GEOLOGY AND MINERAL DEPOSITS OF ALERT BAY - CAPE SCOTT MAP-AREA (92L-102 I) VANCOUVER ISLAND, BRITISH COLUMBIA

By

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ABSTRACT

Alert Bay - Cape Scott map-area is underlain mainly by a Middle Triassic to Lower Jurassic volcanic-sedimentary sequence of the Vancouver Group. The oldest rocks in this group are argillites with thick diabase sills. They are successively overlain by (oceanic?) pillow-basalts, basaltic breccia, and lava. These are succeeded by Upper Triassic carbonate-clastic sediments and Lower Jurassic andesitic to rhyodacitic volcanics with minor sediments.

This complex overlies Pennsylvanian carbonate-clastic sediments and, outside the map-area, older low-grade metamorphic intermediate volcanic rocks.

Granitic rocks range from gabbro to quartz monzonite. Gneissic, agmatitic quartz diorite of the Crystalline complex may have been derived from Paleozoic volcanic rocks and are considered katazonal. The large batholiths of quartz diorite, granodiorite and quartz monzonite are mesozonal; small stocks and dykes of granodiorite, quartz monzonite and quartz feldspar porphyry are epizonal. They were intruded in Early to Middle Jurassic time and are probably directly related to Jurassic volcanism.

The eroded volcanic-plutonic complex is overlain on the west by a clastic wedge of Lower Cretaceous, marine to deltaic clastic sediments, on the east by a wedge of similar Upper Cretaceous sediments, and again on the west by a wedge of young-Tertiary clastic sediments, only present on the continental shelf.

At least one small pluton of quartz diorite was emplaced in the early Tertiary and locally volcanism occurred in late Tertiary time. The region is fractured severely by steep faults, with dominant northwest trend dividing and subdividing the crust in numerous tilted blocks.

Most important metalliferous deposits are those of copper and molybdenum, related to Jurassic (subvolcanic) high-level intrusions and those of copper and iron related to skarn at the contact of Triassic carbonate and granitic rocks.

Coal has been prospected in Lower Cretaceous beds and has been mined with little success in Upper Cretaceous sediments.

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O/F 170

INTRODUCTION

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LOCATION AND ACCESS

Alert Bay and Cape Scott map-areas (lat. 50° - 51° N, Long. 126° - 129° W) occupy the northern part of Vancouver Island and include Scott Islands west of Cape Scott and Hope, Nigei, Balaclava, Malcolm, Cormorant, Hanson and many smaller islands in Queen Charlotte Strait, all within Rupert District. The geology of the northeast part of the map-area in Coast District Range 1, bounded to the southwest by a line through Queen Charlotte and Johnstone Strait, is outside the scope of this report and will be described with Rivers Inlet map-area in a paper by J. A. Roddick and W. W. Hutchison.

Access to the area by motor vehicle is by public paved road from Campbell River to Gold River and thence by private restricted roads via Vernon and Woss Camp to Beaver Cove. Alternatively, a small car-ferry sails daily from Kelsey Bay to Beaver Cove, where a public paved road leads to Port McNeill and Port Hardy. Port Hardy has a modern airport and can be reached directly from Vancouver by several daily scheduled flights. Road transport within the area has improved significantly in the last decade due to the construction of a network of logging roads by the many logging companies operating in the area. To geological exploration, these roads afford the double benefit of easy access and good exposures in road-cuts and quarries for road-surfacing material.

The long, greatly indented coastlines of ocean, straits, lakes, and inlets also provide good transportation as well as excellent exposures. The writers have found rubber inflated rafts with outboard motor, capable of maximum speed of about 20 knots, eminently suitable for coastal traversing.

Access by helicopter to locations not within reach of road or water transport is generally feasible above 3,000 feet elevation, but at lower altitudes natural landing-spots are commonly rare due to dense timber and underbrush.

Larger settlements in the map-area are Port Hardy, Port McNeill and Port Alice (recently moved to Rumble Beach), each providing hotel, restaurant, stores and garages, and Coal Harbour (no hotel). Logging camps are located at these places and also at Holberg (also Canadian Forces Station), Winter Harbour, Beaver Cove, Mahatta, Nimpkish, Woss Camp, Vernon and Zeballos and all these, except Mahatta, can be reached by car. Fish camps at Kyuquot and Winter Harbour also have stores and supply marine gas and oil.

FIELD WORK AND ACKNOWLEDGMENTS

Field work in the area was undertaken in the summers of 1968 and 1969, preceded by a brief reconnaissance of the Port Hardy area in 1966 (Muller, 1967). In 1968 M. V.

"Invader" served as a moving base for the writer's party. The coastline from Tofino on the west coast, northwest to Cape Scott, including all inlets, and thence east and south to Campbell River was investigated using rubber rafts as traversing and landing craft (Muller, 1969). Many logging roads were traversed by truck and by motorcycle. In the following year, the reconnaissance was supplemented by helicopter spot-checks, further road-traverses, some creek-traverses and the measuring of a few sections of Triassic and Jurassic rocks (Muller, 1970; Muller and Rahmani, 1970).

Thanks for able assistance in the field are due to J. R. McLean and P. C. Jackson in 1966; J. F. Childs, C. J. Dodds and D. A. Bridge in 1968, and R. A. Rahmani and P. Tredger in 1969. The writer is also grateful to the able skipper of the "Invader", Dr. D. L. Tiffin, and to G. Soutar and several other pilots of Okanagan Helicopters Ltd.

Most of the modal counts and petrographic examinations of granitic rocks were made by H. Carswell.

Special acknowledgment is due to J. A. Jeletzky, who in 1968 joined the writer in the field for a few weeks and made unpublished parts of his own work in the area available. This work has materially aided in the preparation of the present report, even though in some instances the writer's interpretation of certain data differs from that of Jeletzky.

Since 1968, K. E. Northcote of the British Columbia Department of Mines and Petroleum Resources has been engaged in a detailed investigation of geology mineral deposits in an area between Port McNeil and Cape Scott.

D. Carlisle in 1969 made a detailed survey of Triassic and Paleozoic rocks in Schoen Lake and Adam River region, and after more field work in 1970 as part of a research project with the University of California, Los Angeles, and in 1971 under Geological Survey auspices reported on this work (1972). He also re-examined the Triassic sedimentary sections of Kyuquot area, earlier studied by Jeletzky.

The principal writer is pleased that Drs. Northcote and Carlisle, after pleasant cooperation and exchange of ideas and information in field and office, have consented to join him as co-authors of this report.

Finally, the writers are grateful for discussions with many mining exploration geologists in the field and in the office, and for contributions of many data obtained in their detailed geological work. Courteous cooperation by officials of logging companies operating in the area is also remembered.

Most of this report was prepared by Muller, but the section on metallic mineral deposits was written by Northcote.

SUMMARY OF PHYSIOGRAPHY AND GLACIATION

The map-area lies within two major physiographic subdivisions, distinguished by Holland (1964); the Coastal Trough and the Outer Mountain Area. The Coastal Trough includes the Hecate Depression, comprising Queen Charlotte Strait and islands therein, and Nahwitti Lowland, composed of the low mountains north of Quatsino Sound and the coastal lowland of Suquash Basin, north and east of Rupert Inlet. The

Outer Mountain area is represented by the Vancouver Island Mountains, a more rugged terrain where elevations range between sea-level in the deeply penetrating inlets, or a few hundred feet in several northerly trending finger-lakes, and 5,000 to 7,000 feet for the higher peaks. Victoria Peak at 7,095 feet elevation is the highest point in the map-area.

No study has been made of Pleistocene deposits and glacial history of the map-area. Detailed work by Fyles (1963) and Halstead (1966, 1968) in southern Vancouver Island has established the presence of two glacial tills on the east coast of Vancouver Island, separated by marine and fluvial "Quadra Sediments", ranging in age from 25,000 to 36,000 years. The younger Vashon Till is thought to represent the classical Wisconsin Glaciation of the region (Fyles, 1963). During the climax of that episode, probably about 15,000 years ago (Armstrong et al, 1965), most of Vancouver Island was covered by an ice-sheet, continuous with that of the mainland and flowing southwestward across the island. The sculpture of the mountains suggests that the ice stood to about 4,800 feet at Victoria Peak in the southeast corner of the Alert Bay - Cape Scott map-area and declined westward to about 4,000 feet at Pinder Peak, about 3,500 feet at Garibaldi Peaks and about 3,000 feet at the unnamed peaks south of Neroutsos Inlet and at Mount Wolfenden west of that inlet. North of Quatsino Sound the Nawhitti Lowlands were entirely covered but perhaps tops of Mount Brandes and Mount Hansen above 1,800 feet were free of ice. An erratic of granodiorite, noted by the writer on Triangle Island, 30 miles west of Cape Scott, could be an indication that the ice extended far beyond the present coast or alternatively could have been ice-rafted for that distance.

In Southern Vancouver Island, an episode of valley-glaciation, following the maximum of the Vashon Stade, produced U-shaped valleys, moraines and outwash deposits (Fyles, 1963, Halstead, 1968). However, it is doubtful that valley-glaciers were present in the Alert Bay - Cape Scott map-area for none of the valleys are typical smoooth-walled, U-shaped troughs.

After the retreat of the glaciers, the partly marine "Capilano Sediments" were deposited about 12,350 to 11,500 years ago in southern Vancouver Island (Fyles, 1963). They indicate a post-glacial marine transgression 300 to 500 feet above present sea level that undoubtedly also occurred in the map-area.

PREVIOUS GEOLOGICAL WORK

The first geological examinations in the map-area by the Geological Survey of Canada were made in 1878 by G. M. Dawson (1887) on his return from an exploration-trip of the Queen Charlotte Islands. Dawson returned to Vancouver Island in 1885 and travelling in a small schooner, circumnavigated and surveyed parts of the northern coastline and adjacent islands, from Comox northward and around Cape Scott southward to Quatsino Sound. This inlet was also explored in some detail. He established or confirmed the presence of Vancouver Group volcanic rocks along most of the coast, and the presence of Cretaceous coal-bearing beds on the north coast (Suquash Basin) and in the Quatsino Sound area and published records of some holes drilled in the search for coal.

C. H. Clapp (1912) reported on the Suquash coal field in 1911 and examined alunite and pyrophyllite-bearing rocks of Kyuquot Sound in 1913. V. Dolmage did field work along Quatsino Sound and the west coast in 1918 (1919). He returned in 1920 to study the coast and inlets between Quatsino Sound and Barkley Sound. His reports include general stratigraphy, description of some mining properties and he introduced the name "Quatsino Formations".

H. C. Gunning investigated the Quatsino and Nimpkish areas in 1929 and 1931, (1930, 1932A), and Zeballos area in 1932 (1933); he established a more detailed stratigraphy for the Vancouver Group, and named Karmutsen Formation and Bonanza Group. He provided much information on mineral deposits and classified them according to origin and content. A series of preliminary maps of Nimpkish, Woss Lake and part of Schoen Lake map-areas were published in 1938 after he resigned from the Geological Survey.

J. W. Hoadley continued the mapping of Zeballos map-area (south of Alert Bay map-area) from 1947 to 1950 inclusive, and incorporated Gunning's mapping and geological observations in a memoir on the Zeballo-Nimpkish area (1953).

Finally, J. A. Jeletzky surveyed parts of the Vancouver Island coastline, from Esperanza Inlet north into Quatsino Sound in the years 1949 to 1954 (1950, 1954A, B). He established the basis for detailed Mesozoic stratigraphy by his intensive study of the sedimentary sequences and numerous fossil collections. He joined Muller's field party for some weeks in 1968 for stratigraphic consultation, and made several visits to the region since that time (Jeletzky, 1969, 1970, 1973). The results of this work are contained in one condensed and one lengthy report on Mesozoic stratigraphy and geological history of the region (1970B, unpub. Ms.).

In addition, numerous reports dealing with parts of the area have been published in the Annual Reports of the British Columbia Minister of Mines and Petroleum Resources. In later years, W. G. Jeffery of that Department examined the Empire and Coast Copper iron and copper deposits, and mapped an area between Benson Lake and Neroutsos Inlet in 1960 and 1961. K. E. Northcote (1969, 1971) has recently carried out detailed mapping in a mineralized belt from north of Rupert Arm to west of Cape Scott, and examined the Island Copper deposit in detail.

D. Carlisle of University of California, Los Angeles, and his students, have conducted field work for many years on Vancouver Island under grants from the National Science Foundation (Carlisle, 1963, 1972; Carlisle and Susuki, 1965; Surdam, 1968). He has contributed important information on detailed work on the Paleozoic and Triassic formations of the map-area.

D. J. T. Carson in 1964 and 1965 made a study of mineral deposits and granitic rocks of Vancouver Island for a doctoral thesis. The field work was sponsored by the Geological Survey of Canada, and was designed to complement the regional geological studies of the Island with more detailed information on the economic geology. Apart from his own publications (Carson, 1969, 1973; Carson et al., 1971), his work formed part of an earlier regional geological report (Muller and Carson, 1969). Much of Carson's work on mineral deposits and granitic rocks has also been used in the present report.

IOD		STAGES	GROUP OR FORMATION	MAP UNIT	LITHOLOGY	THICK-NESS (Feet)
		Miocene?	Tertiary Volcanics, Sediments	Tv Ts	Basaltic to dacitic lava, tuff, breccia; conglomerate conglomerate	1,000
		Not in contact; disconformable?				
		Eocene?	Tertiary Intrusions	Tg	Quartzdiorite	
		Intrusive contact in Alberni map-area				
	UPPER	Maestrichtian? Campanian	Nanaimo Group (incl. Suquash Fm.)	uKN	Greywacke, siltstone, shale conglomerate, coal	400
		Disconformable contact?				
	UPPER	Cenomanian Albian	Queen Charlotte Group	lKQC	Greywacke, conglomerate, siltstone, shale, coal	1,000 - 3,500
		Disconformable contact				
	LOWER	Barremian Hauterivian Valanginian	Longarm Formation	lKL	Greywacke, conglomerate, siltstone	200 - 1,300
		Equal age but diverse tectonic setting				
			Pacific Rim Sequence	JKs	Argillite, greywacke ? conglomerate	
		Unconformable contact				
	MIDDLE		Island Intrusions	Jg	Quartzdiorite, granodiorite, quartz monzonite, quartz-feldspar porphyry	
		Intrusive contact				
			Vancouver Group (gradational contacts within group)			
	LOWER	Pliensbachian Sinemurian	Bonanza Volcanics	lJBV	Andesitic to rhyodacitic lava, tuff, breccia;	1,000 - 8,500
			Harbledown Fm.	JH	greywacke, argillite, tuff	
	UPPER	Norian	Parson Bay Fm.	uTRPB	Calcareous siltstone, shale, greywacke, conglomerate, breccia	1,000 - 2,000
			Quatsino Fm.	uTRQ	Limestone	100 - 2,500
		Karnian	Karmutsen Fm. includes in upper part	muTRK	Basaltic lava, pillow-lava, breccia	10,000 - 20,000
			Intervolcanic Limestone	uTRQ2	Limestone	
iddle		Ladinian	sediment-sill unit		diabase, argillite	2,500
			Disconformable or unconformable contact			
PENNSYLVANIAN?			Sicker Group	Ps	Limestone, siltstone	700
			Migmatic contact?			
			Westcoast Complex	PMdin	Quartz diorite, agmatite, amphibolite, gneiss	

GENERAL GEOLOGY

The map-area is chiefly underlain (figure 2) by the Vancouver Group, consisting of a basal Middle Triassic sediment-sill unit, a thick pile of Triassic basaltic volcanics (Karmutsen Formation), Upper Triassic carbonate, pelitic and volcanoclastic sediments (Quatsino and Parson Bay Formations), and a lower Jurassic sequence of basaltic to dacitic effusive and pyroclastic volcanics with minor intercalated sediments (Bonanza Subgroup). The mainly sedimentary Lower Jurassic beds of the islands in Queen Charlotte Strait are called Harbledown Formation. The Vancouver Group is intruded by large and small bodies of Middle Jurassic Island intrusions, and is overlain unconformably by remnants of a Lower Cretaceous clastic wedge on the southwest side, and similar Upper Cretaceous beds on the northwest side of Vancouver Island. The Sicker Group with Pennsylvanian and (?) Permian limestone and argillite near Schoen Lake, and probably also the Westcoast Gneiss Complex of Brooks Peninsula, are older than the Vancouver Group. Some late Tertiary volcanic rocks of the Port McNeill area are the youngest rocks in the area.

The region may be divided into several great structural blocks, separated mainly by important near-vertical faults and themselves fractured into many small fault-segments (Figure 10). As defined in this report, these blocks are divided by the Brooks Fault-zone into southeastern and northwestern groups. The southeastern group contains, from northeast to southwest, White River Block, Victoria Arch, Nimpkish Block, Karmutsen Block, Kyuquot Block and Kyuquot Swell; the northwestern group is composed of Nahwitti Block, Quatsino Block, Cape Scott Block and Brooks Peninsula Block. Suquash Basin borders these blocks on the northeast, and Pacific Rim Block forms the continental slope on the southwest.

SICKER GROUP

Nomenclature

The Sicker Group, consisting of a lower part of metavolcanic rocks, a middle part of greywacke, argillite and minor tuff, and an upper part of limestone, named Buttle Lake Formation, is extensively exposed in Alberni map-area and was described in the report concerning that region (Muller and Carson, 1969). The group was named for low-grade metamorphic volcanic and clastic rocks on Mount Sicker near Duncan (Clapp and Cooke, 1917). It was tentatively divided (Muller and Carson, 1968) into a lower formation of mainly tuff and volcanic breccia, a middle formation of mainly argillite and greywacke, and an upper formation of mainly limestone. The limestone formation had earlier been named Buttle Lake Formation by Gunning (1931). Yole (1969) introduced the name Youbou Formation for all Sicker rocks below the limestone, including volcanics and clastic sediments. The writers prefer to retain the name Sicker Volcanics for Paleozoic volcanic rocks on Vancouver Island until the stratigraphy of the group has been worked out in more detail.

Paleozoic Sicker volcanics are very similar in lithology to Jurassic Bonanza Volcanics, but are commonly more strongly metamorphosed. It is possible that some volcanic rocks west of Nimpkish River between Woss and Vernon Camps are Sicker volcanics underlying Karmutsen Volcanics. However, due to lack of evidence they have been included in the Bonanza Group.

UPPER PALEOZOIC LIMESTONE

Distribution and Lithology

Late Paleozoic limestone is mainly exposed in low-lying parts of the area between Schoen Lake and Victoria Peak.

In a gully one quarter mile north of Nisnac Lake, 670 feet of coarse to fine bioclastic and coralline limestone were measured by Carlisle. This sequence includes a diabase sill 150 feet thick. The limestone is generally unmetamorphosed, well bedded, light to medium blue-grey with lesser amounts of darker siliceous thinly bedded limestone and siltstone, and includes some mafic sills. The formation is inferred to have been formed on shallow inter-island reefs and shelves of a late Paleozoic volcanic arc.

Age and Correlation

The age of the formation is only generally determined by the contained corals. E. C. Wilson of the University of California, Los Angeles, tentatively identified Caninia (?) sp. indicating an age-range from Mississippian through Permian in corals collected northeast of Schoen Lake.

The following reports were obtained for coralline limestone exposed over a thickness of 100 feet.

G. S. C. Loc. 86301, lower northeast flank of Mt. Adam (elev. 2300'), 50° 7'57" N, 126° 10'52" W

E. W. Bamber of the Geological Survey reported as follows: "autophyllid coral, not identifiable to genus because of poor preservation; age: Carboniferous to Permian".

B. E. B. Cameron of the Geological Survey reported as follows: "The insoluble residue of this limestone yielded the following fossils:

Miscellaneous: fish teeth, abundant bryozoa, abundant productid brachiopod spines, brachiopod fragments;

Ostracoda: Rectobairdia sp., Bairdiacypris sp.

Foraminifera: Globivalvulina sp., Climacammina sp. Palaeotextularia (2 spp.), Palaeobigenerina? sp.

Conodontophorida: Streptognathodus sp., Idiognathodus sp. (aff. Streptognathodus), Ozarkodina sp., hindeodellid

In general the total assemblage is of Lower Permian to Upper Carboniferous (Pennsylvanian) age. A check of available literature indicates the specimens of Streptognathodus and Idiognathodus are probably new species which show greatest affinities with Middle or Upper Pennsylvanian (Desmoinesian to Virgilian) assemblages known in the U.S.A. (Kansas, Missouri)."

The report favors a tentative conclusion that the rocks are more likely of Pennsylvanian than of Permian age. In another limestone, occurring south of the map-area on Magee Creek, Cameron discovered silicified foramanifera indicating an Early Pennsylvanian age (Muller, 1972). Other Pennsylvanian ages, based on microfauna, have been reported from the Ballenas Islands off Vancouver Island (Muller and Carson, 1968) and from Cowichan Lake area (Muller, 1971).

The Buttle Lake limestone in the vicinity of Buttle, Horne, and Cowichan Lakes was assigned an early Permian age by Yole (1963, 1969) but from Yole's first paper it is apparent the age is based on brachiopods mainly and not on microfossils. Also, Girty, (see Yole, 1963) had earlier assigned Pennsylvanian age to fossils from Buttle Lake limestone. Thus a Pennsylvanian age-correlation of the limestone near Schoen Lake and Buttle Lake limestone is conceivable. Their stratigraphic position between Sicker Volcanics and Karmutsen Volcanics is also similar.

VANCOUVER GROUP

Nomenclature

The Vancouver Group is by far the areally most extensive unit of Vancouver Island and of Alert Bay - Cape Scott map-area in particular. G. M. Dawson (1887, p. 103) introduced the name Vancouver Series for all volcanic and sedimentary rocks unconformably underlying the Cretaceous of Vancouver Island and Queen Charlotte Islands. He suggested that if Triassic and Carboniferous rocks could eventually be separated, the name should be retained for the former. The name Vancouver Group is now well established for all Triassic and Lower Jurassic volcanic and sedimentary rocks of the Insular Belt (Vancouver Island, Queen Charlotte Islands and some smaller islands in Strait of Georgia and Queen Charlotte Sound). The group is subdivided in this report in a basal sediment-sill unit, Karmutsen, Quatsino, Parson Bay and Harbledown Formations, and the Bonanza Volcanics.

SEDIMENT-SILL UNIT

Stratigraphic position and distribution

Yole (1969) recognized an "unnamed unit" of thin-bedded clastic rocks between Buttle Lake Formation and Karmutsen Formation west of Buttle Lake. Work in the area east of Schoen Lake, chiefly by Carlisle, has now revealed the presence of a unit of basic sills and minor sediments between underlying Sicker sediments and overlying Karmutsen pillow lavas (Figure 3 and Carlisle, 1972). Carlisle originally included this unit in the Sicker Group, but the Triassic age of the sediments and the probably co-magmatic relationship of sills and Karmutsen basalts argue for their inclusion in the Vancouver Group. The rocks underlie the lower parts of the northeasterly slopes of the range from Mt. Schoen to Victoria Peak. The total thickness of the sediment-sill unit is estimated to be 2,500 to 3,000 feet, of which the sedimentary part is about 500 to 600 feet thick.

Lithology and Origin

The sedimentary layers between the sills are from one foot to roughly 200 feet in thickness. The rocks are laminated to graded-bedded black shales and siltstones, generally considered silicified by diagenesis and contact metamorphism by the invading sills.

The sills are diabases that commonly exhibit a marked increase in grain-size from the contacts to the central part.

The fine-grained, laminated, graded-bedded sediments were apparently deposited in off-shore and possibly deeper water anaerobic conditions, with periodic influx of turbidity currents. The sills are thought to be in part coeval with the sediments, but most of them were probably emplaced simultaneously with extrusion of the Karmutsen basalts. Deformation of the sediments suggests that in places they were unconsolidated at the time of intrusion. Sills also occur, with upward decreasing frequency, in Karmutsen Formation.

Age and Correlation

The age of the unit was established in 1971 by the discovery by mining geologists of a five foot thick layer of pelecypod-rich fissile black shale within one of the siliceous sedimentary layers in a steep gully on the northeast flank of Mt. Schoen at elevation 3,250 feet. This fossil layer occurring at about one third of the total thickness below the top of the sediment-sill unit (G.S.C. Loc. 88029; Lat. 50° 10'10"; Long. 126° 13'27") contains according to E. T. Tozer, Daonella sp. Group D. tyrolensis indicating a Late Ladinian age.

The age indicates a rather close time-relationship between the sediment-sill unit and Karmutsen Volcanics, dated Late Triassic (Upper Karnian) by the fauna in intervolcanic sediments in the upper 1,000 feet of that formation (e.g. Muller and Carson, 1969). On the other hand, a considerable time-gap separates the Pennsylvanian or possibly Early Permian limestone from the Middle Triassic sediments. Thus it seems appropriate to consider this unit as the basal part of the Vancouver Group, rather than the top of the Sicker Group.

KARMUTSEN FORMATION

Nomenclature

The Karmutsen Formation forms the largest part of the Vancouver Group and is the thickest and most wide-spread formation on the island and in Alert Bay - Cape Scott map-area. The name "Karmutsen volcanics" was introduced by Gunning (1932, p. 23A) for the volcanic rocks underlying Upper Triassic limestone of the Quatsino Formation. They are well exposed in Karmutsen Range west of Nimpkish Lake and are present throughout Vancouver Island and many smaller islands to the northeast. It has earlier been proposed (Muller and Carson, 1969) to abolish other local names such as Valdez Group, Texada Formation, Vancouver Volcanics, and Franklin Creek Basalt in favour of Karmutsen Formation.

Distribution and Thickness

Within the map-area, the Karmutsen Formation underlies two-thirds of the Victoria Arch (see introduction to this chapter), northeast parts of Karmutsen, Nahwitti and Quatsino Blocks and small infaulted areas in Cape Scott and Kyuquot Blocks.

The total thickness can be estimated in a homoclinally tilted panel of the formation in Karmutsen and Haihte Ranges. There a thickness of about 20,000 feet underlies Quatsino Limestone, but the base is cut off by a fault. Although, in Victoria Arch, the formation is present in greatest areal expanse, low, less regular dips, faults and intrusive contact preclude a thickness estimate, but it may well be of the same order of magnitude. A similar total thickness of 19,000 feet was inferred west of Buttle Lake in Alberni map-area (Muller and Carson, 1969, p. 11). The limited extent of Karmutsen rocks in the Coastal Block may suggest that the formation is thinner there.

Subdivisions

The stratigraphic succession within the Karmutsen Formation was briefly described by Carlisle (1972) for the Bute Inlet map-area and adjacent part of Alert Bay map-area. Three divisions were recognized (see Figure 3), a lower one of pillow-lavas, a middle one of pillow-breccias and aquagene tuffs, and an upper one of layered flows. He also established that these subdivisions are mappable on a scale of 1:50,000. The writer's reconnaissance indicates that all of these units are represented in Alert Bay map-area in Victoria Arch. Farther west, pillow-lavas and breccias are rare and Karmutsen Formation, where exposed, consists almost exclusively of lavas.

The basal contact with the sediment-sill unit is exposed on the east flank of a westward tilted fault block that includes Mt. Schoen and Victoria Peak, at the headwaters of White and Adam Rivers. There pillow lavas overlie with apparent conformity a few feet of lenticular black and grey siliceous sediments that are, in turn, underlain by massive, bluff-forming diabase.

Pillow lavas form the tops of Sutton Range, including Victoria Peak, Mount Schoen and Maquilla Peak to the west, and the block east of Gerald Creek Fault, which includes Mt. Romeo and extends to Johnstone Strait east of Robson Bight. Pillow lavas are also exposed in the east part of Karmutsen block (Figure 9), west of Vernon Lake on Haihte Range and southwest of Keogh Lake, along the Coast Copper mine road, but northwest and west of that Lake only higher parts of Karmutsen Formation are exposed.

Breccias and aquagene tuffs overlying the pillow lavas are found on the slopes west of Eve River and from Mount Palmerston to Johnstone Strait. They also outcrop on the coast east of Beaver Cove. Basaltic flows forming the upper part of the formation constitute most of the remaining area mapped as Karmutsen.

Lithology, Pillow-lavas

Karmutsen rocks of Alert Bay - Cape Scott map-areas are essentially identical to those encountered in Alberni map-area (Muller and Carson, 1969), and the lithological description is repeated here, with further reference to Carlisle's detailed study (1963). Pillows of the lower subdivision vary in shape from rough spheres, 6 inches to 1 foot in diameter, to irregular ellipsoids up to 4 feet wide and 1 foot to 2 feet high. Many pillows have chilled rims of aphanitic rock, about 1/4 to 1/2 inch thick, enveloping fine-grained, commonly porphyritic and amygdaloidal basalt. Typically, the roughly tetrahedron-shaped open spaces between pillows are filled with quartz and less pumpellyite or epidote. Such quartz nests are in places the only indicators of pillow structure in otherwise massive-looking basaltic rock.

Lithology, Pillow-breccias

Pillow breccia of the middle subdivision consists of pillows, broken into angular fragments of diverse size, some showing parts of the original chilled rims. Carlisle (1963) distinguished 'isolated-pillow breccias' with a few unbroken pillows between fragments and 'broken-pillow breccias' containing mainly broken pillows. Pillows and breccia fragments carry white or light green plagioclase phenocrysts, singly or in clusters which in a few instances are as much as 4 mm in size. Amygdales occur throughout or are concentrated just inside the chilled rims and are filled with quartz, epidote, prehnite and pumpellyite. The matrix between breccia fragments contains finer fragmented material and green, lighter-rimmed glass globules that are detectable with the hand lens.

Thin sections of basalt from pillows and pillow fragments show plagioclase phenocrysts An_{60} to An_{85}, in part or entirely sericitized and albitized. Augite, in single or clustered equi-dimensional grains, is near-colourless or uralitized to green actinolitic hornblende. The matrix is brown devitrified glass, consisting of minute spherules and sheaves of a highly refractive and birefringent mineral and some microlites of plagioclase and augite. The pyroclastic matrix between pillow-fragments contains broken feldspar and augite, angular, partly devitrified shards, and flattened globules largely altered to chlorite, pumpellyite, quartz and carbonate.

Lithology, Lava-flows

The lavas of the upper subdivision are layered and the flows, where clearly discernible, measure 5 to 10 feet in thickness in some sections, and 50 to 100 feet in others. In road-cuts and quarries, jointing, roughly perpendicular to the layering is commonly more conspicuous than layering itself, and provides indirectly a guide to the attitude of the rocks. Columnar jointing is very rare. Amygdales are concentrated near the tops of flows and to a lesser extent at the bottoms. Thin sections of these rocks show ophitic assemblages of calcic plagioclase, up to An_{85} or albite, and augite, with interstitial devitrified glass and amygdales filled with quartz, carbonate, chlorite, and in many instances prehnite and pumpellyite.

Intervolcanic Limestone

Limestone similar to the overlying Quatsino Limestone, but only a few feet thick has been noted in the upper thousand feet of Karmutsen Formation (see Figure 2), in several places in Alberni map-area (Muller and Carson, 1969, p. 13). There the sedimentary sub-unit lies on layered lavas in the upper subdivision of the Karmutsen Formation, but is commonly overlain in turn by a thin sequence of pillow-lavas, followed by more layered lavas. In Cape Scott area, a rocky point in Nissen Bight and another point between Nels and Nissen Bights exhibit fine crystalline limestone, only a few feet thick, underlain by lavas and overlain by well-pillowed lavas. In the poorly exposed area north of Rupert Inlet and Island Copper Mines, several limestone lenses are also exposed within Karmutsen lavas, indicating one or perhaps two zones of intervolcanic limestone. Limestone on the larger Hisnit Island in Ououkinsh Inlet, originally discovered by J. A. Jeletzky and mentioned by Tozer (1967, p. 82) is probably also an intervolcanic lens.

Chemical Composition

No analyses are available of Karmutsen lavas in the map-area, but a few analyses of samples from Alberni map-area (Muller, 1971B) are reproduced to show their general chemistry. The analyses (Table 2) as well as the mineralogy indicate that the rocks are basalts of tholeitic composition as defined by Kuno (1968). The relatively high sodium-content in several samples (2.7 - 3.5) coincides with partial or complete albitization of the plagioclases observed in the thin-sections.

Table 2. Karmutsen volcanics, Mount Flanigan, west of Campbell Lake, Alberni map-area.

K - Ray Fluroescence, supplemented by rapid chemical analysis for FeO, Na_2O, P_2O_5, CO_2 and total H_2O, by S. Courville, Geological Survey of Canada.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	CO_2	H_2O	Total	R.I.
	49.2	1.56	15.0	4.4	7.3	0.18	6.9	10.0	3.4	0.4	0.12	tr	1.1	99.1	1.598
2	47.3	2.38	13.0	5.2	8.8	0.23	7.0	9.3	2.7	0.5	0.21	tr	2.9	99.5	1.622
3	47.4	1.25	13.9	4.1	6.5	0.17	7.7	10.5	3.5	tr	0.10	0.1	3.8	99.0	1.601
4	47.7	2.24	13.9	4.6	9.0	0.20	6.3	10.4	1.7	0.2	0.18	tr	2.8	99.2	1.618
5	48.8	2.31	12.9	4.3	9.1	0.19	6.4	11.2	1.9	0.1	0.21	tr	1.7	99.1	1.618
6	49.5	1.23	17.1	1.5	7.5	0.14	5.4	13.1	2.3	0.1	0.12	tr	1.1	99.1	1.596

1 - 4: basalt flows, finely amygdaloidal; 5: pillow-lava;
6: porphyritic basalt flow.

Metamorphism

Metamorphism of Karmutsen volcanics was studied in detail by Surdam (1968). Karmutsen rocks generally exhibit partial albitization of plagioclase and fairly commonly amygdules of pumpellyite, prehnite, epidote, quartz, carbonate and chlorite, indicating the sub-greenschist pumpellyite facies of metamorphism. At granitic contacts the basaltic rocks are converted to massive dark coloured hornfels, consisting mainly of hornblende with minor plagioclase.

Structure

The structure of Karmutsen volcanics is generally marked by gentle folding and intense faulting and fracturing, a consequence of the relative rigidity of thick basaltic flows. Victoria Arch trends north-northwest and is composed of a narrow northeast flank and a broad southwest flank. The latter is a gently dipping lava sequence 15,000 feet thick or more, traversed by a system of north-northwesterly and east-northeasterly faults and fractures. In Karmutsen, Quatsino and Nahwitti blocks (Figure 10), the formation underlies the northeastern margin of southwest dipping fault-bounded panels, internally fractured in two or three sets of faults. In contrast to the large continuous areas underlain by Karmutsen volcanics in these blocks, only a few small unconnected areas underlain by more fractured, disturbed and in many places, thermally metamorphosed Karmutsen lavas are present in the Cape Scott and Kyuquot blocks.

Origin

The ubiquitous presence of piles of Karmutsen basalt-flows on all of Vancouver Island except the southern tip, makes it apparent that the entire island region, as well as Queen Charlotte Islands consisted of great basaltic lava-plateaus near the end of Upper Triassic time. The pillow-lavas, aquagene tuffs and breccias were poured out in submarine oceanic environment, the bedded lavas perhaps accumulated as sub-aerial flood-basalts, forming shield-volcanoes.

It appears that the concept of the Inter-Arc Basin, developed by Karig (1971a, b) may be applicable to the origin of Karmutsen volcanics. According to that author, inter-arc basins develop by apparently longitudinal rifting of a volcanic island arc. The resulting rift-basin is bounded by fault-scarps and has a ridge-trough topography (e.g. Tonga-Kermadec area). The floor of the basin consists of fresh pillow-basalts, apparently younger than the enclosing (and partly underlying?) volcanic arc-rocks. The basin contains a shallow area, midway between the boundary scarps, informally referred to as "axial high". This setting would account for older paleozoic arc-type rocks (Sicker Group) and basic metamorphic rocks (Westcoast Complex) underlying "oceanic" Karmutsen Volcanics. Perhaps the medial "ridge" of Karmutsen Volcanics, roughly coincident with Victoria Arch, represents the "axial high" (see Figure 11).

Age and Correlation

The age of Karmutsen rocks is now well-established. The underlying sediment-sill unit contains, as mentioned previously, a rich pelecypod-layer, which according to E. T. Tozer contains Daonella sp., Group D. tyrolensis indicating Middle Triassic, probably early Late Ladinian age.

The top of the Karmutsen is also well-dated by the faunas collected from the inter-volcanic limestone that occurs near the top of the formation, as well as from the overlying Quatsino Formation (see below). The following collections were made by J. A. Jeletzky (G.S.C. Loc. 23147, 23939) and J. E. Muller (G.S.C. Loc. 82852) from the larger Hisnit Island, northwest end of Ououkinsh Inlet, and were identified by E. T. Tozer:

> Tropites sp. indet., Paratropites sellai Mojsisovics (of Smith), Paratropites cf. P. sulcatus (Calcara of Gemmellaro), Trachysagenites cf. T. herbichi Mojsisovics, Pleuronautilus cf. P. alaskensis Kummel.

According to Tozer they represent the Dilleri Zone of the Upper Karnian stage. Accordingly extrusion of Karmutsen volcanics occurred in the later part of the Ladinian and the earlier part of the Karnian stages, a time-span of approximately five to ten million years.

