A continuous Upper Jurassic to Lower Cretaceous section may also be present in the Nooksack Group, Washington (Fig. 7). Local uplift and erosion during this hiatus unroofed plutons that may have been associated with the Middle and Late Jurassic (170 Ma; Friedman and Armstrong, 1990) volcanic arc along the western margin of the basin. These plutons were the source for granitic material found in the basal conglomerates of the Gambier Group and Peninsula Formation, in the southwest Coast Mountains. Magmatic activity resumed along this western arc in the Early Cretaceous as shown by the presence of flows and pyroclastic rocks in the Gambier Group (Hauterivian to Barremian) (Roddick, 1965) and Brokenback Hill Formation (Late Valanginian to Middle Albian) and widespread Early Cretaceous granitic rocks.

The Albian marked the last marine sedimentation over much of the region and faunas of this age are recorded from isolated localities throughout the Tyaughton and Methow troughs and the Georgia Basin (Gambier Group). Marine sedimentation continued in the Tyaughton and Methow troughs through Albian time with sources from both the west and east (Coates, 1974), but by the end of this stage the trough ceased to exist as a marine basin (Jeletzky, 1977b) due to infilling, uplift

and regression. Mid-Cretaceous nonmarine sediments (e.g. Pasayten Group) overlie the Albian Jackass Mountain Group in the eastern part of the basin and are probably equivalent to the Virginian Ridge and Winthrop formations in the Methow Trough, Washington (Trexler, 1985). The source of these sediments was in the east (Spences Bridge volcanic arc) and in the west (uplifted Bridge River and Hozameen groups (Coates, 1974)).

Marine sedimentation ended in the Harrison Lake area in Middle Albian time with uplift of the Coast Belt. This event is possibly related to the final amalgamation of Wrangellia with the North American plate in the Cretaceous. The rocks of the Tyaughton and Methow troughs from Harrison Lake to the Coquihalla area were subsequently disrupted by transpressional faulting along the Harrison, Ross Lake, Hozameen and Pasayten faults in post-Albian to pre-Late Eocene time (Monger, 1986). This was followed by transtensional faulting along the Fraser River-Straight Creek fault system in Late Eocene time, which disrupted the earlier structures (Monger, 1986).

SYSTEMATIC PALEONTOLOGY

Introduction

The fossil localities from the study area and the faunas collected from them are shown in Figure 25.

The classification of the Jurassic ammonites in this study follows that of Donovan et al. (1981) with the exception of *Erycitoides* which is kept as a separate genus (Westermann, 1964a; Poulton and Tipper, 1991); Donovan et al. (1981) included it as a synonym of *Podagrosiceras*.

Measurements and abbreviations

Specimens measured but not figured have locality numbers next to their measurements. All ammonite measurements are in millimetres. Abbreviations used are as follows (Smith, 1986):

| | | |
|------|---|--|
| * | = | type material |
| c | = | circa |
| D | = | shell diameter at which the following measurements were made |
| UD | = | umbilical diameter |
| U | = | UD/D x 100 |
| WH | = | whorl height |
| WHD | = | WH/D x 100 |
| WW | = | whorl width |
| WWD | = | WW/D x 100 |
| WWWH | = | WW/WH x 100 |
| PRHW | = | primary ribs per half whorl |
| SRHW | = | secondary ribs per half whorl |

Repositories for the material described herein are the Geological Survey of Canada type collections in Ottawa (type number prefix GSC) and the M.Y. Williams Museum at the University of British Columbia (type number prefix UBC).

SYSTEMATIC DESCRIPTIONS

Order AMMONOIDEA Zittel, 1884

Suborder AMMONITINA Hyatt, 1889

Superfamily EODEROCERATACEAE Spath, 1929

Family DACTYLOCERATIDAE Hyatt, 1867

Genus *Dactylioceras* Hyatt, 1867

Type species. *Ammonites communis* Sowerby, 1815 by subsequent designation.

Remarks. The genus is evolute with bifurcating, usually straight ribs that pass over the venter rectiradiately or with a gentle forward inclination.

Age and distribution. The genus *Dactylioceras* is a pandemic form found over much of Europe, North Africa, Persia, Japan, Indonesia, New Zealand, Arctic Islands, Alaska, western Canada and northwestern United States. It is Early to Middle Toarcian in age (Tenuicostatum to Bifrons zones of Europe) and may be as old as Late Pliensbachian (Spinatum Zone) (Donovan et al., 1981).

Dactylioceras? sp.

Plate 1, figures 1,2.

Material. Five poorly preserved specimens in a dark grey calcareous siltstone.

Description. Evolute; ribs are rectiradiate, straight and begin about the umbilical wall. Some primaries bifurcate in upper flank region but poor preservation makes this difficult to see. There are about 23 ribs per half whorl at a diameter of 34 mm.

Discussion. The specimens are very poorly preserved making confident identification impossible.

Occurrence. *Dactylioceras?* sp. is found in the Francis Lake Member of the Harrison Lake Formation at locality 7 associated with *Harpoceras?* sp. and *Phymatoceras?* sp. In British Columbia the genus *Dactylioceras* is also found in the Fernie Group (Friebold, 1976), Queen Charlotte Islands (Cameron and Tipper, 1985) and the Spatsizi area (Thomson et al., 1986).

Age. Toarcian.

Superfamily HILDOCERATACEAE Hyatt, 1867

Family HILDOCERATIDAE Hyatt, 1867

Subfamily HARPOCERATINAE Neumayr, 1875

Genus *Harpoceras* Waagen, 1869

Type species. *Ammonites falcifer* Sowerby, 1820 by subsequent designation.

Remarks. Midvolute; flanks flat to gently convex. Sharp umbilical shoulder and venter, which is unicarinate. Falcoid ribs, which become stronger on upper part of flank.

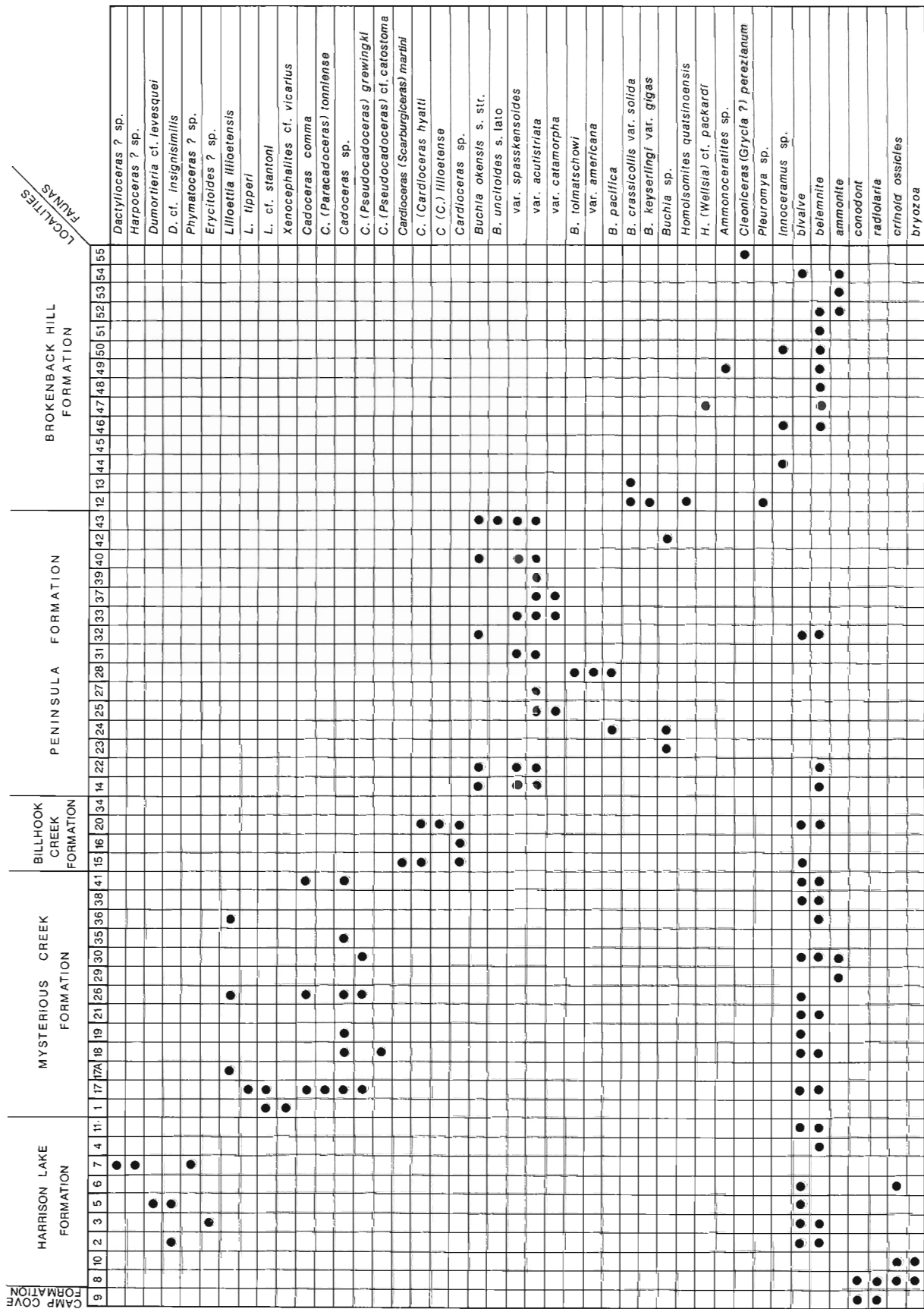


Figure 25. Locality chart by formation showing faunas found at each locality.

Age and distribution. *Harpoceras* is a widespread form found in Europe, North Africa, Japan, Indonesia, western Canada, Chile and Argentina. It ranges from the European Falcifer Zone to Bifrons Zone of the Toarcian.

Harpoceras? sp.

Plate 1, figures 3-5.

Material. About 18 specimens poorly preserved as molds in a dark grey calcareous siltstone.

Description. Fairly involute; shell expands rapidly. Strong falcoid ribs begin at the low umbilical wall; a weak keel is evident.

Discussion. Poorly preserved state of the specimens does not allow confident identification. *Pseudolioceras* which is more common in the Upper Toarcian in North America, differs from these specimens by being more involute and having a more pronounced keel.

Occurrence. Found associated with *Dactylioceras?* sp. and *Phymatoceras?* sp. at locality 7 in the Francis Lake Member of Harrison Lake Formation.

Age. Toarcian.

Subfamily GRAMMOCERATINAE Buckman, 1905

Genus *Dumortieria* Haug, 1885

Type species. *Ammonites levesquei* d'Orbigny, 1844.

Remarks. Fairly evolute genus with nearly straight rectiradiate ribbing, which commonly projects onto the venter from the ventro-lateral shoulder.

The similar genus *Catullocceras* Gemmellaro and its synonym *Dactylogammmites* Buckman have been regarded as a synonym of *Dumortieria* by several workers (Donovan, 1958; Setti, 1968), but Arkell et al. (1957) and the more recent work of Donovan et al. (1981, p. 141) regard *Catullocceras* as a separate genus.

Age and distribution. The pandemic genus *Dumortieria* is found in many parts of the world including Europe, North Africa, Persia, Indochina, Borneo, western North America and Argentina. It ranges in age from the Levesquei Subzone to the Moorei Subzone of the Levesquei Zone, Late Toarcian (Donovan et al., 1981).

Dumortieria cf. *levesquei* d'Orbigny, 1842

Plate 1, figures 6-10.

- cf.* 1842 *Ammonites levesquei* d'Orbigny, p. 230, pl. 60.
- cf. 1925 *Dumortieria levesquei* d'Orbigny; Ernst, p. 48, pl. 3, fig. 4-9; pl. 4, fig. 13; pl. 8, fig. 12.
- cf. 1961 *Dumortieria levesquei* d'Orbigny; Dean et al., p. 488, pl. 73, fig. 5.
- cf. 1968 *Dumortieria* cf. *levesquei* d'Orbigny; Setti, p. 324, pl. 30, fig. 2.

Material. Seven secondarily compressed but identifiable specimens and about 25 poorly preserved specimens found in a brown, non-calcareous shale and calcareous siltstone.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | PRHW |
|-----------|------|------|------|------------|------|
| GSC 91562 | 27.3 | 8.9 | 32.6 | 10.9(39.9) | 21 |
| GSC 91563 | 27.7 | 10.0 | 36.1 | 10.0(36.1) | 21 |
| GSC 91564 | 15.4 | 5.6 | 36.4 | 5.9(38.3) | 14 |
| GSC 91565 | 19.5 | 8.2 | 42.1 | 6.6(33.8) | 18 |
| GSC 91566 | 12.7 | 4.2 | 33.1 | 5.0(39.4) | 14 |

Description. Midvolute coiling. Ribs are fairly sharp, rectiradiate and begin on the umbilical wall. In smaller specimens and inner whorls of larger ones, the ribs are straight and rectiradiate until the upper flank where they flex adorally. In the later whorls of larger specimens, however, the ribs are more gently curved, beginning on the mid or upper flank. Number of ribs per half whorl increases with increasing size (Fig. 26). Ribs end on the venter just before the low keel which is poorly preserved in specimen GSC 91563 (Pl. 1, fig. 7).

Discussion. The specimens of *D. cf. levesquei* collected from locality 5 west of Harrison Lake are all small in size when compared with other figured specimens. They most closely resemble two specimens of *D. levesquei* figured by Ernst

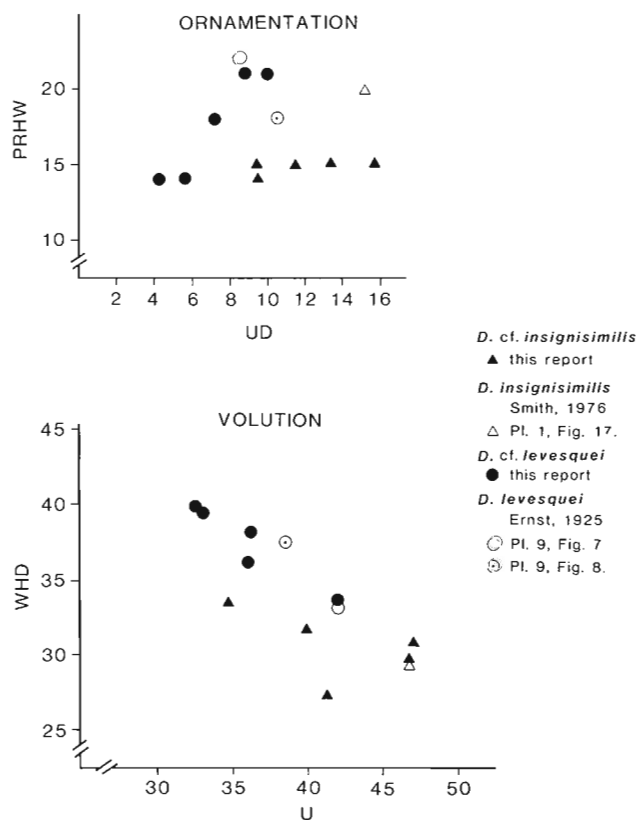


Figure 26. Ornamentation and volution plots for data from *D. cf. insignisimilis* and *D. cf. levesquei* plus data from other sources.

(1925, pl. 3, fig. 7, 8) (Fig. 26). *D. cf. levesquei* differs from *D. cf. insignisimilis* by being more densely ribbed and being slightly less evolute.

Occurrence. *D. cf. levesquei* is associated with *D. cf. insignisimilis* at locality 5 of the Francis Lake Member. It has not been recorded from western Canada previously, but similar species (*D. insignisimilis*, *D. raricostata*, *D. exacta*) are found in Oregon (Smith, 1976).

Age. Late Toarcian (Levesquei Zone – Levesquei to Moorei subzones of Europe).

Dumortieria cf. insignisimilis (Brauns)

Plate 1, figures 11-15.

- cf. 1925 *Dumortieria insignisimilis* (Brauns); Ernst, p. 56, pl. 9, fig. 1-3.
 cf. 1967 *Dumortieria insignisimilis* (Brauns); Geczy, p. 144, pl. 31, fig. 6.
 ? 1967 *Dumortieria insignisimilis* new subspecies; Geczy, p. 145, pl. 32, fig. 5.
 cf. 1976 *Dumortieria insignisimilis* (Brauns); Smith, p. 81, pl. 1, fig. 17.

Material. Seven moderately preserved specimens and about 20 poorly preserved specimens found in a brown, non-calcareous shale and calcareous siltstone.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | PRHW |
|-----------|------|------|------|-------------|------|
| GSC 91567 | 23.8 | 9.5 | 39.9 | 7.5 (31.6) | 15 |
| GSC 91568 | 28.4 | 13.4 | 47.2 | 8.7 (30.6) | 15 |
| GSC 91569 | 33.0 | 11.5 | 34.8 | 11.0 (33.3) | 15 |
| GSC 91572 | 37.7 | 15.8 | 46.9 | 11.2 (29.7) | 15 |
| GSC 91573 | 23.0 | 9.5 | 41.3 | 6.3 (27.4) | 14 |

Description. Shell is fairly evolute. A poorly preserved low keel can be seen on some of the specimens. Rectiradiate ribs begin on the umbilical wall and are straight until the upper flank, where they flex adorally. The ribs taper and fade as they cross the ventro-lateral shoulder. Ribs are fairly distant, averaging about 14 ribs per half whorl at a diameter of 20 mm. On larger specimens (Pl. 1, fig. 14, 15) ribs become more distant and less sharp, suggesting that maturity was reached at fairly small diameters.

Discussion. The specimens are similar in ribbing and volution to *D. insignisimilis* especially in the inner whorls. The more distant ribbing on the outer whorls of the two larger specimens mentioned earlier differs from other figured specimens of similar size. *D. cf. insignisimilis* has fewer, straighter ribs than *D. cf. levesquei* and is slightly more evolute (Fig. 26).

Occurrence. Found with *D. cf. levesquei* in the Francis Lake Member at locality 5. The locality yields predominantly ammonites with rare bivalves (two in this collection). A specimen that resembles *D. cf. insignisimilis* but is too poorly preserved for positive identification, was collected from locality 2 where it is associated with belemnites.

Age. Late Toarcian (Levesquei Zone of Europe).

Family PHYMATOCERATIDAE Hyatt, 1867

Subfamily PHYMATOCERATINAE Hyatt, 1867

Genus *Phymatoceras* Hyatt, 1867

Type species. *Phymatoceras robustum* Hyatt, 1867 (young of *Ammonites tirolensis* Dumortier, 1874, non Hauer).

Remarks. Evolute; planulate whorl shape with flat to carinate-bisulcate venter. Ribs are sigmoidal and commonly branch out in twos and threes from tubercles on the umbilical edge.

Age and distribution. *Phymatoceras* ranges from the Bifrons Zone to Variabilis Zone of the European Toarcian (Donovan et al., 1981). It is found in Europe, North Africa, Anatolia, Japan, southern Alaska, British Columbia and Chile.

PLATE 1

[All figures natural size. The last suture is marked by an arrowhead.]

Figures 1,2. *Dactylioceras?* sp.

- GSC 91558, GSC Loc. No. C-118595, Locality 7; Middle Toarcian?
- GSC 91557, GSC Loc. No. C-118595, Locality 7; Middle Toarcian?

Figures 3-5. *Harpoceras?* sp.

- GSC 91560, GSC Loc. No. C-118595, Locality 7; Middle Toarcian?
- GSC 91561, GSC Loc. No. C-118595, Locality 7; Middle Toarcian?
- GSC 91559, GSC Loc. No. C-118595, Locality 7; Middle Toarcian?

Figures 6-10. *Dumortieria cf. levesquei* d'Orbigny

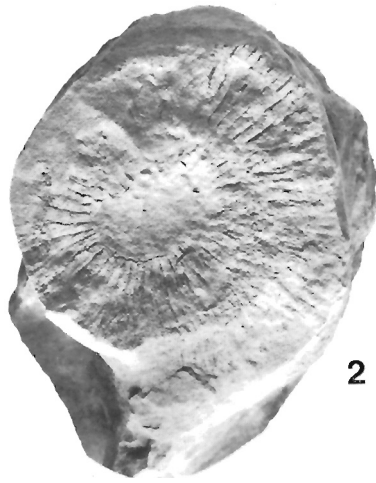
- GSC 91562 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.
- GSC 91563, GSC Loc. No. C-118594, Locality 5; Late Toarcian.
- GSC 91564 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.
- GSC 91565 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.
- GSC 91566 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.

