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JURASSIC STRATIGRAPHY OF THE QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA

B.E.B. Cameron
H.W. Tipper

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Cover photo: Skidegate Inlet looking northwest from Alliford Bay with Maude Island on the left, Queen Charlotte City on Extreme right and Slatechuck Mountain in background (GSC 190984)

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Preface

The stratigraphy and paleontology of the Mesozoic rocks of the Queen Charlotte Islands on the west coast of British Columbia have presented problems and contradictions since the earliest geological studies in 1872.

During the course of the present detailed stratigraphic studies careful attention was paid to occurrences of bitumen, dead oil, fetid lithologies, and possible porous intervals within the Jurassic rocks. Hydrocarbons, derived from normal petroleum type hydrocarbons, were noted throughout the lower and middle Jurassic. The present evidence suggests that hydrocarbon reserves may be encountered in the subsurface in northern Graham Island, southern Hecate Strait, and Queen Charlotte Sound. These potential resources involve mesozoic oil within the Jurassic or Cretaceous rocks, or escape oil of Mesozoic age in Tertiary sandstone units.

This report on the stratigraphy of the Jurassic strata is another step towards a fuller understanding of the geology of these beautiful islands.

R.A. Price
Director General
Geological Survey of Canada

Avant-propos

La stratigraphie et la paléontologie des roches mésozoïques des îles de la Reine-Charlotte sur la côte ouest de la Colombie-Britannique ont présenté des problèmes et des difficultés depuis les premières études géologiques entreprises en 1872.

Au cours des études stratigraphiques détaillées qu'ils ont effectuées, les auteurs ont porté une attention toute particulière aux venues de bitume et d'huile morte, aux lithologies fétides et aux intervalles poreux possibles dans les roches jurassiques. Ils ont observé la présence d'hydrocarbures, dérivés d'hydrocarbures normaux de pétrole, partout dans les roches du Jurassique inférieur et moyen. Selon les indices, il pourrait y avoir des réserves souterraines d'hydrocarbures dans la partie nord de l'île Graham, dans le sud du détroit d'Hécate et dans le détroit de la Reine-Charlotte. Ces ressources éventuelles comprennent du pétrole mésozoïque dans des roches jurassiques ou crétacées ou du pétrole d'échappement d'âge mésozoïque dans des unités de grès tertiaire.

Le présent rapport sur la stratigraphie des couches jurassiques est une autre étape vers une connaissance plus complète de la géologie de ces îles magnifiques.

R.A Price
Directeur général
Commission géologique du Canada

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JURASSIC STRATIGRAPHY OF QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA

Abstract

Detailed investigations of the Jurassic rocks of the Queen Charlotte Islands have necessitated a complete revision of the stratigraphic nomenclature. The Kunga, Maude and Yakoun formations are elevated to group status. One new group name, the Moresby Group, is introduced for rocks of Late Bathonian to Early Callovian age. Eleven new formational names and ten new informal member names are proposed.

The Jurassic rocks of the Queen Charlotte Islands are mainly clastic sediments indicating a variety of depositional environments and range from deep water euxinic shale to shallow marine coarse sandstone and conglomerate. Five major transgressive cycles are recorded. One rock group is essentially volcanic. The strata were deposited in a back-arc basin, as part of the Wrangellia allochthonous terrane.

The faunas of the Jurassic strata are dominantly of Tethyan affinities. Both the macro- and microfaunas are diverse, well-preserved, abundant, and show great promise for effective biostratigraphic zonation.

The Sandilands and Ghost Creek formations are confirmed to be hydrocarbon source beds from which oil has migrated. Entrapment of these hydrocarbons is possible in the sandstones of the Moresby Group, or in the Cretaceous rocks beneath the Tertiary Masset volcanics. Indications are that some of the rocks are probably present beneath the Masset in northern Graham Island, southern Hecate Strait and Queen Charlotte Sound. Potential oil resources of these areas involve Mesozoic oil or escape oil of Mesozoic age into Tertiary rocks.

Résumé

Les études détaillées des roches jurassiques des îles Reine-Charlotte ont exigé la révision complète de la nomenclature stratigraphique. Les formations de Kunga, de Maude et de Yakoun sont devenues des groupes. Un nouveau groupe, celui de Moresby, comprend les roches du Bathonien tardif au Callovien ancien. Onze nouvelles formations et dix nouveaux termes officieux sont proposés.

Les roches jurassiques des îles Reine-Charlotte se composent principalement de sédiments clastiques accumulés dans différents milieux: ces sédiments varient des schistes argileux euxiniques d'eau profonde aux grès et aux conglomérats grossiers d'eau marine peu profonde. Cinq grands cycles transgressifs ont été identifiés. Un groupe de roches est d'origine essentiellement volcanique. Les couches se sont accumulées dans un bassin d'arrière-arc et elles font partie du terrain allochtone de Wrangellia.

Les faunes des couches jurassiques sont d'affinité surtout mésogéenne. Les macrofaunes et les microfaunes sont toutes variées, bien conservées et abondantes et s'avéreront très utiles pour la zonation biostratigraphique.

Les formations de Sandilands et de Ghost Creek sont des roches mères, les hydrocarbures ayant migré ailleurs. Ces hydrocarbures ont peut-être été piégés dans les grès du groupe de Moresby, ou dans les roches crétacées sous-jacentes aux roches volcaniques tertiaires de Masset. Certaines des roches seraient présentes sous la formation de Masset dans la partie nord de l'île Graham, dans le sud du détroit d'Hécate et dans le détroit de la Reine-Charlotte. Les ressources pétrolières possibles de ces régions comportent du pétrole mésozïque ou du pétrole mésozoïque ayant migré dans des roches tertiaires.

Summary

The stratigraphy and faunas of the Jurassic rocks of the Queen Charlotte Islands have received much attention by geologists since 1872. Unfamiliarity with the faunas and similarities of the rock units with those of the Cretaceous have led to considerable confusion in the past. The Jurassic succession, as presently understood, represents a synthesis of many fault-bounded exposures of rocks, principally in Skidegate Inlet and central Graham Island. Since no one area satisfactorily exposes major portions of the complete succession, it has been necessary to compile detailed stratigraphic sequences wherever possible and rely heavily on the

Sommaire

La stratigraphie et les faunes des roches jurassiques des îles de la Reine-Charlotte font l'objet d'une attention toute particulière de la part des géologues depuis 1872. L'aspect inconnu des faunes et la similarité des unités lithologiques avec celles du Crétacé ont été la cause de beaucoup de confusion dans le passsé. La succession jurassique, telle qu'on la connaît présentement, représente une synthèse d'un grand nombre d'affleurements rocheux limités par des failles, surtout dans l'inlet Skidegate et la partie centrale de l'île Graham. Puisqu'aucune région ne présente à elle seule et de façon satisfaisante de grandes parties de la succession complète, il a été nécessaire de compiler des séquences stratigraphiques détaillées à divers endroits et de se fonder sur les faunes contenues dans les

contained faunas for local correlation. The stratigraphic succession herein presented is the result of eighteen detailed measured sections, and extensive study of many isolated road, quarry and creek exposures scattered throughout the area. As a result of these studies, we herein propose four groups, eleven formations, and ten informal members which are necessary to adequately describe and understand these rocks. Most of these names are new. The lithological character, age, areal distribution and depositional environment of each unit is summarized as follows, in ascending order:

Kunga Group. This unit, previously known as the Kunga Formation, includes rocks of Late Triassic and earliest Jurassic age. Only the upper part of the group is dealt with in this report, for which a new name, the Sandilands Formation is proposed. The Sandilands Formation is exposed in most areas of the Queen Charlotte Islands and consists of thinly interbedded siltstone, shale, fine sandstone and minor tuffs. Sediments were deposited in a relatively deep water back-arc basin. This basin was remote from the centres of volcanism and received only fine volcanic detritus either as air-fall tuff or as fine detritus swept into the basin from a volcanic terrane. The thickness of the Sandilands approaches 500 m but fault repetition in some areas greatly influences these estimates. On the basis of good paleontological control, the Sandilands Formation ranges in age from Early to Late Sinemurian.

Maude Group. This unit, previously known as the Maude Formation, includes rocks ranging in age from Early Pliensbachian to Aalenian. On the basis of distinctive lithologies, the group is herein subdivided into five new formations. These are in ascending order: the Ghost Creek Formation (lower Pliensbachian), Rennell Junction Formation (lower Pliensbachian), Fannin Formation (upper Pliensbachian to lower Toarcian), Whiteaves Formation (middle Toarcian), and Phantom Creek Formation (middle Toarcian to Aalenian). The upper two formations are further subdivided into four informal members, the septarian shale and concretionary shale members of the Whiteaves Formation, and coquinoid sandstone and belemnite sandstone members of the Phantom Creek Formation. The main areas of exposure of the Maude Group are in the Skidegate Inlet area and in central Graham Island. In addition, other fragmentary outcrops are known throughout most areas of the Queen Charlotte Islands. Lithologies of the Maude Group are highly variable and represent two eustatic sea level changes. The Ghost Creek Formation represents sedimentation in a relatively deep water back-arc basin and thus is a continuation of the same depositional environment of the underlying Sandilands Formation, but without the volcanic input. Rock types consist of dark, often fetid, shale and siltstone and minor flaggy and lenticular limestone. Partial infilling of the basin and shallower water depths occur in the overlying Fannin Formation, where more sandstone

roches pour établir les corrélations locales. La succession stratigraphique présentée dans le présent rapport est fondée sur l'examen détaillé de 18 sections et l'étude approfondie d'un grand nombre d'affleurements isolés répartis un peu partout dans la région le long de routes et de cours d'eau et dans des carrières. Quatre groupes, onze formations et dix niveaux officieux, dont la plupart sont nouveaux, sont proposés dans le présent rapport. Ils permettent de décrire et de bien comprendre la composition de ces roches. La nature lithologique, l'âge, la répartition et le milieu de sédimentation de chaque unité sont résumés dans les paragraphes suivants, en ordre ascendant:

Groupe de Kunga. Cette unité, anciennement la formation de Kunga, comprend des roches de la fin du Trias et du tout début du Jurassique. Le présent rapport ne décrit que la partie supérieure du groupe, pour laquelle on propose un nouveau nom, la formation de Sandilands. Cette formation affleure presque partout dans les îles de la Reine-Charlotte et comporte de minces interstratifications d'aleurolite, de schiste argileux, de grès fin et de petites quantités de tuf. Les sédiments se sont accumulés dans un bassin d'arrière-arc, en eau relativement profonde. Ce bassin était éloigné des centres de volcanisme et n'a reçu que des débris volcaniques fins sous forme de tuf projeté ou de débris fins provenant d'un terrain volcanique. L'épaisseur de la formation de Sandilands atteint près de 500 m mais la répétition des couches due à la formation de failles dans certaines régions influe beaucoup sur ces estimations. De bons indices paléontologiques révèlent que l'âge de cette formation varie du Sinémurien inférieur au Sinémurien supérieur.

Groupe de Maude. Cette unité, anciennement la formation de Maude, comprend des roches dont l'âge varie du Pliensbachien supérieur à l'Aalénien. Le groupe est subdivisé en cinq nouvelles formations, caractérisées par leurs lithologies, qui sont présentées en ordre ascendant: la formation de Ghost Creek (Pliensbachien inférieur), la formation de Rennell Junction (Pliensbachien inférieur), la formation de Fannin (Pliensbachien supérieur au Toarcien inférieur), la formation de Whiteaves (Toarcien moyen) et la formation de Phantom Creek (Toarcien moyen à Aalénien). Les deux formations supérieures sont en outre subdivisées en quatre niveaux officieux, soit le schiste argileux à septarias et le schiste argileux concrétionné de la formation de Whiteaves, et le grès lumachellique ainsi que le grès à bélemnites de la formation de Phantom Creek. Le groupe de Maude affleure surtout dans la région de l'inlet Skidegate et dans la partie centrale de l'île Graham. En outre, d'autres affleurements détritiques sont connus presque partout dans les îles de la Reine-Charlotte. Les lithologies du groupe de Maude sont très variées et représentent deux changements eustatiques. La formation de Ghost Creek a été mise en place en eau relativement profonde dans un bassin d'arrière-arc; ce milieu de sédimentation est donc une continuation de celui de la formation sous-jacente de Sandilands, mais sans apport volcanique. Les roches comportent des schistes argileux et des aleurolites foncés et souvent fétides ainsi que des quantités moindres de calcaire lenticulaire et de calcaire se débitant en dalles. Dans la formation sus-jacente de Fannin, où l'on trouve plus de grès et moins de schiste argileux, le bassin s'est partiellement rempli et le niveau de l'eau a donc baissé. Ce processus s'est poursuivi dans cette formation où l'on trouve surtout du grès fin et de l'aleurolite. À cette époque, il y a

and less dark shale occur. At this time, volcanic activity increased in remote areas and as a result the sequence contains many more tuffaceous sandstones and siltstones. A second depositional cycle began with the deeper water grey-green shales of the Whiteaves Formation followed by dominantly shallower water sandstones of the Phantom Creek. Lithologies vary from soft, green weathering shale with septarian nodules and concretions at the base to chaotically bedded sandstones at the top. In various areas of exposure, the Maude Group varies in thickness from 120 m to a maximum of near 300 m. All rocks of this unit are richly fossiliferous and are well controlled biostratigraphically.

Yakoun Group. This unit, previously known as the Yakoun Formation, includes rocks of Early Bajocian age. Two new formational names are proposed for the group, the Graham Island Formation and the younger Richardson Bay Formation. These formations are further subdivided into informal members; the shale-tuff, mottled siltstone, volcanic sandstone and lapilli members of the Graham Island Formation, and the dark sandstone and volcanic breccia members of the Richardson Bay Formation. Rocks of the Yakoun Group represent the major volcanic event in the Jurassic of the Queen Charlottte Islands. These rocks are highly variable lithologically depending in large part on their proximity to the volcanic vents. Certain formations and members are considered to be partly facies equivalents of others. The Yakoun Group is distributed over vast areas of the Queen Charlotte Islands. In the Skidegate Inlet area and to the south, the rocks are volcanic breccias, lapilli tuffs and agglomerates with minor lenticular sandstone and siltstone. To the north, in central Graham Island, rocks are mainly sedimentary with minor tuffaceous components reflecting their remoteness from the main volcanic source. The sequence on Graham Island begins in relatively deep water, dark brown partly tuffaceous shale and siltstone and is followed by a thick interval of coarse- to fine-grained sandstone reflective of a much shallower environment. In this area, erosion has removed the overlying Richardson Bay Formation locally. As is the case with most dominantly volcanic units of this type, the thickness of the Yakoun Group is highly variable. Estimates of from 500 m to over 1100 m have been suggested.

Moresby Group. This is a new group name for rocks ranging in age from late Bathonian to Early Callovian. Three new formational names are herein proposed, in ascending order: the Robber Point Formation, Newcombe Formation and Alliford Formation. At the present time, these rocks are known only from the Skidegate Inlet area. Unlike the underlying Yakoun Group, the rocks of the Moresby Group are entirely sedimentary and were deposited in a shallow marine basin after a period of uplift and erosion of the earlier rocks. The sequence begins with shallow marine con-

eu accroissement de l'activité volcanique dans les régions éloignées et la séquence contient donc beaucoup plus de grès et d'aleurolite tufacés. Un deuxième cycle de sédimentation a commencé en eau plus profonde avec l'accumulation des schistes argileux gris vert de la formation de Whiteaves, suivie par l'accumulation en eau généralement moins profonde des grès de la formation de Phantom Creek. La lithologie varie, de la base de la section jusqu'au sommet, d'un schiste argileux mou à surface altérée verte, contenant des nodules à septarias et des concrétions, aux grès à stratification chaotique. L'épaisseur du groupe de Maude varie de 120 m à un maximum de presque 300 m. Toutes les roches de cette unité sont très fossilifères et présentent un bon contrôle biostratigraphique.

Groupe de Yakoun. Cette unité, anciennement la formation de Yakoun, comprend des roches du Bajocien inférieur. Deux nouvelles formations sont proposées, la formation de Graham Island et la formation plus récente de Richardson Bay. Ces formations sont subdivisées en niveaux officieux: le schiste argileux et tuf, l'aleurolite tachetée, le grès volcanique et le lapilli de la formation de Graham Island ainsi que le grès foncé et la brèche volcanique de la formation de Richardson Bay. Les roches du groupe de Yakoun représentent le principal événement volcanique du Jurassique des îles de la Reine-Charlotte. La lithologie de ces roches est très variée et dépend en grande partie de leur proximité aux cheminées volcaniques. Certaines formations et certains niveaux sont considérés comme ayant des faciès équivalents en partie à d'autres formations et niveaux. Le groupe de Yakoun est réparti sur de vastes étendues dans les îles de la Reine-Charlotte. Dans la région de l'inlet Skidegate et au sud, les roches sont des brèches volcaniques, des conglomérats volcaniques à lapilli et des agglomérats avec de petites quantités de grès lenticulaire et d'aleurolite. Vers le nord, dans la partie centrale de l'île Graham, les roches sont surtout d'origine sédimentaire, la présence de petites quantités de matériaux tufacés indiquant leur éloignement de la principale source volcanique. La séquence de l'île Graham commence par des schistes argileux et des aleurolites brun foncé partiellement tufacés, mis en place en eau relativement profonde; vient ensuite un intervalle épais de grès dont la taille des grains varie de grossier à fin et dont l'accumulation a eu lieu en milieu beaucoup moins profond. Dans cette région, l'erosion a par endroits enlevé la formation sus-jacente de Richardson Bay. Comme c'est le cas pour la plupart des unités principalement volcaniques de ce genre, l'épaisseur du groupe de Yakoun varie énormément, les estimations allant de 500 m à plus de 1 100 m.

Groupe de Moresby. Ce nouveau nom de groupe a été donné à des roches dont l'âge varie de la fin du Bathonien au début du Callovien. Trois nouvelles formations sont présentées en ordre ascendant: la formation de Robber Point, la formation de Newcombe et la formation d'Alliford. Ces roches sont présentement connues seulement aux alentours de l'inlet Skidegate. Contrairement au groupe sous-jacent de Yakoun, les roches du groupe de Moresby sont toutes d'origine sédimentaire et ont été mises en place dans un bassin marin peu profond après une période de soulèvement et d'érosion des roches plus anciennes. La séquence commence par un conglomérat, un grès et un schiste argileux d'eau

glomerate, sandstone, and shale and is followed by progressively deeper water, fine sandstone and shale. The youngest rocks in the Skidegate Inlet area are exposed in the Alliford Bay syncline at Alliford Bay. In the Skidegate Inlet area the thickness of the Moresby Group varies from about 100 m to a maximum of close to 200 m.

Late Jurassic rocks. Rocks of Kimmeridgian and/or Tithonian age are known from isolated exposures on reefs along the northwest coast of the Queen Charlotte Islands. Their areal extent, thickness and lithological detail are presently poorly understood and thus no formal stratigraphic terminology is proposed.

With the exception of the volcanic rocks of the Yakoun Group, all of the Jurassic rocks of the Queen Charlotte Islands are richly fossiliferous. Zonal schemes involving ammonites, foraminifers, ostracods, bivalve molluscs and radiolarians are presently under preparation by various workers. Ultimately, the resulting biostratigraphic control in combination with detailed stratigraphy of this report will provide an excellent reference section for the lower and middle Jurassic of the west coast of North America.

Detailed analyses of fossil faunas and lithologies have led to an understanding of the depositional environments of the various rock units. These vary from the relatively deep water, partly euxinic shales of the Sandilands and Ghost Creek formations to shallow marine and/or continental laharic volcanic piles of the Yakoun Group. Five eustatic cycles are recognized in the lower and middle Jurassic. These relative rises and falls of the sea level are seen to be in generally good agreement with the world-wide curves proposed by various authors.

Faunal and stratigraphic evidence indicate the presence of several unconformities within the Jurassic sequence. Most of these are of small significance, however, and are represented by paraconformable contacts where breaks in the faunal succession are apparent. An exception to these small breaks is the erosional interval between the lower Bajocian and upper Bathonian rocks, where in addition to the major hiatus, a slight angular discordance is suggested. Perhaps this is to be expected since a stratigraphic break of this age is known in many areas of the Canadian Cordillera. The unconformity suggested for the lower Callovian to Kimmeridgian/Tithonian interval is somewhat speculative. The outcrop belt where the intervening late Callovian, Oxfordian, and lower Kimmeridgian rocks might be expected is covered by a thick blanket of Tertiary volcanic rocks. These upper Jurassic rocks may be eventully discovered in subsurface in the north and northwest part of Graham Island.

The Queen Charlotte Islands are on the western edge of the Wrangellia allochthonous terrane, and the lithological units there can be related to those within

marine peu profonde, suivis par un grès fin et un schiste argileux accumulés en eau progressivement plus profonde. Les roches les plus récentes de la région de l'inlet Skidegate affleurent dans le synclinal d'Alliford Bay à la baie Alliford. Dans la région de l'inlet Skidegate, l'épaisseur du groupe de Moresby varie d'environ 100 m à près de 200 m.

Roches du Jurassique supérieur. Les roches du Kimméridgien ou du Tithonique ou les deux se présentent en affleurements isolés sur des récifs le long de la côte nord-ouest des îles de la Reine-Charlotte. Puisque leur étendue, leur épaisseur et leurs caractéristiques lithologiques sont encore mal connues, aucune terminologie stratigraphique officielle n'est proposée.

À l'exception des roches volcaniques du groupe de Yakoun, toutes les roches jurassiques des îles de la Reine-Charlotte sont très fossilifères. Divers chercheurs préparent présentement des plans des diverses zones à ammonites, à foraminifères, à ostracodes, à mollusques bivalves et à radiolaires. Le contrôle biostratigraphique qui en résultera, ainsi que la stratigraphie détaillée présentée dans le présent rapport, fourniront éventuellement une excellente section de référence pour le Jurassique inférieur et moyen de la côte ouest de l'Amérique du Nord.

L'analyse détaillée des faunes fossiles et des lithologies a permis de mieux connaître le milieux de sédimentation des diverses unités lithologiques comme les schistes argileux partiellement euxiniques mis en place en eau profonde des formations de Sandilands et de Ghost Creek et les lahars d'origine marine peu profonde ou continentale, ou les deux, du groupe de Yakoun. On reconnait cinq cycles eustatiques au cours du Jurassique inférieur et moyen. En général, ces remontées et chutes relatives du niveau de la mer concordent assez bien avec les courbes mondiales proposées par divers auteurs.

Les indices fauniques et stratigraphiques révèlent l'existence de plusieurs discordances au sein de la séquence jurassique. La plupart d'entre elles sont toutefois peu importantes et représentées par des paraconformités là où il y a des lacunes évidentes dans la succession faunique. Il y a exception dans le cas de l'intervalle d'érosion situé entre des roches du Bajocien inférieur et celles du Bathonien supérieur où il pourrait y avoir une légère discordance angulaire en plus de l'importante lacune. Cet intervalle n'est pas inattendu puisqu'une lacune stratigraphique de cet âge a été identifiée à de nombreux endroits dans la Cordillère canadienne. Toutefois, il n'a pas encore été établi de façon certaine que l'intervalle entre le Callovien inférieur et le Kimméridgien et Tithonique soit réellement une discordance. La zone d'affleurements où l'on pourrait s'attendre à trouver les roches intermédiaires du Callovien suprérieur, de l'Oxfordien et du Kimméridgien inférieur est recouverte d'une épaisse couche de roches volcaniques d'âge tertiaire. Ces roches du Jurassique supérieur seront peut-être un jour découvertes enfouies dans la partie nord et nord-ouest de l'île Graham.

Les îles de la Reine-Charlotte gisent sur la marge ouest du terrain allochtone de Wrangellia et les unités lithologiques qui s'y trouvent peuvent être rattachées à celles de ce terrain dans l'île de

that terrane on Vancouver Island and on the mainland of southwest British Columbia. Throughout this region, rocks can be found that are correlative with each of the Jurassic stratigraphic units presently known in the Queen Charlotte Islands. Time equivalent rock units are known throughout British Columbia including rocks of the Stikinia and Quesnellia tectonic terranes. The latter represent very different rock types however, and while a time equivalency can be demonstrated, the genetic relationship between these rocks on different terranes is highly speculative. Independent of the other tectonic terranes, paleomagnetic and faunal evidence suggest a northward translation of the Wrangellian block in the order of 2500 km since they were deposited. Both macrofaunas and microfaunas support a strong Tethyan influence of low-latitude origin. Evidence of this low-latitude origin is further supported by the discovery of the authigenic mineral chamosite in beds of the Fannin Formation (Late Pliensbachian). World-wide occurrences of this mineral in the Jurassic are presently known from the latitude of the present day mediterranean, approximately 30° north. If this distributional pattern is accurate, a northward translation of Wrangellia since Jurassic time of at least 1500 km is suggested. A warm humid climate with abundant rainfall is further indicated in Bajocian time by the development of coal deposits, abundant plant material and microflora.

During the course of these detailed stratigraphic studies, careful attention was paid to the occurrences of bitumen, dead oil, fetid lithologies, and possible porous intervals within the Jurassic rocks. Bitumen and/or dead oil was noted throughout the lower and middle Jurassic and in subsequent geochemical testing has proven to be derived from normal petroleum type hydrocarbons. Further evidence suggests that these hydrocarbons have, at least in part, been flushed and migrated. This migration may have been into the more porous Cretaceous Haida Formation. A possible caprock overlying these porous rocks is the thick, mainly Miocene, Massett volcanics. Present evidence suggests that the Jurassic and Cretaceous rocks underlie the Masset Formation offshore in Hecate Strait and Queen Charlotte Sound areas to the east of the Queen Charlotte Islands. If this is the case, significant hydrocarbon reserves may be encountered in subsurface within the Jurassic or Cretaceous rocks or, where the Masset is breached, as escape oil into Tertiary sandstone units.