Karmutsen Formation is known through the Insular Belt (Vancouver and Queen Charlotte Islands) and is roughly correlative to Triassic volcanics in Interior British Columbia like the lower parts of Nicola and Takla Groups and like the lower parts of Much Lake and Lewes River Groups in Yukon Territory.

QUATSINO FORMATION

Nomenclature

The name Quatsino was first used by Dolmage (1919, p. 52), and later by Gunning (1932, p. 23) for the Upper Triassic limestone formation outcropping on Quatsino Narrows and vicinity. The limestone commonly grades upward into calcareous clastic sediments which Gunning included in the Bonanza Group. The Bonanza sediments, now called Parson Bay Formation, form with the Quatsino Formation essentially one group of Upper Triassic sediments.

Distribution and Thickness

The formation has its greatest extent in Alert Bay - Cape Scott map-area and is exposed in three more or less linear belts, broken by faults. The northeast belt is part of Nahwitti and Nimpkish blocks, the middle belt is in Quatsino and Karmutsen blocks, and the southwest belt occurs as many small faulted fragments in Cape Scott and Kyuquot Blocks. To the east, a fourth and minor belt of Upper Triassic sediments is exposed east of Adam River.

The greatest thickness of 2,500 feet was measured in Karmutsen Block south of Alice Lake and greater thicknesses may be present elsewhere in that belt between Quatsino Sound and Atluck Lake. Sections a few hundred to one thousand feet thick are present in Nahwitti, Vernon, Kyuquot and Adam River Blocks. Quatsino and Parson Bay Formations are shown as one map-unit in the west part of the accompanying map, due to the small thickness of the former and difficulty of separation.

Stratigraphic Sections

Stratigraphic sections including both Quatsino and Parson Bay Formations were studied in some detail in each of the sedimentary belts just mentioned. They were reconstructed by elimination of faults and intrusive sills, and are shown in Figure 4; locations are shown in Figure 5, and contained fossils are given in Table 3.

The sediments are less resistant to erosion than the underlying and overlying volcanic rocks and therefore generally underlie low-lying areas. As most of these sedimentary areas are densely forested, sections can only be studied along the seashore, along some creeks, and in a few areas where logging has exposed hillsides.

Klaskino Section, in the Cape Scott Block, was measured along the coast north of Klaskino Inlet, west of Red Stripe Mountain, between latitudes 50° 18'50", and at longitude about 127° 51'50".

The Union Island and combined Walters and Amos Island sections were studied in detail by Jeletzky about 1953 but only the fossil-collections have so far been published as part of Tozer's synthesis of the Triassic biostratigraphy of western Canada. The sections were restudied in 1971 by D. Carlisle and Jeletzky's fossil-localities were inserted as far as possible from the available descriptions of locations, and air photo locations, supplied by Jeletzky to the writer in 1968. Approximate longitudes and latitudes determined by the present writers, have been added to Jeletzky's locations shown in Table 3.

The section on Union Island is on the island's southwest side, starting on a faulted Karmutsen - Quatsino contact in a bay at about 50° 00'10" latitude and 127° 19'00" longitude, crosses several basic sills and faultzones (not shown) and ends near Raccoon Point, outside of the Alert Bay map-area. The Walters, Amos and "Little Amos" Island sections are generally on the southwest sides of those islands. The sections are near the major Westcoast Fault and therefore highly disturbed. However, their known faunal content, provided by Jeletzky's collections, is much superior and farther ranging than that of the similar but less disturbed Klaskino Section.

The lower part of the Alice Lake Section in Karmutsen Block was measured across a logged off area east of the south end of Alice Lake, between Malook Creek and Benson River. The middle part (medium-bedded limestone and Monotis-bearing beds) was partly exposed along logging-spur 64B of the McMillan Bloedel Company's Tree Farm Licence Area 39, and the upper part was studied along Yootook Creek, in the Rayonier Company's Tree Farm Licence Area 6. Topographic coordinates are Latitude 50° 25'30' - Longitude 127° 20'05" for the base, and Latitude 50° 22'55" - Longitude 127° 19'20" for the top of the section.

The northeastern Beaver Cove Section in Nimpkish Block was studied on a tributary of Tsulton River, just south of Beaver Cove, in an area logged by Crown Zellerbach Company in the "Nimpkish Provincial Forest". Coordinates are Latitude 50° 29'50" -- Longitude 126° 53'20" for the base and Latitude 50° 28'35" -- Longitude 126° 52'30" for the top of the section.

The sixth section, shown for comparison, is from Iron River near Campbell River, Alberni map-area, and was studied in detail by D. Carlisle and co-workers (Surdam et al. 1963, Surdam, 1968).

Lithology

The lower part of Quatsino Formation, resting paraconformably on Karmutsen Volcanics, consists of thick-bedded to massive, brown-grey to black, light-grey to white weathering, fine to microcrystalline, but locally coarse-crystalline, commonly stylolitic limestone. In places it contains recrystallized corals, pelecypods, and algal balls. It is about 1,600 feet thick in Alice Lake Section, only 80 feet in Klaskino Section and 250 feet or more in Beaver Cove Section.

The upper part of Quatsino Formation consists of medium-to-thin-bedded limestone (thickness 6 to 18 inches), interlaminated with black, calcareous stilstone (thickness 1/2 inch to 3 inches). The beds are commonly lenticular and outcrops have a "ribbed" appearance. They contain locally abundant ammonites and pelecypods. Cherty nodules are present at several stratigraphic levels. Approximate thicknesses are 160 feet in Klaskino Section, 990 feet in Alice Lake Section, and 460 feet in Beaver Cove Section.

As noted, the contact of Quatsino Limestone and overlying Parson Bay Formation is gradational and indicated by the appearance of laminae and layers of black calcareous shale, commonly containing Halobia, between limestone beds. Upwards, the shale-intercalations increase in thickness while limestone beds become thinner. The contact is most logically placed where black shale and arenite first predominate over pure, light-grey carbonate.

Thin sections of limestone show grains of recrystallized calcite 0.01 mm. to 0.2 mm. in size, in some instances surrounding cloudy detrital pellets of carbonate, fossil fragments, chert and feldspar. Some rocks exhibit partial replacement of calcite by larger dolomite grains. However, the generally low dolomite and silicate content is shown by analyses of 30 samples collected by McCammon (1969) in the map-area, averaging only 1.15% MgO and 1.17% insolubles.

Limestone near granitic intrusions is in many places, for instance the area south of Nahwitti Lake, partly or completely silicified. These rocks weather yellowish white to dark rusty, with irregular rusty-coloured veining and have either retained their bedded structure or are brecciated. Thin sections show very fine (0.01 mm.) quartz-mosaic or coarser grained carbonate surrounding chert-fragments. At the contact with granitic rock, skarn is commonly present containing garnet, epidote and pyroxene together with magnetite and chalcopyrite. Economic skarn-deposits are discussed in the chapter on economic geology.

Origin

Deposition of the limestone in open sea, on the submerged Karmutsen lava-plateau, is indicated by the lack of volcaniclastic material and the composition of fine-grained clastic and biogenic carbonate matter. The presence of coral and pelecypod debris suggests the presence of shallow banks on the highest part of the plateau supplying carbonate debris to the surrounding marine platforms. The thick limestone-layer deposited in Karnian time on the southwest flank of the plateau was lens-shaped and attained its greatest thickness in the Karmutsen Block. If Karmutsen volcanic rocks were extruded in an inter-arc basin, as suggested earlier in this report, this same basin may later have been the setting for Quatsino and Parson Bay sedimentation. In that event thick limestone of the medial limestone belt was formed where subsidence kept pace with carbonate deposition without addition of volcaniclastic material. To the southwest and to the northeast, the arcs enclosing the basin may have started shedding debris into it of gradually increasing grain-size. Thus Parson Bay lithologies may have been deposited near the arcs while in the medial belt Quatsino limestone continued to accumulate.

Age and Correlation

The age of Quatsino Limestone is well documented by extensive fossil collections made by J. A. Jeletzky, 1950 - 1954, by the writers and Jeletzky, 1968 - 1969, and by several others. E. T. Tozer of the Geological Survey examined all these collections and the earlier ones were extensively dealt with in his comprehensive work on Triassic biostratigraphy (Tozer, 1967). Localities of diagnostic fossils as they occur singly or in stratigraphic sections are shown on Figure 5; stratigraphic sections are given on Figure 4, and detailed localities and identifications of fossils in the sections by E. T. Tozer follow on Table 3.

The following additional collections are noted: Field No. 68-73B; G.S.C. Loc. 82970: Quarry on N E Main Logging Road, near junction with Branch NE 60, Rayonier Company, near Holberg; Latitude 50° 40'40"; Longitude 127° 59'15". Tropites cf. T. welleri Smith; Discotropites cf. D. mojvarensis Smith; Halobia sp. Age: Upper Karnian, Welleri Zone. Field No. 68-47 C; G.S.C. Loc. 82905: 1 1/4 mile east of Christensen Point; Latitude 50° 50'10"; Longitude 128° 10'55". Halobia cf. H. superba Mojsisovics; Hannaoceras? sp. (with ventral clavi); Tropites sp.; "Arcestes" sp. Age. Upper Karnian .

Collections by Jeletzky from Quatsino limestone near Kenny Point, at the south end of Rupert Inlet, are of special interest. They are G.S.C. Loc. 23266 and G.S.C. Loc. 23269, respectively about 2,400 and 1,900 feet northeast of Kenny Point. The collections, referred to by Tozer (1967) and Jeletzky (1970) contain Stikinoceras cf. kerri McLearn indicating the lower Norian Kerri Zone.

On the basis of available collections Tozer (1967) showed the Quatsino-Karmutsen contact as diachronous through the (early Late Karnian) Dilleri time-zone and the Quatsino-Bonanza (i.e. Parson Bay) contact as diachronous through the (early Early Norian) Kerri Zone. Subsequently Muller and Carson (1969) and Jeletzky (1970) suggested that Dilleri Zone was restricted to intra-Karmutsen limestone. Zone determinations by Tozer of present collections seem to confirm that Karmutsen-Quatsino contact coincides with the Dilleri-Welleri time-boundary.

Tozer, in his 1967 publication and in more recent fossil-reports, placed almost all collections by Jeletzky and Muller from Quatsino Formation in the Welleri Zone, except those from the Kenny Point locality. Collections from the lower part of Parson Bay Formation, commonly containing Halobia alaskana Smith were placed in the Kerri Zone. The intervening Macrolobatus Zone is apparently not represented on Vancouver Island. Thus the Quatsino-Parson Bay contact appears to be between Welleri and Kerri Zones, at the Karnian-Norian boundary, in the western and eastern belts, and somewhat higher, within the Kerri Zone, in the central belt.

The correlation of lithological and biostratigraphic boundaries is not entirely clear-cut, owing to diverse interpretations by individual workers. Carlisle, a co-author of this paper, and T. Susuki (in preparation), have somewhat different views than those just stated, and have found that:

1) Tropites dilleri and therefore Dilleri Zone is represented in the Quatsino limestone of Klaskino section. Dilleri Zone is accordingly shown in the basal Quatsino of that section on Figure 3.
2) The Welleri Zone fauna occurs in the lower part of Parson Bay Formation.

However, these differences of interpretation are relatively minor and do not conflict with the general concept of a gradual change from reefoid carbonate sedimentation of Quatsino Formation to mixed clastic-carbonate sedimentation of Parson Bay Formation taking place approximately at the Karnian - Norian time boundary.

Limestone units, approximately correlative to Quatsino Formation are widespread in British Columbia. The limestone-member of the Kunga Formation of Queen Charlotte Islands is the nearest such unit (Sutherland Brown, 1966, 1968). Other formations containing Welleri Zone faunas cited by Tozer (1967, p. 82) from northern and interior British Columbia appear to have been collected from clastic and volcanic rocks and the overlying limestone there is generally of Norian age.

Table 3

FAUNA OF UPPER TRIASSIC SECTIONS

Kyuquot Section (collections J.A.Jeletzky)

Field No.	G.S.C. Loc.	Lat.	Long.	Walters Island	Substage/ Zone
177/2	21823	50°01'40"	127°22'45"	Paracochloceras cf Suessi Mojsisovics	upper Norian upper Suessi
177/17	21825			Rhabdoceras sp.	
177/17A	23072			Astarte cf.appressa Gabb	
177/19A	23022			Cassianella lingulata Gabb	
				Parallelodon sp.	
170/17	21829	50°00'45"	127°20'45"	Plicatula perimbricata Gabb	
	23081			Pecten cf.tyaughtoni McLearn	
				Amos Island	
	21830	50°00'55"	127°21'10"	Monotis subcircularis Gabb	upper Norian lower Suessi
170/14	21430	50°00'50"	127°21'05"	Allloclionites sp.	lower Norian Columbianus zone
170/15	21431			"Dittmarites" cf."D" hindei Mojsisovics	
170/15a	24350			Himavatites sp.	
170/15b	24352			Parajuvavites cf.P.buddhaicus Mojsisovics	
170/15c	24351			Proclydonautilus sp.	
				Placites sp.	
				Steinmannites cf.S.undulatostriatus Mojsisovics	
				Union Island	
47/4	20674	49°59'50"	127°18'50"	Monotis subcircularis Gabb	upper Norian lower Suessi
47/5F	20255	50°00'00"	127°19'00"	Placites sp.	lower Norian Columbianus zone
47/5F1	20523			Sandlingites ex.gr. striatissumus Diener	
47/2a	23076	50°00'05"	127°19'00"	Halobia sp. indet	lower Norian Kerri zone
	20237			Halobia alaskana Smith	
9/1	20524	49°59'25"	127°18'20"	Anatomites sp.	upper Karnian Welleri zone
9/2	20526			Discotropites sp.	
9/3	20234			Hannaoceras cf.major Smith	
				Sirenites? sp.	
				Tardeceras sp.	
				Trachysagenites sp.	
				Tropitid, indet.	
				Paratropites	
7/2	24033	50°00'10"	127°19'00"	Paratropites cf.P.sulcatus (Calcara of Gemmelaro)	upper Karnian Dilleri zone
				Pleuronautilus cf. P. alaskensis Kummel	

Table 3

Klaskino Section (collections J.E.Muller, J.A.Jeletzky)

eld .	G.S.C. Loc.	Lat.	Long.	Feet from base		Substage/ Zone
-S2- .5	84035	50°19'08"	127°51'50"	1188	Monotis subcircularis Gabb	upper Norian lower Suessi
.4	84041	50°19'08"	127°51'50"	1117	Monotis cf.subcircularis Gabb (or possibly M.haueri Kittl)	upper Norian
.3	84044	50°19'11"	127°51'44"	1028	Monotis subcircularis Gabb	upper Norian
.2	84034	50°19'15"	127°51'45"	953	Monotis cf.salinaria (Schlotheim)	upper Norian
.1	84042	50°19'18"	127°51'44"	771	Monotis sp.(small right valve with byssal ear)	
.1	84049	50°18'59"	127°51'37"	305	Halobia cf.alaskana Smith	lower Norian Kerri zone
.1	84033	50°18'59"	127°51'30"	129	Halobia cf.ornatissima Smith Trachysagenites sp. Tardeceras sp.	upper Karnia
-F67- 5.2	82936	50°18'50"	127°51'29"	109	Halobia sp. Pamphagosirenites cf.P. pamphagus (Dittmar) Tropites sp. Tardeceras sp. Trachysagenites sp. "Juvavites" cf.J.brockensis Smith Juvavites cf.J. hyatti (Smith)	upper Karnia Welleri zone

Alice Lake Section

-110H	84062	50°22'41"	127°19'10"	4517	Undetermined corals	undetermined
-S4 12 C	84065	50°23'12"	127°19'53"	4356	Pectenids indet.	undetermined
8 M	84064	50°23'43"	127 19'58"	3966	Pectenids indet.	undetermined
7·A	84009	50°23'58"	127°19'45"	2870	Monotis subcircularis Gabb	upper Norian lower Suessi
6 D	84020	50°24'03"	127°19'45"	2455	Juvavites s.lato, sp. indet Gastropods indet Bivalves indet.	upper Triassic

Beaver Cove Section

9-S3 5 E	84027	50°28'37"	126°52'28"	894	Halobia cf.alaskana Smith	upper Norian Kerri zone
5 A	84031	50°28'47"	126°52'28"	710	Arcestids indet.	upper Karnia
3·B	84026	50°29'00"	126°52'35"	454	Tropites sp. Halobia cf ornatissima Smith	upper Karnia
2 F	84024	50°29'14"	126°52'49"	366	Arcestids indet.	upper Karn-ian?

PARSON BAY FORMATION

Nomenclature

The name Parson Bay Group was introduced by Bancroft (1913) for shales, limestones and minor volcanic rocks exposed at Parson Bay, Harbledown Island. The rocks were said to contain the Upper Triassic *Pseudomonotis subcircularis* and *Halobia* and also *Celtites vancouverensis*. Crickmay (1928) identified the latter fossil as *Melanhippites harbledownensis* Crickmay sp. nov. and considered it to indicate Early Jurassic age. On this basis, he divided the beds of Parson Bay in an Upper Triassic Parson Bay Formation, and a Lower Jurassic Harbledown Formation. The Parson Bay formation has so far not been used as a geological map-unit, but it can be usefully applied to define Upper Triassic clastic-carbonate sediments of Vancouver Island, that overlie Quatsino Formation, and are overlain by Jurassic volcanic rocks. Thus the name is here reintroduced as a substitute for the Upper Triassic part of the "Sedimentary Division of Bonanza Group" originally proposed by Gunning (1932, p. 23A) and followed by Hoadley (1953, p. 23), Jeletzky (1954, p. 10), or later "Sedimentary Division of Bonanza Subgroup" (Muller and Carson, 1969; Jeletzky, 1970B).

The formation, as defined in this report, includes many members distinguished earlier by Jeletzky, namely "Thinly bedded Member", "Arenaceous Member", and "Limestone Member" (= "Sutton Limestone" of later publications) (Jeletzky, 1954, p. 7; Tozer, 1967, p. 78 - 81). The writer has also included Jeletzky's "Waterlain breccia unit" (1970B, p. 5), included by that author in the Volcanic Division of the Bonanza Subgroup. It should be borne in mind that of all the lithologies mentioned only that of the "Thinly bedded Member" is present at Parson Bay. The "Klaskino Section" affords the most continuous section of the formation known at present, although it lacks the Sutton Limestone member.

Distribution and Thickness

Parson Bay Formation is exposed adjacent to Quatsino Formation in the western, central and eastern Triassic sedimentary belts, referred to in the discussion of the Quatsino. The latter formation is too thin to be mapped separately in the western and part of the eastern belt and is in those areas included in Parson Bay Formation. Observed thicknesses exclusive of diabase sills are about 1,000 feet in Klaskino section (top not exposed), 2,000 feet in Alice Lake section (partly exposed and with many covered intervals) and about 200 feet in Beaver Cove section (see Figures 4 and 5).

Basal contact

The Quatsino-Parson Bay contact is gradational in a sequence of interbedded grey, rather pure limestone, characteristic of Quatsino limestone, and black to dark-grey calcareous siltstone, shale and shaly limestone, commonly with *Halobia* and characteristic of the Parson Bay Formation. The contact is most suitably defined at the lowest stratigraphic level, where Parson Bay type black limestone, shale and siltstone predominate over grey limestone. However, in some sections, for instance Klaskino section, another sequence with predominant grey limestone overlies Parson Bay beds with mainly shale and siltstone. These beds are by definition included in Parson Bay although it might be impossible to distinguish them from Quatsino limestone in an isolated outcrop.

Lithology, Western Belt

In Klaskino section (see Figure 3) the lower part of the formation is thin-bedded to laminated calcareous siltstone and shale, interbedded with lenticular limestone beds up to about 15 inches thick and containing Welleri Zone ammonites. Succeeding beds of feldspathic greywacke, 3 to 4 inches thick and exhibiting small-scale intraformational slumping contain Halobia cf. H. alaskana Smith suggesting the younger Kerri Zone. The thin-bedded sediments are succeeded by a remarkable limestone breccia up to 10 feet thick consisting of limestone blocks up to 3 feet long and 1 1/2 feet thick. The fragments are light-grey, fairly pure calcarenite, the matrix is black shaly limestone. It is apparent that the bed is an intraformational slump-breccia. The breccia is succeeded by alternating grey and black limestone beds averaging respectively one foot and a few inches in thickness, generally similar to medium-bedded Quatsino limestone and containing a few thin limestone breccias. The upper part of Klaskino Section consists of calcareous feldspathic greywacke, volcaniclastic grit and pebble-conglomerate with calcareous matrix, interbedded with laminated black shaly limestone. The clastic beds exhibit graded bedding and slumping and are apparently of turbidite origin. The shaly limestones contain in places abundant Monotis.

The uppermost part of Parson Bay Formation is not present in Klaskino section but was studied by Jeletzky (1950) and later by Carlisle in Kyuquot area (Union, Walters and Amos Island sections of figure 3). There massive coralline limestone and thinly bedded fragmental limestone, 60 to 90 feet thick, overlies fine-grained calcareous greywacke and is in turn overlain by grey to maroon coloured volcanic sandstone and tuffaceous limestone. Jeletzky called this limestone in a later publication (1970, p. 5) Sutton Formation or Sutton limestone, on the basis of a fauna that is coeval to the late Norian fauna of the Sutton limestone, of Cowichan Lake (Tozer, 1967). In this report the limestone is considered as a lithologic member, at or near the top of Parson Bay Formation.

Lithology, Medial Belt

In Alice Lake Section a covered interval separates thick-bedded Quatsino Limestone with Juvavites in its uppermost part, from black, brown-weathering calcareous siltstone and shale of Parson Bay Formation, containing Monotis subcircularis. Higher beds include many layers of tuffaceous feldspathic grit and breccia. The top of the formation is only exposed in Yootook Creek. The beds are brown-weathering silty limestone with some indeterminate pectenids, calcareous shale with limestone-nodules and nodular limestone with shale interbeds. These are overlain by a distinctive reef of coralline limestone 20 feet thick. Unfortunately the corals have not provided a useful age-determination, and thus the limestone may be either Norian, correlative to Sutton limestone or (less likely) Rhaetian or Lower Jurassic. The limestone is overlain by volcanic breccias and flows assigned to the Bonanza Volcanics. A section overlying Quatsino limestone and exposed on Drake Island in Quatsino Sound, exhibits alternating sequences several hundred feet thick of calcareous tuff, grit and breccia; and medium-bedded limestone, with irregular black shaly interbeds, locally containing pelecypods, corals, gastropods, crinoids and possible ammonite-fragments, none of which could be extracted. There may be one or more fault repititions, but clearly there is an alternation of a mainly clastic and a mainly carbonate type of lithology. Another section of volcaniclastic and carbonate beds is exposed just east of the old Quatsino Hotel and Jesdal Islet. These beds were examined in detail by Jeletzky in 1954 and 1968, and by Muller in 1971. This 'Waterlain Breccia Unit' as named by Jeletzky (1969, p. 5) does not, as Jeletzky believed overlie Sutton limestone everywhere on northern Vancouver Island. It may be a facies equivalent of "Arenaceous Member" and "Sutton Limestone", with uncommonly abundant admixture of volcaniclastic material.

The breccia-unit consists of silty limestone, calcareous siltstone, interbedded with units of volcaniclastic breccias and greywackes, generally with carbonate matrix up to several hundred feet thick. Limestone occurs in these breccias as blocks, fragments and large concretions. Disregarding the thickness of intrusive sills, a total thickness of 1,600 feet was measured and estimated by Muller in the partly covered and locally disturbed coastal section. A somewhat larger thickness of about 2,000 feet was found by Jeletzky.

Lithology, Eastern Belt

The section of the eastern belt is poorly known and incomplete. Only a few hundred feet of Halobia-bearing black and silty limestone are present above thick- to medium-bedded Quatsino limestone; they are intruded and overlain by andesitic sills, related to Bonanza volcanics.

Origin

Regarding the depositional environment of Parson Bay strata one may refer again to the hypothetical inter-arc basin that became floored by Karmutsen basalts. The basalts were succeeded byshelf carbonates and in later stages sediments were carried in from the enclosing island arcs.

In the beginning, the source of/inorganic clastic material was distant and the water fairly deep, resulting in thin inter-bedding of fine-grained clastics and carbonates (thin-bedded member). Later during emergence of the ridge, deposition occurred in shallower water. Silty and nodular limestone were formed by carbonate-deposition, probably by algal accumulations and sedimentation of fine clastic material; turbidity currents periodically washed in greywacke sands and grits and breccias of limestone and volcanic material from shoreline areas, and coral reefs existed for brief periods ("Arenaceous Member, Sutton Limestone and Waterlain Breccia"). Thin-shelled pelagic Halobia, Monotis and ammonites are found in the lower, quiet water sediments, but thick-shelled pelecypods and aberrant forms of ammonites like Rhabdoceras (straight) and Paracochloceras (helicoid), possibly bottom dwellers (Tozer, 1962, p. 2) are found in the higher beds laid down in the Sutton reef environment of shallow waters disturbed by wave-action.

Age

The age of the formation is well documented though fossils are only locally abundant. Thin-bedded shales and siltstones in the lower part of Parson Bay formation commonly contain fine imprints of Halobia, in many instances not specifically determinable.

In Klaskino and Beaver Cove Sections, E. T. Tozer determined Halobia cf. alaskana Smith, probably indicating the Lower Norian Kerri Zone. Other occurrences of this fossil are cited by Tozer (1967, p. 81) in Parson Bay Formation of Harbledown Island (Crickmay, 1928, p. 59), in the Thinly Bedded Member of Union Island (Jeletzky, 1950, p. 7), and in a collection by H. C. Gunning from the southwest end of Nimpkish Lake. The occurrence of Mojsisovicsites kerri (McLearn) and Halobia alaskana reported by Jeletzky in "Quatsino Formation" at several localities between 2,000 and 3,000 feet northeast of Kenny Point at the entrance of Rupert Inlet (G.S.C. Loc. 23259, 23263, 23269) suggests that Quatsino Limestone, at that point, is coeval with Parson Bay beds elsewhere.

Fossils of the following Dawsoni, Magnus, and Rutherfordi Zones have not been found in the map-area, but the succeeding, high middle Norian Columbianus Zone is according to Tozer (1967, p. 81) well represented as follows:

> "From the NW part of Union Island, Jeletzky obtained "Sandlingites" cf. "S." striatissimus Diener and Placites sp. (20255) from beds 33 feet below the first occurrence of Monotis subcircularis (Lower Suessi Zone). This is the only known occurrence of this species of "Sandlingites" in Canada and is tentatively regarded as representing the Columbianus Zone." (See Figure 4).
>
> "On Amos Island, the following representatives of the Columbianus Zone were obtained by Jeletzky from several "nests" occurring in about 12 feet of strata: Steinmannites cf. S. undulatostriatus Mojsisovics, Himavatites sp., Thetidites cf. T. brysonis Diener, Parajuvavites cf. P. buddhaicus Mojsisovics, Placites sp. (21431, 24352, 24351). About 15 feet lower in the section specimens or "Dittmarites" cf. D. hindei Mojsisovics were collected (21430). "

The highest Triassic faunal zone known in the Insular Belt is the upper Norian Suessi Zone. Tozer has recognized a lower division of the zone, containing Monotis subcircularis and an upper division containing the fauna associated with the Sutton Limestone. But he emphasized (Tozer, 1967, p. 39) that "the difference between the faunas of the upper and lower parts of the Suessi Zone are largely due to environmental influences, and it is unlikely that the boundary between the two parts of the zone represents a constant time-stratigraphic plane".

The Lower Suessi (Monotis subcircularis) zone is known from many places in the map-area, including the measured sections (in Beaver Cove Section not found in place), and about 20 localities are shown on Figure 5. The small number of localities in the eastern part of the map-area is probably due to less intensive collecting.

Documentation of the Upper Suessi Zone is based on the collections of J. A. Jeletzky in Kyuquot and Quatsino Sound area and the writer's party did not obtain any further material. According to Tozer (1967, p. 80) they include Plicatula perimbricata Gabb; Cassianella Lingulata Gabb, Myophoria cairnesi McLearn, Rhabdoceras Suessi Hauer and Paracochloceras suessi Mojsisovics.

Fossils from the "Waterlain Breccia Unit" collected by Jeletzky at Hecate Cove

(GSC Loc. 82932) include, according to E. T. Tozer Neomegalodon sp., Palaeocardita sp. and indeterminate bivalves, gastropods and corals of probable Upper Triassic age, while a Plicatula sp. and Pectenids indet. suggest Late Norian age. Jeletzky's tentative assignment of these rocks to the Rhaetian Stage appears therefore to lack positive biostratigraphic support.

As stated earlier, the writers found no evidence for the systematic superposition of a "Waterlain Breccia Unit" on a Sutton Limestone Member, but consider these to be interdigitating members of Parson Bay Formation. This interpretation implicitly negates the orogenic phase separating Sutton Formation and Waterlain Breccia Unit postulated by Jeletzky (1970, p. 8).

HARBLEDOWN FORMATION

Nomenclature

The presence of Lower Jurassic rocks in the map-area was first established by Crickmay (1928). The sediments, together with those of Late Triassic age, had first been named Parson Bay Group by Bancroft (1913). Crickmay reserved the original name for the Triassic part of the sequence and named the Jurassic beds "Harbledown Formation".

The formation constitutes the total of Lower Jurassic beds in that area, but appears to be devoid of thick volcanic assemblages like the Bonanza Volcanics sequence of western Vancouver Island (Jeletzky, 1970B, p. 18). However, minor volcanism is indicated by the presence of andesitic dykes. The formation name is used in this report to designate the non-volcanic Lower Jurassic argillite-greywacke sequence on the islands of Queen Charlotte Sound that are correlative with the Bonanza Volcanics of western Vancouver Island. At present the rocks are known on Harbledown, Swanson, Balaclava, Nigei and some smaller islands.

Lithology

The lithology of the Harbledown Formation at the type-locality is according to Crickmay (1928, p. 56) mainly argillite, distinct from Parson Bay beds by its non-calcareous character. At the base, 200 feet of black argillite contain intercalations of "thin beds of green cherty quartzite which give the rock a strongly banded appearance". These beds, not seen by the writer, are most likely tuffaceous and contain the Upper Sinemurian Melanippites (name now according to H. Frebold amended from Melanhippites.) They are succeeded by about 1,400 feet of black argillites. On the east side of Nigei Island and the west side of Balaclava Island, a steeply northeast dipping turbidite sequence of black, brown-weathering greywacke and argillite with graded bedding are well exposed. On the latter island, they contain Pliensbachian ammonites indicating that both lower stages of the Lower Jurassic sequence are represented in that area. To the south on the same island, the sediments appear to grade upward into silty limestone, calcareous siltstone and cross-bedded feldspathic sandstone with coquinas of non-distinctive pelecypods.

Age

Several Lower Jurassic faunal zones have been identified in Harbledown beds (see Figure 5). Frebold and Tipper (1970) quoting Crickmay (1928) list Arniotites kwakiutlanus Crickmay and Melanippites harbledownensis Crickmay from Harbledown Island as defining the Lower and Upper Sinemurian stages.

H. Frebold also identified a lower Pliensbachian fauna containing Acanthopleuroceras cf. A. mc learni Frebold (nov. sp.) in a collection (GSC Loc. 82897) found by the writer's party on the west side of Balaclava Island (Frebold and Tipper, 1970). Thus it seems that Harbledown Formation spans a time interval including Sinemurian and Lower Pliensbachian beds. The Harbledown Formation is coeval with the upper part of the Kunga Formation of Queen Charlotte Islands. Sinemurian and Pliensbachian sediments are also widely known in Interior British Columbia and Yukon Territory.

BONANZA VOLCANICS

Nomenclature

The name Bonanza Group was introduced by Gunning (1932, p. 23A) for the assemblage of sedimentary and volcanic rocks exposed above the Quatsino Formation on the upper slopes west of Bonanza Lake. Hoadley (1953) and Jeletzky (1954) divided the group into a lower Sedimentary Division and an upper Volcanic Division. Muller and Carson (1968) modified the term to Bonanza Subgroup, as it is part of the Vancouver Group. In that subgroup, they included Upper Triassic sediments that overlie the Quatsino Formation, in this report identified as Parson Bayand Harbledown Formation.

In the present report the term "Sedimentary Division of the Bonanza Group (Subgroup)"is abandoned and thename "Bonanza" is restricted to volcanic rocks overlying Lower Jurassic (or if these are missing, Upper Triassic) sediments. The name "Bonanza Volcanics" is substituted for the rather awkward and now redundant "Bonanza Subgroup". In west coast areas where minor Jurassic sediments are intercalated within the volcanics, these are to be considered as part of the volcanics, but on the east coast Lower Jurassic Harbledown sediments and Bonanza Volcanics, mapped by Carlisle east of the map-area in Bute Inlet area, are two distinct formations.

Basal contact

The base of the Bonanza volcanics is thus taken either at the lowest andesitic lava or volcanic breccia overlying Parson Bay sediments (the latter including waterlain volcaniclastic breccia, taken by Jeletzky as lowest unit of the "Volcanic Division") or, in the east, above greywacke and argillite containing a Lower Jurassic fauna (= Harbledown Formation). Carlisle (1972A; Figure 3 of this paper) considers the basal contact of Bonanza Volcanics in Bute Inlet map-area to be an unconformity, but one resulting from slumping of pyroclastic debris on the flanks of volcanic highs rather than from deformation of underlying sediments.

Admittedly it may be impossible in some instances to distinguish between waterlain volcaniclastic breccia of Parson Bay and a lahar-type volcanic breccia of Bonanza volcanics. In western areas the top of the highest beds of Sutton-type limestone may correspond to the Parson Bay - Bonanza contact.

Jeletzky has recently (1970) proposed a subdivision of the Bonanza Subgroup (Volcanics) into nine alternating volcanic and sedimentary units. He constructed this complex sequence by stacking partial sections examined by him, each containing two or three units. Only the middle (fifth) unit of this reconstructed sequence is reliably dated by fossils (Lower Sinemurian) and other correlations between partial sections appear to be based on lithological similarity. Although interfingering of sedimentary and volcanic units in Bonanza Volcanics undoubtedly occurs, a consistent division into nine units is in this writer's view by no means established, cannot be mapped in the field, and may well include one or more duplications of individual units. For the purpose of this report Bonanza Volcanics are treated as one unit.

Distribution and Thickness

Most of the southwestern half of northern Vancouver Island facing the Pacific Ocean is underlain by Bonanza Volcanics. Northeast of the Holberg and Nimpkish Faults, they are only represented in small areas and, on the Queen Charlotte Strait Islands, only Harbledowne sediments are present. The thickness of about 8,000 feet, found in Cape Parkins section, is probably a representative average thickness.

Lithology

The lithology of the Bonanza Volcanics is varied and heterogeneous, in contrast to the monotonous uniform sequences of the Karmutsen volcanics. Lavas range in composition from basaltic andesite commonly amygdaloidal, to rhyodacite and are interbedded with maroon and green tuffs and breccias and several clastic sedimentary units, some of which contain Lower Jurassic (Sinemurian) fossils. A section, that appears to represent most of the Bonanza volcanics, was measured along the Pacific Coast north of Cape Parkins (north side of entrance of Quatsino Sound), and its major lithologies are tabulated below.