Figures 11-15. *Dumortieria cf. insignisimilis* (Brauns)

- GSC 91567 (latex cast), GSC Loc. No. C-143283, Locality 5; Late Toarcian.
- GSC 91568 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.
- GSC 91569 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.
- GSC 91570 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.
- GSC 91571 (latex cast), GSC Loc. No. C-118594, Locality 5; Late Toarcian.



1



2



3



6



4



5



7



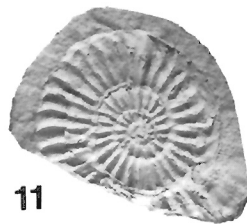
8



9



10



11



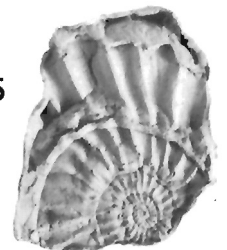
12



13



14



15

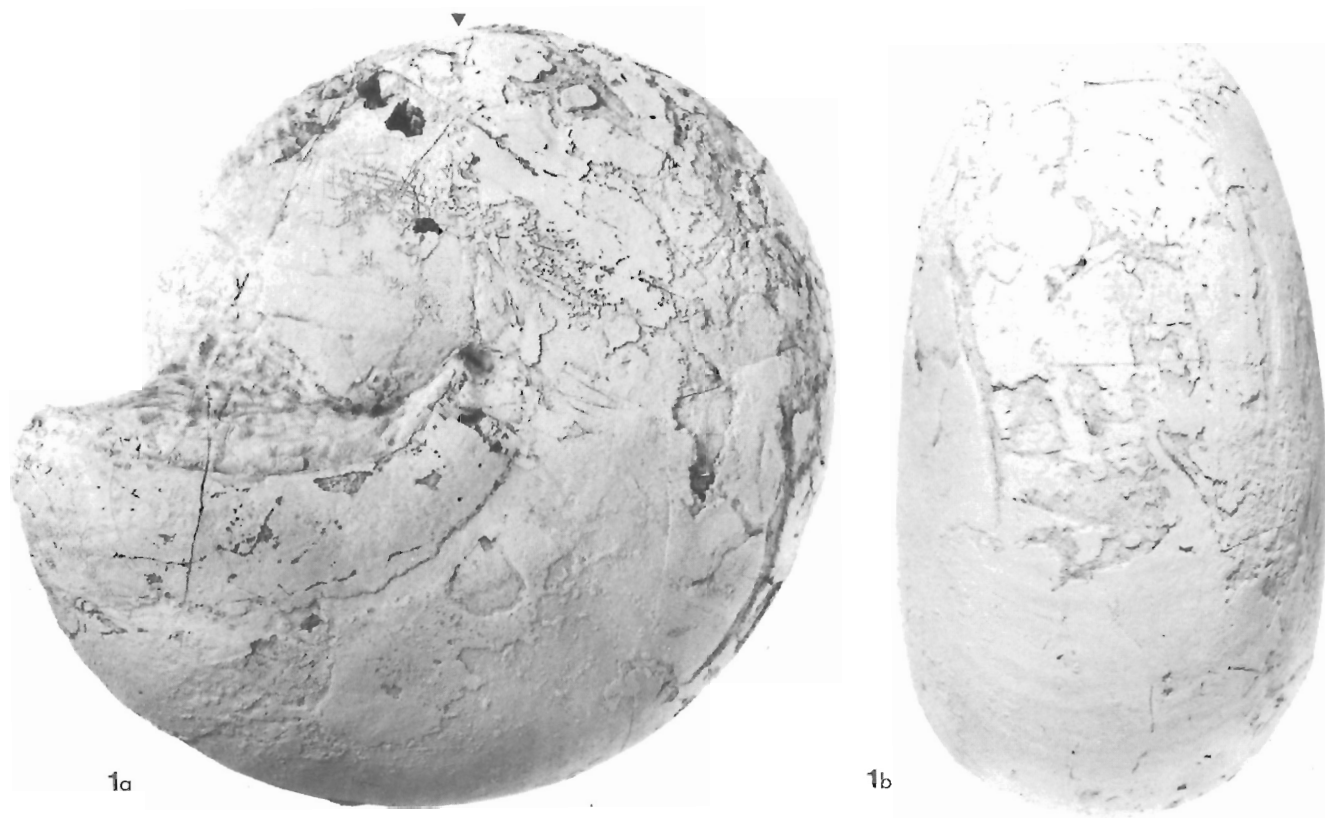


PLATE 2

[Natural size. The last suture is marked by an arrowhead.]

Figure 1. *Lilloettia tipperi* Frebold.

1. GSC 91617, GSC Loc. No. C-118586, Locality 17; a. lateral view, b. ventral view.

Phymatoceras? sp.

Plate 3, figure 1.

Material. One poorly preserved specimen in grey calcareous siltstone.

Description. Evolute; ribs are sigmoidal, become thicker away from the umbilical shoulder and are moderately dense. Some swellings can be seen near the umbilical shoulder but the specimen is too poorly preserved for better identification. Such swellings are not characteristic of the hildoceratid *Fucinieras* which it otherwise resembles.

Occurrence. Found at locality 7 with *Dactylioceras*? sp. and *Harpoceras*? sp. in the Francis Lake Member. *Phymatoceras* is also found in the Spatsizi Group (Thomson et al., 1986), Queen Charlotte Islands (Cameron and Tipper, 1985) and in South America where it ranges from the *Collina chilensis* Zone to the lower *Phlyseogrammoceras tenuicostatum* Zone of Hillebrandt (1987).

Age. Toarcian.

Family HAMMATOCERATIDAE Buckman, 1887

Subfamily HAMMATOCERATINAE Buckman, 1887

Genus *Erycitoides* Westermann, 1964a

Type species. *Ammonites (Lillia) howelli* White, 1889 by subsequent designation (Westermann, 1964a).

Remarks. Evolute; planulate; whorl section rounded to subrectangular. Keel present; lateral spines or tubercles may be present. Long primary ribs and more or less projecting secondaries. Septal suture as in *Hammatoceras*.

Erycitoides is included as a synonym of *Podagrosiceras* Maubeuge and Lambert by Donovan et al. (1981) but is kept as a separate genus in this report. *Podagrosiceras* lacks a keel, has alternating ribs on the venter and suture patterns of the two genera differ (Westermann, 1964b; Poulton and Tipper, 1991).

Age and distribution. Aalenian (Murchisonae to Concavum zones of Europe). Found in Alaska, Yukon, western British Columbia and eastern Russia. Part of the Boreal Realm (Bering Province) of Taylor et al. (1984).

Erycitoides? sp.

Plate 3, figure 2.

Material. One very poorly preserved specimen in brown shale.

Description. Evolute; umbilical wall steep and may be undercut. Flanks broad and gently convex; poorly preserved keel noted. Ribs begin on umbilical wall, are prorsiradiate until the lower flank and then curve becoming rectiradiate. No tubercles are evident but this may be due to the specimens poor preservation.

Discussion. The specimen resembles *Erycitoides profundus* Westermann in ribbing, volution and its umbilical shoulder (Westermann, 1964a) but poor preservation precludes a confident identification.

Occurrence. Found at locality 3 with abundant pectinid bivalves and rare belemnites. This locality lies in the uppermost part of the Francis Lake Member.

Age. Aalenian.

Superfamily STEPHANOCERATAEAE Neumayr, 1875

Family SPHAEROCERATIDAE Buckman, 1920

Subfamily EURYCEPHALITINAE Thierry, 1976

Genus *Lilloettia* Crickmay, 1930

Type species. *Lilloettia lilloetensis* Crickmay, 1930a (p. 62, pl. 18, fig. 1, 2) by original designation.

Remarks. The type species *L. lilloetensis* was collected from the Billhook Creek valley at the 3100 foot level (Crickmay, 1930a) west of Harrison Lake. The genus is involute with fine to moderately ribbed inner whorls. On later whorls the ribbing fades. *Lilloettia* has been synonymized with *Arctocephalites* (Spath, 1933) and has been placed as a subgenus within *Macrocephalites* (Arkell, 1956) and *Eurycephalites* (Westermann, 1981). It has been considered to range from Middle Bathonian (Westermann, 1981) to Middle Callovian (Imlay, 1953b; Frebold and Tipper, 1967). A recent reassessment by Callomon (1984) indicates that assignment to the early Early Callovian is a more reasonable interpretation of the data based on regional faunal associations from Alaska to Oregon. Recent descriptions of new collections from southern Mexico (Sandoval et al., 1990) and Argentina (Riccardi et al., 1989) suggest a latest Bathonian age for some species of *Lilloettia* found there.

The species *Lilloettia lilloetensis* Crickmay, *L. buckmani* Crickmay, *L. mertonyarwoodi* Crickmay and *L. milleri* Imlay may simply "represent no more than the partial range of variability of a single biospecific assemblage" (Callomon, 1984). They may all belong to one species (*L. lilloetensis*) as suggested by Callomon (1984) with *L. milleri* and *L. buckmani* representing depressed end members and *L. lilloetensis* the more compressed end member. Many such cases of intraspecific variability have been cited by Kennedy and Cobban (1976).

Crickmay (1930a) collected the type specimens of *L. lilloetensis*, *L. mertonyarwoodi* and *L. buckmani* (*L. milleri* came from Alaska (Imlay, 1953b)) from the 3100 foot level in the Billhook Creek valley at his locality 15. Only one specimen was found in this valley and there is not enough material to contribute to the discussion of the synonymy of these three species. Locality 17A, from which *L. lilloetensis* was collected, did not yield the depressed end members of *Lilloettia* that were found by Crickmay (1930a) at his locality 15.

Age and distribution. *Lilloettia* has been found in Alaska, western British Columbia, the Canadian Rocky Mountains, Oregon, southern Mexico and the Argentine Andes. It is characteristic of the East Pacific Realm (Taylor et al., 1984) and ranges from Late Bathonian to early Early Callovian (Callomon, 1984).

Lilloettia tipperi Frebold, 1967

Plate 2, figure 1.

* 1967 *Lilloettia tipperi* Frebold in Frebold and Tipper, p. 9, pl. 1, fig. 1-6; pl. 3, fig. 2.

Material. One specimen in dark calcareous siltstone.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | WW(WWD) | WWWH |
|-----------|-----|----|-----|-----------|-----------|------|
| GSC 91617 | 147 | 3 | 2.0 | 80 (54.4) | 77 (52.4) | 96.3 |

Description. A convolute specimen with a very small umbilicus. The flanks are convergent and the venter relatively narrow but the venter broadens on the last half-whorl to give a subquadrate whorl section. This is a mature individual with the last 2 cm of the shell preceding the peristome being weakly contracted and marked by a black strip reminiscent of modern *Nautilus* when it reaches maturity. The peristome swings forward ventrally.

Except for the broad, densely spaced ribs on the venter of its first quarter, the last whorl is smooth.

Occurrence. Collected from the Mysterious Creek Formation (locality 17). This species was hitherto only known from the Nechako River area and its age was uncertain. Callomon kept *L. tipperi* as a separate fauna (B8d) to emphasize its uncertain stratigraphic position but the Harrison Lake occurrence confirms its Early Callovian age and suggests an assignment to his fauna B8e (Callomon, 1984). *L. tipperi* has now also been collected from the Smithers area but has not yet been documented in the literature. A very similar species is also known from the Upper Bathonian of Mexico (Westermann et al., 1984).

Age. Early Callovian (Macrocephalus Zone of Europe), possibly late Bathonian.

Lilloettia lilloetensis Crickmay, 1930a

Plate 3, figures 3-6.

* 1930a *Lilloettia lilloetensis* Crickmay, p. 62, pl. 18, fig. 1-4.

- 1953b *Lilloettia lilloetensis* Crickmay; Imlay, p. 77, pl. 30, fig. 1, 2, 4, 8.
 1967 *Lilloettia lilloetensis* Crickmay; Frebold and Tipper, p. 11, pl. 1, fig. 7, 8; pl. 3, fig. 3.
 1978 *Lilloettia* cf. *L. lilloetensis* Crickmay; Frebold, p. 8, pl. 8, fig. 1-3.

Material. Three internal molds from sheared siltstone (locality 17A); two poorly preserved external molds (localities 26 and 35) from fine grained sandstone and a single fragment of a whorl from locality 36 (Crickmay's locality 15).

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | WW(WWD) | WWW | PRHW | SRHW |
|-----------|------|-----|------|-------------|-------------|------|------|------|
| GSC 91576 | 51.4 | 4.2 | 81.7 | 26.5 (51.6) | 20.7 (40.3) | 78.1 | 11 | 27 |

Description. Umbilicus very narrow; umbilical wall smooth and moderately steep. Whorl shape compressed. Flanks gently convex; venter is plain and inflated (Fig. 27). Ribs are faint on umbilical shoulder and rectiradial. They become stronger on lower flank and flex prorsiradially. About mid-flank or slightly above, the primary ribs bifurcate; very few remain single to the venter. Intercalated secondaries are common and begin around the furcation points. Ribs pass over the venter, where they flex gently prorsiradially. Suture line is not preserved.

Discussion. *L. lilloetensis* differs from *L. stantoni* Imlay by having denser, less coarse ribs, although both species are compressed. The type specimen has fine, dense ribbing on inner whorls. The ribs begin to fade on later whorls starting with the primaries and the whorl is smooth beyond a diameter of 85 mm (Crickmay, 1930a).

Occurrence. *L. lilloetensis* has been found in southern Alaska (Imlay, 1953b), the Smithers area (Frebold, 1978), the Taseko Lakes region (Frebold and Tipper, 1967) and the Harrison Lake area where it was first described from the Mysterious Creek Formation (Crickmay, 1930a). The specimens were collected from locality 17A, which lies about 10 to 15 m stratigraphically beneath locality 17 where *Cadoceras*

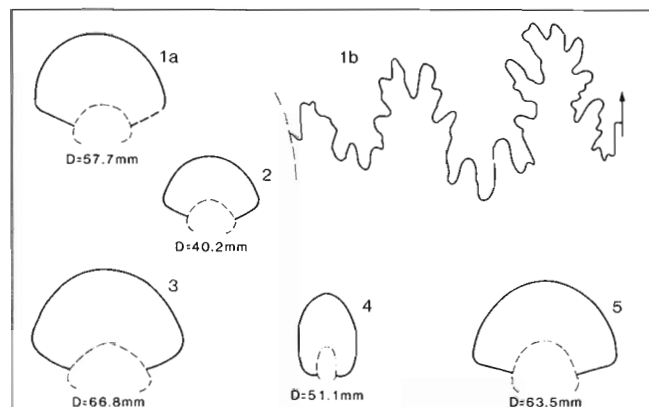


Figure 27. Whorl shapes and suture patterns noted on Callovian ammonites from localities 17 and 17A. *Cadoceras* (*Paracadoceras*) *tonniense*. 1a. 91589, whorl shape; 1b. 91589, suture pattern; 2. 91592, whorl shape; 3. 91590, whorl shape; 4. *Lilloettia lilloetensis*, 91576, whorl shape; 5. *Cadoceras comma*, 91582, whorl shape.

comma and *Cadoceras* (*Pseudocadoceras grewinkii*) were collected. The latter locality belongs in Callomon's Fauna B8e. *L. lilloetensis* belongs to Callomon's Fauna B8c which is slightly older than Fauna B8e. Therefore, these localities agree well with the faunal assemblage zones of Callomon (1984). Single specimens of *L. lilloetensis* were collected from section 1 (locality 26) and localities 35 and 36 (Fig. 4).

Age. Early Callovian (Macrocephalus Zone of Europe) – Fauna B8(c) of Callomon (1984).

Lilloettia cf. *stantoni* Imlay, 1953b

Plate 3, figure 7.

- * 1953b *Lilloettia stantoni* Imlay, p. 77, pl. 29, fig. 1-5,9,10.

PLATE 3

[All figures natural size. The last suture is marked by an arrowhead.]

Figure 1. *Phymatoceras*? sp.

- GSC 91574 (latex cast), GSC Loc. No. C-118595, Locality 7; Middle Toarcian?

Figure 2. *Erycitoides*? sp.

- GSC 91575 (latex cast), GSC Loc. No. C-118592, Locality 3; Aalenian.

Figures 3-6. *Lilloettia lilloetensis* Crickmay

- GSC 91579, GSC Loc. No. C-118577, Locality 36; a. lateral view, b. ventral view; Early Callovian.
- GSC 91578 (latex cast), GSC Loc. No. C-118557, Locality 26; a. ventral view, b. lateral view; Early Callovian.
- GSC 91576, GSC Loc. No. C-149641, Locality 17A; a. lateral view, b. ventral view; Early Callovian.
- GSC 91577, GSC Loc. No. C-149641, Locality 17A; a. ventral view, b. lateral view; Early Callovian.

Figure 7. *Lilloettia* cf. *stantoni* Imlay

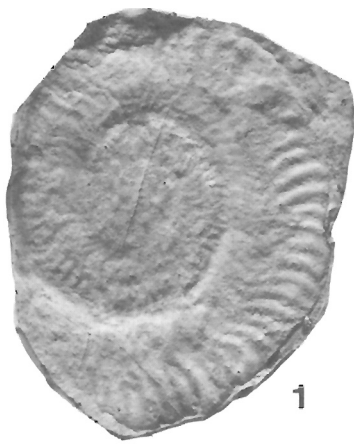
- GSC 91580, GSC Loc. No. C-118600, Locality 1; Early Callovian.

Figure 8. *Xenoceras* cf. *vicarius* Imlay

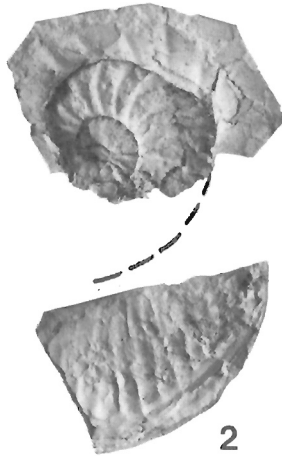
- GSC 91581, GSC Loc. No. C-118600, Locality 1; Early Callovian.

Figures 9,10. *Cadoceras comma* Imlay

- GSC 91587 (latex cast of a completely septate specimen), GSC Loc. No. C-118557, Locality 26; a. lateral view, b. ventral view; Early Callovian.
- GSC 91583, GSC Loc. No. C-118586, Locality 17; Early Callovian.



1



2



3a



3b



4a



4b



5a



5b



6a



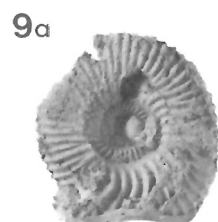
6b



7



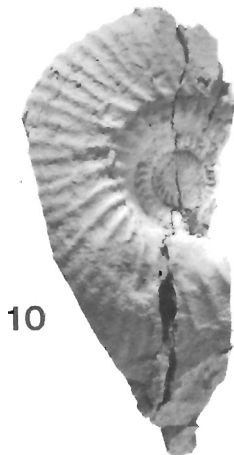
8



9a



9b



10

- 1964 *Lilloettia* cf. *stantoni* Imlay, p. D14, pl. 2, fig. 13,16.
 1981 *Lilloettia stantoni* Imlay, p. 18, pl. fig. 20-26.

Material. One specimen preserved as an internal mold in dark grey siltstone; it has been compressed in the plane of coiling.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | PRHW |
|-----------|------|-----|-----|-------------|------|
| GSC 91580 | 43.9 | 2.9 | 6.6 | 24.5 (55.8) | c9 |

Description. Involute with a low umbilical wall passing abruptly into a flat, becoming gently convex flank. The specimen is secondarily compressed. Ribbing is strong, sinuous and generally prorsiradiate. Primary ribs bifurcate near the middle of the flanks.

Discussion. The specimen is similar in ribbing and volution to *L. stantoni* Imlay which has been found in southern Alaska (Imlay, 1953b) and Oregon (Imlay, 1964, 1981). However, the whorl shape cannot be determined making positive identification impossible.

