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Tertiary Mineral Deposits of Vancouver Island

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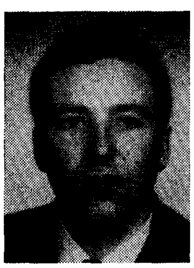
ABSTRACT

The metalliferous deposits of Vancouver Island have generally been assigned to the Mesozoic "Coast Range Orogeny." However, a metallogenic study by the writer has revealed that several important classes are early or middle Tertiary. Included are porphyry coppers, and gold-quartz, arsenic and copper-arsenic veins.

The porphyry coppers and many gold-quartz veins are within and adjacent to Oligocene-Eocene quartz diorite intrusive complexes. Arsenic and copper-arsenic veins have a close spatial relationship to sills and laccoliths of Oligocene dacite porphyry which intrude the late Cretaceous Nanaimo Group.

Other deposits of demonstrable Tertiary age include a molybdenum stockwork related to a relatively potassic Eocene plug and a few small copper-skarn occurrences. Some copper stockworks and a mercury deposit are probably also Tertiary.

The copper deposits of previously recognized Tertiary age are those of the Sooke area that occur in Eocene basalts and Oligocene gabbros.



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Dr. Carson has carried out geological mapping work and metallogenic studies with the GSC in Ontario and British Columbia. He then joined Noranda Exploration Company Limited in July, 1967, in British Columbia. In his present capacity as research geologist, he is now working out of Toronto doing geological work in Canada and the United States.

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INTRODUCTION

DURING THE COURSE OF A METALLOGENIC STUDY of Vancouver Island sponsored by the Geological Survey of Canada (Carson, 1968), the writer found that many of the mineral deposits generally believed to have formed during the Mesozoic "Coast Range Orogeny" are of early to middle Tertiary age.

The previously recognized Tertiary deposits are near Sooke (Clapp and Cooke, 1917; Fyles, 1949) and Mount Washington (Carson, 1960). The deposits of these two areas are in rocks of Tertiary (Sooke) and late Cretaceous and Tertiary (Mount Washington) ages. In most other areas of Vancouver Island, host rocks for the mineral deposits are late Paleozoic, Triassic or Jurassic and, in almost all cases, the deposits were believed to have formed from solutions emanating from granitic intrusions emplaced during the "Coast Range Orogeny."

The metallogenic project involved studies of both mineable deposits and "showings." They were classified on the basis of metal content, mineralogy, structures, host rocks and, where applicable, the petrography of related intrusions. Potassium-argon age determinations were very useful for indirectly dating some deposits by yielding the ages of gangue minerals or of related intrusions. The data for these age determinations have been published by the Geological Survey of Canada (Wanless *et al.*, 1967, 1968). The seven Tertiary determinations referred to in this paper were made on single specimens of granitic intrusions from widespread localities. The Tertiary age of all seven intrusions is supported by chemical and petrographic data (Carson, 1968), and in two cases the ages are confirmed by intrusive relationships.

The writer would like to express much appreciation to J. E. Muller of the Geological Survey of Canada, who is currently doing regional mapping on Vancouver Island, and who supplied geological information and aid in the field. E. Leigh Scales of Noranda Exploration Company, Limited kindly prepared the figures for publication.

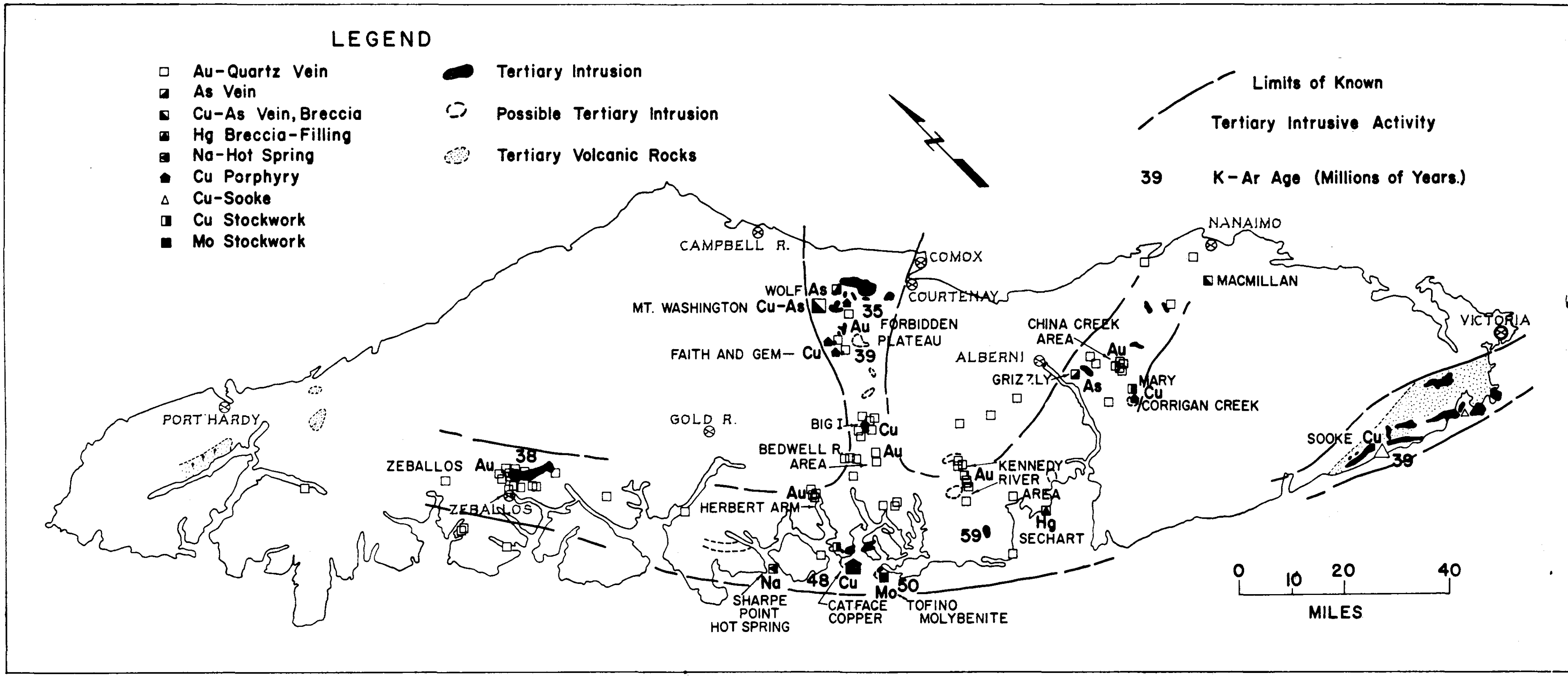

Figure 1.—Known and Probable Tertiary Mineral Deposits and Zones of Tertiary Intrusive Activity.

ARSENIC VEINS

Two arsenic-carbonate veins, the Grizzly and Wolf deposits, occur on Vancouver Island (*Figure 1*). Neither has been mined, but the Grizzly has yielded some native arsenic samples for mineralogical collections. Their main characteristics are given in Table I.

Both arsenic deposits are in steeply dipping brecciated fault zones and have close spatial relationships with Tertiary dacite porphyry sills or laccoliths intruding sedimentary rocks of the late Cretaceous Nanaimo Group. Grizzly is Tertiary, because it occurs in argillites assigned to the Nanaimo Group (Muller, 1964). Wolf (*Figure 2*) is probably Tertiary (Gunning, 1931) because of its spatial relationship to Tertiary dacite porphyry and its proximity to Mt. Washington, which is the locus of much Tertiary mineralization (Carson 1960; 1968).

COPPER-ARSENIC DEPOSITS

Three distinguishing features of the two known members of this class, Mt. Washington Copper and Macmillan (Table I), are the copper-arsenic content, the exotic mineralogy and their occurrence near the unconformity between the Triassic Karmutsen basalts and late Cretaceous sedimentary rocks of the Nanaimo Group.

The Mt. Washington Copper orebody is a gently dipping tabular body of quartz and sulphides deposited in a fault or sheeted zone. It partly follows the contact between Upper Cretaceous sedimentary rocks and a Tertiary dacite porphyry sill. Chalcopyrite is the most important constituent of the ore, but the deposit contains numerous other minerals including chalcostibite and the rare bismuth telluride, wehrlite (Table I). The copper-arsenic orebody is stratigraphically a few hundred feet above the Karmutsen-Nanaimo un-

Table I — Characteristics of Arsenic and Copper-Arsenic Deposits of Vancouver Island

Deposits	Metals, Tenor	Mineralogy, Textures (important newly-reported minerals in bold face)	Textures, Physical Forms	Host Rocks, Associated Rocks	Alteration	Structural Controls	Main References
ARSENIC VEINS — **Grizzly**	As; negligible Au, Ag.	Native As, arsenopyrite, carbonate, quartz.	Arsenopyrite stringers, disseminations and native As "kidneys" in veins up to 2′ wide, 50′ — 60′ long.	Argillites of the Nanaimo Gp., Tertiary dacite porphyry sills nearby.	Limited carbonatization and silicification of wallrocks.	Vertical fracture or fault with brecciated wallrocks.	Laanela (1964) Muller (1964)
Wolf	As	Realgar, arsenopyrite; minor native As; calcite, quartz.	Realgar masses up to 4′ x 9″, lenses of calcite up to 6′ wide, stringers of arsenopyrite, all in steeply dipping veins 2′-12′ wide and 250′ long.	Andesite of Karmutsen Fm. Nanaimo Gp. sediments and Tertiary dacite porphyry sill nearby.	as for Grizzly	Steeply-dipping brecciated fault.	Hurst (1927) Gunning (1931)
COPPER-ARSENIC VEIN, BRECCIA ZONE, — **Mt. Washington Copper**	Cu 1.40%; As apprec. Au 0.015 oz/ton Ag 1.20 oz/ton	Abundant quartz and minor calcite, dolomite with main ore minerals chalcopyrite, pyrrhotite, pyrite, arsenopyrite, realgar. Minor orpiment, bornite, tetrahedrite, molybdenite, marcasite, sphalerite, magnetite, galena, chalcocite, covellite, **native arsenic,** malachite. Rare hessite, wehrlite, **native Au, chalcostibite,** molybdite, Cu.	Nearly-horizontal quartz-filled vein or sheeted zone 250′ x 600′ x 7′—15′. Sulphides are in quartz and also replace wallrocks. Banded, crustiform, vuggy, brecciated.	Argillite and quartzite of Nanaimo Gp. and Tertiary dacite porphyry sills, and dykes near border of quartz diorite stock.	Intense silicification of wallrocks.	Nearly flat-lying fracture or sheeted zone, possibly a fault. Located near Nanaimo-Karmutsen unconformity, a zone of weakness. Nanaimo sediments and dacite sills may have been impermeable cappings.	Carson (1960) deVoogd (1964) McKechnie (1961b) Carson (1968)
Macmillan	Cu < 1% As < 1% Au and Ag = trace	Abundant calcite, quartz, with bornite, tetrahedrite, covellite. chalcocite, **corynite.** Very minor chalcopyrite, hematite, native As (?)	Breccia zone 335′ x 60′ surface area but unknown depth or origin. Ore minerals dissem. or in veinlets in the breccia. Bornite intergrown with tetrahedrite. Chalcopyrite blades in bornite.	Siliceous calcareous breccia zone in Karmutsen andesite. Contains porphyritic fragments (Tertiary dacite ?) in sheared crushed rock. Nanaimo sediments nearby.	Intense silicification and carbonatization of breccia.	Breccia zone formed near Nanaimo-Karmutsen unconformity. May be a tectonic breccia.	Laanela (1964) Carson (1968)

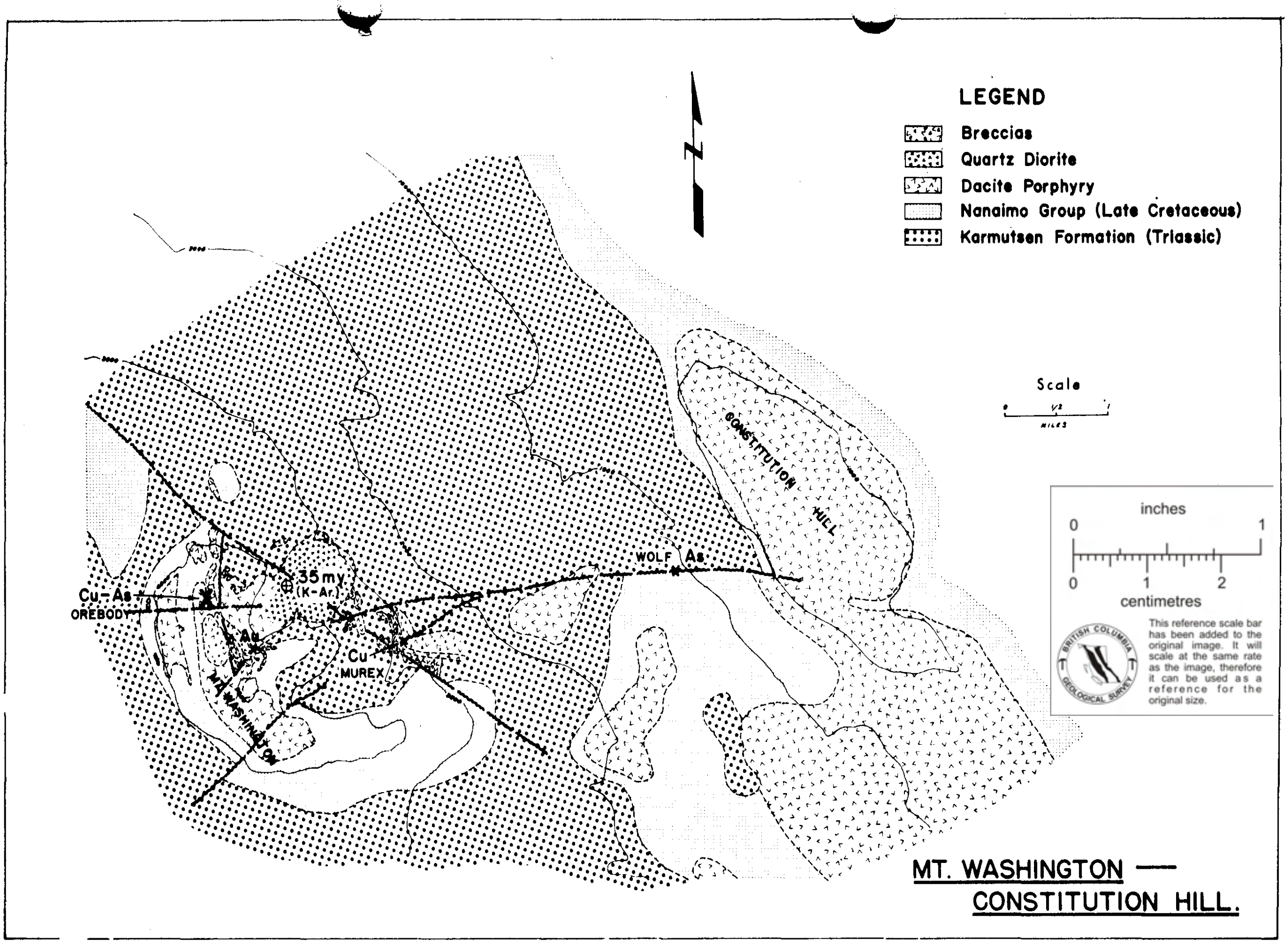

Figure 2.—Geology of the Mount Washington Area. Geology by D. J. T. Carson, 1965. Includes previous work by Carson (1960) and de Voogd (1964).

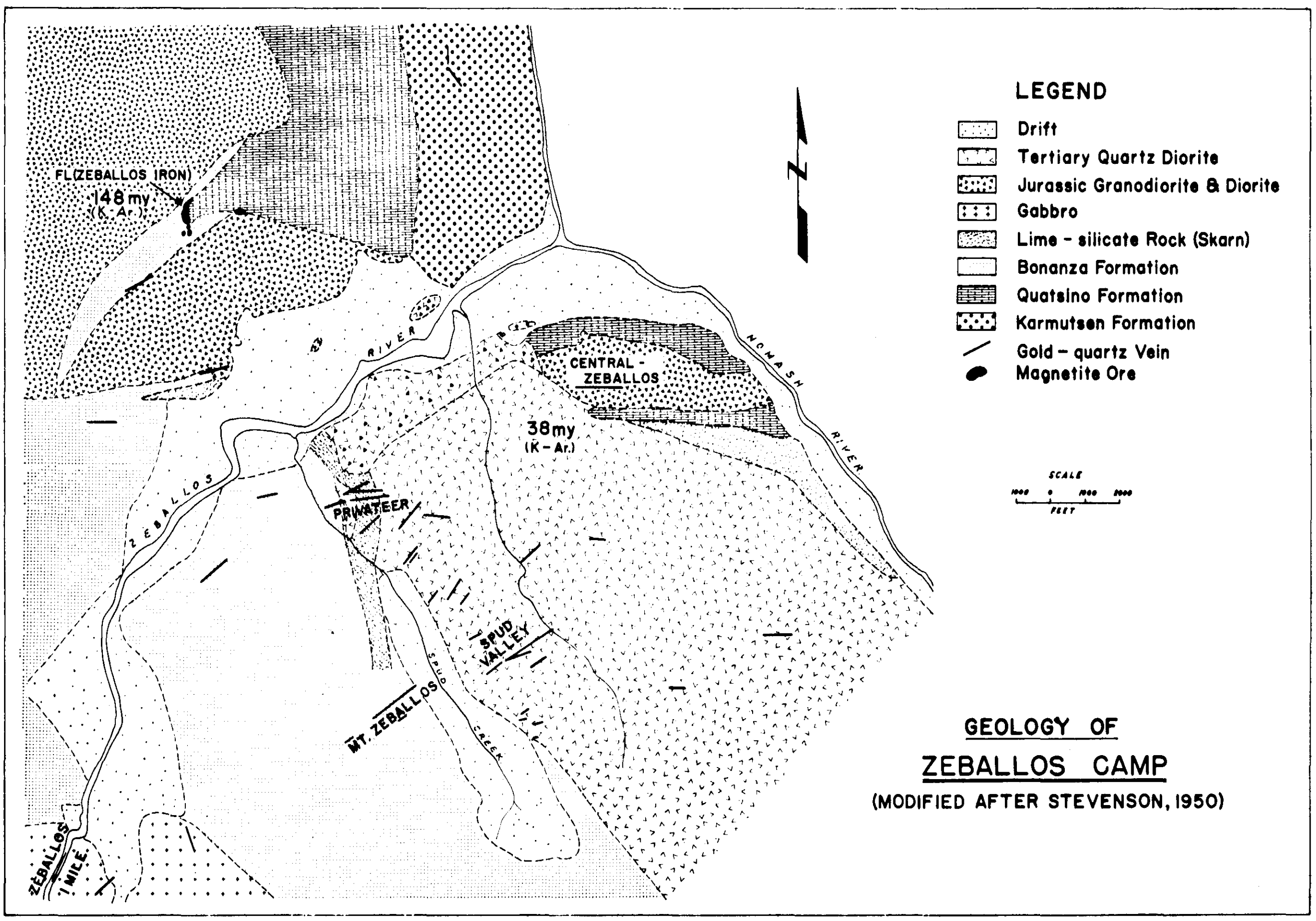

Figure 3.—Geology and Mineral Deoosits of the Zeballos Area.

conformity and adjacent to a quartz diorite stock that has a K-Ar age of 35±6 million years[1] (*Figure 2*). It has yielded approximately 400,000 tons of ore, but is not being mined at present.