Cape Parkins Section, Bonanza Volcanics

		Thickness (Feet) Unit	Total from base
Unit 12	Rhyodacite, massive and well laminated flows, up to 3 feet thick, reddish grey, fine-grained, pink or white feldspar-phenocrysts to 3 millimetres long	1,000	8,485
Unit 11	Basaltic andesite; pillowed, brecciated flows (blocks to 5-foot size) bedded granule-breccia and tuff (beds up to 10 feet thick), reddish to greenish grey; lavas are vesicular with calcite and zeolite-rosettes and porphyritic with clear white or pink plagioclase	450	7,485
Unit 10	Greywacke, pebble-conglomerate with shale and coal fragments. Numerous fossils (GSC Loc.84046; Weyla, Trigonia, corals, ammonites)	25	7,035
Unit 9	Andesite and basaltic andesite, laminated flows with ropy brecciated tops, 4 to 20 feet thick, dark greenish to reddish grey, in places amygdaloidal and porphyritic	1,500	7,010
Unit 8	Andesite and basaltic andesite, flows 3 to 15 feet thick, dark greenish grey, commonly with reddish flow-tops, fine-grained to aphanitic, locally with small black amygdules. Several flows exhibit colorless plagioclase phenocrysts to 3/4 in.(2 cm) long.	1,070	5,510

		Thickness (Feet) Unit	Total from base
Unit 7	Basaltic andesite, tuff, pillow-breccia and minor lava, limestone lenses, dark greenish grey, weathers light brown, mafic phenocrysts 1 - 2 mm. long	545	4,440
Unit 6	Andesite and basaltic andesite, mainly agglomerate and broken-pillow breccia. Greenish grey fragments with small white feldspar phenocrysts in green matrix of aquagene tuff, calcite and quartz in vesicles	1,375	3,895
Unit 5	Andesite, interbedded flows, 2 to 30 feet thick, and breccias with fragments up to 4 inches in size, dark grey, weathers reddish grey, fine-grained and partly amygdaloidal, mafic phenocrysts to 1 mm. size, dark red hematitic spots, and calcite amygdules in places	260	2,520
	Covered interval	110	2,260
Unit 4	Andesite, flows are vesicular and brecciated at top or throughout, maroon to reddish brown, white to pink feldspar phenocrysts up to 2 mm. in size and calcite amygdules	525	2,150
Unit 3	Greywacke, argillite and breccia, beds 1 inch to 2 feet thick, in part well laminated, fragments to 4 inches in size, contains coaly fragments and lenticles fine, medium and coarse-grained, light greenish grey to reddish, weathers dark brownish grey, in part calcareous. Fossil-beds at 95 feet above base of unit (GSC Loc. 84047; Weyla); 120 ft. above base (Rhynchonellids); 330 ft. above base (GSC Loc. 84048; pelecypods, brachiopods, ammonites); and 585 ft. above base (GSC Loc. 84036; Pelecypods).	750	1,625
Unit 2	Rhyodacite, in massive or in laminated flows up to 5 inches thick, light grey, weathers pinkish grey, white or pink feldspar phenocrysts to 2 mm. long	120	875
Unit 1	Dacite and rhyodacite, massive or in flows 1 to 5 feet thick, locally laminated, medium reddish to greenish grey, weathers reddish brown, with pink or white feldspar phenocrysts 1 to 4 mm. long or with amygdules filled with quartz, carbonate or chlorite	755	755

No stratigraphic section can be measured in this region without crossing several faults. As good markers are lacking, the continuity of the section described above is somewhat subjective. Ammonites from Unit 3 (GSC Loc. 84048, Arnioceras sp. indet.) indicate according to H. Frebold early Sinemurian age; those from Unit 10 (GSC Loc. 84046, Echioceras cf. harbledownense) are late Sinemurian. Some doubt may be expressed if Unit 3 is indeed underlain by about 900 feet of dacite and rhyodacite of Units 1 and 2 as the contact is disturbed. Alternatively, Units 1 and 2 would be equivalent to Unit 12, requiring about 7,000 feet of fault-displacement. Definite evidence for such a fault is lacking.

Bonanza andesites are dark reddish to greenish grey rocks, less massive and more coarsely vesicular than Karmutsen basalts. They are generally fine-grained to aphanitic, but there are distinctive coarse porphyries containing densely packed plagioclase phenocrysts to 1 cm. long. The larger vesicles contain calcite, quartz and rosettes of zeolites.

Thin sections show saussuritic plagioclase, commonly in two generations and where determinable and not albitized with composition of either andesine or labradorite, and intersertal grains of clinopyroxene. Hypersthene, definitely identified in some samples as a second pyroxene, may also be represented by rectangular pseudomorphs of talc and serpentine in other thin sections. The mesostatis consists mainly of chlorite (ripidolite), serpentine and opaque matter.

Bonanza dacites are reddish to greenish grey rocks of lighter hues than the andesites, commonly containing conspicuous white or pinkish plagioclase phenocrysts 1 to 2 mm. long, and small specks of hematite. Thin sections show phenocrysts of largely altered oligoclase-andesine and minor pyroxene, also mostly altered, in a diffuse matrix of feldspar and interstitial quartz. Bonanza rhyodacites are reddish, greenish and pinkish grey aphanitic or vitrophyric rocks with white or pink feldspar phenocrysts, a few mm. long. Thin sections show the albitic phenocrysts in a matrix of fine feldspar and quartz, chlorite and hematite. Staining of some sections of these rocks by Northcote revealed some potash feldspar in the matrix of rhyodacite from the Cape Scott region. Rhyodacite from Kyuquot Sound contains phenocrysts of potash feldspar with Karlsbad twinning and with sodic feldspar with albite twins. Many of these silicic rocks exhibit typical welded tuff texture on the outcrop and under the microscope. They also exhibit in some places complex folds within the outcrop, apparently the result of the crumpling of a moving flow .

Chemistry

Chemical analyses of 19 samples of the Cape Parkins section were made to aid classification of Bonanza Volcanics (Table 4), and to determine any difference with Karmutsen Volcanics (Table 3). Table 4 shows the results, tabulated in stratigraphic order; unit members correspond to units of the section described above.

Figure 5 shows a Larsen (1938) plot of the data, together with some average compositions of classes of volcanic rocks according to Nockolds (1954).

The plot shows excellent separation of Karmutsen and Bonanza Volcanics. The cluster of Karmutsen lavas, between -11.2 and -15.3 on the abscissa, contains, on the silicic side, Nockolds' "normal tholeitic basalt". Values for three analyses of Karmutsen Volcanics from Queen Charlotte Islands (Sutherland Brown, 1968) could not be plotted separately: two coincide with values on opposite ends of the Karmutsen-cluster and one coincides with the basic end of the Bonanza andesite group. Plotted on Kuno's (1968) Alkali - Silica diagram, the Karmutsen rocks are partly in the Tholeite - and partly in the High-alumina-basalt field.

The largest group of Bonanza Volcanics plots between -0.5 and -6.7 on the abscissa of the Larsen diagram. This cluster coincides, on its silicic side, with Nockolds' "average andesite"; the average of 5 Aleutian basaltic andesites (Coats, 1968) agrees with the basic side of this cluster. One basalt, similar in chemistry to Karmutsen Volcanics is also present. Plotted on Kuno's Alkali-Silica diagram, Bonanza Volcanics are scattered across the three (tholeite, high alumina and alkali) fields, but most of them are within the alkali field. As the petrographic character of these rocks, so far as can be ascertained in spite of fine grain-size and alteration, is calc-alkaline, but albitized, it is suggested that the high alkali values are due to secondary enrichment, mainly in sodium.

Two analyses plot close to the "average dacite" of Nockolds (1954), and five analyses cluster between the points for "average rhyodacite" and "average dellenite" (= quartz-latite). An analysis of "andesite" from the Yakoun Formation of Queen Charlotte Islands (Sutherland Brown, 1968) would plot slightly to the left of the Bonanza dacites.

Table 4. Analyses of Bonanza Volcanics, North of Cape Parkins

Analyst: S. Courville, Geological Survey of Canada.
Method: X-Ray Fluorescence, supplemented by rapid chemical analysis for FeO, Na_2O, P_2O_5, CO_2 and total H_2O.

Refraction indices (R.I.) determined by L.E. Sheppard and E. F. Karpick, of British Columbia Department of Mines and Petroleum Resources.

it	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	CO_2	H_2O	Total	R.I.
2B	68.6	0.55	15.2	2.4	2.0	0.03	1.7	1.2	5.0	3.1	0.12	0.7	1.1	101.8	1.504
2A	67.8	0.55	15.1	2.3	1.8	0.03	1.5	1.4	5.2	2.6	0.12	1.6	0.9	100.9	1.504
1	48.6	1.02	19.6	2.8	5.6	0.16	4.5	9.3	3.7	0.8	0.05	0.5	2.2	98.8	1.574
9E	48.7	1.53	17.2	3.7	6.4	0.26	8.0	5.6	4.4	1.0	0.42	0.1	3.9	101.2	1.578
9D	50.0	2.03	15.8	3.8	7.4	0.24	6.2	4.8	5.2	1.1	0.52	0.2	3.3	100.6	1.574
9C	53.5	1.96	14.8	3.6	7.4	0.19	5.2	5.8	4.2	1.5	0.61	0.1	2.5	101.4	1.567
9B	51.1	1.40	15.4	4.4	5.4	0.14	5.1	6.8	4.8	1.7	0.42	1.6	2.5	100.8	1.570
9A	52.1	1.70	15.3	4.3	5.7	0.18	4.7	6.4	3.8	1.5	0.37	0.1	2.4	98.6	1.569
8B	47.9	1.23	19.2	3.9	5.3	0.14	3.7	9.4	3.3	0.7	0.23	2.5	3.0	100.6	1.580
8A	43.7	1.59	16.9	7.1	4.7	0.16	9.3	5.8	3.8	1.0	0.09	0.8	4.6	99.5	1.594
6C	50.1	0.86	17.4	2.9	4.9	0.14	6.7	5.4	4.5	2.2	0.17	1.0	3.6	99.9	1.559
6B	55.7	0.69	16.5	1.9	5.2	0.17	4.7	9.0	3.4	1.0	0.18	0.2	2.7	101.3	1.558
6A	49.4	0.82	17.5	1.9	4.5	0.15	4.2	10.9	4.4	1.2	0.22	2.8	1.4	99.4	1.570
4B	69.6	0.27	13.5	0.9	1.8	0.05	1.4	2.2	2.3	2.1	0.03	2.9	2.0	99.1	1.506
4A	72.4	0.30	13.0	0.5	2.9	0.11	1.9	1.3	4.4	2.2	0.03	0.3	1.1	100.4	1.493
3	51.4	2.21	14.2	2.4	7.9	0.26	5.1	7.4	3.9	0.8	0.63	1.4	2.6	100.2	1.583
2	74.4	0.29	12.8	0.3	2.2	0.09	1.6	0.7	5.0	1.5	0.03	0.1	0.7	99.7	1.491
1B	60.4	1.11	15.3	2.1	5.0	0.16	3.1	4.1	4.2	2.8	0.26	1.0	1.9	101.4	1.533
1A	61.2	1.13	14.9	2.7	4.0	0.14	3.3	2.4	5.4	1.9	0.29	0.2	1.7	99.3	1.525

3, 6A, 6B, 6C, 8A, 9A, 9B, 9C, 9D, 9E, 11: aphanitic and fine-grained andesite; 3 is dyke

8B: coarsely porphyritic andesite

1A, 1B: fine-grained and aphanitic porphyritic dacite

2, 4A, 4B, 12A, 12B: fine-grained and aphanitic porphyritic rhyodacite

Refraction indices of fused rock were determined also according to Mathews' (1951) method by courtesy of B. M. Church of the British Columbia Department of Mines and Petroleum Resources. The results, shown on table 1 and figure 1, correlate very well with the analyses. Karmutsen basalts (see table 3) range between R. I. = 1.596 and 1.622. Bonanza andesites between R.I. = 1.558 and 1.583, and the one sample of basalt has an index of 1.594. Bonanza dacites (only two samples) range from R.I. = 1.525 to 1.583 and rhyodacites from 1.491 to 1.504. Clearly this method can be used as a fairly reliable tool to determine the general composition of these volcanic rocks. Bearing in mind that apparently there are a few basaltic andesites in Karmutsen volcanics and a few basalts in Bonanza Volcanics, the method can be used with discretion to distinguish the two rock-groups. This has already been put into practice by Northcote in the course of detailed work in Cape Scott area.

Metamorphism

Regional metamorphism of the volcanics, if any, is of zeolite facies. Plagioclase is commonly albitized and saussuritized and chlorite laumontite and epidote occur in the matrix veinlets, and amygdules. Contact metamorphism around larger intrusions has resulted in hornfelsic rocks, but around small stocks, sills and dykes extensive alternation may be in part pre-intrusive and subvolcanic and is characterized by silicification, kaolinisation, pyrophyllitisation and the introduction of sulphide minerals (see section on economic geology).

Dr. P. B. Read of the University of British Columbia kindly examined secondary material in samples of the Cape Parkins section by means of X-Ray diffraction. He identified laumontite in amygdule and fracture fillings in Units 1, 4, 5; analcime in Unit 3, and adularia in Unit 11. Chlorite - montmorillonite assemblages and calcite were also identified in several samples.

Age and Correlation

The age of the Bonanza Volcanics is well established by fossils in interbedded sediments. The section at Cape Parkins, cited above, contains two datable sedimentary zones, separated by about 5,800 feet of volcanics. The lower zone contains, according to H. Frebold of the Geological Survey, Arnioceras sp. indet. and Weyla sp. indicating Early Sinemurian age (GSC Loc. 84048), the upper zone contains Echioceras (Melanippites) cf. E. harbledownense (Crickmay), Weyla sp., Trigonia sp. together with unidentified gastropods and corals (GSC Loc. 84046). The ammonite indicates Late Sinemurian (Lotharingian) age.

Lower Sinemurian faunas were also found east of Cape Scott, between Nels Bight and Experiment Bight (GSC Loc. 84058), on Moketas Island in Kyuquot Sound (GSC Loc. 82845) and (by J. A. Jeletzky) on the northwest side (GSC Loc. 23290) and the middle east side (GSC Loc. 23949) of Matthews Island in Forward Inlet. They include Arniotites sp. cf. A. kwakiutlanus Crickmay, Trigonia sp., Rhynchonella sp. indet., and Weyla sp. A. indet., according to H. Frebold. "The ammonite has hitherto been found mainly in the shaly argillites of the Harbledown Formation and indicates a position close to the zone of Arnioceras semicostatum."

The upper Sinemurian Obtusum zone including Asteroceras aff. A. obtusum (J. Sowerby) has been found on Cox Island (GSC Loc. 84077), San Josef Bay (GSC Loc. 82892, 82893); the Raricostatum zone with Echioceras (Melanippites) harbledownense (Crickmay) was collected on a tributary of Fisherman River (GSC Loc. 86514) at San Josef Bay near the head of Stranby River on a Rayonier logging road (GSC Loc. 82844), at Nordstrom Cove on Quatsino Sound, (GSC Loc. 82886; E. sp. indet.), east of the mouth of Mahatta River on that same sound and on Balaclava Island north of Vancouver Island (GSC Loc. 82878; E. sp. indet.).

Jeletzky (1970, p. 13) distinguished within the Bonanza sequence a unit of Lower Pliensbachian Argillites, which he believed was separated by a volcanic unit from "Sinemurian Argillites" carrying Arniotites and Echioceras. The Pliensbachian age was based on a collection from the shore of Quatsino Sound, just west of the mouth of Mahatta River (GSC Loc. 24311), which contained an ammonite fragment that according to H. Frebold (pers. comm.) was too poorly preserved to warrant unequivocal identification, but reminded him of Microderoceras and Acanthopleuroceras. In an earlier internal report, he identified it as ?Crucilobiceras, late Sinemurian or early Pliensbachian?

The writer recollected at the same locality in 1971 (GSC Loc. 88620) and H. Frebold identified the fossils as Crucilobiceras sp. indet. and Entolium balteatum Crickmay, indicating a Late Sinemurian age, upper part of Raricostatum Zone. Thus only a range of Sinemurian ages has so far been established for Bonanza Volcanics of the map-area. Lower Pliensbachian fossils have however been found in Bonanza Volcanics in Kyuquot Sound map-area, south of Alert Bay map-area (Frebold and Tipper, 1970).

Regarding correlation of Harbledown Volcanics of east Vancouver Island and Bonanza Volcanics of west Vancouver Island, one may conclude that they are for a large part coeval: both formations contain early and late Sinemurian as well as early Pliensbachian fossils. Bonanza Volcanics are coeval with the non-volcanic Maude Formation of Queen Charlotte Islands (Sutherland Brown, 1968); there the volcanics of the Yakoun Formation are of Bajocian and Callovian age, apparently younger than the Bonanza Volcanics.

Potassium-argon Ages

J. E. Harakal and the late W. H. White made potassium-argon determinations on whole-rock samples of Bonanza Volcanics collected by Northcote and the results are listed in Table 5.

According to the Geological Society of London time-scale (see Wanless et al, 1972) these ages range from earliest Late Jurassic (161) to late Early Cretaceous (103). The whole rock ages are considered to be only minimum ages, and it is not likely that the volcanics are quite that young, because known sediments of these ages carry only volcanic debris but no flows or tuffs. However, compared with isotopic datings of granitic rocks, these dates show the close time-correlation between volcanic and granitic rocks.

Table 5

Potassium-argon Age Determinations

J. E. Harakal and the late W. H. White for B. C. Dept. of Mines (G.E.M. 1972)

Sample	Material	Location	%K	%Ar	Rock type	Age m.y.
KN68-168	Whole rock	Apple Bay, Holberg Inlet 50°36'06"N 127°39'23"W	1.59	86	Bonanza Andesite	161±6
KN69-8	Whole rock	Cape Scott 50°47'08"N 128°25'30"W	3.18	81	Bonanza Rhyodacite	135±4
KN69-8 (re-run)	Whole rock	" " "	3.18	74	" "	135±4
KN69-10	Whole rock	South of Hansons Lagoon 50°43'20"N 128°22'50"W	2.55	79	Bonanza Rhyodacite	103±4
KN69-98VI	Whole rock	Hansons Lagoon 50°43'50" N 128°22'35"W	2.12	87	Bonanza Rhyodacite	139±4
KN69-327	Whole rock	San Josef 50°38'30" N 128°07'47"W	3.36	81	Bonanza Rhyodacite	145±6

ISLAND INTRUSIONS AND WESTCOAST CRYSTALLINE COMPLEX

Granitic rocks are widespread throughout the map-area as well as other parts of Vancouver Island. Most granitic intrusions are Jurassic in age and have been designated Island Intrusions in recent publications (Eastwood, 1965, Muller and Carson, 1969, Carson, 1973).

A complex of amphibolite, basic migmatite and gneissic quartz diorite and gabbro was named Westcoast Crystalline Complex (Muller and Carson, 1969). The complex is apparently equivalent to the gneissic complexes of southern Vancouver Island, named Wark Gneiss and Colquitz Gneiss by Clapp (1913) and Clapp and Cooke (1917). As Island Intrusions and Crystalline Complex appear to be intimately related they will be discussed together. Locations and lithologies of plutonic rocks are shown on Figure 6.

Island Intrusions have invaded all Vancouver Group rocks and are elongated in a northwesterly direction. Vernon Batholith is largest among them and entirely surrounded by Karmutsen volcanics. It probably exhibits the deepest level of erosion. In contrast, Amai and Kashutl Intrusions appear on the map as small elliptical bodies of about one mile width and are clearly high-level intrusions with corresponding mineral composition and texture.

The intrusions have been separated into 6 zones, from northeast to southwest, as follows:

Zone Ia	Adam River Batholith
Zone Ib	Hope, Nigei, Balaclava Islands
Zone II	Vernon Batholith
Zone IIIa	Nimpkish-Bonanza Batholith and Satellites
Zone IIIb	Nahwitti Batholith and Satellites
Zone IV	Zeballos, Kauwinch, Merry Widow, Victoria, Neroutsos Intrusions
Zone V	Amai, Kashutl, Mahatta Intrusions
Zone VI	Westcoast Crystalline Complex: Brooks Peninsula and Scott Islands

These intrusive zones exhibit rocks varying in composition from leuco quartz monzonite to gabbro, but the majority are grano-diorite and quartz diorite. Small high-level bodies and cores of the larger bodies contain leuco granodiorite and quartz monzonite, and deeper and marginal parts contain diorite and gabbro. Distribution of these rock-types and modal compositions are shown on Figure 7 and Table 6. Lithologies of each individual classification vary little from zone to zone and are described successively.

Zone II and III are the most extensive and exhibit the widest range of rock-types in the samples examined in thin section, from leuco quartz monzonite to quartz diorite and they will be discussed first. Quartz gabbro was found only in Zones Ib and VI. Diorite and gabbro are only represented by single samples in Zone VI.

TABLE 6

MODAL COMPOSITIONS OF GRANITIC ROCKS

Zone I a	Adam River Batholith
Zone I c	Hope - Nigei Island Group
Zone II	Vernon Batholith
Zone III a	Nimpkish - Bonanza Batholith and Satellites
Zone III c	Nahwitti Batholith and Satellites
Zone IV	Zeballos, Kauwinch, Merry Widow, Victoria Lake, Neroutsos Intrusions
Zone V	Amai, Kashutl, Mahata Intrusions
Zone VI	West Coast, Scott Islands gneiss-diorite Complex

Zone	No. of Samples		Quartz	Plagioclase	Potash Feldspar	Biotite	Hornblende	Pyroxene	Chlorite	Epidote	Opaque	Accessories	Specific Gravity	Ave. for (.) Samp
LEUCO QUARTZ MONZONITE						Average Specific Gravity 2.68 (15)								
	4	Ave.	34.5	36.7	25.2	2.4	*	-	0.4	0.1	0.7	*	2.64	(4)
		Min.	27.4	33.0	19.2	1.0	-	-	0.2	-	0.4	-		
		Max.	40.8	38.2	36.0	3.2	0.2	-	1.0	0.2	1.1	0.2		
Ia	3	Ave.	34.0	36.7	22.8	1.5	0.7	-	1.9	0.1	1.3	0.9	2.69	(3)
		Min.	31.4	38.5	22.1	-	-	-	-	-	0.5	0.2		
		Max.	35.9	39.0	24.0	4.4	2.1	-	4.1	0.4	2.3	1.8		
Ib	3	Ave.	26.6	40.2	24.6	5.0	1.4	-	1.6	0.1	0.4	0.1	2.65	(3)
		Min.	17.6	38.0	21.0	2.1	0.2	-	0.3	0.1	0.2	0.1		
		Max.	33.3	43.5	27.9	6.5	3.9	-	4.0	0.2	0.5	0.3		
	5	Ave.	22.9	40.1	30.6	1.3	1.9	-	0.8	0.1	1.2	0.7	2.72	(5)
		Min.	14.5	29.0	23.1	0.4	1.1	-	0.2	-	0.6	0.1		
		Max.	29.0	50.8	37.3	4.5	4.4	-	2.0	0.5	3.2	1.9		
LEUCOGRANODIORITE						Average Specific Gravity 2.68 (11)								
	6	Ave.	33.2	48.3	14.0	0.9	1.1	-	2.2	0.4	1.3	0.9	2.68	(6)
		Min.	27.9	41.2	8.6	0.4	0.2	-	0.6	-	0.5	0.1		
		Max.	40.1	57.8	20.1	2.2	3.9	-	4.2	1.9	2.3	2.8		
Ia	4	Ave.	29.9	52.3	12.6	1.8	1.1	-	1.3	0.2	0.5	0.4	2.70	(4)
		Min.	25.1	48.9	8.1	0.5	0.3	-	0.6	-	-	-		
		Max.	38.1	57.9	17.6	3.8	4.0	-	2.0	1.0	1.3	1.5		
	1	-	35.2	42.7	17.3	-	-	-	3.2	-	1.6	-	2.63	(1)

	No. of Samples		Quartz	Plagioclase	Potash Feldspar	Biotite	Hornblende	Pyroxene	Chlorite	Epidote	Opaque	Accessories	Specific Gravity	Ave. for (.) Sample
			GRANODIORITE		Average		Specific		Gravity		2.71 (25)			
:	2	Ave.	23.7	47.5	10.5	6.6	7.6	11	0.8	0.7	1.0	0.5	2.73	(2)
		Min.	17.1	44.1	5.9	2.2	–	–	0.5	0.6	0.4	0.2		
		Max.	30.3	51.0	15.0	11.0	15.2	2.2	1.2	0.7	1.6	0.8		
o	2	Ave.	13.0	59.3	7.6	5.7	10.2		2.5	0.4	1.0	0.3	2.74	(1)
		Min.	12.8	54.6	4.2	–	6.0		0.5	0.4	0.3	0.2		
		Max.	13.1	64.0	11.6	11.3	14.5		4.5	0.5	1.6	0.4		
I	6	Ave.	19.0	49.2	9.2	5.4	13.3		1.0	–	1.1	0.4	2.77	(6)
		Min.	4.5	41.8	6.5	0.8	3.9		0.4	–	0.5	–		
		Max.	28.6	57.6	16.6	11.8	40.2		4.0	0.2	2.0	1.1		
Ia	6	Ave.	29.7	46.2	14.5	4.8	2.5		0.7	0.1	0.9	0.5	2.69	(6)
		Min.	21.5	38.9	8.3	2.2	–		–	–	0.1	–		
		Max.	38.1	53.0	18.8	6.2	4.6		1.5	0.7	2.0	2.0		
Ib	4	Ave.	24.4	51.1	12.8	2.5	2.8		5.5	0.5	1.0	0.2	2.71	(1)
		Min.	19.5	43.0	7.5	1.6	1.0		0.2	–	0.6	–		
		Max.	30.4	58.5	19.0	5.6	6.6		14.8	2.0	1.6	1.0		
7	4	Ave.	23.9	51.8	14.1	0.9	0.7		4.3	1.3	2.4	0.7	2.69	(3)
		Min.	15.1	40.6	11.2	–	–		–	–	0.2	–		
		Max.	35.0	58.0	19.4	2.6	2.2		7.7	3.8	4.0	1.2		
	5	Ave.	23.0	51.5	16.3	1.0	1.6		2.4	1.3	2.3	0.8	2.68	(5)
		Min.	13.0	47.3	12.7	–	–		0.2	–	1.3	–		
		Max.	27.1	58.8	20.5	3.5	5.4		4.5	3.9	3.2	2.6		
I	1		20.6	60.2	5.6	6.1	3.1		4.2		0.2		2.67	(1)
			QUARTZ-FELDSPAR (GRANODIORITE-) PORPHYRY											
Ib	1	Ave.	34.0	42.5	15.5		0.5		4.5	2.5	0.5			
		Min.	14.5	34.5	– – – – – – phenocrysts									
		Max.	19.5	8.0	15.5	– – – matrix								
	I	Ave.	29.3	46.6	24.3				3.0		1.1		2.61	(1)
		Min.	5.0	22.3	– – – – phenocrysts									
		Max.	20.0	24.3	24.3	– – – – matrix								

Zone	No. of Samples		Quartz	Plagioclase	Potash Feldspar	Biotite	Hornblende	Pyroxene	Chlorite	Epidote	Opaque	Accessories	Specific Gravity	Ave. for (.) Samples
			QUARTZDIORITE			Average Specific Gravity 2.74 (30)								
			(Leuco quartz diorite in Zone V)											
Ia	2	Ave.	17.0	51.0	3.2	7.5	17.5	0.4	1.8	0.2	1.0	0.4	2.81	(2
		Min.	15.4	45.0	3.1	5.0	13.9	–	0.4	–	0.9	–		
		Max.	18.6	57.0	3.3	10.1	21.0	0.8	3.2	0.5	1.0	0.8		
II	7	Ave.	17.8	58.2	2.5	4.1	11.0	0.3	3.3	0.3	1.8	0.3	2.77	(7)
		Min.	8.8	53.2	0.4	–	2.3	–	0.5	–	1.0	–		
		Max.	30.3	62.0	5.0	8.7	20.0	1.2	11.0	1.2	4.2	0.9		
IIa	6	Ave	20.2	58.1	1.3	0.7	14.8	0.1	2.9	0.1	1.2	0.4	2.76	(4)
		Min.	7.4	47.9	–	–	0.3	–	2.0	–	–	–		
		Max.	42.7	69.0	3.4	2.0	31.1	0.6	4.3	0.5	3.1	1.0		
IIb	5	Ave.	19.1	55.7	1.8	1.4	13.3		3.8	2.2	2.3	0.5	2.71	(1)
		Min.	10.1	49.0	–	–	6.2		1.2	–	1.2	–		
		Max.	33.5	66.0	4.0	6.2	17.6		5.6	6.0	3.0	2.0		
IV	4	Ave.	13.6	64.4	2.9	3.5	6.5	3.1	3.7	1.4	1.4	0.3	2.74	(4
		Min.	6.1	55.3	2.2	–	–	–	0.3	–	–	–		
		Max.	30.0	71.1	3.4	10.0	14.6	9.9	9.8	5.4	3.5	1.2		
V	4	Ave.	28.1	62.7	0.2	0.3	0.7		3.9	0.4	0.7	0.4	2.70	(4
		Min.	18.9	55.0	–	–	–		–	0.2	0.2	–		
		Max.	40.0	71.4	0.6	0.8	2.8		4.8	13.3	1.3	1.4		
VI	10	Ave.	26.2	57.6	1.0	3.0	6.4		3.4	0.3	1.4	0.8	2.72	(3
		Min.	10.4	48.0	–	–	–		0.1	–	0.1	–		
		Max.	43.4	65.9	4.3	7.7	20.5		6.6	1.3	5.1	2.9		
				DIORITE										
VI	1		–	55.6			35.8	1.9			6.7		3.00	(1)
				QUARTZGABBRO		Average Specific Gravity 2.81 (3)								
I b.	2	Ave.	12.8	61.4	1.8	0.4	16.9	0.3	4.0	0.2	1.8	0.4	2.78	(2)
		Min	8.2	51.2	–	–	16.8	0.2	–	0.2	1.4	–		
		Max.	17.4	71.6	3.5	0.8	17.0	0.5	7.9	0.2	2.2	0.9		
VI	1		11.5	48.9	–	0.1	–	35.9		0.1	3.5		2.89	(1)
				GABBRO		Average Specific Gravity 3.04 (3)								
IV	3	Ave.	–	55.2	–	1.5	12.8	20.7	0.9		7.4	0.7	3.04	(3)
		Min.		31.9		–	4.0	11.0	–		2.8	0.6		
		Max.		76.8		4.5	26.5	35.8	2.8		14.4	1.0		
			ZEBALLOS PLUTON (QUARTZDIORITE OF TERTIARY AGE)											
	3	Ave.	27.9	57.0	1.0	9.9	2.8	–	0.7	–	0.2	0.5	2.75	(2)
		Min.	23.2	54.8	–	7.2	0.3		–	–	–	0.2		
		Max.	29.0	58.4	3.0	11.5	5.0		1.8	–	0.4	0.7		

Modal counts of 98 samples, including 26 by D. Carson (1973) are represented in the average modes shown in Table 6. Also given are specific gravities determined on some of the samples. The averages show a progression of specific gravity as follows (number of determinations in brackets):

Quartz-feldspar porphyry	2.61 (1)
Leuco-quartz monzonite	2.68 (15)
Leuco-granodiorite	2.68 (11)
Granodiorite	2.71 (25)
Quartz diorite	2.74 (30)
Quartz gabbro	2.81 (3)
Gabbro	3.04 (3)

Zone II, Vernon Batholith

Vernon Batholith is a large rather homogeneous body of medium to coarse grained plutonic rocks ranging from biotite-hornblende quartz diorite to leuco quartz monzonite. It is elongate in an approximate north-south direction, up to about 10 miles wide and occupies much of the upper Nimpkish Valley with northward extension in the headwater area of Tsitika River. To the south it connects with the Nootka and Bedwell Batholiths. It is entirely enclosed by Karmutsen Volcanics.

The rocks are readily divisible into two distinct petrographic groups. Light-pink coloured leuco-granodiorite and leuco-quartz monzonite are exposed in an elongate central core marked by Klaklakama Lakes in its middle part, and a poorly defined area east of Vernon Lake, but most of the batholith consists of dark-grey biotite-hornblende quartz diorite and granodiorite (see Table 6, Figure 7).

Biotite-hornblende quartz diorite and granodiorite are fairly dark ($\pm$ 15% mafics) medium grained (2 - 4 mm) equigranular rocks. Subhedral plagioclase is generally fresh, in part with continuous normal zoning and some oscillatory zoning between An 20 and An 70, but average composition is An 40 to An 50. It may contain inclusions of hornblende and is altered to saussurite, sericite and in places larger flakes of muscovite. Quartz, the next most abundant mineral, occurs in clear, equant anhedral grains as well as interstitial masses and anhedral K-feldspar may form large poikilitic to small interstitial masses. Quartz and K-feldspar include plagioclase, hornblende, biotite and opaques. Green pleochroic hornblende and reddish brown biotite, euhedral to subhedral, are separate or intimately mixed and include plagioclase and opaques. Minor relict-pyroxene is present. Apatite zircon, rutile, and sphene are occasional accessories and epidote, chlorite, prehnite and carbonate are products of incipient low-grade metamorphism.

Leuco granodiorite and leuco quartz monzonite are medium- to coarse-grained pinkish-grey light coloured rocks and occupy the core-part of the batholith. Hand specimens of the coarse grained varieties exhibit considerable amounts of pink potash feldspar that on stained surfaces can be seen to occur as large crystals, to about 1 cm size as well as interstitial material. Plagioclase and quartz are smaller, and biotite is present as large dark brown flakes, to 5 mm in size. Thin sections show subhedral plagioclase that is commonly saussuritized and sericitized in the core, whereas the rim is unaltered. Cores as determined on maximum extinction-angles of albite-twins are up to about An 45 and the rims down to about An 15. Quartz is the next most abundant mineral and is present as anhedral, equant, generally inclusion-free individuals as well as interlocking interstitial material that includes all other minerals. Potash feldspar is subhedral to interstitial, is at least partly microperthitic and contains some fine hematite. Myrmekite may occur at grain-boundaries. Biotite, generally present in a few per cent, is intergranular and euhedral or corroded and commonly partly altered to chlorite. Hornblende, when present in small amounts, is similar to that of the quartz diorites. Apatite and zircon and sphene are minor constituents, and epidote, chlorite are (metamorphic?) alteration products. The inclusion relationships are similar to those in the quartz diorites, showing quartz and potash feldspar to have crystallized late. Early grains of quartz and potash feldspar may occur in the other minerals.

Intrusive contact-relations with Karmutsen volcanics have not been studied in detail but it is clear that in places wide transitional zones occur where the volcanics have been recrystallized into gabbros and dioritized into dark hornblende diorite.

Zone IIIa, Nimpkish, Bonanza Intrusions and Satellites

Nimpkish intrusion appears on the map as an irregularly shaped intrusion, only five miles or less in width, enclosing various roof pendants. It is situated between the north end of Woss Lake and the east shore of Nimpkish Lake. In the south it appears to be connected, across two major faults and an area of porphyry quartz feldspar intrusions south of Woss Camp, with Vernon batholith. Bonanza intrusion east of Bonanza Lake, the Beaver Cove plutons and small plutons on the west side of Nimpkish Lake and northeast of Keogh Lake, are included in this group. These bodies intrude Quatsino, Parsons Bay and Bonanza rocks as well as Karmutsen volcanics.

Contact relations of Nimpkish Batholith were studied and described by Gunning (1932B) as follows:

> "The trend of the contact on the surface is exceedingly irregular. Right-angled turns and re-entrant angles are common, and in many places, as in the small stream valley immediately west of the south end of Bonanza Lake, the contact had to be mapped, on a scale of 1 mile to 1 inch, more or less diagrammatically on account of the large number of small tongues and dykes which extend out into the surrounding rocks. The latter are frequently much contorted, fractured and sheared near the intrusive and in a number of places are silicified and mineralized with pyrite, pyrrhotite and calcite. In a few places, and particularly where the granodiorite intrudes limestone, contact metamorphic silicates, magnetite, and copper, iron or zinc sulphides are quite extensively developed. Throughout some of its extent the contact of the granodiorite cuts sharply across the bedding of the adjoining rocks; but there are not a few places, particularly around the northwestern part of the body, where the bedding, due to contortion in the vicinity of the intrusion, strikes about parallel to the contact and dips very steeply or vertically."

With detailed mapping, supplemented by information from drill-holes on the "Kinman" replacement copper deposit in limestone he demonstrated that the intrusive did not expand at depth but was floored by limestone. He thereby questioned the prevailing assumption that batholiths expand and merge with one another at depth. Selective intrusion of the Quatsino-Parson Bay sedimentary sequence by granitic rock appears to be rather common throughout Vancouver Island.

The rocks are petrographically similar to those of Vernon batholith and can be subdivided in the same manner, but the divisions appear to be scattered irregularly. More detailed mapping and sampling would be required to outline areas underlain by the various classes of rocks.

Among hand specimens of Nimpkish rocks, almost identical to those of Vernon Batholith, more fine-grained varieties were noted but this difference could be due to uneven sampling. Thin sections show the same mineral characteristics as already described for the Vernon rocks.

A comparison of averages of mineral compositions of the four rock-classes, the two intrusions show very similar percentages for leuco granodiorite and leuco quartz monzonite and a little more difference for granodiorite and quartz diorite. Minor quartz-feldspar (granodiorite) porphyry is present.

Zone IIIb, Nahwitti and Wanokana Intrusions and Satellites

These intrusions are exposed as a string of east-west oriented, ellipse-shaped outcrop areas in the Nahwitti block. The Nahwitti Batholith is the largest body and extends from Nahwitti Lake to Shuttleworth Bay on the north coast. The smaller bodies are in part high-level quartz-feldspar porphyry plutons that appear to be related to Cu-Mo mineralization at the present Island Copper mine near Rupert Inlet and in other places farther to the west. The porphyries are described under a separate heading.

The few examined samples of Nahwitti Batholith suggest that this body too may have a core of quartz monzonite and a rim of granodiorite. The rocks are almost identical in composition and texture to those of Zone II and IIIb. The Wanokana and Coal Harbour bodies contain only granodiorite and quartz diorite. Possibly they represent small culminations in a batholithic roof that are not pierced by the felsic core of quartz monzonite.

Zone I a, Adam River Batholith

Adam River Batholith underlies a belt of subdued topography, about 4 miles wide, trending northwesterly between Adam River and Newcastle Ridge at the east border of the map-area. Most of the intrusion consists of biotite hornblende granodiorite and quartz diorite similar to the principal rock-types of Zone II and III, but generally grain-size is finer and mafic content is higher. As in Zones II and III a leucocratic core is present and exposed along Johnstone Strait from 2 miles east to 2 miles west of Windy Point.

The main part of the batholith consisting of quartz diorite and granodiorite is exposed farther west along the coast. It contains various amounts of inclusions of dioritized volcanic rock and grades into agmatitic complexes where the dioritized rock predominates over surrounding lighter-coloured granodiorite. In the contact zone of quartz diorite and granodiorite, veins and dykes of the lighter material are injected into the darker rocks.