Two other resources in the Jurassic rocks of the Queen Charlotte Islands have received attention during the past few years, namely oil-shale and coal. Our assessments and that of various colleagues, indicate that these resources are too little developed to be considered economic at this time.

Vancouver et sur la partie continentale du sud-ouest de la Colombie-Britannique. On peut trouver partout dans cette région des roches susceptibles d'être mises en corrélation avec chacune des unités stratigraphiques d'âge jurassique présentement connues dans les îles de la Reine-Charlotte. Des unités lithologiques d'âge équivalent, y compris les roches des terrains tectoniques de Stikinia et de Quesnellia, sont connues partout en Colombie-Britannique. Toutefois, les roches de ces terrains tectoniques sont de nature très différente et bien que leur chronologie soit équivalente, l'existence d'un lien génétique entre ces roches dans différents terrains reste à établir. Des indices paléomagnétiques et fauniques indépendants des autres terrains tectoniques semblent indiquer qu'un mouvement de translation aurait déplacé le bloc wrangellien environ 2 500 km vers le nord depuis la mise en place des roches. Les macrofaunes et les microfaunes indiquent que la mer Téthys a joué un rôle important dans les latitudes inférieures. La découverte d'un minéral authigène, la chamosite, dans les couches de la formation de Fannin (Pliensbachien supérieur) vient d'ailleurs appuyer cette hypothèse. Ce minéral a été trouvé dans les roches jurassiques partout dans le monde à partir de la latitude de la Méditerranée actuelle à environ 30° Nord. Si ce modèle de répartition est exact, le bloc wrangellien se serait déplacé d'au moins 1 500 km vers le nord depuis le Jurassique. L'accumulation de gisements de charbon, de grandes quantités de végétaux et de microflores porte à croire que le climat bajocien se caractérisait par un haut degré de chaleur et d'humidité et de pluies abondantes.

Au cours de ces études stratigraphiques détaillées, les auteurs ont porté une attention toute particulière aux venus de bitume et d'huile morte, aux lithologies fétides et aux intervalles possiblement poreux dans les roches jurassiques. Ils ont trouvé du bitume, de l'huile morte, ou les deux, partout dans les roches du Jurassique inférieur et moyen; des essais géochimiques ultérieurs ont montré que cette huile morte était dérivée d'hydrocarbures normaux de pétrole. D'autres indices révèlent que ces hydrocarbures ont été au moins partiellement lavés et qu'ils ont migrés, peut-être dans les roches plus poreuses de la formation crétacé d'Haida. Les roches volcaniques épaisses de Massett, qui datent surtout du Miocène, pourraient recouvrir ces roches poreuses. D'autres indices semblent indiquer que les roches jurassiques et crétacées reposent sous la formation de Massett, au large de la côte, dans le détroit d'Hécate et dans le détroit de la Reine-Charlotte, à l'est des îles de la Reine-Charlotte. Si tel est le cas, on pourrait trouver d'importantes réserves d'hydrocarbures dans ces roches jurassiques ou crétacées enfouies ou encore, là où la formation de Massett a été perçée, sous forme de pétrole d'échappement dans les unités de grès du Tertiaire.

Deux autres ressources trouvées dans les roches jurassiques des îles de la Reine-Charlotte ont fait l'objet d'études au cours des quelques dernières années: le schiste bitumineux et le charbon. D'après les évaluations des auteurs et celles de divers collègues, l'état de développement de ces ressources est encore trop peu avancé pour qu'elles puissent être considérées rentables.

INTRODUCTION

The Queen Charlotte Islands, on the west coast of Canada (Fig. 1), have been of considerable interest to naturalists for many years. From the earliest geological studies in 1872 to the present work, the stratigraphy and paleontology of the Mesozoic rocks, particularly the Jurassic, have presented problems and contradictions that have not been fully resolved by the many workers who have faced the bewildering array of evidence. Many problems apparently arose from imprecision in collecting and, in some cases, unfamiliarity with the significance of some of the faunas. This report is another step toward a fuller understanding of the Jurassic strata of these beautiful islands.

In 1974, at the urging of the late Hans Frebold, Tipper briefly visited Maude Island in Skidegate Inlet to study the Jurassic strata and collect fossils. In 1975 and 1976 he returned to continue collecting from the Lower Jurassic sections on Maude Island, on Moresby Island and in central Graham Island. Selected samples submitted to Cameron for the extraction of microfossils provided intriguing, well-preserved, abundant, varied, and essentially unknown faunas, and he joined the study in 1978. From 1978 to 1984, work was expanded in all areas previously studied, and brief visits were made to the west coast of Graham Island. Many new mappable stratigraphic units were revealed and a more refined stratigraphic nomenclature became necessary.

Observations on potential hydrocarbon source beds and reservoir beds, beyond those previously published (Cameron and Tipper, 1981), have also been made. In this report conclusions on the lithostratigraphy with brief references to the foraminiferal and ammonite biostratigraphy are presented. Studies of the ammonite biostratigraphy by Tipper and P.L. Smith (University of British Columbia), bivalve and other molluscan biostratigraphy by T.P. Poulton (ISPG, Calgary), foraminiferal biostratigraphy by Cameron and radiolarian biostratigraphy by E. Carter (consultant, Vernonia, Oregon) are currently underway. Samples submitted to W.A.S. Sargeant (University of Saskatchewan) for palynological studies proved to be barren of dinoflagellates whereas other spores were poorly represented and apparently not very distinctive (Sargeant, personal communication, 1983). This result is rather surprising insofar as megaspores are very common in several localities; better collections may prove more fruitful.

Acknowledgments

The writers received many courtesies and helpful advice during the course of fieldwork and the preparation of this report. Assistance in the field was ably provided by D.A. Seemann, S.E. Cameron, A. Vichert, E. Carter, and numerous other students. Mr. and Mrs. Nick Gessler of the Queen Charlotte Museum, Skidegate, B.C., were most helpful in providing advice on accessibility and collecting localities. We express our appreciation to the logging companies, in particular McMillan-Bloedel Ltd. and Crown Forest Ltd. in granting us access to their logging roads and quarries.

Intercoast Resources Ltd. permitted us to examine the cores of three drillholes from central Graham Island for which we are grateful. The detailed analyses of chamosite ooliths by John Wilson and Don MacDonald of the Alberta Geological Survey is greatly appreciated.

P.L. Smith, University of British Columbia, offered much advice in the study of the ammonoid faunas and critically reviewed the manuscript. J.A. Roddick, Geological Survey of Canada, Vancouver also reviewed and edited the final manuscript. The constructive criticism of both colleagues is greatly appreciated.

Previous work

Earlier workers on the Queen Charlotte Islands summarized previous stratigraphic interpretations so that there are many records. The most succinct and informative is that of F.H. McLearn (1949), from which, part of the following account is derived.

Richardson – 1872

James Richardson (1873, pp. 56-63) examined the "coal-bearing rocks of the Queen Charlotte Islands" and made a general three-fold division of these strata. The lowest division, "the lower shales with Coal and Iron Ore" (part of subdivision C of Dawson, see below) was examined and

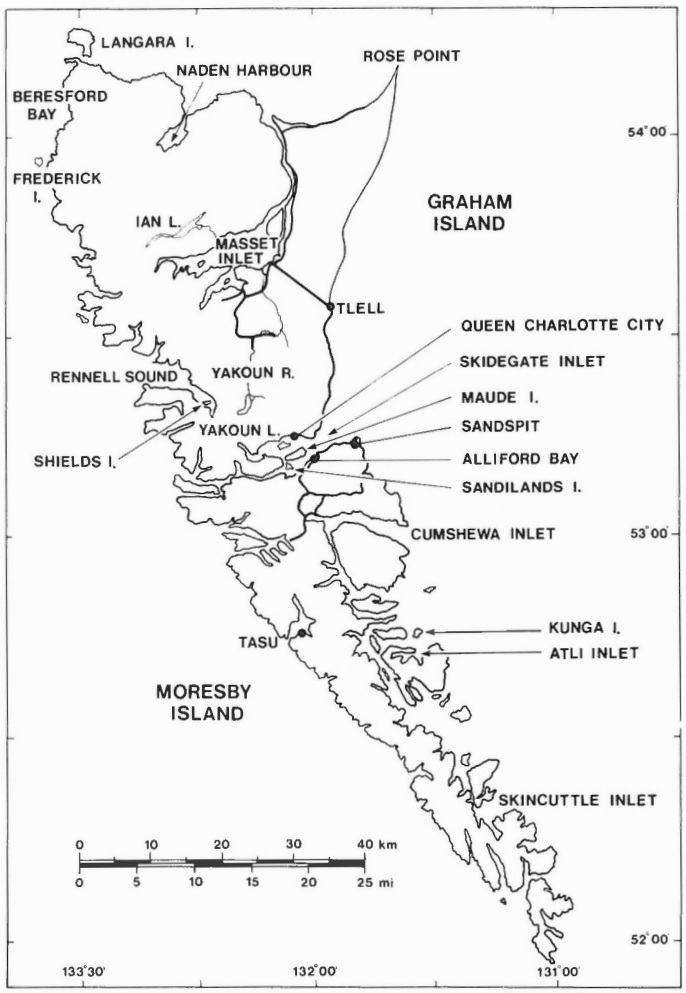

Figure 1. Locality map, Queen Charlotte Islands

found to contain organic remains that were most abundant near its base on Maude Island and other nearby islands.

Billings – 1872

The fossils collected by Richardson from Skidegate Inlet, were first examined by E. Billings (1873; p. 71-75) who identified several ammonites, one nautilus, belemnites, gastropods, and pelecypods. Regarding the age of the faunas he concluded that some were Jurassic and some were Cretaceous.

Dawson – 1878, 1889

G.M. Dawson (1880) examined the Mesozoic rocks of the Queen Charlotte Islands and discussed them generally as two informal groups; 1) the Triassic rocks which might also extend downward into the Carboniferous and 2) the Cretaceous coal-bearing rocks. The Triassic rocks were mainly volcanics, limestone, and argillite; included here were rocks on Maude and Moresby islands that are now known to be Lower Jurassic.

The Cretaceous coal-bearing rocks were subdivided into five units by adding two more to Richardson's three subdivisions.

A. Upper Shales and Sandstones
B. Coarse Conglomerates
C. Lower Shales with Coal and Iron Ore
D. Agglomerates
E. Lower Sandstones

Dawson believed these five units to be a single conformable sequence laid down on the northeastern flank of the Triassic rocks. The relation of the two groups, the Triassic and Cretaceous rocks, was described as an "unconformity, but without evidence of great disturbance".

Although Richardson suggested that his three units (A, B and C) were deposited in a northwesterly trending trough on a volcanic basement (= D) supposedly unconformably, Dawson dismissed this relationship as an "important intercalation of contemporaneous volcanic matter" with shales above (= C) and "ordinary sediments" below (= E). Some fossils of subdivision E were thought to be specifically identical with some in subdivision C thus lending credence to the inclusion of all five units in a conformable sequence. Dawson's fossils were examined by Whiteaves who saw no Jurassic elements in the collections and concluded that they were all Cretaceous. As will be explained, units E, D, and part of C are Jurassic.

1889 – Dawson retained Whiteaves' group name, Queen Charlotte Island Group, (see below) but limited it to the lower three subdivisions (C, D and E) and established it as the Queen Charlotte Formation.

Whiteaves – 1876, 1883, 1884, 1900

1876 – J.F. Whiteaves (1876) examined Richardson's faunas and concluded that although there were some fossils with Jurassic similarities, there were none that were exclusively and specifically identifiable as Jurassic. On the other hand there were identifiable Cretaceous forms present. He preferred to place Richardson's fauna near the base of the Cretaceous, but noted their Jurassic affinities.

1883 – Whiteaves (1883, p. 81) referred to the fauna of Dawson's subdivisions B, C, D, and E as being of "Middle Cretaceous" age. Whiteaves, (1883, p. 85) referred to the "Middle Cretaceous" strata as the Queen Charlotte Island Group, thus introducing a name for rocks now known to be both Cretaceous and Jurassic.

1884 – Whiteaves (1884) presented no additional arguments for the age of subdivision C and still contended that the definite identification of some Cretaceous ammonites argues for a "Middle Cretaceous" age. Subdivision D provided no index fossils. Whereas nearly half of the species collected from subdivision E were also present in subdivision C, Whiteaves held to a "Middle Cretaceous" age for subdivision C, despite admitting that two species from C taken by themselves would almost certainly be placed in the Jurassic. Five species from E (including one ammonite) were new and undescribed. In spite of the strong Jurassic elements and new species, Whiteaves did not waver in his conviction of a Cretaceous age, nor was there any evidence to indicate to him that he was dealing with Cretaceous and Jurassic collections.

1900 – Whiteaves (1900) was still convinced of the Cretaceous age, so much so that he changed several identifications that would conflict, to names of somewhat similar unquestionably Cretaceous forms.

Ells – 1906

R.W. Ells (1906) explored Graham Island and paid particular attention to the coal-bearing rocks. However he added no new evidence to our knowledge of the stratigraphy but accepted the interpretation of Dawson and Whiteaves. He did, however, correctly refer to Dawson's agglomerates (subdivision D) as pre-Cretaceous without giving any reason.

Stanton and Martin – 1905

In discussing the Mesozoic rocks of Cook Inlet in Alaska, Stanton and Martin (1905) compared some of their faunas to those of Queen Charlotte Islands, supposedly from the Cretaceous. These they clearly indicated to be Jurassic.

Dowling – 1906

Dowling (1906) compared some fossils from the Fernie shales with those of the Queen Charlotte Islands and in citing the work of Stanton and Martin (1906) accepted the Jurassic age proposed.

Clapp – 1912

In 1912 C.H. Clapp (1914) applied group names to the Mesozoic beds. The name, Vancouver Group, was applied to Jurassic and Triassic rocks, both volcanic and sedimentary, adopted from usage on Vancouver Island. The usage is close to that as used at present and included subdivisions E, D, and part of C of Dawson as well as the Triassic volcanics, limestone and shale that underlie those subdivisions.

The confusion of ages and rock units arose from the lithological similarity of the Cretaceous (Haida) sandstone (part of C) and the Middle Jurassic sandstone (part of C). Although Richardson apparently saw the unconformity between Cretaceous and Jurassic rocks and Billings recognized both Jurassic and Cretaceous species in the fossils collected by Richardson, Dawson dismissed Richardson's unconformity and considered the two sandstone units to be the same, i.e. subdivision C. Naturally when Whiteaves examined the fossils and was only able to provide positive identifications of a few species and these were all Cretaceous, it was not unreasonable to consider the whole to be Cretaceous in spite of strong similarities of some forms to Jurassic species. Clapp followed the nomenclature of Whiteaves except that he shortened the name to "Queen Charlotte series" with three members, the Haida, Honna, and Skidegate, in ascending order. MacKenzie changed the member status to formations (see below) but except for this, Clapp's usage has persisted for the Cretaceous Queen Charlotte Group.

MacKenzie – 1913, 1914

The Jurassic rocks of Queen Charlotte Islands were included by MacKenzie (1916, p. 40) in the Vancouver Group and subdivided into the Maude and the Yakoun formations. The former was described as argillites, sandstones, and tuffs, and the latter as basaltic agglomerates. A Middle Jurassic age was indicated for the Yakoun Formation and a probable Early Jurassic age for the Maude Formation. Known Triassic argillites were also suggested as part of the Maude Formation. The Jurassic was established as clearly unconformable below the Cretaceous Queen Charlotte Series (Group).

McLearn – 1921

Detailed stratigraphic and paleontological studies were undertaken around Skidegate Inlet by F.H. McLearn in 1921 and several publications on the paleontology and stratigraphy of both the Jurassic and Cretaceous formations resulted (1927, 1929, 1932, 1949, 1972). In Geological Survey of Canada Bulletin 12 (1949, p. 2-5) he gave a lucid explanation of the problems of the Jurassic-Cretaceous nomenclature and the paleontological difficulties that arose. His work was the first real attempt to describe stratigraphic sections, to systematically describe carefully collected faunas, and to describe new species and new genera. He recognized in the Maude Formation two faunas – one characterized by **Fanninoceras** and one characterized by **Harpoceras** and **Dactylioceras**, both of which he placed in the Toarcian. He recognized the possibility of pre-Toarcian strata in the Maude Formation, particularly Triassic. His map of Maude Island (McLearn, 1949) and his collections retained by the Geological Survey clearly indicate he collected from beds on Maude Island stratigraphically below the **Fanninoceras** fauna, but he never published on the subject.

Sutherland Brown – 1958 to 1965

The most recent understanding of the Jurassic stratigraphy of Queen Charlotte Islands was enunciated clearly by A. Sutherland Brown of the British Columbia Department of Energy, Mines and Petroleum Resources in Bulletin 54 (1968). He defined the Vancouver Group as comprising four formations: 1) the Karmutsen Formation, an extension of the formation from Vancouver Island and composed of basic pillow lavas, fragmentals and minor sediments of Triassic age, 2) the Kunga Formation comprising Upper Triassic to Lower Jurassic (Sinemurian) argillites and limestones, 3) the Maude Formation comprising Lower Jurassic argillite, shale, limestone, and sandstone, and 4) the Yakoun Formation made up of Middle Jurassic tuff, agglomerate, volcanic sandstone, shale, sandstone, and conglomerate. This study provided much detailed information in a systematic manner through measured sections with numerous large collections of well-preserved fossils.

Preliminary accounts of the stratigraphy and faunas of the Jurassic strata have been published by the writers as the present work progressed (Tipper, 1975, 1976, 1977; Tipper and Cameron 1979, 1980; Cameron and Tipper 1981; Sutherland Brown, Yorath and Tipper, 1983). These reports were prepared in the context of Sutherland Brown's stratigraphic concept and no revision was attempted. As will be described, stratigraphic names have since been revised and preliminary generic identifications changed or refined. Our previous accounts do not necessarily reflect our present conclusions. Our present study has expanded on Sutherland

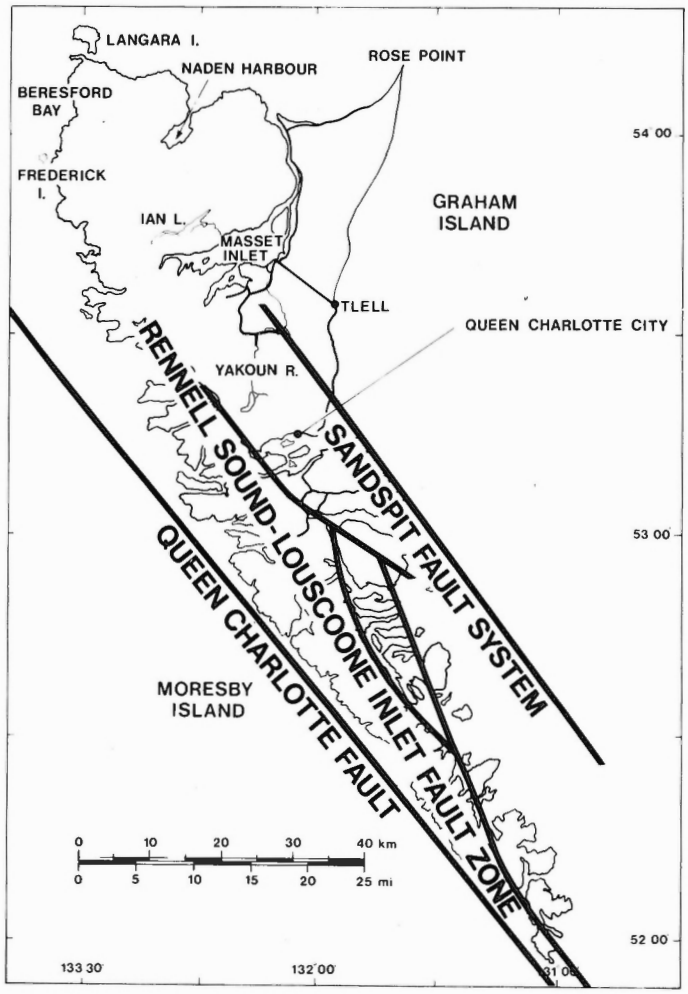

Figure 2. Structural setting of the Queen Charlotte Islands (modified after Yorath and Hyndman, 1983)

Brown's excellent work, by elevating old formational names to group status, introducing new formational names, subdividing formations into informal members, and adding new informal members previously not defined.

TECTONIC SETTING OF QUEEN CHARLOTTE ISLANDS

The Queen Charlotte Islands are on the western edge of the Wrangellia allochthonous terrane, and the lithological units there can be related to those within that terrane on Vancouver Island and on mainland British Columbia possibly as far east as Fraser River near Lillooet. Throughout this region rocks can be found that are correlative with each of the Jurassic stratigraphic units presently known in the Queen Charlotte Islands. The western margin of Wrangellia is defined as the Queen Charlotte Fault, which lies along the west side of the Queen Charlotte Islands (Fig. 2). The eastern margin is open to debate and several interpretations are extant (Yorath and Chase, 1981; Coney et al., 1980; Tipper, 1984). There is general agreement that the Queen Charlotte Islands, Vancouver Island, and the western half of the southern Coast Mountains have evolved together and accumulated in the same basin or associated basins.

A Sinemurian volcanic arc is considered, in this report, to have lain offshore from the craton and trended northwesterly through Vancouver Island. A shale basin lay to the northeast and tuffaceous air-fall material was deposited with each recurring volcanic eruption producing a shale-tuff, thinly bedded sequence (Kunga Group). This was followed, with decreasing volcanism, by the Lower Pliensbachian shale-siltstone sequence (Maude Group) including a coarser Upper Pliensbachian sequence. The Toarcian strata (Maude Group) comprise first a shale sequence (Whiteaves Formation) followed abruptly by a coarse sand unit (Phantom Creek Formation), a possible forerunner of renewed volcanism in the Bajocian stage. The products of this Middle Jurassic volcanism clearly lie somewhat northeast of the earlier Sinemurian volcanism and may be an extension of some volcanic units on the mainland, such as the Harrison Lake Formation.

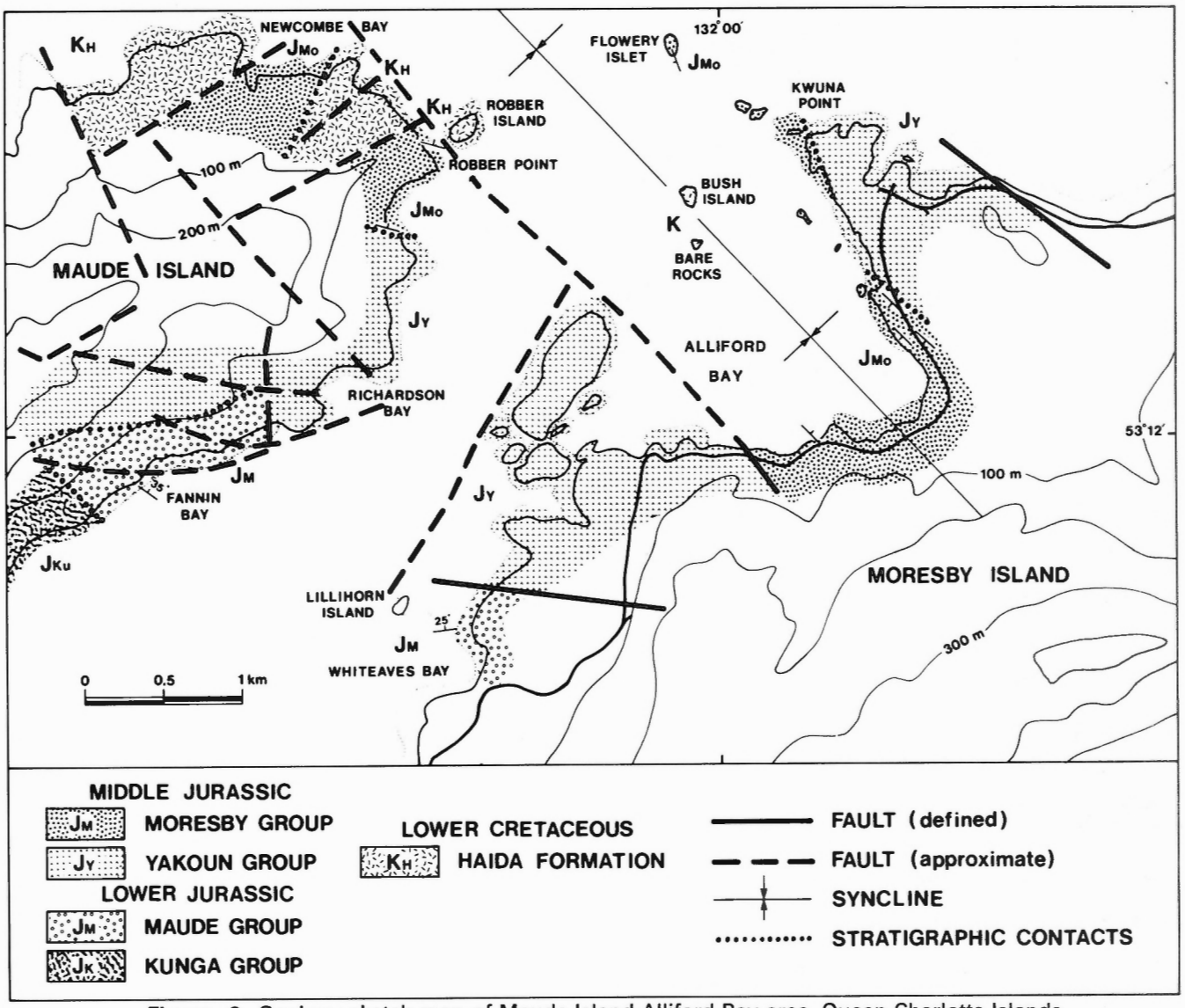

Figure 3. Geology sketch map of Maude Island-Alliford Bay area, Queen Charlotte Islands

The cessation of volcanism was followed by a sedimentary episode (Moresby Group) in Bathonian and Callovian time, which coincided more or less with the start of sedimentation in the successor basins of the mainland, namely, the Bowser Basin, Nechako Basin, and the Tyaughton Trough.