Occurrence. Collected at locality 1 (Crickmay's locality 8) on the south shore of Harrison River from the Mysterious Creek Formation. It was associated with *Xenocephalites* cf. *vicarius*. *L. stantoni* has also been found in the Chinitna and Shelikof formations of Alaska (Imlay, 1953b) and the Trowbridge and Luresome formations of Oregon (Imlay, 1964, 1981).

Age. Early Callovian (Macrocephalus Zone of Europe).

Genus *Xenocephalites* Spath, 1928

Type species. *Macrocephalites neuquenensis* Stehn, 1924 (p. 86, pl. 1, fig. 3) designated by Spath, 1928 (p. 175).

Remarks. Involute forms with a broad venter and coarse bifurcating ribs.

Age and distribution. *Xenocephalites* characterizes the Bathonian and Early Callovian of the eastern Pacific (Taylor et al., 1984; Callomon, 1984).

***Xenocephalites* cf. *vicarius* Imlay, 1953**

Plate 3, figure 8.

- * 1953b *Xenocephalites vicarius* Imlay, p. 78, pl. 28, fig. 1-8.
 1953b *X. hebetus* Imlay, p. 78, pl. 29, fig. 6,7 only.

1964 *X. vicarius* Imlay; Imlay, p. D14, pl. 1, fig. 23-27.

1981 *X. vicarius* Imlay; Imlay, p. 18, pl. 1, fig. 6,8-18.

Material. One internal mold in dark grey siltstone.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | PRHW | SRHW |
|-----------|------|-----|-----|-------------|------|------|
| GSC 91581 | 40.8 | 3.6 | 8.8 | 21.5 (52.7) | 9 | 17 |

Description. Involute with convex flanks bearing coarse ribs that bifurcate on the lower part of the flank where they become less prorsiradiate.

Occurrence. Collected from locality 1 and associated with a similarly poorly preserved *Lilloettia* cf. *stantoni*. If *L. cf. stantoni* and *X. vicarius* are correctly identified, they duplicate an association recorded from the Lower Callovian part of the Trowbridge Formation in east-central Oregon (Imlay, 1981).

Age. Early Callovian.

Family CARDIOCERATIDAE Siemiradzki, 1891

Subfamily CADOCERATINAE Hyatt, 1900

Genus *Cadoceras* Fischer, 1882

Type species. *Ammonites sublaevis* Sowerby, 1814 by subsequent designation (Spath, 1932).

Remarks. Inner and middle whorls well ribbed, becoming smooth on later whorls. Diagnostic of this genus is a sharp umbilical shoulder on mature whorls. Forms accommodated in the subgenus *Paracadoceras* tend to be smaller and more evolute on the inner whorls whereas microconchs of the genus are accommodated in the subgenus *Pseudocadoceras* (Callomon, 1984).

Age and distribution. *Cadoceras* is characteristic of the Boreal Realm being common over much of northern and central Europe, Russia, Siberia, Arctic Islands, East Greenland and localities along the western edge of North America from southern Alaska to the 49th parallel and possibly to California. The genus ranges in age from Late Bathonian to Early Callovian.

***Cadoceras comma* Imlay, 1953b**

Plate 3, figures 9,10.

Plate 4, figure 1.

Plate 5, figures 1-4.

- * 1953b *Cadoceras comma* Imlay, p. 83, pl. 35, fig. 1-8; pl. 36, fig. 1-5.

Material. Eight specimens from three localities; five represent mature growth stage.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | WW(WWD) | WWWH | PRHW |
|-----------|------|------|------|-------------|-------------|-------|------|
| GSC 91582 | 73.9 | 29.1 | 39.4 | 25.7 (34.8) | 47.3 (64.0) | 184.0 | c15 |
| GSC 91583 | 45.8 | 13.4 | 29.2 | 18.9 (41.3) | -- | -- | 14 |
| GSC 91584 | 24.0 | 6.0 | 25.0 | 9.7 (40.4) | 12.8 (53.3) | 132.0 | c12 |
| GSC 91587 | 23.5 | 7.3 | 31.1 | 8.3 (35.3) | 11.2 (47.7) | 135.0 | 15 |

Description. Immature specimens have an ovate whorl shape; adult whorls are coronate in section and the shell is globose (Fig. 27). Umbilicus narrow and deep; wall steep and high especially on outer whorls. Umbilical shoulder curved on inner whorls and angular in adult stages. Flanks gently curve on inner whorls to an inflated, plain venter; flanks on outer whorls indistinguishable from convex venter.

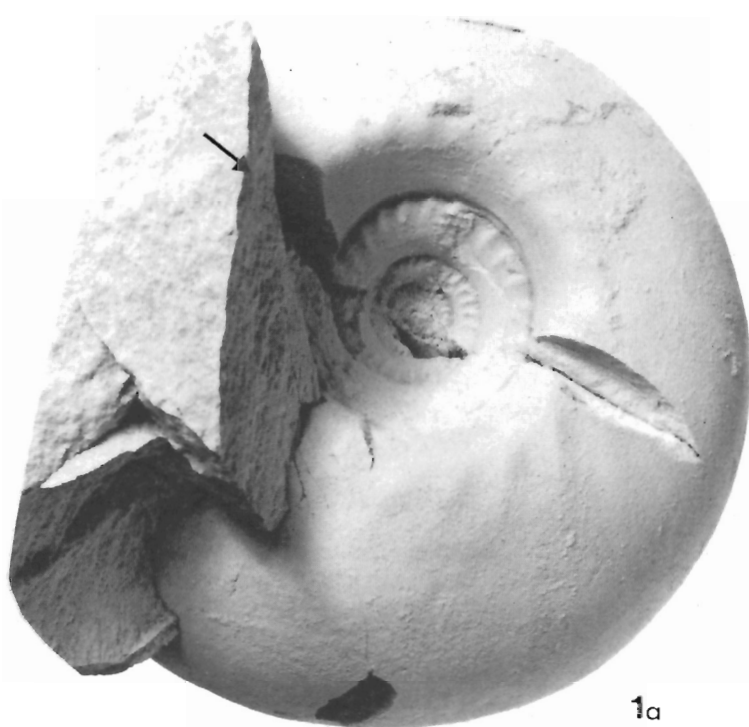


PLATE 4

[Natural size. The last suture is marked by an arrowhead.]

Figure 1. *Cadoceras comma* Imlay

1. UBC 008, GSC Loc. No. C-118586, Locality 17; a. lateral view, b. ventral view.

This is a mature specimen but the nature of the peristome cannot be determined because the donor stipulated it be left in the matrix.

Ribs are strong and fairly distant (13 primary ribs per half whorl) on inner and intermediate whorls. They begin on umbilical wall and pass prorsiradially onto the lower flank where they bifurcate into strong secondaries which flex slightly back and pass over the venter. Changes in ribbing occur during growth. Furcation points become indistinct and some intercalated ribs begin to appear; the venter and then flanks become smooth (some striae can be seen) leaving only coarse umbilical swellings across the umbilical shoulder. Striae divide out from these swellings. The suture line is not preserved in any of the specimens.

Discussion. Imlay (1953b) stated that "this species is characterized by its globose, coronate form, by coarse ribbing that passes into striae on the last two whorls and by the persistence of comma-shaped swellings on the umbilical edge." *Cadoceras comma* resembles *C. glabrum* Imlay, but is less evolute, remains ribbed longer and retains the strong comma-shaped swellings on its mature whorls. *C. barnstoni*

Meek is similar in form to *C. comma* but ribs, although weaker, still occur on adult whorls and the umbilical wall is steeper (see Frebold, 1964). There are also marked similarities between *C. comma* from Harrison Lake and *C. cf. elatmae* Nikitin figured by Schlegelmilch (1985, pl. 41, fig. 12). A zonal scheme set up by Imlay (1975) placed *C. comma* into his "*Cadoceras catostoma*" zone which is Early Callovian. This zone has been abandoned and replaced by the *Cadoceras comma* Fauna B8 assemblage for reasons discussed by Callomon (1984, p. 159). Its age, however, remains Early Callovian. The species *C. comma* is placed in Callomon's (1984) *C. wosnessenskii* Fauna B8(e).

Occurrence. *C. comma* is found in the Mysterious Creek Formation at locality 17 associated with *C. (Paracadoceras) tonniense*, *C. (Pseudocadoceras) growingki* Pompeckj and *L. tipperi* Frebold and at locality 41. *C. comma* is also found in the Chinitna and Shelikof formations, Alaska (Imlay, 1953b).

Age. Early Callovian (Macrocephalus Zone of Europe) – Fauna B8(e) of Callomon (1984).

Subgenus *Paracadoceras* Crickmay 1930

Cadoceras (*Paracadoceras*) *tonniense* Imlay

Plate 5, figures 6-9.

- * 1953b *Cadoceras* (*Paracadoceras*) *tonniense* Imlay, p. 88, pl. 43, fig. 9-11, 13.

Material. Four specimens from a calcareous siltstone; one shows a cross-sectional view.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | WW(WWD) | WWWH | PRHW |
|-----------|------|------|------|-------------|-------------|-------|------|
| GSC 91589 | 70.0 | 16.6 | 23.7 | 24.1 (34.4) | 35.1 (50.1) | 145.6 | c14 |
| GSC 91590 | 66.8 | 14.8 | 22.2 | 29.6 (44.3) | 35.3 (52.8) | 119.2 | 13 |
| GSC 91591 | 31.7 | 9.4 | 29.6 | 13.3 (42.0) | 15.5 (48.9) | 116.5 | -- |
| GSC 91592 | 40.0 | 10.1 | 25.3 | 16.3 (40.8) | 25.1 (62.8) | 154.0 | 12 |

Description. Whorl shape ellipsoidal to shell diameters of approximately 40 mm, becoming more rounded on later whorls (Fig. 27). Whorl width widest at umbilical shoulder. Umbilicus deep and moderately narrow; wall low and gently inclined on inner whorls, becoming steeper and higher on later whorls. Umbilical shoulder strongly curved; flanks gently curve onto an arched venter on inner whorls or a rounded venter on outer whorls.

Ribs begin part way down umbilical wall. They project straight up and flex anteriorly at umbilical shoulder onto the flanks. Ribs are gently prorsiradiate across flanks; at mid-flank primaries bifurcate although some remain single; intercalated secondaries are present. Ribs continue up flanks and cross over venter on inner whorls but begin to fade on venter and flanks of last whorl leaving only swellings on umbilical shoulder. Suture line can not be traced.

Discussion. The specimen most closely resembles *Cadoceras* (*Paracadoceras*) *tonniense*. It differs from *C. (P.) multiforme* Imlay, which has a wider, deeper umbilicus, sharper umbilical shoulder and a broader whorl shape. *C. comma* has a more globose whorl shape, sharper umbilical shoulder with more pronounced umbilical swellings and a steeper umbilical wall than *C. (P.) tonniense*.

Occurrence. *C. (P.) tonniense* is found at locality 17 in the Mysterious Creek Formation. Associated faunas at this locality include *C. comma* Imlay and *Pseudocadoceras grewinkii* Pompeckj. These three species are also found together in the lower part of Chinitna Formation, Alaska (Imlay, 1953b) although not from the same localities. Locality 17 is placed into Fauna B8e of Callomon (1984) based on the presence of *C. comma*. *C. (P.) tonniense* may range from Callomon's (1984) Fauna B8b through to Fauna B8e although it is most common in the older Fauna B8b.

Age. Early Callovian (Macrocephalus Zone of Europe) – Fauna B8(e) of Callomon (1984).

Subgenus *Pseudocadoceras* Buckman, 1918

Cadoceras (*Pseudocadoceras*) *grewinkii* (Pompeckj)

Plate 6, figures 1-5.

- 1953b *Pseudocadoceras grewinkii* (Pompeckj); Imlay, p. 93, pl. 49, fig. 1-12.
1961 *Pseudocadoceras grewinkii* (Pompeckj); Imlay, p. D21, pl. 2, fig. 1-8, 11-13.
1961 *Pseudocadoceras* cf. *P. grewinkii* (Pompeckj); Imlay, p. D21, pl. 2, fig. 22.
1967 *Pseudocadoceras grewinkii* (Pompeckj); Frebold and Tipper, p. 15, pl. 2, fig. 5, 6.
1981 *Pseudocadoceras grewinkii* (Pompeckj); Imlay, p. 20, pl. 2, fig. 3-8.

Material. Twenty or more fragments and complete specimens preserved in a calcareous siltstone. Many specimens have been distorted to some degree in the plane of coiling.

PLATE 5

[All figures natural size. The last suture is marked by an arrowhead.]

Figures 1-4. *Cadoceras comma* Imlay

1. GSC 91582, GSC Loc. No. C-118586, Locality 17; a. ventral view, b. view of whorl shape, c. lateral view; the last half whorl is non-septate; Early Callovian.
2. GSC 91584 (latex cast), GSC Loc. No. C-118586, Locality 17; a. ventral view, b. lateral view; Early Callovian.
3. GSC 91585, GSC Loc. No. C-118562, Locality 41; Early Callovian.
4. GSC 91586 (latex cast), GSC Loc. No. C-118562, Locality 41; Early Callovian.

Figure 5. *Cadoceras* (*Pseudocadoceras*) cf. *catostoma* Pompeckj

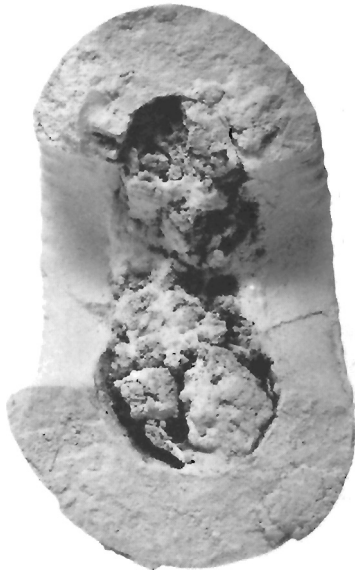
5. GSC 91588, GSC Loc. No. C-118554, Locality 18; Early Callovian.

Figures 6-9. *Cadoceras* (*Paracadoceras*) *tonniense* Imlay

6. GSC 91592, GSC Loc. No. C-118586, Locality 17; Early Callovian.
7. GSC 91589, GSC Loc. No. C-118586, Locality 17; a. lateral view, b. ventral view; Early Callovian.
8. GSC 91590, GSC Loc. No. C-118586, Locality 17; Early Callovian.
9. GSC 91591, GSC Loc. No. C-118586, Locality 17; view of whorl shape; Early Callovian.



1a



1b



1c



2a



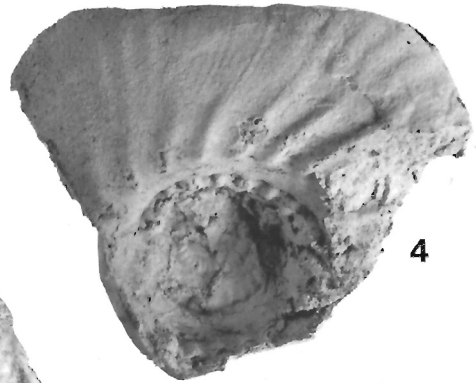
2b



6



3



4



5



7a



7b



8



9

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | WW(WWD) | WWW | PRHW |
|-----------|------|-------|------|--------------|------------|-------|------|
| GSC 91593 | 41.2 | 11.1 | 26.9 | 16.5 (40.0) | -- | -- | 17 |
| GSC 91594 | 15.6 | 4.1 | 26.3 | 7.0 (44.9) | 5.8 (37.2) | 82.9 | 17 |
| GSC 91595 | c45 | c11.7 | 26.0 | c19.1 (42.4) | -- | -- | 16 |
| GSC 91596 | 20.9 | 6.0 | 28.9 | 8.0 (38.3) | 8.3 (39.7) | 103.8 | 16 |
| GSC 91597 | 18.1 | 4.5 | 24.9 | 8.0 (44.2) | 6.0 (33.1) | 75.0 | -- |

Description. Shell is midvolute. Whorl shape ellipsoidal, being slightly higher than wide; widest on lower to mid-flank. Umbilicus fairly shallow and moderately wide. Umbilical wall low and moderately steep on inner whorls; becomes higher and steeper on outer whorls. Flanks are slightly convex and round onto a plain venter. Some specimens have tectonically distorted whorls which have exaggerated umbilical depths. Specimen GSC 91596 (Pl. 6, fig. 5), which is well preserved but incomplete, shows signs of egression and a coarsening of the ribbing indicating the onset of maturity.

Ribs begin about the middle of umbilical wall inclining rursiradiately. At umbilical shoulder they flex prorsiradiately onto flanks. About mid-flank, some primaries bifurcate; this occurs more frequently on the outer whorls. Some secondaries are only loosely attached at a furcation point; still others remain unattached. These unattached secondaries usually separate two non-bifurcating primary ribs. At the ventro-lateral shoulder, ribs thicken slightly and project onto venter. Ribs are fine and closely spaced on inner whorls, becoming stronger, sharper and more widely spaced on outer whorls. Suture can not be seen on any of the specimens.

Discussion. *Pseudocadoceras petelini* Pompeckj is similar to *P. growingki* but has a flatter whorl shape, finer ribs and a narrower umbilicus (see Imlay, 1953b, pl. 48, 49). *P. growingki* and *Cadoceras comma* are both found at locality 17 and a single specimen of *P. growingki* was recovered from locality 30. The two species are also found together in Chinitsna Formation (Imlay, 1953b) at U.S.G.S. Mesozoic localities 2921, 3028, 3029, 21344, 21348, 22432, 22435 and 22452 and from isolated localities in the Shelikof Formation, Alaska. *P. growingki* is also known from the Taseko Lakes region of British Columbia (Frebold and Tipper, 1967), Oregon (Imlay, 1981) and California (Imlay, 1961).

Age. Early Callovian (Macrocephalus Zone of Europe) – possibly Fauna B8e of Callomon (1984).

Cadoceras (Pseudocadoceras) cf. catostoma Pompeckj

Plate 5, figure 5.

1953b *Cadoceras catostoma* Pompeckj; Imlay, p. 82, pl. 34, fig. 1-14.

Material. One specimen from grey to black shale.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | WW(WWD) | WWW | PRHW |
|-----------|------|------|------|-------------|-------------|-------|------|
| GSC 91588 | 39.9 | 13.3 | 33.3 | 15.5 (16.7) | 16.7 (41.9) | 107.7 | c13 |

PLATE 6

[All figures natural size. The last suture is marked by an arrowhead.]

Figures 1-5. *Cadoceras (Pseudocadoceras) growingki* Pompeckj

1. GSC 91593, GSC Loc. No. C-118586, Locality 17; a. lateral view, b. ventral view, Early Callovian.
2. GSC 91595, GSC Loc. No. C-118586, Locality 17; a. lateral view, b. ventral view, Early Callovian.
3. GSC 91597 (latex cast), GSC Loc. No. C-118557, Locality 26; a. lateral view, b. ventral view; Early Callovian.
4. GSC 91594, GSC Loc. No. C-118586, Locality 17; a. lateral view, b. ventral view; Early Callovian.
5. GSC 91596, GSC Loc. No. C-118586, Locality 17; a. lateral view, b. ventral view; Early Callovian.

Figures 6-11. *Cardioceras (Scarburgiceras) martini* Reeside

6. GSC 91599 (latex cast), GSC Loc. No. C-118570, Locality 15; Early Oxfordian.
7. GSC 91600 (latex cast), GSC Loc. No. C-118570, Locality 15; Early Oxfordian.
8. GSC 91601 (latex cast), GSC Loc. No. C-118570, Locality 15; Early Oxfordian.
9. GSC 91602 (latex cast), GSC Loc. No. C-118570, Locality 15; Early Oxfordian.
10. GSC 91604, GSC Loc. No. C-118570, Locality 15; a. lateral view of whorl fragment, b. ventral view; Early Oxfordian.
11. GSC 91603, GSC Loc. No. C-118570, Locality 15; Early Oxfordian.