The Macmillan showing, near Nanaimo Lakes, is believed by the writer to be Tertiary because of its metal content and its structural setting, which is somewhat similar to that of the Mt. Washington copper-arsenic orebody. It is a silicified copper-bearing breccia zone of unknown form in volcanic rocks of the Karmutsen formation.

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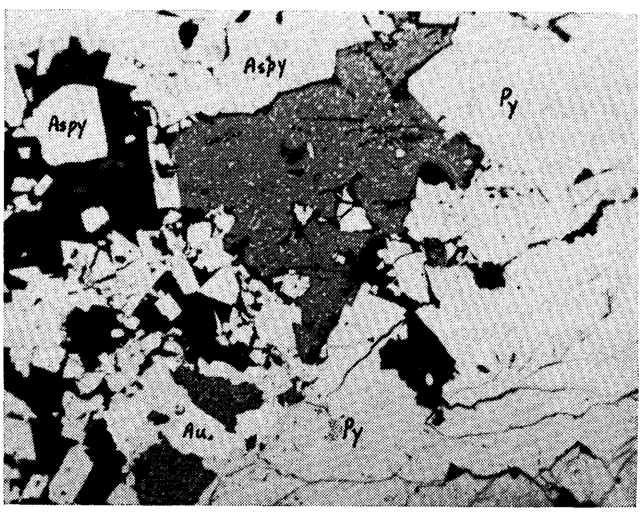
[1] — The significance and calculation of the experimental errors for the Geological Survey of Canada age determinations such as those referred to in this paper are outlined in Wanless *et al.*, 1965.

GOLD-QUARTZ VEINS AND FISSURE ZONES

Characteristics of the gold-quartz veins and fissure zones of the various areas of Vancouver Island are summarized in Table II. The veins of the various areas are remarkably alike in most aspects. Past production has occurred mainly at Zeballos, where the veins are especially persistent along strike.

The gold-quartz deposits have an over-all spatial relationship to Tertiary intrusions (*Figure 1*). Those that can be shown to be spatially and probably genetically related to intrusions of known age are at Zeballos, Faith lake and Mount Washington. The intrusive rocks associated with these veins are Oligocene quartz diorites and related dacite porphyries, both of which contain little or no potash feldspar. The conspicuous absence of gold-quartz veins near the more potassic Jurassic intrusions, such as the Saanich, Cowichan, Nanaimo River, Quinsam, Nimpkish and Bonanza granodiorite batholiths, is noteworthy.

Pyrite, sphalerite, arsenopyrite, galena and minor chalcopyrite, pyrrhotite and marcasite are found in most veins of all areas. The high content of galena and sphalerite appears to be associated with high gold values (Bancroft, 1937). Under the microscope, native gold was observed in samples from all the main areas. Exsolution chalcopyrite in sphalerite is a ubiquitous texture.



Photomicrograph of gold-quartz sample from the Lemay vein west of Catface Peninsula. Native gold veinlet (lower left) cuts pyrite and arsenopyrite (white to light grey) and sphalerite (grey). Sphalerite contains exsolution blebs of chalcopyrite. Plane reflected light; field length approximately 1.1 millimeters.

At the Zeballos mining camp (*Figure 3*), the gold-quartz veins are spatially related to the youngest major granitic intrusion of the area, a body of quartz diorite that has a K-Ar age of 38±14 million years.

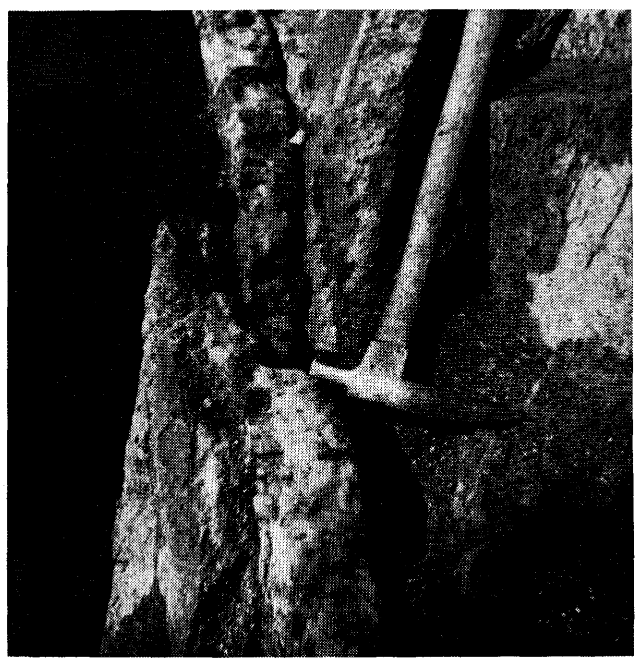
J. S. Stevenson studied the Zeballos gold veins and stated (1950, p. 33):

"They are younger than the quartz diorite and also have a close spatial relationship to it, and it is probable that, though the vein matter need not have come from the quartz diorite, it may be genetically related in coming from the same deep source."

It is significant that phlogopite from the magnetite skarn deposit of Zeballos Iron Mines Limited (*Figure 3*) yields at K-Ar age of 148 ± 8 million years (late Jurassic). The skarn is related to granodiorite that, according to field relationships, is older than the quartz diorite (Stevenson, 1950), so that the K-Ar age determination supports the field observations.

The original mineral discoveries at Mount Washington (*Figure 2*) were gold-quartz veins. However, the orebody of Mount Washington Copper Company is a copper-arsenic vein or sheeted zone, and irregular zones of fracture-filling and disseminated sulphides, such as the Murex showing, are found within and adjacent to the Mount Washington quartz diorite stock. These can be classified as porphyry copper deposits.

At Faith lake on the Forbidden Plateau, a few miles southwest of Mount Washington (*Figure 1*), a gold-quartz vein occurs in a small quartz diorite plug that has a K-Ar age of 39 ± 7 million years. Other gold-quartz veins are also present on the Forbidden Plateau where extensive Tertiary intrusive activity has occurred (Gunning, 1931; Muller, 1965).



Gold-quartz vein in Tertiary quartz diorite at Faith lake on the Forbidden Plateau. Note comb texture and banding of the quartz and sulphides.

Many deposits in the Bedwell River area occur in the Bedwell batholith, which may be Mesozoic. However, they are probably genetically related to nearby quartz diorite and dacite porphyry dykes and plugs that are petrographically similar to many known Tertiary intrusions (Carson, 1968). Some of these are well exposed at Big Interior mountain.

Table II — Characteristics of the Gold-Quartz Veins of the Various Areas of Vancouver Island

Main Areas of Occurence	Tenor Au Ag oz/ton oz/ton	Mineralogy	Textures, Paragenesis	Physical Forms	Host Rocks, Alteration	Structural Controls	Main References
Zeballos Area	Au .44, Ag .19 (avg. grade of ore mined). Pb, As < 1%. Highest grade is in sulphide -rich veins, esp. those with abundant galena and sphalerite.	Pyrite, sphalerite, arsenopyrite, chalcopyrite, native gold. Some pyrrhotite, marcasite.	Banding, comb-texture, brecciated vein and wallrocks; ubiquitous exsolution blebs of chalcopyrite in sphalerite. Paragenesis (oldest first) is pyrrhotite-sphalerite-arsenopyrite-pyrite-sphalerite-chalcopyrite-galena-native Au.	Massive quartz or ribbon quartz in veins or sheeted zones mostly < 1′ wide, uniform for several 100′ and vertical. Some sheeted zones contain lenses of quartz up to 4′ wide.	Spatially related to Tertiary quartz diorite stock. Occur in quartz diorite, granodiorite, diorite, gabbro, skarn, and dacite, andesite, tuff of Vancouver Gp. Limited sericite, chlorite, silica alteration of wallrocks.	Fractures, shears, sheeted zones, near NW nose of quartz diorite stock, possible locus of deformation due to NNW — SSE tension.	Stevenson (1950) Stevenson (1947)
Herbert Arm	Mainly lower grade than Zeballos	Similar to Zeballos but sulphides generally less abundant.	Similar to Zeballos	Similar to Zeballos but discontinuous lenses of quartz traceable only few tens of feet common.	Dacites, andesites of Vancouver Gp. and younger porphyries.	Fractures, fissures, sheeted zones.	Bancroft (1937) Min. of Mines, B.C., ann. rept. (1935)
Bedwell-Big Interior	Similar to Zeballos for mines	Similar to Zeballos. Arsenopyrite less abundant.	Similar to Zeballos	Moderately to steeply-dipping veins, fissures, sheeted zones up to 20′ wide. Some persistent.	Quartz diorite, volcanics of Sicker Gp. and Vancouver Gp.	Fractures, fissures, sheeted zones.	Sargent (1941) Sargent (1940) McKechnie (1961a)
Kennedy Lake Area	Mainly lower grade than Zeballos	Similar to Zeballos but some tetrahedrite reported, less arsenopyrite. Some ankerite.	Similar to Zeballos	Similar to Zeballos but most << 1′ wide; a few traceable several 100′.	Andesitic volcanics of Karmutsen Fm. Near fine grained diorites.	Fractures, fissures, sheeted zones.	Bancroft (1937) Min of Mines, B.C., ann. rept. (1935) Dolmage (1920)
China Creek	Au .3, Ag .9 (avg. grade ore mined)	Similar to Zeballos but no pyrrhotite or marcasite reported, more carbonate including ankerite.	Similar to Zeballos	Moderately to steeply-dipping veins, many containing quartz lenses up to a few feet wide.	Volcanics, chert of Sicker Gp. and feldspar porphyry. Feldspar porphyry stocks, dykes near.	Fractures, fissures, sheeted zones.	Stevenson (1945)
Forbidden Plateau	Lower grade than Zeballos	Similar to Zeballos but more arsenopyrite, minor tetrahedrite. Rare carrollite, native arsenic.	Similar to Zeballos	Nearly flat-lying and moderately to steeply-dipping veins up to sev. feet wide, some traceable for several 100′.	Nanaimo sediments, Tertiary breccia, Karmutsen Fm., quartz diorite. Tertiary quartz diorite spatially related.	Fractures, sheeted zones. Flat-lying veins in fractures formed at stratigraphic and conformable intrusive contacts.	Carson (1960) McDougall (1963) Carson (1968)

According to Stevenson (1945), the gold-quartz veins in the China Creek area occur along a belt of feldspar porphyry intrusions. Their age is unknown, but they are in a zone of known Tertiary intrusive activity (*Figure 1*).

At Kennedy river, the gold deposits were believed by Dolmage (1921) to be related to "diorite" intrusions that cut granodiorite of the "Coast Range Batholith." Dolmage stated (p. 19A):

"The diorite . . . belongs either to an exceedingly late phase of the batholithic period or to some subsequent period of intrusion."

On the basis of the evidence presented above, the writer believes that the gold-quartz veins of Vancouver Island post-date the Jurassic "Coast Range Orogeny" and that most, if not all, are Tertiary. It is interesting and possibly significant to note that gold-quartz veins in Washington State are related to Tertiary quartz diorites (Huntting, 1966).

In considering the origin of the gold-quartz veins of Vancouver Island, the following should be noted:

(1) — Host rocks for the deposits are extremely variable in composition, origin and age (Table II). Included are Tertiary and Jurassic intrusive rocks, gneisses and skarns, and varied rocks of the Sicker Group, Karmutsen formation, Bonanza formation and Nanaimo Group.

(2) — Intrusive rocks that are spatially related to many of the deposits are quartz diorites and dacite porphyries, both low in potash feldspar and uniform in composition (Carson, 1968). They probably originated at considerable depth, as they occur in linear zones and were likely intruded along major fault zones. Also, there is no evidence of widespread regional metamorphism at the time they were emplaced. Comparable intrusions in Washington State are believed by Misch (1966) to be products of fusion at deep crustal levels.

(3) — The mineral content of the gold-quartz veins is very uniform in all areas where they occur and the veins from the different areas are alike in most aspects. Further, at all deposits studied, an increase in

Table III — Characteristics of Known Porphyry Copper Deposits of Vancouver Island

Deposit	Tenor	Mineralogy Cpy-Chalcopyrite Py-Pyrite Bn-Bornite	Type of Mineralized Zone	Host Rocks	Structural Controls	Associated Alteration	Main References
Catface	Cu < 1% Very minor Mo, Au.	Cpy,Py,Bn. Minor molybdenite, pyrrhotite, magnetite, chalcocite, cuprite, native Cu, azurite, malachite.	Zones of low grade Cu up to several 100′ long and wide, consisting of seams, disseminations, veinlets. Cpy, Py, Bn replace mafic minerals in intrusions and volcanics. Bn masses up to several inches wide. Cpy veins up to 6″ wide. Py, molybdenite disseminated in all rocks.	Intrusive complex of older quartz monzonite and quartz diorite, fresh Tertiary quartz diorite and dacite porphyry, and the country rocks —Karmutsen (?) Fm., — basic volcanics.	Fractures within or adjacent to intrusive complex possibly emplaced along major north-northwest fault. The complex occurs in domal uplift occupying Catface Peninsula. Volcanics may have acted as impermeable capping.	Silicification, kaolinization, hematitization of quartz monzonite. Chloritization of mafic minerals in volcanics and quartz monzonite. Quartz diorite and dacite porphyry largely unaltered	McDougall (1962) Carson (1968) Carr (1964a)
Big I	Cu << 1% Very minor Mo, Au.	Cpy, Pyrrhotite, Py. Minor molybdenite, malachite.	Very large zones of << 1% Cu. Disseminations, seams, veinlets of Cpy, Py with minor molybdenite in places. Cpy locally replaces xenoliths in quartz diorite. Pyrrhotite masses up to 3′ wide cut by Py-Cpy-Quartz veinlets.	Probable Tertiary quartz diorite and intrusive breccia, and volcanics and sediments of Sicker Gp. Dykes of dacite porphyry and diabase common.	Fractures in quartz diorite, intrusive(?) breccia and adjacent Sicker Gp. rocks.	Silification, minor skarnification.	Sargent (1941) Carson (1968)
Faith Copper	Cu < 1% Minor Au, As. Very minor Mo.	Cpy, Py, Pyrrhotite. Minor molbydenite, arsenopyrite.	Large zones of very low-grade Cu in volcanics near quartz diorite plug; zones of low grade Cu and Mo several tens of feet wide in the plug. Disseminations, seams, veinlets.	Tertiary quartz diorite, dacite porphyry and intrusive breccia, and Karmutsen Fm.	Fractures within the plug and adjacent volcanics.	Silicification, chloritization and pyritization of volcanics.	McDougall (1963) Carson (1968)
Gem Lake	Cu < 1% Very minor Mo, Au	Cpy, Py. Minor bornite, molybdenite, magnetite, hematite, ilmenite, pyrrhotite.	Large zones of very low grade Cu in brecciated volcanics, quartz diorite, breccia pipe. Ilmenite and magnetite replace matrix of breccia. Disseminations, seams, veinlets, breccia fillings.	Same as Faith Copper	Same as Faith Copper	Same as Faith Copper	Gunning (1931) McDougall (1961) Carson (1968)
Mt. Washington-Murex	Cu < 1% Very minor Au, Mo.	Cpy, Py, Pyrrhotite, Bn. Very minor molybdenite, molybdite, native copper, specularite, magnetite; rare wolframite.	Large zones of low-grade Cu. Disseminations, seams, veinlets, breccia fillings. Magnetite part of matrix of Washington breccia, specularite of Murex breccia.	Tertiarty quartz diorite stock, dacite porphyry sills, dykes, irregular bodies, breccias; Karmutsen Fm. basic volcanics; Nanaimo Gp. argillite and quartzite.	Fractures in quartz diorite stock or adjacent rocks near the Karmutsen-Nanaimo unconformity. Stock is located in structural dome. Nanaimo sediments may have acted as impermeable capping.	Silicification, chloritization and biotitization of mafic minerals. Sericitization widespread but weak. Intense local argillitization.	Carson (1960) de Voogd (1964) Gunning (1931) Carson (1968) Carr (1964b)

the amount of galena and sphalerite is accompanied by an increase in the gold content.

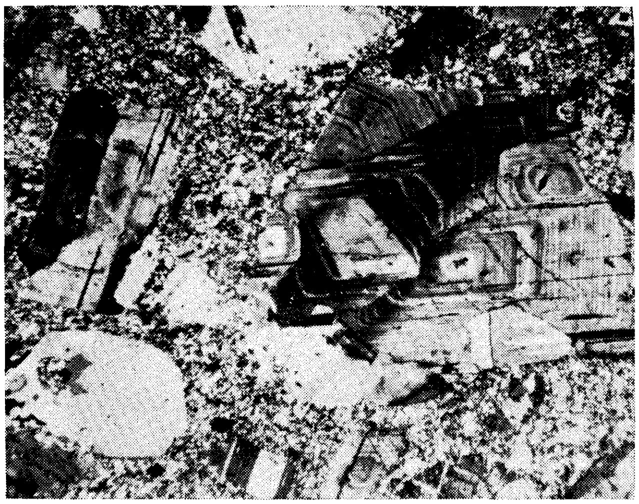
The over-all uniformity of the veins despite widely varying host rocks indicates that the host rocks had little effect on the composition of the veins. An origin involving secretion of gold from the host rocks into fractures is highly unlikely. Rather, the veins were probably derived from solutions originating in a homogeneous source outside their host rocks and, like the related quartz diorites, probably at great depths.