Both the general depositional history and the deformational pattern are compatible with a fracture system developed along the three major northwesterly oriented faults, Queen Charlotte, Rennell Sound-Louscoone Inlet, and Sandspit faults. The structural interpretation of the Queen Charlotte Islands was discussed fully by Sutherland Brown (1968, p. 147-163) and has been little altered by the present study. His interpretation emphasized faulting and related most of the folds to faults as secondary features. The present study supports the interpretation and shows that the fracturing was even more intense than depicted by Sutherland Brown, as

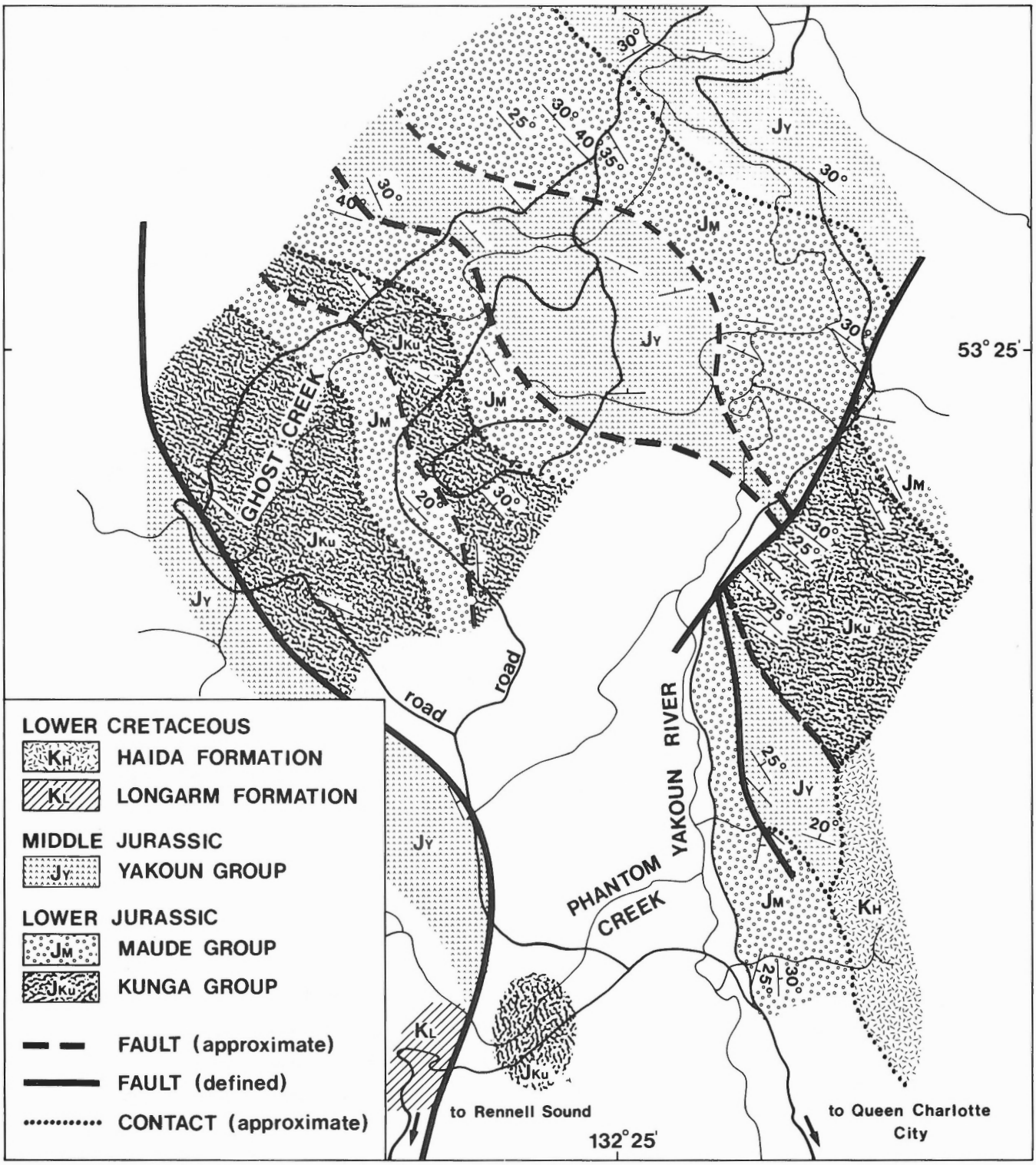

Figure 4. Geology, central Graham Island area

testified by the myriad of closely spaced faults which complicate the record (Fig. 3, 4).

STRATIGRAPHY

General statement

The Jurassic succession as presently understood represents a synthesis of many fault-bounded exposures of rocks, principally in Skidegate Inlet (Fig. 3) and central Graham Island (Fig. 4). As no one area satisfactorily exposes major portions of the complete succession, it has been necessary to compile detailed stratigraphic sequences wherever possible and rely heavily on the contained faunas for local correlation. The stratigraphic succession herein presented is the result of eighteen detailed measured sections (in pocket) from these areas (Fig. 5, 6, in pocket) and extensive study of many isolated road, quarry, and creek exposures scattered throughout the area. As a result of these studies we herein propose that four groups, eleven formations, and ten informal members (Table 1) are necessary to adequately describe and understand these rocks.

Kunga Group

The Kunga "Formation" was named by Sutherland Brown and Jeffery (1960, p.2) for an essentially sedimentary sequence of limestone and argillite of Carnian to Sinemurian age (early Late Triassic to mid-Early Jurassic). It was recognized as a distinctive unit by Dawson (1880) but not named. Sutherland Brown subdivided it into three members, in descending order: black argillite, black limestone, and grey limestone.

The highest member is Sinemurian (Early Jurassic) and the other two are Late Triassic. The Triassic members have not been examined by the writers and the reader is referred to Sutherland Brown's bulletin (1968) for details.

The term, Vancouver Group, although applicable to Vancouver Island cannot be applied to the Queen Charlotte Islands because of very dissimilar lithologies. In our proposed new nomenclature, the term, Vancouver Group is abandoned. Because of the distinctive lithologies and lateral persistence of Sutherland Brown's members of the Kunga Formation, it is raised to group status and Sutherland Brown's members are now considered to be formations. It is also proposed that the black argillite member of Sutherland Brown become the Sandilands Formation after a typical exposure on the southeast shore of Sandilands Island. This is designated the type area. The other two "members" must also become formations but a geographic name is not adopted for them, awaiting further study of the Triassic strata.

Sandilands Formation
Stratigraphic sections 1,2,3

This formation has been found throughout Queen Charlotte Islands, commonly in small fault blocks or in fairly widespread, generally recessive outcrops, commonly obscured by forest cover. Shoreline and artificial outcrops in roadcuts and quarries provide the best exposures. Only outcrops around Skidegate Inlet, in central Graham Island and on the west coast of Graham Island were examined. Much of the information presented here is derived from Sutherland Brown's bulletin (1968), from three diamond drill cores in the formation (courtesy of Intercoast Resources), and from our studies of several exposures.

The thickness of the formation appears to be variable but faulting may be responsible for making this more apparent than real. At the section on Kunga Island, Sutherland Brown reported a thickness of 497 m and at another section on Burnaby Island a part section of 108 m. The three cores examined by the writers (Sections 1,2,3 in pocket) indicate thicknesses for the Sandilands Formation of 90, 230 and 157 m. The sections, however, are apparently highly faulted and probably do not reflect accurate thicknesses. The few macrofossils obtained from the cores suggest that the rocks penetrated are Late Sinemurian and surface exposures of the lowest beds in this formation, both at the type section and other sections examined by the writers, are Early Sinemurian. The thickness of the formation at Sutherland Brown's section on Kunga Island (497 m) probably is closer to the true thickness but even that is not complete (Sutherland Brown 1968, p. 57-59).

Lithology

The dominant rock type is a thinly bedded, hard, dense, black to dark grey siliceous siltstone or argillite in beds 2.5 to 10 cm thick. It is interbedded with minor beds of grey siliceous tuff, lithic sandstone derived mainly from tuffs, green to grey-green shale (possibly tuffaceous), fine volcanic breccia with clasts to 2.5 cm in diameter and thin laminations of black shale or siltstone. Buff-weathering radiolarian-rich sandy limestones up to 10 cm thick are a minor component of the formation. Individual beds may show fine laminations within the beds, the sandier beds are commonly graded, rare fine crossbedding is seen in the sands as well. Generally the rock displays a prominent thin banded appearance with alternations of black and white or grey bands (Fig. 7). In general aspect the outcrops present a dark grey appearance but a few are distinctly greenish, commonly low in the section where there may be a greater amount of volcanic detritus in the clastic sediments. In general the rock is fissile along bedding planes and commonly the macrofossils are present as flattened impressions on bedding surfaces. A prominent jointing at right angles to bedding commonly within a single bed, gives the outcrop a rubbly angular appearance. The oldest known beds are a moderately soft shale, not unlike shales of the underlying black limestone formation (member). The youngest beds of the formation show a decrease in tuff and a transition to the shales and siltstones of the overlying Maude Group. The rocks are commonly fetid and may show oil-staining (Fig. 8).

Internal structural relations

The Sandilands Formation is a conformable, more or less continuous sequence deposited in a single broad basin under similar conditions throughout its history. The beds are thin but maintain their thickness over considerable distance. Lenses and lenticular beds are uncommon. Sedimentary

Table 1. Jurassic formations, Queen Charlotte Islands. Members are informal.

STAGE	GROUP	FORMATION	MEMBER	LITHOLOGY	THICKNESS	TYPE STRAT. SECTION	
probable unconformity							
KIMMERIDGIAN to TITHONIAN				Sandstone, grit, fine conglomerate, woody fragments	unknown		
unconformity							
L. CALLOVIAN to U. BATHONIAN	MORESBY	ALLIFORD		Siltstone, shale, minor sandstone	60 m	S.S. 16	
		NEWCOMBE		Sandstone, minor pebble congl.	30 – 45 m	S.S. 18	
		ROBBER POINT		Shale, siltstone, pebble congl.	15 – 90 m	S.S. 17	
erosional interval, possible slight angular discordance							
LOWER BAJOCIAN	YAKOUN	RICHARDSON BAY	VOLCANIC BRECCIA	Volcanic breccia	60 – 530 m	MAUDE ISLAND TYPE AREA (Figure 5)	
			DARK SANDSTONE	Sandstone	30 – 110 m		
		GRAHAM ISLAND	LAPILLI	Lapilli tuff, agglomerate	200 m	S.S. 14	MAUDE ISLAND
			VOLCANIC SANDSTONE	Sandstone, conglomerate, minor shale	140 – 170 m		S.S. 14
			MOTTLED SILTSTONE	Siltstone	30 m		S.S. 5
			SHALE-TUFF	Shale, tuff	75 – 85 m		S.S. 14
hiatus, paraconformity							
AALENIAN to U. TOARCIAN	MAUDE	PHANTOM CREEK	BELEMNITE SANDSTONE	Belemnite sandstone	3 – 5 m	S.S. 12	S.S. 12
			possible paraconformity				
U. TOARCIAN to M. TOARCIAN			COQUINOID SANDSTONE	Coquinoid sandstone, minor shale	5 – 25 m		S.S. 12
MIDDLE TOARCIAN		WHITEAVES	CONCRETIONARY SHALE	Shale, minor sandstone, limestone nodules	3 – 30 m	S.S. 15	S.S. 15
			SEPTARIAN SHALE	Shale, septarian nodules	15 – 55 m		S.S. 15
		hiatus, paraconformity					
L. TOARCIAN & U. PLIENSBACHIAN		FANNIN		Tuffaceous sandstone, minor limestone, siltstone, tuff	26 – 64 m	S.S. 4	
		minor hiatus, paraconformity					
LOWER PLIENSBACHIAN		RENNELL JUNCTION		Shale, siltstone, limestone, minor sandstone	25 – 50 m	S.S. 10	
		GHOST CREEK		Shale, siltstone, minor flaggy limestone	45 – 68 m	S.S. 10	
conformable contact							
UPPER & LOWER SINEMURIAN	KUNGA (in part)	SANDILANDS		Shale, tuff, sandstone, limestone, siltstone	500 + m	SANDILANDS ISLAND TYPE AREA	
contact not seen							

Figure 7. Well bedded colour-banded Sandilands Formation. Typical exposure on Maude Island, Skidegate Inlet. (GSC 190985)

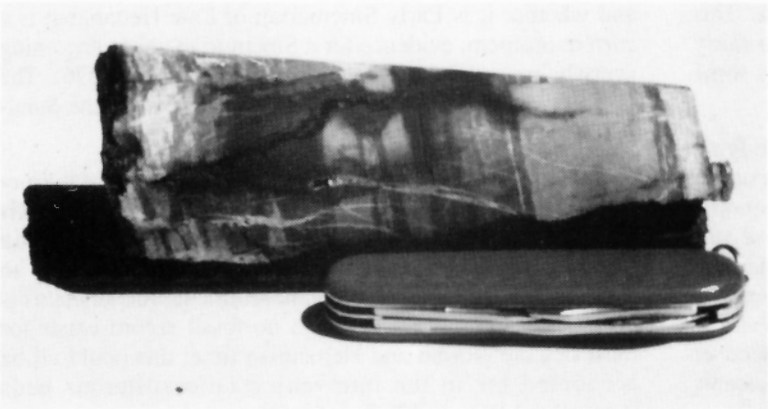

Figure 8. Oil stain along fractures in Sandilands Formation. Intercoast Resources diamond drill hole I-278. Stratigraphic section 1. (GSC 190986)

structures such as crossbedding, ripple marks, or bottom features are also uncommon and where seen are vague and ill-defined. The formation is monotonously similar throughout and if a section were repeated, it would be impossible to recognize without fossil control.

External structural relations

According to Sutherland Brown, this formation rests wherever visible on his black limestone "member" (Sutherland Brown, 1968, p. 56). The writers have not observed the basal contact but outcrops closely adjacent suggest this is a reasonable interpretation. The formation is conformable with the overlying Maude Group into which it grades abruptly. The upper beds of the formation become more shaly and less tuffaceous, limy or sandy. Thicker, massive shale beds mark the beginning of the Ghost Creek Formation of the Maude Group, in contrast to the laminated character of the Sandilands Formation.

Origin and Depositional Environment

The Sandilands Formation, like others of the Kunga Group, was deposited, according to Sutherland Brown (1968, p. 59), in a marine basin more or less remote from shore as indicated by the regular-bedded character and dominance of ammonites and thin-shelled bivalves. However, we disagree with Sutherland Brown in that we believe it was not a time of volcanic quiescence but rather the basin was remote from the centres of volcanism and received only fine volcanic detritus either as air-fall tuff or as fine detritus swept into the basin from a volcanic terrane. As such it would be considered a back-arc basin.

The thin regular bedding, dark and commonly pyritic nature of the sediments suggest a relatively deep water environment which might have been partly euxinic. Minor parts of the formation are graded and apparently were deposited by turbidite sedimentation. The deep water, partly euxinic interpretation is further attested to by the poorly developed benthic macrofossils and microfossils, and by laminations undisturbed by bioturbation of benthic forms.

In the area around Skidegate Inlet and northwestward, ammonites are by far the most abundant fossil. Bivalves are rare consisting of a few thin-shelled small forms, commonly pectinids. However Sutherland Brown collected bivalves on Moresby Island to the south of Skidegate Inlet fairly commonly, including a few large, coarse-shelled **Weyla.** This genus, particularly large specimens, are confined to fairly shallow water (Taylor, 1982). Scant evidence suggests some shallowing in a south or southwestward direction.

Thus for the Sandilands Formation a broad basin lying east of a volcanic terrane is proposed, close enough for ash to settle out but far enough away to be beyond the depositional site of coarse pyroclastic material. But where are these volcanic centres? They could have lain west of Queen Charlotte Islands and have been cut off and transported northwesterly along the Queen Charlotte Fault on the west side of the islands. (Alternatively the Bonanza Group on Vancouver Island may have been the source.) In any event, the volcanic source has not been identified.

Age and biostratigraphy

The Sandilands Formation has yielded a great variety of ammonites, locally in great abundance. The ornamentation is preserved but the tests are flattened on bedding planes, usually in shales or siltstones. The tuffs and sands are less commonly fossiliferous. No complete section has been found from which a good biostratigraphic sequence can be determined but many short sections provide some relations from which a tentative sequence can be assembled. The following faunas in descending biostratigraphic sequence have been noted:

(1) **Entolium balteatum** Crickmay
(2) **Paltechioceras** (= **Melanhippites**) sp.
(3) oxynoticeratids and ? **Paltechioceras** sp.
(4) **Asteroceras** sp.
(5) **Arnioceras** sp.
(6) **Arnioceras** (= **Arniotites**) sp.
(7) **Badouxia** sp.

The ammonite fauna from the Sandilands Formation was examined by Hans Frebold, Geological Survey of Canada and preliminary identifications were attempted. No detailed study of the biostratigraphic sequence has been undertaken but a strong similarity to the Northwest European succession is known, particularly at the generic level. The faunas listed suggest that all or most of Sinemurian time is represented in the formation, as the uniform, uninterrupted sedimentary cycle might suggest.

The highest fauna found at several localities is the pelecypod **Entolium balteatum** Crickmay, first described from Harbledown Island (Crickmay, 1928; Tipper, 1977); it is also known from several localities throughout British Columbia. It is always found in beds above the highest occurrence of **Paltechioceras** or associated with that genus. It has not been found lower in the sequence. A few oxynoticeratid ammonites have been found below **Paltechioceras** or with it. **Asteroceras** has been found in isolated localities but its relationship to other faunas was not determined. Tentatively these genera are assumed to be Late Sinemurian.

The most common genus from the lower part of the formation is **Arnioceras** and probably several species are represented, possibly most of Early Sinemurian time is accounted for. The **Badouxia** fauna is the lowest fauna noted and whether it is Early Sinemurian or Late Hettangian is a current problem; evidence for a Sinemurian age is becoming overwhelming (Frebold, 1967; Guex and Taylor, 1976). The fauna is known at one locality only and is part of the Sandilands Formation.

The highest fauna found in the underlying black limestone formation is the Upper Triassic pelecypod **Monotis subcircularis** Gabb. Between this and the higher **Badouxia** fauna the beds are unfossiliferous. Without evidence for an unconformity or an interruption in sedimentation an hiatus is difficult to suggest even though no fossil record exists for most of Late Norian and Hettangian time; this could all be accounted for in the intervening unfossiliferous beds (Sutherland Brown, 1968, p. 60-61).

Table 2 Sinemurian Rocks of the Canadian Cordillera that are correlated in whole or in part with the Sandilands Formation of the Kunga Group

GROUP OR FORMATION	AGE	LOCATION	LITHOLOGY
Bonanza Gp. (in part)	Early and Late Sinemurian	Vancouver Island 92F	Red, green, grey mainly pyroclastic rock with interbedded tuff, shale, siltstone
Harbledown Formation	Early and Late Sineurian	Harbledown Island 92L	Finely interbedded shale, tuff, siltstone, sandstone; minor limestone
Cultus Group (in part)	Early Sinemurian	Hope 92H	Shale, siltstone
Ladner Group (in part)	Early Sinemurian	Hope-Princeton 92H	Shale, siltstone, breccia
Nicola Group (in part)	Early Sinemurian	Bonaparte Lake 92P	Pyroxene-bearing basaltic breccia, tuff, and siltstone
Archibald Formation	Early and Late Sinemurian	Rossland 92F	Interbedded tuff, siltstone, shale, fine breccia
Elise Formation	Early and Late Sinemurian	Rossland 92F	Pyrozene-bearing basaltic breccia, tuff and siltstone
Quesnel River Group (in part)	Early and Late Sinemurian	Quesnel Lake 93A	Pyroclastic volcanic rocks, conglomerate, breccia, tuff
Takla Group (in part)	Sinemurian	Fort St. James and Aiken Lake 93K, 93N, 94C	Pyroxene-bearing pyroclastic rocks
Telkwa Formation	Early and late Sinemurian	Smither 93L Hazelton 93M McConnell Cr. 94D	Red, green, grey mauve andesitic to rhyolitic breccias, tuff, and minor sediments
unnamed (in part)	Early Sinemurian	Telegraph Creek 104G Iskut River 104B	Volcanic tuff and sediments
Inklin (in part)	Early and Late Sinemurian	Atlin 104N Tulsequah 104K Dease Lake (?) 104J Cry Lake 104I	Shale, siltstone, conglomerate
Laberge Gp. (in part)	Early Sinemurian	Whitehorse 105D Laberge 105E Carmacks 115I	Shale, siltstone, conglomerate
unnamed beds	Sinemurian	Dease Lake 104J	Volcanogenic sediments and pyroxene-bearing breccias
Tyaughton Gp. (in part)	Early and Late Sinemurian	Taseko Lakes 920 Mt. Waddington 92N	Shale, siltstone, minor conglomerate and greywacke
Nordegg Member and unnamed beds of Fernie Formation	Early Sinemurian	Rocky Mountains 82G, 82J, 82O, 83C, 83E	Limestone, shale

Foraminifers are poorly known from the Sandilands Formation due either to unfavourable bottom conditions (euxinic) which preclude their development, or to the difficulty of disintegrating the hard tuffaceous rock. A good foraminiferal collection, found on northern Moresby Island, was previously thought to be Late Triassic (Cameron and Tipper, 1981). This fauna consists predominantly of several species of **Lenticulina,** agglutinating foraminifers, **Frondicularia** sp. **F. brizaeformis** Bornemann, **Geinitzinita tenera** sbsp. and abundant radiolaria. This microfauna is now thought to be early Sinemurian, possibly equivalent to the **Badouxia** ammonite fauna.

Radiolaria are abundant in the Sandilands Formation and several species were described and illustrated by Pessagno and Blome (1980). They suggested that one of their samples contains "pre-Sinemurian", post-Norian radiolaria and was dated as Hettangian, possibly Rhaetian solely on the basis of its unique appearance. No objective evidence is presented, however, to suggest this radiolarian collection is not basal Sinemurian (**Badouxia** equivalent) as this ammonite has not yet been recorded from Kunga Island. Historically, many rocks for one reason or another, whether they carry distinctive faunas or not, have been placed in the Hettangian (Jeletzky, 1970; Sutherland Brown, 1968, p. 60).

It now appears that most reports of Hettangian age rock in the allochthonous terranes of British Columbia are erroneous or at best, highly suspect.

Regional Correlation of the Sandilands Formation

Sinemurian rocks are known throughout the Canadian Cordillera (Table 2). They vary in lithology from virtually every type of sedimentary rock through volcaniclastic sequences to coarse breccias, agglomerates and flows. Many of the volcaniclastic units are coeval with and lithologically equivalent to the Sandilands Formation. Their relations to the Sandilands Formation are largely speculative as they are parts of the three main tectonic terranes of the Cordillera, Wrangellia, Stikinia and Quesnellia. Except for the Fernie Formation on the craton, most are stratigraphic units produced in basins adjacent to, or on, volcanic island arcs, as is clearly the case with the Sandilands Formation.

Formations with a similar lithology are known throughout British Columbia and are correlative with the Sandilands Formation. In the Rossland Group of southeastern British Columbia (Little, 1982) the Elise Formation is almost entirely volcanic breccia, tuff, minor flows, and thin sedimentary interbeds and the Archibald Formation is almost identical to the Sandilands Formation in lithology, sedimentary character, and age. Fossils from both Rossland formations and from the Sandilands Formation indicate they are all correlative. The Telkwa Formation of the Hazelton Group in the Smithers area (Tipper and Richards, 1976) is almost entirely volcanic and some facies are indistinguishable from the Sandilands Formation; they are in whole, or in part, correlative.

The most significant correlation is with the Harbledown Formation east of Vancouver Island. There a sequence of interlayered and laminated black argillite, tuff, and thin limy beds (Crickmay, 1928) is indistinguishable in outcrop from the Sandilands Formation of the Kunga Group. The volcanoes that supplied the tuff lay to the west on Vancouver Island, and formed the Sinemurian Bonanza Group, which is the same age as the Harbledown Formation. We envisage wind-transported ash settling into the basin producing intermittent tuffaceous layers, but farther east, Sinemurian shale should be present without tuffaceous interbeds. This is what is found in the few scattered remnants of Sinemurian rocks in the Coast Mountains as far east as Yalakom fault on the east side. This back-arc basin and the volcanic arc comprise several formations all of which are, in whole or in part, correlative with the Sandilands Formation.

Maude Group

The Maude "Formation" was named by MacKenzie (1916) for predominantly sedimentary sequences in Skidegate Inlet exposed on the southeast side of Maude Island and on the shores of South Bay. As previously explained, it is herein raised to group status. The best exposure in Skidegate Inlet is on Maude Island and it is this section that has been considered the type Maude by previous workers. During this study many new exposures were examined in the Skidegate Inlet and Yakoun River (central Graham Island) areas. This resulted in a substantially expanded stratigraphic sequence, the discovery of many new macrofaunas and microfaunas and refinements to the age constraints for the Maude Group. Cameron and Tipper (1981) included in the Maude Group a newly discovered sequence of dark shale, tuff and sandstone in central Graham Island. Because they are tuffaceous, they are herein reassigned to the basal part of the Yakoun Group, (Graham Island Formation, shale-tuff member).

Due to hiatuses, structural breaks and discontinuous exposures, no one locality exposes the Maude Group in its entirety, but composite sections of the Maude Group have been constructed (Fig. 9, 10) which represent the successions to be expected in the Skidegate Inlet and central Graham Island areas. The group is herein subdivided into five formations on the basis of their relatively distinctive lithologies. These are in descending order:

(1) Phantom Creek Formation
(2) Whiteaves Formation
(3) Fannin Formation
(4) Rennell Junction Formation
(5) Ghost Creek Formation

The highest formation ranges from late Middle Toarcian to Early Aalenian whereas the Ghost Creek Formation at the base is assigned an Early Pliensbachian age.