Figures 12-16. *Cardioceras (Cardioceras) cf. hyatti* Reeside

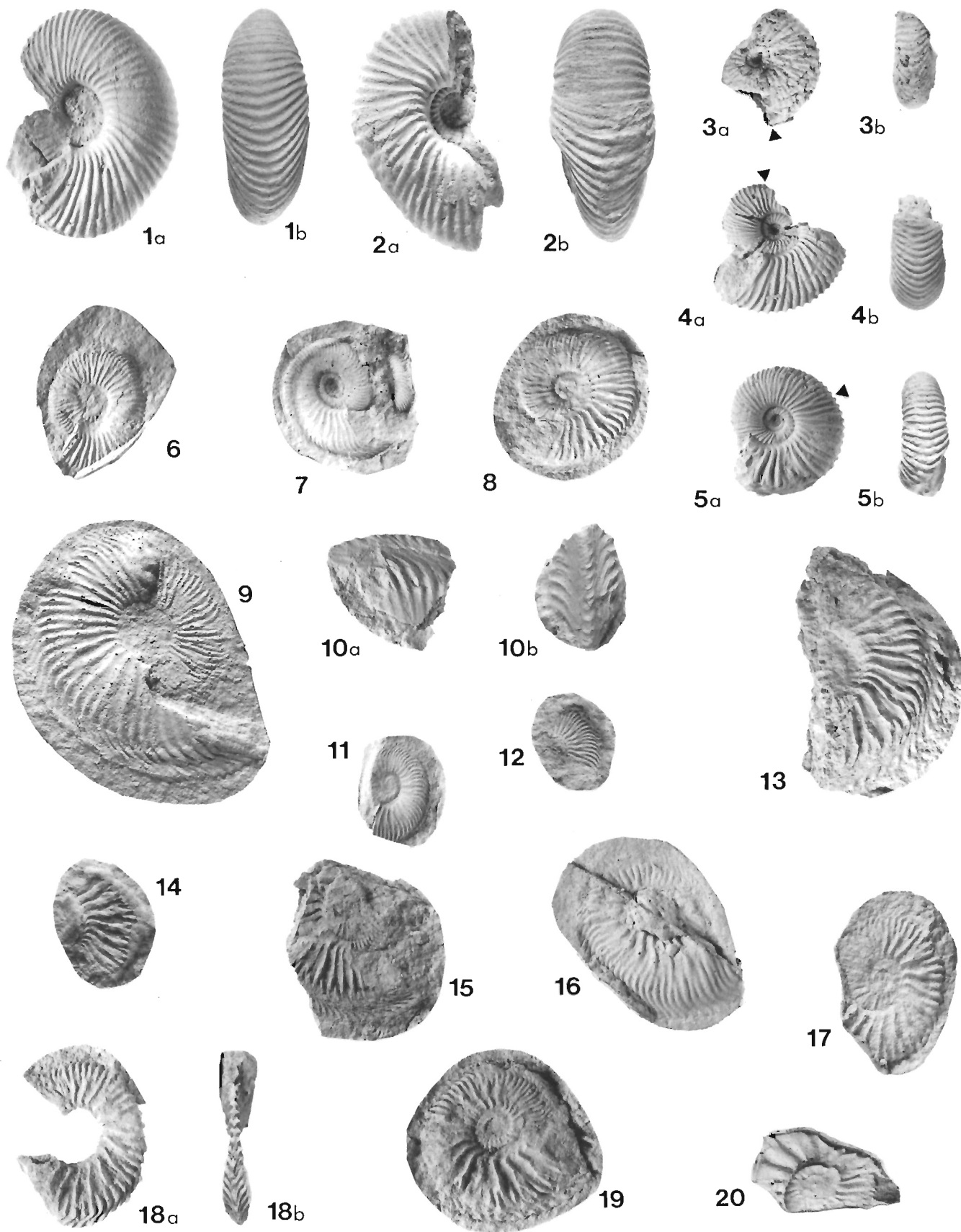
12. GSC 91609, GSC Loc. No. C-118598, Locality 20; Early Oxfordian.
13. GSC 91606, GSC Loc. No. C-118598, Locality 20; Early Oxfordian.
14. GSC 91608, GSC Loc. No. C-118598, Locality 20; Early Oxfordian.
15. GSC 91607, GSC Loc. No. C-118598, Locality 20; Early Oxfordian.
16. GSC 91610 (latex cast), GSC Loc. No. C-118570, Locality 15; Early Oxfordian.

Figures 17-19. *Cardioceras (Cardioceras) lillooetense* Reeside

17. GSC 91613 (latex cast), GSC Loc. No. C-118598, Locality 20; Early Oxfordian.
18. GSC 91614, GSC Loc. No. C-118598, Locality 20; a. lateral view, b. ventral view; Early Oxfordian.
19. GSC 91615, GSC Loc. No. C-118598, Locality 20; Early Oxfordian.

Figure 20. *Cardioceras* sp.

20. GSC 91616 (latex cast), GSC Loc. No. C-118570, Locality 15; Early Oxfordian.



Description. Mid-volute; umbilicus moderately deep with step-like whorls on this specimen. Umbilical wall steep on inner whorls but lowers toward the peristome. Sub-ovate whorl shape; wider than high on last whorl.

Ribs begin low on umbilical wall and project rectiradiately or gently rursiradiately towards umbilical shoulder at which point they curve anteriorly and become prorsiradiate. Just below mid-flank some primaries bifurcate, others remain single. Intercalated ribs are present and begin about mid-flank. Ribs continue up flanks and cross over venter where they arch gently forward. The outer whorl is incomplete but is non-septate and shows weak egression.

Discussion. No large specimens of *Cadoceras catostoma* were found at Harrison Lake but this specimen (Pl. 3, fig. 7) resembles figured specimens in Imlay (1953b e.g., pl. 34, fig. 6) which represent the microconch. *C. catostoma* is placed in the *C. wosnessenskii* Fauna B8(e) of Callomon (1984) and its age is Early Callovian. Crickmay (1925, 1930a) discussed *C. catostoma* and stated its presence at Harrison Lake but he did not figure the specimen. *C. (Pseudocadoceras) crasscostatum* (Imlay, 1953b, pl. 49, fig. 24) is also similar except for its narrower venter.

Occurrence. Locality 18 from which *C. (Pseudocadoceras) cf. catostoma* was collected is found several tens of metres stratigraphically above locality 17 from which *C. comma* Imlay and *C. (Pseudocadoceras) growingki* Pompeckj were collected. These species are found together (Imlay, 1953b) in the lower two-thirds of the Chinitsna Formation, Alaska and in the lower member of the Shelikof Formation, Alaska.

Age. Early Callovian (Macrocephalus Zone of Europe) – Fauna B8(e) of Callomon (1984).

Subfamily CARDIOCERATINAE Siemiradzki, 1891

Genus *Cardioceras* Neumayr and Uhlig, 1881

Type species. *Ammonites cordatus* Sowerby, 1813 by subsequent designation (Buckman, 1920).

Remarks. *Cardioceras* has a keeled venter. Whorl shape is moderately compressed. Ribs are well differentiated and secondaries project strongly onto venter.

Age and distribution. *Cardioceras* is found in Europe, Russia, northern Siberia and localities between Alaska and Utah along the western margin of North America. The genus characterizes the Boreal Realm and ranges through the Early Oxfordian.

Subgenus *Scarburgiceras* Buckman, 1924

Cardioceras (Scarburgiceras) martini Reeside, 1919

Plate 6, figures 6-11.

- * 1919 *Cardioceras martini* Reeside, p. 27, pl. 9, fig. 5-8.
- 1930a *Anacardioceras perrini* Crickmay, p. 58, pl. 17, fig. 1-3.
- 1938 *Cardioceras (Anacardioceras) martini* Reeside; Maire, p. 65, pl. 9, fig. 7, 8.

1964 *Cardioceras (Scarburgiceras) martini* Reeside; Imlay, p. D15, pl. 2, fig. 1-5.

1975 *Cardioceras (Scarburgiceras) martini* Reeside; Frebold and Tipper, p. 152, pl. 2, fig. 8-10.

1981 *Cardioceras (Scarburgiceras) martini* Reeside; Imlay, p. 33, pl. 10, fig. 12-22.

Material. More than 25 specimens and fragments preserved as internal and external molds in dark grey calcareous shale and siltstone.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | PRHW | SRHW |
|-----------|------|------|------|-------------|------|------|
| GSC 91600 | 23.6 | 6.8 | 28.8 | 10.6 (44.9) | 14 | -- |
| GSC 91601 | 27.2 | 8.4 | 30.9 | 11.8 (43.4) | 14 | 17 |
| GSC 91602 | 46.5 | 11.8 | 25.4 | 20.1 (43.2) | 15 | 14 |
| GSC 91605 | 24.8 | 7.3 | 29.4 | 10.0 (40.3) | 16 | -- |

Description. Umbilicus fairly narrow; wall low, steep. Flanks are very gently curving (almost flat); keel is fairly high and serrated. Whorls are moderately expanding and whorl shape is ogivale.

Ribs begin on umbilical wall inclining gently rursiradiately to umbilical shoulder where they curve slightly to become rectiradiate. They are moderately sharp but low; at mid-flank most primaries bifurcate, especially on the more immature whorls. The more posterior of the bifurcating ribs commonly arches back forming a sickle-like shape as it crosses the upper half of the flank. The anterior rib is usually straighter but may flex somewhat. At ventro-lateral shoulder the ribs project onto venter; some secondaries may fork again on venter (91604, pl. 4, fig. 10). Ribs cross over keel forming an anteriorly pointing chevron pattern when looking down on the venter.

Discussion. *Cardioceras (Scarburgiceras) martini* resembles the European species *C. (S.) praecordatum* Douville but is less evolute and usually has fewer, coarser ribs (some *C. praecordatum* figured in Maire (1938, pl. 6) are coarser ribbed varieties). It also closely resembles the somewhat problematic species *C. (S.) reesidei* Maire (see Maire, 1938, p. 61, pl. 7, fig. 5, 6; Imlay, 1982, p. 36, pl. 16, fig. 1-8) but *C. (S.) martini* appears to be slightly less evolute. The two species would perhaps be better described under the single species *C. (S.) martini* Reeside.

Occurrence. *C. (S.) martini* is found in the Billhook Creek Formation on the southwest shore of Cascade Peninsula at locality 15. It is the dominant species at this locality, but two specimens of *C. (C.) cf. hyatti* Reeside and a single *Cardioceras* sp. were also collected. *C. (C.) martini* has also been collected from the Taseko Lakes region, British Columbia (Frebold and Tipper, 1967) and from southern Alaska (Reeside, 1919). The species is also found in France (Maire, 1938).

Age. Early Oxfordian (Bukowskii Subzone of Europe) – Fauna B12 of Callomon (1984).

Subgenus *Cardioceras* Arkell, 1946

Cardioceras (*Cardioceras*) cf. *hyatti* Reeside, 1919

Plate 6, figures 12-16.

- * 1919 *Cardioceras hyatti* Reeside, p. 26, pl. 15, fig. 1-4.
- 1938 *Cardioceras* (*Anacardioceras*) *hyatti* Reeside; Maire, p. 75, pl. 13, fig. 2.
- 1981 *Cardioceras* (*Cardioceras*) *hyatti* Reeside; Imlay, p. 32, pl. 9, fig. 6.
- 1982 *Cardioceras* (*Cardioceras*) *hyatti* Reeside; Imlay, p. 31, pl. 15, fig. 1-14.

Material. Eight specimens from two localities (15 and 20) preserved as internal and external molds in siltstone and sandstone.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | PRHW |
|-----------|------|------|------|------------|------|
| GSC 91606 | 41.3 | 10.6 | 25.7 | 17.5(42.4) | 12 |
| GSC 91611 | 18.7 | 6.3 | 33.7 | 8.2(43.9) | 13 |
| GSC 91612 | 28.2 | 8.1 | 28.7 | 11.7(41.5) | 12 |
| GSC 91610 | 35.0 | 10.2 | 29.1 | 17.0(48.6) | 13 |

Description. Umbilicus poorly preserved in all specimens but is fairly narrow; umbilical wall low and steep. Flanks flat; curved ventro-lateral shoulder and a sharp, high keel. Whorl shape is ogival with the addition of a keel.

Ribs are moderately distant and begin on umbilical wall. They are rectiradial to the umbilical shoulder where they curve onto the flanks becoming prorsiradial. The ribs are sharp, strong and fairly straight on the lower flank. In mid-flank area the ribs become higher; an elongated node-like projection becomes prominent on some primary ribs. This persists to the furcation point where ribs become lower but still remain fairly sharp. Some ribs bifurcate, but many remain single and are separated by one or two intercalated ribs. At the ventro-lateral shoulder ribs project strongly onto venter and cross over keel forming an anteriorly pointing chevron pattern when looking down onto the venter. No suture line is preserved.

Discussion. All specimens of *C. (C.) cf. hyatti* collected from the Harrison Lake area are immature forms; the largest specimen being 41.3 mm in diameter. *C. (C.) cf. hyatti* is similar in form to *C. (S.) wyomingense* Reeside but is slightly less evolute and has fewer, sharper and straighter ribs. Also, the furcation points start slightly higher on the flanks of *C. (C.) cf. hyatti*. A specimen figured as *C. cordiforme* Meek and Hayden in Reeside (1919, pl. 7, fig. 5, 6) was assigned to *C. praecordatum* Douville by Maire (1938). Imlay (1982, p. 33) considered the same figured specimen in Reeside (1919, pl. 7, fig. 5, 6) to be an immature form of *C. (C.) cf. hyatti*.

Occurrence. *Cardioceras* (*Cardioceras*) cf. *hyatti* has not been reported from Harrison Lake area previously. It is associated with *C. (C.) lillooetense* at locality 20 in the Billhook Creek Formation. Also at this locality are abundant bivalves, including *Pinna*. At locality 15 two

specimens of *C. (C.) cf. hyatti* were found associated with many specimens of *Cardioceras* (*Scarburgiceras*) *martini*. *C. (C.) cf. hyatti* has also been collected from France, Utah, Wyoming, South Dakota and Montana. It is placed in Callomon's (1984) Fauna A14(a) of the Western Interior region, which is approximately equivalent to Fauna B13 of his Cordilleran region (Callomon, 1984, p. 155).

Age. Early Oxfordian (Costicardia Subzone of Europe) – Fauna A14a (equivalent to Fauna B13) of Callomon (1984).

Cardioceras (*Cardioceras*) *lillooetense* Reeside, 1919

Plate 6, figures 17-19.

- * 1919 *Cardioceras lillooetense* Reeside; p. 27, pl. 17, fig. 20-23.
- 1975 *Cardioceras* (*Cardioceras*) cf. *C. (C.) lillooetense* Reeside; Frebold and Tipper, p. 150, pl. 2, fig. 5.
- 1981 *Cardioceras* (*Cardioceras*) *lillooetense* Reeside; Imlay, p. 32, pl. 9, fig. 1-5.
- 1981 *Cardioceras* (*Cardioceras*) cf. *C. (C.) lillooetense* Reeside; Imlay, p. 32, pl. 9, fig. 7-21.

Material. Three specimens preserved as internal and external molds in a medium- to coarse-grained green calcareous sandstone.

Measurements

| SPECIMEN | D | UD | U | WH(WHD) | PRHW | SRHW |
|-----------|------|-----|------|-------------|------|------|
| GSC 91613 | 27.3 | 8.9 | 32.6 | 9.7 (35.5) | 9 | 16 |
| GSC 91614 | 30.2 | 9.4 | 31.1 | 11.0 (36.4) | 9 | 14 |
| GSC 91615 | 29.1 | 7.6 | 26.1 | 12.9 (44.3) | 9 | 14 |

Description. Specimen midvolute, suture line not preserved; umbilical wall fairly low and steep. Umbilical shoulder round; flanks are gently convex and curve over ventro-lateral shoulder onto a keeled venter. Shell compressed.

Ribs are distant; primaries begin part way up umbilical wall. They are rectiradial to slightly rursiradial to the umbilical shoulder where they bend sharply forward to become prorsiradial. Ribs are fairly high and sharp; they continue straight to slightly flexed until just above mid-flank where the primaries end in an elongated node. Most bifurcate although a few may continue singly onto venter. Intercalated secondaries are common; the secondary ribs remain fairly strong although not quite as high as the primaries. At ventro-lateral shoulder ribs project onto the venter and climb over the sharp keel giving it a serrated or chevron-like appearance.

Discussion. *Cardioceras* (*Cardioceras*) *lillooetense* was originally described from *Cardioceras*-bearing beds at the head of Big Creek, Lillooet, British Columbia (Reeside, 1919, p. 27). It is characterized by its distant primaries, which are high and sharp, and elongated nodes found at furcation points. *C. (C.) lillooetense* was tentatively placed in *C. spiniferum* Fauna B13 by Callomon (1984, p. 163) and its occurrence at locality 20 with *C. (C.) cf. hyatti* seems to support this view.

Occurrence. *C. (C.) lillooetense* is found in the Billhook Creek Formation along the Harrison Lake shore, west of Long Island (locality 20). It has also been found near Smithers and Lillooet, British Columbia.

Age. Early Oxfordian (Costicardia Subzone of Europe) – Fauna B13 of Callomon (1984).

Cardioceras sp.

Plate 6, figure 20.

Material. One incomplete specimen preserved as an external mold in calcareous shale and siltstone.

Description. Moderately evolute; vertical umbilical wall. Ribs begin on umbilical wall and incline anteriorly at umbilical shoulder. Ventral area not preserved. Ribs fairly distant and broad, becoming even more so on later whorls.

Discussion. The specimen resembles *C. (C.) distans* Whitefield (see Imlay, 1982, pl. 17) in ribbing and by having a vertical umbilical wall.

Occurrence. Found with *Cardioceras* (*Scarburgiceras*) *martini* and two specimens of *Cardioceras* (*Cardioceras*) cf. *hyatti* at locality 15 on Cascade Peninsula.

Age. Early Oxfordian (Bukowskii Subzone of Europe) – based on associated fauna.