The leuco granodiorite is coarse-grained, almost white-weathering biotite-granodiorite similar in appearance but more mafic and with less K-feldspar than the leucocratic core rocks of Zone II and III. It contains large lustrous masses of quartz, up to 7 mm in size and almost equally large plagioclase and, in modal counts of one thin section and several stained slabs, 10 to 15% mafics, mainly biotite. The thin section shows irregular masses of stained quartz and potash feldspar filling the spaces between euhedral to somewhat corroded plagioclase and biotite.

Zone I b, Hope, Nigei Island Group

A large fault in Goletas Channel probably separates the Hope-Nigei Island Group from Vancouver Island. The intrusive rocks of the islands, possibly extending over much of the south part of Queen Charlotte Sound, are mainly granodiorite and quartz gabbro. They are in irregular contact with a broad zone of hornfelsic sediments and have agmatitic to gneissic borders. The rocks contain subhedral plagioclase (An 60-70) and hornblende, 2 to 4 mm in size and somewhat larger than anhedral quartz, potash feldspar, biotite, and the alteration and accessory minerals mentioned in the other zones. Minor relict-pyroxene occurs in the quartz gabbros.

Zone IV, Zeballos, Kauwinch, Merry Widow, Victoria Plutons

The rather small intrusions of this group have a maximum width of about 3 miles and form a northwesterly trending "string" between Zeballos River and the north end of Victoria Lake. These rocks are, like the Wanokana and Coal Harbour plutons of intermediate to basic composition, including granodiorite, quartz diorite and quartz gabbro. The rocks are fine- to medium-grained and mostly mesocratic. Several quartz diorite specimens contain relict-pyroxene together with hornblende and biotite. As in other intrusions plagioclase is prominently euhedral and commonly zoned. It and the large mafic minerals are surrounded by finer grained anhedral quartz and K-feldspar.

Zone V, Amai, Kashutl, Mahatta Plutons

A series of small plutons, one to three miles in width, are aligned at about 10 miles distance of the west coast and are mainly enclosed by Bonanza volcanics. Amai and Kashutl Plutons straddle the upper parts of Amai and Kashutl Inlets; Mahatta Plutons are several discrete small bodies exposed in the Mahatta Valley. Smaller related plutons, one square mile or less in area, are present on upper Klaskish River, at the head of Colonial Creek, and on Ououkinsh River and Inlet.

The plutons, consisting of leucocratic quartz monzonite, granodiorite, quartz diorite and granodiorite-porphyry are apparently epizonal. Contacts shown on the accompanying map do not show the complex systems of dykes and sills intruding the surrounding volcanics.

Hand specimens of the central parts of the plutons commonly show whitish rectangular plagioclase phenocrysts, 2 to 4 mm in size and smaller equant quartz. These are, together with a few per cent of mafics, embedded in a quartz-feldspar matrix that commonly imparts a peculiar brick red colour to the rock.

Thin sections show subhedral plagioclase phenocrysts with normal, more or less oscillatory zoning, averaging about An 30 to An 40. The matrix varies in proportion from a few to 40 per cent and consists of plagioclase, quartz and K-feldspar; the latter mineral in equal or smaller amounts than plagioclase and quartz.

The feldspars are commonly altered to saussurite and argillic material and small amounts of hornblende and biotite are converted to chlorite, and epidotite. White mica, carbonate, leucoxene, sphene and apatite are further alteration products and accessories. Quartz feldspar (granodiorite) porphyry is a more conspicuously porphyritic variety of these rocks.

Quartz-feldspar porphyries

Quartz-feldspar (granodiorite-) porphyries are of small areal extent and have not been shown separately on the accompanying geological map. However, they are of importance in view of their obvious relationships to late magmatic and subvolcanic deposits of copper and molybdenum. They occur together with fine-grained, light-coloured and commonly porphyritic granitic rocks in zones IIIa, IIIb, and V.

At the Island Copper deposit, quartz-feldspar porphyry occurs as an elongate body, about 500 feet wide, interdigitating with and roughly perpendicular to the bedding of Bonanza volcanics. The envelope of alteration is described by Northcote (1971 and this report). Similar porphyries are present southwest of Nahwitti Lake on Hep and Expo claims, and northwest of Nahwitti Lake on the Red Dog claims. The porphyries also occur on the periphery of Kashutl Pluton and on the ridge south of Woss Camp near the microwave transmitter. Dykes of quartz-feldspar porphyry are not uncommon in Bonanza Volcanics.

The porphyries are generally reddish-coloured rocks exhibiting lustrous grey, common spindle-shaped quartz phenocrysts up to 5 mm long and smaller, roughly rectangular white plagioclase phenocrysts in a red matrix. Thin sections show the quartz phenocrysts to be rounded and embayed. The plagioclase phenocrysts are resorbed to a lesser extent and are commonly highly saussuritized. Where determinable the composition is albite or oligoclase. The matrix, generally of grain-size less than 0.1 mm, consists of a microgranitic, in part granophyric assemblage of equant quartz, subhedral plagioclase and anhedral orthoclase. K-feldspar is generally distinct from plagioclase by more intense alteration to dark-brown argillic matter. A few modal analyses are given in Table 6.

Finer grained porphyries show more intensely resorbed and rounded quartz and plagioclase in a microcrystalline matrix, consisting partly of small clots of micropegmatite, apparently centred on cores of ?feldspar laths and diffuse very fine quartz-feldspar mosaic. Etching and staining has shown that, even though it may be barely detectable, K-feldspar is always present in the matrix.

Hoadley (1953) described sills and dykes of micropegmatite intrusive into Bonanza and Karmutsen Volcanics. These rocks also belong to the same suite of rocks. One sample examined by him contained 30% albite and 2% quartz (phenocrysts ?) in a matrix of micrographic intergrowth of quartz and albite.

Zone VI, Brooks Peninsula, Islands in Checleset Bay, Scott Islands

This zone comprises the Westcoast Crystalline Complex and includes a heterogeneous group of granitoid rocks, mainly of quartz dioritic composition but ranging from leuco granodiorite to quartz gabbro. The granitoid rocks are rarely homogeneous and show agmatitic or gneissic structure. They grade into banded, medium-grained hornblende-plagioclase gneiss and dark green fine-grained plagioclase-amphibolite. As this complex of rocks is evidently not a simple plutonic mass but a mixture of recrystallized migmatic basic rocks and crystalline dioritic rocks they have been named Westcoast Crystalline Complex (Muller and Carson, 1969). It is shown as a separate unit on the accompanying geological map. The complex underlies Brooks Peninsula except for a small area southeast of Cape Cook, a narrow belt from upper Klaskish Inlet southwest to the small islands in Checleset Bay, and most of the Scott Islands.

The most completely recrystallized rocks are mainly fine- to medium-grained, medium- to dark-coloured quartz diorite with more or less clearly directed texture. The composition is quite similar to that of quartz diorite in the other zones. Subhedral plagioclase, 3 to 7 mm. in size is the main component and where unaltered, shows complex twinning and oscillatory zoning in the An 15 to An 45 range, but in many instances, the mineral is completely saussuritized. Quartz, the next most abundant constituent, occurs as anhedral equant masses and as interstitial clusters. Minor amounts of K-feldspar are interstitial. Euhedral to subhedral hornblende with green to brown pleochroism may be an important constituent, but is exceeded in several samples by biotite. Large plagioclase crystals include small hornblende and opaque minerals and hornblende includes plagioclase. Accessories are zircon, apatite, and secondary minerals epidote, chlorite, carbonate. In addition to quartz diorite, the complex contains granodiorite, diorite and quartz gabbro. Of two samples of agmatite from the central part of Brooks Peninsula, the dark phase is medium grained melanocratic diorite with directed texture containing 55.6% zoned plagioclase (average An 48), 35.8% hornblende, 1.9% relict-pyroxene and 6.7% opaques. The light phase is leuco quartz diorite with 53.2% plagioclase (average An 30), 43.4% quartz, 0.1% biotite, 1.8% chlorite, 1.4% white mica and 0.1% opaques. Although the two rock types each contain about 50% plagioclase, the other minerals appear to be mutually exclusive. Furthermore, it would appear that a mixture of these two rock types would produce a hornblende quartz diorite.

The darker phases of the complex have not been sampled extensively but are apparently quartz-free or quartz-poor hornblende-plagioclase rocks, generally with directed texture.

One medium-grained gneissic gabbro shows equigranular xenomorphic grains of labradorite, colourless clinopyroxene, irregular much-altered masses of orthopyroxene and magnetite. Another metagabbro consists of a fine-grained sub-diabasic plagioclase-pyroxene-magnetite assemblage containing knots and crosscutting veinlets of yellow-green pleochroic hornblende - porphyroblasts and minor plagioclase in an apparent transition from pyroxene-gabbro to hornblende-plagioclase gneiss.

Metamorphism of the complex apparently consisted firstly of recrystallization of original plagioclase-pyroxene rocks into plagioclase-amphibole rocks. Addition or selective mobilization of quartzo-feldspathic material is indicated by the lighter coloured quartz-dioritic components. Retrograde metamorphism at a later time resulted in partial to complete alteration into low-greenschist-facies assemblages.

SUMMARY OF PLUTONIC ROCKS

Zonal Distribution

The plutonic masses of the map-area have been divided into more or less parallel, northwest striking zones. Compositional and structural similarities and differences have been noted from zone to zone and these appear to be related to depth at time of crystallization. It is possible to apply Buddington's (1959) system of epi-, meso-, and kata-zones of plutonic rocks to the crystalline rocks of the map-area.

The epizone is represented by stocks, sills and dykes, emplaced near the surface in penecontemporaneous and probably genetically related volcanics and sediments, with sharp contacts and limited metamorphism. They are the smaller plutons of quartz diorite to quartz monzonite and associated quartz-feldspar porphyries of Zones III and V.

The mesozone contains the batholiths and plutons, generally unrelated to the intruded volcanics and sediments, with more intense metamorphism of the country rock and with composite character. A core of quartz monzonite of similar light-coloured rock appears to be present within darker granodiorite to quartz diorite in all the larger bodies. The smaller bodies probably represent domed roof portions of not yet uncovered larger masses where the leucocratic rock may be farther below. These are the intrusions of Zones I, II, IV and most of III.

The katazone, characterized by intimate association of gneiss, migmatite and more or less foliated granitic rocks is without doubt exemplified by the Westcoast Crystalline Complex of Zone VI and possibly by at least part of Zone I b.

Potassium-argon Age

A few potassium-argon determinations have been made of Island Intrusions in the map-area by the Geochronology Section of the Geological Survey of Canada and these were reviewed recently by Carson (1973). Further dates were obtained by J. E. Harakal and the late W. H. White of the University of British Columbia on samples submitted by K.E. Northcote. The ages obtained are shown on Figure 7 and Table 7. They range from 148± 8 to 181± 8 m.y. These ages indicate that the rocks crystallized in Early to Middle Jurassic Sinemurian to Bathonian time (Harland et al., 1964).

No determinations are available within the map-area on the age of the crystalline complex. But one determination on hornblende from an amphibolized basic dyke that intrudes the complex in Pacific Rim National Park (Alberni map-area), recently obtained from R. K. Wanless of the Geological Survey of Canada, yielded an age of 192± 9 m.y. This indicates that the dyke, possibly a feeder of Triassic basalts, was amphibolized at the start of the Jurassic period, a few million years before Crystallization of the oldest Island Intrusions. The complex, intruded by the dyke, is therefore older and may well be of Paleozoic age, but was recrystallized in Jurassic time. According to its original, pre-Jurassic but unknown age, it is placed at the bottom of the Table of Formations (Table 1).

Table 7

Potassium-argon age-determinations of granitic rocks

Laboratory: Geological Survey of Canada, Collectors (J.E. Muller, D.J.T. Carson)

Sample	Material	Location	% K	% Ar	Rock type	Age m. y.
GSC 65-14	Biotite	Nimpkish Batholith 50°16'35" N 126°51'21" W	5.23	74	Granodiorite	151 ± 14
GSC 66-27	Biotite	Bonanza Batholith 50°22'15" N 126°45'40" W	6.01	85	Granodiorite	150 ± 8
GSC 66-27 (re-run)	Biotite	" "	6.01	86	Granodiorite	152 ± 7
GSC 66-28	Phlogopite	Zeballos Iron Deposit 50°02'58" N 126°49'56" W	5.47	84	Skarn	148 ± 8
K-Ar-1652	Phlogopite	Empire Development Mine	7.29	85	Skarn	181 ± 8
K-Ar-1652 (re-run)	Phlogopite	Empire Development Mine	7.29	89	Skarn	178 ± 8
K-Ar 1694	Hornblende	Nahwitti Lake 50°43'05" N 127°52'30" W	0.40	61	Granodiorite	154 ± 8
K-Ar-1703	Hornblende	Nigei Island 51°54'30" N 127°44'25" W	0.52	62	Granodiorite	173 ± 9
K-Ar-1704	Biotite	Nigei Island 51°54'30" N 127°44'25" W	7.32	78	Granodiorite	153 ± 7

Laboratory: University of British Columbia, Collector, K. E. Northcote

Sample	Material	Location	%K	%Ar	Rock type	Age m.y.
KN68-177A	Biotite	Rupert Inlet Stock 50°35'35" N 127°25'15" W	3.07	55	Quartz Monzonite	154 ± 6
KN69-234	Biotite	N.Nahwitti Lake 50°42'40" N 127°50'16" W	5.40	92	Granodiorite	163 ± 6
KN69-264A	Biotite	N.W.Nahwitti Lake 50°43'05" N 127°52'30" W	5.83	93	Granodiorite	169 ± 6
CN70-152	Biotite	S.E.Nahwitti Lake 50°41'18" N 127°46'15" W	3.34	87	Granodiorite	159 ± 5
CN70-204B	Biotite	Soren Hill 50°49'50" N 128°04'20" W	6.28	96	Granodiorite	166 ± 5
PN70-179A	Biotite	Hepler Creek 50°41'43" N [illegible]	1.78	76	Granodiorite	145 ± 5

A comparison of the ages of granitic rocks (Table 7, 148 - 181 m.y.) and of Bonanza Volcanics (Table 5, 103 - 161 m.y.) shows they have similar age-ranges. As the dates on the volcanics are whole-rock minimum ages, their true ages would probably correspond more closely to those of the granitic rocks. Potassium - argon datings therefore indicate Early to Middle Jurassic ages for plutonic as well as volcanic rocks.

Geological Age

The maximum geological age of the intrusions is provided by high-level porphyries of the plutonic complex which intrude the lower part of Bonanza Volcanics including Sinemurian to Pliensbachian sediments. The porphyries were probably feeders to now-eroded rhyodacite-flows or sills at higher stratigraphic levels of the Bonanza Volcanics. Age, geological relationship, and similar, intermediate calc-alkalic, composition are strong arguments for cogenetic association of Lower (to Middle ?) Jurassic volcanics and intrusions (Northcote and Muller, 1972). The minimum geological age is given by Lower Cretaceous, Valanginian greywacke and conglomerate in the map-area, and Callovian greywacke and conglomerate of Kyuquot Sound map-area that overlie Bonanza Volcanics, although they are not found in unconformable contact with Island Intrusions. Granitic clasts were reported by Jeletzky (1954, unpub. Ms.) in Callovian conglomerate at Tatchu Creek in Kyuquot Sound map-area, but neither Carson (1973, p. 14) nor the writer found any but volcanic and sedimentary clasts at that locality. Likewise no granitic clasts were found in basal conglomerate of Valanginian age overlying Bonanza Volcanics on Quatsino Sound, although fine-grained and porphyritic rocks of Bonanza lithology are abundant in Callovian as well as Valanginian conglomerate. Abundant granitic clasts, mainly of high-level quartz-feldspar-porphyries, are present in Albian (?) Queen Charlotte Group conglomerates. It is therefore concluded that unroofing of the intrusions, if any, was very minor in Late Jurassic to Early Cretaceous time, but had become extensive by late Early Cretaceous, Albian (?) time. The period of non-deposition of marine sediments spanning the interval between Pliensbachian and Callovian time was apparently one of major uplift attendant to and directly following the major Early to Middle Jurassic - volcanic event.

Origin

The reconnaissance investigation of the plutonic rocks of the map-area barely warrants an elaborate model for their origin. However, the gross characteristics and suggested depth zonation permit some speculation in this regard. The writers believe that middle to late Paleozoic Sicker volcanics ranging from basic to salic rocks, with minor sediments, were originally laid down on a simatic (oceanic) substratum. The Vancouver Group, likewise composed of basic to intermediate volcanics and minor sediments, was superimposed on these rocks, possibly after minor folding. Rising of thermal gradients within the volcanic complex caused partial melting and migmatization of the Sicker Group rocks, perhaps including basaltic substratum, resulting in amphibolite, basic gneiss and quartz-diorite of the Westcoast Crystalline Complex in the katazone. Upward mobilization of granitic material to the mesozone produced the central leuco-quartz monzonitic to granodioritic cores of the major batholiths by intrusion and the peripheral zones of granodiorite to quartz diorite and gabbro by recrystallization and metamorphism of the volcanic country rocks. The roof-portion of the batholith, where broadly domed, was, like the periphery, composed of granodiorite and quartz diorite and is now exposed as some smaller intrusive areas of Zones III and IV. Stocks, dykes and sills rose from other parts of the roof and there epizonal plutons of porphyritic granodiorite, quartz monzonite and quartz feldspar porphyry were intruded, with attendant mineralization (Northcote and Muller, 1972). Where these intrusions broke through to the surface they resulted in lavas and pyroclastics of the Bonanza Volcanics.

LONGARM FORMATION

Nomenclature

Clastic sediments of Early Cretaceous age have been known in the Quatsino Sound area since the first explorations of G. M. Dawson (Dawson, 1887). He investigated the rocks in some detail, as thin coal seams had been discovered about that time in the vicinity of Coal Harbour, and outlined the main areas of Cretaceous exposures. The formations were studied in considerable detail by J. A. Jeletzky in 1953 and 1954, with some additional work in 1968, 1969. Much of the following account of the Cretaceous formations of the map-area has been condensed from his published and unpublished data, augmented by the observation of the writers. Jeletzky distinguished a lower group of Cretaceous beds carrying Early Cretaceous, Valanginian, Hauterivian and Barremian fossils. These were equivalent in age to the Longarm Formation, introduced in the Queen Charlotte Islands for similar beds by Sutherland Brown (1968). Age and lithology of the Queen Charlotte and Vancouver Island sediments are sufficiently similar to carry the name into Vancouver Island.

Lithological and Faunal Subdivisions

Jeletzky divided the Longarm into six units, partly on age and partly on facies. These may be grouped together into one lower and one upper member of the Longarm Formation (see Table 8).

The lower member, Valanginian to Hauterivian in age, is exposed in a few occurrences along the Pacific Coast, the west part of Quatsino Sound (south side) up to Salmon Islets near Mahatta and in Winter Harbour. The basal beds up to an estimated 400 feet thick *, are mainly greenish grey feldpathic, medium- to coarse-grained greywacke, grey calcareous argillite, and, at the base, pebble conglomerate containing rhyodacite tuff, argillite and chert derived from Bonanza volcanics in a greywacke matrix.

These beds in many places contain nests and coquinas of _Buchia crassicollis_. On the southeast shore of Winter Harbour and a small island near Galato Creek, these _Buchia_ bearing beds are overlain by a sequence of grey massive siltstone and fine-grained greywacke with calcareous locally fossiliferous concretions. Jeletzky estimated these beds to be more than 1,200 feet thick and recognized a lower faunal zone of _Homolsomites oregonensis_ and an upper one of _Simbirskites broadi_.

* Thicknesses, mainly obtained from estimates by Jeletzky (unpub. Ms.) have been reduced to even fifties.

Table 8 Lower Cretaceous units of Alert Bay – Cape Scott area

	Pacific coast, Winter Harbour, outer Quatsino Sound, Salmon Islets	Middle Quatsino Sound, Kewquodie Creek	Apple Bay, Coal Harbour, Rupert Inlet	North shore, Laura Creek to Christensen Point, Holberg Inlet
Cenomanian		siltstone, shale, fine-grained greywacke 100 feet Desmoceras (Pseudoligella) ex aff. ezoanum		siltstone, shale 1000 ft? Puzosia (Puzosia) aff. P. dilleri Tetragonites ex aff. T. jacksonense Inoceramus aff. I. incelebratus
Albian		conglomerate, greywacke 3000 ft	conglomerate, greywacke, coaly shale 1200 ft. Cicatricosporites	
Aptian?	greywacke, siltstone, conglomerate, coal 3000 feet	greywacke, siltstone 200 ft U N C O N F O R M I T Y ?	greywacke, siltstone, coaly shale 50 ft.	
upper and middle Barremian	(Islets) fine-grained greywacke 100 ft. Eulitoceras aff. phestum	fine-grained greywacke 1300 ft Heteroceras (Heteroceras) cf. heliceroides Hemihoplites ? sp. indet. Eulytoceras aff. phestum	greywacke, siltstone, conglomerate 200 ft. Quoiecchia aliciae	greywacke, siltstone, conglomerate 250 feet Quoiecchia aliciae Inoceramus colonicus
upper Hauterivian and lower Barremian	(Salmon) greywacke, siltstone 200 ft Inoceramus colonicus Shastricrioceras cf. pontiente		U N C O N F O R M I T Y Jurassic volcanics	U N C O N F O R M I T Y Triassic and Jurassic volcanics
Hauterivian	(Winter Harbour) siltstone, greywack 200 ft Simbirskites (Simbirskites) broadi Homolsomites oregonensis	U N C O N F O R M I T Y Jurassic volcanics		
upper Valanginian	greywacke, conglomerate 400 ft Buchia crassicolis			

It is believed that to the southeast, this siltstone unit grades into greywacke and conglomerate, exposed on Salmon Islets and east of Kewquodie Creek, on the south side of Quatsino Sound. Thus the lower part of Longarm Formation appears to represent a northeastward transgressive wedge with a sandy (near-shore) lower part, containing Buchias and a silty (off-shore) upper southwestern part, containing ammonites.

The upper member of the Longarm, latest Hauterivian to Barremian in age, consists of a basal calcareous greywacke, siltstone, sandy limestone and minor conglomerate, carrying coquinas of Inoceramus colonicus. These beds, about 200 feet thick, were found at Salmon Islets near Mahatta and at Spencer Cove on Quatsino Sound, northeast of Jeune Landing near Lippy Creek, on Holberg Inlet, north of the upper part of Stranby River and on the north shore west of Laura Creek, as well as west of Christensen Point.

The Inoceramus beds are succeeded by a sequence, according to Jeletzky about 1,300 feet thick near Kewquodie Creek, of fine-grained greywacke and sandy siltstone, that contain calcareous pods and lenses with ammonite faunas of two distinct zones. They are exposed at Koprino Harbour, Salmon Islets and Kewquodie Creeks in Middle Quatsino Sound. There too, upward transition is observed from near-shore Inoceramus beds to off-shore ammonite bearing beds. Farther northeast, in Coal Harbour area, about 300 feet of greywacke and siltstone, and minor pebble conglomerate, with the pelecypod Quoiecchia aliciae, probably a coeval to or younger than the Inoceramus beds, directly overlie Bonanza Volcanics. Northeast of Jeune Landing, near Lippy Creek, Bonanza Volcanics are overlain by greywacke and conglomerate, with the belemnite Acroteuthis. The upper member of the Longarm Formation thus forms another northeastward thinning wedge of clastic sediments with coarser-grained near-shore facies in its lower and northeastern part and finer-grained off-shore facies in its southwestern part.

Age

The age of the Longarm Formation is well known by the many collections made and evaluated by Jeletzky and additional material obtained by the senior author's parties (see Figure 8 and Table 4).

The oldest post-volcanic-plutonic clastic sediments are exposed on Grassy Islands and along the coast just south of Kyuquot Sound (Jeletzky, 1950, 1965). They contain late Jurassic and earliest Cretaceous ammonite and buchia faunas. Within the map-area, Buchia crassicollis (Keyserling, 1846) of late Valanginian age is the oldest Cretaceous index fossil. (GSC Loc. 23275, 23281, 23945, 23946, 23977, 24283, 24284, 82857, 82859, 82861, 82868, 82869, 82884). As mentioned, it occurs only along the Pacific Coast, in Winter Harbour and on western Quatsino Sound, and is associated with Homolsomites quotsinoenses Whiteaves, Acroteuthis (Acroteuthis) sp. indet. and Inoceramus sp. indet. (GSC Loc. 23275, 82868).

The next younger faunal zones are those of Homolsomites oregonensis (Anderson) and Simbirskites (Simbirskites) broadi (Anderson), only found on the southeast shore of Winter Harbour. H. oregonenses (GSC Loc. 24286, 24289, 24290) is accompanied by Protetragonites sp. indet. Inoceramus sp. indet., indeterminate phylloceratids, gastropods and pelecypods and is lower Hauterivian in age. Simbirskites broadi was found (GSC Loc. 24285, 24291, 24294, 24298) with Acroteuthis (Boreioteuthis) ex. gr. impressa Gabb, Protetragonites cf. quadrisulcatus (d'Orbigny), Trigonia (Pterotrigonia?) cf. kaiana Anderson, Astarte ? sp. indet. indeterminate gastropods and pelecypods, and represents the upper part of the Hauterivian stage. Jeletzky noted that the fauna and lithology indicated offshore deposition in deeper water for these Hauterivian beds. They are the upper and western facies of the lower part of the Longarm Formation.

The basal beds of the upper Longarm Formation are characterized by Inoceramus colonicus (Anderson), generally in coquinas without other fossils but in one instance (GSC Loc. 24296) associated with a single juvenile specimen of Shastricrioceras cf. pontiente Anderson. The fossils occur in calcareous greywacke, siltstone and sandy limestone with minor conglomerate, exposed on Salmon Islets north of Mahatta River (GSC Loc. 24279, 24296, 24299, 24300, 24343), and at Spencer Cove on Quatsino Sound; northeast of Jeune Landing near Lippy Creek (GSC Loc. 55109, 82956); on Holberg Inlet (GSC Loc. 82863); north of the upper part of Stranby River (GSC Loc. 82867); on the north shore west of Laura Creek (GSC Loc. 82883); and west of Christensen Point (GSC Loc. 82877). Jeletzky considered these beds to be latest Hauterivian to early Barremian in age and they were probably laid down in near-shore shallow water. They are succeeded by fine-grained greywacke and siltstone, exposed on Salmon Islets and Kewquodie Creek containing two faunal assemblages. The lower zone contains Eulytoceras aff. phestum (Matheson), Argonauticeras aff. argonautarum Anderson, Phyllopachyceras infundibulum (d'Orbigny), Acroteuthis (Boreioteuthis ex aff. impressa (Gabb), Inoceramus aff. quatsinoensis Whiteaves, Aucellina ? sp. indet., Astarte sp indet. indeterminate gastropods and pelecypods (GSC Loc. 24278). The younger assemblage contains Heteroceras (Heteroceras) cf. heliceroides (Karsten), Hemihoplites ? sp. indet. and Eulytoceras n. sp. aff. inequalicostatum (d'Orbigny) (GSC Loc. 23274, 23276, 23278, 23280, and 23282). These faunas are according to Jeletzky indicative of Barremian age, probably the later part of that stage. He notes also that the faunas contain no thick-shelled, obviously neritic to littoral pelecypods, but mostly closely packed small immature thin-shelled forms. The ammonite fauna are open sea forms.

Another fauna indicating perhaps partly non-marine beds occurs in greywacke and siltstone, containing marine fossils and local plant fragments exposed near Christensen Point, at Apple Bay, Nukneemish Creek and in a quarry north of Coal Harbour (GSC Loc. 24274, 24292, 82929, 82930, 82931, 82863, 82867, 83925). The fossils are Quoiecchia aliciae Crickmay, Aucellina ? sp. indet., Pholadomya ? sp. indet. Mya ? sp. indet., Tancredia sp. indet. In the Christensen Point locality (GSC Loc. 83925) Q. aliciae is found together with Acroteuthis (Boreioteuthis) aff. impressa (Gabb) and Inoceramus colonicus. Jeletzky considered this fauna to be Barremian. The late W. A. Bell of the Geological Survey of Canada identified the following flora from a collection on the north shore of Apple Bay (GSC Loc. 7820): Cladophlebis alberta? (Dawson), Sagenopteris williamsii (Newberry), Nilssonia nigracollensis Wieland, and a very small unidentifiable fragment of a dicotyledonous leaf. Dr. Bell made the following remarks:

> "This is a small florule for which it is difficult to make a refined age correlation. Sagenopteris elliptica, small forms of which are perhaps not distinguishable

from some forms of S. williamsii, is a member of Upper Blairmore (Albian) floras. The single fragment of a dicotyledonous leaf suggests too a late Aptian or Albian age. Nilssonia nigracollensis, however, has been recorded to present only from late Jurassic and Neocomian floras. Yet small forms of Nilssonia with undivided pinnae e.g. N. canadensis have a time range from Neocomian to Albian and the larger form N. vancouverensis (Dawson) occurs in Campanian deposits of the Nanaimo Group. Lacking a larger assemblage of specific megaplants the age of the above florule cannot be interpreted as definitely Albian, although an early Albian age is considered more probable."

Considering the long ranging character of fauna and flora, a compromise-age of upper Barremian to lower Aptian would seem indicated.

Origin

In summary, it appears that the Longarm Formation of northern Vancouver Island consists of two separate superposed clastic wedges that onlap eastward on a more or less bevelled pre-Cretaceous volcanic-plutonic massive. The lower and northeasterly part of each wedge is coarse-clastic, of near shore, shallow water origin; the upper and south-western part is a fine-grained clastic off-shore deposit. The ages of the wedges are upper Valanginian to Hauterivian and latest Hauterivian to Barremian. The formation may be considered as the oldest phase of molasse-type deposits resulting from the breaking down of the volcanic-plutonic mountain chain that was constructed in Early to Middle Jurassic time. Jeletzky (1971, p. 36 - 39) shows on paleogeographic maps Early Cretaceous Seas covering Queen Charlotte Islands, but fringing Vancouver Island, and only flooding its northern tip. These waters were bordered on the east by a land mass or island-chain, encompassing Vancouver Island and Coast Ranges. They were connected with the Tyaughton trough east of that landmass by a seaway possibly following the present Fraser River system, and were also connected with the present Richardson Mountains in Mackenzie Delta region. The present writers have generally adopted this concept, but would prefer to see the present Insular Belt as a newly formed volcanic land or island, shedding clastic sedimentary wedges over a shallow shelf bordering the ocean, rather than a distinct trough.

QUEEN CHARLOTTE GROUP

Nomenclature

The Longarm Formation is generally overlain by another sequence of clastic Cretaceous sediments, apparently Albian to Cenomanian in age and including siltstone, greywacke, conglomerate and minor coal. In Queen Charlotte Islands Sutherland Brown (1968) recognized an assemblage of equal age and lithology and named it Queen Charlotte Group. The writers have little hesitation in carrying this name to northern Vancouver Island for the equivalent succession. In the type-area, the group is subdivided in a lower Haida Formation of shale, siltstone and minor grit and sandstone, a middle Honna Formation of conglomerate and grit, and an upper Skiddegate Formation of siltstone and sandstone.

The subdivision broadly follows the original division by Dawson (1880) in "Lower Shales", "Conglomerates" and "Upper Shales and Sandstones". The "Lower Shales" or Haida carry a marine Albian to Cenomanian fauna. The Honna conglomerate and Skiddegate or "Upper Shale" do not have a diagnostic fauna.

It is not yet possible to carry the formational subdivision of the Queen Charlotte Group unchanged from the type-area to northern Vancouver Island. Jeletzky (unpub.) suggested a three-fold succession of a lower greywacke-siltstone-minor conglomerate-coal formation, a middle boulder conglomerate-greywacke formation and an upper greywacke-siltstone formation. Although this succession resembles that of the type-area, the middle conglomerate unit carries a microflora of probable Albian age and the upper greywacke-siltstone unit contains sparse Cenomanian marine fossils. In contrast the lower Haida Formation on Queen Charlotte Islands carries an Albian to Cenomanian marine fauna. Furthermore, the relative position of conglomerate-formation and Cenomanian upper (?) shale - greywacke formation has not been established with certainty. The group is therefore described without formal formational divisions (see Table 8).

Lithological subdivisions

Along the north shore of Winter Harbour, the lower part of the group is exposed in several partial sections. Jeletzky (unpub. Ms.) estimated a total thickness of a "coarse arenite unit" to be "at least 5,891 feet" in a section between the mouths of Galato and Klayina Creeks. However, a major fault cuts this section in its middle part near Denad Creek. This fault probably repeats the section and a total thickness of 3,000 feet appears to be more probable.

The beds consist of coarse to gritty greywacke, in beds several feet thick, finer silty greywacke and siltstone in beds a few inches thick, and layers of calcareous concretions. Intraformational shale-pebble conglomerate is fairly common. The highly disturbed upper part of the section contains beds of pebble conglomerate that may be equivalent to the middle conglomerate formation of Quatsino Sound.

On the north shore of the middle part of Quatsino Sound the group is exposed for considerable distance but low and obscure attitudes in the conglomerates, faults and covered intervals impede interpretation of the stratigraphic succession. The basal part of the group consists of less than 200 feet of greywacke and siltstone, exposed west of Aweisha Creek and on Ildstad Islands (2 and 4 miles west of Quatsino Village) and near Lind Islet (2 miles north of Mahatta River). It is overlain by the conglomerate formation.

A thickness of 3,000 feet of conglomerate and greywacke estimated by Jeletzky is considered to be a maximum possibly attained in the range between Koprino Harbour and Mount Byng, but a total thickness of a few hundred feet is more common. The conglomerate is irregularly interbedded with greywacke. It contains well-rounded cobbles and boulders, commonly to about 6 inches but in places to one foot in size in greywacke matrix. They are predominantly volcanic rocks of Bonanza Volcanics lithology and less granitic and sedimentary rocks.

Medium-grained feldspathic greywacke with shale-pebble conglomerate and with a sparse Cenomanian marine fauna was discovered by Jeletzky just west of Bish Creek, 5 1/2 miles west of Quatsino (1970 and unpub. Ms.) The section less than 10 feet thick, is not in exposed contact with the conglomerate formation, and the beds are sufficiently disturbed to make it impossible to judge whether they should project under or over the conglomerate. However, the formation appears to be the same as sandstone and siltstone exposed on Ildstad Island and the shoreline east of Bish Creek and these appear to underlie conglomerate formation exposed inland. Thus the Cenomanian beds could be equivalent to the lower part of the Queen Charlotte Group (Haida Formation), which in the type locality also carries Cenomanian as well as Albian fossils. Nonetheless, an Albian microflora, found in the conglomerate formation of Rupert Inlet suggested to Jeletzky (1970, unpub. Ms.) that the conglomerate is older than the Cenomanian beds.

In Coal Harbour and Rupert Inlet area, the Queen Charlotte Group is exposed along the shoreline and inland, and has been penetrated by some drill holes for coal. The section measured by Jeletzky westward from the present mill-site of Island Copper Mines contains less than 50 feet of the greywacke-siltstone formation, overlain by an estimated 1,200 feet of conglomerate, greywacke and one minor shaly coal seam containing an Albian microflora. Similar beds are also exposed on the bay of Coal Harbour and were probably penetrated in the drill holes for coal north of the village, reported by Dawson (1887). A boring near the shoreline, about one mile southwest of Coal Harbour, penetrated more than 700 feet of sandstone, shale, conglomerate and shaly coal of the Queen Charlotte Group.

Cretaceous rocks exposed on the north coast of Vancouver Island, between Laura Creek and Christensen Point are also part of the Queen Charlotte Group. The generally flat-lying sequence, disturbed by some faults and cut by felsic dykes, consists of siltstone and shale in fault contact with, but presumably overlying greywacke and siltstone of Barremian age. These rocks are probably several hundred feet, and in the estimate of Jeletzky (1969), 1,000 feet thick. They consist of grey siltstone and silty argillite, with lenticular calcareous layers a few inches in thickness.

The sediments are apparently derived from the pre-existing volcanic-plutonic complex. One thin section of greywacke from the north side of Quatsino Sound shows angular to subangular grains of clear quartz, plagioclase (An $\pm$ 45 according to extinction on albite twins), quartz-mosaics, some micropegmatite, and a little orthoclase in a sericitic matrix. This material was apparently mainly derived from granitic rock. Another thin section contained closely packed grains, mainly of albitized, probably volcanic plagioclase, volcanic fragments with feldspar laths, chloritized mafic minerals, epidote and uralite in chloritic matrix. This material appears to be mainly volcanogenic. A third thin section shows about equal amounts of volcanic and plutonic debris in carbonate matrix. In general, green-coloured sediments contain mainly volcanic material, whereas brown colours prevail in the plutonic-derived greywackes.

The conglomerate east of Coal Harbour contains black chert, finely banded rhyodacite, feldspar-porphyries, probably mostly derived from Bonanza volcanics, and granitic rocks. Carson (1973) determined modes of about 40 granitic pebbles from conglomerate in that area and found their lithologic distribution similar to that of Island intrusions. Most were granodiorite and quartz monzonite, with minor (less than 10%) quartz-diorite and granite.