The type section of the former Maude Formation (Section 8) on Maude Island represents approximately one-half of the total Maude Group as herein recognized. The **"Harpoceras" propinquum** beds of Sutherland Brown (1968, p.64) which occur above approximately 45 m of beach cover, are structurally discordant with the underlying rocks when traced along strike, and their true stratigraphic position cannot be ascertained with respect to the type Maude exposure. They are not therefore included in the type Maude section but form part of a different sequence (Section 6) exposed in a creek bed directly above the **propinquum** beds. Although this section on Maude Island was the basis for establishing the Maude Formation, it is not adequate for the expanded Maude Group. The new formations of this group can be better understood by reference to formational type sections at various localities, but this section on Maude Island is one of the most fossiliferous and is typical of the Pliensbachian part of the group.

Ghost Creek Formation
Stratigraphic sections 4,7,8, and 10

The basal formation of the Maude Group is the Ghost Creek Formation. It is a recessive unit exposed at Skidegate Inlet (Fig. 3, 5) and central Graham Island (Fig. 4, 6) in low shoreline exposures, creeks, and roadcuts. The most complete section for study is in central Graham Island, and section 10 is selected as the type section. The thickness in the type section is 68.5 m whereas the thickest section in Skidegate Inlet area is 46 m but is discontinuously exposed.

Lithology

Characteristically, the Ghost Creek Formation is dark grey shale, silty shale with in places, pale grey to cream limestone interbeds and lenses. It is commonly bituminous and fetid; oil stain and bitumen are fairly common within this formation. It differs from the underlying Sandilands Formation of the Kunga Group in being softer, in having more shale and much less volcanic material; a few thin, harder bands a

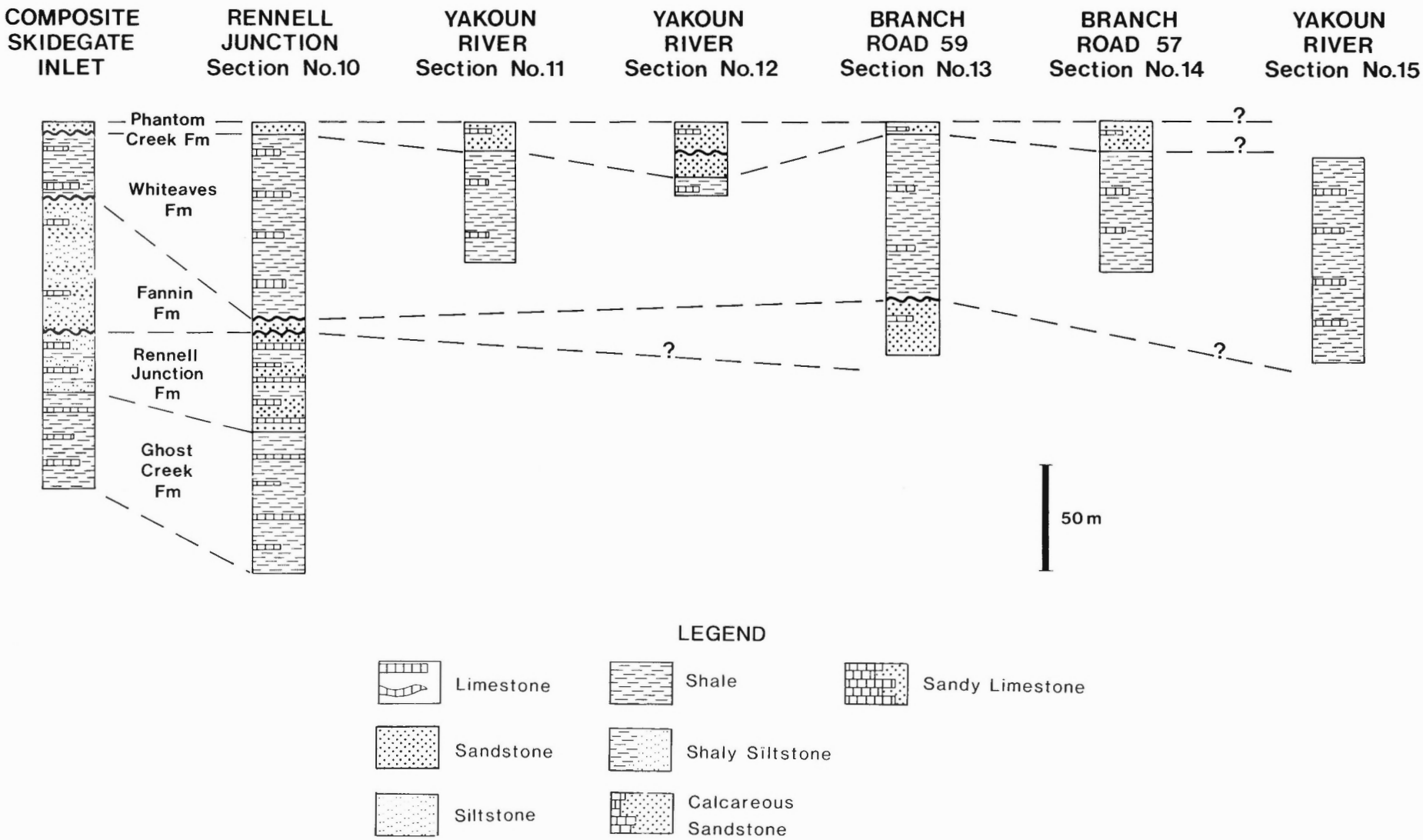

Figure 9. Stratigraphy of the Maude Group, Skidegate Inlet to central Graham Island

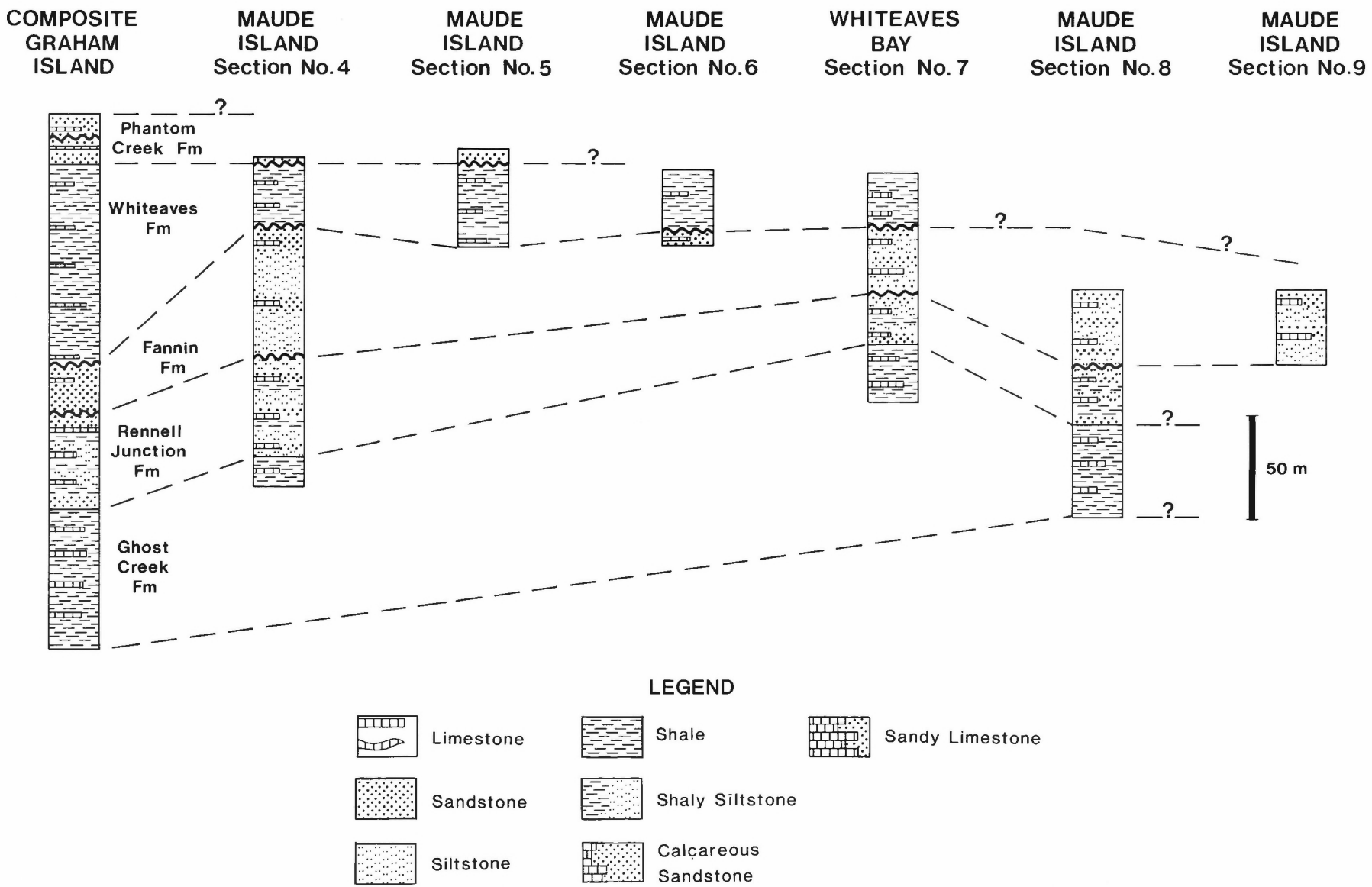

Figure 10. Stratigraphy of the Maude Group, central Graham Island to Skidegate Inlet

Figure 11. Basal Ghost Creek Formation showing dominance of recessive dark grey fetid shale. South coast of Maude Island, stratigraphic section 8. (GSC 190987)

few centimetres thick are thought to be ash beds or tuffaceous shale (Fig. 11, 12). It lacks the laminated bedding of the underlying Sandilands Formation. The shales of the Skidegate Inlet area tend to be harder and break into rectangular fragments, and are possibly more tuffaceous, whereas the shales of central Graham Island are typically soft and fissile with no tuffaceous component. This would suggest that the Skidegate Inlet depositional site was closer to the volcanic source.

The lower part of the Ghost Creek Formation in the Skidegate Inlet area differs from the same rocks in central Graham Island in having some highly contorted beds, irregular white calcite veins and some shale rip-up clasts. These features suggest a much higher energy regime. In central Graham Island, the formation is very regularly bedded and becomes somewhat glauconitic near the top. In this area sedimentation appears to have been slow, uniform and in relatively deep water.

Internal Structural Relations

The Ghost Creek Formation, as represented by type section 10 is a regularly bedded unit with no apparent structural break or hiatuses. The faunal evidence tends to support this interpretation.

External structural relations

The upper contact of the Ghost Creek Formation with the Rennell Junction Formation appears to be conformable and gradational in places. The lower contact with the Kunga Group, although not seen in outcrop, is thought to be essentially conformable, defined mainly by the cessation of air-fall tuff deposition.

Origin and depositional environment

The Ghost Creek Formation was deposited in a relatively deep sedimentary basin in the central Graham Island area which obviously shallows somewhat to the south. Sediments are more or less pyritic in all areas of outcrop and are typically dark, especially in the lower parts of the formation. As such they appear to be partly euxinic and represent an environment similar to the underlying Sandilands Formation. Further testimony as to the partly euxinic nature of the lower Ghost Creek Formation is provided by the poor diversification of the benthic fossils. Higher in the formation, diversification increases substantially and the beds become somewhat glauconitic. The upper parts of the formation thus lose their euxinic character and appear to have been deposited in a somewhat shallower environment. In the Skidegate Inlet area common bioturbation features, such as burrows and bedding plane trails and furrows, as well as in the increase in coarser clastics, are further evidence of a shallower environment.

The same volcanic source is envisaged for the Ghost Creek Formation as was suggested for the Sandilands Formation but the amount of tuffaceous and ash-fall material is considerably less.

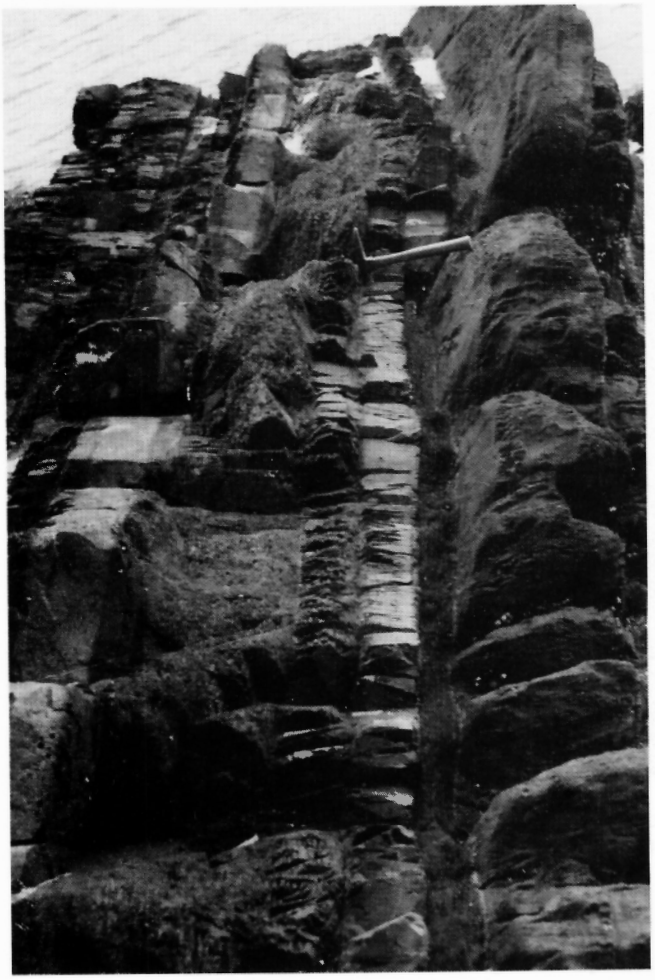

Figure 12. Ghost Creek Formation, Maude Island. stratigraphic section 8. Blocky to fissile dark grey shale (right side), tuffaceous hard siltstone (left side; GSC 190988)

Age and biostratigraphy

The Ghost Creek Formation is Early Pliensbachian, the earliest part of the substage. Although an ammonite zonation has not been attempted for North America, the Jamesoni zone of the Northwest European zonation would be the closest zonal correlation suggested for at least part of the formation.

In Table 3, the tentatively identified ammonites of the formation are listed. These are only the more obvious and there are several genera as yet undetermined. Preservation as flattened impressions in some parts of the formation commonly makes generic identification difficult and specific identification impossible.

In the lowest beds of the formation flattened pectinoid bivalves are characteristic, indicating a depositional environment similar to part of the underlying Sandilands Formation.

Like the ammonites, radiolaria are abundant in the formation with well preserved specimens recovered from most limestones. Foraminifers, although relatively uncommon, are distinctive (Table 3) and show great promise for an effective zonation of the rocks. This is especially true of the **Geinitzinita** and **Frondicularia** lineages which are used effectively as guide fossils in the Pliensbachian of Europe and other areas.

Rennell Junction Formation
Stratigraphic sections 4, 7,8, and 10

The Rennell Junction Formation is a relatively recessive unit exposed in shoreline outcrops, in creek banks and quarries in both the Skidegate Inlet area (Fig. 3, 5) and central Graham Island (Fig. 4, 6). The best exposed and most complete sections are in the central Graham Island area where the formation attains a thickness of 47 m. Stratigraphic section 10 is the designated type section. The formation appears to be relatively uniform in thickness throughout its area of exposure; 49 m was observed in the Skidegate Inlet area (Section 4).

Lithology

The Rennell Junction Formation is composed of generally fine clastic sediments consisting of fine grained, commonly flaggy sandstone, argillaceous siltstone and grey shale with irregularly bedded limestone and limestone lenses. Rare, partly tuffaceous sandstone and soft pale grey ash beds also are present. It differs from the underlying Ghost Creek Formation in being more resistant, having less shale, more siltstone, and lacking the dark grey bituminous shales which characterize the Ghost Creek Formation. Occasional fine pebble pockets have been noted. The formation is somewhat glauconitic near the base and a few low angle crossbeds were observed in the Skidegate Inlet area.

Internal structural relations

Like the underlying Ghost Creek Formation, the Rennell Junction is a sequence of regularly bedded sediments with no evidence of structural interruptions or hiatuses. The thickness of individual beds varies greatly but each bed appears to maintain its individual thickness over a considerable distance. The limestone beds in particular show a greater tendency to be lenticular. The ammonite succession tends to support the premise that the unit is a regularly bedded uninterrupted sequence.

External Structural Relations

The contact with the overlying Fannin Formation on the basis of certain excluded ammonite genera, is apparently a paraconformable hiatus; in several exposures erosion, bioturbation (Fig. 13), and channelling is apparent at this contact (Fig. 14, 15, 16). The contact with the underlying Ghost Creek Formation is gradational and conformable.

Table 3. Faunal succession of the Maude Group

STAGES	SUB-STAGES	MAUDE GROUP (composite)	AMMONITE FAUNAS (typical representatives)	OTHER MACRO FAUNAS	MICROFAUNA (typical representatives)
AALEN - IAN	upper	hiatus			
	lower	PHANTOM	*Tmetoceras* sp., *Hammatoceras* cf. *H. semilunatum* (Quenstedt) *Erycitoides* *Dumortieria* cf. *D. pusilla* Jaworski	terebratulid brachiopods pectinoid bivalves belemnites	common Radiolaria
TOARCIAN	upper	hiatus	*Esericeras* aff. *E. eseri* Oppel	ostreoid bivalves	
	?	CREEK	*Haugia (Haugiella)* spp., *Grammoceras?* sp., *Hammatoceras* cf. *H. speciosum* Janensch *Denckmannia* n. spp., *Haugia* sp.	*Dicoelites*	*Lenticulina d'Orbignyi* (Roemer) var., *Falsopalmula jurensis* (Franke), *Pseudonodosaria pygmaea* (Terquem), *Citharina* sp. cf. *C. longemari* (Terquem), abundant Radiolaria
	middle	WHITEAVES	*Denckmannia* aff. *D. fabilis* (Simpson), *Denckmannia* spp. *Phymatoceras* sp., *Peronoceras* sp. *Phymatoceras* sp., *Peronoceras* sp., *Hildoceras* sp., *Hildoceratoides chrysanthemum* Yokoyama	nautiloid trigonid bivalves scleractinid coral	*Lenticulina d'Orbignyi* (Roemer), *Pseudonodosaria* sp., *Lenticulina prima* (d'Orbigny), *Falsopalmula varians* (Bornemann), *Vaginulina listi* (Bornemann), *Citharina sagittiformis* (Terquem), common Radiolaria, common Ostracoda especially *Kinkolinella* sp.
PLIENSBACHIAN	lower	hiatus			
	upper	FANNIN	*Dactylioceras kanense* McLearn *"Tiltoniceras" propinquum* (Whiteaves), *Arieticeras, Amaltheus?* sp., *Fanninoceras carlottense* McLearn, various harpoceratids *Protogrammoceras* cf. *P. argutus* (Buckman), *Arieticeras* sp., *Fanninoceras* sp. *Amaltheus* cf. *A. stokesi* (J. Sowerbyi), *Arieticeras* cf. *A. algovianum* (Oppel), *Fanninoceras fannini* McLearn, *Becheiceras* sp. *Fanninoceras fannini* McLearn, *F. kunae* McLearn, *F. dolmagei* McLearn, *F. carlottense* McLearn, *F. bodegae* McLearn; *F. lowrii* McLearn, *Arieticeras* sp., *Protogrammoceras* sp., *Phylloceras* sp.	nautiloid *Weyla* rhynchonellid brachiopods pectinoid bivalves	*Marginulina prima prima* d'Orbigny, *Nodosaria* sp. common agglutinating foraminifers including *Reophax, Ammobaculites, Ammodiscus* abundant Radiolaria, common agglutinating forminifers, as above *Geinitzinita tenera tenera* (Bornemann), *Marginulina prima burgundiae* Terquem, *Conorboides* sp., *Lingulonodosaria* sp., abundant small pyritized foraminifers
		hiatus			
	lower	RENNELL JUNCTION	*Prodactylioceras* sp., *Arieticeras* sp., *Dayiceras dayiceroides* (Mouterde), *Phylloceras* sp. *Dayiceras dayiceroides* (Mouterde) *Metaderoceras* sp., *Acanthopleuroceras* sp. *Tropidoceras actaeon* (d'Orbigny), *Metaderoceras* sp., *Acanthopleuroceras* sp., *Becheiceras* sp.		abundant small pyritized foraminifers, *Reophax* sp., *Ammobaculites* sp. *Geinitzinita tenera subprismatica* (Franke), *Bigenerina* sp., *Frondicularia pygmaea* Franke, *Conorboides* sp., *Opthalmidium* sp., *Astacolus* sp., *Nodosaria* sp., abundant Radiolaria
		GHOST CREEK	*Tropidoceras actaeon* (d'Orbigny), *T. masseanum* (d'Orbigny) *Coeloceras* sp., *Acanthopleuroceras* sp., *Phricodoceras* sp.	pectinoid bivalves	*Dentalina tenuistriata* Terquem, *Geinitzinita tenera pupa* (Terquem), *Frondicularia brizaeformis* Bornemann, *F. bicostata bicostata* d'Orbigny, *F. bicostata mesoliassica* Brand, rare Ostracoda abundant Radiolaria

Origin and depositional environment

The Rennell Junction Formation grades from a relatively deep water, somewhat glauconitic unit at the base to a shallower water somewhat coarser facies at the top. As was the case with the Ghost Creek Formation, sediments of the Rennell Junction appear to deepen somewhat north of Skidegate Inlet. The crossbedded heterogeneous sediments of the Skidegate Inlet area are represented in central Graham Island by uniformly bedded sandstones, siltstones, and shales. A comparison of the microfaunas in the two areas indicates a somewhat deeper facies in the northern area as well. The Rennell Junction Formation represents a continuation of basinal sedimentation with the introduction of a regressive phase in its upper part. This regressive cycle is continued in the overlying Fannin Formation.

Age and biostratigraphy

The Rennell Junction Formation is Early Pliensbachian, probably, in part equivalent to the Northwest European Ibex and Davoei zones. The ammonites present show strong affinities to ammonites of these zones in Europe.

The ammonites listed, (Table 3) particularly **Tropidoceras, Metaderoceras,** and **Dayiceras,** are common, well-preserved as three-dimensional forms in limestone lenses. **Dayiceras dayiceroides** is a widespread form found in Oregon, Nevada, Alaska and in many parts of British Columbia (Smith, 1983).

The foraminifers of the lower part of the Rennell Junction Formation are well preserved and diverse. Species of **Geinitzinita, Frondicularia** and other nodosarids appear to

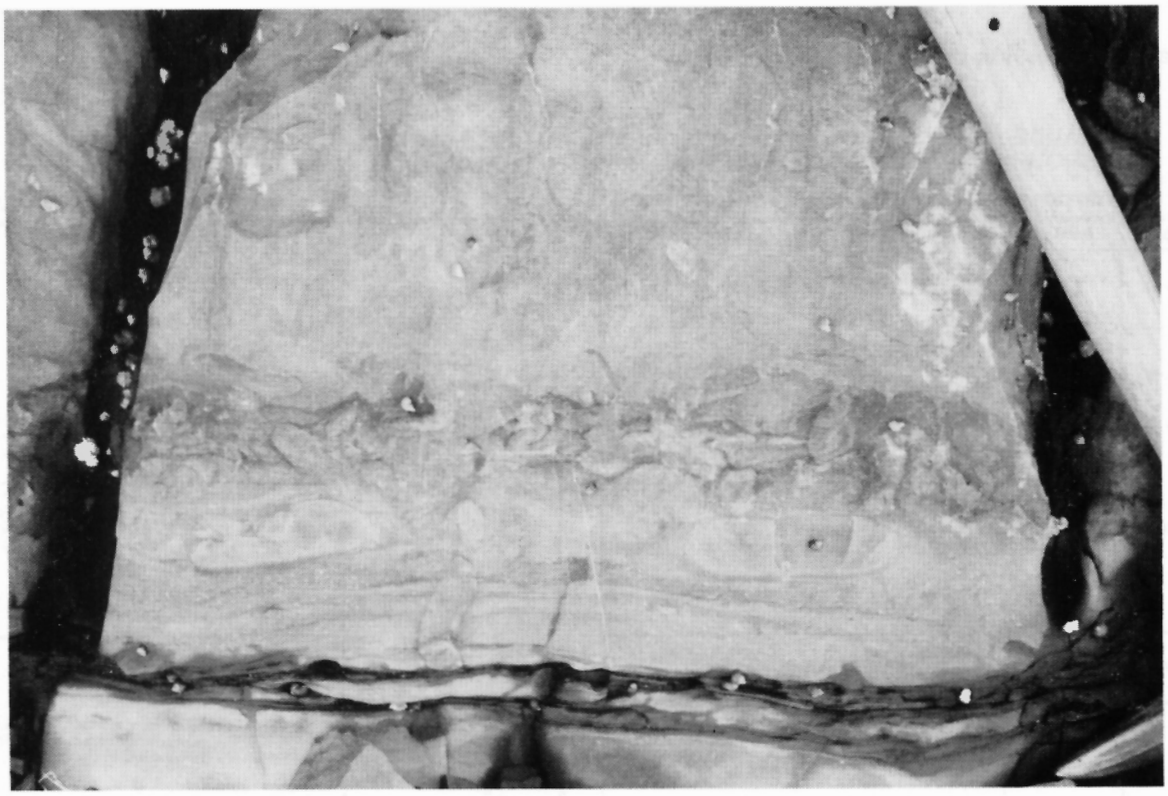

Figure 13. Burrows and bioturbation, Rennell Junction Formation, south shore of Maude Island. Stratigraphic seciton 8. (GSC 190989)

be distinctive in these beds (Table 3). Higher in the section, shallower water, dominantly agglutinated foraminifers are common. Associated with these is a rather unusual completely pyrite replaced fauna consisting of very small sized **Ammodiscus, Trochammina, Nodosaria, Dentalina** and others. In spite of this fauna's peculiar preservation, it is present in all exposures of the Rennell Junction Formation and is presumed to reflect a rather specialized environment. As was the case in the Ghost Creek Formation, radiolarians are abundant in the shales and limestones of the Rennell Junction Formation.