PORPHYRY COPPER DEPOSITS

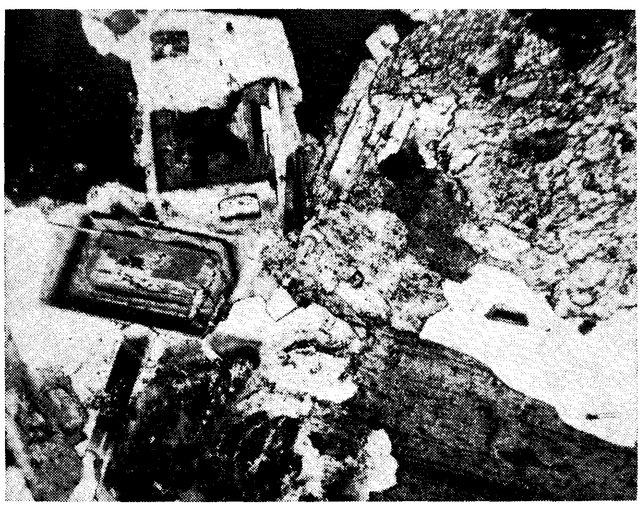
The deposits of Vancouver Island which can be classified as porphyry coppers are Catface, Big I, Faith Copper, Gem Copper, Mount Washington - Murex, and Corrigan Creek (*Figure 1*). All six deposits are of demonstrable or probable Tertiary age. None of these has so far proved to be mineable, but Catface is of considerable size and may be put into production in the near future. Their characteristics are given in Table III.

All members of this class consist of large scattered zones of low-grade disseminated and fracture-filling chalcopyrite with minor to negligible gold, and very minor molybdenum, occurring largely within intrusive complexes that possess prominent porphyritic phases. These complexes are epizonal and most contain irregular zones or pipe-like bodies of intrusive breccia.

Pyrite and chalcopyrite are the most abundant minerals in all deposits. Pyrrhotite is less common and bornite and molybdenite are very minor constituents.



Photomicrograph of Tertiary dacite porphyry from Mount Washington. Oscillatory-zoned plagioclase phenocrysts, including fragment of coalesced plagioclase crystals in optical continuity, and quartz phenocryst (lower left). Crossed nicols; field length approximately 3.2 millimeters.



Photomicrograph of Tertiary quartz diorite from Catface Peninsula. Oscillatory-zoned plagioclase, clear quartz, biotite (lower right) and hornblende (upper right). Crossed nicols; field length approximately 2.4 millimeters.

Gold-quartz veins are known to occur near all the porphyry copper deposits. A copper-arsenic orebody is found at Mount Washington and minor occurrences of sulphides in skarn are found at Catface and Big I.

The epizonal complexes related to the porphyry copper deposits are small post-tectonic stocks and plugs consisting largely of quartz diorite grading to quartz diorite porphyry (dacite porphyry), and related breccia zones. They are much smaller and much less abundant than the Jurassic intrusions of the main orogenic period. Petrographically, they differ from the mesozonal Jurassic intrusions in that they contain large virtually unaltered zones, little or no potash feldspar (most Jurassic intrusions are granodiorite with 10-20 per cent potash feldspar), strongly zoned unclouded plagioclase and prominent porphyritic phases. However, strongly altered equigranular quartz monzonite forms part of the Catface complex. Quartz diorites from Catface, Faith lake and Mount Washington yield mid-early Tertiary K-Ar ages[(1)] (*Figure 1*). All but the Corrigan Creek deposit are in a northeast-trending zone that may be the locus of a major fault system.

Fracturing of the outer portions of the complexes, and doming, fracturing and brecciation of host rocks due to forcible intrusion, crystallization and/or faulting, have provided favourable zones for mineral deposition at the Mount Washington - Murex, Faith Copper and Catface deposits and probably also at the Gem Copper and Big I.

(1) Since the completion of this manuscript, a sample of the Corrigan Creek quartz diorite submitted to the Geological Survey of Canada by the writer has been determined to have a K-Ar age of 38±2 million years (R. K. Wanless, personal communication, May 16, 1969).

SOOKE COPPER DEPOSITS

The copper deposits of the Sooke - Jordan River area include the Sunro mine at Jordan River and several occurrences on the Sooke Peninsula (*Figure 4*). They are spatially and probably genetically related to Oligocene gabbros. Clapp and Cooke (1917), Fyles (1949) and Stevenson (1951) have described the various deposits in some detail.

The Sooke deposits consist of zones containing disseminations and veinlets of chalcopyrite, pyrrhotite and pyrite in fractured and sheared Tertiary gabbro and basalt. They are found at intervals along vertical fracture zones that are up to 3,000 feet long. Smaller, mainly vertical, fractures and shears control the local distribution of sulphides. Zones of ore grade vary from 3 to 100 feet in width, but are generally less than 50 feet wide.

The grade of copper in mineable deposits is generally 1-1.5 per cent, but some higher-grade zones also occur. Molybdenum, nickel and cobalt are present in amounts of up to 0.05 per cent, and gold and silver are each present in high-grade zones at approximately 0.1 ounce per ton.

Two types of alteration are associated with the deposits, but both occur in some unmineralized areas as well. The first involves weak to intense amphibolization of pyroxene and plagioclase in gabbro and basalt. The second involves the combined feldspathization and scapolitization of gabbro and basalt. The plagioclase and scapolite commonly occur in white lacework stringers near the copper zones.

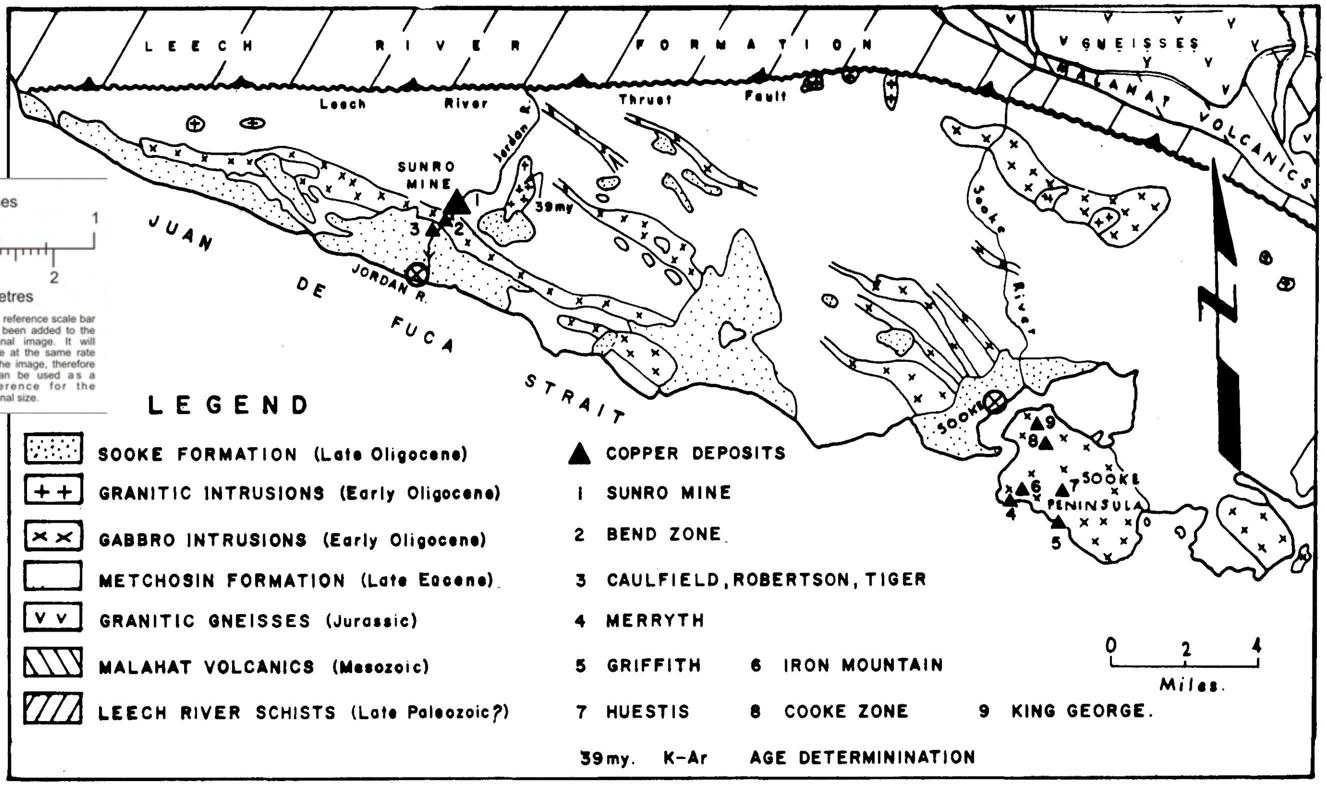


Figure 4.—Geology and Mineral Deposits of the Sooke - Jordan River Area (after Clapp and Cooke, 1917, and unpublished map of Macsan Exploration Co. Ltd.)

OTHER TERTIARY DEPOSITS

Skarn Deposits. The only significant skarn deposits of known Tertiary age on Vancouver Island are two small chalcopyrite-pyrrhotite showings on the north and east edges of the Tertiary quartz diorite intrusion at Zeballos (*Figure 3*).

All other copper skarn deposits of known age and all iron skarn deposits of demonstrable age (Brynnor, Argonaut, Nimpkish, Zeballos Iron, etc.) are related to intrusions that are unconformably overlain by late Cretaceous sedimentary rocks and/or yield potassium-argon ages ranging from 143 to 167 million years — i.e., middle to late Jurassic (Carson, 1968).

Molybdenum Stockwork. A small network of quartz veins containing molybdenite, pyrite and minor chalcopyrite occurs within and adjacent to a granodiorite porphyry stock near Tofino (*Figure 1*). Biotite in a sample of this stock collected by J. E. Muller yields a K-Ar age of 50 $\pm$ 5 million years. This is the only molybdenum stockwork of proven Tertitary age on Vancouver Island, but others may well be present. The largest deposit of this class discovered to date is the Allies occurrence, which is related to Jurassic granodiorite near Cowichan lake (Fyles, 1955). Whereas known porphyry copper deposits of Vancouver Island are related to potassium-feldspar-poor intrusions of quartz diorite composition and contain very minor molybdenite, the molybdenum stockworks are related to relatively potassic intrusions and copper is very minor or absent.

Copper Stockworks. This class of deposit is defined by the writer to include large zones of low-grade disseminated and fracture-filling copper mineralization, similar to porphyry copper deposits in many aspects, but not as closely related to intrusive complexes. Minor molybdenite may be present. These deposits occur in volcanic, sedimentary or gneissic host rocks and are at varying distances from major intrusions. However, many contain porphyritic dykes and sills. Most possess strong alteration zones including wide pyrite halos. The Mary deposit on Mt. Spenser (McKechnie, 1967) is of this type. The sulphides are spatially related to feldspar porphyry dykes of possible Tertiary age.

Mercury Breccia-Filling. The only known mercury deposit on Vancouver Island is at Sechart (*Figure 1*). It was described by Dolmage (1920), who reported that limited mining had taken place prior to his investigation. Cinnabar replaces quartz and limestone fragments in a siliceous limestone breccia. A composite sample taken by Dolmage across the ore dump averaged 0.38 per cent mercury.

Dolmage believed that the Sechart mercury deposit was probably related to Tertiary magma and noted the occurrence of unaltered granodiorite dykes ¼ mile from the deposits. The subsequent discovery of several Tertiary intrusions on Vancouver Island, including that by J. E. Muller at Paradise Creek a few miles west of the deposit (Wanless *et al.*, 1968), supports Dolmage's conclusion. Further evidence of magmatic activity on the west coast is indicated by the presence of probable Tertiary dacite-tuff and ignimbrite, also near Paradise Creek (Muller, 1968), and of a hot spring at Sharpe Point (Clapp, 1914).

IMPORTANT PRE-TERTIARY DEPOSITS

Copper and iron skarn deposits, such as Coast Copper, Blue Grouse (Cowichan Copper), Argonaut, Brynnor, etc., comprise the best-known class of mineral deposits on Vancouver Island. As stated above, the vast majority of these are related to intrusions of Mesozoic age.

The Bay deposit of Utah Mining and Construction near Port Hardy is potentially the largest copper producer on Vancouver Island. Its host rocks are andesitic volcanics of the Triassic-Jurassic Bonanza formation, and, although information on it is sparse, it appears to be a copper stockwork as defined above. This deposit is spatially related to a granodiorite porphyry intrusion at the east end of Rupert Arm (Muller, 1967). This intrusion possesses conspicuous quartz eyes and biotite and plagioclase crystals crowded together in a very fine grained matrix of quartz and potassium feldspar. Such a texture has not been observed elsewhere on northern Vancouver Island (Carson, 1968), but pebbles with this texture are abundant in lower Cretaceous conglomerates at the west end of Rupert Arm. Thus, the intrusion is probably Jurassic and if the Utah deposit is related to the intrusion, it too is probably Jurassic. The absence of gold-quartz veins in the Rupert Arm area also suggests a pre-Tertiary age for the Utah deposit, as gold-quartz veins are common near most Tertiary copper deposits (*Figure 1*).

Zinc-copper-lead massive sulphide deposits, including those at Western Mines and at the Twin "J" mine near Duncan, are restricted to cherty tuffs of the late Paleozoic Sicker Group. They are believed to have formed at the same time as the deposition of the Sicker tuffs, with further concentrations during later deformation (Carson, 1968), or, alternatively, from hydrothermal solutions emanating from granitic intrusions (Stevenson, 1945; Jeffery, 1965) that are probably Jurassic. They show no affinity to known Tertiary deposits.

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Geology and mineral possibilities of Vancouver Island

By J. E. MULLER and D. J. T. CARSON

Geology and mineral possibilities of Vancouver Island

Presented at the 1969 Annual Meeting of the Prospectors and Developers Association

By J. E. MULLER* and D. J. T. CARSON**

■ Increased exploration activity of the last years on Vancouver Island warrants a review of the presently known geology and its relationships to mineral deposits. A considerable body of geological knowledge has accumulated since the early explorations of the coalfields (1872-1878) by Richardson and the coastal reconnaissance by Dawson (1887). Important contributions were made by Clapp, Mackenzie, Dolmage, Gunning, Buckham, Jeletzky and Hoadley of the Geological Survey of Canada and Stevenson, Sargent, Fyles, Jeffery and Eastwood of the British Columbia Department of Mines. Of the present writers Muller undertook in 1963 the systematic reconnaissance mapping and Carson examined a large number of representative mineral deposits. The geological compilation shown in Figure 1 is based on the work of all those named. It is similar to an unpublished map placed on open file with the Geological Survey in 1968, but the part west of longitude 26° is revised on the basis of 1968 fieldwork. The geology of the area southwest of Cowichan Lake is based on very limited information.

Sequence of formations

The island is underlain chiefly by two main groups of predominantly volcanic rocks with subordinate clastic and calcareous marine sediments of late Palaeozoic to middle Mesozoic age. The oldest, Sicker Group, consists mainly of 5,000 feet or more of volcanic tuff and breccia of intermediate composition. These rocks are altered and in certain zones converted to chlorite-schist and sericite-schist with intense shear-folding. A few thousand feet of middle Pennsylvanian and argillite overlying the volcanic rocks are also highly folded. At the top of the group a maximum 1,000 feet of Lower Permian Buttle Lake limestone, intruded in places by diabase-sills, appears to be only slightly disturbed.

Deposition of the succeeding Vancouver Group may have been preceded by a period of uplift and erosion as indicated in places by a basal conglomerate with clasts of Sicker Group rocks. The Vancouver Group is the thickest and the most wide-spread rock unit and is divided into three formations.

The Karmutsen Formation consists of 5,000 to 20,000 feet of slightly altered, basaltic pillow lavas and related breccias (mainly in the lower part) and regular, massive, commonly amygdaloidal and porphyritic lava-flows, of Triassic and possibly Permian age.

The Quatsino Formation, overlying the Karmutsen, is 500 to 2,000 feet thick and ranges upward from massive grey to thin-bedded black limestone, in places with an upper part of calcareous greywacke and limestone-breccia. In some areas the Quatsino consists of two or three limestone-layers 10 to 100 feet thick, separated by several 100 feet of Karmutsen-type basaltic rocks.

The Bonanza Subgroup, possibly up to 8,000 feet thick and the youngest part of the Vancouver Group, contains a lower division of altered basaltic to andesitic tuff, breccia and lava, interbedded with Lower Jurassic greywacke and argillite. The upper division consists largely of commonly red-coloured felsitic lavas, tuffs, breccias and ignimbrites.