Age

The age of the Queen Charlotte Group of Vancouver Island is still not precisely known. Jeletzky (1969, 1970) obtained marine fossils in a few localities (see Figure 8). On the north coast, west of Laura Creek, he found in the siltstones that overlie beds of Barremian age: Puzosia (Puzosia) aff. P. dilleri Anderson, Tetragonites ? sp. indet., indeterminate desmoceratid ammonite and Inoceramus aff. I. incelebratus Pergament. He considered the fauna Albian or (?) Cenomanian in age. Near Christensen Point he collected Tetragonites ex. aff. T. jacksonense Anderson (GSC Loc. 83926, 83927) and Eulacoceras ? ex. aff. shastense Reagan (GSC Loc. 83229) to which he assigned a late Cenomanian or (?) basal Turonian age. On the north shore of Quatsino Sound, about 600 feet west of the mouth of Bish Creek, he found (Jeletzky, 1970, and unpub. Ms.)(GSC Loc. 83932) Desmoceras (Pseudouhligella) ex. aff. ezoanum Matsumoto, Baculites (Sciponoceras) n. sp. ex. aff. kossmati (Nowak), Eogunnarites unicum Yabe and Inoceramus ex. aff. I. crippsi Mantell, indicating Cenomanian age.

Jeletzky also collected coaly material interbedded with pebble conglomerate exposed on Rupert Inlet southwest of the present Island Copper Mine (GSC Loc. C.4309). W. S. Hopkins extracted and identified palynomorphs from this sample as follows:

Lycopodiumsporites austroclavatidites (Cookson) Pocock, Lycopodiumsporites sp., Gleicheniidites senonicus Ross, Deltoidospora sp., Cyathidites cf. C. Minor Couper, Triplanosporites sp., Osmundacidites wellmanii Couper, Acanthotriletes cf. A. varispinosus Pocock, ? Selaginella sp. Verrucosisporites sp., Cicatricosisporites perforatus (Baranov, Nemkova, and Kondratiev) Singh, Cicatricosisporites sp., Appendicisporites perplexus Singh, Vitreisporites pallidus (Reissinger) Nilsson, Pinus, sp. haploxylon-type, Cupressaceae (Juniperus ?), Tsugaepollenites cf. T. mesozoicus Couper, Monocolpate, ? Tricolpate.

Hopkins commented as follows:

"Although most of the palynomorphs could be either Jurassic or Cretaceous, several indicate a Cretaceous age, especially Cicatricosisporites. Furthermore, the doubtful presence of dicotyledons would suggest we are dealing with Lower or Middle Cretaceous rocks. However, there are two spores, both present in considerable numbers, which suggest a more definitve age."

"The first is Cicatricosisporites perforatus which has been found to have a range restricted to Aptian to Turonian in Alberta and Siberia. The second is Appendicisporites perplexus which is, so far as I know, restricted to the Middle Albian of Alberta. The age restrictions indicated by these two spores would refine the age as already suggested by the other elements of the florule. As a result, on the basis of this florule, I would venture the opinion that these rocks are Albian, and probably lower to middle Albian."

Origin

The rocks of the Queen Charlotte Group, like those of the Longarm Formation, are molasse-type clastic sediments, derived from the early-Mesozoic volcanic-plutonic insular mountain chain, built up in a wedge along its seaward slope. The intensifying uplift and consequent erosion in Albian to Cenomanian time are apparent from the coarseness of the debris and the appearance of non-marine, coal- and plant-bearing strata. The first appearance of granitic debris derived from mid-Jurassic Island Intrusions also witness the deeper erosion of the older complex. Furthermore, Jeletzky (1971) has pointed out that in this time, the connection between the North Pacific and Boreal basins of deposition was broken, as shown by the completely different local faunas.

PACIFIC RIM SEQUENCE

A highly disturbed, steeply folded and faulted sequence of slaty argillite and fine-grained greywacke-sandstone, partly calcareous and partly quartzitic, is exposed on the southwest coast of Brooks Peninsula, 4 to 8 miles southeast of Cape Cook. Similar beds are also present on Triangle Island, 30 miles west of Cape Scott and they are inferred to be present in the "Pacific Rim Block", occupying the continental shelf and in part covered by upper Tertiary sediments.

The rocks were not studied in any detail but are apparently an off-shore flysch-type turbidite sequence. They have been thrown into asymmetrical to isoclinal folds, striking northwest and with northeast dipping axial planes. At Brooks Peninsula several sub-units of the sequence may be distinguished. One unit consists mainly of thinly banded, graphitic, slaty argillites, another unit contains predominant massive feldspathic greywacke and minor argillite. A third unit, only represented in large loose blocks on the tidal shelf, is a cobble conglomerate with granitic clasts.

The assemblage is very similar in lithology and structure to the Pacific Rim sequence of Pacific Rim National Park near Tofino, recently examined in some detail by Muller (1973) and earlier called "Tofino Greywacke" (Muller and Carson, 1969). There a few lenses of <u>Buchia</u>, according to a preliminary examination by J.A. Jeletzky (pers. comm.) probably <u>Buchia pacifica</u>, date the black argillite-sequence tentatively as Valanginian in age. The greywacke-sequence of Tofino area, which contains conglomerate with chert and granitic clasts is suggested to be correlative to the conglomerate of Queen Charlotte Group of Quatsino Sound area, of Albian to Cenomanian age.

On Brooks Peninsula as well as in Pacific Rim Park the deformed flysch-sequence is in fault-contact with Westcoast Complex metamorphic rocks to the northeast. They are provisionally inferred to be ?.late Jurassic to Cretaceous deposits on the Pacific continental slope and ? trench, coeval to Longarm and Queen Charlotte shelf-deposits of the Insular Belt, and analogous to roughly coeval deposits in Western California (Franciscan Terra and Western Alaska (Chugach Terrane). Presumably they were deformed by underthrusting at the continental margin in late Cretaceous to early Tertiary time.

NANAIMO GROUP

Clastic sediments of Late Cretaceous age underlie the low-lying area bordering Queen Charlotte Sound between Port Hardy and Beaver Cove. The area is known as

Suquash Basin, and some coal was mined there by Hudson's Bay Company miners as early as 1836. Dawson first described the coal-bearing sediments (1887), and considered them to be of the same age or slightly older than the coal measures of the Nanaimo region, which he named "Nanaimo Group" in 1890. The group-name is clearly applicable to the beds of Suquash Basin where depositional environment and age are almost identical. Small outliers of similar beds occur directly to the west, in Hardy Bay and a small area of Upper Cretaceous sandstones was also found by Dawson on the east side of Hope Island. In addition, some Upper Cretaceous sediments are also known west of Alice Lake.

The geology of the Upper Cretaceous sediments was studied concurrently by Muller and by Jeletzky (Muller and Jeletzky, 1970, Jeletzky, 1970A, unpub. Ms.). As in the Nanaimo and Comox Basins, the sediments exhibit cyclical successions of basal near-shore or lagoonal sandstone, conglomerate, coaly shale and coal, succeeded by marine siltstone and shale. Low dips, faults and limited outcrops hamper the recognition of a complete stratigraphic section. Two formations at least can be recognized corresponding to the two constituent formations of a typical sedimentary cycle in Nanaimo and Comox Basins (Muller and Jeletzky, 1970; Figure 9).

SUQUASH FORMATION

Nomenclature

The name Suquash Formation is hereby introduced for the sequence of greywacke, pebble conglomerate, minor coaly shale and coal that directly overlies Karmutsen Volcanics and contains the Suquash coal in its upper part. Dawson (1887, p. 66B) recorded one old boring made below a cliff exposure of coal seams. No coal was encountered but hard rock, most likely Karmutsen Volcanics, was reached at 327 feet. The top of the formation is inferred to be slightly above the coal. Total thickness of the formation is therefore in the order of 350 feet.

Lithology

The basal part of the formation ("Basal Greywacke") is exposed about one mile west of Fort Rupert, but the contact with Karmutsen Volcanics is not seen. It consists predominantly of buff- to rust-coloured, coarse- to medium-grained, commonly gritty, intensively cross-bedded and locally calcareous greywacke with some lenticular interbeds and lenses of fine to coarse-grit and fine pebble-conglomerate. Some poorly exposed interbeds of friable fine-grained, locally carbonaceous to coaly greywacke and sandy siltstone occur in this unit.

In the upper part of the formation, outcropping west of the mouth of Keogh River, the greywacke is interbedded with light- to pinkish-grey buff to light grey weathering well sorted and rounded, fine- to medium-grained sandstone. The sandstone is cross-bedded, ripple-marked, or thinly laminated. Tidal reefs of calcareous and carbonaceous siltstone, thinly, irregularly laminated and interlayered with coaly shale to shaly coal, less than one foot thick and containing red-brown ironstone concretions are exposed in two places. The two are perhaps the same layer, repeated by faulting.

The seam at Suquash may well represent the same stratigraphic zone. There two 4-inch coal seams, separated by one foot of shale, are interbedded with feldspathic fine-grained sandstone containing scattered coaly laminae.

Thick-bedded and coarsely cross-bedded arkosic sandstone and thinly bedded shaly sandstone with fossil leaves are exposed at Broughton Point, north of Port McNeill. These beds are considered to be correlative with the basal greywacke formation in the Keogh River and Suquash areas, but alternatively, they might overlie the marine shale-siltstone formation and thus represent a later depositional cycle.

West of Alice Lake, on logging spurs crossing Lippy Creek, 2,000 feet elevation, Nanaimo Group sediments have also been identified in a few exposures. There, in a small quarry about 40 feet of massive to faintly-laminated locally cross-bedded greywacke and pebbly greywacke is exposed. Pelecypods collected and identified by Jeletzky (1969, unpub. Ms.) indicate correlation with other Nanaimo Group beds. Within the same area, other outcrops of clastic sediments contain Barremian marine fossils and a sill of rhyolite is also present, but contact-relations between the Upper and Lower Cretaceous beds are not apparent.

Age

The age of the Suquash Formation is fairly well established on the basis of flora, microflora, and some marine fossils (see Figure 8). G.M. Dawson (1887) made a large collection of plants near Port McNeill and at Beaver Harbour. They were identified by his father, Sir William Dawson (1893) and were again studied by W.A. Bell (1957), who published a revised list of plants. Dawson concluded that the Port McNeill flora was approximately the same age as the coal measure s of Comox and Nanaimo, or somewhat younger, and Bell considered that the Port McNeill flora could be of the same age or somewhat older than the Comox Formation. Neither paleobotanist was aware that the Comox coal measures are older than those of Nanaimo (Muller and Jeletzky, 1970).

The writers obtained another small collection of plants from the Port McNeill locality and the late W.A. Bell commented on these as follows:

"GSC Plant Loc. No. 7819. North shore of Port McNeill, near Broughton Point. Florule: Pseudoctenis latipennis (Heer), Quereuxia angulata (Newberry) Kryshtofovich, Trochodendroides (Cercidiphyllum?) artica (Heer), Rhamnites eminens (Dawson).

Pseudocycas latipennis, Trochodendroides artica and Rhamnites eminens are members of Nanaimo Group floras. Quereuxia angulata, formerly known widely as Trapa? microphylla, occurs in St. Mary River, and Edmonton (both lower and upper parts) Formation, as well as in Wapiti Group, and Paleocene beds of Alberta and Saskatchewan, but was not until present recorded from the Nanaimo Group. It is concluded that the above florule falls within the time limits Campanian - Maestrichtian and more probably within age limits of the Nanaimo Group".

The complete list of species, collected by Dawson and re-identified by Bell, is given in Bell's 1957 publication. Spores and pollen from the same locality were examined by W.S. Hopkins of the Geological Survey, who commented as follows:

"GSC Plant Loc. 7819, Port McNeill. Florule: Pinus sp. Cicatricosisporites intersectus Rouse, 1962, Gleicheniidites senonicus (Ross, 1949) Delcourt and Sprumont 1955, Gleichenis sp., Lycopodium sp., Conclavipollis sp., Concavisporites sp., Laevigatosporites sp., ? Lygodium sp., ? Cedrus sp., ? Corylus sp., Proteacidites sp. Trilete verrucatus, Unidentified Angiosperm pollen, Latonisporites cf. M. phlebopteroides Couper, 1958, various fungal spores, age: Senonian.

Preservation of pollen and spores from these rocks is very poor and the density is low. As a result, some of the determinations are questionable, while other determinations are to a generalized level.

The relative abundance of angiosperm pollen suggests a post-early Cretaceous age; furthermore there is nothing characteristic of an Eocene or younger age. Gleichenia is most abundant in Paleocene and Upper Cretaceous rocks, although it does occur farther down the column. Proteacidites seems, at the present time, to be restricted to Upper Cretaceous rocks in western North America. Most of the other forms are found in Jurassic, Cretaceous and Tertiary rocks, but none are incompatible with an Upper Cretaceous age. It is the opinion of the writer that this florule is Senonian in age, probably Maestrichtian".

In addition, Hopkins later examined the microflorule from the coaly beds near Keogh Creek: "GSC Plant Loc. No. 8026 (Shoreline 0.2 miles east of Keogh Creek). Florule: Tricolporopollenites spp. Triporopollenites sp., Proteacidites sp., Proteacidites thalmanni Anderson 1960, ? Lycopodium sp., Ludwigia cf. L. trilobopollenites Rouse 1962, Gleicheniidites sp., Gleicheniidites senonicus Ross 1949, Nymphoides tripollenites Rouse 1962, Laevigatosporites sp., Myrtaceoipollenites cf. M. peritus Newman 1965, Potamogeton sp., Aquilapollenites sp. Age: Campanian or Maestrichtian."

"Preservation of pollen and spores from this sample (8026) is quite poor. Physical damage has resulted in abrasion and crumpling of the grains. Furthermore, palynomorph density is low. As a result of this poor preservation and low density, analysis of this sample was not very satisfactory and results are not as useful as might be hoped.

"However, limited age conclusions can be drawn from the small florule listed above. Firstly, the abundance of tricolporate and tricolpate grains indicate a Senonian or younger age. Secondly, general like Proteacidites, Aquilapollenites, and Gleicheniidites strongly indicate a Late Cretaceous age, because in Western Canada these forms are exceptionally rare in the Lower Tertiary and absent in the Upper Tertiary. Thirdly, several of the species suggest a Latest Cretaceous age. Nymphoides tripollenites Rouse 1962 is found in the Upper Cretaceous Brothers Creek outcrop north of Vancouver, but has not been found in the Eocene Burrard and Kitsilano Formations immediately to the south. Myrtaceoipollenites peritus Newman is found in Campanian rocks of Colorado but not in the overlying Paleocene. Proteacidites thalmanni Anderson 1960, is found in the Campanian and Maestrichtian formations of New Mexico, but not in the overlying Tertiary. Gleicheniidites senonicus Ross 1949, is largely a Cretaceous form, although it is not unknown in the Lower Tertiary.

The evidence is far from conclusive, but the data so far as they go, strongly indicate Campanian or Maestrichtian age".

In summary, the palaeobotanical conclusions about the age of the Suquash Formation are unanimous that the beds are equivalent to part of the Nanaimo Group and the later reports favour Campanian to Maestrichtian age.

In addition, J.A. Jeletzky (1969) collected a marine fauna from the sandstone-coal formation near Port Hardy Airport, and identified the following: (GSC Loc. 82952) Inoceramus subundatus Meek, Inoceramus aff. vancouverensis Shuward, Trigonia cf. tryonana Gabb, Pectunculus weatchii Whiteaves. In immediately overlying beds, he collected (GSC Loc. 83922, 83923) Baculites chicoensis Gabb sensu Usher, 1952. He concluded that the beds were of the Hoplitoplancenticeras vancouverense zone of the Nanaimo Basin, which is mid-Campanian in age, and suggested equivalence with the Cedar District Formation. On the Hope Island outlier, he found Inoceramus vancouverensis Shumard and I. subundatus Meek which indicated that the beds were not older than the Cedar District Formation. In the beds west of Alice Lake, he found and identified (GSC Loc. 82958) Baculites cf. chicoensis Meek Inoceramus chicoensis Anderson, Inoceramus ex. aff. balticus Bohm, "Rhynchonella" suciensis Whiteaves. These were also considered to be Cedar District equivalents, of Early-Late Campanian age. The plant-bearing beds and the near-shore marine beds are considered to be more or less coeval.

MARINE SILTSTONE UNIT

Lithology

The Suquash Formation is overlain conformably and gradationally by a marine siltstone-shale sequence, less than 50 feet thick. Outcrops of the siltstone formation are only known for a short distance along the shore east of the mouth of Keogh River, and also on the west fork of that river, upstream from the highway bridge. Despite a distinctive but very rare fauna, the unit is not well enough defined to deserve formational status.

It consists of grey, fine-grained sandstone and siltstone, thinly and faintly cross-bedded and containing many small bell-shaped calcareous concretions.

Age

Marine fossils had already been found by Dawson's party (1887) on the west branch of Keogh River and Jeletzky collected the following in the coastal exposures: (GSC Loc. 82962, 82963) Metaplacenticeras occidentale (Whiteaves), Schluteria cf. selwyniana (Whiteaves) juvenile ammonite, Pseudophyllites indra Forbes? Trigonia (Pterotrigonia) cf. evansana Meedk, various pelecypods, gastropods (Muller and Jeletzky, 1970). According to Jeletzky this fauna represents his Metaplacenticeras cf. pacificum subzone of the Nanaimo faunal sequence, indicating late Campanian age.

Higher Units of Nanaimo Group?

According to Jeletzky (Muller and Jeletzky, 1970; Figure 9), there are higher formational Nanaimo Group units in the Suquash Basin. An "Upper Greywacke Unit" was said to overlie the "Metaplacenticeras siltstone" east of the mouth of Keogh River. The beds in question are those in a tidal reef containing the coaly beds with microflora described with the Suquash Formation. Although indeed the marine siltstones appear to dip below these beds, the contact is inferred to be faulted and the succession thus seemingly reversed. Thus Jeletzky's "Upper Greywacke Unit" is probably identical to Suquash Formation. An "Upper Siltstone Unit" was also said to be exposed 1 3/4 miles above the mouth of Keogh River. This is the location where Dawson's party found Metaplacenticeras, described with the Marine Siltstone Unit. Jeletzky had originally placed Dawson's locality farther downstream, near the coastal locality, but later realized the shales there were glacial clay (Muller and Jeletzky, 1970, addendum 5, p. 70). In 1972 (pers. comm.) he discovered Metaplacenticeras on the west fork of Keogh River, the locality given for the "Upper Siltstone Unit", and thus confirmed that the two siltstone-units are identical.

Thus at present there is no cogent reason for assuming the existence of beds higher than the Metaplacenticeras - bearing marine siltstone unit. However, in view of the fact that the Port McNeill sandstones are separated by a drift covered area from the Suquash exposures and have been interpreted as late Cretaceous, probably Maestrichtian, it is conceivable that these sandstones are indeed younger than the marine shales. Such a relationship appears to have been suspected by G. M. Dawson.

Correlation and Paleogeography

The available paleontological dating permits a tentative correlation of Suquash Basin depositional events with the depositional cycles of Nanaimo and Comox Basins (Muller and Jeletzky, 1970, see Figure 9).

It is suggested that the "basal greywacke" of Suquash Formation carrying marine fossils of Cedar District age represents a partly developed second cycle, missing the basal lagoonal deltaic succession and containing near-shore marine sandstone instead of an off-shore siltstone-shale sequence. The Suquash coal-bearing beds may be coeval with the De Courcy Formation and the Marine Siltstone Unit is of the same age as the Northumberland shales, thus constituting the equivalent of the third depositional cycle of the Nanaimo Basin.

The Nanaimo sea was no doubt a "restricted basin", the "Georgia Seaway". It was bordered on the southwest by a land mass of pre-Cretaceous rocks of Vancouver Island, probably including the present continental shelf and covered on its western side by uplifted Lower Cretaceous sediments. To the northeast there was probably the beginning of the Coast Range Belt. Whether the basins within this seaway were connected is uncertain. Suquash Basin was probably not flooded during the first late Santonian depositional cycle. The Nanaimo and Comox Basins were closed off to the north and had a southward connection with the sea.

During the second early Campanian cycle flooding of the south area was extensive and may well have had a southward connection. At that time minor transgression in Suquash Basin resulted in the "Basal Greywacke".

During the third, middle Campanian cycle the Nanaimo sea also invaded Suquash Basin and deposited a bedded sequence similar to those of Nanaimo Basin, beginning with near-shore and lagoonal sandstone with minor coal and ending with off-shore marine siltstone and shale. Jeletzky (1970A, 1971) suggested that at this time the Suquash Basin was connected northward with the ocean and was not linked to Comox and Nanaimo Basins.

No sediments of the fourth, upper Campanian to Maestrichtian depositional cycle are preserved in Suquash Basin, unless the plantbearing beds near Port McNeill are of that sequence. At this time, it is almost mandatory that the Nanaimo and Comox Basins connected northward through Suquash Basin as there are strong indications that the south end of these basins was blocked by land shedding considerable debris northward into the basin (Muller and Jeletsky, 1970).

TERTIARY INTRUSIONS

Occurrence

Although most granitic plutons of the map-area and of other parts of Vancouver Island can be shown to be mid Jurassic in age, there are some that have yielded early Tertiary potassium-argon ages. So far, only one Tertiary intrusion, the south Zeballos pluton, has been identified in the map-area but several more may be present but unrecognized.

The Tertiary pluton was described first by Stevenson (1950) as the principal intrusive body in the Zeballos mining camp that contains most of the rich gold veins. According to him outcrops are conspicuously jointed, with a "bouldery or hummocky appearance" due to rounding by exfoliation of angles between joint planes.

Lithology

The medium-grained quartzdiorite consists mainly of quartz, oligoclase-andesine, and biotite. The average of three modal analyses by Carson (1973) is shown on Table 6. The rocks contain more biotite and generally more quartz than the quartz-diorites of the Island Intrusions, are lacking in epidote, and low in chlorite and opaques. Carson describes the plagioclases as zoned with intricate oscillations, varying in composition from An 15 to An 65 and almost entirely free from clouding. Contact breccia, consisting of recrystallized fragments of volcanic rock and fragments of older granodiorite in a matrix of quartz-diorite, up to an outcrop width of 2,000 to 3,000 feet is common around the plutons. Stevenson infers that the contacts dip steeply away from the intrusion.

Some large dykes invade lower Cretaceous strata near Christensen Point and similar ones occur in Winter Harbour area. The dykes, striking about east-west, are generally fine-grained and in part exhibit dark-grey colours typical of unaltered basaltic rocks but mainly the buff and orange colours of rhyodacitic rocks. They are plagioclase-quartz assemblages in a mesostasis of chlorite and carbonate. Plagioclase in one dark-coloured rock is labradorite but in other specimens it is entirely changed into carbonate and quartz.

Age and Relationship

Carson (1969) first recognized the relationship of many mineral deposits to granitic intrusions of Tertiary rather than of Mesozoic age. While porphyry-copper deposits on Vancouver Island are now known to be associated with Jurassic as well as Tertiary Intrusions, gold-quartz veins appear to be mainly or exclusively related to Tertiary plutons.

Structural conditions determining the location of Tertiary Intrusions are as yet unknown. Carson indicated they are confined to narrow belts crossing Vancouver Island

and radiating out from the Tofino region. The least well-defined of these is the belt linking Tertiary Intrusions near Tofino with the Zeballos pluton which lacks other plutons in intermediate positions.

A potassium-argon age-determination of quartz-diorite from Central Zeballos Mine was made by the Geological Survey Isotope Laboratory for D.C.T. Carson in 1965 and yielded an age of 38 ± 14 m.y. This age is at the boundary of Eocene and Oligocene, according to the Geological Society of London (Harland 1964) timescale. The age is almost identical to that of similar intrusions on Mount Washington and on Forbidden Plateau on eastern Vancouver Island but slightly younger than the Catface Mountain and Tofino Intrusions on the west coast (48 and 50 m.y.). Quartz-feldspar-biotite porphyry from the dykes near Christensen Point on the north coast, dated by Harakal and White at University of British Columbia for Northcote yielded an age of 50.6 ± 1.7 m.y.

TERTIARY VOLCANICS AND SEDIMENTS

Occurrence

Volcanic rocks of Tertiary age and associated volcanic conglomerates are present in a few locations within the map-area, confined to the vicinity of what has been named Brooks Peninsula Fault Zone, extending from Brooks Peninsula to Port McNeill. The largest outcrops are those of Twin Peaks, also the conspicuous butte southwest of Port McNeill, and Haddington Island in Broughton Strait.

Dawson (1887, p. 61B) already recognized the Tertiary volcanics of Eel Reef in the harbour of Port McNeill, an agglomerate or breccia "chiefly of brownish, blackish and reddish basalt, compact or vesicular in texture". Fragments of green altered volcanics and Cretaceous sandstone were also present.

Lithology

Twin Peaks and two small buttes southwest of Port McNeill are remnants of Tertiary volcanic structures. On Twin Peaks, fresh black vesicular basaltic rock apparently overlies Karmutsen low-grade metamorphic basaltic rock. The contact was not seen but is about flat and at approximately 2,000 feet elevation. On the Rayonnier Company logging roads on the north and west sides of Twin Peaks Mountain, there are limited exposures of grey-black basaltic flows and dykes, in places exhibiting columnar jointing. Unconsolidated bright red, yellow and orange coloured tuffs are also visible in a few roadcuts. At about 2,600 feet elevation, large bluffs of poorly consolidated conglomerate are exposed above road-branch C 22 on a northwest-flowing tributary of Waukwass Creek. The boulders are sub-rounded, poorly sorted, and up to 2 feet in diameter. The conglomerate is apparently a stream-deposit with rough but distinct general bedding and contains boulders of in part vesicular and in part feldspar-porphyritic basaltic lava. This flat-lying deposit suggests the former existence of a rather extensive lava-tuff cone that could support streams with large boulders. The tops of Twin Peaks consist of light brown, fine-grained basaltic rock with near-horizontal platy jointing. These do not appear to be remnants of flows but could be parts of a sill, dyke or volcanic neck.

Cuts in the access road near the forestry lookout on the hill southwest of Port

McNeill exhibit well-jointed, light-buff coloured dacite with indistinct banding. Haddington Island, 13 miles east of Port McNeill, also consists of massive, well-jointed light-buff coloured, fine-grained volcanic rock. These rocks were described by Dawson in a rare erroneous statement, (1887, p. 57B) as grey Cretaceous sandstones, and he recommended them for quarrying material. Indeed they were quarried in the early part of this century and were used for the entire facade of parliament buildings in Victoria, B.C., and several other buildings (Parks, 1917).

The other butte near Port McNeill, about 2 miles west-northwest of the forestry lookout, consists of volcanic breccia and conglomerate. At one place a vertical bluff, about 50 feet high, contains angular pieces of unaltered dark-grey basalt, up to 2 feet in size. Some fragments contain large, open vesicles, some have transparent plagioclase crystals to 3 mm in length. The matrix is finer-grained tuffaceous material with smaller pieces of basalt. This breccia, occurring in an isolated butte, surrounded by glacial deposits, probably covering Nanaimo Group sediments, is perhaps a vent-breccia.

Clasts in unconsolidated tuff and breccia as well as dykes of distinctive coarsely porphyritic basalt with large, clear, colourless to light-yellow plagioclase phenocrysts up to 1 cm. in length were noted on Twin Peaks and also on logging spurs on the mountain northeast of Jeune Landing and on the coast of Brooks Peninsula, opposite Solander Island. It has not been possible to work out detailed structural relationships of these volcanic rocks but their position on a line from Brooks Peninsula to Port McNeill may be significant.

Thin sections of the Tertiary volcanics all exhibit fine-grained, unaltered holocrystalline to hypocrystalline assemblages consisting mainly of a fine mesh of plagioclase laths. Basalt, on Twin Peaks, is dark-to-medium-grey on fresh surface and weathers to dark and light brown colours. Phenocrysts of labradorite as well as the plagioclase matrix enclose grains of pyroxene and some magnetite. The rock of Haddington Island is a dacite containing clear plagioclase phenocrysts to 1 mm in size with normal, slightly oscillatory zoning, and according to extinction angles on one albite-karlsbad twin, with composition about An 35. The matrix consists of plagioclase laths of similar composition, about 0.1 mm in size and anhedral quartz. There is about 5 percent magnetite and minor biotite and very fine hornblende. No potash feldspar was detected in these rocks.

Age

The young age of these rocks was originally inferred from the unaltered character of the crystalline rocks and the unconsolidated nature and vivid red and orange colours of the associated tuffs. It was confirmed by palaeomagnetic and radiometric methods. Symons (1971) concluded that basalt from the west side (branch C 10) of Twin Peaks and "rhyolite" flow and tuff from the forestry lookout near Cluxewe River gave divergent times of extrusion. The Twin Peaks basalt, giving a paleomagnetic pole closest to the present earth's geographic pole, he judged to be the youngest. The rocks from the lookout-hill, by the Cluxewe River, showed a pole close to that of the Tertiary stock of Mt. Washington with an Oligocene (37 $\pm$ 5 m.y.) radiometric age.

Whole-rock potassium-argon dating of the Twin Peaks basalts is still in progress at the Geological Survey Isotope Laboratory. However, preliminary results for two samples are as follows: (R.K. Wanless, pers. comm. 1972).

K-Ar 1802, from Twin Peaks, waterfall above Branch C 22; 50° 30' 0" N., 127° 18" 10" W. Fine-grained microporphyritic basalt. Age: 18.7 m.y. The age was obtained by double extraction of argon, first by pre-heating to 300° C. and then by bringing the sample to fusion temperature.

K-Ar 2017, north top of Twin Peaks, 50° 30' 30" N., 127° 15' 0" W., fine-grained light-brown microporphyritic basalt; age: 7.6 m.y.

These preliminary results, to be confirmed by further analyses, indicate Miocene to Pliocene age for this volcanic complex.

One other date was obtained on a basaltic dyke from East Straggling Island in the middle part of Holberg Inlet, 50° 35' 55" N., 127° 40' 25" W. The age, obtained by J. E. Harakal and the late W. H. White of University of British Columbia, is 32.3 ± 1.6 m.y.

In summary, one may conclude that Tertiary volcanism was, unlike on Queen Charlotte Islands, very limited on Vancouver Island and was possibly confined to activity along the Brooks Peninsula fracture zone, and perhaps others like Holberg Fault.

STRUCTURAL GEOLOGY

Fault Blocks

The structure of the area is dominated by block faults and exhibits a medial north-northwest trending arch, flanked by fault-blocks with outward dipping strata. The entire region is criss-crossed by irregular sets of steep to vertical faults of normal or strike-slip, but largely unknown, displacement. Main structural features are shown on Figure 10.

Victoria Arch is the structural culmination of the map-area and apparently represents the axial high of the early-Mesozoic volcanic plateau that contains the central batholiths and forms the backbone of Vancouver Island. It is in direct alignment with Buttle Lake Arch in Alberni map-area (Muller and Carson, 1969) and its culmination is in the headwater region of White River, where Paleozoic rocks are exposed and includes Victoria Peak, the second highest peak on the island (7,095 feet). Within the map-area, the arch is bounded by Nimpkish and Woss Fault on the west, and Eve River Fault on the east. Southwest of Victoria Arch, Vancouver Group rocks are displayed in southwestward tilted panels and normal northwesterly faults tend to repeat the southwestward facing stratigraphic sequences. Conversely, panels northeast of the central arch are inclined to the northeast corner of the map-area. The great central batholiths of Vancouver Island make up the backbone of the arch. They are in the shape of a tight letter X, lying west of the axial culminations, and with apex near Vernon and northerly arms formed by Vernon and Nimpkish Batholiths. The arch is fractured by several sets of faults, some parallel, some perpendicular, and some oblique at about 60 degrees to its axial direction.

White River Block, on the east flank of Victoria Arch, contains generally north-east to northward tilted Karmutsen lavas and minor Quatsino limestone, intruded by Adam River Batholith. It contains several faults in a general northerly direction.

Nimpkish Block, a relatively small wedge on the west side of White River Arch, between Nimpkish and Bonanza Faults exposes mainly southwest dipping Upper Triassic sediments and Lower Jurassic sediments intruded by basic sills as well as small granitic laccolithic masses of Bonanza and Nimpkish Batholiths.

Karmutsen Block is the broad west flank of White River Arch, bounded by Nimpkish and Woss Faults on the east, Ououkinsh Fault on the southwest, and Brooks Fault Zone on the northwest. It consists of a rather regular and complete southwest dipping sequence of the Vancouver Group, intruded by smaller medium and high-level plutons, one of them of Tertiary age. It is broken by several strike-faults, a set of north-northwesterly faults with mainly left-lateral separation cutting Karmutsen rocks, and some easterly faults cutting the intrusions.

Kyuquot Block, southwest of Karmutsen Block and separated from it by Ououkinsh Fault, contains a jumbled group of smaller blocks of Vancouver Group rocks, intruded by several small stocks. The internal structure of this block is as yet poorly defined.

Kyuquot Swell underlies shoreline and shelf-area of Checleset Bay. The shelf-area off Vancouver Island south of Brooks Peninsula has recently been named Tofino Basin (Tiffin and Cameron, 1972). In this basin Eocene, Oligocene, and Miocene sediments unconformably overlie rocks of the Vancouver Group and superjacent Jura-Cretaceous sediments. The northern part of the basin, where the pre-Tertiary "basement", mainly Bonanza Volcanics and granitic rocks, is exposed in the shelf-area was called "Kyuquot Uplift" by these writers. In the context of Vancouver Island tectonics where this block is structurally relatively low, "Kyuquot Swell" appears to be more appropriate.

Suquash Basin is located at the convergence of several major faults and fault zones, and the fault blocks between them. It is separated from Nahwitti Block by a fault and the sub-Cretaceous unconformity. It is underlain by Upper Cretaceous Nanaimo Group sediments, overlying Karmutsen lavas and is pierced by several late Tertiary volcanic structures.

Nahwitti Block is considered as the indirect continuation of White River Arch, perhaps shifted westward along Holberg Fault, its south boundary. Its north limit is Goletas Fault, and the block forms a southward inclined panel. It exhibits a southwest dipping sequence from Karmutsen volcanics to Lower Cretaceous Longarm and Queen Charlotte beds, intruded by Nahwitti Batholith and small high-level satellites.

Hope - Nigei Block is on the northeast flank of the Nahwitti Block culmination and includes Hope, Nigei and several small islands. It is underlain by some Jurassic sediments, and possibly some of Upper Triassic age, but the islands consist mainly of granitic intrusions. The block could be considered as a northward extension of Adams River Block, shifted westward along Goletas Channel Fault.

Quatsino Block is the northwestward continuation of Karmutsen Block, but less deeply eroded and separated from it by Brooks Fault Zone. It is bounded by Mahatta Fault to the southwest and Holberg Fault to the north. It contains a southwest dipping sequence of Vancouver Group rocks, but mostly the younger formations of that sequence. In the Quatsino Sound area, it is overlain by Lower Cretaceous sediments. It is fractured by an irregular pattern of northerly and northwesterly faults.

Cape Scott Block lies southwest of Nahwitti Block and, as northward continuation of Kyuquot Block, forms the Pacific coastline. It is underlain mainly by Bonanza Volcanics, overlain by small patches of Lower Cretaceous Longarm sediments. It is slightly arched along its long northwest axis, and inclined northeast along its northeast margin and southwest-to-west along its southwest side. Subsidiary faults within the block run parallel, perpendicular and at about 60 degree angle to that direction of elongation.

Brooks Peninsula Block is bounded on the northeast by the Westcoast fault zone and on the southwest by the Cape Cook fault. It is as yet to be established by marine geological and geophysical work if faults of the Brooks fault zone also bound the northwest as well as southeast shores of the Peninsula, thus forming a rectangular horst-like mass. The block may continue northwestward, however, and include the shelf-area off the Cape Scott Block, separated from it by a northwestward continuing Westcoast fault zone. Thus while Brooks Peninsula exposes the structurally lowest Westcoast Crystalline Complex, the northwesterly shelf-area may well contain Vancouver Group rocks. These are covered by a wedge of Miocene and Pliocene sediments. Unlike on the Kyuquot Swell, Eocene and Oligocene are missing (Tiffin et al., 1972). Possibly the Scott Islands should also be included in this block. There, dioritic rocks similar to those of Westcoast Crystalline Complex are present, but they are in intrusive contact with Lower Jurassic sediments.

Pacific Rim Block is only exposed in a small area near Cape Cook on Brooks Peninsula. It contains highly disturbed greywacke, argillite and conglomerate, separated by Cape Cook Fault from the Crystalline Complex. These rocks are probably equivalent to similar ones of late Jurassic to early Cretaceous age in Pacific Rim National Park near Tofino (Muller, 1973), and perhaps to those of Triangle Island. They constitute the contorted late Mesozoic sediments off the slope and bottom deposits, tectonically emplaced between ocean floor and Vancouver Island in early Tertiary time.