Fannin Formation
Stratigraphic sections 4,6,7,8,9,10 and 13

The Fannin Formation is a moderately resistant unit distributed around Skidegate Inlet and in central Graham Island. It is best exposed in creek outcrops on Maude Island and is partly represented in a few quarries and streamcuts on Graham Island.

The formation is also known from Sialun Bay on northwestern Graham Island. An harpoceratid ammonite collected by the late T. Potter Chamney of Petro-Canada from this locality is currently included in the **"Tiltoniceras" propinquum** group which are typical of the Fannin Formation.

It is difficult to select a type section but the best is Section 4 on Maude Island near Fannin Bay but even this is not a complete sequence. The Fannin Formation attains a maximum thickness of 64 m on Maude Island (Section 4) but, in central Graham Island, although poorly exposed, is represented by a maximum of 26 m. The latter is believed to represent the middle and upper parts of the formation.

The heterogeneity of the formation is the main distinctive and unifying characteristic. If exposure were better it is possibly divisible into members but more probably the diversity of lithology results from rapid and profound facies changes.

Lithology

The Fannin Formation represents a heterogeneous succession of sediments on Maude Island. The base of the formation is readily recognized by an abrupt change from the fine clastics of the Rennell Junction Formation to coarse, more tuffaceous and thicker bedded sediments (Fig. 16). The rocks consist of hard, partly tuffaceous, partly calcareous sandstones with minor siltstone and very rare thin waxy green and blue-grey shales. A few thin limestone interbeds and lenses are also present. Small, fine-pebble conglomerate lenses have been observed at the base. The upper part of the formation consists of mostly earthy calcareous sandstones and tuffaceous shales with rare sandy limestone interbeds and lenses. On Maude Island the upper beds become harder and more tuffaceous. In central Graham Island, the rocks consist of partly calcareous sandstones with little if any tuffaceous influence. Locally cream-coloured tuffs form important sections. Concretionary limestones are fairly common in the formation and most are composed of cemented masses of rhynchonellid brachiopods and/or pectinoid bivalves (Table 3). In all areas where the upper part of the formation has been

Figure 14. Well bedded, flaggy sandstones of the Rennell Junction Formation overlain unconformably by the calcareous, buff weathering Fannin Formation. Central Graham Island, stratigraphic section 10. (GSC 190990)

observed, chamosite ooliths are an abundant component (Fig. 17). These pale grey pellets occur in both dark shale and dark sandstone matrices and impart a distinctive salt and pepper appearance to the rock. The pellets were examined by petrographic studies of thin sections, chemical analyses and X-ray diffraction (XRD) through the courtesy of John Wilson and Don MacDonald of the Alberta Geological Survey; their significance is discussed further under depositional environment.

Internal structural relations

Erratic exposure and rapid facies changes within the formation make it difficult to determine whether or not the Fannin Formation is an uninterrupted sequence. The fossil fauna clearly indicates a very shallow basin of deposition with the possibility of unidentified periods of erosion or non-deposition. Although the ammonites cannot be used to support a thesis of an uninterrupted sequence, the faunas from all sections of Fannin Formation do not suggest any missing faunas of regional extent. Possible gaps and structural discontinuities can be attributed to facies changes and very minor and local slumps.

External structural relations

As previously stated the contact with the underlying Rennell Junction Formation is an hiatus, a paraconformable contact. The upper contact with the Whiteaves is characterized by an hiatus with possible erosion and possibly even a slight angular relation. In the section at Whiteaves Bay (Section 7) the Fannin Formation reaches as high as the earliest Toarcian but elsewhere the formation never is younger than Late Pliensbachian.

Origin and depositional environment

The Fannin Formation is the end of a depositional sequence that began in the back-arc basin of the Sandilands Formation and part of the Ghost Creek Formation, and became shallow through the upper Ghost Creek and Rennell Junction formations, and in the Fannin Formation reached a minimum sea level stand. The regressive cycle is reflected in the change in benthic foraminiferal faunas from diverse, predominantly calcareous faunas at the base of the formation to less diverse, dominantly agglutinated forms at the top. The presence of the trace fossil, **Thalassinoides,** in the **"Tiltoniceras" propinquum** beds, (P.L. Smith, personal communication, 1985) is an indicator of the **Skolithos** ichnofacies, a shallow nearshore environment (Section 6). Further evidence of the shallow nature of the upper parts of the formation are provided by the aforementioned chamosite ooliths. In an unpublished report to the writers, Wilson and MacDonald concluded that the ooliths probably formed in a shallow marine (inner shelf) environment in at least intermittently high energy conditions. Hallam (1984) suggested that kaolinite, which is a significant associated mineral with the chamosite ooliths, is the product of intense chemical weathering, "a sure indication of warm and humid conditions". Furthermore Hallam pointed out that an important condition for such ironstones to form is a continental lateritic source where iron can be concentrated. It is apparent therefore that the upper part of the Fannin Formation was deposited in a shallow marine environment close to a landmass with a warm and humid climate. The fact that the presently known global distribution of such ironstones in the Early Jurassic is in central and southern Europe (Hallam, 1984 p. 200) may lend some support to the relatively low latitude origin of the Queen Charlotte Island Early Jurassic rocks.

Age and biostratigraphy

The Fannin Formation is Late Pliensbachian to Early Toarcian. Late Pliensbachian time is recognized by the common occurrence of two genera, **Fanninoceras** and **Arieticeras** both of which span the substage. The great number and diversity of genera and species is characteristic and three-dimensional preservation is good. The second stratigraphically highest fauna in the formation, **"Tiltoniceras" propinquum** has been here included in the Pliensbachian rather than in the Toarcian as was done by McLearn (1929). Significant elements of the fauna include several specimens of **Fanninoceras,** rare **Arieticeras,** and a single specimen tentatively identified as an amaltheid. These three associated genera argue strongly for a Late Pliensbachian assignment.

Figure 15. Contact between Rennell Junction Formation and overlying Fannin Formation south shore of Maude Island. Stratigraphic seciton 8, cliff-forming Yakoun Group in background. (GSC 190991)

Figure 16. Contact between Rennell Junction Formation below and Fannin Formation above. Contact is approximately 10 cm below the tip of hammer. Rennell Junction Formation here is a grey limestone and Fannin Formation is a siltstone. Stratigraphic section 8, Maude Island. (GSC 190992)

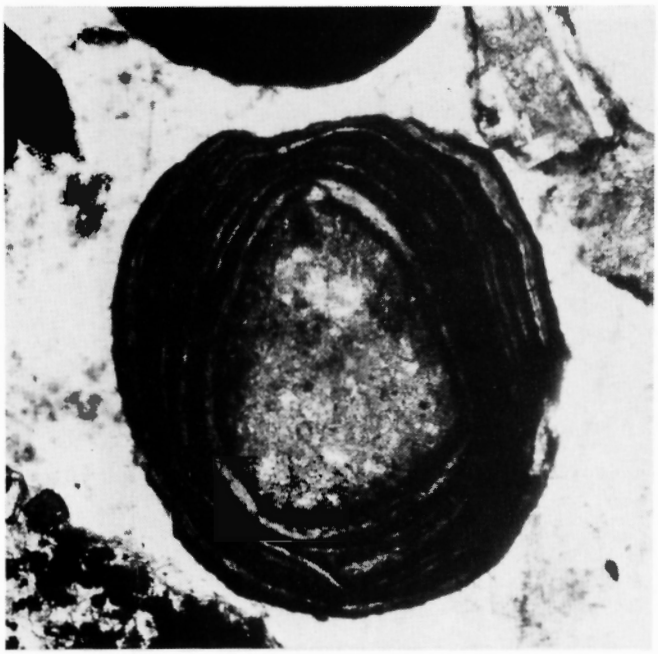

Figure 17. Chamosite oolith, Relatively regular laminae indicate high mobility of particles during authigenesis. Nucleus consists of volcanic rock fragments. Diameter of oolith approximately 2.0 mm. Fannin Formation, stratigraphic section 4, Maude Island. GSC 190993)

The genera of this formation are typically of Tethyan derivation. Two specimens of the boreal genus **Amaltheus** apparently indicate the extremity of its southward range. The highest fauna, **Dactylioceras kanense** McLearn, is selected as the first indicator of the Toarcian stage and in Queen Charlotte Islands is the only indicator of Lower Toarcian beds. Beside ammonites, there are numerous other faunas, rhynchonellid brachiopods, small **Weyla,** a wide variety of small smooth to ornate pelecypods, small gastropods, and a few specimens of the coleoid **Atractites** identified by J.A. Jeletzky. Large nautiloids are noted with the **"Tiltoniceras" propinquum** fauna.

Throughout the Fannin Formation the foraminifers continue to indicate increasingly shallow water environments from bottom to top. Several species of **Geinitzinita, Marginulina** and **Nodosaria** (Table 3), however, appear to be restricted to various parts of the formation. Foraminiferal faunas are dominated by agglutinating genera which are presumed to be more a reflection of facies rather than of restricted ranges. Radiolaria are abundant in the Late Pliensbachian part of the formation but have not been observed in the Early Toarcian part.

Whiteaves Formation
Stratigraphic sections 4,5,6,7,10,11,12,13,14 and 15

The Whiteaves Formation is exposed around Skidegate Inlet in creeks and shoreline exposures on Maude Island and at Whiteaves Bay. An ammonite collected by Sutherland Brown from Atli Inlet, Lyell Island, southern Moresby Island was previously identified as a sonninid by Hans Frebold (GSC Loc 36986). Re-examination of this specimen, however, indicates a more probable identification as **Phymatoceras** sp., a form typical of the Whiteaves Formation. It appears, therefore, that the Whiteaves Formation extends over much of the Queen Charlotte Islands. In central Graham Island the formation is exposed on creeks and roadcuts with the best exposures being on the banks of the Yakoun River. Being the softest Jurassic unit, however, it is always recessive and in many areas poorly exposed. The formation is named after the exposure at Whiteaves Bay, northern Moresby Island (Section 7) which, although an incomplete section only 26 m thick, represents a typical exposure. The type section is designated as section 15 (Fig. 18), on the Yakoun River a much more complete section with a total thickness of 98 m.

Lithology

The Whiteaves Formation consists of a recessive sequence of pale grey-green weathering shale and sandy or silty shale with minor argillaceous sandstone interbeds and pale grey weathering nodular and concretionary limestones and thus is distinctly different from the underlying Fannin Formation. The formation is glauconitic throughout but especially near the base. Sandstone interbeds, where they occur, are usually near the top of the formation and are variously argillaceous and recessive. The shales typically are slightly carbonaceous throughout and contain a few small coalified wood fragments towards the base of the formation. Thin pale grey to blue-grey bentonitic ash beds are fairly common in parts of the unit. The formation is divisible into two lithologically distinctive units, the septarian shale member and the concretionary shale member. The designated type section of these informal members is also Section 15 on the Yakoun River.

Septarian Shale Member: The lower member of the Whiteaves Formation consists of the typical grey-green weathering shale but with characteristic pale grey weathering septarian nodules. The septaria are sandy and somewhat carbonaceous. The calcite veins within the nodules have commonly crystallized as large crystals within hollow central cavities. These septaria are present in all areas where the lower part of the Whiteaves Formation is exposed.

Concretionary Shale Member: The upper member of the Whiteaves Formation differs from the lower member in being more sandy, in lacking septarian nodules and in being less glauconitic. Small spherical to discoidal calcareous nodules are abundant in this member, many of which form ammonite and nautiloid concretions. The member is represented wholly or in part throughout the outcrop area of the Whiteaves Formation.

Internal Structural Relations

The Whiteaves Formation, although relatively uniform in lithology, represents a sequence in which deposition was slow, and probably frequently interrupted in a moderately deep basin. Pale grey ash beds are not uncommon. Fragmented bivalve shells concentrated in small sandy pockets suggest intermittent high energy influences which scoured and resedimented parts of the unit. Pockets of glauconite,

Figure 18. Whiteaves Formation, Yakoun River. Stratigraphic section 15 showing recessive nature of these grey-green weathering shales. (GSC 190994)

especially near the base of the formation indicate possible minor hiatuses or at least very low sedimentation rates. These possible hiatuses within the formation appear to be minor, however, as the faunal sequences are relatively uniform and gradational.

External Structural Relations

The contact with the underlying Fannin Formation is abrupt and marks an erosional hiatus indicated by the non-uniform removal of most Lower Toarcian beds. This relationship is emphasized further by the abrupt change in lithology and change in depositional environment. As previously stated, the upper part of the Fannin Formation is a heterogeneous sequence of nearshore sediments which represent the end of an Early Jurassic regressive sequence. The Whiteaves Formation on the other hand is a relatively deep-water deposit. The contact with the overlying Phantom Creek Formation is gradational and conformable in the central Graham Island area. In Skidegate Inlet the contact is an erosional hiatus which excludes the uppermost part of the Whiteaves Formation and the coquinoid sandstone member of the Phantom Creek Formation. This hiatus is marked by a paleosoil in at least one area (Section 4).

Origin and depositional environment

Following the erosional hiatus that marks the top of the Fannin Formation, the Jurassic seas transgressed rapidly depositing the Middle Toarcian Whiteaves Formation. This moderately deep basin received ash-fall material sporadically from a far distant source. Microfaunas are rich and diversified throughout the formation and suggest a slow infilling of the basin towards the top of the unit where the beds become more sandy and benthic faunas somewhat less diverse. Glauconite is a common component of the sediment particularly near the base of the unit. This authigenic mineral forms apparently in areas with a very low or nil sedimentation rate at water depths ranging from 50 to 500 m (Giresse and Odin, 1973; Odin and Matter, 1981). Great abundance of glauconite, however, is suggestive of depths ranging from 200 to 300 m.

Age and biostratigraphy

The Whiteaves Formation is tentatively considered to be wholly Middle Toarcian. The association of the genera **Hildoceras(?), Peronoceras, Phymatoceras** and the species **Hildoceratoides chrysanthemum** Yokoyama tends to support this interpretation. However, the biostratigraphic succession and correlation with European forms is still being studied; there are strong similarities to genera and species in South America and in Europe.

The macrofauna are well preserved in nodules and concretions and generally are three-dimensional and undistorted. Some specimens of **Phymatoceras** reach 30 cm across but commonly these are not in concretions and are badly fractured. The ammonite fauna, although common and varied is rarely concentrated in large numbers.

The doubly-grooved dicoelitid belemnites make their first appearance near the base of the formation associated with the ammonite **Hildoceratoides chrysanthemum** and, in Queen Charlotte Islands, this is the earliest appearance of any true belemnite.

Nautiloids were noted infrequently but usually near the base of the concretionary shale member and associated with the highest occurrence of **Peronoceras**.

The microfaunas of the Whiteaves Formation are very well developed and contain abundant foraminifers and ostracods with some significant radiolarian occurrences (Carter, 1985). Some of the most common and characteristic forms (Table 3) are **Lenticulina d'Orbignyi** (Roemer). **Pseudonodosaria** sp. and the ostracod **Kinkelinella. L. d'Orbignyi** appears to be an excellent marker for the Middle Toarcian in this area although a more advanced variety does occur in the overlying Phantom Creek Formation. Several other distinctive species of **Lenticulina** suggest that the Whiteaves Formation in the type area (Section 15) is either somewhat older in the Middle Toarcian than in other areas, or represents a somewhat deeper environment. Final compilation of the foraminiferal range charts should indicate whether the base of the formation is diachronous to some degree.

Phantom Creek Formation
Stratigraphic sections 4,5,10,11,12,13 and 14

The Phantom Creek Formation is a relatively resistant unit best exposed in central Graham Island in stream cuts and quarries. Much abbreviated sections are exposed in stream cuts in the Skidegate Inlet area. The best and most complete section is on the banks of the Yakoun River (Section 12) where a total thickness of 26 m is represented. This is herein designated the type section. Only the upper part of the formation is exposed in the Skidegate Inlet area where a maximum of 5.5 m was observed.

Lithology

The Phantom Creek Formation is composed essentially of pale brown to buff weathering, fine- to coarse-grained sandstones. The sandstones are partly calcareous and commonly argillaceous imparting a rather earthy appearance to the rocks. Sandy, brown thin shale interbeds are fairly common in the lower part. The uppermost sandstones of the unit become more massive, more uniformly bedded and have some very hard calcareous, fine- to medium-grained, green sandstone interbeds. The sandstones are generally richly fossiliferous with a great variety of ammonites, bivalves and belemnites. The formation is divisible into two informal lithologically distinctive units, the coquinoid sandstone member and the belemnite sandstone member, both of which have their reference localities on Yakoun River (Section 12).

Coquinoid sandstone member: The lower member of the Phantom Creek Formation is a richly fossiliferous, earthy, pale brown sandstone unit, typically with sandy shale interbeds and common buff weathering sandy limestone lenses (Fig. 19). This member is further characterized by rather irregular bedding at the base with much thinning and thickening of individual beds. The coquinoid sandstone member has not been found in the Skidegate Inlet area; it has apparently been cut out by erosion. The name is derived from the rich and commonly tightly packed randomly oriented ammonite and bivalve faunas. The random orientations and abundant broken fossils further attest to the high energy and irregular deposition of these beds.

Belemnite sandstone member: The upper member of the Phantom Creek Formation, as the name implies, is characterized by abundant belemnites (Fig. 20), common pectinoid bivalves and rare ammonites. Generally the sandstones are more massive, harder, carbonaceous, and more uniformly bedded than the underlying member. The belemnite sandstone member is represented in all areas, to one degree or another, wherever the Phantom Creek Formation is exposed.

Internal structural relations

The internal structure of the Phantom Creek Formation is somewhat chaotic. The coquinoid sandstone member in central Graham Island displays irregular bedding, scouring, slumping, and great variation in thickness. The fauna may be slightly mixed in some sections but the interval involved may be short and the disruptions may be local and of little significance. The belemnite sandstone member by contrast, is a regular, uniformly thick-bedded member. The formation thins from place to place and some sections may be condensed, but no important hiatuses are evident on Graham Island. In the Skidegate Inlet area, however, the coquinoid sandstone member is missing and the belemnite sandstone member rests directly on the Whiteaves Formation. In one section (Section 4) the development of a paleosoil may be related to this hiatus.

External structural relations

As described above, the lower contact with the Whiteaves Formation is paraconformable in the Skidegate area and conformable on Graham Island. The upper contact with the Graham Island Formation of the Yakoun Group is marked by a paraconformable hiatus and by a marked change in lithology (Fig. 21).

Origin and depositional environment

In central Graham Island the shallowing trend noted in the Whiteaves Formation appears to continue through the lower and upper members of the Phantom Creek Formation. Unlike the lower formations of the Yakoun Group, the Phantom Creek appears to have little volcanic input in the form of tuff-fall or ash beds. Hence a cessation of volcanic activity at this time is indicated. The lower member of the formation is not represented in Skidegate Inlet whereas this unit is well represented to the north in relatively shallow water sandstones. The top of the coquinoid sandstone member marks the end of another regressive cycle. A new transgressive cycle began with the belemnite sandstone member in which very shallow water sandstones are followed abruptly over a paraconformable contact by the deeper water shale-tuff member of the Graham Island Formation.

Age and biostratigraphy

The Phantom Creek Formation is mainly Late Toarcian as indicated (Table 3) by the ammonite fauna. The coquinoid sandstone member may be Middle Toarcian in the lower beds where **Denckmannia** and **Haugia** predominate but for the remainder of the member where **Hammatoceras**, possibly **Grammoceras**, and **Esericeras** are common, a Late Toarcian age is indicated. The belemnite sandstone member with

Figure 19. Coquinoid sandstone member of Phantom Creek Formation, Yakoun River, showing well cemented calcareous sandstones and nodular buff weathering sandy limestones. Stratigraphic section 12. (GSC 190995)

Figure 20. Belemnite sandstone member of the Phantom Creek Formation. Typical frequency and mode of occurrence of belemnites within this member. Central Graham Island. Stratigraphic section 10. (GSC 190996)

Figure 21. Contact between the belemnite sandstone member of the Phantom Creek Formation, below the dashed line and the shale-tuff member of the Graham Island Formation above the line. Stratigraphic section 13, central Graham Island. (GSC 190997)

Dumortieria and with **Tmetoceras** is confidently dated as latest Toarcian and Aalenian.

The ammonite fauna of the formation is commonly well preserved, in many places packed into limestone nodules, and commonly disoriented relative to bedding. Many species show a marked similarity to European forms such as those studied by Gabilly (1976) in France. In North America the **Denckmannia** and Haugia fauna is uncommon and its position in the biostratigraphic sequence has still to be established.

The dicoelitid belemnites are found in this formation only as high as the ammonite **Esericeras** although other belemnites are abundant in the upper member of this formation. This shows the range of dicoelitid belemnites in Queen Charlotte Islands to be from low in the Middle Toarcian (Whiteaves Formation) to probable mid-Late Toarcian (Lower Phantom Creek Formation).

The belemnites (non-dicoelitid) of the belemnite sandstone member are present at the base of the unit wherever the member is found. The profusion of belemnites make this unit readily recognizable in the field.

The microfaunas of the basal part of the Phantom Creek Formation represent a continuation of the well developed fauna of the Whiteaves Formation. The fauna is somewhat less diverse, but has several distinctive forms (Table 3). These include several species of **Lenticulina** in addition to a distinctive variety of **L. d'Orbignyi**, less frequent species of **Citharina**, **Astacolus**, **Nodosaria**, **Dentalina**, **Pseudonodosaria** and **Falsopalmula**. The lower member carries abundant radiolaria as well as an increasingly diverse agglutinating foraminiferal fauna. The belemnite sandstone member has yielded little in the way of foraminifers. This is due to either the difficulty in extracting microfossils from the very hard sandstones, or the poor development of benthic fauna in the very shallow depositional environment. Radiolaria are fairly well represented in the more calcareous parts of the belemnite sandstone member.

Regional correlation of the Maude Group

The Maude Group correlates with many Pliensbachian and Toarcian groups and formations in the Canadian Cordillera (Table 4). Pliensbachian strata, particularly the Upper Pliensbachian beds, are the most widespread Jurassic beds in the Cordillera. Wherever Lower Jurassic sequences are known, Pliensbachian beds are almost always part of the section and commonly make up the thickest parts of the section. Only in the Fernie Formation are the Pliensbachian beds a minor part of the sequence but they may be unrecognized owing to the lack of fossils.

Correlative Toarcian beds are less common but this too may reflect a failure to find fossils. The Toarcian beds are almost invariably sedimentary with a major shale component in all sections. In this respect the Toarcian Maude beds are typical.

Yakoun Group

The Yakoun "Formation" was named by MacKenzie for the volcanic rocks around Yakoun Lake. As already pointed out in this paper the usage has changed with each worker. The last account by Sutherland Brown (1968, p. 66-76) is the most thorough treatment, but for the most part is only typical of the Skidegate Inlet area. During the course of the present study, new sections were discovered, mainly in central Graham Island, that expanded the applicability of the name. New faunas were found that indicated a much longer time span than previously envisioned. As a result the present account proposes a new definition that we believe is more usable. The upgrading of the unit from formation to group is in keeping with our treatment of other formations.

In his type Yakoun "Formation" on Maude Island Sutherland Brown proposed five members for the unit, A to E. The upper member, E and part of D , is entirely sedimentary with a pebble conglomerate at the base. As this is markedly different than the other volcanogenic members and as there is an apparent hiatus between E and part of D and the

underlying part of member D, we have removed this section from the "formation" and have raised it to the rank of group, the Moresby Group, which will be discussed later.

Three of Sutherland Brown's members, B, C and most of D are a conformable sequence with volcanic affinities. These have been combined into a single formation, the Richardson Bay Formation. In the Skidegate Inlet area a second formation, the Graham Island Formation, made up of Sutherland Brown's member A and a new mottled siltstone member underlies conformably and grades into the Richardson Bay Formation. The Richardson Bay Formation is largely eroded in the main study area of central Graham Island but is present in other parts of the island. These two formations make up the Yakoun Group whose characteristic is proximity to contemporaneous volcanism. The two formations are further subdivided into members with, at least in the case of Graham Island Formation, facies equivalent members in the Skidegate Inlet area.