REFERENCES

- Anderson, P.**
1976: Oceanic crust and arc-trench gap tectonics in southwestern British Columbia; *Geology*, v. 4, p. 70-75.
- Arkell, W.J.**
1956: *Jurassic geology of the world*; Oliver and Boyd, London, 806 p., 46 pls.
- Arkell, W.J., Kummel, B., and Wright, C.W.**
1957: Mesozoic Ammonoidea; in *Treatise on Invertebrate Paleontology*, pt. L, Mollusca 4 - Cephalopoda, Ammonoidea, (ed.) R.C. Moore; New York, Geological Society of America and University of Kansas Press, 490 p.
- Arthur, A.J.**
1985: Biostratigraphy of the Lower to Middle Jurassic sediments, Ashcroft area, south-central British Columbia; BSc Thesis, University of British Columbia, Vancouver, 50 p., 6 pl.
1986: Stratigraphy along the west side of Harrison Lake, southwestern British Columbia; in *Current Research, Part B*; Geological Survey of Canada, Paper 86-1B, p. 715-720.
1987: Mesozoic stratigraphy and paleontology of the west side of Harrison Lake, southwestern British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, 171 p., 4 pl.
- Beatty, R.J.**
1974: Low grade metamorphism of Permian to Early Cretaceous volcanic and volcanoclastic rocks near Chilliwack, British Columbia; B.Sc. thesis, University of British Columbia, Vancouver, 51 p.
- Brookfield, M.E.**
1973: Lower Oxfordian (Upper Jurassic) sediments at Harrison Lake, British Columbia, and the age of the 'Agassiz Orogeny'; *Canadian Journal of Earth Sciences*, v. 10, p. 1688-1692.
- Brown, E.H.**
1987: Structural geology and accretionary history of the northwest Cascades system, Washington and British Columbia; *Geological Society of America Bulletin*, v. 99, p. 201-214.
- Buckman, S.S.**
1887- Monograph of the ammonites of the Inferior Oolite Series;
1907: Palaeontographical Society of London, 456 p., 103 pl.
1909- Yorkshire Type ammonites I and II, and Type ammonites III to VII,
1930: reprinted 1976, Wheldon and Wesley Ltd., London, England, and Verlag Cramer, Lehre, Germany, Herts., v. 1-7, pls. 1-790.
- Cairnes, C.E.**
1944: Geology of Hope area, British Columbia; Geological Survey of Canada, Map 732A.
- Callomon, J.H.**
1984: A review of the biostratigraphy of the post-Lower Bajocian ammonites of western and northern North America; in *Jurassic-Cretaceous Biochronology and Biogeography of North America*, (ed.) G.E.G. Westermann; Geological Association of Canada Special Paper 27, p. 143-174.
- Cameron, B.E.B. and Tipper, H.W.**
1985: Jurassic stratigraphy of the Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 365, 49 p.
- Church, B.N.**
1973: Geology of the White Lake Basin; British Columbia Department of Mines and Petroleum Resources, Bulletin 61, 120 p.
- Coates, J.A.**
1974: Geology of the Manning Park area, British Columbia; Geological Survey of Canada, Bulletin 238, 177 p.
- Cockfield, W.E. and Bell, A.H.**
1926: Whitehorse district, Yukon; Geological Survey of Canada, Memoir 150, 63 p.
- Coney, P.J., Jones, D.L., and Monger, J.W.H.**
1980: Cordilleran suspect terranes; *Nature*, v. 288, p. 329-333.
- Cordey, F., Mortimer, N., DeWever P., and Monger, J.W.H.**
1987: Significance of Jurassic radiolarians from the Cache Creek terrane, British Columbia; *Geology*, v. 15, p. 1151-1154.
- Crickmay, C.H.**
1925: The geology and paleontology of the Harrison Lake District, British Columbia, together with a general review of the Jurassic faunas and stratigraphy of western North America; Ph.D. thesis, Stanford University, Stanford, California, 140 p., 5 pl.
1930a: Fossils from Harrison Lake area, British Columbia; National Museum of Canada, Bulletin 63, p. 33-66, pl. 8-23.
1930b: The structural connection between the Coast Range of British Columbia and the Cascade Range of Washington; *Geological Magazine*, v. 67, p. 482-491.
1931: Jurassic history of North America and its bearing on the development of continental structure; *Proceedings of the American Philosophical Society*, v. 70, no. 1, p. 15-102.
1962: Gross stratigraphy of Harrison Lake area, British Columbia; published by author (article 8). Available from Evelyn deMille Books, Calgary, Alberta, 12 p.
- Danner, W.R.**
1960: An introduction to the stratigraphy of southwestern British Columbia and northwestern Washington; in *Guidebook for Geological Field Trips in Southwestern British Columbia*, Geological Society of America, Cordilleran Section Annual Meeting, p. 1-6.
- Davis, G.A., Monger, J.W.H., and Burchfield, B.C.**
1978: Mesozoic construction of the Cordilleran "collage", central British Columbia to central California; in *Mesozoic Paleogeography of the Western United States*, (ed.) D. Howell and K. McDougal; Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 1-32.
- Dean, W.T., Donovan, D.T., and Howarth, M.K.**
1961: The Liassic ammonite zones and subzones of the north-west European Province; *Bulletin of the British Museum (Natural History)*, v. 4, no. 10, p. 435-505, pl. 63-75.
- Donovan, D.T.**
1958: The ammonite zones of the Toarcian (Ammonitico Rosso Facies) of southern Switzerland and Italy; *Ecolae Geologicae Helvetiae*, v. 51, p. 33-60.

- Donovan, D.T., Callomon, J.H., and Howarth, M.K.**
1981: Classification of the Jurassic Ammonitina; in *The Ammonoidea*, (ed.) M.R. House and J.R. Senior; Systematics Association Special Volume No. 18, London and New York, Academic Press, p. 101-155.
- d'Orbigny, A.**
1842- *Paléontologie française, terrains jurassiques*, Part 1, Céphalopodes;
1860: Masson, Paris, 642 p., 234 pl.
- Dumortier, E.**
1874: *Études paléontologiques sur les dépôts jurassiques du Bassin du Rhone*; v. 4, Lias supérieur, 335 p., 62 pl.
- Engelbreton, D.C., Cox, A., and Gordon, R.G.**
1985: Relative motions between oceanic and continental plates in the Pacific Basin; Geological Society of America, Special Paper 206, 54 p.
- Ernst, W.**
1923- *Zur stratigraphie und fauna des Lias zeta im nordwestlichen*
1925: Deutschland; *Palaeontographica* (Stuttgart), v. 65-66, 122 p., 14 pl.
- Fischer, P.**
1880- *Manuel de Conchyliologie et de Paléontologie conchyliologique*;
1887: 1369 p., 23 pl.
- Frebold, H.**
1957: The Jurassic Fernie Group in the Canadian Rocky Mountains and Foothills; Geological Survey of Canada, Memoir 287, 197 p., 44 pl.
1964: The Jurassic faunas of the Canadian Arctic - Cadoceratinae; Geological Survey of Canada, Bulletin 119, 27 p., 20 pl.
1976: The Toarcian and lower Middle Bajocian beds and ammonites in the Fernie Group of southeastern British Columbia and parts of Alberta; Geological Survey of Canada, Paper 75-39, 33 p., 6 pl.
1978: Ammonites from the Late Bathonian "Iniskinites Fauna" of central British Columbia; Geological Survey of Canada, Bulletin 307, 27 p., 9 pl.
- Frebold, H. and Tipper, H.W.**
1967: Middle Callovian sedimentary rocks and guide ammonites from southwestern British Columbia; Geological Survey of Canada, Paper 67-21, 29 p., 3 pl.
1970: Status of the Jurassic in the Canadian Cordillera of British Columbia, Alberta and southern Yukon; Canadian Journal of Earth Sciences, v. 7, p. 1-21.
1975: Upper Callovian and Lower Oxfordian ammonites from southeastern Bowser Basin, British Columbia; Canadian Journal of Earth Sciences, v. 12, p. 145-157, 2 pl.
- Frebold, H., Mountjoy, E., and Reed, R.**
1959: The Oxfordian beds of the Jurassic Fernie Group, Alberta and British Columbia; Geological Survey of Canada, Bulletin 53, 47 p., 12 pl.
- Friedman, R.M. and Armstrong, R.L.**
1990: U-Pb dating, southern Coast Belt, British Columbia; Lithoprobe, southern Canadian Cordilleran Transect Workshop, University of Calgary, Alberta, 3-4 March 1990, p. 146-155.
- Friedman, R.M., Monger, J.W.H., and Tipper, H.W.**
1990: Age of the Bowen Island Group, southwestern Coast Mountains, British Columbia; Canadian Journal of Earth Sciences, v. 27, p. 1456-1461.
- Gabriele, H. and Yorath, C.J. (editors)**
1991: Geology of the Cordilleran orogen in Canada; Geological Survey of Canada, Geology of Canada, no. 4, 844 p.
- Geczy, B.**
1967: Ammonoides Jurassiques de Csernye, Montagne Bakony, Hongrie, Part II (excl. Hammotoceratidae); *Geologica Hungarica*, Series Palaeontologica, v. 35, 413 p., 65 pl.
- Hall, R.L.**
1987: New Lower Jurassic ammonite faunas from the Fernie Formation, southern Rocky Mountains; Canadian Journal of Earth Sciences, v. 24, p. 1688-1704, 5 pl.
- Hallam, A.**
1975: *Jurassic environments*; Cambridge University Press, Cambridge, 269 p.
- Haug, E.**
1885: Beiträge zu einer Monographie der Ammoniten-gattung *Harpoceras*; N. Jb. Beilage, v. 3, p. 585-722, pl. 11, 12.
- Haugerud, R.A.**
1985: Geology of the Hozameen Group and the Ross Lake shear zone, Maselpanik area, North Cascades, southwest British Columbia; Ph.D thesis, University of Washington, Seattle, 268 p.
- Hillebrandt, A. von**
1987: Liassic ammonite zones of South America and correlations with other provinces, with descriptions on new genera and species of ammonites; in *Biostratigrafica de los sistemas regionales del Jurásico y Cretácico en América del Sur*, Mendoza, p. 111-157, 14 pl.
- Hyatt, A.**
1867: Fossil cephalopods of the Museum of Comparative Zoology; *Bulletin Museum Comparative Zool.*, Harvard, Cambridge, v. 1, p. 71-102.
1889: Genesis of the Arietidae; *Smithsonian Contribution to Knowledge*, v. 26, 250 p., 14 pl.
1900: Cephalopoda; in *Textbook of Paleontology*, 1st. English edition, (ed.) K.A. Zittel; p. 502-592.
- Imlay, R.W.**
1947: Marine Jurassic of Black Hills area, South Dakota and Wyoming; *Bulletin of the American Association of Petroleum Geologists*, v. 36, p. 227-273.
1953a: Callovian (Jurassic) ammonites from the United States and Alaska, Part I: Western Interior United States; United States Geological Survey, Professional Paper 249-A, p. 1-39, pl. 1-24.
1953b: Callovian (Jurassic) ammonites from the United States and Alaska, Part II: Alaska Peninsula and Cook Inlet regions; United States Geological Survey, Professional Paper 249-B, p. 41-108, pl. 25-55.
1960: Ammonites of Early Cretaceous age (Valanginian and Hauterivian) from the Pacific Coast States; United States Geological Survey, Professional Paper 334-F, p. 167-228, pl. 24-43.
1961: Late Jurassic ammonites from the western Sierra Nevada, California; United States Geological Survey, Professional Paper 374-D, 30 p., 6 pl.
1964: Upper Jurassic mollusks from eastern Oregon and western Idaho; United States Geological Survey, Professional Paper 483-D, 21 p., 4 pl.
1968: Lower Jurassic (Pliensbachian and Toarcian) ammonites from eastern Oregon and California; United States Geological Survey, Professional Paper 593-C, 51 p., 9 pl.
1975: Stratigraphic distribution and zonation of Jurassic (Callovian) ammonites in southern Alaska; United States Geological Survey, Professional Paper 836, 28 p., 6 pl.
1981: Jurassic (Bathonian and Callovian) ammonites in eastern Oregon and western Idaho; United States Geological Survey, Professional Paper 1142, 24 p., 5 pl.
1982: Jurassic (Oxfordian and Late Callovian) ammonites from the Western Interior region of the United States; United States Geological Survey, Professional Paper 1232, 44 p., 26 pl.
- Irving, E., Woodsworth, G.J., Wynne, P.J., and Morrison, A.**
1985: Paleomagnetic evidence for displacement from the south of the Coast Plutonic Complex, British Columbia; Canadian Journal of Earth Sciences, v. 22, p. 584-598.
- Jeletzky, J.A.**
1965: Late Upper Jurassic and early Lower Cretaceous fossil zones of the Canadian Western Cordillera; Geological Survey of Canada, Bulletin 103, 70 p.
1976: Mesozoic and Tertiary rocks of Quatsino Sound, Vancouver Island, British Columbia; Geological Survey of Canada, Bulletin 242, 243 p.
1977a: Mid-Cretaceous (Aptian to Cenomanian) history of Pacific Slope of Canada; Paleontological Society of Japan, Special Papers, No. 21, p. 97-126, pl. 3.
1977b: Causes of Cretaceous oscillations of sea level in western and Arctic Canada and some general geotectonic implications; Paleontological Society of Japan, Special Papers, No. 21, p. 233-246.
1984: Jurassic-Cretaceous boundary beds of western and Arctic Canada and the problem of the Tithonian-Berriasian stages in the Boreal Realm; in *Jurassic-Cretaceous Biochronology and Biogeography of North America*, (ed.) G.E.G. Westermann; Geological Association of Canada Special Paper 27, p. 175-255, 8 pl.

- Jeletzky, J.A. and Tipper, H.W.**
1968: Upper Jurassic and Cretaceous rocks of the Taseko Lakes map-area and their bearing on the geological history of southwestern British Columbia; Geological Survey of Canada, Paper 67-54, 75 p.
- Johnson, S.Y.**
1981: The Spieden Group: an anomalous piece of the Cordilleran paleogeographic puzzle; Canadian Journal of Earth Sciences, v. 18, p. 1694-1707.
- Kennedy, J.W. and Cobban, W.A.**
1976: Aspects of ammonite biology, biogeography and biostratigraphy; Special Papers in Palaeontology, No. 17, 94 p.
- Lowe, B.E.**
1972: Metamorphic petrology and structural geology of the area east of Harrison Lake, British Columbia; Ph.D. thesis, University of Washington, Seattle, 162 p.
- McLearn, F.H.**
1972: Ammonoids of the Lower Cretaceous sandstone member of the Haida Formation, Skidegate Inlet, Queen Charlotte Islands, western British Columbia; Geological Survey of Canada, Bulletin 188, 78 p., 45 pl.
- Maire, V.**
1938: Contributions a la connaissance des Cardioceratides; Mémoires de la Société Géologique de France, Nouvelle Serie, v. 15, No. 2/3 (Memoire 34), 132 p., 22 pl.
- Meledina, S.V.**
1977: The ammonites and zonal stratigraphy of the Callovian of Siberia; Trudy, Institut Geologii i Geofiziki, Akad. Nauk S.S.S.R., Sibirskoe otdel., v. 356, 290 p.
- Misch, P.**
1966: Tectonic evolution of the Northern Cascades of Washington State; a west-Cordilleran case history; in Tectonic History and Mineral Deposits of the Western Cordillera of British Columbia and Neighbouring Parts of the United States; Canadian Institute of Mining and Metallurgy, Special Paper, 8, p. 101-184.
- Monger, J.W.H.**
1966: The stratigraphy and structure of the type area of the Chilliwack Group, southwestern British Columbia; Ph.D. thesis, University of British Columbia, Vancouver, 173 p.
1970: Hope map-area, west half, British Columbia; Geological Survey of Canada, Paper 69-47, 75 p.
1984: Cordilleran tectonics: a Canadian perspective; Bulletin du Société Géologique de France, v. 26, no. 2, p. 255-278.
1986: Geology between Harrison Lake and Fraser River, Hope map area, southwestern British Columbia; in Current Research, Part B; Geological Survey of Canada, Paper 86-1B, p. 699-706.
1989a: Geology of Hope and Ashcroft map areas, British Columbia; Geological Survey of Canada, Maps 41-1989 and 42-1989.
1989b: Isotopic date locations, Hope, British Columbia; Geological Survey of Canada, Map 41-1989.
1991a: Correlation of Settler Schist with Darrington Phyllite and Shuksan greenschist, Coast and Cascade mountains, British Columbia and Washington; Canadian Journal of Earth Sciences, v. 28.
1991b: Georgia Basin Project: structural evolution of parts of southern Insular and southwestern Coast belts, British Columbia; in Current Research, Part A; Geological Survey of Canada, Paper 91-1A, p. 219-228.
- Monger, J.W.H. and Price, R.A.**
1979: Geodynamic evolution of the Canadian Cordillera – progress and problems; Canadian Journal of Earth Sciences, v. 16, p. 770-791.
- Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J.**
1982: Tectonic accretion and the origin of the two major metamorphic and tectonic belts in the Canadian Cordillera; Geology, v. 10, p. 70-75.
- Muller, J.E., Northcote, K.E., and Carlisle, D.**
1974: Geology and mineral deposits of Alert Bay-Cape Scott map-area Vancouver Island, British Columbia; Geological Survey of Canada, Paper 74-8, 77 p.
- Nelson, S.J.**
1979: Paleontological field guides, northern Canada and Alaska; Bulletin of Canadian Petroleum Geology, v. 23, no. 3, 1975, p. 428-683, 71 pl.
- Neumayr, M.**
1875: Die Ammoniten der Kreide und die Systematik der Ammonitiden; Deutsche Geologische Gesellschaft, Zeitschrift, XXVII, p. 854-942.
- Neumayr, M. and Uhlig, V.**
1881: Über Ammonitiden aus den Hilsbildungen Norddeutschlands; Palaeontographica, v. 27, p. 129-303, pl. 15-57.
- O'Brien, J.A.**
1986: Jurassic stratigraphy of the Methow Trough, southwestern British Columbia; in Current Research, Part B; Geological Survey of Canada, Paper 86-1B, p. 749-756.
- Pearson, D.E.**
1973: Harrison, Lucky Jim; in Geology, Exploration and Mining in British Columbia, British Columbia Department of Mines and Petroleum Resources, p. 125-128.
- Potter, C.J.**
1983: Geology of the Bridge River Complex, southern Shulaps Range, British Columbia: a record of Mesozoic convergent tectonics; Ph.D. thesis, University of Washington, Seattle, 192 p.
- Poulton, T.P. and Tipper, H.W.**
1991: Aalenian ammonites and strata of western Canada; Geological Survey of Canada, Bulletin 411, 71 p.
- Ray, G.E.**
1986: The Hozameen fault system and related Coquihalla serpentine belt of southwestern British Columbia; Canadian Journal of Earth Sciences, v. 23, p. 1022-1041.
- Ray, G.E., Coombes, S., Macquarrie, D.R., Niels, R.J.E., Shearer, J.T., and Cardinal, D.G.**
1985: Precious metal mineralization in southwestern British Columbia; Geological Society of America Field Trip 9.
- Reeside, J.B. Jr.**
1919: Some American Jurassic ammonites of the genera *Quenstedoceras*, *Cardioceras*, *Amoeboceras*, family Cardioceratidae; United States Geological Survey, Professional Paper 118, 64 p., 24 pl.
- Riccardi, A.C., Westermann, G.E.G., and Elmi, S.**
1989: The Middle Jurassic Bathonian-Callovian ammonite zones of the Argentin-Chilean Andes; Geobios, v. 22, p. 553-597, 11 pls.
- Roddick, J.A.**
1965: Vancouver North, Coquitlam and Pitt Lake map-area, British Columbia; Geological Survey of Canada, Memoir 335, 276 p.
- Rusmore, M.E.**
1985: Geology and tectonic significance of the Upper Triassic Cadwallader Group and its bounding faults, southwestern British Columbia; Ph.D. thesis, University of Washington, Seattle, 174 p.
- Sandoval, J., Westermann, G.E.G., and Marshall, M.C.**
1990: Ammonite fauna, stratigraphy and ecology of the Bathonian-Callovian (Jurassic) Tecocoyunga Group, South Mexico; Palaeontographica, v. A210, p. 93-149, 20 pls.
- Schlegelmilch, R.**
1985: Die Ammoniten des süddeutschen Doggers; G. Fischer, Stuttgart, New York, 284 p., 59 pl.
- Schuchert, C.**
1923: Sites and nature of the North American geosynclines; Bulletin of the Geological Society of America, v. 34, p. 151-230.
- Selwyn, A.R.C.**
1888: Director's Report; Geological Survey of Canada, Annual Report, v. 3.
- Setti, F.L.**
1968: Ammoniti del genere *Dumortieria* nella serie Toarciana del Passo del Furlo (Appennino Centrale); Atti della Società Italiana di Scienze Naturali, v. 107, p. 317-347, pl. 30-32.
- Siemiradzki, I.**
1891: Die oberjurassische Ammonitenfauna von Polen; Z. deutsch. geol. Ges., v. 44.
- Smith, P.L.**
1976: Biostratigraphy of the Snowshoe Formation (Jurassic) in the Izee area, Grant County, Oregon; M.Sc. thesis, Portland State University, Portland, Oregon, 213 p., 9 pl.
1986: The implications of data base management systems to paleontology: a discussion of Jurassic ammonoid data; Journal of Paleontology, v. 60, no. 2, p. 327-340.

Smith, P.L., Thomson, R.C., and Tipper, H.W.

1984: Lower and Middle Jurassic sediments and volcanics of the Spatsizi map-area, British Columbia; in *Current Research, Part A*; Geological Survey of Canada, Paper 84-1A, p. 117-120.

Sowerby, J.

1812: *The Mineral Conchology of Great Britain; or Coloured Figures and*
1846: *Descriptions of those Remains of Testaceous Animals or Shells, which have been Preserved at Various Times and Depths in the Earth*; 7 volumes, London, 383 pl.

Spath, L.F.

1928: Revision of the Jurassic cephalopod fauna of Kachh (Cutch); *Palaeontologia Indica*, v. 9, mem. 2, p. 163-278, pl. 20-47.
1929: Corrections of cephalopod nomenclature; *Naturalist*, no. 871, p. 269-271.
1932: The invertebrate faunas of the Bathonian-Callovian deposits of Jameson Land (East Greenland); *Meddelelser om Gr-nland*, v. 87, no. 7, 158 p., 26 pl.
1933: The evolution of the Cephalopoda; *Biol. Review*, v. 8, p. 418-462.