The Westcoast Gneiss Complex, of hornblende-plagioclase-gneiss and amphibolite, is probably the product of regional metamorphism of Sicker and Vancouver Group rocks, recrystallized during a major Middle Jurassic orogeny. Hornblende diorite and agmatite, also common in the westcoast area, are inferred to be the result of further migmatization of the same rocks. The gneiss complex grades eastward into the Island Intrusions, large batholiths of granodioritic to quartz dioritic com-

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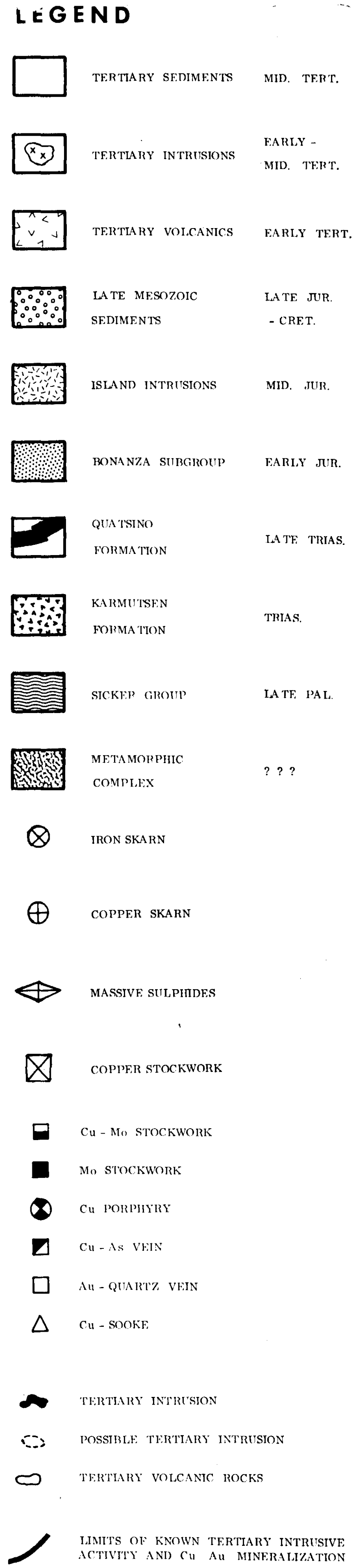

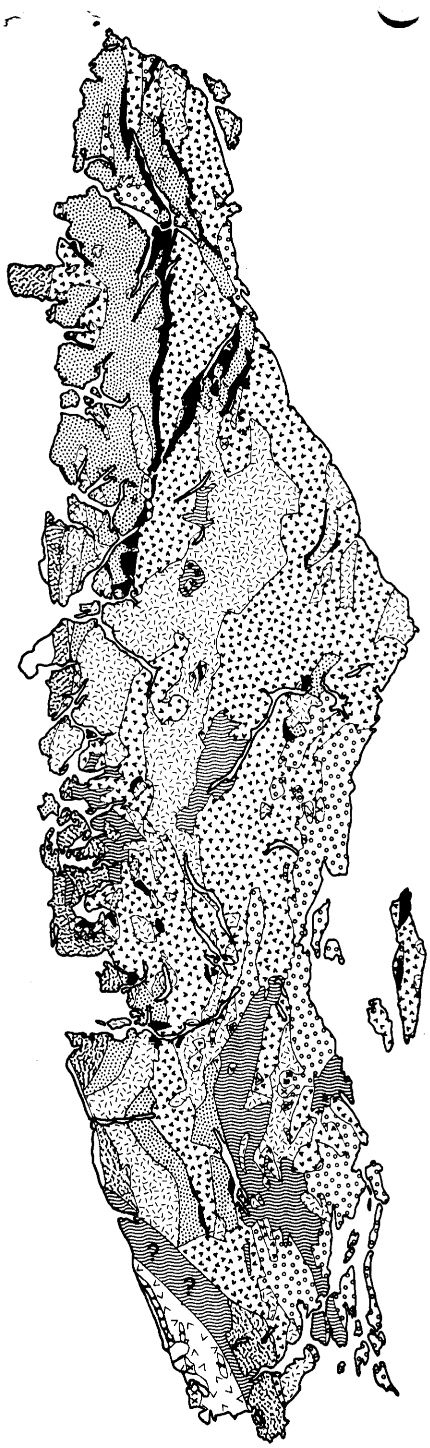

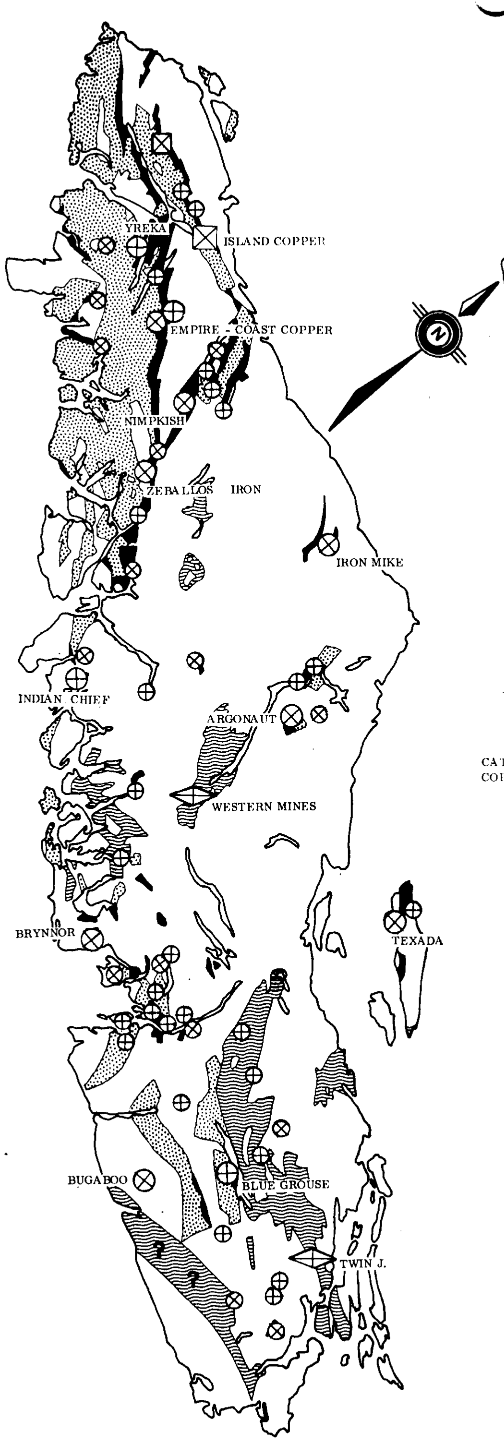

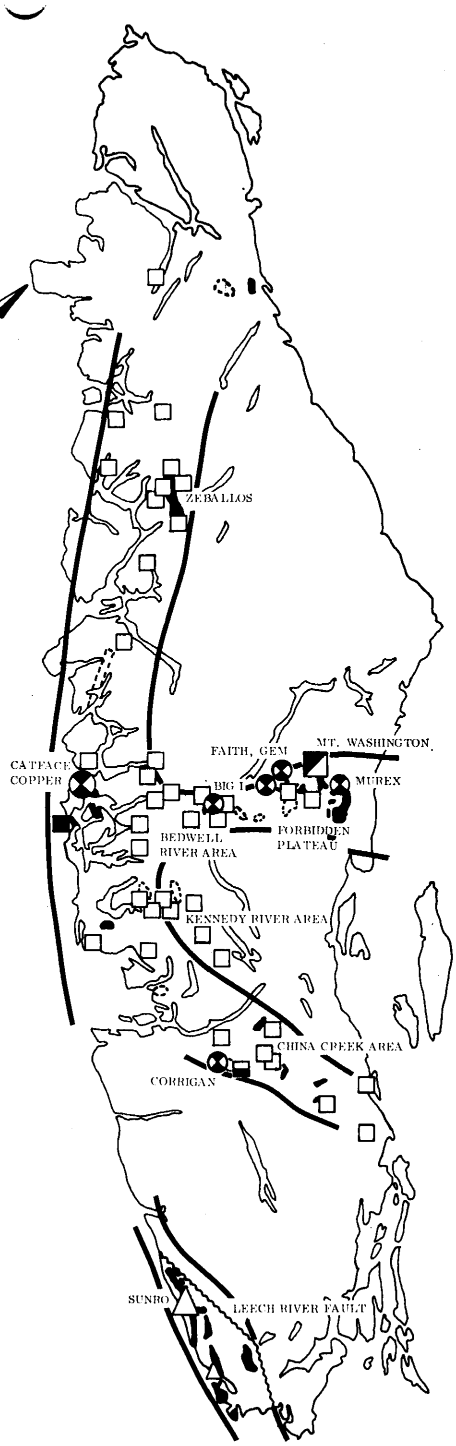

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Fig. 1 Geological map of Vancouver Island

Fig. 2 Distribution of Sicker group, Quatsino formation, Bonanza subgroup and associated mineral deposits

Fig. 3 Known and probable tertiary mineral deposits and zones of tertiary intrusive activity position that have invaded both Sicker and Vancouver Group rocks. Potassium-argon ages, obtained on these rocks range from 167 to 143 million years, indicating Middle to Upper Jurassic age.

Greywacke, sandstone, conglomerate and shale form a major assemblage that was laid down unconformably on both older groups and on the granitic rocks after considerable uplift and erosion. The older Upper Jurassic to Lower Cretaceous sediments form a clastic wedge on the western side of the island. The younger Upper Cretaceous Nanaimo Group of conglomerate, sandstone, shale and commercial coal forms another wedge along the eastern side. The detailed stratigraphy of these fluvio-deltaic to marine sediments is now well established.

Metchosin basaltic volcanics of probable Eocene age are present only at the south end of the island. They are intruded by gabbroic and granitic stocks, the Sooke Intrusions. Other intrusions of Tertiary age, mostly stocks and sills of quartz diorite and dacite porphyry, intrude Nanaimo Group and older rocks in several areas.

Oligocene to Miocene sandstone, shale and conglomerate, the youngest deposits, form a narrow wedge along part of the west coast and unconformably overlie various older rock-groups.

Structure

The oldest structures, marked by the Buttle Lake, Horne Lake, and Nanoose axes, are three north-northwest trending arches that expose oldest Sicker rocks and were probably positive elements since late Palaeozoic time. The arches are bounded by faults or flexures. Shearfolding of the Palaeozoic rocks appears to be confined to broad fault-zones, trending northerly to northwestly. Folding in the Vancouver Group is restricted to broad tilting of the massive Karmutsen and Bonanza volcanic rocks but is locally intense in the thinly-bedded sediments, mainly along fault-zones and intrusive contacts. Post-intrusive sediments generally dip gently and uniformly within the fault-blocks but exhibit severe disturbance and steep dips in fault-zones.

A structural style of block-faulting prevails throughout the island. The faults are steeply dipping normal and reverse faults and in some a strike-slip component of movement is indicated. Although the predominant direction is northwest, another set of northeasterly to northerly striking faults intersects and in several instances offsets the northwesterly faults. Many faults are clearly marked by topographic lineaments marked by valleys, lakes and tidal inlets. On the west coast they are locally well exposed and some exhibit mylonite and crushed rock in zones up to several hundred feet wide.

Mineral possibilities

General

The most important metals found on Vancouver Island are Cu, Fe, Zn, Mo, Au and Ag. Many types of deposits are present and the following classes are of considerable economic importance as past, present or possible future producers.

Class of deposits	Examples	Metals	Host rocks	Related intrusions
Massive zinc-copper sulphides	Western Mines Twin J	Zn, Cu, Pb (Ag, Au, Ba)	Palaeozoic Sicker Volcanics	None
Iron + copper skarns	Brynnor Coast Copper etc.	Fe, Cu (Au, Ag)	Quatsino Limestone + adjacent volcanics and intrusions	Jurassic granitic intrusions
Copper-molybdenum stockworks	Island Copper Hep	Cu, Mo (Ag, Au)	Jurassic Bonanza sediments and volcanics	Granitic (porphyritic) intrusions
Molybdenum stockworks	Allies	Mo (Cu)	Potassic Jurassic + Tertiary intrusions	Potassic Jurassic + Tertiary intrusions
Porphyry coppers	Catface Gem	Cu (Mo, Au, Ag)	Tertiary intrusions + adjacent host rocks	Tertiary stocks + plugs
Gold-quartz veins	Privateer Musketeer etc.	Au, Ag (Pb, Zn, Cu, As)	All rocks, Palaeozoic to Tertiary	Deposits are in zones of Tertiary intrusive activity
Sooke copper deposits	Sunro	Cu	Tertiary basalts and gabbros	Tertiary gabbros

A knowledge of the differences among the above classes is essential to the exploration geologist because each class has its own geological setting, geochemical expression, and geophysical response.

On Vancouver Island, orthoclase-rich true granites and the metals generally associated with acidic and pegmatitic granitic rocks (Li, Be, U, etc.) are very rare, possibly due to a thin continental crust at the Pacific margin. Also, because the oldest rocks are late Palaeozoic (Figure 1), the Pb-Zn-Ag deposits typical of late Precambrian and early Palaeozoic sediments of the eastern British Columbia and Yukon are missing.

Massive sulphides

Two massive Zn-Cu sulphide deposits are Western Mines (Jeffery, 1965) and the inactive Twin J mine (Stevenson, 1945). They are shown in Figure 2. The host rocks for these deposits are sheared cherty tuffs and volcanic breccias of the Sicker Group. The orezones are tabular, lens-like, and irregularly-shaped and are a few to several hundred feet long. Ore minerals sphalerite, pyrite, chalcopyrite, galena, and tetrahedrite generally constitute more than fifty per cent of the material in the orezones. Barite is a major gangue mineral.

The authors believe that the metals were deposited at the same time as their Sicker host rocks, though further concentration of metals may have occurred during later deformation and metamorphism.

Exploration for massive Zn-Cu sulphide deposits should be restricted to areas underlain by sheared volcanic tuffs and breccias of the Sicker Group. Sicker rocks underlie less than fifteen percent of Vancouver Island (Figure 2). Geological investigations may reveal that the host cherty tuff horizons are at a definite stratigraphic position in the Sicker Group. Abundant disseminated pyrite is found on the fringes of the known deposits and could be a useful guide in exploration.

Geochemically, Zn and Cu are the most obvious indicator metals and other metals, such as Mo, would not be expected. Geophysical surveys should be planned to allow that the massive sulphide orebodies are non-magnetic conductors.

Iron and copper skarn deposits

As shown in Figure 2 iron and copper skarn deposits are abundant on Vancouver Island. Most of the largest known deposits yielded ore in the past and are named on the figure. Only Coast Copper is being mined at the present. The ore minerals in the skarn deposits are magnetite and chalcopyrite, either of which may predominate. Some uneconomic Zn-Pb and Mo-Cu skarns also occur on Vancouver Island.

The largest skarn deposits are at or near to the contact between Triassic Quatsino limestone and Jurassic intrusions. Host rocks may be limestone, volcanic rocks or intrusive rocks. Faulting and deformation are anomalously intense in the vicinity of the deposits (Sangster, 1964; Eastwood, 1965).

Geochemical methods utilizing stream silts and soils, and magnetic and electromagnetic surveys, are useful in exploration for copper and iron skarn deposits. However, much caution should be employed because the great majority of the skarn deposits are small erratic lenses and pockets that do not justify extensive exploration

Copper-molybdenum stockworks

Copper-molybdenum stockworks are defined here as large zones of low grade fracture-filling and disseminated copper mineralization, generally with minor molybdenite, which are somewhat similar to porphyry copper deposits but do not occur within intrusive complexes. However, granitic and porphyritic stocks or plugs that are probably the sources of the ore are generally nearby. Also, porphyritic dykes and sills are present at the mineralized zones. Because copper-molybdenum stockworks are not within intrusions, local stratigraphy, and local structures not directly related to intrusive activity, are more important ore controls than they are for porphyry copper deposits.

Several promising prospects including the Island Copper deposit of Utah Mining and Construction Company near Port Hardy (Figure 2) are of this class. Somewhat similar deposits on the British Columbia mainland, are the Ingerbelle and Copper Mountain orebodies near Princeton.

Island Copper is the largest copper deposit yet discovered on Vancouver Island. It contains more than 180 million tons grading 0.52% copper and 0.25% molybdenite. The ore is in silicified andesitic volcanics and greywackes of the lower Bonanza Formation. It is spatially and probably genetically related to a Jurassic granodiorite porphyry stock at the east end of Rupert Inlet (Figure 1) and a dyke (?) of similar composition occurs near the ore zone. This deposit may owe its origin to a copper-rich intrusion which, unlike most Jurassic intrusions, continued upward past the Quatsino limestone (site of the Cu, Fe skarns) and expelled its metals into a favourable structure in the overlying Bonanza Formation. The Bonanza rocks are hydrothermally altered and pyritized for several thousand feet outward from the ore-zone. Skarn mineralization occurs in Quatsino limestone that is exposed about one mile north of Island Copper (Figure 2).

Assuming that the origin of the Island Copper deposit is as suggested above, exploration for similar deposits should be restricted to the Bonanza Formation, and in the vicinity of intrusions, preferably porphyritic. Detailed mapping of the Bonanza may reveal that a given stratigraphic level, such as the contact between the lower sedimentary and upper volcanic units, was favoured by rising copper-bearing intrusions. Other exploration targets are strong faults and hydrothermal alteration and pyritization of the Bonanza.

Geochemical soil surveys to detect Cu and Mo were apparently most useful in helping to delimit the Island Copper orebody. In regional stream silt surveys, the Mo content should serve to distinguish this type of deposit from the widespread sporadic syngenetic copper found in basalts of the Karmutsen Formation.

Magnetic surveys tend to outline skarn deposits which are at some distance from the known copper-molybdenum stockworks, and also some peripheral uneconomic magnetite-chalcopyrite stringers. The response of copper-molybdenum stockworks to induced polarization surveys is probably overshadowed by the effects of widespread peripheral pyrite.

Molybdenum stockworks

A few molybdenum stockwork occurrences in geological environments that are somewhat similar to Endako and Boss Mountain mines, are present on Vancouver Island. However, none has proven to be mineable. These deposits occur in relatively silicic and potassic Tertiary stocks, or the acidic roof facies of Jurassic granodiorite batholliths. They consist of network stringers of quartz, pyrite, and molybdenite.

The Allies deposit near Cowichan Lake (Fyles, 1955) is one of the largest known occurrences. Other such deposits may be found. However, molybdenum-rich intrusions are generally very high in silica and potash feldspar, and such acidic intrusions are very rare on Vancouver Island.

Porphyry copper deposits

Known porphyry copper deposits are Catface, Big I, Gem Copper, Faith Copper, Murex and Corrigan (Figure 3). Of these, only Catface (Carr, 1964) is of probable economic value, and it is of considerable size.

The porphyry coppers consist of very large zones of low grade (1% copper) disseminated and fracture-filling copper mineralization which, unlike the copper-molybdenum stockworks are largely within intrusive complexes. The main ore minerals are chalcopyrite and pyrite. Bornite is minor and molybdenite is very minor.

Intrusions related to all the known porphyry coppers are Tertiary stocks and plugs consisting largely of quartz diorite and related porphyries (Carson, 1968). Unlike the older Jurassic intrusions, these rocks contain little or no potash feldspar and possess prominent porphyritic phases, large virtually unaltered portions, and commonly pipes and irregular zones of breccia. However, the intrusive complex at Catface consists in part of highly altered quartz monzonite.

Rocks surrounding the porphyry copper deposits are pyritized and exhibit typical porphyry copper alterations including biotitization, chloritization, kaolinization, etc. Potash feldspar alteration is not common because of the nature of the country rocks which are mainly basic volcanics.

Exploration for porphyry copper deposits should be confined to intrusive plugs and stocks in the zones of known Tertiary intrusive activity and Cu-Au mineralization (Figure 3). Hydrothermal alteration, especially pyritic and potassic (biotite), is a very useful indicator. The geophysical and geochemical responses of porphyry coppers are roughly similar to those of the copper stockworks (above).

Gold-quartz veins

Gold-quartz veins are abundant on Vancouver Island (Figure 3). Most of these veins are too small to mine but some, especially those at Zeballos (Stevenson, 1950), have in the past yielded moderate quantities of gold and silver. An increase in the price of gold could reactivate some of the old mines.

Exploration for gold-quartz veins should be concentrated in the zones of known Tertiary intrusive activity and Cu-Au mineralization (Figure 3). Many of the known veins are within or alongside the same quartz diorite plugs and stocks that contain the porphyry coppers.

Sooke copper deposits

The Sooke copper deposits including the Sunro Mine (Stevenson, 1951) are spatially related to elongate Tertiary gabbroic intrusions (Figure 3). Host rocks include the gabbros and Tertiary basalts. The deposits consist of disconnected zones of disseminated and fracture-filling chalcopyrite-pyrite-pyrrhotite within larger fracture or shear zones. Amphibolization of the gabbros and basalts, and white network veinlets containing scapolite and feldspar are common near mineralized areas.