Graham Island Formation
Stratigraphic sections 4,5,10,13,14 and 16

The Graham Island Formation is an heterogeneous resistant to recessive unit well exposed in creeks, roadcuts and shoreline exposures in all areas studied. The varying volcanic input into the rocks creates an extreme contrast in their resistance to weathering. In the Skidegate Inlet area the lapilli tuffs and siltstones are massive and form high, resistant ridges. By contrast the shales and shale tuffs in central Graham Island are much more recessive. The formation is named for an excellent stream cut succession in central Graham Island, Section 14, the designated type section. At

Table 4 Groups and formations in British Columbia and southern Yukon with which the Maude Group is correlated in whole or in part

GROUP OR FORMATION	AGE	LOCATION	LITHOLOGY
Bonanza Gp. (in part)	Late Pliensbachian	Vancouver Island 92L 92F	Porphyritic volcanic tuff, breccia and volcanogenic sediments
unnamed	Early Pliensbachian	Vancouver Island 92L	Volcanogenic sediments
Cultus Gp. (in part)	Late Pliensbachian	Hope 92H	Shale, siltstone
unnamed (?)	Late Pliensbachian	Hope 92H	Shale, siltstone
Ladner Gp. (in part)	Early Pliensbachian Toarcian Aalenian	Hope 92H	Siltstone, shale, sandstone
Ashcroft Fm. (in part)	Late Pliensbachian	Nicola 92I	Sandstone, siltstone
Tyaughton Gp. (in part)	Early and Late Pliensbachian, Toarcian, Aalenian	Taseko Lakes 92O	Shale, siltstone
unnamed	Early Pliensbachian	Bonaparte Lake 92P	Siltstone
Quesnel River Group (in part)	Early and Late Pliensbachian, Toarcian(?), Aalenian	Quesnel, Quesnel Lake, Prince George 93A, 93B, 93G	Siltstone, shale
unnamed	Toarcian	Fort St. James 93K, 93N	Siltstone, shale, sandstone
Nilkitka Fm.	Pliensbachian, Toarcian Aalenian	Hazelton, Smithers McConnell Creek 93L, 93M, 94D	Volcanic breccia, tuff siltstone, shale, volcanogenic sediments
Toodoggone volcanics	Pliensbachian Toarcian	Spatsizi, Toodoggone River, 104H, 94E	Porphyritic feldspathic tuff, breccia, flows, minor sediments
Spatsizi Gp.	Pliensbachian, Toarcian Aalenian	Spatsizi 104H	Siltstone, shale, tuffaceous siltstone, tuff, silty limestone
Takwahoni Fm.	Late Pliensbachian Toarcian	Tulsequah, Telegraph Creek, Dease Lake, 104K, 104G, 104J	Conglomerate, shale siltstone, sandstone
Inklin Fm.	Early and Late Pliensbachian	Atlin, Tulsequah, Dease Lake, Cry Lake, 104N, 104K, 104J, 104I	Greywacke, conglomerate, siltstone, shale
unnamed	Late Pliensbachian Toarcian	Telegraph Creek 104G	Siltstone, shale, tuff, tuffaceous sediments, silty limestone
Laberge Gp.	Late Pliensbachian Toarcian Aalenian	Whitehorse, Laberge, Carmacks 105D, 105E, 115J	Siltstone, conglomerate, shale sandstone
Fernie Fm.	Early and Late Pliensbachian Toarchian	Rocky Mountains 82G, 82J, 82O, 82N, 82C, 82E	Shale, siltstone

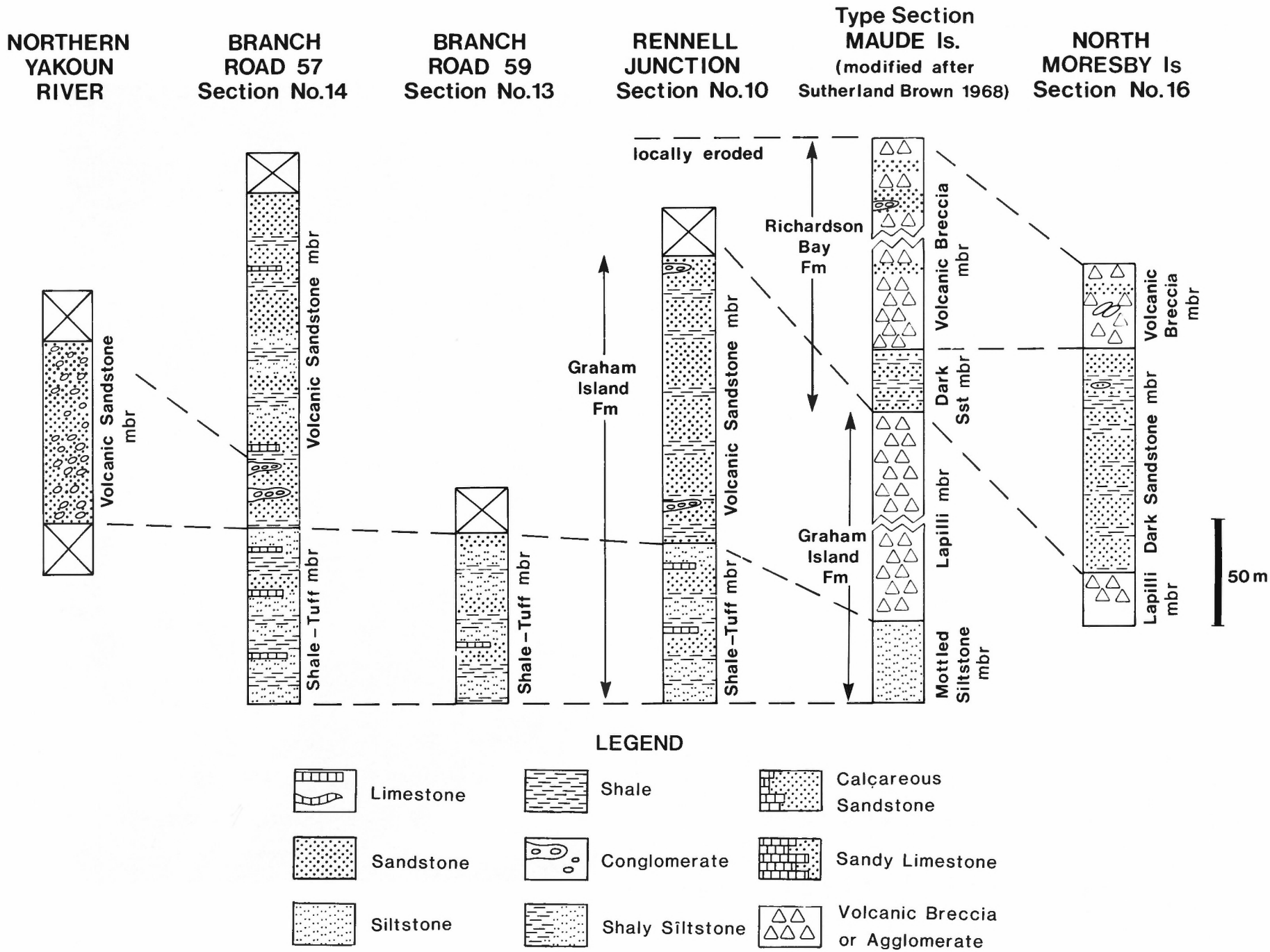

Figure 22. Stratigraphy of the Yakoun Group, central Graham Island to Skidegate Inlet. Members are informal.

this locality 245 m of sandstone, siltstone, shale and tuffaceous shale are exposed. In the Skidegate Inlet area 235 m of massive siltstone, lapilli tuff, and agglomerate are exposed. The contrasting lithologies in these two areas are herein considered facies equivalents (Table 1) and are reflective of proximity to the volcanic source. The formation is recognized by four contrasting facies (Fig. 22) which are designated as informal members.

Lithology and internal structural relations

Shale-tuff member, mottled siltstone member The lower two members of the Graham Island Formation differ greatly in lithology but are obviously at least partly time equivalent. The shale-tuff member (Section 14, designated reference section) has only been observed in the central Graham Island area where the rocks consist of a well-bedded sequence of soft brown slightly sandy shales, argillaceous partly tuffaceous siltstones with minor laminated and crosslaminated buff-weathering sandstones (Fig. 23, 24). The unit is predominantly recessive shale in the lower half and the rocks are somewhat fetid and bituminous. The upper part is more sandy and tuffaceous and as a result is much more resistant. Carbonaceous debris and pyrite replacement of microfossils are not uncommon in the lower part. Ammonites and foraminifers are rare in this member but the microfossils recovered are generally indicative of relatively deep water in a somewhat restricted environment.

Equivalent rocks in the Skidegate Inlet area are represented in the mottled siltstone member (Section 5, designated reference section). There the rocks consist of massive dark grey and mottled pale to dark grey siltstone. These beds are probably tuffaceous in part and attain a thickness of at least 30 to 40 m. Faunas are rather sparse and probably reflect a marine environment somewhat shallower than the shale-tuff member.

Volcanic sandstone member, lapilli member As in the underlying members of the Graham Island Formation, the overlying volcanic sandstone member, which occurs in central Graham Island, is believed to be stratigraphically equivalent to the lapilli member of the Skidegate Inlet area (Table 1). A thickness of approximately 200 m is suggested for the lapilli member (member A of Sutherland Brown, 1968) in the Skidegate area (Table 5, reference area). According to Sutherland Brown, the rocks are predominantly lapilli tuff, tuff and minor andesitic agglomerates. In most areas examined some reworked limestone nodules occur in the base of the unit. The lapilli member was apparently deposited in close proximity to the volcanic source.

To the north, some distance from the volcanic source, the rocks comprising the volcanic sandstone member (Section 14, designated reference section) consist of interbedded green to brown, fine- to coarse-grained sandstone, argillaceous dark grey to brown siltstones with occasional buff weathering fine grained partly calcareous sandstone (Fig. 25). Shales are rare in the unit and are usually grey to green and are waxy; they probably represent minor ash-fall intervals. The overall green of the sandstone suggests a genetic relationship to the green lapilli member to the south.

Figure 23. Deeply weathered shale-tuff member, Graham Island Formation, central Graham Island. Stratigraphic section 14. Light grey bands are tuff and darker bands are shale. Very near base or member. (GSC 190998)

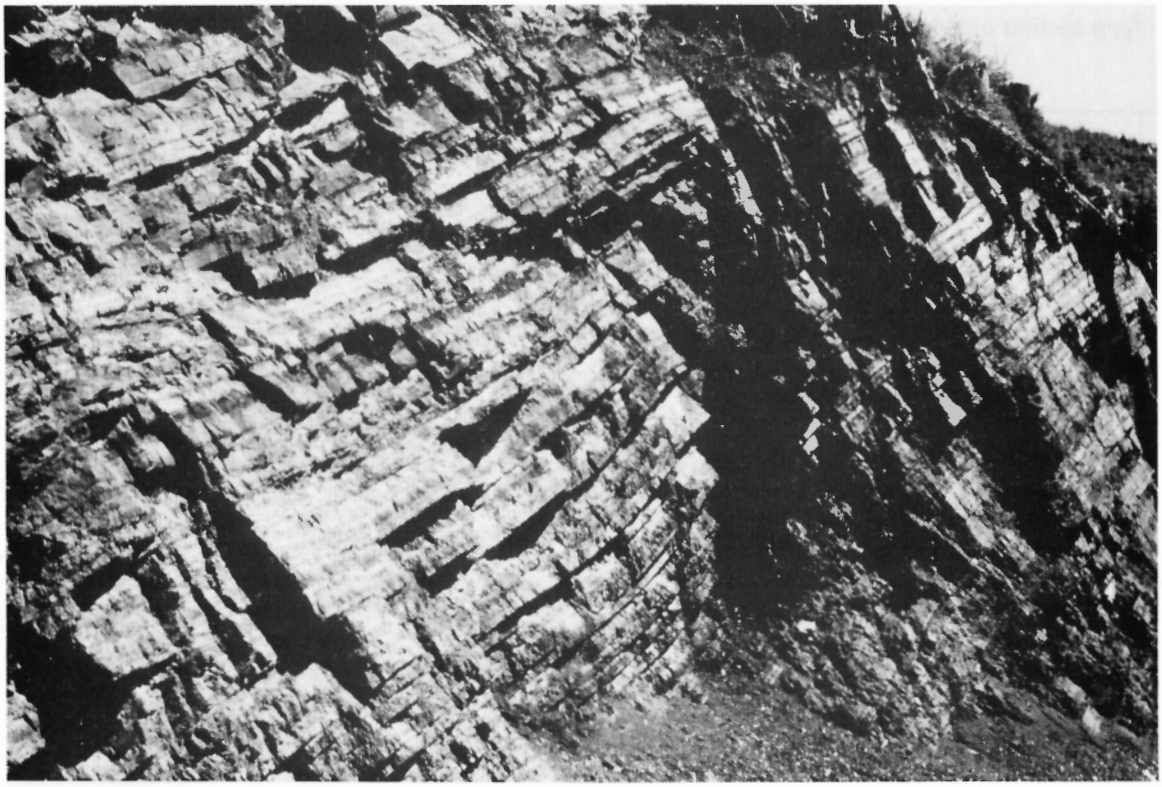

Figure 24. Shale-tuff member, Graham Island Formation. Stratigraphic section 13. Typical banded section near the base of the member. (GSC 190999)

Figure 25. Exfoliation weathering of the volcanic sandstone member of the Graham Island Formation. Ghost Creek area, central Graham Island. (GSC 191000)

Table 5. Type section of Yakoun Group modified after Sutherland Brown

					Thickness in Feet		
			Haida Formation				
MORESBY GROUP			E member				139m
				Poorly exposed crystal lithic tuff and lapilli tuff and(?) volcanic sandstone	370	(113m)	
				Volcanic sandstone and minor conglomerate and pebbly sandstone	50	(15m)	
YAKOUN GROUP	RICHARDSON BAY FM	VOLCANIC BRECCIA MEMBER	D member	Fine crystal lithic tuff	100	(30.5m)	244m
				Cross-bedded volcanic sandstone	50	(15m)	
				Tuff and lapilli tuff	100	(30.5m)	
				Lapilli tuff	20	(6m)	
				Cross-bedded volcanic sandstone, a few brachiopods	50	(15m)	
				Fine porphyritic andesite agglomerate grading to crystal lithic tuff at top	60	(18m)	
			C member	Porphyritic andesite agglomerate, mostly massive with blocks to 3 feet in diameter but most large ones 6 inches to 1 foot	950+	(290m)	290m
				Fault with horizontal movement, fairly important.			
		DARK SANDSTONE MEMBER	B member	Interbedded shale, tuffaceous shale, tuffaceous sandstone and tuff; sharply folded and attenuated near fault; (Chondroceras spp., Stephanoceras sp., belemnites, Pholadomya and other pelecypods, gastropods); mostly from lowest shales; much calcitized wood	100+	(30.5m)	30m
	GRAHAM ISLAND FM.	LAPILLI MEMBER	A member	Fine porphyritic andesite agglomerate	20	(6m)	198m
				Green tuff with some exotic blocks	30	(9m)	
				Lapilli tuff and tuff, buff-weathering, olive, finely scoriaceous, aphanitic fragments in white calcareous cement, becoming less calcareous toward top	600	(183m)	
		MOTTLED SILTSTONE MEMBER		Not recognized by Sutherland Brown			
			Maude Group				

Ammonites collected from the sandstones tend to support this interpretation. A few fine pebble conglomerate lenses near the base of the member at several localities (Fig. 9) thicken to the north and on the Yakoun River are at least 100 m thick. This exposure was discontinuous, however, and not amenable to precise inspection.

External structural relations

The base of the formation is exposed on Road 59, Graham Island (Section 13). Here tuffaceous shale with thin tuff bands, replete with belemnite guards, rests conformably, or with very slight angularity, on Lower Aalenian sandstone of the Maude Group. An hiatus certainly characterizes the contact as beds referrable to the Upper Aalenian and possibly parts of the Lower Bajocian are missing. An abrupt change from sandstone below to shale and tuff above the contact makes it readily identifiable. Contact between the shale-tuff member and the volcanic sandstone member is conformable and gradational, and is marked by a change from dominantly dark shales and siltstones to dominantly green more massive sandstones and siltstones. The upper contact of the Graham Island Formation with the overlying Richardson Bay Formation, although present elsewhere on Graham Island, is nowhere exposed.

In the Skidegate area the mottled siltstone member rests paraconformably across an erosional hiatus on the Maude Group. The contact between the mottled siltstone member and the lapilli member was not observed but is believed to be abrupt. The Lapilli Member passes abruptly and conformably into the overlying Richardson Bay Formation. Due to the complexity of these volcanic units, it is to be expected that contacts are diachronous. A volcanic pile in one area, for example, can be represented by volcanic sandstones in another. Insofar as the Graham Island lithologies have not been observed or reported from Moresby Island, rocks of this age may be represented by volcanic breccias and tuffs to the south. This would indeed make the volcanic breccia member of the Richardson Bay Formation a very diachronous unit (see below).

Origin and depositional environment

As previously stated, the wide range of lithologies represented by the four members of the Graham Island Formation are solely dependent for their development on the distances from the volcanic source. The lower two members of the formation were deposited in a marine environment, the shale-tuff member probably representing the deepest water. The shale-tuff is typically dark, euxinic to some degree, with a low diversity calcareous foraminiferal fauna. No distinctive benthic faunas have been recovered from the mottled siltstone member. It is assumed to represent a somewhat shallower environment. The sequence in central Graham Island becomes shallower marine in the volcanic sandstone member. Faunas of agglutinating foraminifera, bivalves and brachiopods have been recovered. The depositional environment represented by the lapilli member is difficult to interpret. The somewhat poorly bedded and rapid accumulation over a broad area suggest shallow marine or possibly even partly non marine accumulation.

Age and biostratigraphy

The Graham Island Formation is Early Bajocian and its fauna correlates best with the **Docidoceras widebayense** assemblage zone as proposed by Hall and Westermann (1980, p. 19) thus representing the lower half of the Early Bajocian.

The macrofossil preservation is generally poor. Scattered, flattened ammonites are found as faint imprints or slightly distorted specimens. Rarely are they in concretions. Pelecypods are rare, and commonly thin-shelled. Most fossils are found oriented parallel to the bedding plane. Belemnites in some beds, particularly near the base, are common. The fauna of the Graham Island Formation is dominated by ammonites of the family Sonninidae. From the section on Maude Island, Hans Frebold identified **Docidoceras** aff. **D. warmspringsensis** Imlay, **Sonninia** aff. **S. modesta** Buckman, **Docidoceras** sp. indet, **Sonninia** sp. ?. From sections on Graham Island several forms are noted but a careful study has not been undertaken. The following species apparently are present, **Witchellia** sp., **Dorsetensia** sp., **Sonninia** sp., **Guhsania** cf. **G. bella** McLearn, **Bradfordia**? sp., and sonninids with rather simple ornament.

Microfaunas in the Graham Island Formation are rare. Several apparently distinctive species of **Lenticulina, Astacolus** and **Marginulina** have been recovered from the shale-tuff member. Higher in the formation several species of **Marginulinopsis** occur and finally in the shallowest part of the formation agglutinating forms predominate. These include **Ammodiscus, Bigenerina** and **Ammobaculites**, all from the volcanic sandstone member. Radiolaria occur fairly abundantly in the calcareous sandstone interbeds and lenses. No microfaunas have been recovered from the mottled siltstone member nor the lapilli member.

Richardson Bay Formation
Section modified after Sutherland Brown, 1968 (Table 5) and Stratigraphic section 16

The Richardson Bay Formation is one of the most widespread and possibly thickest Jurassic rock unit in Queen Charlotte Islands. It is the most important volcanic unit of the Jurassic. Because of its resistance to erosion it outcrops on many of the higher hills north and south of Skidegate Inlet, particularly the east entrance. The thickness varies dramatically as might be expected in an island arc environment. The section on the north shore of Moresby Island between Alliford Bay and Whiteaves Bay is in excess of 180 m whereas the section measured by Sutherland Brown directly north on Maude Island is reported to be 760 m; faulting may have reduced the Moresby Island section somewhat. The belt of volcanics trending northwest on Moresby and Graham islands, immediately west of Sandspit probably is the thickest section of volcanics. This belt was probably the source area with numerous vents (see Sutherland Brown, 1968, p. 75-76).

The type section of the Richardson Bay Formation is selected as part of Sutherland Brown's "type section, Yakoun Formation" (1968, p. 73). In Table 5 this section is modified and its relation to the proposed nomenclature of this paper is demonstrated. This is the designated type area for the forma-

tion. The name is selected for the exposure at Richardson Bay on Maude Island and eastward. Here the thickness is interpreted to be 435 m but other sections, such as section 16 (165 m) demonstrate a marked reduction in thickness over a short distance. Unmeasured sections on Moresby Island south of Sandspit suggest thicknesses, far in excess of any measured for the formation. On the road to Rennell Sound on the west coast of Graham Island, the formation seems thin, but this can be explained by erosion. A great variation in thickness of such a volcanic unit is to be expected with a thick build up of volcanic material near a vent and an abrupt tapering of the formation on the margins of the vent through slumping and sliding into the adjacent basins. Chaotic bedding, scour and fill structures, and other irregular and nonuniform features are to be expected around an eruptive centre and they are commonly seen. However, as the only Jurassic volcanic unit in Queen Charlotte Islands with thick, very coarse andesitic breccias as the main component, the formation is easily recognized; it is resistant, and forms prominent hills.

Lithology

The Richardson Bay Formation is dominated by volcanic rocks and its make-up varies from place to place. The unifying rock type that apparently is present wherever the unit is found, is a porphyritic andesitic agglomerate or breccia and tuffs. Locally sedimentary rocks, largely derived from volcanic tuffs, form important sections but do not appear to have great lateral extent. The writers did not devote much time to the study of the volcanic rocks *per se* and the reader is referred to Sutherland Brown's exhaustive account (1968, p. 66-72). The formation is divided into two informal members, the volcanic breccia member which is ubiquitous in the formation, and the dark sandstone member which is local in origin and extent.

Volcanic breccia member The volcanic breccia member is composed mainly of porphyritic andesite breccia and tuff in massive beds (Fig. 26) and is poorly sorted (Table 5, designated reference area). In places tuffs and fine breccias are waterlain, well bedded and moderately well sorted (Fig. 27). Blocks of derived fine grained buff sandstones up to 2 m across are common in parts of the unit. Pink-weathering andesite clasts are a fairly common component. Thicknesses are highly variable in the Skidegate area and range from an estimated 530 m on Maude Island (Sutherland Brown, 1968) to only 60 m on northern Moresby Island. This variability is to be expected in volcanic piles across very short distances.

Dark sandstone member The lower member of the formation, the dark sandstone member, is of local extent and lithologically highly variable. In the type area at Richardson Bay (Table 5), it is dark greenish grey with a rich bivalve fauna, much fossil wood and plant debris, and comprises sandstone, shale, and siltstone. The sediments grade laterally into more obviously volcanic detritus. The sediment source for this member is reworked volcanic material. In other areas the interval is represented by volcanic breccias. A few lithologically similar sections closely associated with the volcanic breccia member may or may not be correlative with the dark sandstone member. On Maude Island, the dark sandstone member is 30.5 m thick (Fig. 22). On Moresby Island, however, a thickness of 110 m was measured. This apparent thickening across Skidegate Inlet is thought to be a local phenomenon.

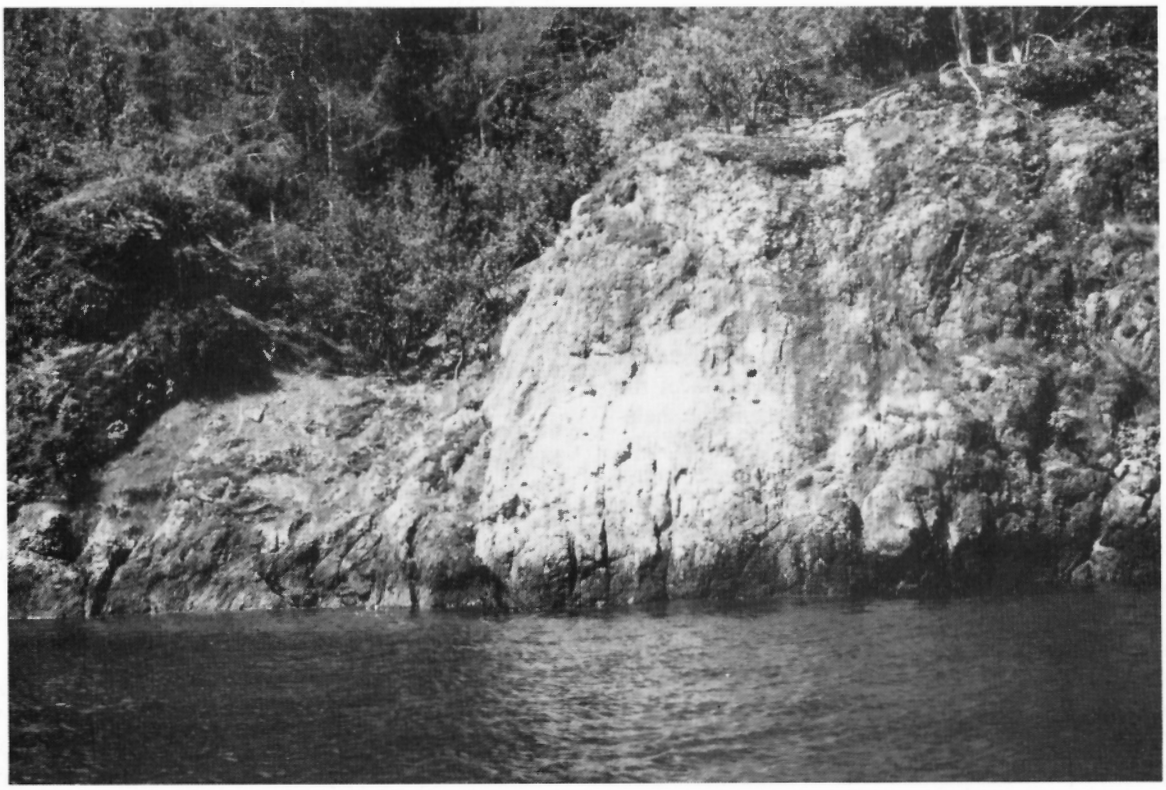

Figure 26. Cliff-forming volcanic breccia member, Richardson Bay Formation on east side of Richardson Bay, Maude Island, Skidegate Inlet. (GSC 191001)

Figure 27. Upper part of volcanic breccia member, Richardson Bay Formation southeast side of Maude Island. Near top of the formation showing banded, moderately fine breccia and tuff. Moresby Group outcrops on Robber Point in middle background. (GSC 191002)

Internal Structural Relations

The Richardson Bay Formation is the result of volcanic eruptions along a northwest-trending belt near the east end of Skidegate Inlet. The formation is thickest along this belt with the highest percentage of coarse volcanic material. Although not proven, there appears to be a thinning of the formation away from this eruptive belt and the development of local sedimentary basins. In different places identical macrofaunas occur in both sediments (dark sandstone member) and in coarse breccias (volcanic breccia member) indicating that the volcanic breccia commonly comprises the entire formation with the concomitant wedging out of the dark sandstone member. Internally the formation is chaotic, but hiatuses within it are not apparent.