Stehn, E.

1924: Beiträge zur Kenntnis des Bathonien und Callovien in Südamerika; *Neues Jahrbuch für Mineralogie, Beilageband*, v. 49, p. 52-158, 8 pl.

Sutherland-Brown, A.

1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Taylor, D.G.

1982: Jurassic shallow marine invertebrate depth zones with exemplification from the Snowshoe Formation, Oregon; *Oregon Geology*, v. 44, p. 51-56.

Taylor, D.G., Callomon, J.H., Hall, R.L., Smith, P.L., Tipper, H.W., and Westermann, G.E.G.

1984: Jurassic ammonite biogeography of western North America: the tectonic implications; in *Jurassic-Cretaceous Biochronology and Biogeography of North America*, (ed.) G.E.G. Westermann; Geological Association of Canada, Special Paper 27, p. 121-142.

Thierry, J.

1976: Essai de taxonomie et de phylogénie de la famille des Macrocephalitidae (Ammonitina, Stephanocerataceae: Jurassique moyen); *Réunion Annuelle des Sciences de la Terre, Société Géologique de France*, Paris, 1 p.

Thompson, R.I.

1972: Harrison, Lucky Jim; in *Geology, Exploration and Mining in British Columbia*, British Columbia Department of Mines and Petroleum Resources, p. 102-114.

Thomson, R.C.

1985: Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy and Pliensbachian ammonite fauna of the northern Spatsizi area, north-central British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, 211 p., 11 pl.

Thomson, R.C., Smith, P.L., and Tipper, H.W.

1986: Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy of the northern Spatsizi area, north-central British Columbia; *Canadian Journal of Earth Sciences*, v. 23, p. 1963-1973.

Thorkelson, D.J. and Smith, A.D.

1989: Arc and interplate volcanism in the Spences Bridge Group, British Columbia; *Geology*, v. 17, p. 1093-1096.

Tipper, H.W.

1969: Mesozoic and Cenozoic geology of the northeast part of Mount Waddington map-area (92-N), Coast District, British Columbia; Geological Survey of Canada, Paper 68-33, 103 p.

Tipper, H.W. and Richards, T.A.

1976: Jurassic stratigraphy and history of north-central British Columbia; Geological Survey of Canada, Bulletin 270, 73 p.

Trexler, J.H. Jr.

1985: Stratigraphy, sedimentology and tectonic significance of the Upper Cretaceous Virginian Ridge Formation, Methow Basin, Washington: implications for tectonic history of the northern Cascades; Ph.D. thesis, University of Washington, Seattle, 234 p.

Waagen, W.

1869: Die Formenreihe des *Ammonites subradiatus*; *Geogn.-Palaont. Beitr.*, v. 2, no. 2, p. 181-256, pl. 16-20.

Westermann, G.E.G.

1964a: The ammonite fauna of the Kialagvik Formation at Wide Bay, Alaska Peninsula Part I, Lower Bajocian (Aalenian); *Bulletins of American Paleontology*, v. 47, No. 216, 503 p., 76 pl.

1964b: El Hammatoceratido *Podagrosiceras athleticum* Maubeuge y Lambert, del Bayociano inferior (aaleniano) del Neuquén central, Argentina (Ammonitina, Jurasico); *Ameghiniana, Revista de la Asociación Paleontológica Argentina*, Tomo III, no. 6, p. 173-181.

1981: Ammonite biochronology and biogeography of the Circum-Pacific Jurassic; in *The Ammonoidea*, (ed.) M.R. House and J.R. Senior; Systematics Association Special Volume No. 18, London and New York, Academic Press, p. 459-498.

Westermann, G.E.G., Corona, R., and Carrusco, R.

1984: The Andean Mid-Jurassic *Neuquenicer* ammonite assemblage of Cualac, Mexico; in *Jurassic-Cretaceous Biochronology and Biogeography of North America*, (ed.) G.E.G. Westermann; Geological Association of Canada, Special Paper 27, p. 99-112.

White, C.A.

1889: Mesozoic molluscs from the southern coast of the Alaskan Peninsula; *United States Geological Survey, Bulletin* 51, p. 64-70.

Whiteaves, J.F.

1889: On some Cretaceous fossils from British Columbia, the Northwest Territories and Manitoba; *Geological Survey of Canada, Contributions to Canadian Paleontology*, v. 1, Part 2, No. 4.

Zittel, K.A. von

1884: *Handbuch der Palaeontologie*; Abt. 1, Band, 2, 1109 fig. (cephalopods, p. 329-522).

APPENDIX 1

Fossil Localities

CAMP COVE FORMATION

Locality No. 9

Field No. MVA(F)85-292 GSC No. C-117703

Location: 49°20'59";121°49'55". Roadcut beneath powerline. Turnoff from Forest Service road at Topkapi Resources road then left at powerline road. Outcrop is well bedded, light to dark grey indurated siltstone of Camp Cove Formation.

Neogondolella cf. *N. constricta* (Mosher and Clark)
Emiluvia sp.
radiolarians

Age and Correlation: Middle Triassic (Ladinian?). Conodonts identified by M.J. Orchard of the Geological Survey of Canada; radiolaria examined by E.S. Carter.

GSC type specimens from this locality: 91617-91619.

HARRISON LAKE FORMATION

Celia Cove Member

Locality No. 8

Field No. MVA(F)85-330A GSC No. C-117704

Location: 49°20'41";121°49'52". Outcrop found in roadcut about 50 m from turnoff from Forest Service road along Topkapi Resources road which leads down to powerline. Fossils found in pale green chert clasts and weathered limestone clasts of the basal conglomerate (Celia Cove Member) of the Harrison Lake Formation.

In chert clasts:

Neohindeodella sp.
Pseudostylosphaera aff. *compacta* (Nakaseko and Nishimura)
Paraoerilspongia? sp.
Triassocampe sp. B? (Yao, Matsuoka and Nakatani)
?Tripocyclus cf. *acanthus* Dewever

In limestone clasts:

Parafusulina sp.
Fenestellid bryozoa
Crinoid ossicles
Corals
Brachiopods

Age and Correlation: The Celia Cove Member is Early Jurassic in age, but fossils from the clasts are much older.

Chert clasts: The conodonts and radiolaria suggest a Middle to Late Triassic (Ladinian to Early Carnian) age for the chert clasts.

Limestone clasts: *Parafusulina* is of Early Permian age and the faunas in these limestone clasts are similar to faunas found in the Chilliwack Group lying south of Fraser River.

The conodonts were identified by M.J. Orchard of the Geological Survey of Canada; radiolaria identified by E.S. Carter (Report No. 86-8(ESC)) and fusulinids were identified by W.R. Danner of the University of British Columbia.

Locality 10 is found in the Celia Cove Member and contains fossiliferous clasts like those at locality 8.

GSC type specimens from this locality: 91620-91627.

Francis Lake Member

Locality No. 2

Field No. MVA(F)85-19 GSC No. C-118596

Location: 49°19'37";121°49'02". Roadcut beneath powerline 750 m west of Celia Cove. Outcrop poorly exposed dark grey siltstone, shale and rare volcanogenic sandstone of the Francis Lake Member of Harrison Lake Formation.

Dumortieria sp.
Belemnites
Bivalves

Age and Correlation: Early Jurassic (Toarcian) based on the presence of a single poorly preserved *Dumortieria* which may belong to the species *D. insignisimilis*. Probably about the same age as locality 5.

Locality No. 3

Field No. MVA(F)85-289 GSC No. C-118592

Location: 49°19'48";121°49'25". Located on old roadcut about 1 km from turnoff from Forest Service road. Turnoff is about 150 m east of locality 5. Outcrop occurs where old road turns sharply to the northeast and is mainly manganese-stained, dark grey to black shale of the Francis Lake Member.

Erycitoides? sp.
Oxytoma sp.
Bivalves
Belemnites

Age and Correlation: Middle Jurassic (mid-Aalenian) based on the single poorly preserved *Erycitoides*? sp. found. This is the youngest locality of the Francis Lake Member. An ammonite specimen collected by H. Frebold of the Geological Survey of Canada in 1955 was identified by H.W. Tipper of the Survey as *Tmetoceras scissum* of mid-Aalenian age and it was probably collected from this locality.

GSC type specimens from this locality: 91575.

Locality No. 5

Field No. MVA(F)85-30 GSC No. C-118594/C143283

Location: In small road ballast quarry along Forest Service road about 2 km beyond Weaver Lake road turnoff. Rock is mainly non-calcareous dark brown shale of the Francis Lake Member which has been folded and later intruded by a small dyke.

Dumortieria cf. *levesquei* d'Orbigny
Dumortieria cf. *insignisimilis* (Brauns)
Bivalves

Age and Correlation: Early Jurassic (Late Toarcian) based on the ammonites. *Dumortieria* is first recorded from the Harrison Lake area in this report but is known from other areas in the western Cordillera (see Stratigraphy).

GSC type specimens from this locality: 91562-91573.

Locality No. 6

Field No. MVA(F)85-16A GSC No. C-118552

Location: 49°20'13";121°49'32". Roadcut beneath powerline road 1.7 km northwest of Celia Cove. Light to dark grey calcareous shales and siltstones of the Francis Lake Member outcrop along west side of road about 1 km from Topkapi Resources road turnoff.

Pentacrinus sp.
Gryphea sp.
Bivalves

Age and Correlation: *Pentacrinus* is typical of the Jurassic and in Alaska is most commonly found in the Lower Jurassic (Nelson, 1979). *Pentacrinus* are also found stratigraphically beneath locality 7 and about 800 m along a roadcut west of locality 10.

Locality No. 7

Field No. MVA(F)85-308 GSC No. C-118595

Location: 49°20'34";121°49'52". On Forest Service road about 1.5 km along road northeast from locality 5 is a large outcrop of well bedded calcareous siltstone and shale belonging to the Francis Lake Member. Fossils are rare and were only found in the northern part of this well exposed outcrop.

Dactylioceras? sp.
Harpoceras? sp.
Phymatoceras? sp.
Fish skeletons
Bivalves

Age and Correlation: The three ammonite genera, if correctly identified, have overlapping ranges suggesting an Early Jurassic (Middle Toarcian) age for the locality equivalent to the Bifrons Zone of Europe. The rare fish skeletons are poorly preserved and suggest deposition in oxygen minimum waters.

Dactylioceras was first reported in the Harrison Lake area by Brookfield (1973) although he believed they were found in rocks of the Camp Cove Formation. *Harpoceras*? and *Phymatoceras*? have not been recorded from the Harrison Lake before. Middle Toarcian rocks containing some or all of these ammonite genera are common over much of British Columbia and southern Yukon.

GSC type specimens from this locality: 91557-91561; 91574.

Weaver Lake Member

Locality No. 4

Field No. MVA(F)85-2 GSC No. C-117411

Location: 49°19'53";121°51'26". On south side of Forest Service roadcut about 700 m east of Weaver Lake road turnoff. Rare belemnites found in a brown volcanogenic sandstone of the Weaver Lake Member.

Belemnites
Plant debris

Age and Correlation: The belemnites only indicate a general Jurassic or Cretaceous age.

Locality No. 11

Field No. MVA87-4 GSC No. C-81986

Location: About 1 km north of Weaver Lake on an old roadcut on the west slope of a valley. Grey to black shales are poorly exposed and are overlain and underlain by volcanic breccia and flows of the Weaver Lake Member.

Belemnites
Bivalves

Age and Correlation: Fossils were collected by D.E. Pearson of the British Columbia Department of Mines in 1973. They could not date the unit and indicated only that marine conditions did occur.

MYSTERIOUS CREEK FORMATION

Locality No. 1

Field No. MVA(F)85-329 GSC No. C-118600

Location: 49°17'48";121°50'42". South shore of Harrison River on a small point about 3.5 km from Harrison Lake outflow. Ammonites found in dark grey siltstone of the Mysterious Creek Formation.

Lilloettia cf. *stantoni* Imlay
Xenoccephalites cf. *vicarius* Imlay

Age and Correlation: Locality 1 is equivalent to locality 8 of Crickmay (1930a). *L. stantoni* is also found in Alaska and Oregon and belongs in Fauna B8(g) of Callomon (1984). *X. vicarius* is also found in Oregon associated with *L. stantoni* (Imlay, 1981). The locality is Early Callovian in age,

equivalent to the Macrocephalus Zone of Europe and is the youngest recorded locality in the Mysterious Creek Formation.

GSC type specimens from this locality: 91580-91581.

Locality No. 17

Field No. MVA(F)85-255

GSC No. C-118586

Location: 49°28'37";121°53'07". On Forest Service roadcut about 150 m beyond Hale Creek bridge (24 km marker). Outcrop occurs on north side of road and is mainly calcareous, grey to black siltstone and shale of the Mysterious Creek Formation. Fossils are abundant at this locality but are mainly fragmented, but some well preserved specimens were collected.

Cadoceras comma Imlay
Cadoceras (Paracadoceras) cf. tonniense Imlay
Cadoceras (Pseudocadoceras) growingki Pompeckj
Lilloettia tipperi Frebold
Bivalves

Age and Correlation: These fossils belong in Callomon's (1984) *Cadoceras comma* Fauna B8 for the western Cordillera of North America which is equivalent in part to the Macrocephalus Zone of Europe of Early Callovian age. The faunal association at locality 17 suggests a more precise correlation to Callomon's zonation; namely the *Cadoceras wosnessenskii* Fauna B8(e) found in the Chinitna Formation, southern Alaska (Imlay, 1953b).

GSC type specimens from this locality: 91582-91584; 91589-91596; 91598; 91617. UBC-008.

Locality No. 17A

Field No. MVA(F)85-11A

GSC No. C-149641

Location: 49°28'37";121°53'08". In small gully on bank of Forest Service roadcut about 20 m beyond Hale Creek bridge (24 km marker). Outcrop of sheared, calcite veined siltstone and shale contains rare fossils and is part of the Mysterious Creek Formation.

Lilloettia lilloetensis Crickmay

Age and Correlation: This species belongs in Callomon's (1984) *Cadoceras comma* Fauna B8 for the western Cordillera of North America and is Early Callovian in age. Its placement in the *L. lilloetensis* Fauna B8(c), which is a sub-fauna of Fauna B8 slightly older than Fauna B8(e) (locality 17), agrees well with its stratigraphic position about 10 m beneath locality 17.

GSC type specimens from this locality: 91576-91577.

Locality No. 18

Field No. MVA(F)85-24

GSC No. C-118554

Location: 49°28'47";121°53'27". On old roadcut. Turnoff from Forest Service road is about 600 m north of Hale Creek bridge (24 km marker). Locality 24 found on north bank of

old road 700 m from the turnoff. Grey to green fine grained sandstone forms much of the outcrop along this road and represents the upper section of the Mysterious Creek Formation. Glass shards are noted in thin sections of some of these sandstone samples.

Cadoceras (Pseudocadoceras) cf. catostoma Pompeckj
Cadoceras sp.
Bivalves
Belemnites

Age and Correlation: Early Callovian (Macrocephalus Zone of Europe) belonging in Callomon's (1984) Fauna B8(e). Locality 18 lies several tens of metres stratigraphically above locality 17.

GSC type specimen from this locality: 91588.

Locality No. 19

Field No. MVA(F)85-25

GSC No. C-118555

Location: 49°28'55";121°53'40". The locality is 1.2 km from turnoff to old road which is 600 m north of Hale Creek bridge. Fine grained sandstone of the Mysterious Creek Formation outcrops and contains ammonites and shell fragments.

Cadoceras sp.
Bivalves

Age and Correlation: The localities stratigraphic position and fauna present suggest an Early Callovian age.

Locality No. 21

Field No. MVA(F)85-26

GSC No. C-118556

Location: 49°29'05";121°53'57". Locality is 1.7 km from turnoff from Forest Service road. Fine grained grey sandstone of the Mysterious Creek Formation outcrops.

Bivalves
Belemnites
Carbonized wood debris

Age and Correlation: The fossils give little information as to the age of the locality, but lithological and stratigraphic similarities to surrounding localities (e.g. 19,26) suggest an Early Callovian age.

Locality No. 26

Field No. MVA(F)85-34

GSC No. C-118557

MVA(F)85-260

C-149639

MVA(F)85-262

C-149640

Location: 49°29'37";121°54'35". Section 1 was measured at this locality which is situated about 200 m southeast of a small lake 1 km north of Hale Creek.

Lilloettia lilloetensis Crickmay
Cadoceras (Pseudocadoceras) growingki Pompeckj
Cadoceras sp.
Trigonia sp.

Age and Correlation: Early Callovian based on the ammonites (Fauna B8 of Callomon, 1984). The ammonites were found near the base of the section (C-118557) and the trigonids higher up (C-149639, C-149640). The lower part of section 1 is roughly equivalent to localities 17 and 17A.

GSC type specimens from this locality: 91578; 91587; 91597.

Locality No. 29

Field No. MVA(F)85-230 GSC No. C-118581

Location: 49°30'26"; 121°57'49". About 400 m northwest of point where Billhook Creek joins Mystery Creek on old roadcut. Massive siltstones of the Mysterious Creek Formation outcrop.

Ammonite fragment

Age and Correlation: The fragment is of the venter and may be a *Lilloettia* but this is uncertain.

Locality No. 30

Field No. MVA(F)85-68 GSC No. C-118560

Location: 49°30'28"; 121°55'32". On old roadcut, southwest slope of small hill south of Mystery Creek. Rare fossils found in tuffaceous siltstone of the Mysterious Creek Formation.

Cadoceras (Pseudocadoceras) grewinkii Pompeckj
Bivalves
Belemnites

Age and Correlation: Early Callovian (Macrocephalus Zone of Europe). *C. (P.) grewinkii* is known from Alaska, Taseko Lakes area, Oregon and California.

Locality No. 35

Field No. MVA(F)85-232 GSC No. C-118581

Location: 49°30'50"; 121°57'47". Locality is 1.1 km north of point where Billhook and Mystery creeks join. Fossils found in fine grained grey sandstone of Mysterious Creek Formation.

Cadoceras sp.
Wood fragments

Age and Correlation: Early Callovian based on *Cadoceras*.

Locality No. 36

Field No. MVA(F)85-197 GSC No. C-118577

Location: 49°30'53"; 121°58'26". Located at the 2800 foot level in the Billhook Creek valley where fine grained sandstone of the Mysterious Creek Formation outcrops.

Lilloettia lilloetensis
Belemnites

Age and Correlation: Early Callovian. The ammonite specimen may be a *L. lilloetensis* but this is tentative.

GSC type specimen from this locality: 91579.

Locality No. 38

Field No. MVA(F)85-233 GSC No. C-118582

Location: 49°31'09"; 121°57'45". Located 1.6 km north of point where Billhook and Mystery creeks join. Variable lithologies including, volcanoclastic rock, sandstone, siltstone some of which is convolute bedded.

Belemnites
Bivalves

Age and Correlation: Ages cannot be obtained based on these fossils. The bivalves are probably *Pleuromya*. The localities' stratigraphic position within the Mysterious Creek Formation suggests an Early Callovian age.

Locality No. 41

Field No. MVA(F)85-94 GSC No. C-118562

Location: 49°31'13"; 121°55'45". On old logging roadcut on the north slope of Mystery Creek Valley. Abundant fossils found in light grey sandstone of the Mysterious Creek Formation.

Cadoceras comma Imlay
Cadoceras sp.
Trigonia sp.
Belemnites
Bivalves

Age and Correlation: Early Callovian (Macrocephalus Zone of Europe). This locality is roughly age equivalent to locality 17 and both belong in Callomon's (1984) *Cadoceras wosnessenskii* Fauna B8(e) of the Western Cordillera. *C. comma* is also known from Alaska (Imlay, 1953b).

GSC type specimens from this locality: 91585-91586.

BILLHOOK CREEK FORMATION

Locality No. 15

Field No. MVA(F)85-151 GSC No. C-118570

Location: 49°22'47"; 121°47'06". Southwest shore of Cascade Peninsula on west side of point which is situated one-third of the way up the peninsula. Calcareous siltstone and shale of the Billhook Creek Formation contains abundant fossils.