Faults

Faults have been mentioned as the boundaries between major fault blocks and as fractures within the blocks. The names of major faults are shown on Figure 9. They have mainly been recognized as abrupt offsets of certain formations but for most of their length well exposed fault zones have not been observed. They are all steeply inclined, and west of Victoria Arch they generally dip steeply northeast towards the down-dropped block. Thus the major faults are antithetic faults, separating a series of southwestward tilted panels on the west side of White River Arch. All these panels are broken by subsidiary faults, some parallel with the main fault direction, some at oblique angles to it. The irregularity of their pattern apparently reflects the great heterogeneity of the affected complex of rocks.

Steep faults are the dominant structural discontinuities. They are commonly expressed in wide zones of shattered rocks that have been worn down into valleys and thus their trace is commonly obscured by recent deposits and water. Best exposures of shatter zones are present along the west coast between Kyuquot and Quatsino Sound. They exhibit highly altered, whitish to light-rusty volcanic, sedimentary and plutonic fragments separated by several sets of faults. The main faults within the zones are northwesterly striking, about parallel to the coast, and, with steep northeast dips, but there are northeasterly faults as well. As yet, it has not been possible to determine a direction of movement in these complexly shattered rocks.

The writers have earlier (Muller and Carlisle, 1972) attempted to analyse the fault pattern of the Insular Belt. Northwesterly faults are considered to be most important ones and in a few instances, in the Queen Charlotte Islands, right-lateral movement on these has been demonstrated (Sutherland Brown, 1968). Northerly and westerly striking faults may be second-order faults to first-order northwesterly faults. The northerly faults are in Karmutsen rocks and have, within and outside Alert Bay - Cape Scott map-area, in several instances right-lateral separation. The westerly faults, apparently predominating in granitic areas of Vancouver Island, show in most cases left-lateral separation.

Although the map shows several horizontal separations of formation-contacts along faults, no actual strike-slip movement has been demonstrated. Matching distinct lithological facies on either side of the fault, generally required for such proof, are not available. It is therefore assumed that the faults are largely normal faults that separate independently tilted fault blocks. However, Carlisle will, in a forthcoming paper on adjacent Bute Inlet map-area, present arguments, based on detailed mapping and structural analysis, in favour of important strike-slip components for several major faults.

Several of the faults shown on Figure 10 deserve special mention:

Gerald and Eve Faults trend northwesterly along the crest and on the east side of Victoria Arch and exhibit eastward downthrow.

Nimpkish, Bonanza, and Woss Faults - the latter continuing into Tahsis Inlet - appear to be faults with variable displacements and are in part only conspicuous valley lineaments within Vernon and Bonanza Batholiths.

Mahatta and Ououkinsh Faults are probably the same fault, broken up by Brooks Peninsula Fault zone. They separate, partly with northeast downthrow, two generally southward tilted blocks.

Westcoast Fault, characterized by its wide shatter-zone in several places, also exhibits northeastward downthrow. More detailed work on the fault zone is necessary to determine its character and whether a transcurrent component is present. Faults in the continental shelf area are tentatively outlined from available seismic records (Tiffin and Cameron, 1972) and are probably roughly parallel and similar in offset to Westcoast Fault.

Holberg Fault, partly in Holberg Inlet and partly slightly north of it was first described by G. M. Dawson (1887). Like Mahatta Fault, it separates with northward downthrow two southward-to-southwestward tilted blocks. In addition it may well have considerable transcurrent movement. For Victoria Arch and Vernon Batholith appear to be continued by Nahwitti Block and Nahwitti Batholith, and left lateral offset of about 50 miles is thus suggested.

Goletas Fault and Johnstone Strait Fault may be principal faults of a system of faults in Hecate - Georgia Depression. Like Holberg Fault, which splays off Johnstone

Strait Fault near Port McNeill, the faults may have a large left lateral offset if Hope and Nigei Islands are taken as the northward continuation of Adam River Batholith.

Brooks Peninsula Fault zone is a zone of northeasterly cross-faults that offset several northwesterly faults. Late Tertiary volcanics are believed to be related to this fault zone. The zone is conspicuous by the offset of magnetic anomalies on aeromagnetic maps.

Northwesterly and northerly faulting has affected Lower and Upper Cretaceous rocks intensively in the map-area and in other parts of Vancouver Island. However, faulting of uppermost Eocene and younger rocks is much less severe and for a large part in northeasterly direction. It is suggested that most faulting occurred in late Cretaceous and early Eocene time but that northwesterly directed faulting, including that of Brooks Peninsula Fault zone, took place in late Tertiary time.

GEOLOGICAL HISTORY

The following summarizes briefly the volcanic, sedimentary, plutonic and tectonic history of the map-area. Stages in this history, from late Paleozoic time to the present, are diagrammatically shown on Figure 11, A to E and numbers in brackets in the following resume refer to numbered formations in the figure.

It is unlikely that Precambrian granitic crust underlies any part of Vancouver Island. Rather, the Westcoast Crystalline Complex (1) of quartz-dioritic to gabbroic composition, is inferred to be metamorphosed and dioritized oceanic crustal material.

On this crust a volcanic arc was built in Pennsylvanian or earlier time and formed the Sicker Volcanics (2). Volcanism ceased probably in early Pennsylvanian time and volcaniclastic sediments (3) and limestone (4) of Pennsylvanian and perhaps Permian age were laid down. The thickness of late Paleozoic sedimentation is small and although Lower Triassic fossils have not been found the transition from upper Paleozoic to Middle Triassic sediments without apparent disconformity suggests submersion with minimal deposition rather than emersion in early Triassic time (Figure 11A).

In late Middle Triassic time a few hundred feet of black argillite and siltstone containing pelagic Daonella were laid down (5). It is inferred that somewhat later, rifting of the Paleozoic island arc occurred, thus forming an inter-arc basin, similar to inter-arc basins of the western Pacific Ocean today. Basaltic lava welled up, forming diabase sills and dyke-complexes between the older Paleozoic rocks and, in particular, in the recently deposited Middle Triassic siltstones; it also was extruded in large quantity. The lower part of the basaltic (tholeiitic) sequence formed up to 10,000 feet of pillow-lavas (Karmutsen, 6) possibly with a "medial high" in the middle part of the basin, now represented by the Victoria Arch. As the water became shallow and subject to wave-action, close packed pillow-lavas were replaced by pillow-breccias and aquagene tuffs. Eventually the volcanic shield rose above the water and basaltic flows, with vesicular tops and bottoms were erupted and reached a maximum thickness of about 10,000 feet (Karmutsen, 7). However, to the west and southwest of the medial ridge, possibly near the emerged outer arc, the basaltic accumulation was considerably thinner (Figure 11 B). In Late Triassic, late Karnian time rifting and related basaltic extrusion gradually ceased and limestone (Quatsino, 8), more than 2,000 feet thick near the medial high and much thinner towards southwest and northeast was laid down. The limestone was followed by carbonate-volcaniclastic sediments in latest Triassic-Norian time (Parson Bay, 9). The clastic sequence was thicker and coarser-grained on the southwest side of the basin. The volcaniclastic material may not have been derived from the basaltic medial high but from "arc-type" intermediate volcanic rocks of the outer arc, either older Sicker Volcanics or the beginnings of the new volcanic arc that was to emerge in Early Jurassic time.

In Early Jurassic time renewed arc-type volcanism occurred and formed the Bonanza Volcanics (10). Volcanism was confined mainly to the southwestern part of the basin and/or the outer arc where andesitic to rhyodacitic lava, tuff and breccia were erupted, intercalated with a few marine (Sinemurian) clastic sediments. To the northeast mainly volcaniclastic pelitic sediments (Harbledown, 11) were deposited. Volcanism was coupled with major plutonic activity. It is conjectured that migmatization, differentiation and mobilization of the old Paleozoic "basement" produced quartzdiorite to quartz-monzonite migma that formed batholiths in the mesozone, quartzfeldspar-porphyry stocks and dykes in the epizone, and extrusive andesite to rhyodacite. Plutonism ceased in Middle or early Late Jurassic time (Figure 11 C).

Uplift and erosion followed in Late Jurassic time and clastic wedges were laid down on the outer shelf, within the map-area during Early Cretaceous time (Longarm and Queen Charlotte, 13). Figure 10 D shows these sediments in Kyuquot area, but their former presence there is hypothetical; they now only occur on and north of Quatsino Sound. Farther oceanward flysch-type sedimentation occurred on the continental slope, or slope of the outer arc and possibly in a trench west of the arc (14). Successively overlapping sediments show the eastward transgression of shelf-sedimentation in Early Cretaceous time. Valanginian sediments are volcanic-derived but Albian to Cenomanian beds contain granitic clasts and quartz-feldspar sandstones in addition to volcanigenic material, indicating that by that time granitic plutons were being unroofed.

By late Cretaceous time the outer shelf apparently emerged and sedimentation was shifted to a northeasterly inner basin with varying marine, deltaic and lagoonal conditions (Nanaimo, Suquash, 15) (see Figure 11 D); the former's presence in the section is only assumed.

Only a few events are recorded from the Tertiary Era. Some small plutons were intruded in Eocene time and in the late Tertiary fracturing along the Brooks Peninsula Fault zone appears to have been coupled with minor basaltic to rhyodacitic volcanism; Miocene and Pliocene sediments were laid down on the present continental shelf. Figure 11 E does not show these events but represents the inferred present cross-section through the map-area from Kyuquot in the southwest to Johnstone Strait in the northeast.

TABLE 10 CLASSES OF METALLIFEROUS DEPOSITS

Known or Probable Age	Class	Metal	Example (Map)	Mineralogy	Host and Associated Formations
Recent	M Bog Iron	Fe 55%	Quatsino Iron # 87	Limonite, Pyrite	Hydrothermally altered, pyritized Bonanza andesite and basalt.
Jurassic Tertiary (?)	K Aluminum Deposit	Al, Al_2O_3	Morris # 72	Alunite (natroalunite) pyrophyllite, quartz, sericite, diaspore, kaolin, pyrite and limonite.	Rhyodacite tuff of Bonanza Volcanics.
Mid Jurassic	H-1 Porphyry Copper	Cu 0.5%	Island Copper # 158	Chalcopyrite, molybdenite, (bornite) magnetite pyrite, hematite	Bonanza subgroup pyroclastic rocks of andesite and basalt composition. To a lesser extent brecciated and altered quartz-feldspar porphyry.
Tertiary	G-8 Gold quartz veins, fissures	Au, Ag (Pb, Zn, Cu, As)	Privateer # 8	Pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, native gold.	Varied: Sicker Group, Vancouver Group, Nanaimo Group, Intrusive rocks.
Jurassic and Tertiary	G-2 Copper-bearing Quartz Veins & Shear Zones	Cu (Mo, Ag, Au, Zn)	Quatsino King, # 54	Chalcocite, chalcopyrite, (pyrite, pyrrhotite, molybdenite)	Sicker Group, Karmutsen Formation, Bonanza Volcanics, granitic rocks.
Jurassic and Tertiary	F-4 Lead-Zinc Skarn or Replacement in Limestone	Pb, Zn, (Ag, Au)	H.P.H. # 69	Sphalerite, galena	Limestone of Sicker Group, upper Karmutsen and Quatsino Formations
Jurassic and Tertiary	F-2 Copper Skarns	Cu (Au, Ag, Fe)	Old Sport-Benson Lake # 91	Chalcopyrite, bornite, magnetite	Sicker limestone, in skarnified volcanic and sedimentary rocks at Quatsino - Karmutsen contact. Some deposits in Quatsino - Karmutsen limestones.
Jurassic and Tertiary	F-1 Iron Skarns	Fe (Cu)	Merry Widow # 44	Magnetite, minor specularite and sulphides	Quatsino formation and/or adjacent skarnified volcanic and intrusive rocks.
Upper Triassic	C Copper in basic Volcanics	Cu	Millington, Rick # 219	Chalcopyrite, bornite, native copper	Karmutsen basalt, tuff and breccia

TABLE 10 (Cont.) (After D. J. T. Carson, 1968)

Structural Control	Associated Alteration	Intrusive (Genetic-Spatial)
	Derived from pyrite in hydrothermally altered Bonanza andesite and basalt.	Indirect relationship to Rupert Inlet-Stranby stocks which altered and mineralized rocks of Bonanza Volcanics.
Fractured and sheared rock. Result of hydrothermal alteration of Bonanza pyroclastic rocks.	Sericite, quartz, kaolin, natroalunite, pyrophyllite, dumortierite.	Acid intrusive rocks.
Brecciation in and adjacent to quartz-feldspar porphyry intruding Bonanza rocks presumably following shear zones.	Epidote, chlorite, sericite, pyrite, biotite, silica, kaolin, pyrophyllite, dumortierite, carbonate, laumontite, pyrobitumin.	Silicic stocks and quartz-feldspar porphyry complex.
Fractures, faults, sheeted zones, fissure zones.	Some silicification, sericitization, carbonatization, chlorization.	Tertiary quartz diorite stocks, plugs and related dacite porphyry dykes, sills, laccoliths.
Narrow shear zones, large fractures, fracture zones near faults and contacts.	Strong silicification and/or carbonatization may or may not be present.	Granitic to gabbroic and porphyritic intrusions believed to be genetically related to these deposits.
?	Silification, skarn.	Granitic to gabbroic and porphyritic intrusions.
Limestone-intrusive contacts folds, fractures, breccia zones and favourable horizons.	Skarnification, epidote, garnet, various other calcium silicates including wollastonite, diopside, actinolite, hedenbergite, etc., and ilvaite.	Jurassic and Tertiary intrusives of varied composition.
Intrusive contacts, folds, fractures, stratigraphic contacts, breccia zones	Skarnification as for F-2	Jurassic and Tertiary intrusives of varied composition.
Amygdaloidal beds, fractures small shears in basic volcanic rocks.	May or may not be associated with carbonate and/or quartz.	None; thought to be generated within the volcanic rocks.

ECONOMIC GEOLOGY

by

K. E. Northcote

Introduction

Metalliferous deposits within the Alert Bay - Cape Scott map-area are listed on Table 9 and are shown on Map 2 . This map is derived from B.C. Department of Mines and Petroleum Resources, Mineral Inventory Maps 92-L and 102-I by E. V. Jackson and G. E. P. Eastwood. Information for mineral showings and mines within the map-area is taken from mineral inventory cards compiled by Jackson and Eastwood, publications by B.C. Department of Mines and Petroleum Resources and by the Geological Survey of Canada, and from data collected by Northcote in the field.

Information is scanty for many of the deposits listed on Table 9. Mineral inventory cards and maps are continually being updated as new data are available. This report summarizes the information available as of December 1972 for mineral deposits and mines within the map-area.

Metalliferous Deposits

For ease of referring from one map-area to another the same symbols are used to depict type or class of deposit on Map 2 (in pocket) as were used by Muller and Carson for the Alberni area (Muller and Carson, 1969, Figure 3).

Table 10, Classes of Metallic Mineral Deposits of the Alert Bay - Cape Scott map-area is modified only slightly from Carson's classification (Muller and Carson, 1969, Table 3; Carson, 1968, Table 7). Provision is made for porphyry copper deposits in which the bulk of mineralization occurs largely in the country rock surrounding or enveloping granitic rocks and their porphyritic phases. Copper in Shear Zones, Class G 3, is included with Copper in Veins, Class G 2, where both are apparently the result of intrusive activity. Class C deposits refers to copper occurring in basic volcanic rocks in amygdules, fractures, small shears and quartz-carbonate veins and has no apparent relationship to intrusive activity. This type of mineralization is thought to be derived from copper charged solutions originating from within the volcanic sequence (Gunning, 1930, p. 138-9).

Most deposits will be accommodated most readily in one class. Many, however, have characteristics of two or more classes. This is indicated in Table 9 by placing the class in brackets for which the deposit has subordinate characteristics.

Class M. Bog Iron

Characteristics and examples of Class M deposits are given in Table 10. Iron oxide forming this type of deposit is believed to have been derived as a result of oxidation of pyrite occurring in hydrothermally altered Bonanza volcanics on the north side of Holberg Inlet.

Class K. Potassium and Alumina Deposits

Potassium and alumina deposits of this class in the Alert Bay - Cape Scott map-area may be the result of hydrothermal alteration (pyrometasomatism) accompanying intrusion of granitic rocks and their differentiated offshoots into pyroclastic Bonanza rocks. These deposits may also be the result of hydrothermal alteration and hotsprings activity near volcanic centres during periods of volcanism.

Minerals composing Class K. deposits include alunite, natro-alunite and pyrophyllite. Other common minerals in these deposits are sericite, pyrite and lesser amounts of dumortierite. Natro-alunite occurs with pyrophyllite at the Morris deposit (Map 2 ,72) at Easy Inlet. Pyrophyllite was mined from the Monteith deposit (Map 117) on the west side of Kashutl Inlet, and occurs with dumortierite at Island Copper Mine (Map , 138) on Rupert Inlet.

Class H - 1. Copper (Molybdenum)

Class H - 1 deposits have the following characteristics:

(1) Most of the mineralization occurs within an envelope of alteration around plutons or dykes intruding the volcanic rocks. Some mineralization, however, may occur in the brecciated, altered, porphyritic plutons.

(2) One or more stages of brecciation and fracturing are evident.

Island Copper Deposit

The Island Copper mine, (92-L-138) represents the H-1 class of porphyry copper deposit in the Alert Bay - Cape Scott map-area. The mine is on the north side of Rupert Inlet and is about 8 miles south of Port Hardy. Mineralization is associated with a quartz-feldspar porphyry which intrudes the Bonanza pyroclastic volcanic sequence. Emplacement and crystallization of the porphyry occurred in a subvolcanic environment and was accompanied by a complex history of brecciation and fracturing, metasomatism, hydrothermal alteration and mineralization (Northcote & Muller, 1972; Northcote, 1971; 1972).

Age of the Deposit

The quartz-feldspar porphyry at Island Copper has characteristic coarse-grained, rounded, resorbed quartz phenocrysts similar to those in a porphyritic quartz monzonite pluton which is exposed two miles to the east at the end of Rupert Inlet. The quartz-feldspar porphyry and the Rupert Inlet quartz monzonite are considered to be genetically related; the quartz-feldspar porphyry is a differentiate of the quartz monzonite. An age determination on biotite, by J. E. Harakal and the late Dr. W. H. White at U.B.C., gave a K/Ar age of 154 ± 6 m.y. for the Rupert Inlet porphyritic quartz monzonite. The 154 ± 6 m.y. age is therefore also considered to be the approximate age of the Island Copper quartz-feldspar porphyry (Northcote, 1972, in press).

Geological Environment

The comagmatic relationship between Bonanza Volcanics and Island Intrusions and the subvolcanic environment that probably existed at the time Island Copper deposit was formed are diagrammatically illustrated on Figure 12 (reproduced from Northcote and Muller, 1972).

Similar chemistry, history of magmatic evolution and similar age determinations suggest the Bonanza Volcanics and Island Intrusions are comagmatic. Figure 12 shows Island Intrusions following Bonanza volcanic centres upwards. It illustrates the rising magma intruding earlier volcanic rocks while extrusion of younger volcanics still continues. The thin cover of overlying Bonanza Volcanics apparently resulted in subvolcanic conditions existing at the tops of the magma chambers. Tapping of reservoirs of varied stages of differentiation within the magma chambers may account for interbedded flows and pyroclastic rocks ranging from basaltic andesite to rhyolite.

Geology of Island Copper

Figure 13 is a diagrammatic plan of the Island Copper deposit. The orebody lies within moderately southerly dipping brecciated tuff, lapilli and tuff breccia of andesite and basaltic andesite composition which comprises the lower part of the Bonanza pyroclastic sequence. These volcanic rocks are cut by a northerly dipping, northwesterly trending, digitating, quartz-feldspar porphyry dyke which presumably was emplaced in a pre-existing fracture or shear zone.

The quartz-feldspar porphyry is flanked by a complex multi-generation breccia zone and fracture system. Breccias containing rounded or milled fragments of quartz-feldspar porphyry and altered Bonanza rocks adjacent to and overlying the porphyry suggest at least one but possibly several episodes of explosive brecciation or gaseous venting. The complexity and intensity of brecciation and fracturing is particularly well displayed in the open pit on the north side of the porphyry. Brecciation becomes less intense a short distance outwards from the porphyry and within about 200 feet the dislocated breccia gives way to systems of intense fracturing or crackle breccia. Several generations of fracturing are evident by cross-cutting relationships of veins of similar and differing composition.

A gross zoned pattern of alteration of the wall rocks accompanied emplacement of the quartz-feldspar porphyry dyke system. Remnant biotitization is still visible in Bonanza rocks outside of the zone of most intense brecciation and fracturing and where silicification and phyllic alteration is less intense. The biotitized zone grades outwards to propylitic alteration outside of the ore zone and pit-area.

During and between periods of brecciation and fracturing the complex fracture systems were permeated by hydrothermal silica-rich solutions and differentiated porphyry and its siliceous derivatives; some of which carried metals. As a result of this hydrothermal activity systems of quartz veining, silicification and phyllic (quartz-sericite-pyrite) alteration of varied intensity were superimposed on the already biotitized and chloritized wall rocks. Later fracture systems superimposed on phyllic alteration contain carbonate and laumontite, and some very late fractures and shear zones contain pyrobitumen. At the northwest end of the ore zone a complex pyrophyllite-dumortierite-quartz porphyry breccia forms a cap-like zone of intense argillic alteration over the top of the quartz-feldspar porphyry and altered, mineralized, brecciated Bonanza rocks.

Mineralization consists mainly of fine-grained chalcopyrite in fractures, chalcopyrite associated with quartz veinlets and very fine-grained chalcopyrite disseminated in silicified, sericitized and biotitized Bonanza rocks. Fine-grained magnetite is commonly associated with copper mineralization. Molybdenite occurs in fractures and is found throughout the mineralized zone but is particularly abundant in silicified and biotitized rocks. Hematite and pyrrhotite, although they both occur, are not abundant in the altered zone.

Island Copper deposit has reported reserves of approximately 230 million tons of 0.52 per cent copper and 0.029 per cent molybdenum sulphide (Young and Rugg, 1971). Production commenced late in 1971 and the mill is expected to reach a capacity of 33,000 tons per day.

Class G-8 Gold-quartz veins

J. S. Stevenson (1950), J. W. Hoadley (1953), and M. F. Bancroft (1937) have adequately described the gold-quartz vein or fissure type of deposit. The gold-quartz vein or fissure type of deposit. The gold-quartz veins of the Zeballos camp supported the most important mines of this class on Vancouver Island. Production from this camp to the time operations ceased in 1948 totalled 287,811 ounces of gold and 124,700 ounces of silver. Clean-up operations have resulted in a little production since then. The Privateer Mine, the largest producer, has contributed nearly half of the total production of the mining camp.

The general characteristics of the Zeballos gold-quartz vein or fissure deposits, as described by Stevenson, are listed on Table 10 and are summarized here (Stevenson, 1950, p. 40 to 45).

The gold-quartz veins consist of quartz-sulphide filling in well defined fracture systems rarely greater than one foot in width although some sheeted zones are up to four feet wide. They have fairly uniform attitudes for considerable distances. According to Stevenson, veins in northeasterly trending tension fractures seem to have been most favourable for gold mineralization. Sulphides and gold occur in layered veins of quartz, carbonate and sulphide. The sulphides consist of pyrite, sphalerite, arsenopyrite, chalcopyrite, galena pyrrhotite and a little marcasite. Sulphides may total up to one-half of the vein matter with the amount of gold proportional to sulphide content. Gold appears to be most abundant in the presence of sphalerite and galena.

Wallrock alteration occurs in all rock types but is most intense in granodiorite or quartz diorite and has produced sericite, chlorite, pyrite and carbonate.

Several intrusive rock types occur in the Zeballos gold camp but the gold quartz veins are most closely associated with the northwestern end or nose of a quartz diorite stock.

Carson suggests a Tertiary age for the Zeballos camp gold-quartz vein deposits because of an age of 38 million years for the quartz diorite (Muller and Carson, 1969, p. 43).

Class G-2 Copper bearing Veins

Class G-2, copper bearing veins, has been modified from Carson's classification to include copper bearing quartz and carbonate veins, and copper bearing shear zones containing little quartz or carbonate. The class is restricted to those deposits which have a known or presumed genetic relationship to intrusive rocks. Copper bearing stockworks, because of economic implications, are placed in a separate sub-class G-2-a. Although there are a great number of copper bearing veins in the Alert Bay - Cape Scott map-area none have so far proven to be of great economic importance. The main characteristics of this type of deposit are listed on Table 10.

Class F-4. Lead-zinc skarn

Several irregular sphalerite and galena replacement deposits in limestone occur in the Alert Bay - Cape Scott map-area. The ore minerals may be accompanied by pyrite, pyrrhotite, arsenopyrite or chalcopyrite and values in silver and gold. The deposits are thought to be related to intrusive activity. Their mineralogy, particularly silicification of limestone, suggests their close proximity to intrusive rocks. Pyrrhotite and sphalerite probably occur in greater abundance closer to intrusives than pyrite and galena (Gunning, 1930, p. 135). The main characteristics of these deposits are given on Table 10.

Class F-1, F-2. Iron and Copper skarns

Iron and copper skarns are discussed fully by Carson (Muller and Carson , 1969, p. 40). No modifications of Carson's Class F-1 and F-2 deposits have been made for purposes of this report. The characteristics of these classes of deposits are given on Table 10. No magnetite skarns are presently being mined in the map-area but active exploration is being carried on at several such properties in the Nimpkish Lake and Bonanza Lake areas.

Old Sport - Benson Lake Mine, Coast Copper Company Limited

The Coast Copper Company Limited mine is located at Benson Lake, 26 miles southwest of Port McNeill. This mine closed late in 1972 after the Old Sport - Benson Lake deposits produced a total of 91,766,407 lbs. of copper, 385,180 oz. of silver, and 125,383 oz. of gold. In addition, during the period 1964 to 1970, 557,933 tons of iron ore valued at $3,864,076.00 was shipped from the Old Sport mine.

Earlier reports on Coast Copper Company include those by Dolmage, 1919, pp. 33-35; Gunning, 1930, pp. 113-120; Jeffery, 1961, pp. 100-101; Eastwood, 1962, pp. 97-100; and McKechnie, 1967, pp. 66-68. Description of the geology of Coast Copper mine have been taken from these reports and is summarized here.

Rocks of the Vancouver Group are intruded on the southwest side of the Coast Copper mine property by the Coast Copper stock which ranges from gabbro to granodiorite composition. The east margin of the stock dips moderately to steeply outwards. The Vancouver Group in the mine area is comprised of the upper part of the Karmutsen Formation conformably overlain by the lower part of the Quatsino Formation. The rocks are in a monoclinal sequence striking northwesterly and dipping moderately southwesterly into the Coast Copper stock. The Quatsino limestone is fine crystalline except near intrusive contacts where it is metamorphosed to coarse-grained marble and skarn. The Karmutsen, lying northeast of the Quatsino limestone consists of a thick series of basalt, andesite (?) and porphyritic flow rocks.

The mineralized zone at Coast Copper occurs in a skarn and magnetite horizon which is developed at the Quatsino-Karmutsen contact and varies in width from a few feet to about 100 feet. Garnet, epidote, magnetite and calcite are the chief constituents but diopside, actinolite and calcite are also present. A hard, grey "felsite", said to consist of feldspathic, dykes, intruded and replaced the Vancouver group rocks prior to introduction of sulphides. The skarn, magnetite and felsite together constitute the "Old Sport Horizon". Chalcopyrite and bornite, with small quantities of pyrrhotite and pyrite, form veins, lenses and tabular bodies of varied size in skarn and in magnetite. The mineralized zone is divided in some places into a hanging wall and footwall section by a sheet of basaltic rock of uncertain origin which is called "included diorite" at the mine.

Faults are widespread and are divided into two groups. The first group strike northerly at a small angle to the strike of the bedding and may be normal faults. These faults show the most displacement and cause repetition of beds. The second group trend northeast to easterly and show little displacement.

Class C. Copper in basic volcanics

This type of deposit was described by Gunning (1930, p. 138) as copper mineralization occurring in fractures, shear zones, amygdules and disseminated through the matrix of volcanic rocks. He attributed the formation of these deposits to circulation of copper-charged water through channelways in basic volcanic rock. They need have no association with intrusive activity. The characteristics of such deposits are listed on Table 10.

COAL DEPOSITS

by

J. E. Muller

Lower Cretaceous Coal

Coal has been found in Lower and Upper Cretaceous deposits of the map-area but is of only marginal economic importance. Exploration for coal in the Lower Cretaceous strata of Quatsino Sound was carried out around 1885 and was described by G. M. Dawson (1887). Several borings were made in the Coal Harbour area - Dawson mentioned a two-foot seam of fair quality, occurring on the shore of the west side of the harbour (the Coal Harbour bay). He states that the same seam also outcrops 2 1/4 miles northeast of Hanken Point, where it consists of three bands, 6, 6 and 1 inch thick, separated by several feet of shale. This may be the same seam that yielded an Albian microflora. It was also encountered in one boring in Coal Harbour at depth 28 feet, with reported thickness of 5 feet and poor quality. Another outcrop of coal was reported by Dawson on Holberg Inlet, west of Nuknimish River. This location may correspond to the Apple Bay locality where Albian plants were collected. A thickness of 3 1/2 feet of coal reported to Dawson was not seen by him, but he did see a seam 3 inches thick. Mr. D. Bragg showed the writer a coal seam, a few inches thick, on the lower part of Hushamu Creek. Dawson seems to have been uncertain about the economic possibilities of the Quatsino Sound coal and no better prospects have been found to date.

Upper Cretaceous Coal

The possibilities of the Upper Cretaceous coal if Suquash Basin are only slightly better. Data on coal mining at Suquash were obtained from annual reports of the provincial Minister of Mines and from an engineering report on file with the Provincial Mines Department.

Mining of coal was started by the Hudson's Bay Company for use in its vessels and for the post at Fort Rupert, built 1849. However, this work was abandoned in 1852, partly due to the hostility of local Indians and partly because better coal had also been found at Nanaimo. In that time, an estimated 10,000 tons had been mined.

In the period 1908 to 1915, the coal property was worked by Pacific Coast Mines Ltd. The company put down a shaft 173 feet deep and drove 10,000 feet of slopes. Available plans show only development work and no production from any solid block of coal. Total production in those years was about 12,000 tons.

The mine was closed down until 1921, when it was dewatered, but no further production occurred. In 1952 it was acquired by Suquash Collieries Ltd. Engineering studies were made and the workings were briefly reopened, but again no actual production was accomplished.

The very limited success of the mine is well documented in Figure 14 showing representative sections of the coal seam and the extent of the development work. Total thickness of the coal varies from 62 to 83 inches on the sections shown; one section taken in 1952 between sections 2 and 3, 94 inches thick. According to the 1952 engineering report, the average thickness is 84 inches of which 52 or 62 per cent are useable coal. The maximum thickness of top-bench is 24 inches, and of the bottom-bench, 2 inches.

Only a few analyses of the coal are available from the records of the Mines Branch and are given in Table 11, reproduced from D. B. Dowling (1915).

Summary of Investigation by the Department of Mines, Canada, on Regular Commercial Samples of Vancouver Island Coals[1]

Analyses

Source of Coal	Moisture		Proximate Analysis of dry coal			Ultimate Analysis of Dry Coal.					Cal. value dry coal
	Mine	Air Dried	Vol.	F.C.	Ash	C.	H.	N.	O.	S	B.T.U.
ellington seam Extension mine..	1.8	1.1	40.1	49.8	10.1	72.9	4.7	1.2	10.7	0.4	13,160
ouglas seam Nanaimo No.1 mine	2.2	1.6	41.2	48.5	10.3	72.1	4.8	1.2	10.7	0.9	12,830
ewcastle seam Nanaimo No.1 mine	2.4	1.9	41.5	46.6	11.9	69.0	4.6	1.2	12.0	1.3	12,470
omox seam Mines 4 and 7 Lower seam washed.	1.0	.....	30.8	60.3	8.9	77.6	4.6	1.1	7.0	0.8	13,590
uquash seam 6-ton sample	....	7.0	34.3	42.7	23.0	....	....	....	....	1.0	11,100
" washed	....	5.3	36.7	48.2	15.1	....	....	....	....	0.9	11,560
" , sampled by C.H.Clapp		5.63	37.27	42.07	13.85	60.73	4.67	1.18	18.30	1.18	

TABLE 9 MINERAL DEPOSITS AND OCCURRENCES

No.	Name	Class	References
1	Heart	G-2	
2	Power	F-1 ?	MMAR 1962-98
3	Little Lake	F-1 ?	MMAR 1961-100
4	Cordova	F-1 ?	MMAR 1962-103; GSC Mem. 272-60
5	Golden Portal, Golden Gate	G-8	MMAR 1938 F47; GSC Pap. 40-12-8; BCDM Zeballos 1938-5, Bull. 27-52
6	Tagore	G-8	MMAR 1924-223, 1925-269, 1929-376, 1932-205, 1933-252; GSC Mem. 204-17, SR 1932 A II-37, Pap. 40-12-8; BCDM Bull. 27-50
8	Privateer	G-8	MMAR 1948-157, 1961-100, 1964-154, 1967-74; GSC Mem. 204-13, Pap. 40-12-10; BCDM Bull. 27-58, Zeballos 1938-8
9	Prident	G-8	MMAR 1941-69, 1942-65, 1943-66; GSC Pap. 40-12-14; BCDM Bull. 27-13
10	White Star	G-8	MMAR 1935F-38, 1938F-68, 1939-87, 1940-72, 1957-68; GSC Mem.204-14; BCDM Zeballos 1938-13, Bull. 27-77; GSC Pap. 40-12-12
11	Zeballos Pacific, Golden Peak	G-8	MMAR 1938-F49; BCDM Bull. 27-80, Zeballos 1938-15, GSC Pap. 40-12-15
12	Mount Zeballos	G-8	MMAR 1938-F56; GSC Pap.40-12-17; BCDM Bull. 27-83
13	Goldfield, Roper	G-8	MMAR 1938-F68; 1939-87; 1940-72; 1941-70; 1942-65; GSC Mem.204-16; 272-62; BCDM Bull. 27-90; GSC Pap. 40-12-8
14	M Group, Britannia M	G-8	GSC Pap.40-12-20; BCDM Bull. 27-94
15	Lone Star	G-8	MMAR 1938-F57; BCDM Bull.17-97; Zeballos 1938-20; GSC Pap. 40-12-22
16	Rimy	G-8	MMAR 1938-F60; BCDM Bull.27-101; GSC Pap. 40-12-28
17	North Star	G-8	BCDM Bull.27-102; Zeballos 1938-19; GSC Pap. 40-12-26
19	Golden Horn	G-8	MMAR 1938-F52; BCDM Bull.27-113; GSC Pap. 40-12-35
20	King Midas # 1	G-8 (G-2)	MMAR 1932-205; 1933-253; 1934-F6; 1938-F53; BCDM Bull. 27-115; GSC SR 1932 A II-38; Pap. 40-12-30
21	North Fork	G-8	BCDM Bull. 27-117
22	Boden	G-8 ?	BCDM Bull. 27-119
23	Maquinna	G-8	BCDM Bull. 27-120
24	Omega	G-8	MMAR 1938-F60; BCDM Bull. 27-123
25	Peerless	G-8	BCDM Bull. 27-123
26	Pandora	G-8	MMAR 1947-181; BCDM Bull. 27-124
27	Cordova # 1	G-8	BCDM Bull. 27-124; GSC Mem. 272-60
28	F. L.	F-1	MMAR 1951-197; 1952-231; 1960-103; 1961-101; 1962-100; 1963-101; 1964-153; GEM1968-102; 1969-215; BCDM Bull. 27-125; GSC Mem. 272-86
29	Barnacle	G-8	BCDM Bull. 27-128; GSC Mem. 272-60
30	Lucky Strike	G-8	BCDM Bull. 27-131; GSC Mem. 272-59
31	Churchill	F-1	MMAR 1951-197; 1962-101; 1965-232; GSC Mem. 272-68 & Fig. 2, BCDM Bull. 27-132
32	Cavalier	F-1	BCDM Bull. 27-234