The Sunro mine is the only producer of the Sooke region, but similar deposits may be found in the Tertiary rocks south of the Leech River fault (Figure 3). □

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complements of the authors

Geology and mineral possibilities of Vancouver Island

By J. E. MULLER and D. J. T. CARSON

Geology and mineral possibilities of Vancouver Island

Presented at the 1969 Annual Meeting of the Prospectors and Developers Association

By J. E. MULLER* and D. J. T. CARSON**

■ Increased exploration activity of the last years on Vancouver Island warrants a review of the presently known geology and its relationships to mineral deposits. A considerable body of geological knowledge has accumulated since the early explorations of the coal-fields (1872-1878) by Richardson and the coastal reconnaissance by Dawson (1887). Important contributions were made by Clapp, Mackenzie, Dolmage, Gunning, Buckham, Jeletzky and Hoadley of the Geological Survey of Canada and Stevenson, Sargent, Fyles, Jeffery and Eastwood of the British Columbia Department of Mines. Of the present writers Muller undertook in 1963 the systematic reconnaissance mapping and Carson examined a large number of representative mineral deposits. The geological compilation shown in Figure 1 is based on the work of all those named. It is similar to an unpublished map placed on open file with the Geological Survey in 1968, but the part west of longitude 26° is revised on the basis of 1968 fieldwork. The geology of the area southwest of Cowichan Lake is based on very limited information.

Sequence of formations

The island is underlain chiefly by two main groups of predominantly volcanic rocks with subordinate clastic and calcareous marine sediments of late Palaeozoic to middle Mesozoic age. The oldest, Sicker Group, consists mainly of 5,000 feet or more of volcanic tuff and breccia of intermediate composition. These rocks are altered and in certain zones converted to chlorite-schist and sericite-schist with intense shear-folding. A few thousand feet of middle Pennsylvanian and argillite overlying the volcanic rocks are also highly folded. At the top of the group a maximum 1,000 feet of Lower Permian Buttle Lake limestone, intruded in places by diabase-sills, appears to be only slightly disturbed.

Deposition of the succeeding Vancouver Group may have been preceded by a period of uplift and erosion as indicated in places by a basal conglomerate with clasts of Sicker Group rocks. The Vancouver Group is the thickest and the most wide-spread rock unit and is divided into three formations.

The Karmutsen Formation consists of 5,000 to 20,000 feet of slightly altered, basaltic pillow lavas and related breccias (mainly in the lower part) and regular, massive, commonly amygdaloidal and porphyritic lava-flows, of Triassic and possibly Permian age.

The Quatsino Formation, overlying the Karmutsen, is 500 to 2,000 feet thick and ranges upward from massive grey to thin-bedded black limestone, in places with an upper part of calcareous greywacke and limestone-breccia. In some areas the Quatsino consists of two or three limestone-layers 10 to 100 feet thick, separated by several 100 feet of Karmutsen-type basaltic rocks.

The Bonanza Subgroup, possibly up to 8,000 feet thick and the youngest part of the Vancouver Group, contains a lower division of altered basaltic to andesitic tuff, breccia and lava, interbedded with Lower Jurassic greywacke and argillite. The upper division consists largely of commonly red-coloured felsitic lavas, tuffs, breccias and ignimbrites.

The Westcoast Gneiss Complex, of hornblende-plagioclase-gneiss and amphibolite, is probably the product of regional metamorphism of Sicker and Vancouver Group rocks, recrystallized during a major Middle Jurassic orogeny. Hornblende diorite and agmatite, also common in the westcoast area, are inferred to be the result of further migmatization of the same rocks. The gneiss complex grades eastward into the Island Intrusions, large batholiths of granodioritic to quartz dioritic com-

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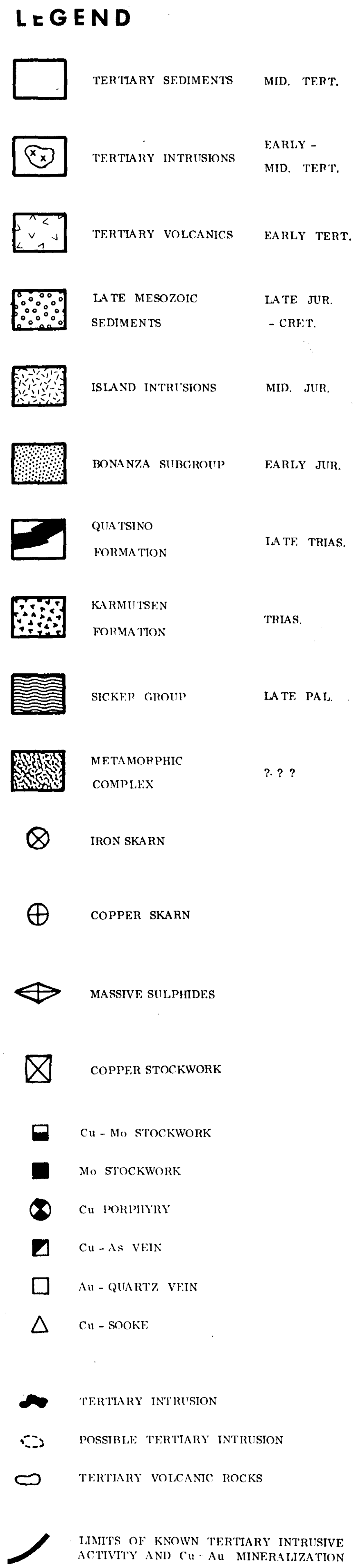

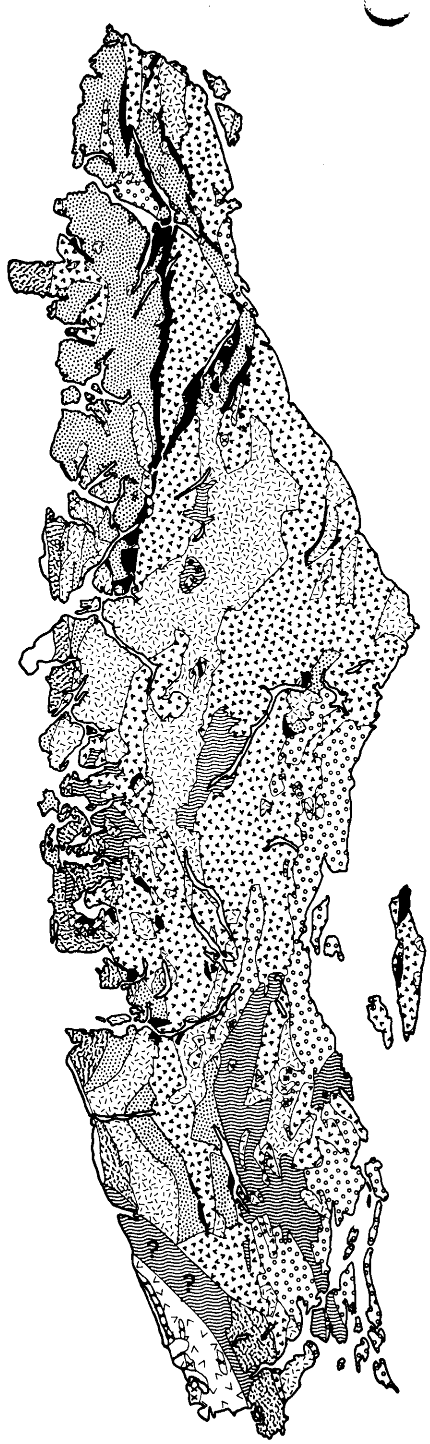

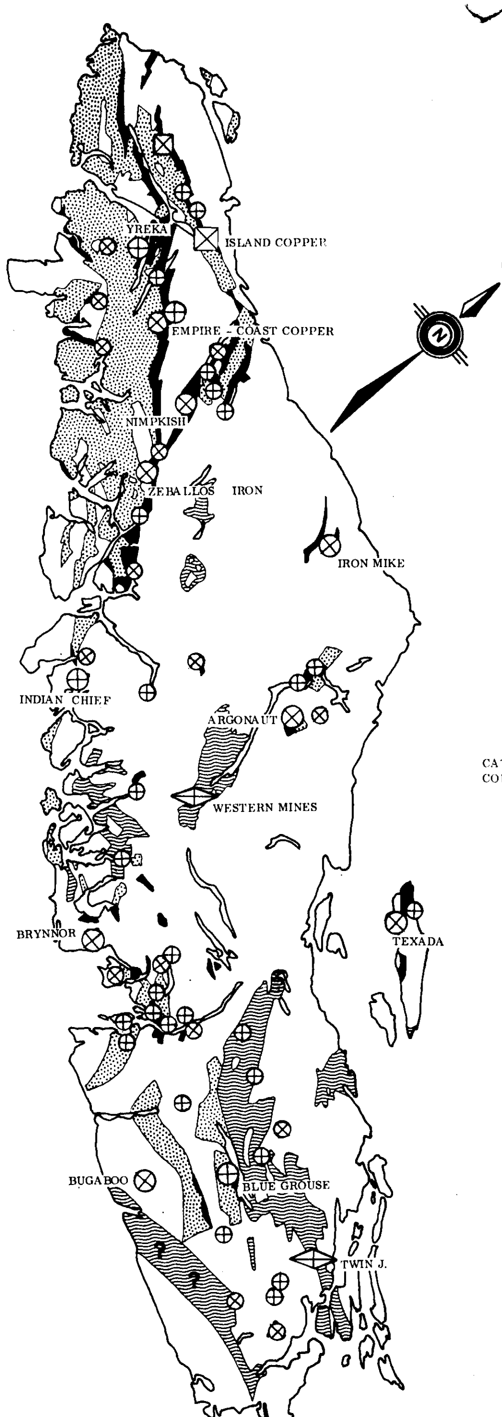

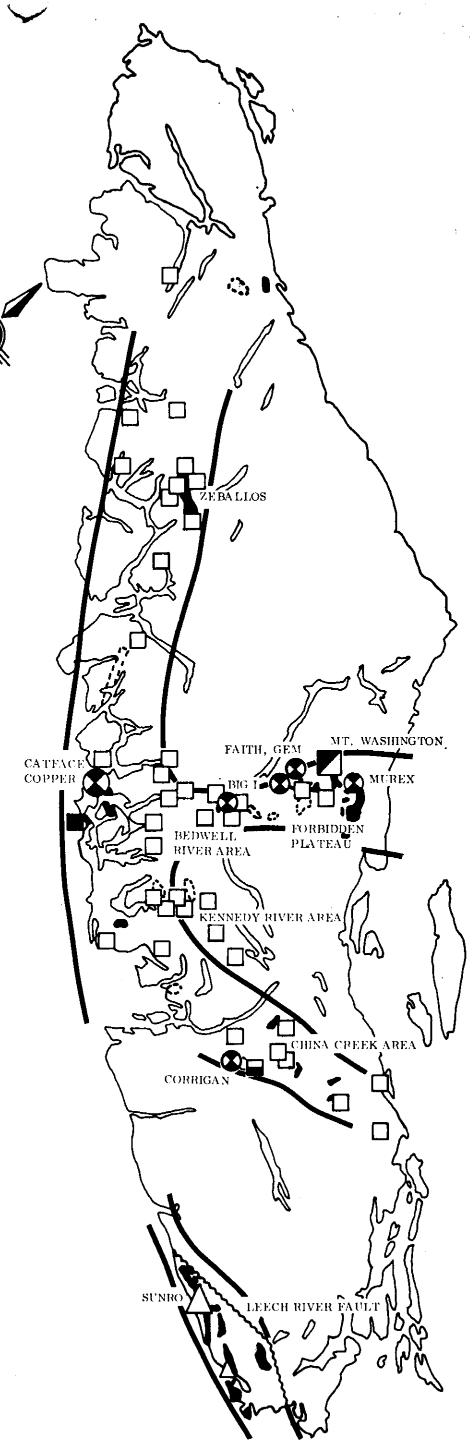

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Fig. 1 Geological map of Vancouver Island

Fig. 2 Distribution of Sicker group, Quatsino formation, Bonanza subgroup and associated mineral deposits

Fig. 3 Known and probable tertiary mineral deposits and zones of tertiary intrusive activity position that have invaded both Sicker and Vancouver Group rocks. Potassium-argon ages, obtained on these rocks range from 167 to 143 million years, indicating Middle to Upper Jurassic age.

Greywacke, sandstone, conglomerate and shale form a major assemblage that was laid down unconformably on both older groups and on the granitic rocks after considerable uplift and erosion. The older Upper Jurassic to Lower Cretaceous sediments form a clastic wedge on the western side of the island. The younger Upper Cretaceous Nanaimo Group of conglomerate, sandstone, shale and commercial coal forms another wedge along the eastern side. The detailed stratigraphy of these fluvio-deltaic to marine sediments is now well established.

Metchosin basaltic volcanics of probable Eocene age are present only at the south end of the island. They are intruded by gabbroic and granitic stocks, the Sooke Intrusions. Other intrusions of Tertiary age, mostly stocks and sills of quartz diorite and dacite porphyry, intrude Nanaimo Group and older rocks in several areas.

Oligocene to Miocene sandstone, shale and conglomerate, the youngest deposits, form a narrow wedge along part of the west coast and unconformably overlie various older rock-groups.

Structure

The oldest structures, marked by the Buttle Lake, Horne Lake, and Nanoose axes, are three north-northwest trending arches that expose oldest Sicker rocks and were probably positive elements since late Palaeozoic time. The arches are bounded by faults or flexures. Shearfolding of the Palaeozoic rocks appears to be confined to broad fault-zones, trending northerly to northwestly. Folding in the Vancouver Group is restricted to broad tilting of the massive Karmutsen and Bonanza volcanic rocks but is locally intense in the thinly-bedded sediments, mainly along fault-zones and intrusive contacts. Post-intrusive sediments generally dip gently and uniformly within the fault-blocks but exhibit severe disturbance and steep dips in fault-zones.

A structural style of block-faulting prevails throughout the island. The faults are steeply dipping normal and reverse faults and in some a strike-slip component of movement is indicated. Although the predominant direction is northwest, another set of northeasterly to northerly striking faults intersects and in several instances offsets the northwesterly faults. Many faults are clearly marked by topographic lineaments marked by valleys, lakes and tidal inlets. On the west coast they are locally well exposed and some exhibit mylonite and crushed rock in zones up to several hundred feet wide.

Mineral possibilities

General

The most important metals found on Vancouver Island are Cu, Fe, Zn, Mo, Au and Ag. Many types of deposits are present and the following classes are of considerable economic importance as past, present or possible future producers.

Class of deposits	Examples	Metals	Host rocks	Related intrusions
Massive zinc-copper sulphides	Western Mines Twin J	Zn, Cu, Pb (Ag, Au, Ba)	Palaeozoic Sicker Volcanics	None
Iron + copper skarns	Brynnor Coast Copper etc.	Fe, Cu (Au, Ag)	Quatsino Limestone + adjacent volcanics and intrusions	Jurassic granitic intrusions
Copper-molybdenum stockworks	Island Copper Hep	Cu, Mo (Ag, Au)	Jurassic Bonanza sediments and volcanics	Granitic (porphyritic) intrusions
Molybdenum stockworks	Allies	Mo (Cu)	Potassic Jurassic + Tertiary intrusions	Potassic Jurassic + Tertiary intrusions
Porphyry coppers	Catface Gem	Cu (Mo, Au, Ag)	Tertiary intrusions + adjacent host rocks	Tertiary stocks + plugs
Gold-quartz veins	Privateer Musketeer etc.	Au, Ag (Pb, Zn, Cu, As)	All rocks, Palaeozoic to Tertiary	Deposits are in zones of Tertiary intrusive activity
Sooke copper deposits	Sunro	Cu	Tertiary basalts and gabbros	Tertiary gabbros

A knowledge of the differences among the above classes is essential to the exploration geologist because each class has its own geological setting, geochemical expression, and geophysical response.

On Vancouver Island, orthoclase-rich true granites and the metals generally associated with acidic and pegmatitic granitic rocks (Li, Be, U, etc.) are very rare, possibly due to a thin continental crust at the Pacific margin. Also, because the oldest rocks are late Palaeozoic (Figure 1), the Pb-Zn-Ag deposits typical of late Precambrian and early Palaeozoic sediments of the eastern British Columbia and Yukon are missing.

Massive sulphides

Two massive Zn-Cu sulphide deposits are Western Mines (Jeffery, 1965) and the inactive Twin J mine (Stevenson, 1945). They are shown in Figure 2. The host rocks for these deposits are sheared cherty tuffs and volcanic breccias of the Sicker Group. The orezones are tabular, lens-like, and irregularly-shaped and are a few to several hundred feet long. Ore minerals sphalerite, pyrite, chalcopyrite, galena, and tetrahedrite generally constitute more than fifty per cent of the material in the orezones. Barite is a major gangue mineral.

The authors believe that the metals were deposited at the same time as their Sicker host rocks, though further concentration of metals may have occurred during later deformation and metamorphism.

Exploration for massive Zn-Cu sulphide deposits should be restricted to areas underlain by sheared volcanic tuffs and breccias of the Sicker Group. Sicker rocks underlie less than fifteen percent of Vancouver Island (Figure 2). Geological investigations may reveal that the host cherty tuff horizons are at a definite stratigraphic position in the Sicker Group. Abundant disseminated pyrite is found on the fringes of the known deposits and could be a useful guide in exploration.

Geochemically, Zn and Cu are the most obvious indicator metals and other metals, such as Mo, would not be expected. Geophysical surveys should be planned to allow that the massive sulphide orebodies are non-magnetic conductors.

Iron and copper skarn deposits

As shown in Figure 2 iron and copper skarn deposits are abundant on Vancouver Island. Most of the largest known deposits yielded ore in the past and are named on the figure. Only Coast Copper is being mined at the present. The ore minerals in the skarn deposits are magnetite and chalcopyrite, either of which may predominate. Some uneconomic Zn-Pb and Mo-Cu skarns also occur on Vancouver Island.

The largest skarn deposits are at or near to the contact between Triassic Quatsino limestone and Jurassic intrusions. Host rocks may be limestone, volcanic rocks or intrusive rocks. Faulting and deformation are anomalously intense in the vicinity of the deposits (Sangster, 1964; Eastwood, 1965).

Geochemical methods utilizing stream silts and soils, and magnetic and electromagnetic surveys, are useful in exploration for copper and iron skarn deposits. However, much caution should be employed because the great majority of the skarn deposits are small erratic lenses and pockets that do not justify extensive exploration

Copper-molybdenum stockworks

Copper-molybdenum stockworks are defined here as large zones of low grade fracture-filling and disseminated copper mineralization, generally with minor molybdenite, which are somewhat similar to porphyry copper deposits but do not occur within intrusive complexes. However, granitic and porphyritic stocks or plugs that are probably the sources of the ore are generally nearby. Also, porphyritic dykes and sills are present at the mineralized zones. Because copper-molybdenum stockworks are not within intrusions, local stratigraphy, and local structures not directly related to intrusive activity, are more important ore controls than they are for porphyry copper deposits.