Cardioceras (Scarburgiceras) martini Reeside
Cardioceras (Cardioceras) cf. *hyatti* Reeside
Cardioceras sp.
Oxytoma sp.
Bivalves

Age and Correlation: Early Oxfordian (Bukowskii Subzone of Europe) and belongs in the *Cardioceras martini* Fauna B12 of Callomon (1984). The locality is slightly older than locality 20 on the west shore of Harrison Lake. Locality 15 is equivalent to locality 24 of Crickmay (1930a) and locality 2

of Brookfield (1973). They both found the long ranging ammonite genus *Phylloceras* at this locality as well as *Cardioceras* and bivalves. *C. (C.) martini* is also found in southern Alaska and the Taseko Lakes area.

GSC type specimens from this locality: 91599-91605; 91610; 91612; 91616.

Locality No. 16

Field No. MVA(F)85-226 GSC No. C-118579

Location: 49°24'35";121°47'26". West shore of Cascade Peninsula about 2 km southwest of the neck of the peninsula. Rare poorly preserved ammonites found in cleaved fine grained sandstone of the Billhook Creek Formation.

Cardioceras sp.

Age and Correlation: Probably Early Oxfordian; specimens too poorly preserved for positive identification to species level.

Locality No. 20

Field No. MVA(F)85-327 GSC No. C-118598

Location: 49°28'50";121°51'41". West shore of Harrison Lake about 300 m north of the mouth of Hale Creek. Fossils found in steeply dipping medium to coarse grained green sandstone of the Billhook Creek Formation.

Cardioceras (Cardioceras) cf. *hyatti* Reeside
Cardioceras (Cardioceras) *lillooetense* Reeside
Cardioceras sp.
Pinna sp.
Belemnites
Bivalves

Age and Correlation: Early Oxfordian (Costicardia Subzone of Europe) and belongs in the *Cardioceras spiniferum* Fauna B13 of Callomon (1984). Locality 20 is equivalent to Brookfield's (1973) locality 1. *C. (C.) hyatti* has been found in the Western Interior Region of the United States (Imlay, 1982) and *C. (C.) lillooetense* has been found near Smithers and Lillooet, British Columbia.

GSC type specimens from this locality: 91606-19609; 91611; 91613-91615.

PENINSULA FORMATION

Locality No. 14

Field No. MVA(F)85-150 GSC No. C-118569
Report No. Km-1-1986-JAJ

Location: 49°22'38";121°46'51". From southeast shore of the point situated one-third of the way up Cascade Peninsula. Abundant fossils found in a fine grained grey sandstone belonging to the Peninsula Formation.

Buchia uncitoides (Pavlow) var.
spasskenoides (Crickmay) (prevalent)

Buchia uncitoides (Pavlow) var.
acutistriata (Crickmay) (rare)
Buchia okensis (Pavlow) s. str. (late forms; rare)
Generically indeterminate, *Cylindroteuthis*-like belemnites

Age and Correlation: The same as for lot C-117409.

Locality No. 22

Field No. MVA(F)85-14 GSC No. C-118553
Report No. Km-1-1986-JAJ

Location: 49°29'06";121°52'48". On old roadcut about 1 km northwest of the mouth of Hale Creek. Dark green medium grained sandstone of the Peninsula Formation contains abundant fossils.

Buchia uncitoides (Pavlow)
var. *spasskenoides* (Crickmay)
(dominates the population sample and is represented by large to very large forms partly transitional to *B. okensis* s. str.) (the same as in the lot C-117409)
Buchia uncitoides (Pavlow) var. *acutistriata* (Crickmay) (less common)
Buchia okensis (Pavlow) s. str.
(rare and represented only by late forms partly transitional to *B. uncitoides* var. *spasskenoides*)
Buchia keyserlingi (Lahusen) var. *visiginensis* (Sokolov) (a solitary shell)
Cylindroteuthis (Arctoteuthis) cf. *baculus* (Crickmay)

Age and Correlation: Lower part of *Buchia uncitoides* Zone and middle Berriasian in terms of international standard stages (see Jeletzky, 1965, loc. cit. and Jeletzky, 1984, loc. cit. for further details). The *Buchia* fauna of the lot C-118553 is the same as that of lot C-117409. Therefore, these two lots are assigned to the same basal part of *Buchia uncitoides* Zone.

Locality No. 23

Field No. MVA(F)85-139 GSC No. C-118566
Report No. Km-1-1986-JAJ

Location: 49°30'26";121°51'03". On west shore of Long Island at the tip of the point located just south of the large island in Long Island Bay. Deformed *Buchia* shells found in tuffaceous sandstone of the Brokenback Hill Formation.

Strongly deformed *Buchia* shells of general Early Cretaceous affinities

Age and Correlation: The strongly deformed *Buchias* of lot C-118566 can belong to one of the following Early Cretaceous species: *Buchia tolmatschowi* (Sokolov), *Buchia pacifica* Jeletzky, and *Buchia crassicolis* (Keyserling). The age of lot C-118566 can range, accordingly, from the late Berriasian *Buchia tolmatschowi* Zone to the late Valanginian *Buchia crassicolis* Zone. It cannot be dated any closer on fossils now available. Nor can it be assigned definitively to the Brokenback Formation.

Locality No. 24

Field No. MVA(F)85-142 GSC No. C-118567
Report No. Km-1-1986-JAJ

Location: 49°29'33";121°50'42". On a small island in Long Island Bay. Grey phyllite contains strongly deformed fossils.

Strongly deformed to completely distorted *Buchias* some of which appear to be assignable to *Buchia pacifica* Jeletzky

Age and Correlation: Unlike specifically indeterminate *Buchia* of the lot C-118566, several *Buchia* of lot C-118567 exhibit very coarse but closely spaced concentric ornament combined with a posteriorly truncated shell shape and large dimensions. This combination of features is only known in the early Valanginian *Buchia pacifica* Jeletzky, 1965. Therefore, lot C-118567 is tentatively assigned to some part of *Buchia pacifica* Zone (see Jeletzky, 1965, loc. cit., p. 43-49, 64-66, fig. 4 for further details). *Buchia pacifica* fauna was never before recorded either from the Peninsula Formation or from the overlying Brokenback Hill Formation in the Harrison Lake area proper. However, it does occur within the area in lot C-118587 (see below) and west of the area in the correlative Fire Lake Group (see Report Km-3-1980-JAJ fossil localities 096920 and 096921 for further details). Please note that lot C-118587 is assigned to the Peninsula Formation by the collector. The same assignment seems also preferable for lot C-118567.

Locality No. 25

Field No. MVA(F)85-61 GSC No. C-118558
Report No. Km-1-1986-JAJ

Location: 49°29'42";121°53'05". On Forest Service roadcut 1.2 km south of Brokenback Hill. Well bedded sandstones of the Peninsula Formation contain abundant fossils.

Buchia uncitoides (Pavlow) var. *catamorpha* (Crickmay) (prevalent)
Buchia uncitoides (Pavlow) var. *acutistriata* Crickmay (less common)

Age and Correlation: Middle part of *Buchia uncitoides* Zone and middle Berriasian in terms of international standard stages (see Jeletzky, 1965, loc. cit. and 1984, loc. cit. for further details). An apparently total absence of *B. u.* var. *spasskenoides* and *Buchia okensis*, prevalence of *B. u.* var. *catamorpha*, and apparent absence of forms transitional to *Buchia tolmatschowi* (Sokolov) indicate the positioning of lot C-118558 in the middle part of *Buchia uncitoides* Zone stratigraphically higher than lots C-117406, C-117409 and C-118553, but stratigraphically lower than lots C-118587 and C-118588.

Locality No. 27

Field No. MVA(F)85-115 GSC No. C-118565
Report No. Km-1-1986-JAJ

Location: 49°29'47";121°53'17". On Forest Service roadcut 900 m southwest of Brokenback Hill. Grey to green sandstones of the Peninsula Formation contain abundant fossils.

Buchia uncitoides (Pavlow) var.
acutistriata (Crickmay) (no other *Buchia* forms noted)
Indeterminate rhynchonellid brachiopod

Age and Correlation: The same as for lot C-117406, see for further details.

Locality No. 28

Field No. MVA(F)85-276 GSC No. C-118587
Report No. Km-1-1986-JAJ

Location: 49°30'05";121°53'21". About 400 m southwest of Brokenback Hill are fossils in the uppermost part of the Peninsula Formation.

Buchia pacifica Jeletzky
(prevalent; mostly early forms and forms transitional to *B. tolmatschowi* var. *americana* Sokolov)
Buchia tolmatschowi (Sokolov) var.
americana (Sokolov) considerably less common

Age and Correlation: Basal part of *Buchia pacifica* Zone and lower Valanginian in terms of international standard stages (see Jeletzky, 1965, loc. cit., p. 43-49, 64-66, fig. 4 and Jeletzky, 1984, loc. cit., p. 217 for further details). Further comments on age and occurrences *Buchia pacifica* Zone in western British Columbia are provided in the discussion of the probably contemporary lot C-118567; see for these details.

Locality No. 28

Field No. MVA(F)85-276A GSC No. C-118588
Report No. Km-1-1986-JAJ

Location: 49°30'05";121°53'21". About 400 m southwest of Brokenback Hill at locality 28, but 3 m stratigraphically beneath the sample C-118587.

Buchia tolmatschowi (Sokolov) f.typ. (common)
B. t. var. *americana* (Sokolov) and forms transitional to *B. pacifica* Jeletzky (more common than the typical form)
Buchia pacifica Jeletzky (exclusively early forms; less common than either of the other two forms present)

Age and Correlation: Topmost part of *Buchia tolmatschowi* Zone (i.e. its overlap-beds with *Buchia pacifica* Zone) and topmost part of the Berriasian stage in terms of the international standard stages (see Jeletzky, 1965, loc. cit., p. 35-38, 64-66, fig. 4 and Jeletzky, 1984, loc. cit., p. 215-217, fig. 5 for further details). The proposed dating of lot C-118588 agrees perfectly with its stratigraphic position 3 m stratigraphically beneath lot C-118587 that contains a fauna assignable to the basal part of *Buchia pacifica* Zone. The previously known localities of *Buchia tolmatschowi* Zone in western British Columbia are listed in Jeletzky, 1984, loc. cit.,

p. 215, 216. The discovery of this zone in lot C-118588 indicates its occurrence in the upper (?uppermost) part of the Peninsula Formation instead of in the lower, predominantly volcanic part of the Brokenback Hill Formation as it was formerly believed (Jeletzky, 1965, p. 64-66, fig. 4).

Locality No. 31

Field No. MVA(F)85-278 GSC No. C-118590
Report No. Km-1-1986-JAJ

Location: 49°30'37"; 121°54'21". About 1.7 km northwest of Brokenback Hill and about 300 m west of the Forest Service road are fossiliferous sandstones of the Peninsula Formation which are caught in a fault slice.

Buchia uncitoides (Pavlov) var.
acutistriata (Crickmay) (common)
Buchia uncitoides (Pavlov) var.
spasskenoides (Crickmay) (less common)
Transitional forms between *B. uncitoides* (Pavlov) and
B. tolmatshowi (Sokolov) f.type. (rare)

Age and Correlation: Upper part of *Buchia uncitoides* Zone and mid-Berriasian in terms of the international standard stages (see Jeletzky, 1965, loc. cit., p. 27-35, 64-66), fig. 4 and Jeletzky, 1984, loc. cit., p. 211, 214, 215, fig. 5 for further details). Please note that lot C-118590 apparently was collected in higher beds of *Buchia uncitoides* Zone than any of its previously discussed lots.

Locality No. 32

Field No. MVA(F)85-64 GSC No. C-118559
Report No. Km-1-1986-JAJ

Location: 49°30'35"; 121°54'07". About 1.5 km northwest of Brokenback Hill on Forest Service roadcut just beyond a small creek. Sandstone of the Peninsula Formation outcrops.

Buchia okensis (Pavlov) s. str. (probably a late typical form)
McLearnia (= *Boreionectes*)? sp. indet.
Indeterminate true belemnite

Age and Correlation: Some part of *Buchia okensis* Zone and lower Berriasian in terms of international standard stages (see Jeletzky, 1965, loc. cit., p. 20-27, 64-66, fig. 4 and 1984, loc. cit. p. 203-205, 207, 209, 210, 211, fig. 5 for further details). Lot C-118559 may represent the same upper part of *Buchia okensis* Zone as lots C-117407 and 117408 but additional, better preserved material of its *B. okensis* s. str. is needed to confirm this suggestion.

Locality No. 33

Field No. MVA(F)85-277 GSC No. C-118589
Report No. Km-1-1986-JAJ

Location: 49°30'40"; 121°54'18". About 1.7 km northwest of Brokenback Hill and about 300 m west of the Forest Service road, sandstones of the Peninsula Formation outcrop.

Buchia uncitoides (Pavlov) var.
acutistriata (Crickmay) (prevalent)
Buchia uncitoides (Pavlov) var.
spasskenoides (Crickmay) (fairly common, includes very rare transitional forms to *B. okensis* s. str.)
Buchia uncitoides (Pavlov) var.
catamorphia (Crickmay) (rare)

Age and Correlation: Lower part of *Buchia uncitoides* Zone. Lot C-118589 appears to be somewhat younger than lot C-117409 and other lots containing large to very large forms of *B. uncitoides* var. *spasskenoides* and very rare representatives of *B. okensis*. At the same time it appears to be somewhat older than lots C-117406, C-118591, etc., the fauna of which is dominated by *B. uncitoides* var. *acutistriata*.

Locality No. 37

Field No. MVA(F)85-306 GSC No. C-118593
Report No. Km-1-1986-JAJ

Location: 49°31'05"; 121°54'27". On Forest Service roadcut 2.3 km northwest of Brokenback Hill on south slope of Mystery Creek Valley. Green, fossiliferous sandstone of the Peninsula Formation outcrops.

Buchia uncitoides (Pavlov) var.
acutistriata (Crickmay) dominates the fauna almost to the exclusion of other *Buchia* forms)
Buchia uncitoides (Pavlov) var. *catamorphia*
(Crickmay) (very rare)

Age and Correlation: The same as for lot C-118591.

Locality No. 39

Field No. MVA(F)85-286 GSC No. C-118591
Report No. Km-1-1986-JAJ

Location: 49°31'18"; 121°58'27". Fossiliferous sandstones of the Peninsula Formation outcrop at headwaters of Billhook Creek.

Buchia uncitoides (Pavlov) var.
acutistriata (Crickmay) (common no other *Buchias* noted)

Age and Correlation: The same as for lot C-117406. Like that lot, lot C-118591 was most likely collected from the middle part of *Buchia uncitoides* Zone.

Locality No. 40

Field No. MVA(F)85-95 GSC No. C-118563
Report No. Km-1-1986-JAJ

Location: 49°31'14"; 121°54'47". In small quarry on north side of Mystery Creek road about 500 m beyond turnoff from Forest Service road.

Buchia okensis (Pavlov) s. str.
(common; late forms, including those transitional to
Buchia uncitoides var. *spasskenoides* Crickmay)

Buchia uncitoides (Pavlow) var.
spasskenoides (Crickmay) (common; includes the
large to very large, early forms as in lot C-117409)
Buchia uncitoides (Pavlow) var. *acutistriata* (Crickmay)
(less common)

Age and Correlation: Upper (probably uppermost) part of
Buchia okensis Zone and lower Berriasian in terms of the
international standard stages. Probably derived from the same
bed(s) as lot C-117408 (see for further details).

Locality No. 42

Field No. MVA(F)85-202 GSC No. C-118578

Location: 49°31'45"; 121°55'32". In saddle 3.3 km due west
of mouth of Mystery Creek. Fossils found in sandstone of
Peninsula Formation near section 3.

Buchia sp.

Age and Correlation: Specimens not studied by Jeletzky but
B. okensis is probably present and the age is Berriasian.

Locality No. 43 (Section 3)

Location: 49°31'42"; 121°55'35". In saddle 3.3 km due west
of mouth of Mystery Creek. Fossils collected along section 3
(Peninsula Formation).

Field No. MVA(F)85-311 GSC No. C-117406
Report No. Km-1-1986-JAJ

Buchia uncitoides (Pavlow) s. lato
(almost exclusively *B. u.* var. *acutistriata* (Crickmay);
mass occurrence in a coquina; no other *Buchia* species
noted)
Fragments of fossil wood

Age and Correlation: *Buchia uncitoides* s. lato Zone and
Middle Berriasian in terms of international standard stages
(see Jeletzky, 1965, loc. cit., p. 27-35, 64-66, Pl. IX; fig. 4
and Jeletzky in *Jurassic-Cretaceous Biochronology and
Paleogeography of North America*, Geological Association
of Canada, Special Paper 27, 1984, p. 211, 214, 215, fig. 5 for
further details). Please note that the *Buchia uncitoides* s. lato
Zone was not recognized as such by Crickmay (see in
Jeletzky, 1965, loc. cit. for further details). The *Buchia* fauna
of lot C-117406 is indistinguishable from that occurring in
the middle part of *Buchia uncitoides* s. lato Zone (including
the topmost part of its overlap beds with *Buchia okensis* Zone
on Vancouver Island; e.g. Pl. IX of Jeletzky, 1965, loc. cit.).
Therefore, this lot is most likely derived from the middle part
of this zone.

This collection lies stratigraphically beneath the other
three (C-117407, C-117408, C-117409) in section 3 and
collection error may have been the reason for its younger age
than C-117407, C-117408 and C-117409.

Field No. MVA(F)85-312 GSC No. C-117407
Report No. Km-1-1986-JAJ

Buchia okensis (Pavlow) s. str. (late forms; prevalent)
Buchia uncitoides (Pavlow) s. lato (very rare and
morphologically transitional to *B. okensis* s. str.)

Age and Correlation: Upper part of *Buchia okensis* Zone and
lower Berriasian in terms of international standard stages (see
Jeletzky, 1965, loc. cit., p. 20-27, 64-66, Pl. VI, fig. 4 and
Jeletzky, 1984, loc. cit. p. 203-205, 297, 209, 210, 211, fig. 5
for further details). The *Buchia* fauna of the lot C-117407 is
the same as that occurring in the topmost part of *Buchia
okensis* Zone on Vancouver Island (e.g. that reproduced in Pl.
VI of Jeletzky, 1965, loc. cit.). Therefore, this lot is inferred
to be derived from the upper part of this zone.

Field No. MVA(F)85-313 GSC No. C-117408
Report No. Km-1-1986-JAJ

Buchia okensis (Pavlow) s. str. (typical and giant forms;
common)
Buchia uncitoides (Pavlow) s. lato (includes *B. u.* var.
spasskenoides Crickmay, *B. u.* var. *acutistriata*
Crickmay and forms transitional to *B. okensis* Pavlow
s. str.; common)

Age and Correlation: The same as for lot C-117407. Like this
lot, lot C-117408 appears to be derived from the upper part
of *Buchia okensis* Zone. However, the common occurrence
of *B. uncitoides* var. *spasskenoides*, *B. u.* var. *acutistriata*
and forms transitional between these variants and *B. okensis*
s. str. suggests its being slightly younger and representing the
topmost beds of this zone. This is consistent with its recorded
stratigraphic position slightly above lot C-117407.

Field No. MVA(F)85-314 GSC No. C-117409
Report No. Km-1-1986-JAJ

Buchia uncitoides (Pavlow) var.
spasskenoides (Crickmay) (dominates the population
sample and is represented almost exclusively by large
to very large forms partly transitional to *B. okensis* s.
str.)
Buchia uncitoides (Pavlow) var. *acutistriata*
(Crickmay) (rare)
Buchia okensis (Pavlow) s. str. (rare; late forms and
forms transitional to *B. uncitoides* var. *spasskenoides*)

Age and Correlation: Lower part of *Buchia uncitoides* Zone
and middle Berriasian in terms of international standard
stages (see Jeletzky, 1965, loc. cit. and 1984, loc. cit. for
further details). The *Buchia* fauna of lot C-117409 resembles
very closely that occurring in the basal beds of *Buchia
uncitoides* Zone on Vancouver Island (e.g. that reproduced in
Pl. VIII of Jeletzky, 1965, loc. cit.), including the overlap beds
between it and *Buchia okensis* Zone. Therefore, and because
of its stratigraphic position slightly above lot C-117408, lot
C-117409 is assigned already to the basal part of *Buchia
uncitoides* Zone.