No.	Name	Class	References
33	Fil	G-8	MMAR 1946-177; 1947-180; 1955-78
34	Iron Crown; Nimpkish Iron	F-1	MMAR 1955-76; 1956-133; 1959-133; 1960-101; 1961-93; 1962-96; 1963-99; GSC SR 1929A-131; Mines Branch, Ottawa publ. 47-19
35	Old Sport	F-2 (F-1)	MMAR 1916-340; 1917-255; 1919-203; 1924-225; 1927-347; 1960-100; 1961-97; 1962-97; 1963-100; 1964-153; 1965-230; 1966-66; 1967-71; 1968-98; GEM 1969-207; 1970-273; 1971-319; GSC SR 1929A-113; SR1918B-33; Prelim. Map BCDM Alice Lake - Benson Lake;
36	Hazel, Nimpkish Copper	F-2	MMAR 1928-379; 1929-381; 1930-299; 1965-230; 1966-68; GEM 1970-273; GSC SR 1929A-127; SR 1931A-26; Mem. 272-71
37	Zip (Smith Copper)	F-2 (F-1,4)	MMAR 1929-382; 1931-172; GSC SR 1929A-130; SR 1931A-30;
38	Van Isle	G-8	MMAR 1935-F40; 1938-F81; GSC Mem. 204-16; Pap. 40-12-9; BCDM Zeballos 1938-6; Bull. 27-53
39	Goldspring	G-8	MMAR 1938-F65; BCDM Bull 27-118; GSC Pap. 40-12-32
40	Shamrock	F-1 (F-2)	MMAR 1960-99; 1961-97
41	Blackjack	F-1	MMAR 1960-99
42	Ajax	F-1	MMAR 1961-97
43	Summit	F-1	
44	Merry Widow	F-1 (F-2)	MMAR 1916-341; 1928-375; 1952-230; 1956-117; 1959-132; 1960-93; 1961-95; 1962-96; 1963-100; 1964-152; 1965-229; 1960-66; 1967-70; BCDM Prelim Map Alice Lake-Benson Lake; GSC SR 1929A-125
45	Kingfisher	F-1	MMAR 1952-228; 1956-117; 1959-132; 1960-96; 1961-95
46	Raven	F-1	MMAR 1960-97
47	Whiskey Jack	F-1	
48	Rambler	F-1	
49	Keystone	F-1	
50	Marten	F-1	
51	Snowline	F-1	
52	Yreka	F-2	MMAR 1904-245; 1916-337; 1955-76; 1953-167; 1964-154; 1965-228; 1966-65; 1967-70; GEM 1970-272; 1971-317; GSC SR 1918-B35; SR 1929A-124
53	Paystreak	G-2	MMAR 1903-195, 200
54	Quatsino King	G-2	MMAR 1904-245; 1906-H200; 1911-192; 1918-267; 1931-170; GSC Sr 1929A-133; SR 1918B-36
55	Alice Lake - Clancy	F-4	MMAR 1924-288; 1930-296; 1932-206; GEM 1969-207 BC Bur. Mines Bull. 1, 1932-135; GSC SR 1929A-135
56	June	F-2	MMAR 1903-201; 1916-341; 1930-296; 1931-170; 1929-378; GEM 1969-207; GSC E.G. Ser.#3, Vol. 1 - 239; SR 1929A-120
57	Victoria - Peerless	F-4	MMAR 1903-202; 1916-342; GEM 1969-207; GSC SR 1929A-138
58	Rainier	G-2 (F-4)	GEM 1969-208; BCDM Prelim. Map Alice Lake - Benson Lake; GSC SR 1929A-134 & 94
59	Blue Ox	G-2 (F-4)	GEM 1969-208; BCDM Prelim Map Alice Lake - Benson Lake; GSC SR 1929A-134
60	F.G.P., Copper King	F-2 ?	MMAR 1922-233; 1968-97; GSC SR 1929A-132
61	Caledonia	F-2 (F-1)	MMAR 1923-253; 1926-322; 1927-352; 1929-380;

No.	Name	Class	References
62	Bay 29,77 (Yankee Girl)	H-1 (G-2)	MMAR 1968-86 & Fig. 13; GSC SR 1929A-134
63	Dem (Rupert)	G-2 (C) ?	MMAR 1910-153; GEM 1969-205; 1970-267 & Fig.2? GSC SR-1929A-142
64	Woss Lake #4	G-2 (C?)	MMAR 1905-233
65	Woss Lake #2	G-2 (C?)	MMAR 1965-233
66	Woss Lake #1	F-1?	MMAR 1965-233
68	Artlish	F-1	MMAR 1962-103; 1966-73
69	H P H, Main & #1	F-4	MMAR 1930-297; 1931-271; 1936-F47; 1965-227; 1966-63; 1968-95; GEM 1970-283; GSC SR 1931A-3?
71	Haw, Princess	G-2 (C)?	MMAR 1916-343; GSC Mem. 23-129
72	Morris	K	MMAR 1920-198; GSC SR 1913-109 & 121
73	Larson	F-2?	MMAR 1929-382; GSC SR 1931A-33
74	Norman, Contact Creek (South Shore)	F-4	MMAR 1936-F52; 1965-227; 1966-64; 1968-95; GEM 1970=263; 1971-323
75	Sun, St. Claire	F-1 (F-4)	GSC SR 1931A-38
76	Rain, Dorlon	F-4	MMAR 1936-F52; 1966-64; GEM 1970-263
77	North Shore, Lake	F-2 (F-4)	MMAR 1936-F51; 1966-65; 1968-94; GEM 1971-323
78	Hep	H-1	MMAR 1966-64; 1967-68; 1968-95; GEM 1970-262; 1969-202; 1971-323
79	Laury, Anan	F-4	
80	Jay, Seal	C	MMAR 1921-237; GSC SR 1929A-138
81	IXL	G-8	MMAR 1946-179; 1947-181; BCDM Bull. 27-79
82	B. Group, Gold Creek, Britannia	G-8	BCDM Bull. 27-97; GSC Pap. 40-12-21
83	Monitor	G-8 (F-2?)	BCDM Bull. 27-114; GSC Pap. 40-12-34
84	IXL, L M	G-8	BCDM Bull. 27-79; GSC Pap. 40-12-26
85	Iron Queen, High Gill	F-1 ?	GEM 1970-272; GSC Ser. # 3 1926-236
86	Blue Bird, D. P.	F-1 (F-2)	MMAR 1903-194; 1906-199; 1968-97; GSC Ser. # 31926-238
87	Quatsino Iron Ore	M	MMAR 1903-202; 1907-149; 1916-295; GSC E.G. Ser. # 3-1, p. 242
88	Prince's	M	MMAR 1907-149; 1916-295; GSC E.G. Ser. 3-1, p. 243
89	Eagle, Sunrise	M ?	Mines Br. Pub. 47-18
90	Stuart	C	MMAR 1928-374
91	Independant, Benson Lake	F-2 (F-1)	MMAR 1928-375; 1959-132; GSC SR 1929A-126
92	White Quartz	G-2	MMAR 1903-H200; 1904-245; 1905-213
97	Magnet	F-1 (F-2)	GSC SR 1931A-32
98	Jean, North Shore	F-2	MMAR 1968-94; GEM 1971
99	Bay 21	H-1	MMAR 1966-65; GEM 1970-254 & 267
100	Scruter, Gold	G-2 (G-8)?	MMAR 1946-178
101	Eclipse	G-8	MMAR 1941-42; 1946-178; 1947-180
102	Snowbird	F-1	
107	Kas (Caledonia, Waterloo)	F-2 (F-1)	MMAR 1920-202; 1925-274; GEM 1969-215; GSC SR 1920A-21; E.G. Ser# 3 (1) - 247
109	Ingersol	F-1 ?	MMAR 1904-194; 1906-199; GSC E.G.3-238
110	Sea, Demerada	C	MMAR 1929-385
111	Kar, Marble Creek	C (G-2)	MMAR 1930-295; 1967-69; 1968-98
112	Minerva Fraction (Olga)	F-4 (F-1)	MMAR 1916-343; 1909-207

No.	Name	Class	References
113	Frances	F-2 (F-4)	MMAR 1959-132
114	Eagle	F-1 (F-2)	MMAR 1924-225
115	Dry Hill	F-2 ?	MMAR 1922-355; 1960-95, 96
116	Lucky Jim	F-2	MMAR 1918-270; 1928-378; 1929-383; BCDM Bull. 1932-136
117	Monteith	K	MMAR 1920-199 & map; GSC SR 1913-109
118	Hazel, Cypress	F-2 (F-4)	MMAR 1928-379; 1929-381; 1930-299; 1965-230; 1966-68; GEM 1970-273; GSC SR 1929A-127
121	Wolf, Storey	F-1 (F-2)	MMAR 1929-382; GSC SR 1931A-32
122	Magnet	F-1	MMAR 1956-133; 1958-72; GSC SR 1929A-131
123	Klaanch	F-1	MMAR 1902-236; 1916-300; 1956-133; GSC SR 1929A-131; Bull. 172-71
124	Welcome Home, Venture, Cracroft	G-2 (C?)	MMAR 1901-1116; 1917-450; 1926-313; GSC Mem. 23-129
125	Lucky Strike, G. Lone Star	G-2 (C?)	MMAR 1901-1115; GEM 1969-190; 1970-228; GSC Mem. 23-129
126	Copper Queen	G-2 (C?)	MMAR 1901-1105; GSC Mem. 23-129
127	Hiller	F-1	MMAR 1965-232; 1966-73
128.	Ridge	F-1	MMAR 1962-103; GSC Mem. 272-68; BCDM Bull. 27-128
129	Extension # 4	G-8	BCDM Bull. 27-129
130	Jack of Spades	F-2	MMAR 1933-253; BCDM Bull. 27-122; GSC SR 1932A II - 45
131	Expo 81, 202, Bowerman, Dictator	F-4 ?	MMAR 1919-205; 1922-232
132	Mac	F-1	
133	Martha	F-1	
134	Bob	F-1	MMAR 1967-71; 1968-100: GEM 1970-274
135	Bay # 56	H-1	MMAR 1966-65
136	Bay # 4	H-1	MMAR 1966-65; 1967-68; 1968-88; GEM 1969-204; 1970-267; Western Miner Feb. 71, p. 31
138	Bay No. 74	K	Western Miner Feb. 71, p. 31
140	Deb	C	MMAR 1968-91; GEM 1969-203
141	Walt	C	MMAR 1968-98; GEM 1970-270
142	Haw 26	C ?	GEM 1970-263
143	Haw 44	C	GEM 1970-263
144	Sinker	MMAR 1967-70	
145	Contact	F-1	
147	Rugged, King	F-2 (F-1)	GSC SR 1932A II -43
148	Nootka	G-8 (F-2)	GSC SR 1932A II - 44
149	Major, Zeballos Dome	F-1 (F-1)	GSC SR 1932A II - 44, pap. 40-12-36
154	Churchill	G-8	MMAR 1945-116; BCDM Bull. 27-134; GSC Mem. 272-69 & Fig. 2
155	Uebel, Fern Hill	G-2	MMAR 1961-100; 1964-154
157	Sonny, Climax	F-2	MMAR 1966-74; GSC Pap. 40-12-35
158	Bay, Island Copper	H-1	MMAR 1966-65; 1967-68; GEM 1969-204; 1970-267; 1971-230; Western Miner, Feb. 1971 - p. 31
159	Little Joe	F-2	MMAR 1963-99; 1968-90; GEM 1970-266
160	Rodd	H-1	MMAR 1968-88

No.	Name	Class	References
161	Bon	C	GEM 1969-209; 1970- 274
162	Haw 24	F-4 ?	GEM 1970-263
163	Rooney, Berna	C	GEM 1969-209
164	Bob 9, 10 (Bonanza)	F-2 (F-1)	MMAR 1967-71; 1968-100
165	Bayes 1, 3	G-2 (C)	MMAR 1967-72; 1968-100; GEM 1969-210; 1970-278; 1971-320
166	Boyes 4	G-2 (C)	MMAR 1967-72; 1968-100; GEM 1969-210; 1970-278; 1971-320
167	George	C	GEM 1969-210; 1970-278; 1971-320
168	Kevin	G-2	GEM 1969-210; 1970-278; 1971-320
169	Bruce	G-2	GEM 1971-320
170	Berna	C ?	GEM 1969-209
171	Bon	F-1?	GEM 1969-209; 1970-277
173	Har, Expo	C ?	GEM 1969-205; 1970-270
174	Kyu	G-2	GEM 1969-215
176	Brad	F-2	GEM 1969-206
180	Cam, Doc	C	GEM 1969-210; 1970-279
181	Mon, Ti	F-2 (F-4)	MMAR 1968-96; GEM 1969-201; 1970-262
182	RH	G-2	MMAR 1968-99; GEM 1969-206
183	Bon	F-1 ?	)
184	Bon	F-1?(F-2)	)
185	Bon	F-1?(F-2)	)
186	Bon	F-1	) GEM 1969-209; 1970-277
187	Bon	F-1 ?	)
188	Bon	F-1	)
189	Bon	C	GEM 1969-209; 1970-278
191	Jurr	F-2	GEM 1970-271; 1971-318
192	Mor	F-2 (F-4)	GEM 1970-264; 1971-322
193	Dia	F-4	GEM 1970-274
194	Haw	F-2	GEM 1970-263
195	Haw 15	C	GEM 1970-263
196	Haw 14	C	GEM 1970-263
197	Haw 34	C	GEM 1970-263
198	Wit	C	GEM 1970-263
199	Laura Lee	G-2	GEM 1970-284
200	Red Dog	H-1	MMAR 1967-69; 1968-96; GEM 1970-259
201	B.P.	G-2	
202	Easy	G-2 (C?)	
203	On	F-4	
204	B.W.	G-2 (C?)	
205	R	F-2	GEM 1971-317
206	East Hazel (Nimpkish Copper)	F-2 (F-4	MMAR 1928-379; 1929-381; 1930-299; 1965-230; 1966-68; GEM 1970-273; GSC SR 1929A-127; SR 1931A-26; Mem. 272-71
207	Copper Creek (Nimpkish Copper)	G-2	MMAR 1928-379; 1929-381; 1930-299; 1965-230; 1966-68; GEM 1970-273; GSC SR 1929A-127; 1931A-26; Mem. 272-71
209	Caledonia	F-1	MMAR 1929-380; 1968-88; GEM 1970-265; GSC SR 1929A-123

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210	Extension No. 4	G-8	BCDM Bull. 27-129
211	Goldfield, Spur	G-8	MMAR 1935-F39; 1938F-68; 1939-87; 1940-72; 1941-70; 1942-65; 1951-40; GSC Mem. 204-16; Mem. 272-62; BCDM Bull. 27-90; GSC Pap. 40-12-1[illegible]
212	Extension No. 6, Bibb, Central Zeballos Mine	G-8	MMAR 1938-F43; BCDM Bull. 27-104; Zeballos Area 1938-21; GSC Pap. 40-12-29
213	Extension No. 5	F-2 (F-1)	MMAR 1938-F-43; GSC Pap. 40-12-30
215	King Midas (Lynch Vein)	G-8	MMAR 1929-376; 1938-F56; BCDM Bull. 27-116
216	King Midas (Contact)	G-8	MMAR 1929-376; 1938-F56; BCDM Bull. 27-116; GSC SR 1932A II-40
217	King Midas (trail vein)	G-2	MMAR 1929-376; 1938-F56; BCDM Bull. 27-116
219	Millington, Rick	C	MMAR 1919-205; 1924-229; 1926-304; 1927-346; 1928-374; 1965-228; 1966-65; 1967-69; GEM 1969-201; GSC SR 1918B-36; SR 1929A-139 (map)
220	Ori	F-1 (F-4)	MMAR 1923-281; 1967-69
221	C.S. 6308	F-2 (F-1)	MMAR 1968-96; GEM 1969-200; 1970-258
222	C.S. 6422	C	MMAR 1968-96; GEM 1969-200; 1970-258
223	C.S. 495	G-2 ?	MMAR 1968-96; 1969-200; 1970-258
224	AAA # 6	C	
225	AAA # 48	C	
226	Kains	G-2 (?)	GEM 1969-206
227	Aird	G-2 (?)	GEM 1969-200
228	Lois	G-2 (?)	GEM 1970-283; 1971-317
229	Davis	G-2 (C)?	
230	Les	G-2 (?)	
231	Blue 1	C	MMAR 1968-98
232	Blue 2	C	MMAR 1968-98
233	Blue 44	C	MMAR 1968-98
234	Ecila	C	
235	Star	H-1(?)	MMAR 1968-99; GEM 1969-206
236	Tuscarora	F-4	MMAR 1953-169
237	Ruf	F-2 (?)	
238	W M	G-2	MMAR 1968-97
239	A	F-4 (F-2)	GEM 1970-263; 1971-321
240	Expo	H-1	MMAR 1968-96; GEM 1969-202; 1970-262; 1971-322
246	C S 1801, 1809, 1910	F-2 (F-1)	
247	Hol	C	
249	Billy	C	
250	Tony	G-2	
251	Brooks	F-2	
252	I	C	
253	Rain	F-4 ?	

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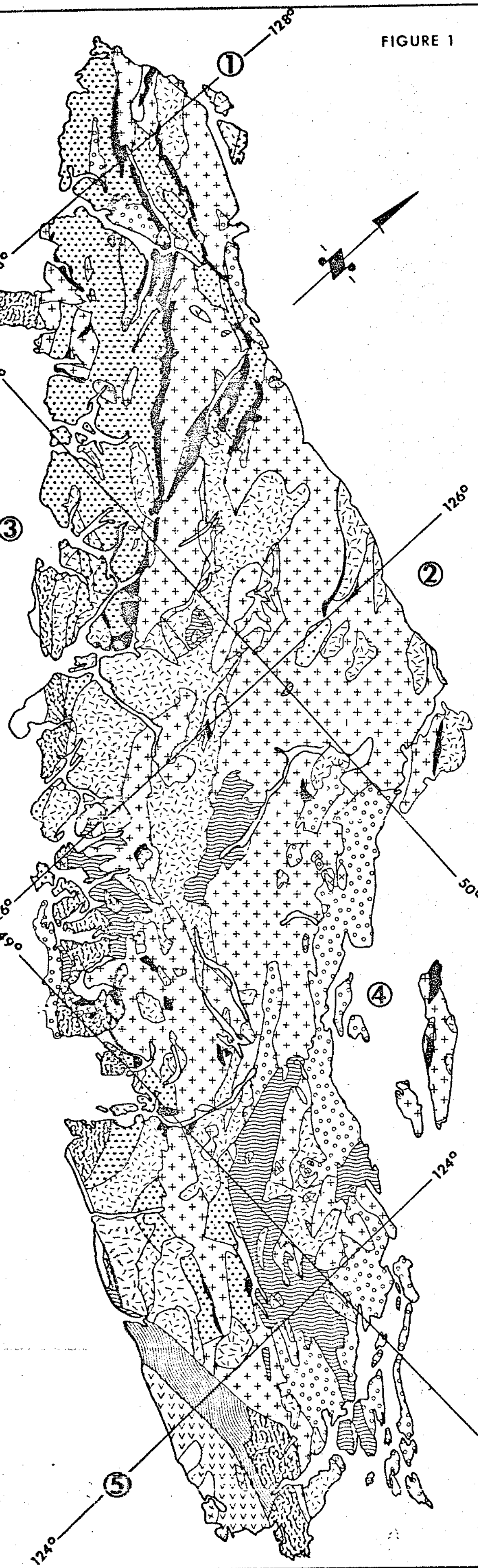
FIGURE 1

INDEX OF GEOLOGICAL MAPPING ON VANCOUVER ISLAND



LEGEND

	TERTIARY SEDIMENTS	MIDDLE TERTIARY
× × ×	TERTIARY INTRUSIONS	EARLY TO MIDDLE TERTIARY
V V V	TERTIARY VOLCANICS	EARLY TERTIARY
	LATE MESOZOIC SEDIMENTS	LATE JURASSIC TO CRETACEOUS
	LEECH RIVER SCHIST	JURA-CRETACEOUS?
	ISLAND INTRUSIONS	JURASSIC
	BONANZA SUBGROUP	EARLY JURASSIC
	QUATSINO, PARSON BAY FORMATIONS	LATE TRIASSIC
+ + +	KARMUTSEN FORMATION	TRIASSIC
	SICKER GROUP	LATE PALEOZOIC
	METAMORPHIC COMPLEX	JURASSIC OR OLDER

① ALERT BAY-CAPE SCOTT, 92 L - 102 I (PRESENT PAPER)

② BUTE INLET, 92K (IN PREPARATION)

③ NOOTKA SOUND, 92 E (IN PREPARATION)

④ ALBERNI, 92 F (G.S.C. PAPER 68-50)

⑤ VICTORIA, 92 B, C (FIELD WORK IN PROGRESS)

MILES
0 20 40

RELATIONSHIPS OF FORMATIONS OF VANCOUVER ISLAND

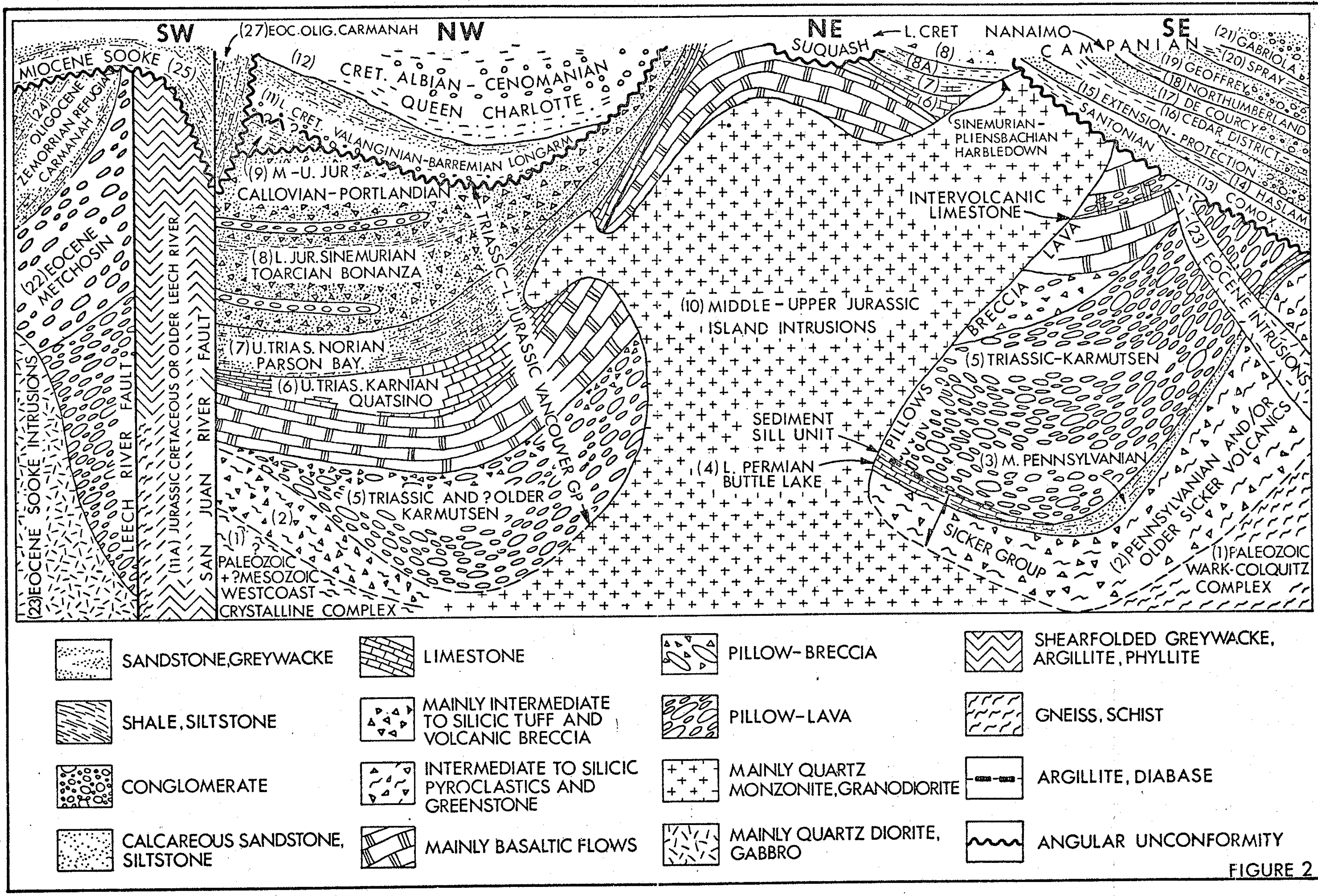
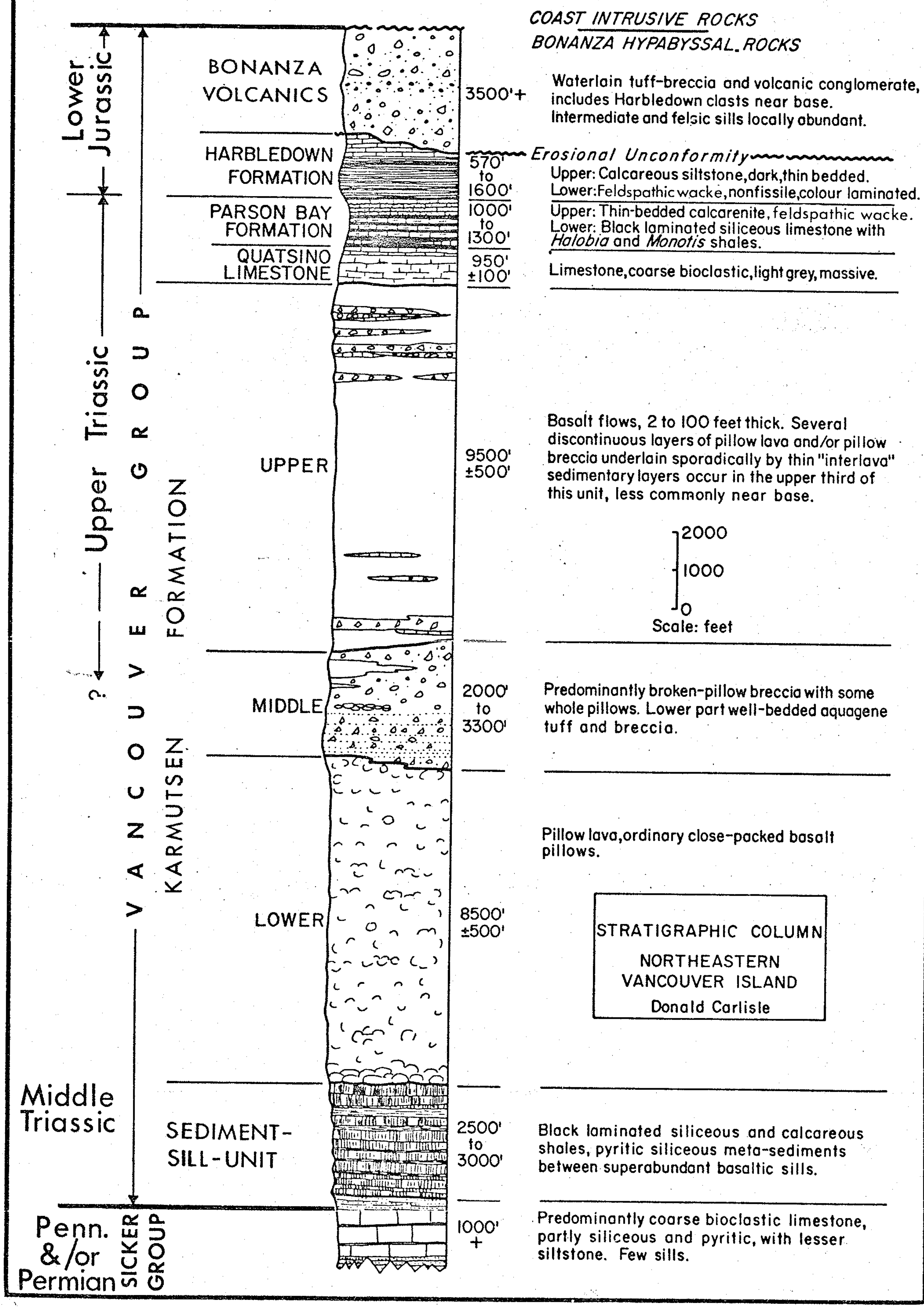
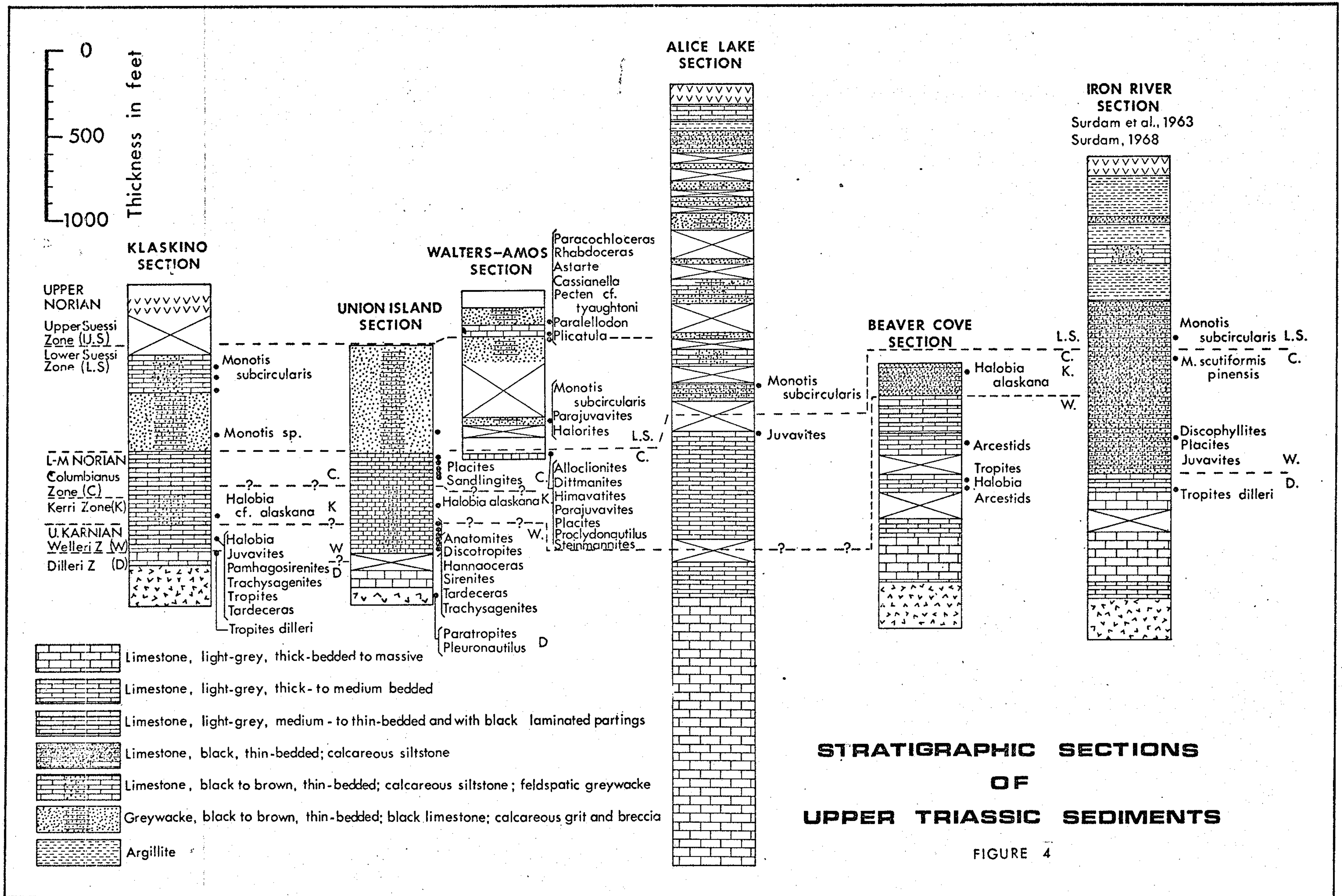


FIGURE 2

Figure 3



COAST INTRUSIVE ROCKS
BONANZA HYPABYSSAL ROCKS
Lower Jurassic
Upper Triassic
?
Middle Triassic
Penn. &/or Permian
VANCOUVER GROUP
SICKER GROUP
KARMUTSEN FORMATION
BONANZA VOLCANICS
3500'+
Waterlain tuff-breccia and volcanic conglomerate, includes Harbledown clasts near base. Intermediate and felsic sills locally abundant.
Erosional Unconformity
HARBLEDOWN FORMATION
570' to 1600'
Upper: Calcareous siltstone, dark, thin bedded.
Lower: Feldspathic wacke, nonfissile, colour laminated.
PARSON BAY FORMATION
1000' to 1300'
Upper: Thin-bedded calcarenite, feldspathic wacke.
Lower: Black laminated siliceous limestone with Halobia and Monotis shales.
QUATSINO LIMESTONE
950' ±100'
Limestone, coarse bioclastic, light grey, massive.
UPPER
9500' ±500'
Basalt flows, 2 to 100 feet thick. Several discontinuous layers of pillow lava and/or pillow breccia underlain sporadically by thin "interlava" sedimentary layers occur in the upper third of this unit, less commonly near base.
2000
1000
0
Scale: feet
MIDDLE
2000' to 3300'
Predominantly broken-pillow breccia with some whole pillows. Lower part well-bedded aquagene tuff and breccia.
LOWER
8500' ±500'
Pillow lava, ordinary close-packed basalt pillows.
STRATIGRAPHIC COLUMN
NORTHEASTERN VANCOUVER ISLAND
Donald Carlisle
SEDIMENT-SILL-UNIT
2500' to 3000'
Black laminated siliceous and calcareous shales, pyritic siliceous meta-sediments between superabundant basaltic sills.
1000' +
Predominantly coarse bioclastic limestone, partly siliceous and pyritic, with lesser siltstone. Few sills.