Several promising prospects including the Island Copper deposit of Utah Mining and Construction Company near Port Hardy (Figure 2) are of this class. Somewhat similar deposits on the British Columbia mainland, are the Ingerbelle and Copper Mountain orebodies near Princeton.

Island Copper is the largest copper deposit yet discovered on Vancouver Island. It contains more than 180 million tons grading 0.52% copper and 0.25% molybdenite. The ore is in silicified andesitic volcanics and greywackes of the lower Bonanza Formation. It is spatially and probably genetically related to a Jurassic granodiorite porphyry stock at the east end of Rupert Inlet (Figure 1) and a dyke (?) of similar composition occurs near the ore zone. This deposit may owe its origin to a copper-rich intrusion which, unlike most Jurassic intrusions, continued upward past the Quatsino limestone (site of the Cu, Fe skarns) and expelled its metals into a favourable structure in the overlying Bonanza Formation. The Bonanza rocks are hydrothermally altered and pyritized for several thousand feet outward from the ore-zone. Skarn mineralization occurs in Quatsino limestone that is exposed about one mile north of Island Copper (Figure 2).

Assuming that the origin of the Island Copper deposit is as suggested above, exploration for similar deposits should be restricted to the Bonanza Formation, and in the vicinity of intrusions, preferably porphyritic. Detailed mapping of the Bonanza may reveal that a given stratigraphic level, such as the contact between the lower sedimentary and upper volcanic units, was favoured by rising copper-bearing intrusions. Other exploration targets are strong faults and hydrothermal alteration and pyritization of the Bonanza.

Geochemical soil surveys to detect Cu and Mo were apparently most useful in helping to delimit the Island Copper orebody. In regional stream silt surveys, the Mo content should serve to distinguish this type of deposit from the widespread sporadic syngenetic copper found in basalts of the Karmutsen Formation.

Magnetic surveys tend to outline skarn deposits which are at some distance from the known copper-molybdenum stockworks, and also some peripheral uneconomic magnetite-chalcopyrite stringers. The response of copper-molybdenum stockworks to induced polarization surveys is probably overshadowed by the effects of widespread peripheral pyrite.

Molybdenum stockworks

A few molybdenum stockwork occurrences in geological environments that are somewhat similar to Endako and Boss Mountain mines, are present on Vancouver Island. However, none has proven to be mineable. These deposits occur in relatively silicic and potassic Tertiary stocks, or the acidic roof facies of Jurassic granodiorite batholiths. They consist of network stringers of quartz, pyrite, and molybdenite.

The Allies deposit near Cowichan Lake (Fyles, 1955) is one of the largest known occurrences. Other such deposits may be found. However, molybdenum-rich intrusions are generally very high in silica and potash feldspar, and such acidic intrusions are very rare on Vancouver Island.

Porphyry copper deposits

Known porphyry copper deposits are Catface, Big I, Gem Copper, Faith Copper, Murex and Corrigan (Figure 3). Of these, only Catface (Carr, 1964) is of probable economic value, and it is of considerable size.

The porphyry coppers consist of very large zones of low grade (1% copper) disseminated and fracture-filling copper mineralization which, unlike the copper-molybdenum stockworks are largely within intrusive complexes. The main ore minerals are chalcopyrite and pyrite. Bornite is minor and molybdenite is very minor.

Intrusions related to all the known porphyry coppers are Tertiary stocks and plugs consisting largely of quartz diorite and related porphyries (Carson, 1968). Unlike the older Jurassic intrusions, these rocks contain little or no potash feldspar and possess prominent porphyritic phases, large virtually unaltered portions, and commonly pipes and irregular zones of breccia. However, the intrusive complex at Catface consists in part of highly altered quartz monzonite.

Rocks surrounding the porphyry copper deposits are pyritized and exhibit typical porphyry copper alterations including biotitization, chloritization, kaolinization, etc. Potash feldspar alteration is not common because of the nature of the country rocks which are mainly basic volcanics.

Exploration for porphyry copper deposits should be confined to intrusive plugs and stocks in the zones of known Tertiary intrusive activity and Cu-Au mineralization (Figure 3). Hydrothermal alteration, especially pyritic and potassic (biotite), is a very useful indicator. The geophysical and geochemical responses of porphyry coppers are roughly similar to those of the copper stockworks (above).

Gold-quartz veins

Gold-quartz veins are abundant on Vancouver Island (Figure 3). Most of these veins are too small to mine but some, especially those at Zeballos (Stevenson, 1950), have in the past yielded moderate quantities of gold and silver. An increase in the price of gold could reactivate some of the old mines.

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Sooke copper deposits

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The Sunro mine is the only producer of the Sooke region, but similar deposits may be found in the Tertiary rocks south of the Leech River fault (Figure 3). □

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With written compliments R.W.Y.

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AN EARLY PERMIAN FAUNA FROM VANCOUVER ISLAND, BRITISH COLUMBIA[1]

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ABSTRACT

An Early Permian formation of the Buttle Lake area in central Vancouver Island, consists of 800 to 1000 feet of limestone, with minor chert, dolomite and sandstone. It contains a fauna of brachiopods, bryozoans, foraminifers, pelecypods, corals, gastropods and ostracods accompanied by abundant crinoidal debris. Distinctive brachiopods of the fauna include species of *Kochiproductus, Echinoconchus, Horridonia, Antiquitonia, Neospirifer?, Laevicamera,* and *Spiriferella.* Faunal relationships with the Coyote Butte Formation of central Oregon, the Black Mountain Formation of northwestern Washington, part of the Cache Creek Group of central British Columbia and certain Alaskan Permian deposits are indicated. The brachiopods also relate this fauna to a Permian boreal realm encompassing the Yukon, Arctic regions, and parts of Russia.

INTRODUCTION

Recent publications have drawn attention to the presence of similar faunas in strata referred to as "Permo-Carboniferous" or "Permian" in several regions of western Canada (Nelson, 1961a, b; 1962; McGugan and Rapson, 1962), Alaska (Dutro, 1961) and the Arctic (Dunbar, 1955; 1962a, b; Harker and Thorsteinsson, 1960). These faunas have been called the "Russian Fauna" (Warren and Stelck, in Nelson, 1961a, p. 4; McGugan and Rapson, 1962, p. 357) and the "Arctic Permian fauna" (Harker and Thorsteinsson, 1958, p. 1577; 1960, p. 15). The latter authors proposed (1960, p. 19) that "common faunal elements" suggest "a fairly free marine connection" between Arctic and western Cordilleran regions in the Permian period. Correlation of Permian faunas of British Columbia with those of Russia, China and the Tethys has been suggested by Crockford and Warren (1935, p. 160).

Vancouver Island Upper Paleozoic faunas are largely undescribed, the major exception being Fritz's (1932) descriptions of the bryozoans from the Buttle Lake area. The present writer has described brachiopods from the same area; this information is being prepared for a future publication. The identified brachiopod species, listed and discussed below, relate this fauna to the "Russian" and "Arctic Permian" faunas.

The fossils and formations discussed are from an area around the southern part of Buttle Lake in Strathcona Provincial Park, thirty miles southwest of the town of Campbell River (Fig. 1). Generalised geology of the area, and a stratigraphic diagram of the fossiliferous Permian section, are shown in Figures 2 and 3, respectively. An informal system of nomenclature for the known Paleozoic formations present in the Buttle Lake area is used herein. This is intended to serve until such time as further work has indicated the most desirable type sections for these formations.

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This paper was presented orally before the Cordilleran Section of the Geological Society of America, 59th Annual Meeting, Berkeley, California, April 9th, 1963.

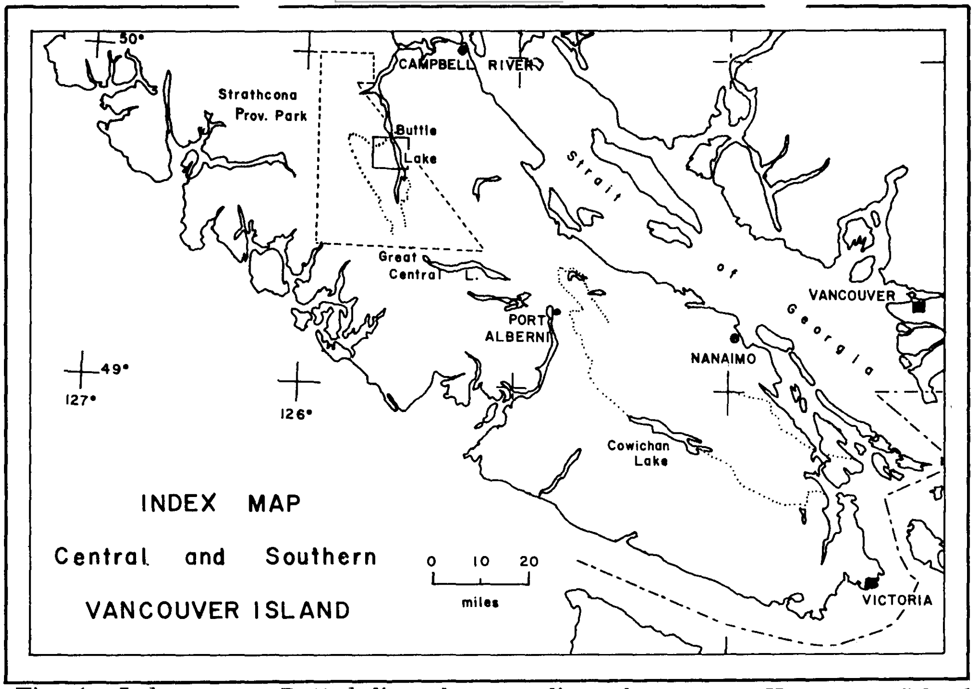

Fig. 1.—Index map. Dotted line shows outline of areas on Vancouver Island where known Upper Paleozoic rocks occur (after G.S.C. Map 932A, 2nd Ed., 1962). Rectangular area in Strathcona Park is that covered by Fig. 2.

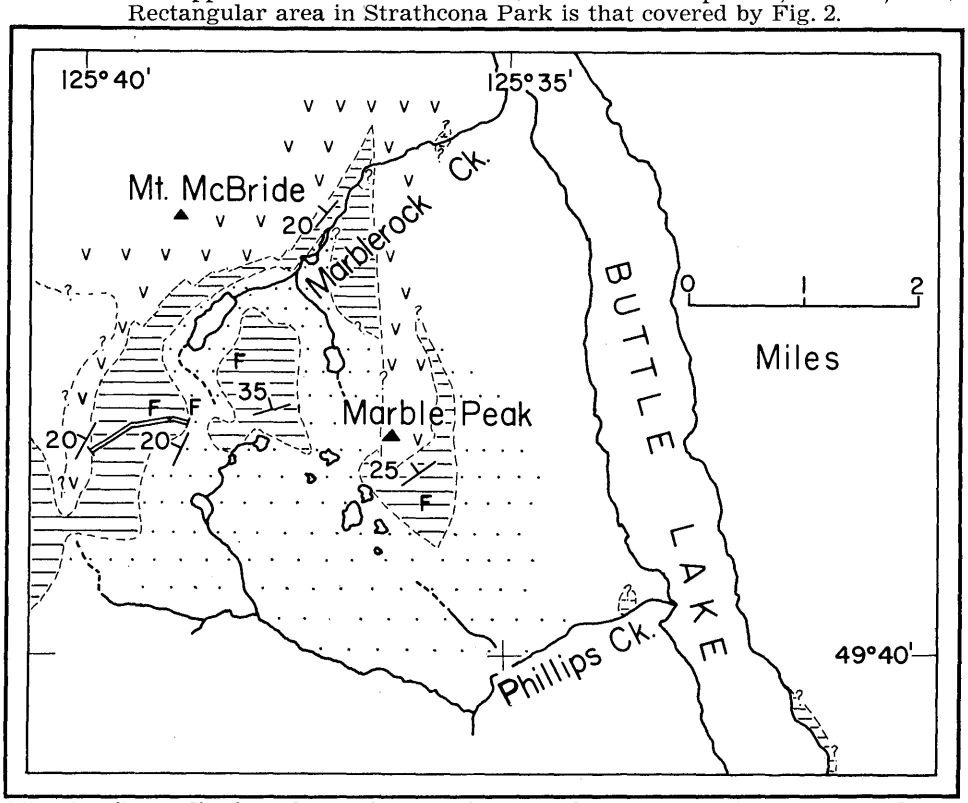

Fig. 2.—Generalised geology of part of Buttle Lake area. Horizontal shading—Formation B and associated basic intrusions. V pattern—rocks younger than Formation B (overlying clastic rocks, Vancouver Group, and associated basic intrusions. Dotted pattern—Formation A and associated intrusions. Double bar—Azure Lake section. F—fossil horizons.

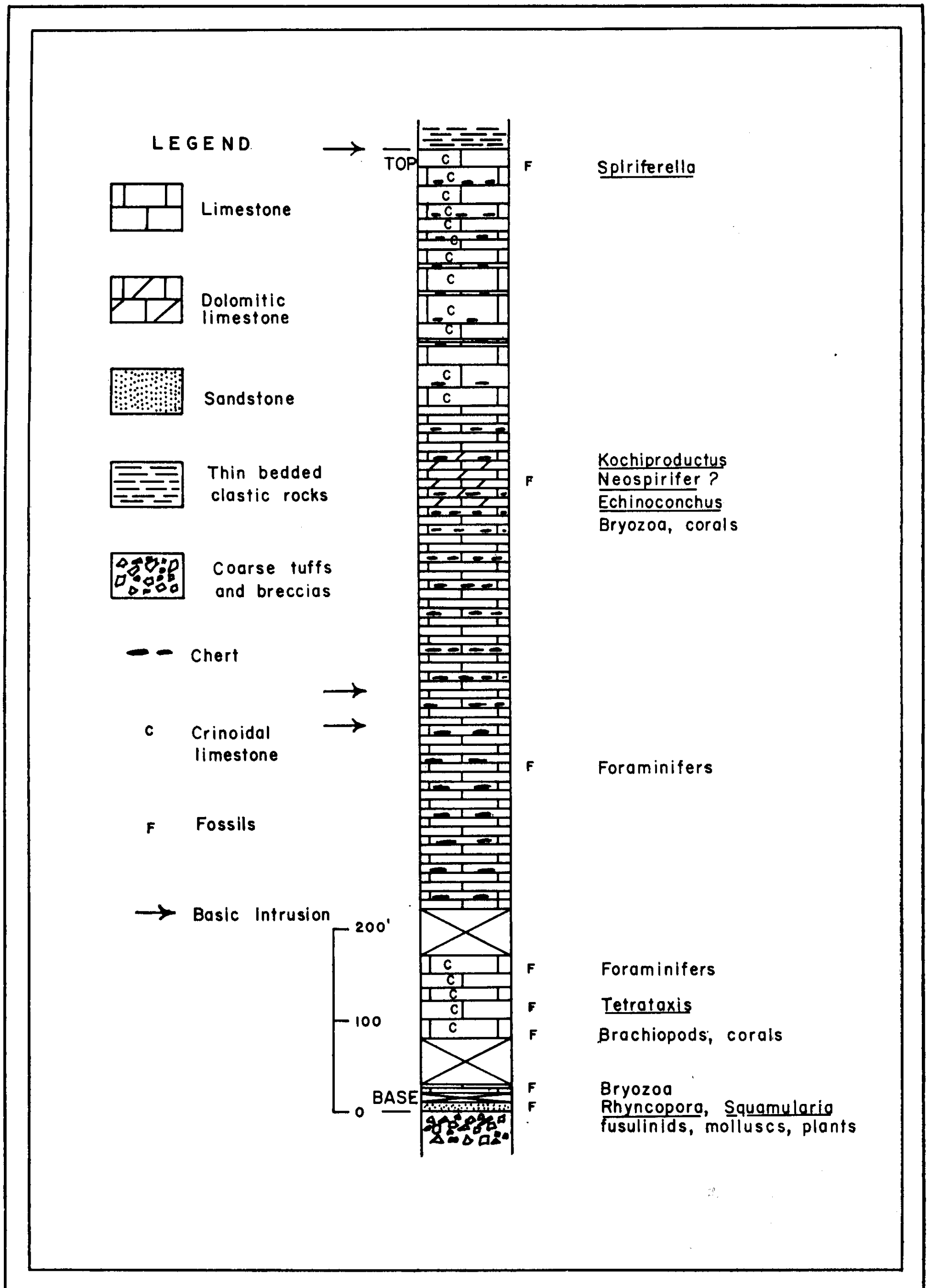

Fig. 3.—Azure Lake section, Formation B, diagrammatic. Distinctive fossils of main fossiliferous horizons indicated.

STRATIGRAPHY

The exposed Upper Paleozoic sequence of the Buttle Lake area of central Vancouver Island may be divided into at least two parts of differing lithology. The lower part of the succession, a complex unit comprised mainly of volcanic rocks, is herein referred to as Formation "A." Above formation "A" is a predominantly limestone unit, for which the term Formation "B" is used.

The rocks assigned to Formation "A," largely green tuffs and breccias, are of great thickness and lithologic variability. Rocks of this formation, reaching several thousands of feet in thickness, are well exposed on and north of Phillips Creek, below limestones of Formation "B" on the south side of Marble Peak. The base has not been seen and detailed stratigraphy of the unit is yet to be determined.

Formation "B" is a well-defined unit. The illustrated section (Fig. 3) is located near the headwaters of the north branch of Marblerock Creek, 0.8 miles southwest of the southwest end of an unnamed lake (referred to herein as "Azure Lake"). The formation here consists of a thin basal sandstone, overlain by thick limestones of the main part of the formation.

The dominant lithology of Formation "B" is medium to coarse-grained, crinoidal, sparsely fossiliferous, light-coloured limestone. Nodules and irregular thin bands of light and dark chert and silicified limestone occur in zones between massive limestone beds. At least one thick bed of dark, richly fossiliferous, dolomitic limestone is present. Dark coloured, fine-grained limestone is present in the lower part of the section. The basal 10 feet consists of brown, thin-bedded, fine to medium-grained, fossiliferous sandstone with pebbly lenses.

The lower contact of the formation is sharp and gently undulating. The basal sandstone is underlain by unstratified coarse tuffs and breccias of Formation "A."

A thick, basic, sill-like intrusion separates the uppermost limestone of Formation "B" from overlying thin-bedded, fine-grained, dark-coloured clastic rocks, in the Azure Lake section. The thickness and age of the clastic rocks have not been determined. They have attitudes similar to those of the underlying limestones of Formation "B." Several thousands of feet of volcanic rocks of the Triassic Vancouver Group, the basal portion of which is composed of basaltic pillow-lavas, occur above the clastic rocks.