External structural relations

The lower contact with the Graham Island Formation is, so far as can be determined, gradational and conformable. It is not readily visible in most places. The upper contact with the Moresby Group may be marked by a slight angular discordance or it may be structurally conformable. The abrupt change from volcanic to sedimentary rocks at the upper contact is marked by distinct pebble conglomerate beds of the Moresby Group west of Robber Point (Fig. 28) and on the northeast side of Alliford Bay. Fossils suggest an hiatus exists between the two groups as no record was found of Late Bajocian and Early Bathonian time.

Origin and depositional environment

Clearly the formation represents pyroclastics from a series of volcanic vents. Sutherland Brown's brief account (1968, p. 75-76) gives a general impression of the origin, particularly of the Richardson Bay Formation. In late Early Bajocian time, great amounts of pyroclastic material accumulated along a northwest-trending line east of Sandspit. The volcanics in places built above sea level as nonmarine beds whereas shallow marine sediments were deposited between those highs. Coal was locally laid down and wood is prevalent in the sedimentary beds. The cessation of volcanism prior to Moresby Group sedimentation was abrupt. This was the main volcanic episode in Jurassic time in Queen Charlotte Islands.

Age and biostratigraphy

The age of the Richardson Bay Formation is confidently determined as late Early Bajocian. Fossils, particularly ammonites, are locally common and, in general, well preserved.

The faunas of the Richardson Bay Formation were discussed in detail in a doctoral study by Russell L. Hall (1976) and in a monograph by Hall and Westermann (1980); the reader is referred to these reports for detailed information. Hall and Westermann placed the fauna of the Richardson Bay Formation in two faunal assemblage zones, the **Chondroceras oblatum** and the upper part of the **Stephanoceras**

kirschneri (i.e. the **Zemistephanus richardsoni** Subzone). The following are lists of faunas recognized in the Skidegate Inlet area by Hall and Westerman (1980, p. 12).

MacKenzie Bay

Zemistephanus richardsoni (Whiteaves)
Z. carlottensis (Whiteaves)
Z. alaskensis Hall
Z. crickmayi (McLearn)
Stephanoceras ex gr. **acuticostatum** Weisert
Chondroceras sp. indet.

South Balch Island

Stephanoceras itinsae (McLearn)
Calliphylloceras sp. indet.
?Eutrephoceras sp. indet.
Chondroceras oblatum (Whiteaves)
C. oblatum (Whiteaves)

Richardson Bay

Stephanoceras skidegatense (Whiteaves)
S. sp. aff. **S. skidegatense** (Whiteaves)
Chondroceras defontii (McLearn)
C. maudense (McLearn)

In addition to the ammonites, the fossil remains include a great variety of pelecypods, belemnites, fossil fruit and plants. Collections by the writers were studied briefly by the late Hans Frebold, Geological Survey of Canada, but nothing new or unusual was found in them.

The coarse and generally volcanic nature of the Richardson Bay rocks are not conducive to the preservation of good microfaunas. A few apparently distinctive forms, however, have been recovered from the dark sandstone member at Richardson Bay. These include **Marginulina turgida** (Schwager), **Marginulinopsis** sp., **Lenticulina** sp. aff. **L. munsteri** (Roemer), **Pseudonodosaria pupoides** (Bornemann), and **Citharina** sp. aff. **C. inconstans** (Terquem). In addition, a few fragmentary ostracods were recovered. Section 16 on Moresby Island represents a shallower environment for the dark sandstone member. Here the faunas are dominated by ostracods and a few agglutinated foraminifers. No ammonites were recovered from Moresby Island.

Regional correlation of the Yakoun Group

The Yakoun Group is important because it is similar to many stratigraphic units in the Cordillera whose highest beds are paleontologically defined as latest Early Bajocian (Table 6). This marked the end of a sedimentary cycle or volcanic episode and was followed by an hiatus of varying duration and, in some areas, tectonism that produced a small angular relation with the next higher unit. Although many of the correlative groups and formations are mainly or entirely sedimentary, most correlative units are, to a greater or lesser degree, volcanic. The volcanics of these units represent the last major volcanic episode of the Jurassic period except for minor events in Callovian to Upper Jurassic time in the

Figure 28. Contact between volcanic breccia member of the Richardson Bay Formation and basal conglomerate of the Robber Point Formation. Recessive weathering Robber Point and Newcombe formations in background at Robber Point, eastern Maude Island. (GSC 191003)

Table 6 Groups and formations of the Canadian Cordillera that are correlated in whole or in part with the Yakoun Group

GROUP OR FORMATION	AGE	LOCATION	LITHOLOGY
Harrison Lake	Early Bajocian	Hope 92H	Andesitic to basaltic pyroclastic rocks
Ladner Gp. (in part)	Early Bajocian and older	Hope 92H	Tuffaceous siltstone, fine breccia, shale, greywacke
Tyaughton Gp. (in part)	Early Bajocian and older	Tasseko Lakes 92O Mt. Waddington 92N	Shale, siltstone
unnamed (in part)	Early Bajocian and older	Prince George 93G	Siltstone, shale
Smithers Fm.	Early Bajocian	Smithers, Hazelton, McConnell Creek, Whitesail Lake, Nechako River, 93L, 93M, 93E, 93G, 94D	Tuff, breccia, volcanogenic sediments
Spatsizi Gp.	Early Bajocian and older	Spatsizi 104H	Tuffaceous siltstone, shale, sandstone limestone
Toodoggone Volcanics (in part)	Early Bajocian and older	Telegraph Creek 104G Cry Lake 104I Spatsizi 104H	Andesitic to basaltic flows and pyroclastic rocks, siltstone
Takwahoni Fm. (in part)	Early Bajocian and older	Tulsequah 104K	Siltstone, shale, greywacke, tuff
Laberge Gp.	Early Bajocian and older	Whitehorse, 105D Laberge 105E Carmacks 115I	Conglomerate, shale, silstone, greywacke
Rock Creek Member of Fernie Formation	Early Bajocian	Southern Rocky Mountains, 83E, 83C, 82O, 82J, 82G	Sandstone, shale

southern Coast Mountains and on the Skeena Arch. In Queen Charlotte Islands the Yakoun Group represents the last volcanic episode in the Mesozoic era.

Moresby Group

The Moresby Group comprises the sedimentary beds previously referred to informally as Upper Yakoun or upper part of Yakoun Formation but more specifically is equivalent to Sutherland Brown's member E and part of member D of the "Yakoun Formation" (1968, p. 73). It has been separated from" Yakoun Formation" because of its sedimentary character in contrast to the redefined Yakoun Group which is predominantly volcanic and because of an apparent major hiatus at the top of the Yakoun volcanics. The name is derived from the group's exposure on the north end of Moresby Island around Alliford Bay, west of Sandspit.

Distribution and thickness

The Moresby Group is exposed around Alliford Bay on Moresby Island, on the south side of Robber Point at the east end of Maude Island, and at Newcombe Bay on the northeast side of Maude Island. These localities are all on Skidegate Inlet. Elsewhere in the Queen Charlotte Islands the group has not been identified. However, an ammonite sent to the writers from Riley Creek on the east side of Rennell Sound suggest that the group may occur there. Fossils collected by Sutherland Brown at Iron Point near the south end of Moresby Island also may suggest a wider distribution of the group. In addition, past confusion with the Haida Formation sandstone may be reason to expect that more exposures around the islands exist than are now recognized, particularly in the forested interior of Graham Island.

The thickness of the group is variable (Fig. 29). At Robber Point (Section 17) it is 160 m thick, at the section on west side of Alliford Bay (Section 16) approximately 635 m, and at Newcombe Bay (Section 18) the sequence is less than 100 m but the base is not exposed.

Lithology

The stratigraphy of this unit was discussed in an earlier paper by the writers (Tipper and Cameron, 1980).

Within the new nomenclature the Moresby Group is divided into three new formations: Robber Point Formation at the base, the Newcombe Formation, and the Alliford Formation at the top. These units were described but not named previously (Tipper and Cameron, 1980, p. 37-38). This discussion is paraphrased below.

The Robber Point Formation is named for a section near the east end of Maude Island (Fig. 29) and the type section (Section 17) was measured there as a basal unit below the sandstone of the Newcombe Formation. The lithologies of the formation are varied. On Robber Point are soft grey siltstones

replete with pelecypods, gastropods, ostracods, and foraminifers. Near Kwuna Point, rocks consist of volcanic breccia and tuffaceous sandstone. At Fossil Point coarse volcanic sandstones and tuffs outcrop. Although these rocks are generally volcaniclastics it is not clear whether they were derived from contemporary volcanism or from the earlier Yakoun volcanic rocks. Probably both possibilities are correct and some of these rocks are the last products of Mesozoic marine volcanism in Queen Charlotte Islands.

The base of the Robber Point Formation is marked by a pebble conglomerate composed of closely packed, well-rounded and sorted clasts of volcanic rock derived from the Yakoun Group. The bed is rarely more than a metre thick but in places there are two or more beds separated by fine volcanic breccia.

The sandstone beds of the Newcombe Formation (Section 18, designated type section) are mainly massive volcanic concretionary sands passing downward into well-bedded sands 10 cm or less in thickness. Generally the bedding is even and planar but on the northeast flank of the syncline near Kwuna Point crossbedding suggests a current direction from the north or northeast. The massive sands and the thicker beds below are commonly concretionary with large pelecypods and relatively rare belemnites and ammonites embedded in the concretions. The sands generally weather buff or pale green and the clastic material is volcanogenic. These sandstones are apparently distributed throughout all parts of the syncline.

The siltstone beds of the Alliford Formation near the top of the section exposed in Alliford Bay (Section 16, designated

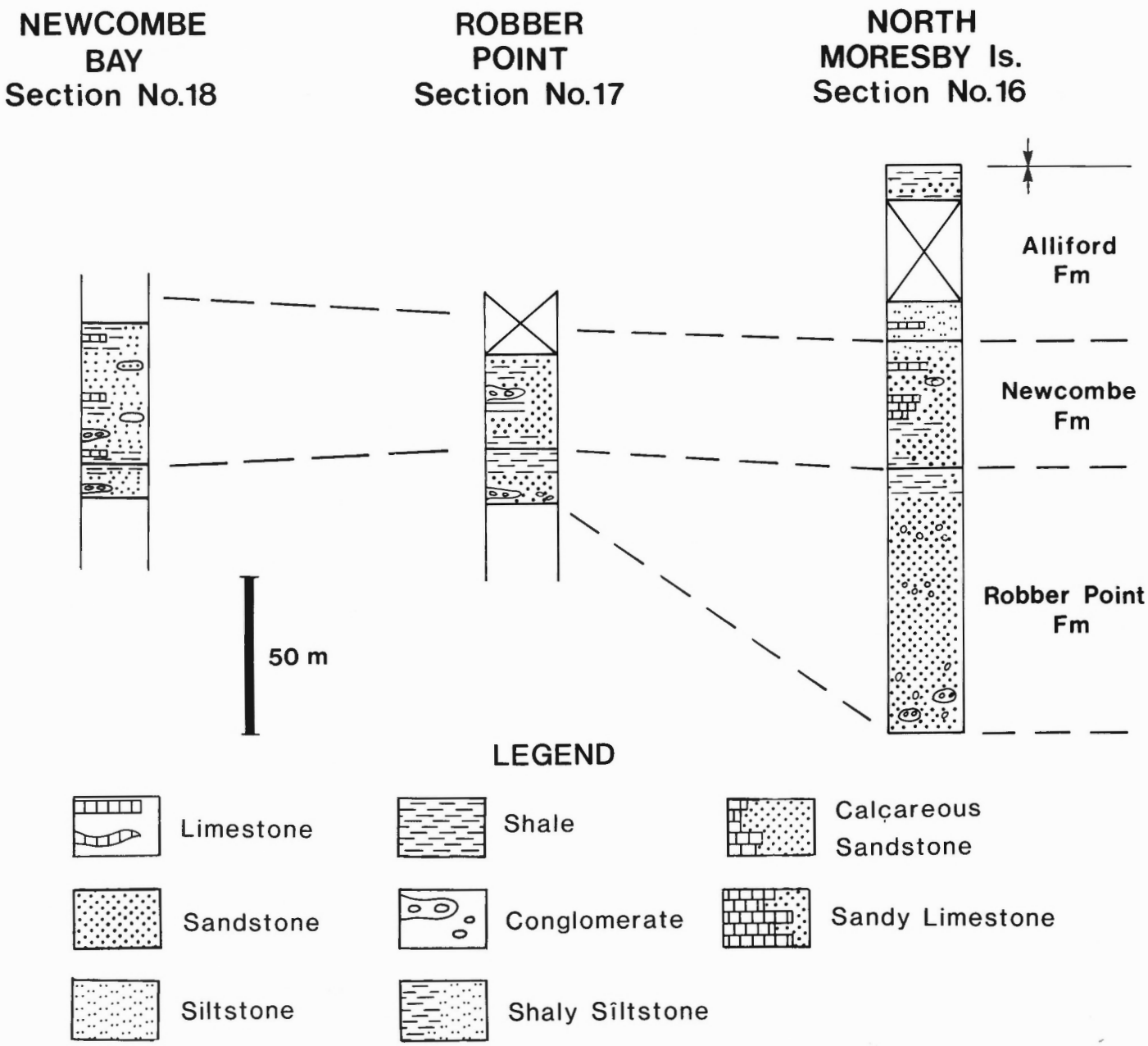

Figure 29. Stratigraphy of the Moresby Group, Skidegate Inlet

type section) are grey to grey-buff, soft, poorly laminated and contain pelecypods, a few ammonites, rare belemnites, abundant ostracods, and abundant foraminifers. Some of the macrofossils are contained in small concretions.

Sections 16 and 17 clearly illustrate the lateral changes and the variable nature of the beds. Without fossils, the sandstones of the Moresby Group are very difficult to distinguish from the Cretaceous Haida Formation. The Moresby Group bears no similarity to the Yakoun Group and is easily distinguished from the Maude Group and older units on lithologic grounds alone.

Internal structural relations

The Moresby Group is a conformable sequence of sedimentary rocks. The sandstones of the Newcombe Formation at Newcombe Bay, Robber Point, and Fossil Point appear to be laterally persistent, but the rocks underlying the sandstones, the Robber Point Formation, vary greatly in lithology and thickness with rapid facies changes which are to be expected in this minor transgressive sequence.

External structural relations

As already described the contact between the Yakoun and Moresby groups is structurally conformable but marks an hiatus in deposition during Late Bajocian and Early Bathonian time. The development of pebble conglomerate with well-rounded clasts of volcanic rock argues strongly for erosion and reworking of underlying Yakoun Group material.

The Albian Haida Formation overlies the Moresby Group on Maude Island and around Alliford Bay. Although the contact is not well exposed, no doubt exists that it marks an angular discordance and an hiatus of major importance. Elsewhere in Queen Charlotte Islands, beds of Late Jurassic (Tithonian) and Early Cretaceous (Valanginian to Hauterivian) age would account for some of the time interval, but in Skidegate Inlet area there is no record.

Origin and depositional environment

The Moresby Group was deposited after the volcanism of the Yakoun Group had essentially terminated. Erosion of the Yakoun Group prior to deposition of the Moresby Group produced a somewhat subdued but irregular basin within the volcanic terrane. Earliest deposition filled the depressions of the surface producing rapid facies changes and a variety of rock types (Robber Point Formation). Later deposition consisted of coarse sand on a more or less smooth surface under shallow waterconditions wherein a prolific pelecypod fauna thrived (Newcombe Formation). Paleocurrent indicators are rare, but one or two features suggest a northeast to southwest direction of transport. The final episode was a sandstone to siltstone sequence (Alliford Formation) with abundant pelecypods and a few ammonites.

Age and biostratigraphy

The age of the Moresby Group is well established by contained ammonites and is graphically outlined in our earlier paper (1980, p.39) in which five faunas are recognized in descending order:

1. **Kepplerites spinosum** (Imlay)
2. **Cadoceras doroschini** (Eichwald)
3. **Oppelia (Oxycerites) aspidoides** (Oppel)
4. **Kepplerites (Seymourites)** spp.
5. **Iniskinites cepoides**

All the ammonite faunas, with the exception of the **Kepplerites spinosum** fauna, are from the Newcombe Formation. The **Iniskinites cepoides** fauna is believed to be Late Bathonian and the **Cadoceras doroschini** faunas is probably Lower Callovian. The **Oxycerites** and **Seymourites** faunas are either Callovian or Bathonian but must wait until studied further in another area to be more precise. The **Kepplerites spinosum** fauna from the Alliford Formation is thought to be Callovian, probably Early Callovian.

One ammonite collected from the Alliford Bay area by Sutherland Brown is identified as **Cadoceras** sp. Several similar or identical specimens were collected by J. Newcombe in 1897 from Alliford Bay, presumably from the Alliford Formation and probably below the **Kepplerites spinosum** fauna. These latter specimens are with the British Columbia Provincial Museum.

No ammonites have been found in the Robber Point Formation. It lies between the Upper Bathonian Newcombe Formation and the late Lower Bajocian Richardson Bay Formation. As the Robber Point Formation has an apparent hiatus at the base and appears to be uninterrupted sedimentologically with the overlying formation, the preferred age of the formation is Bathonian.

The bivalve fauna has been studied and updated by T.P. Poulton (1981, p. 63-71). Although this fauna does little to date the formation more closely, it does confirm ideas on environment of deposition and ecological conditions. The reader is referred to Poulton's publication for a fuller discussion of the varied bivalve fauna.

Microfaunas from the Robber Point and Alliford formations were briefly mentioned in an earlier publication (Tipper and Cameron, 1980). The microfauna of the Robber Point is indicative of a shallow marine transgressive cycle. Ostracods are common whereas foraminifers are quite abundant and include; **Nodosaria fontinensis** Terquem, **N. opalini** Brand, **Tristix** sp., **Geinitzinita** sp., **Falsopalmula radiata** (Terquem), **Pseudolamarckina** sp. and other species of **Citharina, Lenticulina, Marginulina** and **Astacolus**. The microfauna of the Callovian Alliford Formation is much more diverse in radiolarians, ostracods and foraminifers. The environment of these darker shales is clearly deeper than the underlying Robber Point and Newcombe formations. Foraminifers of the Alliford Formation include **Conorboides** sp., **Reinholdella** sp., **Citharinella moelleri** (Uhlig), **Citharina flabellata** (Gumbel), **C. inconstans** (Terquem), **C. proxima** Terquem, **Lenticulina quenstedti** (Gumbel). **Falsopalmula franconica** (Gumbel), and other species of **Marginulina, Astacolus** and **Pseudonodosaria**. Many of these forms appear to have quite restricted ranges and should prove to be useful biostratigraphic markers.

Table 7 Groups and formations of the Canadian Cordillera correlated in whole or in part with the Moresby Group

GROUP OR FORMATION	AGE	LOCATION	LITHOLOGY
Unnamed	Middle and Early Callovian	Vancouver Island 92E	Shale, siltstone
Relay mountain (in part)	Early Callovian and later	Taseko Lakes 92O Mt. Waddington 92N	Siltstone, shale, greywacke, conglomerate
Ashcroft Formation (in part)	Early Callovian	Ashcroft 92I	Shale, siltstone
Mysterious Creek Fm.	Early Callovian	Harrison Lake 92H	Shale, siltstone
Ashman Formation	Late Bajocian to Early Oxfordian	Smithers 93L Whitesail Lake 93E Hazelton 83M McConnell Creek 94D Spatsizi 104H	Shale, siltstone, conglomerate, sandstone
Fernie Formation (in part)	Bathonian – Callovian	Southern Rocky Mountains, 83C, 82O, 82J, 82G	Shale

Regional Correlation of the Moresby Group

Several groups and formations throughout British Columbia are correlative in whole or in part with the Moresby Group (Table 7). In all cases the units are totally or mainly sedimentary. In all units the dominant lithology is shale. Most units are deposited in successor basins that were formed after the cessation of volcanism or after a tectonic episode. Some were formed, apparently, on the allochthonous terranes after they were amalgamated and could in some cases be described as overlap sequences. The oldest basal beds in any of these sequences is Late Bajocian, but this is unusual; commonly the oldest beds are Late Bathonian or Early Callovian. The sequences commonly rest unconformably on Early Bajocian or older strata as the Moresby Group does.

Upper Jurassic sediments

Distribution and thickness

On the west coast of Graham Island, on a small island approximately 35 km southwest of White Point, a short section of sandstone and conglomerate is exposed (Fig. 30). Contained fossils indicate the strata are Late Jurassic, an age not previously indicated by fossils in Queen Charlotte Islands.

Although only the small island is known to have Upper Jurassic strata, other unfossiliferous sections may belong to this formation. As this island was mapped previously as Cretaceous Honna Formation (Sutherland Brown, 1968), other sedimentary exposures identified as Cretaceous along the west coast may in reality be part of this unit. The maximum thickness in unknown.

Lithology

Friable sandstone and pebble conglomerate in fairly massive beds comprise the outcrop on the small island. One bed of sand has an abundance of small bivalves, much broken and abraded. The conglomerate has an abundance of well-rounded granitic clasts.

The sediments are suggestive of a beach deposit. A high energy environment is indicated by the destruction of the enclosed shells. Certainly it was very shallow and nearshore.

Structural relations

As these beds have not been seen in contact with other formations, relations are unknown. However, lithologically they are unlike any of the older Jurassic strata and suggest a different basin of deposition. This, together with the fact that most of Callovian to Tithonian time has not been indicated by fossils in Queen Charlotte Islands, suggests a major unconformity exists below the formation. The relation with the younger Longarm Formation is also speculative; it could be unconformable or conformable. The beds could represent the basal beds of the Longarm Formation of known Early Cretaceous age. If such were the case it would be reasonable to correlate the total sequence with the many Upper Jurassic-Lower Cretaceous successor basin assemblages in British Columbia such as Relay Mountain Group (Jeletzky and Tipper, 1968) or Dewdney Creek Group (Coates, 1974).

Age and correlation

Fossils from the sandstones were identified by J.A. Jeletzky, Geological Survey of Canada, as follows:

Locality:
Small Island south of White Point, west side Graham Island. Lat. 53°58′15″N.; Long. 133°08′30″W. GSC loc. C-081990.

Identifications: **Buchia** cf. **B. fischeriana** (d'Orbigny) s. lato (a few poorly preserved shells). **Buchia** cf. **B. terebratuloides** (Lahusen) s. lato (a few poorly preserved shells). **Buchia** cf. **elderensis** (Anderson) (= ?**B.** n. sp. aff. **piochii** Gabb of earlier papers of Jeletzky and GSC Paper 67-54, p. 9-11) **Buchia** sp. apparently belonging either to small variant of **B.** cf. **blanfordiana** of Jeletzky 1965 or to the late form of **B. mosquensis** s. str. (a few poorly preserved specimens).

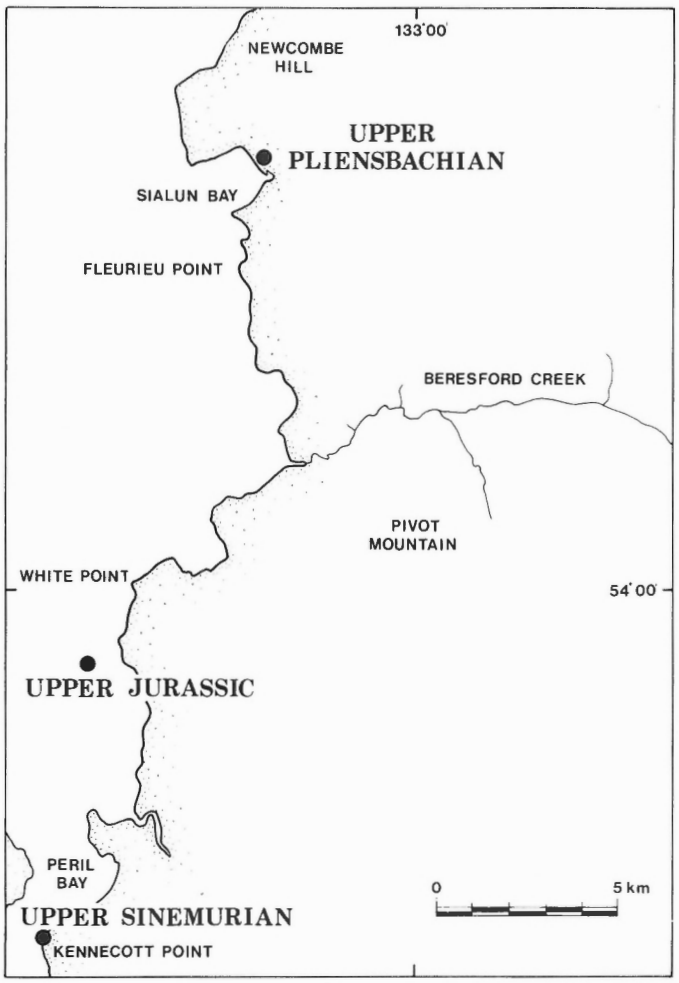

Figure 30. Jurassic fossil localities, northwest Graham Island

Comments: Though poorly preserved and scarce, the **Buchia** fauna of the lot #C-081990 is of a late Late Jurassic age. It can be either of mid- to Late Portlandian (s. str.) or late Late Tithonian age. The choice between these assignments is difficult but I am inclined to place this lot tentatively into the lower part of the latest Tithonian (or latest Volgian) **Buchia terebratuloides** s. lato zone where **Buchia fischeriana** s. lato and **B. piochii** s. str. have almost disappeared and **Buchia** n. sp. aff. **okensis** is still very rare. However, the material is too fragmentary and too scarce to rule out its reference to the lower part of the mid- to Late Portlandian s. str. **Buchia** cf. **blanfordiana** and those of **Buchia elderensis** Anderson (= ?**B.** n. sp. aff. **piochii** of the earlier papers of Jeletzky and the GSC Paper 67-54, p. 9-11) may be indistinguishable from **B. fischeriana** s. lato and **B. terebratuloides** s. lato in a poor preservation characteristic of collection C-081990.