STRATIGRAPHIC SECTIONS OF UPPER TRIASSIC SEDIMENTS

FIGURE 4

Upper Triassic and Lower Jurassic fossil localities and stratigraphic sections

FIGURE 5

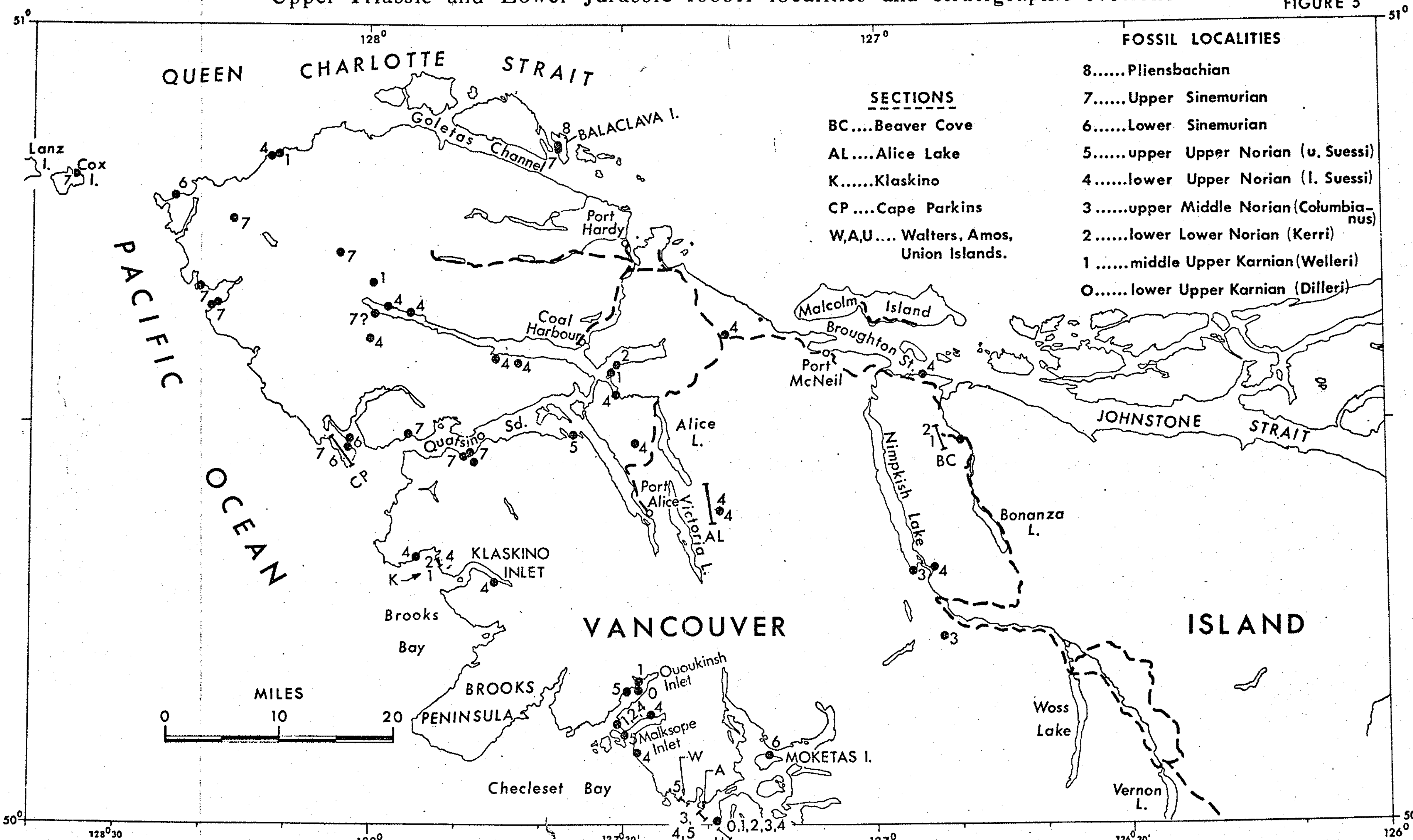
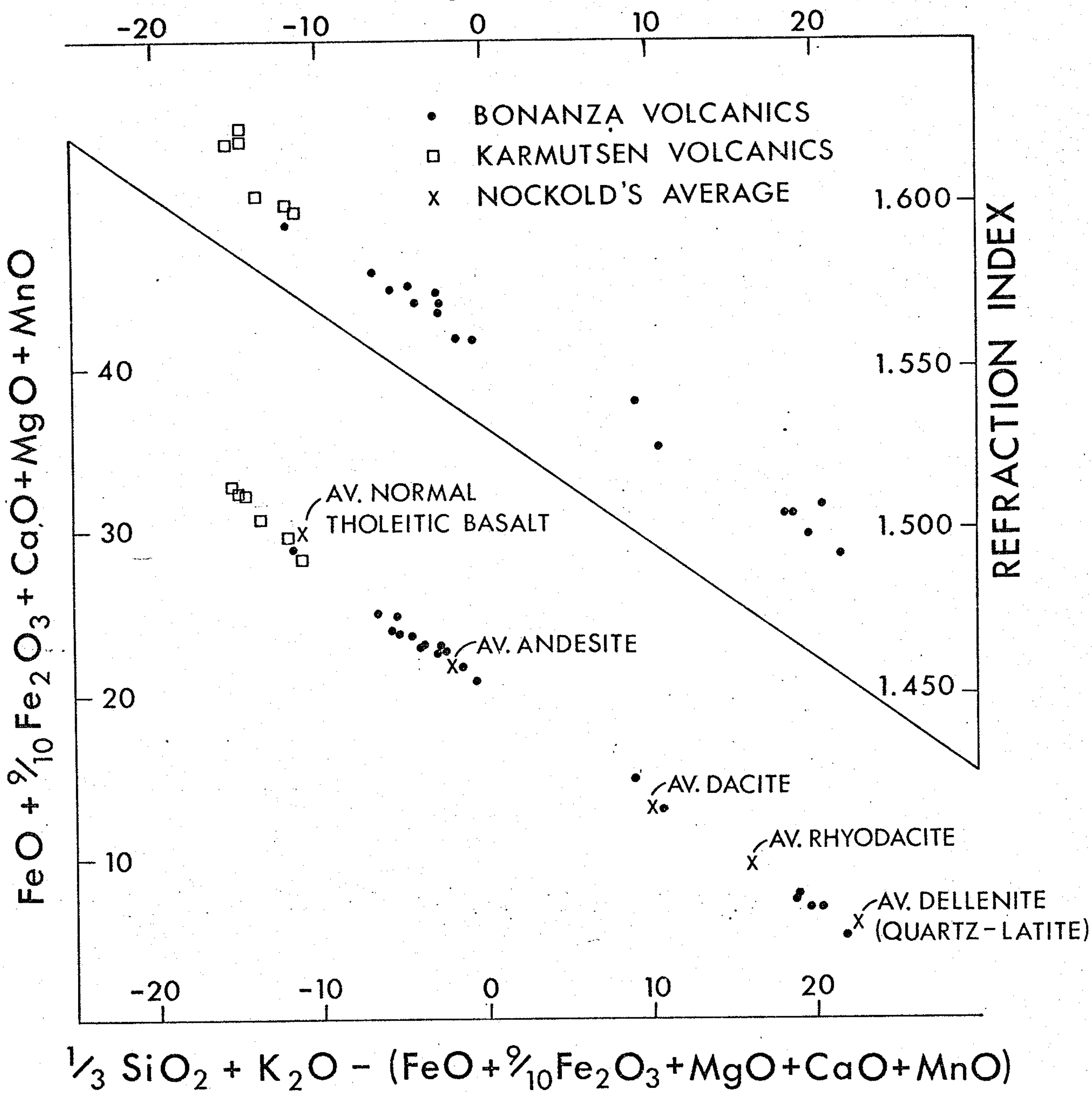


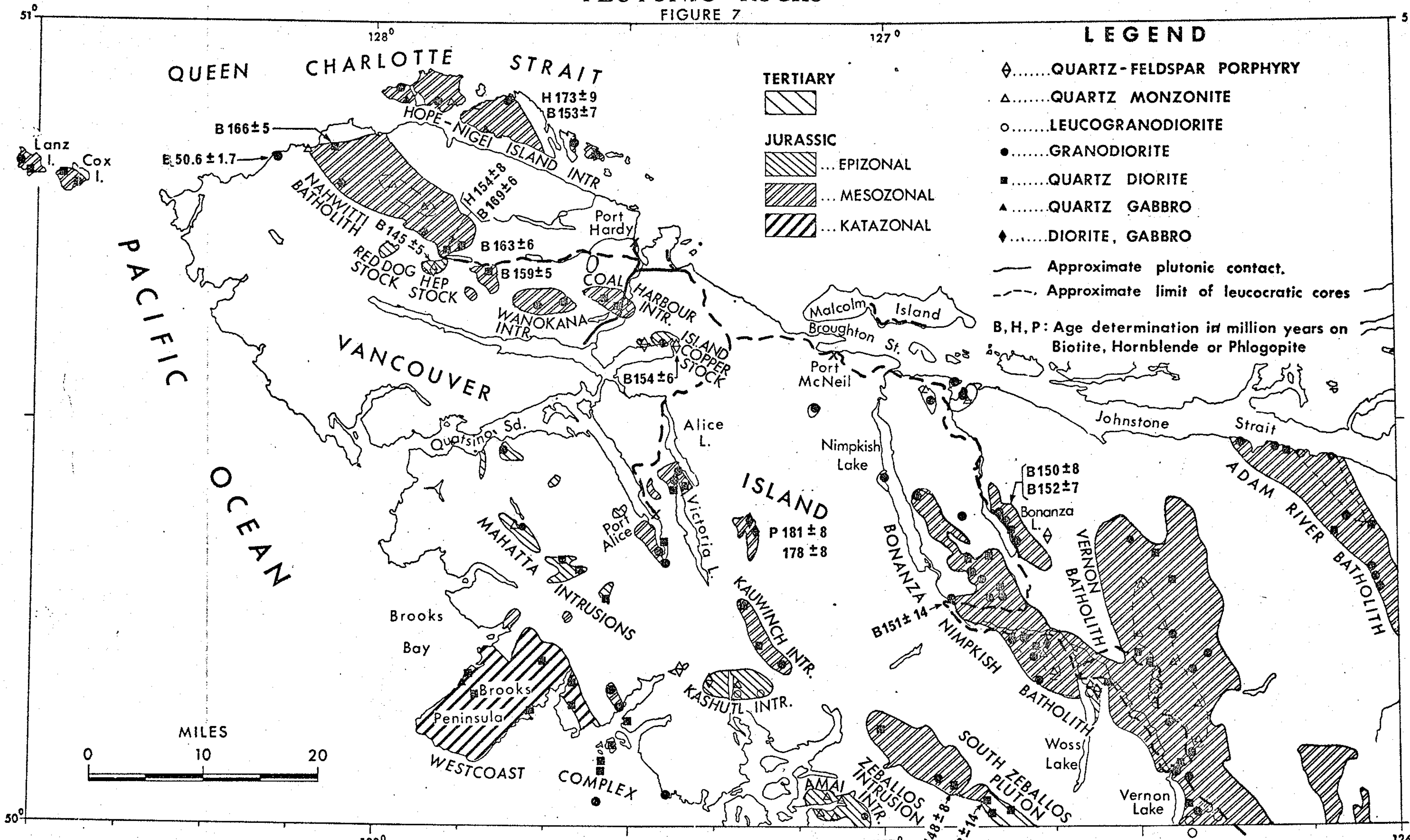
Figure 6



-20
-10
0
10
20
• BONANZA VOLCANICS
□ KARMUTSEN VOLCANICS
X NOCKOLD'S AVERAGE
1.600
1.550
1.500
1.450
REFRACTION INDEX
40
30
20
10
FeO + 9/10 Fe2O3 + CaO + MgO + MnO
AV. NORMAL THOLEITIC BASALT
AV. ANDESITE
AV. DACITE
AV. RHYODACITE
AV. DELLENITE (QUARTZ-LATITE)
-20
-10
0
10
20
1/3 SiO2 + K2O - (FeO + 9/10 Fe2O3 + MgO + CaO + MnO)

PLUTONIC ROCKS

FIGURE 7



Cretaceous fossil localities

FIGURE 8

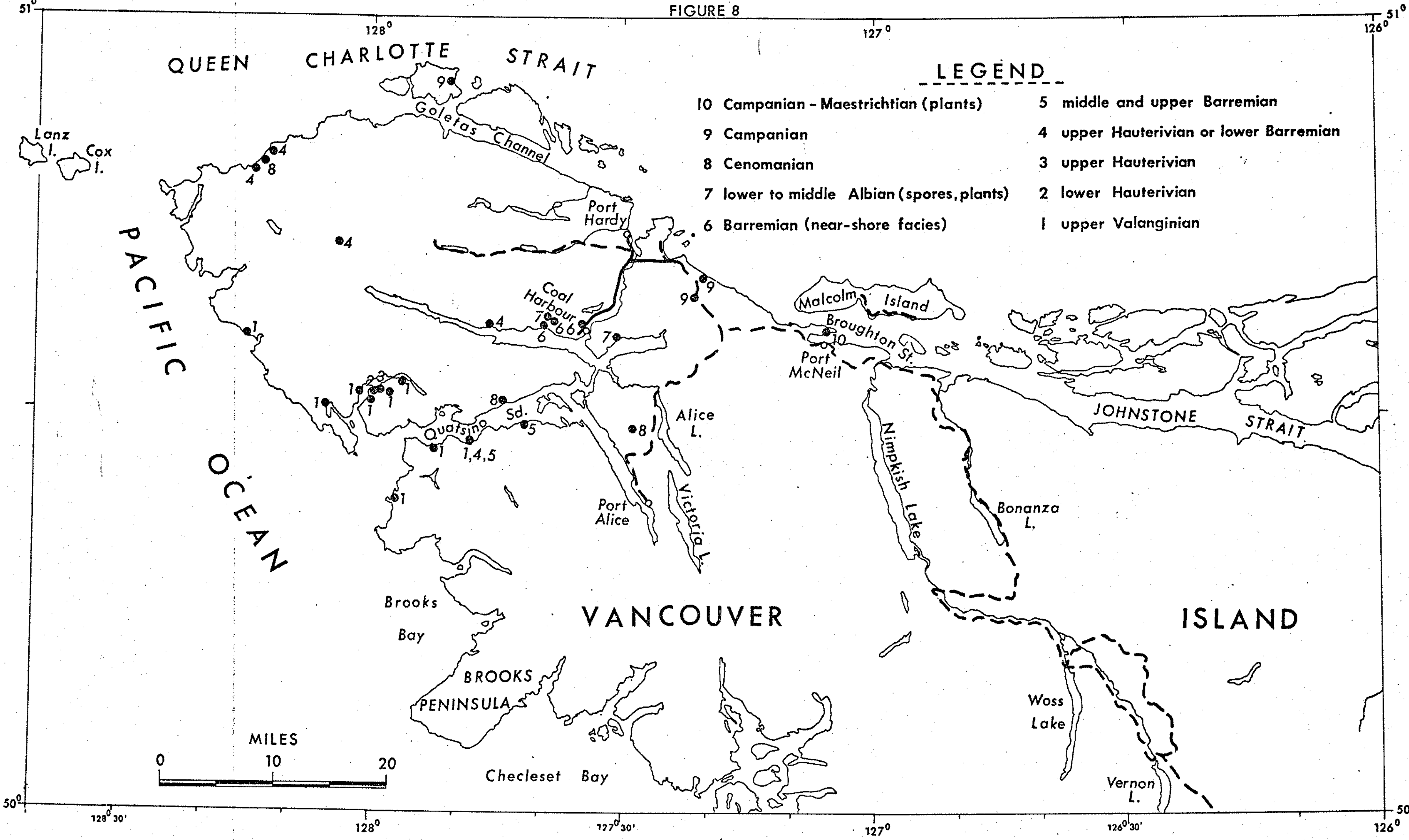


Figure 9 BIOCHRONOLOGICAL AND LITHOLOGICAL DIVISIONS OF NANAIMO GROUP

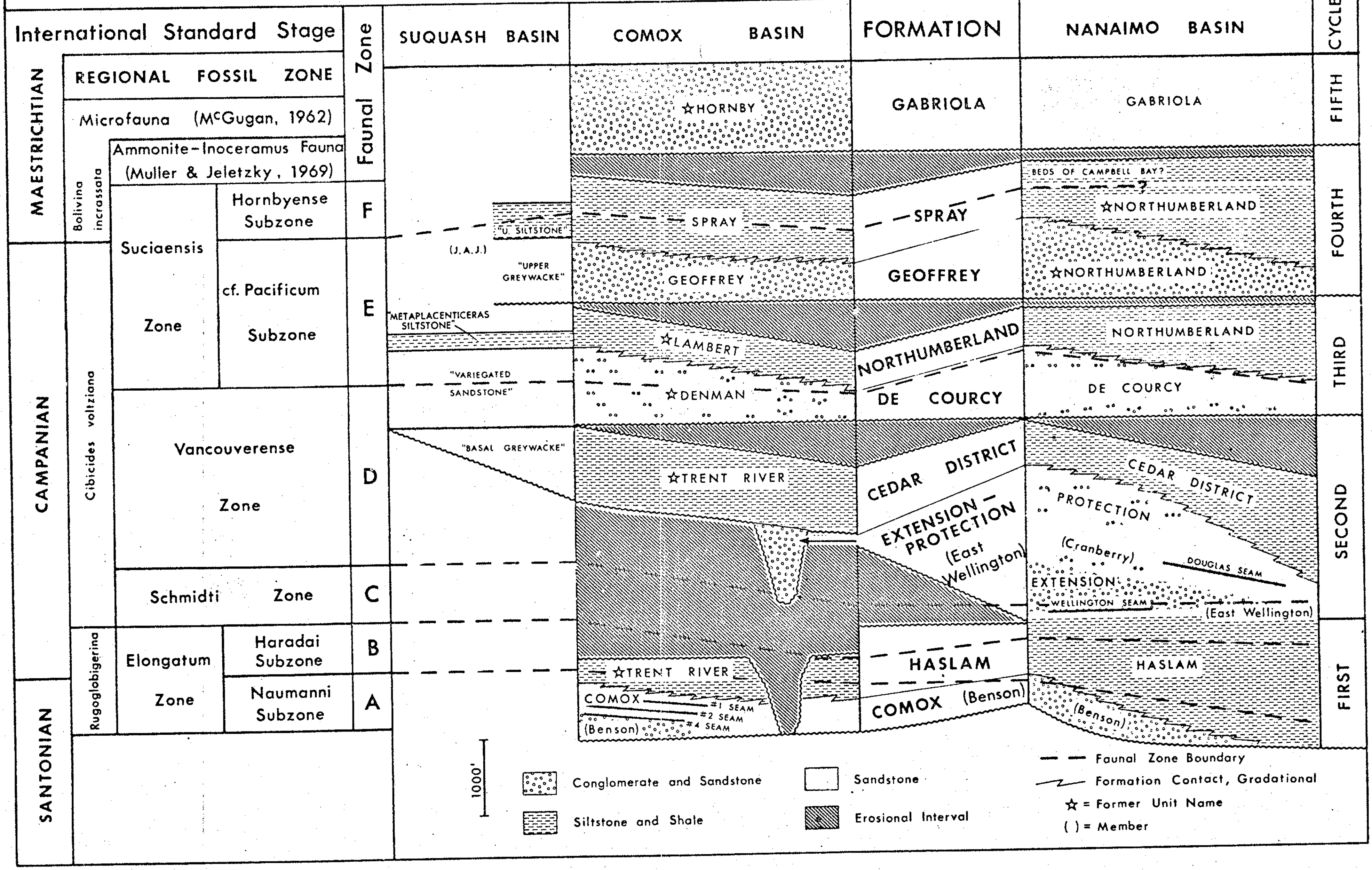
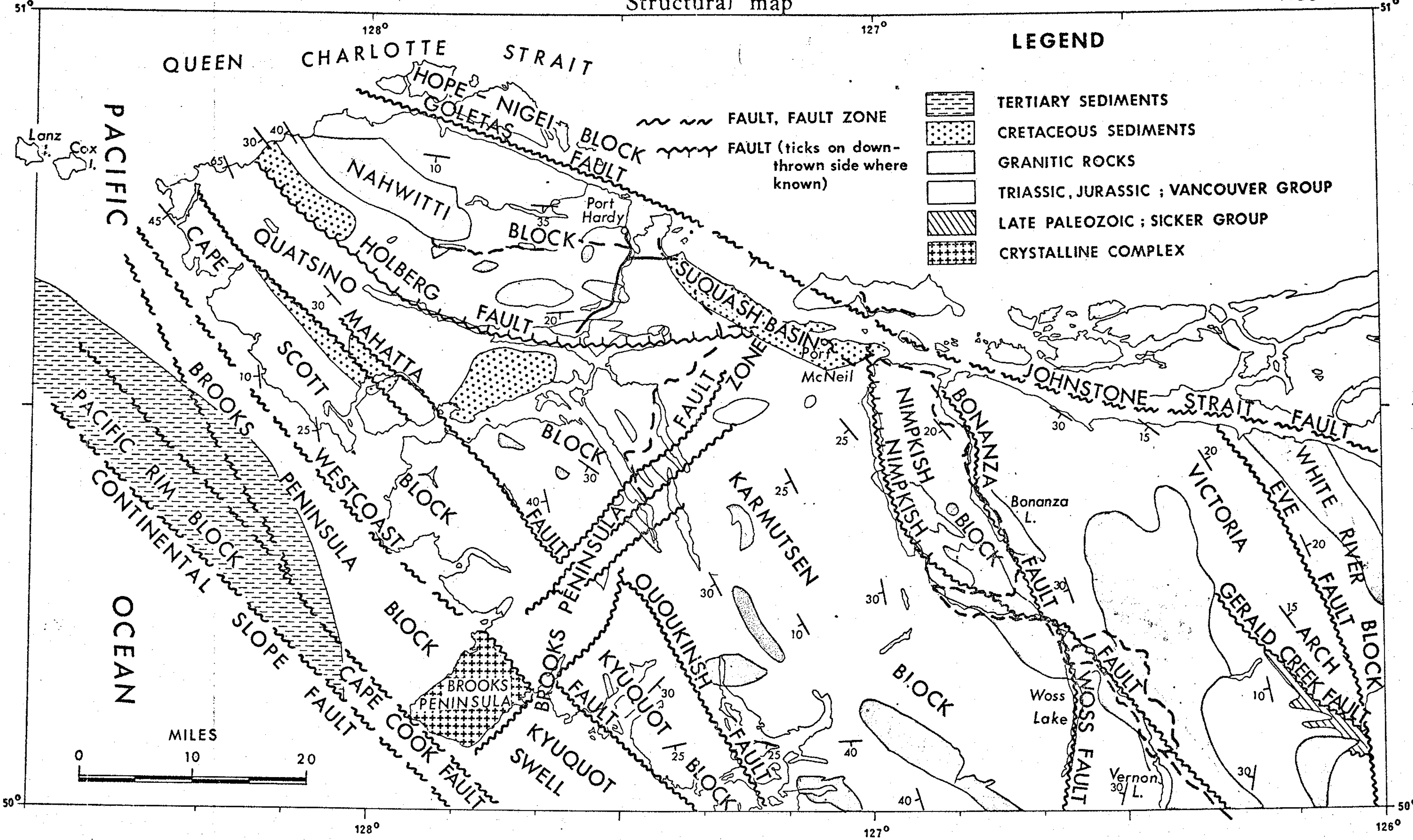


FIGURE 10

Structural map



GEOLOGICAL EVOLUTION, CROSS-SECTION KYUQUOT TO JOHNSTONE STRAIT

FIGURE 11

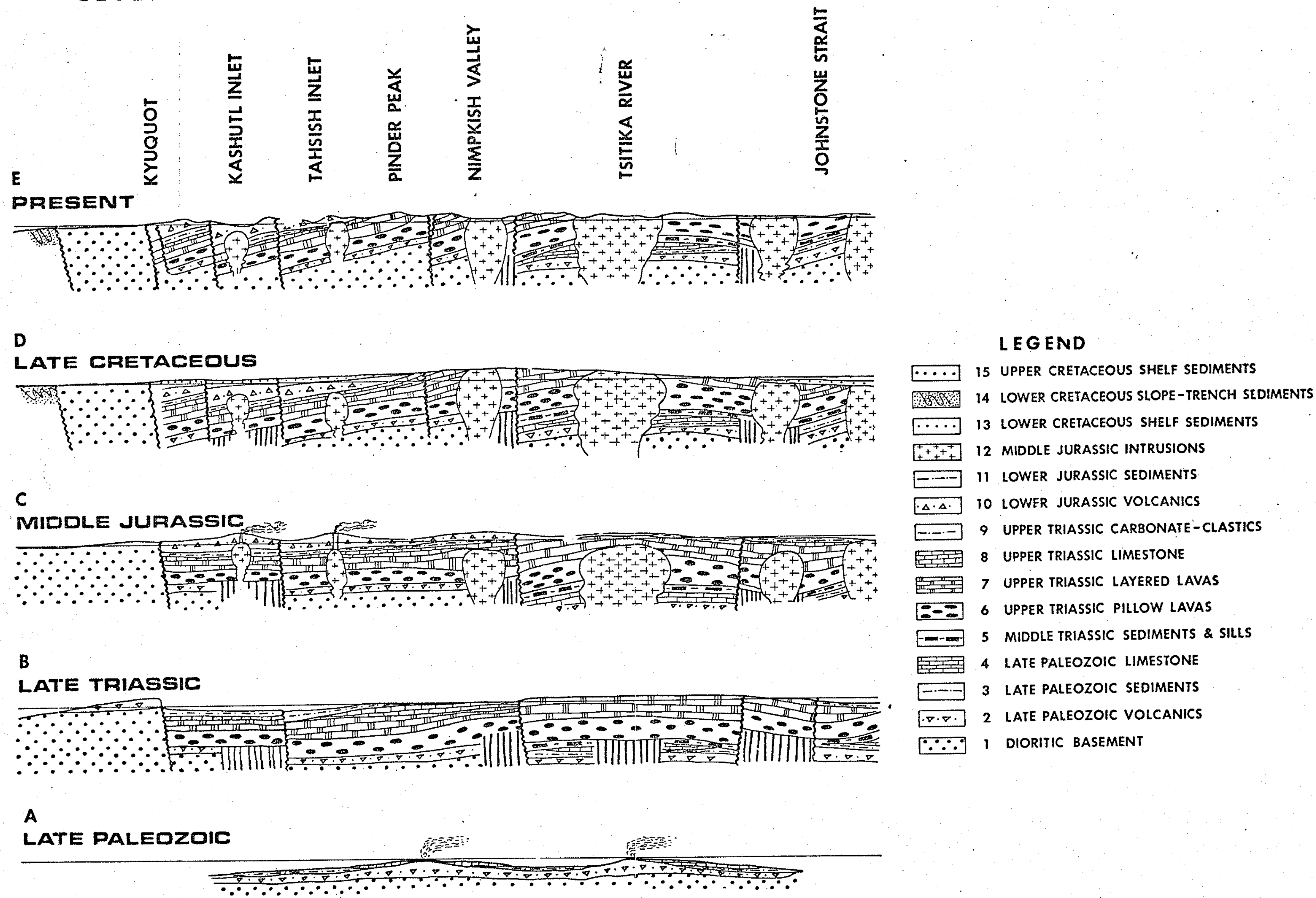
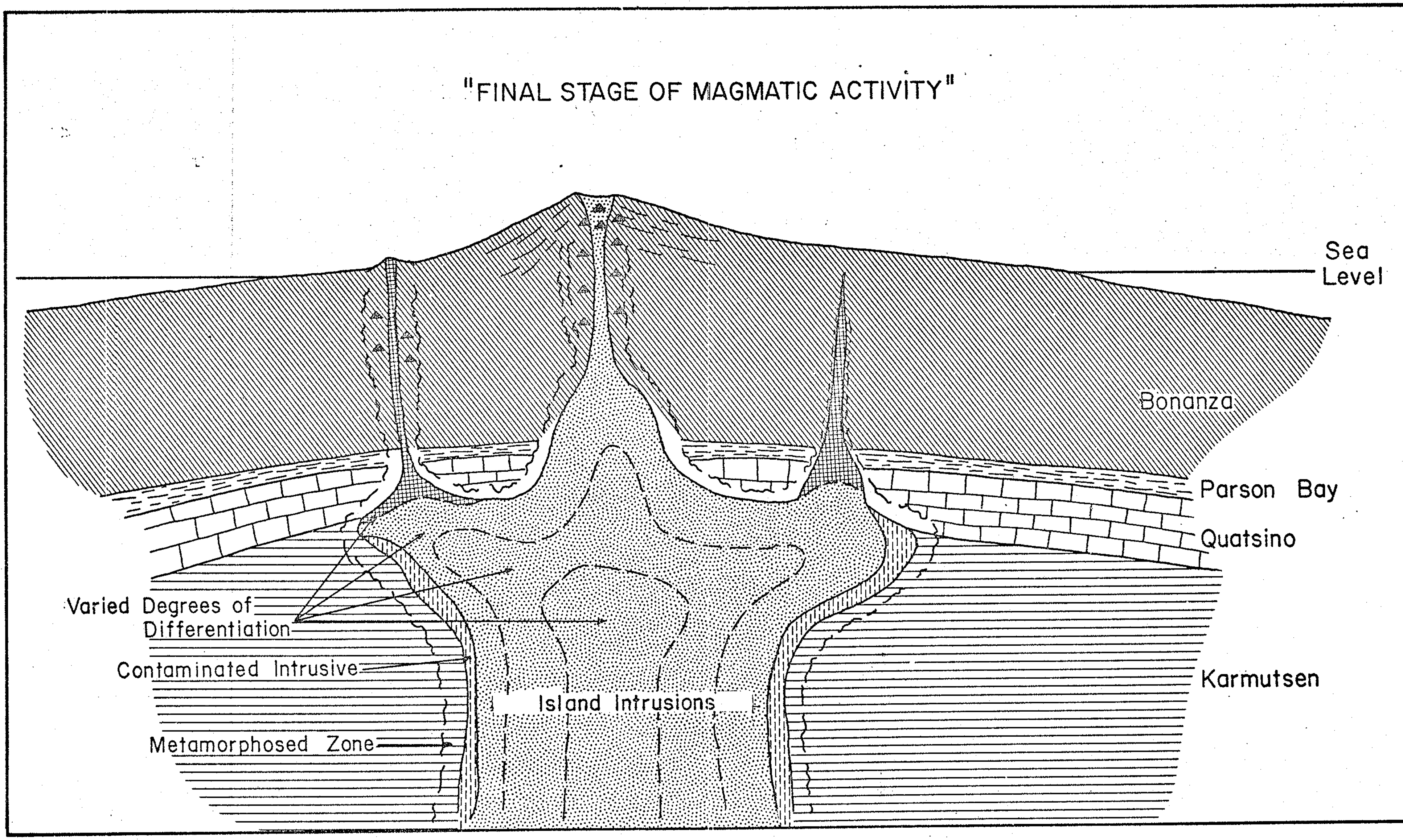
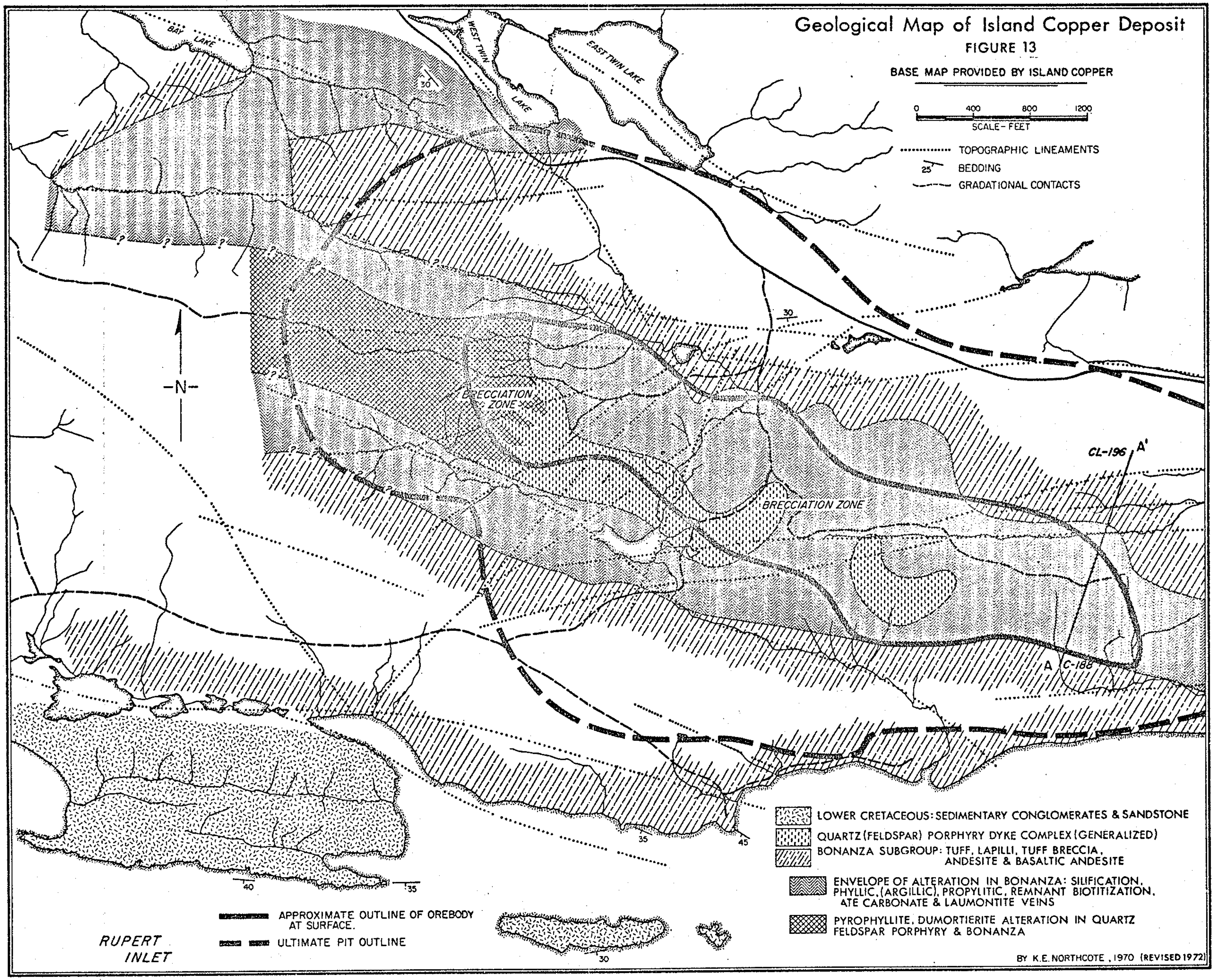


FIGURE 12 COMAGMATIC RELATIONSHIPS BETWEEN ISLAND INTRUSIONS & BONANZA VOLCANICS




Geological Map of Island Copper Deposit
FIGURE 13
BASE MAP PROVIDED BY ISLAND COPPER
0 400 800 1200
SCALE - FEET
TOPOGRAPHIC LINEAMENTS
25 BEDDING
GRADATIONAL CONTACTS
BAY LAKE
WEST TWIN LAKE
EAST TWIN LAKE
-N-
BRECCIATION ZONE
BRECCIATION ZONE
CL-196
A'
A
C-188
RUPERT INLET
LOWER CRETACEOUS: SEDIMENTARY CONGLOMERATES & SANDSTONE
QUARTZ (FELDSPAR) PORPHYRY DYKE COMPLEX (GENERALIZED)
BONANZA SUBGROUP: TUFF, LAPILLI, TUFF BRECCIA, ANDESITE & BASALTIC ANDESITE
ENVELOPE OF ALTERATION IN BONANZA: SILIFICATION, PHYLLIC, (ARGILLIC), PROPYLITIC, REMNANT BIOTITIZATION, ATE CARBONATE & LAUMONTITE VEINS
PYROPHYLLITE, DUMORTIERITE ALTERATION IN QUARTZ FELDSPAR PORPHYRY & BONANZA
APPROXIMATE OUTLINE OF OREBODY AT SURFACE.
ULTIMATE PIT OUTLINE
BY K.E. NORTHCOTE, 1970 (REVISED 1972)

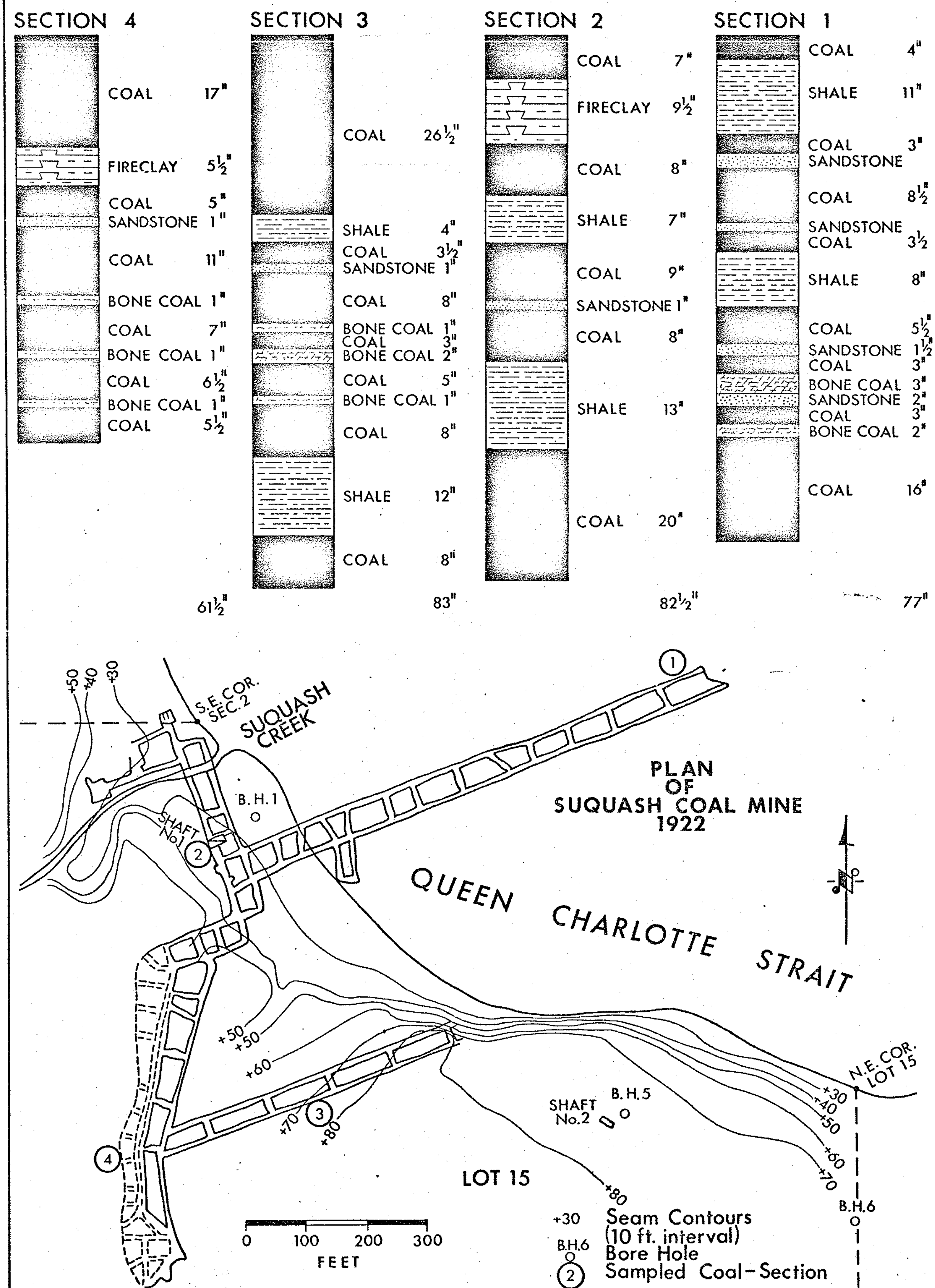

SECTION 4
COAL 17"
FIRECLAY 5½"
COAL 5"
SANDSTONE 1"
COAL 11"
BONE COAL 1"
COAL 7"
BONE COAL 1"
COAL 6½"
BONE COAL 1"
COAL 5½"
61½"
SECTION 3
COAL 26½"
SHALE 4"
COAL 3½"
SANDSTONE 1"
COAL 8"
BONE COAL 1"
COAL 3"
BONE COAL 2"
COAL 5"
BONE COAL 1"
COAL 8"
SHALE 12"
COAL 8"
83"
SECTION 2
COAL 7"
FIRECLAY 9½"
COAL 8"
SHALE 7"
COAL 9"
SANDSTONE 1"
COAL 8"
SHALE 13"
COAL 20"
82½"
SECTION 1
COAL 4"
SHALE 11"
COAL 3"
SANDSTONE
COAL 8½"
SANDSTONE
COAL 3½
SHALE 8"
COAL 5½"
SANDSTONE 1½"
COAL 3"
BONE COAL 3"
SANDSTONE 2"
COAL 3"
BONE COAL 2"
COAL 16"
77"
PLAN OF SUQUASH COAL MINE 1922
QUEEN CHARLOTTE STRAIT
SUQUASH CREEK
S.E. COR. SEC. 2
B.H. 1
SHAFT No. 1
SHAFT No. 2
B.H. 5
B.H. 6
N.E. COR. LOT 15
LOT 15
+30 +40 +50 +60 +70 +80
0 100 200 300
FEET
+30 Seam Contours (10 ft. interval)
B.H.6 Bore Hole
② Sampled Coal-Section

FIGURE 14