The Azure Lake section of Formation "B," from the bottom of the basal sandstone to top of the uppermost massive limestone, measures approximately 1050 feet. A partial section of the formation, with the base not exposed, was obtained on Marblerock Creek, two miles northeast of the Azure Lake section. At this locality, the thickness measured is 858 feet. Transverse faults crossed in obtaining both of these sections may have increased the apparent thicknesses. Therefore, it is estimated that Formation "B" is about 800 to 1,000 feet in maximum thickness.

It should be noted that for both of these sections, only the thickness of sedimentary rocks is recorded here. Thick sill-like intrusions, within the limestones, are present in both sections; the measured thickness of one of these exceeds 300 feet; another was estimated to be 750 feet. These intrusions of dark green to black, fine to medium grained crystalline rock of basaltic composition, are a prominent feature of the Paleozoic sections of this area. At and near the Azure Lake section of Formation "B," these intrusions are mainly sill-like, with few obvious cross-cutting contacts. To the east, however, on Marble Peak, and its subsidiary ridges, the intrusions appear to be more numerous and more irregular in their outlines, disturbing the continuity of the outcrops of stratified rocks much more severely than to the west.

Gunning, (1931, p. 59) suggested the name "Buttle Lake group or formation" for all or part of the Upper Paleozoic succession in this area. The present writer considers that the sequence of Paleozoic rocks of the Buttle Lake area is equivalent to the Sicker Group (Clapp, 1909, p. 56; Fyles, 1955, p. 19) of southern Vancouver Island, and the latter name has priority. Thus, Gunning's suggested name may most conveniently be applied to a formation within the sequence. In the writer's opinion the most suitable formation to bear the name is that referred to as Formation "B" in this paper. Therefore, when further work has permitted the selection of the best type section, and formal nomenclature is adopted, it is recommended that Formation "B" be called "Buttle Lake Formation."

Formation "B" is well exposed on the east face of Marble Peak, along the north bank of Marblerock Creek, around Azure Lake, and on the narrow ridge extending southward from Mount McBride. Large areas of less precipitous ridge-top exposures are found between Marble Peak and Marblerock Creek. Gunning (1931, p. 60) mentions good exposures of the formation west of Wolf River. Poor exposures, near lake level, occur on the east side of Buttle Lake, two miles north of Ralph River (see Fig. 3). Similar exposures are known on Flower Ridge, south of the Lake. Rocks believed to correlate with Formation "B" occur in several other parts of Vancouver Island, south of Buttle Lake. Upper Paleozoic rocks have not been reported from any area of Vancouver Island north or west of the Buttle Lake area. The general distribution of Upper Paleozoic rocks, and limestone bodies, is indicated by Mathews (1947, Fig. 20) and Mathews and McCammon (1957, Fig. 3).

PALEONTOLOGY

The fauna of Formation "B" is rich and varied (see Plates I, II, and faunal list). The principal groups represented are crinoids (as disarticulated skeletal plates), brachiopods and bryozoans. Less common are foraminifers, gastropods, pelecypods, corals and ostracods. A sparse flora of calcareous algae and vascular plant fragments is represented in the basal unit of the formation.

No fossils have so far been found in Formation "A." The following discussion is based on some of the significant fossils of Formation "B."

Gunning's collection of bryozoans from Formation "B" was identified and described by Dr. M. A. Fritz in 1932. Species of *Stenopora, Rhombopora, Streblascopora, Clausotrypa, Fenestella, Polypora, ?Thamniscus, Acanthocladia, Penniretepora, Goniocladia* and *Protoretepora* were recognised. Most of these species have also been found in the writer's collections, with *Rhabdomeson* sp. and others not reported by Fritz.

Gunning (1931, p. 59) submitted another collection, including brachiopods, to G. H. Girty, who reported on the age, but apparently did not describe the fossils. Brachiopods from limestones at or near Gunning's collecting locality have been identified and described by the present writer; the most abundant fossils belong to species of *Kochiproductus, Neospirifer?, Spiriferella,* and *Echinoconchus.* Less abundant are species of *Horridonia, Laevicamera, Antiquitonia, Hustedia* and other genera.

Foraminifers are not common in Formation "B." *Tetrataxis* sp., a small unidentified fusulinid, and several minute indeterminate forms comprise the small collection of this group from the Buttle Lake area.

PARTIAL FAUNAL LIST FORMATION "B"

Acanthocladia multipora Fritz
Clausotrypa spinosa Fritz
Fenestella basleoensis Bassler
F. parviuscula Bassler
F. cf. *F. pulchradorsalis* Bassler
F. cf. *F. rottiensis* Bassler
Goniocladia intermedia Fritz
Penniretepora grandis (Fritz)
Polypora consanguinea Bassler
P. elongata Fritz
P. cf. *P. macrops* Bassler
P. megastoma (Koninck)
P. sykesi (Koninck)
P. vancouverensis Fritz
Protoretepora cf. *P. haimeana* (Koninck)
Rhabdomeson sp.
Rhomboporea porifera Fritz
Stenopora prolifica (Fritz)
?Thamniscus unilateralis Fritz
Tetrataxis sp.
Fusulinids
Cladochonus? sp.
Caninia? sp.
Antiquitonia sulcata Cooper
Avonia? sp.
Cleiothyridina cf. *C. gerardi* (Diener)
Echinoconchus inexpectatus Cooper
Horridonia sp. A.
H. sp. B.
Hustedia cf. *H. meekana* (Shumard)
Kochiproductus n. sp.
Krotovia? sp.
Laevicamera n. sp.
Muirwoodia? sp.
Neospirifer? n. sp.
N. sp.
Rhyncopora cf. *R. magna* Cooper
"Spirifer" cf. *S. ufensis* (Tschern)
Spiriferella cf. *S. saranae* (deVerneuil)
Sqamularia cf. *S. rostrata* (Kutorga)
Parallelodon? sp.
Aviculopecten? sp.
Gastropods
Ostracods

AGE AND CORRELATION

The bryozoan faunule from the Buttle Lake area was stated by Fritz to be of Permian age, with closest affinities to a Permian fauna of Timor (1932, p. 93). According to Girty (Gunning, 1931, p. 59), the brachiopods indicated Late Pennsylvanian, rather than Permian age.

Of the bryozoan species from the Buttle Lake area described by Fritz as new, none has been reported from other localities, to the present writer's knowledge. A species similar to *Streblascopora pulchra* (Fritz) has been found in Upper Permian rocks of Japan (Sakagami, 1961, p. 11). *Fenestella basleoensis* and *F. parviuscula,* or closely related forms, have been reported from Lower Permian beds of Texas, Russia and Australia, in addition to the original Timor locality and Buttle Lake area (Elias and Condra, 1957, p. 78, p. 108). A species related to *F. parviuscula* has been found in the Upper Permian of Japan (*Sakagami,* 1961). Three of the Buttle Lake bryozoans are Salt Range (Pakistan) species; of these, one (*Polypora megastoma*) has been reported from the Upper Carboniferous, in addition to its Permian occurrences (Branson, 1948, p. 270).

As shown in Table I, many of the brachiopods of Formation "B" are Permian, or Upper Carboniferous and Permian species, or have close affinities with species of such ages. Until the Vancouver Island fauna has been more completely studied and collected, statistical correlation with other faunas of similar age is perhaps not warranted. From the data already available, affinities with the Early Permian fauna of the Coyote Butte Formation of Central Oregon are evident. Relationship with the "Permo-Carboniferous" fauna of the Yukon, the "Arctic Permian" fauna, and the fauna of part of the Cache Creek Group

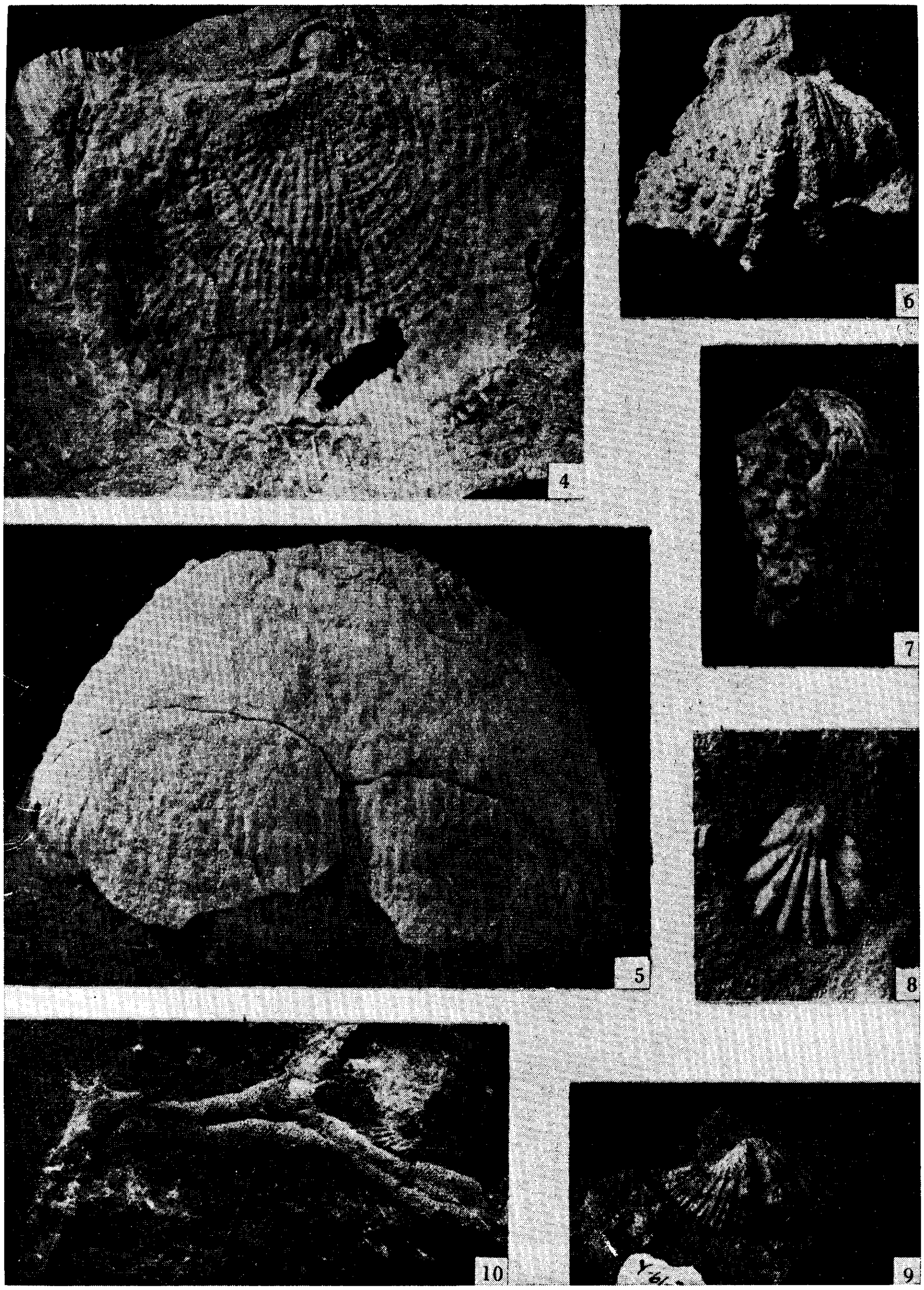

PLATE I.

All figures natural size unless otherwise indicated.

Figs. 4, 5.—*Kochiproductus* n. sp. 4, Brachial view, specimen UBC 20002. 5, Pedicle view, UBC 20001.

Figs. 6, 7.—*Spiriferella* cf. *S. saranae* (de Verneuil). 6, Pedicle view, UBC 20069. 7, Lateral view, same specimen.

Fig. 8.—*Hustedia* cf. *H. meekana* (Shumard), Pedicle view, UBC 20059, x2.

Fig. 9.—*Neospirifer* sp., Pedicle view, UBC 20070.

Fig. 10.—*Stenopora prolifica* (Fritz). External view, UBC 20105.

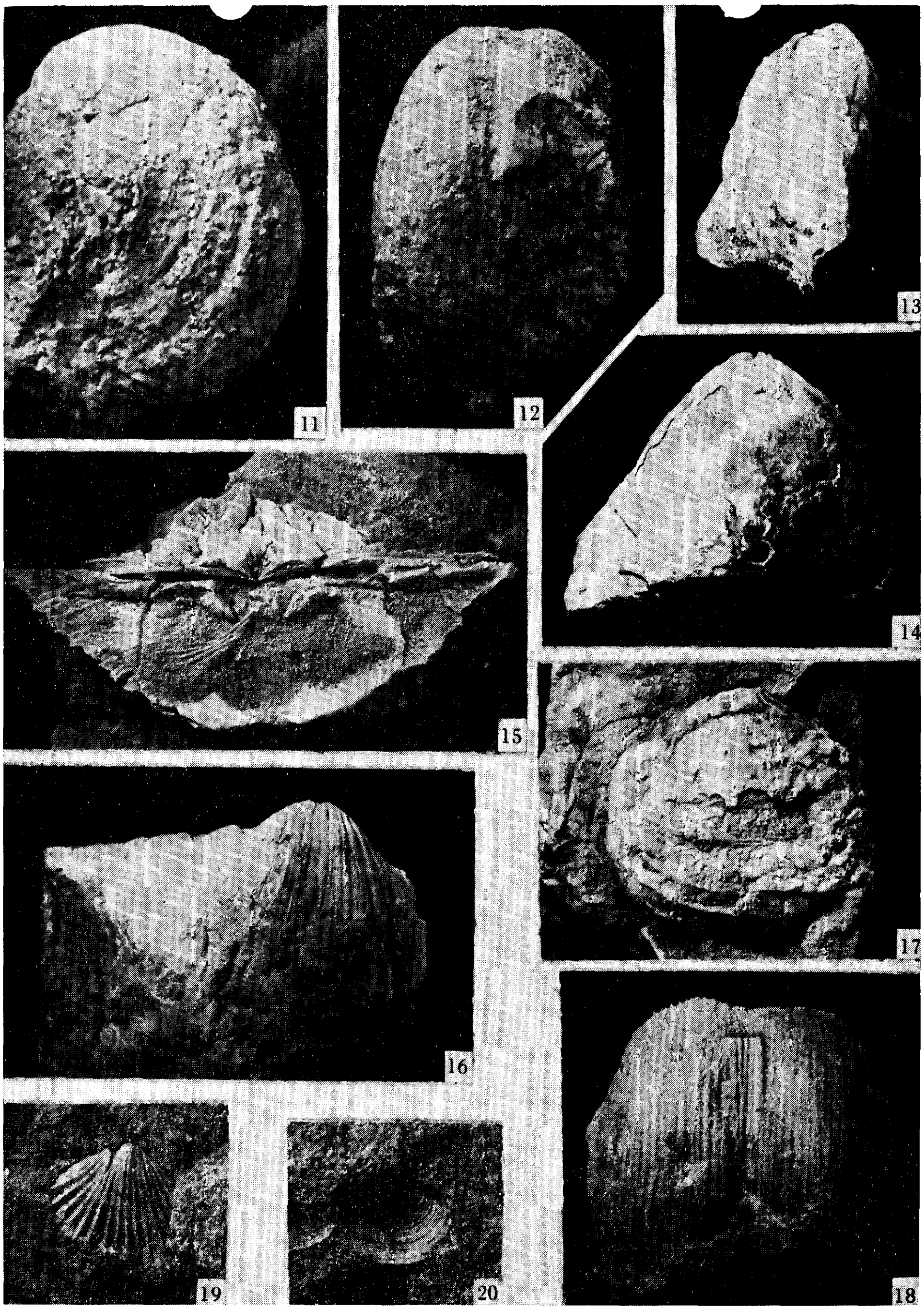

PLATE II.

All figures natural size.

Gigs. 11, 12.—*Horridonia* sp. A. 11, Lateral view, UBC 20200, from Horne Lake. 12, Pedicle view, same specimen.

Figs. 13, 14.—*Laevicamera* n. sp. 13, Lateral view, UBC 20062. 14, Brachial view, same specimen.

Figs. 15, 16.—*Neospirifer?* n. sp. 15, Internal view, UBC 20013. 16, Pedicle view, UBC 20016.

Fig. 17.—*Echinoconchus inexpectatus* Cooper, Pedicle view, UBC 20039.

Fig. 18.—*Antiquitonia sulcata* Cooper, Pedicle view, UBC 20054.

Fig. 19.—*Rhyncopora* cf. *R. magna* Cooper, Pedicle view, UBC 20084.

Fig. 20.—*Squamularia* cf. *S. rostrata* (Kutorga), External mold, brachial valve, UBC 20095.

TABLE I.

	VI	NWW	CO	CBC	A	Y LLs	Y T	GP Bc	GP Ass	NR
Fenestella basleoensis	O	G		X	G					O(L)
Fenestella parviuscula	O									X(L)
Goniocladia intermedia	O				G					*X*
Polypora megastoma	O	G		G	G		G			O(UC)
Antiquitonia sulcata	O		O	X(L)	X				X	*X*
Cleiothyridina gerardi	X		O		G		G			*X*
Echinoconchus inexpectatus	O		O		X		X			*X*
Horridonia sp. A	O		X		X?	X?	X?			*X*?
Horridonia sp. B	O				X?	X?	X?			X?
Hustedia cf. *H. meekana*	O				X		X			
Kochiproductus n. sp.	O		O		X		X		X	X(L)
Krotovia? sp.	O		X		G		G			
Laevicamera n. sp.	O				X(L?)					*X*
Neospirifer? n. sp.	O			X	X	X?	X?		X?	*X*
Rhyncopora magna	X		O	G	G		X			
"*Spirifer*" cf. *S. ufensis*	X				X(L?)	O				*X*
Spiriferella saranae	X		X	X	X		X	X	X	O
Squamularia rostrata	X		O	X	G		G		G	O
Tetrataxis	G			G(U)						G
Parafusulina							G	G		
Parafusulina alaskensis					O(L)					X(L)
Parafusulina? calx			O	X(L)						
Parafusulina gracilis			O	O(L)						
Parafusulina? turgida			O	X(L)						
Pseudofusulinella		G						G		
Pseudofusulinella montis			O	X(L)						
Pseudofusulinella occidentalis			O	O(L)						
Schubertella kingi				O(L)				O		G
Schwagerina		G	G	G(L)			G	G		G

LEGEND: O—species present. X—related species; *X*—also in Upper Carboniferous. G—genus present. (L), (U), (UC)—Lower Permian, Upper Permian, Upper Carboniferous occurrence.