BROKENBACK HILL FORMATION

Locality No. 12

Location: 49°22'18";121°45'47". Southeast shore of Cascade Peninsula about 300 m from southern tip. Abundant fossils found in green sandstone and tuff of Brokenback Hill Formation. Two collections.

Field No. MVA(F)85-328 GSC No. C-117401
Report No. Km-1-1986-JAJ

Buchia crassicolis (Keyserling)
(mostly *B. c.* var. *solida* Lahusen; mass occurrence, no other *Buchias* noted)
Indeterminate ammonite (poor fragment)
Indeterminate belemnite (poor fragment)
Pleuromya cf. *uniformis* (J. Sowerby) (solitary specimen)
Pleuromya ex gr. *uralensis* (d'Orbigny) (solitary specimen)

Age and Correlation: Some part of *Buchia crassicolis* Zone and upper Valanginian in terms of international standard stages (see Jeletzky, 1965, GSC Bulletin 103, p. 49-55, 64-66, fig. 4 for further details).

Field No. MVA(F)85-328 Report No. Km-1-1986-JAJ
GSC No. C-118599

Homolomites quatsinoensis (Whiteaves)
(=*H. poecilohotomus* Crickmay) (common)
Buchia crassicolis (Keyserling) f. typ. and var. *solida* (Lahusen) (common)
Buchia keyserlingi (Lahusen) var. *gigas* (Crickmay) (rare and fragmentary)

Age and Correlation: The same as for lot C-117401 in terms of the standard *Buchia* Zones. However, *Homolomites quatsinoensis* appears to be restricted to the lower part of *Buchia crassicolis* Zone (e.g. Jeletzky and Tipper, 1968, loc. cit., p. 27) and this more exact dating is suggested here for lot C-118599.

Locality No. 13

Field No. MVA(F)85-148 GSC No. C-118569
Report No. Km-1-1986-JAJ

Location: 49°22'22";121°45'50". Southeast shore of Cascade Peninsula about 500 m from southern tip. Fossils found in sandstone and tuff of Brokenback Hill Formation.

Buchia crassicolis (Keyserling) var. *solida* (Lahusen)

Age and Correlation: The same as for lot C-117401.

Locality No. 44

Field No. MVA(F)85-173 Report No. Km-1-1986-JAJ
GSC No. C-118575.

Location: 49°32'21";121°59'01". Headwaters of Twenty Mile Creek at end of roadcut. Fossils collected from light green volcanic sandstone of the Brokenback Hill Formation.

Inoceramus paraketzovi Efimova subsp. *latus*
Pochialainen and Terekhova

Age and Correlation: The same as for lot C-118573.

Locality No. 45

Field No. MVA(F)85-171 GSC No. C-149642

Location: 49°32'41";121°58'27". Grey tuffaceous sandstone of the Brokenback Hill Formation outcrops on roadcut near headwaters of Twenty Mile Creek.

Ammonite fragment

Age and Correlation: Very poorly preserved ammonite fragment which cannot be dated.

Locality No. 46

Field No. MVA(F)85-170 GSC No. C-118573
Report No. Km-1-1986-JAJ

Location: 49°32'55";121°58'25". Near headwaters of Twenty Mile Creek on south slope along roadcut. Grey tuffaceous sandstone of the Brokenback Hill Formation contains numerous fossils.

Inoceramus paraketzovi Efimova cf. subsp. *acutus*
Pochialainen and Terekhova
Acroteuthis (*Acroteuthis*?) sp. indet.

Age and Correlation. *Inoceramus paraketzovi* with several subspecies was described by Nekrassov, Pokhialainen and Terekhova (O nakhodkah goterivskikh inotseramov na poluostrove Taigonos; Ministerstvo Geologii R.S.F.S.F., Ssevero-Vostochnoye Territorial'noye Upravlenie, Materialy po Geologii i Poleznym Iskopayemym Ssevero-Vostoka S.S.S.R., No. 20, 1972, Magadan Publishing House, Magadan, p. 172, 173, 176, 177; Pl. I, Figs. 1a, 1b; Pl. IV, Figs. 1a-1v) from the late Hauterivian *Hertleinites* sp. indet.- and *Inoceramus aucella*-bearing rocks of north-eastern Siberia. So far as known, these large and peculiarly ornamented *Inoceramus* forms are confined to Upper Hauterivian rocks of that region. However, they are known to range down into the lower Hauterivian rocks in western British Columbia (e.g. Taseko Lakes area, unpubl. data). Therefore, they can only be given a general Hauterivian age. Accordingly, the lot can be either contemporary with lot C-118572 or younger than that lot. Furthermore, it could conceivably be a faunal facies of the *Quoieccchia*-bearing Barremian-later Hauterivian beds described by Crickmay (1930a, loc. cit., p. 41, loc. 39) from the Harrison Lake area. *Inoceramus* comparable with *I. paraketzovi* but not definitely identifiable specifically have already been found west of the Harrison Lake area in the Fire Lake Group (see Report Km-3-1980-JAJ, GSC loc. 096923 for further details).

Locality No. 47

Field No. MVA(F)85-165 GSC No. C-118572
Report No. Km-1-1986-JAJ

Location: 49°33'05";121°55'18". Dark grey siltstone of the Brokenback Hill Formation outcrop on roadcut along north slope of Twenty Mile Creek Valley 2.8 km beyond turnoff from Forest Service road.

Homolomites (Wellsia) cf. *packardi* Imlay (two flattened but almost complete shells)

Age and Correlation: Presumably some part of the *Homolomites packardi* Zone and of early Hauterivian age in terms of the international standard stages (see Imlay, 1960, USGS Professional Paper 334-F, p. 176, 206, pl. 33, figs. 26-31 for further details). The regional north Pacific lower Hauterivian *Homolomites (Wellsia) packardi* Zone and the ultimately allied next older *Homolomites (Wellsia) oregonensis* Zone are very little known in British Columbia. So far they were only found in the Taseko Lakes, Quatsino Sound, and Mount Waddington areas (Jeletzky and Tipper, 1968, GSC Paper 67-54, p. 7, 8, 9, 32, 33, 202, 203; Jeletzky, 1976, GSC Bulletin 242, p. 76-77; Tipper, 1969, GSC Paper 68-33, p. 53). The *Homolomites packardi* Zone is younger than the upper Valanginian *Buchia crassicolis* Zone and older than the widespread mid-Hauterivian *Simbirskites (Hollisites) lucasi* and *Speetonicerias* cf. *agnessense* Zone (see Jeletzky and Tipper, 1968, GSC Paper 67-54, p. 7 for further details). It should also be older than the little known Barremian and ?uppermost Hauterivian beds of the Harrison Lake area containing *Quoieccchia aliciae* Crickmay in association with a dubious *Buchia? kwoiekensis* Crickmay (see Crickmay, 1930a, Natn. Museum of Canada, Bulletin 63, p. 41, loc. 39). Except for these *Quoieccchia*-bearing beds, and possibly the *Inoceramus*-bearing lots 118573 and 118575 (see there), the *Homolomites (Wellsia)* cf. *packardi*-bearing beds of the locality C-118572 are the youngest known beds in the Brokenback Hill Formation.

Locality No. 48

Field No. MVA(F)85-164 GSC No. C-118571

Location: 49°33'06";121°55'05". In roadcut about 2 km beyond turnoff from Forest Service road on north slope of Twenty Mile Creek Valley.

Belemnites

Age and Correlation: Fossils collected cannot date locality but its stratigraphic position suggests an Early Hauterivian age based on its proximity to locality 47.

Locality No. 49

Field No. MVA(F)85-182 GSC No. C-118576

Location: 49°33'50";121°57'25". On roadcut along south slope of Kirkland Creek Valley. Tuffaceous sandstone of Brokenback Hill Formation outcrops along roadcut.

Ammonoceratites sp.
Belemnites

Age and Correlation: The ammonite identified as *Ammonoceratites* sp. closely resembles the specimen figured in McLearn (1972, pl. 1, fig. 5) from the Queen Charlottes Islands where it is associated with a Middle Albian fauna; Arkell et al. (1957) suggested a Late Aptian to Cenomanian age for *Ammonoceratites*.

Locality No. 50

Field No. MVA(F)85-181 GSC No. C-117410
Report No. Km-1-1986-JAJ

Location: 49°33'56";121°56'27". On roadcut along south slope of Kirkland Creek Valley.

Inoceramus (s. lato) sp. indet.
Acroteuthis (s. lato) sp. indet.

Age and Correlation: Late Late Jurassic (Tithonian stage) to mid-Early Cretaceous (lowermost Aptian stage) age based on the presently known time range of the genus *Acroteuthis* Stolley. Cannot be dated any closer.

Locality No. 51

Field No. MVA(F)85-248 GSC No. C-118584
Report No. Km-1-1986-JAJ

Location: 49°34'07";121°56'58". On roadcut about 500 m east of bridge crossing Kirkland Creek are fine grained, dark grey tuffaceous sandstones of the Brokenback Hill Formation.

Indeterminate true belemnite
(Order Belemnitida Zittel, 1895 emend. Jeletzky, 1966)

Age and Correlation: Generally speaking, lot C-118584 can only be dated as a general Jurassic or Cretaceous age. However, in Western and Arctic Canada, true belemnites are almost restricted to the upper Lower Jurassic (Toarcian and/or ?uppermost Pliensbachian) to mid-Lower Cretaceous (lower Aptian) rocks. Lot C-118584 therefore, can be dated on its belemnite as being probably of that general age. However, its earlier Jurassic or later Cretaceous age cannot be ruled out on that basis.

Locality No. 52

Field No. MVA(F)85-247 GSC No. C-118583

Location: 49°34'09";121°56'50". On roadcut about 650 m east of bridge crossing Kirkland Creek are massive pyrite-bearing grey sandstones.

Ammonite
Belemnites

Age and Correlation: Fragment of whorl of ammonite cannot be identified with certainty. The fossils are Cretaceous and probably Early Cretaceous based on their stratigraphic position.

Locality No. 53

Field No. MVA(F)85-326 GSC No. C-118597

Location: 49°34'19";121°58'07". North slope of Kirkland Creek on old logging roadcut where siltstone and sandstone of the Brokenback Hill Formation outcrops.

Ammonite specimen

Age and Correlation: Cretaceous. Specimen sent to Jeletzky for identification.

Locality No. 54

Field No. MVA(F)85-252 GSC No. C-118585

Location: 49°34'27";121°57'23". On roadcut about 1 km north of bridge crossing Kirkland Creek are manganese-stained siltstones and shales of the Brokenback Hill Formation.

Ammonite fragment

Bivalve

Wood debris

Age and Correlation: The fossils are fragmentary and cannot be dated.

Locality No. 55

Field No. R-21 GSC No. C-117252
Report No. Km-11-1985-JAJ

Location: 49°38'43";121°59'10". About 1.5 km south of the tip of Doctors Point beneath a powerline tower beside the Forest Service road (see Ray et al., 1985).

Cleoniceras (Grycia?) perezianum (Whiteaves)

Age and Correlation: Identified as *Cleoniceras perezianum* (Whiteaves) by H.W. Tipper and submitted to J.A. Jeletzky for confirmation (Report No. Km-11-1985-JAJ) who stated:

The writer concurs with the original identification of this ammonite by H.W. Tipper made as a personal communication and published by Ray, G.E. and Combes, S. in Harrison Lake Project (92H/S,12; 92G/g,16); Province of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Paper 1985-1, Geological Branch, Geological Fieldwork, 1984. A summary of field activities and current research, 1985, p. 122. As already recognized by these workers, this identification of a Middle Albian ammonite on the western shore of Harrison Lake is paleogeographically and stratigraphically important. It documents for the first time the eastward extension of marine rocks of Gambier Group eastward into the Harrison Lake area. These rocks were previously believed to be restricted to the very poorly understood mid-Cretaceous basin of the Gulf of Georgia. See Jeletzky, J.A., Mid-Cretaceous History of Pacific Slope of Canada; Palaeontological Society of Japan, Special Papers No. 21. Mid-Cretaceous Events-Hokkaido Symposium, 1976; 1977a, p. 101, 111-113; figs. 2,4 for further details concerning the geographical distribution and age of the *Cleoniceras (Grycia?) perezianum* fauna in western British Columbia.

The following are Geological Survey of Canada fossil collections from the Harrison Lake area collected by various geologists. They were submitted by H.W. Tipper to J.A. Jeletzky in 1962 and were described by Jeletzky in his Report No. Km-14-1962-JAJ.

Field No. 808 GSC No. 48928
Report No. Km-14-1962-JAJ

Location: Harrison Lake, B.C. Collected by A. Bowman, Dec. 9, 1882.

Buchia cf. *pacifica* Jeletzky
(no other *Buchia* forms occur in this lot)

Field No. 1031 GSC No. 48929
Report No. Km-14-1962-JAJ

Location: Long Island, Harrison Lake. Stratum No. 43, collected by A. Bowman, Dec. 8, 1882.

Buchia crassicolis (Keyserling) s. str.
Buchia crassicolis (Keyserling) var. *solida* (Lahusen)

Field No. GSC No. 16400
Report No. Km-14-1962-JAJ

Location: Southeast shore of the peninsula, Harrison Lake, B.C. Collected by C.H. Crickmay, 1924. May be equivalent to localities 12 and 13 of this report.

Buchia cf. *crassicolis* (Keyserling) s. str.

Field No. GSC No. 16399
Report No. Km-14-1962-JAJ

Location: Peninsula Formation, Lower Cretaceous, 350 yds from shore, 1000 yds north of Hale Creek. West side of Harrison Lake, B.C. Collected by C.H. Crickmay, 1926.

Buchia uncitoides (Pavlow) s. lato

Field No. GSC No. 9895
Report No. Km-14-1962-JAJ

Location: Jurassic? Cretaceous? Harrison Hot Springs, western slope of Peninsula, elevation 300 ft directly below GSC loc. 9894. Collected by W.E. Snow, 1939.

Buchia uncitoides (Pavlow) s. lato
True belemnites, genus and species indet.

Field No. Report No. Km-14-1962-JAJ
GSC No. 9894

Location: Peninsula Formation; Harrison Hot Springs, on top of ridge of (possibly from Crickmay's (1930a) locality 30). (Location of Crickmay's locality 30 is one-third mile south of the highest peak on the peninsula). Collected by W.E. Snow, 1939.

Buchia pacifica Jeletzky
(no other *Buchia* forms occur in this lot)

Field No. GSC No. 9892
Report No. Km-14-1962-JAJ

Location: Peninsula Formation, Harrison Hot Springs; near north end of Cascade Peninsula, from the Peninsula Formation, 20 ft from the contact with Brokenback Hill Formation which overlies the Peninsula Formation conformably, 1/4 mile south from fault cutting across the north end of the peninsula. Collected by W.E. Snow, 1939.

Buchia pacifica Jeletzky
(no other *Buchia* forms occur in this lot)

Field No. GSC No. 9889
Report No. Km-14-1962-JAJ

Location: Brokenback Formation, southeast tip of Cascade Peninsula, just west of Crickmay's fossil locality 40, Harrison Hot Springs, B.C. (Crickmay's locality 40 is on Lonetree Island, off south tip of peninsula). Collected by W.E. Snow, 1939.

Buchia cf. *crassicolis* (Keyserling) s. str.

Field No. GSC No. 9891
Report No. Km-14-1962-JAJ

Location: Harrison Hot Springs, on west side of Cascade Peninsula, 1 mile northwest of Crickmay's locality 24 (1930a). (Location of Crickmay's locality 24 – southwest side of a narrow point which bounds on the west a small bay on the southwest shore of the peninsula and 1850 yards from the southeast point of the peninsula). Collected by W.E. Snow, 1939.

Buchia ex gr. *uncitoides-tolmatschowi-pacifica*
(cannot be compared with any of these species in preference to the others because of poor preservation).

Field No. GSC No. 9890
Report No. Km-14-1962-JAJ

Location: Peninsula Formation, same locality as Crickmay's (1930a) locality 28, Harrison Hot Springs, B.C. (Location of Crickmay's locality 28 – west shore of a little bay on the southwest shore of the peninsula, Harrison Lake, B.C.). Collected by W.E. Snow, 1939. This locality is equivalent to locality 14 of this report.

Buchia uncitoides (Pavlow) var. *spasskensoides*
(Crickmay)

Field No. F-8 GSC No. 14893
Report No. Km-14-1962-JAJ

Location: Harrison Lake area. In small bay on east side of Long Island, a half mile from south end. Collected by W.E. Snow, 1939. This may suggest that fault slices of Peninsula Formation are present on Long Island.

Buchia cf. *uncitoides* (Pavlow) s. lato
Buchia cf. *okensis* (Pavlow)

Field No. F-9 GSC No. 14894
Report No. Km-14-1962-JAJ

Location: Harrison Lake area, north side of Hale Creek, 1.4 miles from Harrison Lake. Collected by W.E. Snow, 1939.

No identifiable fossils seen

Field No. F-10 GSC No. 14895
Report No. Km-14-1962-JAJ

Location: 1100 ft northeast of loc. 14894 (Harrison Lake area north side of Hale Creek, 1.4 miles from Harrison Lake). Collected by W.E. Snow, 1939.

True belemnites, genus and species indet.
Pecten (*Entolium*) sp. indet.
Gastropod, genus and species indet.

Field No. F-11 GSC No. 14896
Report No. Km-14-1962-JAJ

Location: On logging road, 500 ft due north of loc. 14894 (Harrison Lake area, north side of Hale Creek, 1.4 miles from Harrison Lake). Collected by W.E. Snow, 1939.

True belemnites, genus and species indet.
Pecten (*Entolium*) sp. indet.
Anomia? sp. indet.
Spirorbis? sp. indet.

Field No. F-12 GSC No. 14897
Report No. Km-14-1962-JAJ

Location: A half mile northwest of loc. 14896 (on logging road, 500 ft due north of loc. 14894). Loc. 14894: – Harrison Lake area. North side of Hale Creek, 1.4 miles from Harrison Lake. Collected by W.E. Snow, 1939.

Indeterminate ammonite

Field No. F-13 GSC No. 14898
Report No. Km-14-1962-JAJ

Location: On H & R logging road a half mile from Harrison Lake and 3 miles north of mouth of Hale Creek. Collected by W.E. Snow, 1939.

Buchia okensis (Pavlow)
Buchia trigonoides (Lahusen non? Pavlow)

Field No. F-14 GSC No. 14899
Report No. Km-14-1962-JAJ

Location: On H & R logging road 3 miles northeast of small lake on nose south of Mysterious Creek. Collected by W.E. Snow, 1939.

Buchia uncitoides (Pavlow) var. *spasskensoides*
(Crickmay)
True belemnite, genus and species indet.

Field No. F-15
Report No. Km-14-1962-JAJ

Location: On H & R logging road 1.2 miles southeast of locality 14899 (on H & R logging road, 3 miles northeast of small lake on nose south of Mysterious Creek). Collected by W.E. Snow, 1939.

Buchia uncitoides (Pavlow) s. lato

Field No. F-16
GSC No. 14900

Location: On branch of H & R logging road 1.5 miles east of locality 14903 which is 1.2 miles southeast of locality 14899. Collected by W.E. Snow, 1939.

Buchia pacifica Jeletzky
(no other *Buchia* forms occur in this collection)

Field No. F-17
Report No. Km-14-1962-JAJ

Location: Lower Cretaceous; Harrison Lake area, on large bay on west side of Long Island. Collected by W.E. Snow, 1939. May be from localities 23 or 24 in this report.

Buchia cf. *crassicollis* (Keyserling) s. str.
Buchia cf. *pacifica* Jeletzky

Field No. F-18
Report No. Km-14-1962-JAJ

Location: Harrison Lake area, on east side of Long Island.
Collected W.E. Snow, 1939.

Buchia sp. indet.
(of Early Cretaceous affinities?)