JURASSIC FORMATIONS OF QUEEN CHARLOTTE ISLANDS AND SOME BROADER CONSIDERATIONS

In recent years the study of continental tectonics has involved the concept of terranes accreted to the cratonal margin by collision and/or by transcurrent translation of large segments of strata or terranes. The number of terranes recognized is many, depending on how finely one discriminates the packages. The Queen Charlotte Islands clearly show strong affinities to Vancouver Island, part of the mainland, and parts of Alaska, particularly in Triassic rocks, e.g., the Karmutsen volcanics, but in Jurassic strata the similarities are less apparent. Those areas are referred to as the Wrangellia Terrane.

The Wrangellia Terrane is believed to have been transported northward from its place of origin. Paleomagnetic studies have strongly indicated that Karmutsen volcanics of Triassic age were formed at a latitude many hundreds of kilometres farther south. Triassic faunas are clearly the product of a low latitude environment. But what of the Jurassic strata? The Jurassic faunas of the Queen Charlotte Islands, when examined from a paleobiogeographic viewpoint, show some interesting affinities that were reviewed recently (Taylor *et al.*, 1984) as part of a larger study. The ammonite biogeography relating to the Queen Charlotte Islands is briefly summarized.

Ammonite biogeography

The Jurassic ammonite fauna of Queen Charlotte Islands at different times indicates association with Tethyan, Boreal, and East Pacific Realms as well as including many genera that are informally described as pandemic and "Pacific" (Taylor et al., 1984). The Sinemurian fauna is in general pandemic with nothing strongly suggesting either Boreal or Tethyan influence; only one locality, with a fauna including **Badouxia**, suggests a distribution restricted to the Pacific.

The Pliensbachian faunas are typically Tethyan in affinities. In Early Pliensbachian time Tethyan genera such as **Dayiceras** and **Metaderoceras** abound, associated with numerous specimens of pandemic forms such as **Acanthopleuroceras** and **Tropidoceras**. The Late Pliensbachian substage was the time of strongest provincialism in Early Jurassic time. The faunas of this time in Queen Charlotte Islands were, in general, mainly hildoceratids of Tethyan affinities such as **Arieticeras, Fuciniceras**, and others. One genus, **Fanninoceras**, is characteristic of the East Pacific realm. Ammonites of Boreal affinities, such as amaltheids or liparoceratids, are extremely rare, consisting in total of about five specimens

Toarcian ammonites are mainly pandemic although much work needs to be done on the fauna; one Tethyan form, **Paroniceras**, has been identified. The Aalenian ammonites are rare, comprising one pandemic genus, **Tmetoceras** and one Boreal genus, **Erycitoides**.

The Early Bajocian ammonites are abundant but, except for one genus, are considered pandemic. The one exception, **Zemistephanus**, is typical of Athabaskan Province of the East Pacific Realm and its type locality is, in fact, in Queen Charlotte Islands. The Late Bathonian **Iniskinites** fauna is considered to be an East Pacific Realm representative and the Early Callovian **Kepplerites loganianus** fauna is Sub-Boreal in affinities.

The ammonite faunas of Queen Charlotte Islands are generally pandemic in Sinemurian and Early Pliensbachian time, with important Tethyan forms in Early Pliensbachian time, dominant Tethyan forms in Late Pliensbachian time and a trend toward pandemic forms in the Toarcian to Early Bajocian time span. Minor Boreal incursions occurred in Late Pliensbachian, Aalenian and Early Callovian time. Aside from these minor incursions, the faunas of the Queen Charlotte Islands are notably pandemic with a very strong Tethyan influence.

Significance of the mineral chamosite

The discovery of chamosite in the Late Pliensbachian beds has a geographic significance. Assuming the validity of Hallam's (1984) contention that Jurassic chamosite occurrences are at the latitude of the Mediterranean, approximately 30° north, then the occurrence of chamosite in Queen Charlotte Islands is anomalous at latitude 53°N. If the chamosite were formed at the latitude of the Mediterranean Sea, then a northward translation of Queen Charlotte Islands since Jurassic time of some 1500 km can be suggested.

Faunal evidence for displacement of wrangellia

Studies of Jurassic biogeography, (Tipper, 1981; Taylor et al. 1984; Imlay, 1980; Imlay and Detterman, 1973) suggest the northward movement of Wrangellia in the order of 2500 km. Cameron's study of the foraminifera strongly indicates the dominant Tethyan influence in the microfauna but does not suggest the amount of movement; it must have been large.

The Tethyan affinities of the Jurassic faunas as a whole, both microfauna and macrofauna, the very large numbers of genera and species of all faunas, and the common abundance of individuals in a collection argues convincingly for origin in a low-latitude basin. This is further supported by the development of the lateritic mineral chamosite. The evidence evolving from this study supports the paleomagnetic evidence for a northward translation of Queen Charlotte Islands, possibly from the latitude of northern Mexico.

Eustatic sea level changes

The relative water depths indicated by the Jurassic rocks of the Queen Charlotte Islands (Fig. 31) show a remarkable correspondence with the sea level fluctuations in the model proposed for worldwide eustatic cycles of the Jurassic (Hallam, 1978, 1981). Corresponding high sea levels are noted for the Sinemurian, Lower Pliensbachian, Middle Toarcian, Lower Bajocian and Lower Callovian. Regressive phases in common include the Upper Toarcian to Aalenian and Early Bathonian. Other parts of the Jurassic sequence are unknown or missing on the Queen Charlotte Islands.

Two intervals of dissimilarity between the curves can be explained by local effects of tectonics or sedimentation. The Sinemurian rocks of the Queen Charlotte Islands which do not reflect the sea level fluctuations indicated by Hallam's curve, were deposited probably in a deep water euxinic basin relatively far removed from the sediment source area where fluctuations in sea level would not be as manifest as they would be in a more proximal facies. A second interval of uncertainty occurs in the late Lower Bajocian to Lower Bathonian. That time is represented in the Skidegate Inlet area by a thick volcanic pile and, in part, by a very shallow marine facies. The mass of volcanic material was sufficient probably to mask any local sea level change.

Jurassic climate

Two pieces of evidence bear on the climate that may have existed in Jurassic time. These are the occurrence of chamosite and the presence of coal and plants.

The presence of chamosite in the Fannin member indicates a continental lateritic source area where iron can be preconcentrated. Confirmation of the climatic value of this iron mineral comes from its "characteristic association with kaolinitic clays (Hallam, 1984)". Commonly kaolin is one of the chief minerals deposited from erosion of a lateritic area, a good indicator of a warm humid climate.

Within the Yakoun Group, Richardson Bay Formation, coal deposits, plant material, and microflora (Sutherland Brown, 1968, p. 69) indicate a fairly lush forest was present in Bajocian time with abundant rainfall, and probable a subtropical to temperate climate.

ECONOMIC RESOURCES

During the course of these detailed stratigraphic studies, many features of the rocks bear on their economic potential. Of particular importance are those related to oil and gas potential and to a lesser extent with possible coal reserves. A brief account of the hydrocarbon occurrences was presented previously (Cameron and Tipper, 1981); the present report confirms some of these early observations and supplements them with new information.

Oil and gas

Bitumen and/or dead oil occurrences have been noted in the Sinemurian Sandilands Formation, the Pliensbachian Ghost Creek and Rennell Junction formations, the Toarcian Whiteaves Formation and in the Bajocian Richardson Bay and Graham Island formations. Sutherland Brown (1968) suggested that some of these occurrences especially in the Bajocian may be distillates of "woody material". Organic geochemistry studies undertaken from many horizons throughout the Jurassic as well as younger units, indicate that the tars represent normal petroleum type hydrocarbons of algal origin (T.S. Hamilton, personal communication, 1983) and not wood distillates. Macauley (1983) carried out extensive geochemical studies of the Sandilands and Ghost Creek formations in Skidegate Inlet, Yakoun River, and Rennell Sound areas, confirming the earlier identification of the Sandilands and Ghost Creek formations as hydrocarbon source beds (Cameron and Tipper, 1981) and further suggested that the hydrocarbons have at least in some areas

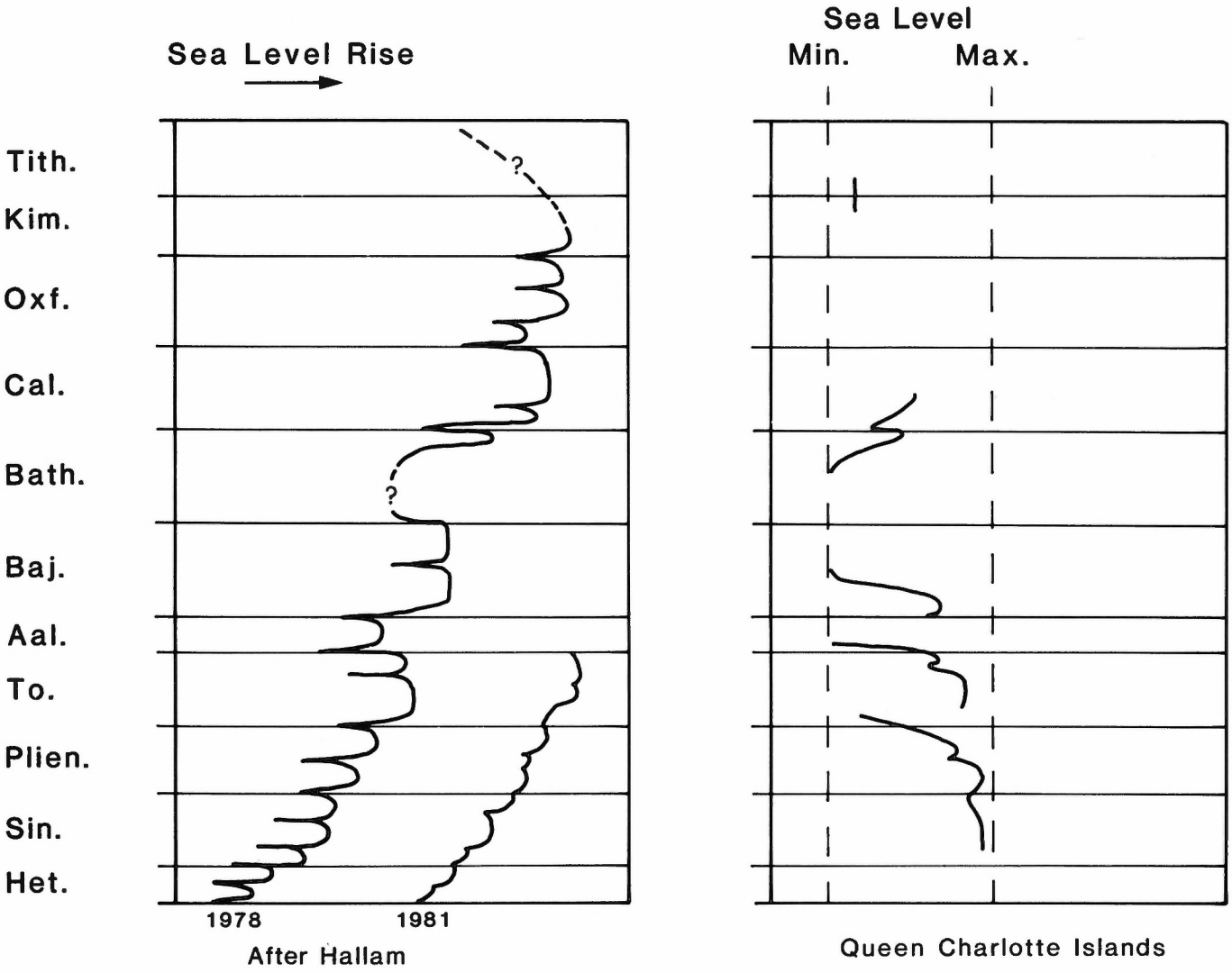

Figure 31. Comparison of eustatic curves for the Jurassic, worldwide, and for the Queen Charlotte Islands

migrated subsequent to their generation. The remaining problems are; 1) when was this migration relative to the emplacement of the Tertiary Masset volcanics, and 2) what is the areal distribution of the Jurassic source beds.

The Masset Formation consists of a relatively thick sequence of principally Miocene volcanic rocks covering much of northwest Graham Island and is variously present in subsurface beneath Hecate Strait to the east. The Masset could form an effective cap over any underlying hydrocarbons of Mesozoic age. Conversely, where the Masset is missing or breached, migration is possible into younger Tertiary rocks. This is believed to be the case in Hecate Strait, where the only oil show encountered during Shell Canada's offshore drilling program occurred where the Masset is apparently missing (Shouldice, 1971, p. 414) and a nonmarine sandstone of early Pliocene age is oil stained. It seems reasonable to suggest therefore that it is escape oil and that migration occurred at least in part after the early Pliocene (i.e. after the generation of the Masset volcanics).

If the above interpretation is valid, the possibility of oil accumulation beneath the Masset Formation over much of northeastern Graham Island depends solely on the distribution of source rocks in subsurface. To date, any investigations of the pre-Masset possibilities have been either precluded for a number of geological reasons, including metamorphic overmaturation (Sutherland Brown, 1968, p. 179), or logistical inability to drill through the Masset Formation. Macauley (1983) identified a broad band of Jurassic rocks extending from Rennell Sound to Skidegate Inlet as being geochemically overmature. The same rocks in the Yakoun River area he classified as mature. This suggests that central Graham Island beneath the Masset volcanics, may be an effective area for an exploration program to assess the possibilities of Mesozoic oil accumulation.

Similarly, recent evidence suggests the presence of relatively thick Mesozoic rocks beneath the Masset in Hecate Strait and Queen Charlotte Sound. If the Jurassic source beds are present in these areas, hydrocarbons may be trapped

beneath the Masset or in some of the porous sandstones of Cretaceous age. It seems reasonable to suggest that any Tertiary oil play will involve Mesozoic escape oil as we suspect that little if any Tertiary oil (i.e. post-Masset) has been generated *in situ*.

Oil shales

Since the early 1970s interest has been expressed by various organizations in the oil shale potential of the Sinemurian Sandilands Formation. In 1974 Skaist Mines Ltd. conducted extensive geological mapping and sample assessments of its properties, principally in the Yakoun River and Rennell Sound areas. In 1978-79 these properties were further investigated by Intercoast Resources Ltd. who carried out a program of drilling through parts of the Ghost Creek and Sandilands formations. The operators kindly allowed the writers to examine these cores and a description of the sequences are included here (Stratigraphic sections 1,2,3). In his oil shale assessment of the Queen Charlotte Islands, Macauley (1983) conducted total organic carbon analyses and applied rock-eval pyrolysis techniques to those drillholes and to rocks from other surface exposures. He concluded that the rocks of the Rennell Sound area had little value for oil shale development due to overmaturity. The rocks of the central Graham Island area, however, contain some high-grade kerogen lenses but not in such abundance as to be economical at this time.

Coal

A good summary of the coal deposits of the Queen Charlotte Islands was given by Sutherland Brown (1968, p. 177-178).A few additional comments on coal of the Jurassic are included here. Carbonaceous debris, fossil wood and megaspores are known to occur in varying amounts throughout the Jurassic sequence. The oldest coal occurrences currently known are in the Toarcian Whiteaves Formation in the Yakoun River area. There the coal occurs as infrequent small rounded grit-sized particles near the base of the formation. The source of the clastic coal particles is not known. The stratigraphically younger Richardson Bay Formation has abundant fossil wood and coal pockets in the dark sandstone member of the Skidegate Inlet area. Actual coal beds or lenses are little developed, however, and are apparently of little economic value. To the north, around Wilson Creek, coal is well developed within the volcanic sandstone member of the Graham Island Formation. The coal there is lenticular, interbedded with shale and sandstone and was deposited near a marginal marine environment. Consequently the coal seams are not considered as sufficiently laterally continuous to be of much economic value at this time. No other significant coal occurrences in the Jurassic are known.

SELECTED BIBLIOGRAPHY

Billings, E.
1873: On the Mesozoic Fossils from British Columbia collected by Mr. James Richardson in 1872; Geological Survey of Canada, Report of Progress, 1872-1873, p. 71-75.

Brooke, M.M. and Braun, W.K.
1972: Biostratigraphy and microfaunas of the Jurassic System of Saskatchewan; Saskatchewan, Department of Mineral Resources, Report no. 161, 83 p.

Brouwer, J.
1969: Foraminiferal assemblages from the Lias of North-Western Europe; Verhandelingen Koninklijke Nederlandse Akademie van Wetenschappen. Afdeling Naturrkunde; v. XXV, no. 4, 48 p.

Cameron, B.E.B. and Tipper, H.W.
1981: Jurassic biostratigraphy, stratigraphy, and related hydrocarbon occurrences of Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 209-212.

Carter, E.S.
1985: Early and Middle Jurassic radiolarian biostratigraphy, Queen Charlotte Islands, British Columbia; unpublished M.Sc. thesis, University of British Columbia.

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

Coates, J.A.
1974: Geology of the Manning Park area, British Columbia; Geological Survey of Canada, Bulletin 238.

Coney, P.J. Jones, D.L. and Monger, J.W.H.
1980: Cordilleran suspect terranes; Nature, v. 288, no. 5789, p. 329-333.

Crickmay, C.H.
1928: The stratigraphy of Parsons Bay, B.C.; University of California Publication, Bulletin, Department of Geological Sciences, v. 18, no. 2, p. 51-70.

Dawson, G.M.
1880: Queen Charlotte Islands; Geological Survey of Canada, Report of Progress, 1878-1879.

1889: On the earlier Cretaceous rocks of the northwest portion of the Dominion of Canada; American Journal of Science, 3rd Ser. v. 38, p. 295-305.

Dowling, D.B.
1906: Cretaceous section in the Moose Mountain district, southern Alberta; Geological Society of America, Bulletin, v. 17, p. 295-302.

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

Exton, J.
1979: Pliensbachian and Toarcian Microfauna of Zambujal, Portugal; Systematic Paleontology. Carleton University, Geological Paper 79-1, 103 p.

Franke, A.
1936: Die Foraminiferen des deutschen Lias; Preussische Geologische Landesanstalt, Abhandlungen, 138 p.

Frebold, H.
1967: Hettangian ammonite faunas of the Taseko Lakes area; Geological Survey of Canada, Bulletin 158.

Gabilly, J.
1976: Le Toarcien a Thours et dans le centre-ouest de la France: Les stratotype Francais; Comite Francais de stratigraphie, C.N.R.S., Paris, v. 3.

Giresse, P. and Odin, G.S.
1973: Nature mineralogique et origine des glauconies du plateau continental du Gabon et du Congo. Sedimentology, v. 20, p. 457-488.

Gordon, W.A.
1967: Foraminifera from the Callovian (Middle Jurassic) of Brora, Scotland; Micropaleontology, v. 13, no. 4, p. 445-464.

Guex, J. and Taylor, D.
1976: La limite Hettangien – Sinemurien, des Prealpes romandes au Nevada; Eclogae geologicae Helvetiae, v. 69, no. 2, p. 521-526.

Hall, R.L.
1976: Lower Bajocian (Jurassic) ammonoid faunas of the western Americas; unpublished Ph.D. thesis, McMaster University, Hamilton Ontario.

Hall, R.L. and Westermann, G.E.G.
1980: Lower Bajocian (Jurassic) cephalopod faunas from western Canada and proposed assemblage zones for the Lower Bajocian of North America; Paleontographica Americana, v. 9, no. 52.

Hallam, A.
1978: Eustatic cycles in the Jurassic; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 23, no. 1/2, p. 1-32.

1981: A revised sea-level curve for the early Jurassic; Geological Society of London, Journal, v. 138, Part 6, p. 735-743.

1984: Continental humid and arid zones during the Jurassic and Cretaceous; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 47, no. 3/4, p. 195-223.

Imlay, R.W.
1980: Jurassic paleobiogeography of the conterminous United States in its continental setting; United States Geological Survey, Professional Paper 1062.

Imlay, R.W. and Detterman, R.L.
1973: Jurassic paleobiogeography of Alaska; United States Geological Survey, Professional Paper 801.

Jeletzky, J.A.
1970: Some salient features of early Mesozoic history of insular tectonic belt, western British Columbia; Geological Survey of Canada, Paper 69-14.

Jeletzky, J.A. and Tipper, H.W.
1968: Upper Jurassic and Cretaceous rocks of Taseko Lakes map area and their bearing on the geological history of southwestern British Columbia; Geological survey of Canada, paper 67-54.

Little, H.W.
1982: Geology of the Rossland-Trail map area, British Columbia; Geological Survey of Canada, Paper 79-26.

Macauley, G.
1983: Source rock – oil shale potential of the Jurassic Kunga Formation, Queen Charlotte Islands; Geological Survey of Canada, Open File 921, p. 1-52.

MacKenzie, J.D.
1916: Geology of Graham Island, British Columbia; Geological Survey of Canada, Memoir 88.

McLearn, F.H.
1927: Some Canadian Jurassic faunas; Royal Society of Canada, Transactions, 3rd series, v. 21, sec. IV, p. 61-73.

1929: Contributions to the stratigraphy and paleontology of Skidegate Inlet, Queen Charlotte Islands, B.C.; Geological Survey of Canada, Museum Bulletin 54, p. 1-27.

1932: Some Canadian Jurassic faunas (continued); Royal Society of Canada, Transactions, 3rd series, v. 26, sec.IV, p. 51-80.

1949: Jurassic formations of Maude Island and Alliford Bay, Queen Charlotte Islands, B.C.; Geological Survey of Canada, Bulletin 12.

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.

Nørvang, A.
1957: The foraminifera of the Lias series of Jutland, Denmark; Meddelelser fra Dansk Geologisk Forening, p. 270-413.

Odin, G.S. and Matter, A.
1981: De glauconiarum origine; Sedimentology, v. 28, no. 5, p. 611-641.

Pessagno, E.A., Jr. and Blome, C.D.
1980: Upper Triassic and Jurassic pantanelliinae from California, Oregon and British Columbia; Micropaleontology, v. 26, no. 3, p. 225-273.

Poulton, T.P.
1981: Stratigraphic distribution and taxonomic notes on bivalves of the Bathonian and Callovian (Middle Jurassic) Upper Yakoun Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part B, Geological Survey of Canada, Paper 81-1B, p. 63-72.

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

Shouldice, D.H.
1971: Geology of the Western Canadian Continental Shelf; Bulletin of Canadian Petroleum Geology, v. 19, no. 2, p. 405-436.

Smith, P.L.
1983: The Pliensbachian ammonite **Dayiceras dayiceroides** and Early Jurassic paleogeography; Canadian Journal of Earth Sciences, v. 20, no. 12, p. 86-91.

Stanton, T.W. and Martin, G.C.
1905: Mesozoic section on Cook Inlet and Alaska Peninsula; Geological Society of America, Bulletin, v. 16, p. 39-410.

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

Sutherland Brown, A. and Jeffrey, W.G.
1960: Preliminary geological map, southern Queen Charlotte Islands; British Columbia Department of Mines.

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

Tappan, H.
1951: Foraminifera from the Arctic slope of Alaska; Part 2, Jurassic Foraminifera; United States Geological Survey, Professional Paper 236-B, p. 21-90.

Taylor, D.G.
1982: Jurassic shallow marine invertebrate depth zones with exemplification from the Snowshoe Formation, Oregon; Oregon Geology, v. 44, no. 5, p. 51-56.

Taylor, D.G., Callomon, J.H., Hall, R., Smith, P.L., Tipper, H.W., and Westermann, G.E.G.
1984: Jurassic ammonite biogeography of western North America: the tectonic implications; Geological Association of Canada, Special Paper 27, p. 121-142.

Tipper, H.W.
1975: Taseko Lakes (92C) and Smithers (93L) map areas, British Columbia; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 75-1 p. 49-50.

1976: Biostratigraphic study of Mesozoic rocks in intermontane and insular belts of the Canadian Cordillera, British Columbia; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 76-1A, p. 57-61.

1977: Jurassic studies in Queen Charlotte Islands, Harbledown Island and Taseko Lakes areas, British Columbia; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 77-1A, p. 251-254.

1981: Offset of an Upper Pliensbachian geographic zonation by transcurrent movement; Canadian Journal of Earth Sciences, v. 18, p. 1788-1792.

1984: The allochthonous Jurassic-Lower Cretaceous terranes of the Canadian Cordillera and their relation to correlative strata of the North American craton; Geological Association of Canada, Special Paper 27, p. 113-120.

Tipper, H.W. and Cameron, B.E.B.
1979: Jurassic biostratigraphy of Skidegate Inlet, Queen Charlotte Islands; *in* Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 396.

1980: Stratigraphy and paleontology of the upper Yakoun Formation (Jurassic) in Alliford Bay syncline, Queen Charlotte Islands, British Columbia; *in* Current Research, Part C, Geological Survey of Canada, Paper 80-1C, p. 37-44.

Tipper, H.W. and Richards, T.A.
1976: Jurassic stratigraphy and history of north-central British Columbia; Geological Survey of Canada, Bulletin 270.

Wall, J.H.
1960: Jurassic microfaunas from Saskatchewan; Saskatchewan, Department of Mineral Resources, Report no. 53, 229 p.

Whiteaves, J.F.
1876: On some invertebrates from the coal-bearing rocks of the Queen Charlotte Islands; Geological Survey of Canada, Mesozoic Fossils, v. 1, Part 1, p. 1-92.

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

1884: On the fossils of the coal-bearing deposits of the Queen Charlotte Islands collected by Dr. G.M. Dawson in 1978; Geological Survey of Canada, Mesozoic Fossils, v. 1, Part 3, p. 191-262.

1900: On some additional or imperfectly understood fossils from the Cretaceous rocks of the Queen Charlotte Islands with a revised list of the species from these rocks; Geological Survey of Canada, Mesozoic Fossils, v. 1, Part 4, p. 263-308.

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

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