COLUMN HEADINGS: VI—Vancouver Island, ~~Buttle Lake~~ Formation. b NWW—Northwest Washington, Black Mountain Formation (Wolfcamp?). CO—Central Oregon, Coyote Butte Formation (Wolfcamp-Leonard). CBC — Central B.C., Cache Creek Group (Pennsylvanian? and Permian). A—Alaska, Permian. Y — Yukon and Alaska border, Permo-Carboniferous; LLs — Lower Limestone (Pennsylvanian?), T—Tahkandit Formation (Leonard?). GP — Grinnell Peninsula, Permian; Bc—Belcher Channel Formation (Wolfcamp-Lower Leonard); Ass—Assistance Formation (Upper Leonard). NR—Northwestern Russia, Permian.

SOURCES: Danner, 1957. Cooper, 1957. Dunbar et al, 1960. Aitken, 1959. Armstrong, 1958. Fritz, 1932, 1946. Jones, 1959. Lord, 1948. Trettin, 1961. Buddington and Chapin, 1929. Dunbar, 1946, Moffitt, 1938, 1954. Wright and Wright, 1908. Nelson, 1961a,b; 1962. Mertie, 1930. Harker and Thorsteinsson, 1960. Branson, 1948. Elias and Condra, 1957. Dutro, 1961.

Table I.—Distribution of certain key fossils in Cordilleran, Arctic and Russian regions.

of mainland British Columbia and Permian beds of Alaska is also apparent. Similar faunas also have been reported from eastern parts of the Canadian Cordilleran region (McGugan and Rapson, 1962).

The fusulinids found to date in Formation "B" of the Buttle Lake area are not diagnostic as to horizon or age. However, fusulinids from the Coyote Butte Formation have been identified (Henbest, *in* Dunbar *et al.*, 1960, p. 1781), and are stated to be of Early Permian (Late Wolfcampian-Leonardian) age. *Schwagerina* and *Pseudofusulinella,* two of the genera represented in the Coyote Butte, occur also in the Early Permian Black Mountain Formation of northwestern Washington (Danner, 1957, p. 152). Pitcher (1960, pp. 19, 21, 23) identified several of the Coyote Butte species of *Pseudofusulinella* and *Parafusulina*, together with *Schwagerina,* in the Early Permian part of the Cache Creek Group of the Stikine River area. Early Permian fusulinids have also been reported from the Cache Creek Group of the Fort St. James area (Armstrong, 1949, p. 45) and of the McConnell Creek area (Lord, 1948, pp. 11, 12).

The evidence presented above suggests that Formation "B" of the Buttle Lake area of Vancouver Island is most probably of Early Permian age. It can be correlated, in whole or part, with the Coyote Butte Formation, the Black Mountain Formation, and the Early Permian portion of the Cache Creek Group. The Permo-Carboniferous sections of the Yukon, the Permian rocks of the Arctic, and Permian beds of Alaska and other Cordilleran regions, contain faunas with distinct relationships to that of Formation "B," and may also include correlatives of the Vancouver Island formation.

DISCUSSION

Harker and Thorsteinsson (1960, p. 19) have suggested that the Arctic Permian fauna represents a widespread Early Permian (Leonardian; Artinskian-Kungurian or Svalbardian) faunal realm. However, several important problems remain to be resolved before the temporal and geographic limits of this "boreal" (Newell, 1957, p. 426) realm can be accurately defined. Strata associated with deposits of this realm may include also some of Pennsylvanian and earliest Permian (Wolfcampian, Sakmarian) (Harker and Thorsteinsson, 1960, p. 9; Nelson, 1961a, p. 4, etc.), or even Late Permian age (Zechstein, Dunbar, 1955, p. 52, *etc.*; Kamian, Dutro, 1961, p. 226). The brachiopod faunules, especially species of *Horridonia,* appear to have predominantly boreal distribution (Gobbett, 1962). Yet the bryozoans, at least of the Vancouver Island Permian, have distinct Asian and Indo-Pacific affinities. "Middle" and Upper Permian fusulinids of northwestern North America seem to have strong Tethyan affinities (Thompson, Wheeler and Danner, 1950, pp. 46, 47). Thus, at the present stage of investigation, different faunal elements suggest significantly differing interpretations of Cordilleran Permian biogeography. Comprehensive studies of the total faunas of the several regions involved are necessary before such problems may be resolved.

CONCLUSIONS

A formation of dominant limestone lithology is a prominent and persistent unit in the upper part of the Paleozoic succession of the Buttle Lake area of central Vancouver Island. The fauna of the formation indicates a probable Early Permian (Wolfcampian-Leonardian?) age, and is related to a widespread boreal realm. The formation can be correlated with such other Cordilleran formations as the Coyote Butte of central Oregon, the Black Mountain Formation of Washington and part of the Cache Creek Group.

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AN EARLY PERMIAN FAUNA FROM VANCOUVER ISLAND, BRITISH COLUMBIA[1]

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ABSTRACT

An Early Permian formation of the Buttle Lake area in central Vancouver Island, consists of 800 to 1000 feet of limestone, with minor chert, dolomite and sandstone. It contains a fauna of brachiopods, bryozoans, foraminifers, pelecypods, corals, gastropods and ostracods accompanied by abundant crinoidal debris. Distinctive brachiopods of the fauna include special of *Kochiproductus, Echinoconchus, Horridonia, Antiquitonia, Neospirifer?, Laevicamera,* and *Spiriferella.* Faunal relationships with the Coyote Butte Formation of central Oregon, the Black Mountain Formation of northwestern Washington, part of the Cache Creek Group of central British Columbia and certain Alaskan Permian deposits are indicated. The brachiopods also relate this fauna to a Permian boreal realm encompassing the Yukon, Arctic regions, and parts of Russia.

INTRODUCTION

Recent publications have drawn attention to the presence of similar faunas in strata referred to as "Permo-Carboniferous" or "Permian" in several regions of western Canada (Nelson, 1961a, b; 1962; McGugan and Rapson, 1962), Alaska (Dutro, 1961) and the Arctic (Dunbar, 1955; 1962a, b; Harker and Thorsteinsson, 1960). These faunas have been called the "Russian Fauna" (Warren and Stelck, in Nelson, 1961a, p. 4; McGugan and Rapson, 1962, p. 357) and the "Arctic Permian fauna" (Harker and Thorsteinsson, 1958, p. 1577; 1960, p. 15). The latter authors proposed (1960, p. 19) that "common faunal elements" suggest "a fairly free marine connection" between Arctic and western Cordilleran regions in the Permian period. Correlation of Permian faunas of British Columbia with those of Russia, China and the Tethys has been suggested by Crockford and Warren (1935, p. 160).

Vancouver Island Upper Paleozoic faunas are largely undescribed, the major exception being Fritz's (1932) descriptions of the bryozoans from the Buttle Lake area. The present writer has described brachiopods from the same area; this information is being prepared for a future publication. The identified brachiopod species, listed and discussed below, relate this fauna to the "Russian" and "Arctic Permian" faunas.

The fossils and formations discussed are from an area around the southern part of Buttle Lake in Strathcona Provincial Park, thirty miles southwest of the town of Campbell River (Fig. 1). Generalised geology of the area, and a stratigraphic diagram of the fossiliferous Permian section, are shown in Figures 2 and 3, respectively. An informal system of nomenclature for the known Paleozoic formations present in the Buttle Lake area is used herein. This is intended to serve until such time as further work has indicated the most desirable type sections for these formations.

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This paper was presented orally before the Cordilleran Section of the Geological Society of America, 59th Annual Meeting, Berkeley, California, April 9th, 1963.

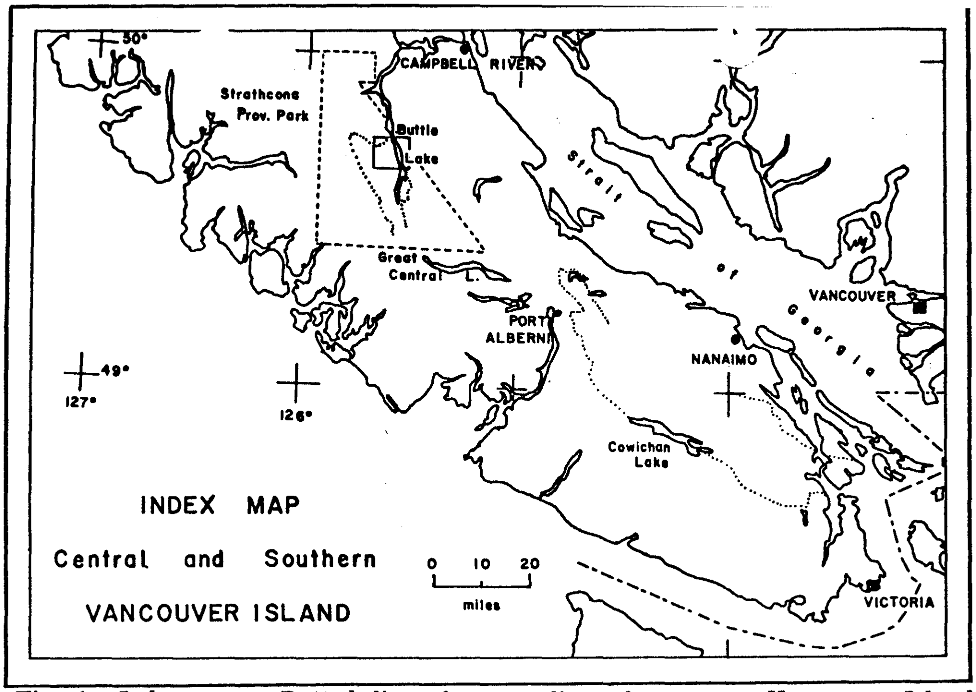

Fig. 1.—Index map. Dotted line shows outline of areas on Vancouver Island where known Upper Paleozoic rocks occur (after G.S.C. Map 932A, 2nd Ed., 1962). Rectangular area in Strathcona Park is that covered by Fig. 2.

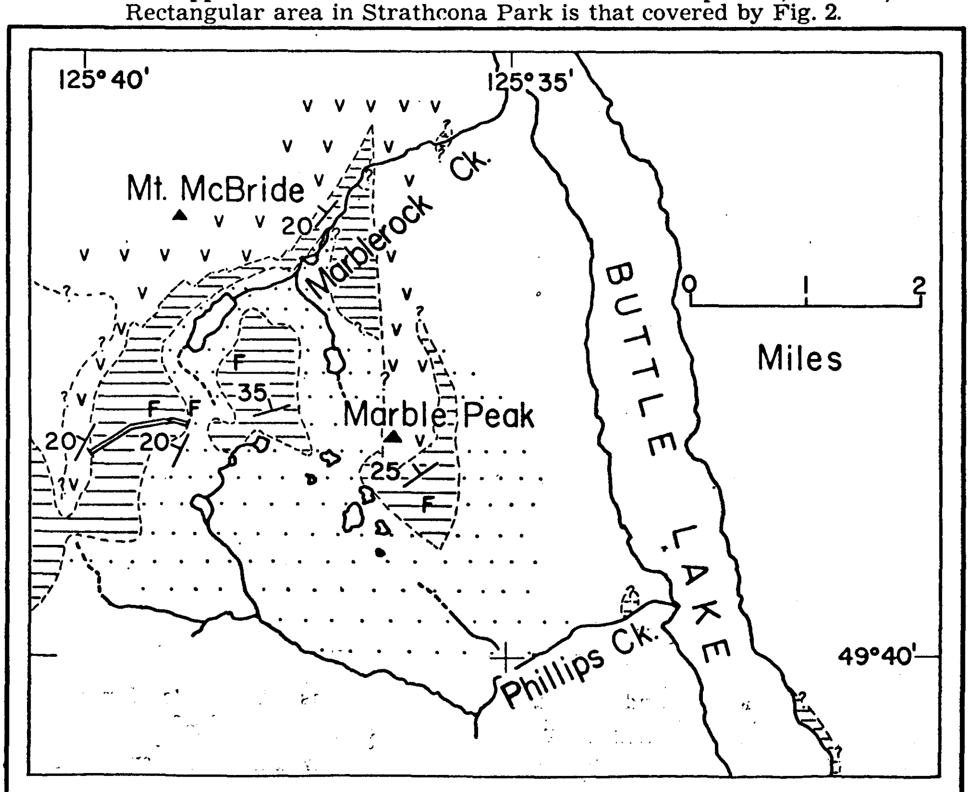

Fig. 2.—Generalised geology of part of Buttle Lake area. Horizontal shading—Formation B and associated basic intrusions. V pattern—rocks younger than Formation B (overlying clastic rocks, Vancouver Group, and associated basic intrusions. Dotted pattern—Formation A and associated intrusions. Double bar—Azure Lake section. F—fossil horizons.

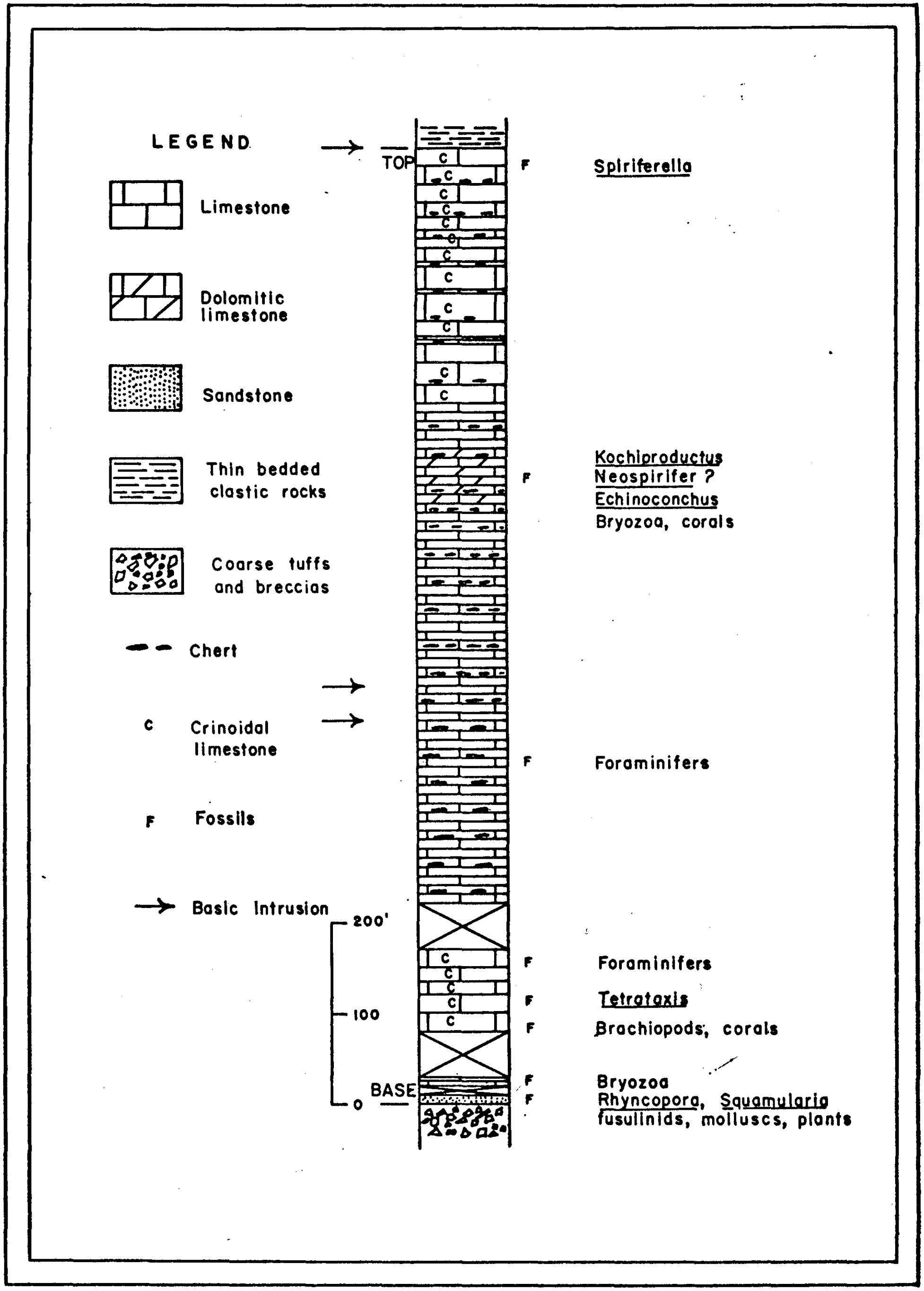

Fig. 3.—Azure Lake section, Formation B, diagrammatic. Distinctive fossils of main fossiliferous horizons indicated.

STRATIGRAPHY

The exposed Upper Paleozoic sequence of the Buttle Lake area of central Vancouver Island may be divided into at least two parts of differing lithology. The lower part of the succession, a complex unit comprised mainly of volcanic rocks, is herein referred to as Formation "A." Above formation "A" is a predominantly limestone unit, for which the term Formation "B" is used.

The rocks assigned to Formation "A," largely green tuffs and breccias, are of great thickness and lithologic variability. Rocks of this formation, reaching several thousands of feet in thickness, are well exposed on and north of Phillips Creek, below limestones of Formation "B" on the south side of Marble Peak. The base has not been seen and detailed stratigraphy of the unit is yet to be determined.

Formation "B" is a well-defined unit. The illustrated section (Fig. 3) is located near the headwaters of the north branch of Marblerock Creek, 0.8 miles southwest of the southwest end of an unnamed lake (referred to herein as "Azure Lake"). The formation here consists of a thin basal sandstone, overlain by thick limestones of the main part of the formation.

The dominant lithology of Formation "B" is medium to coarse-grained, crinoidal, sparsely fossiliferous, light-coloured limestone. Nodules and irregular thin bands of light and dark chert and silicified limestone occur in zones between massive limestone beds. At least one thick bed of dark, richly fossiliferous, dolomitic limestone is present. Dark coloured, fine-grained limestone is present in the lower part of the section. The basal 10 feet consists of brown, thin-bedded, fine to medium-grained, fossiliferous sandstone with pebbly lenses.

The lower contact of the formation is sharp and gently undulating. The basal sandstone is underlain by unstratified coarse tuffs and breccias of Formation "A."

A thick, basic, sill-like intrusion separates the uppermost limestone of Formation "B" from overlying thin-bedded, fine-grained, dark-coloured clastic rocks, in the Azure Lake section. The thickness and age of the clastic rocks have not been determined. They have attitudes similar to those of the underlying limestones of Formation "B." Several thousands of feet of volcanic rocks of the Triassic Vancouver Group, the basal portion of which is composed of basaltic pillow-lavas, occur above the clastic rocks.

The Azure Lake section of Formation "B," from the bottom of the basal sandstone to top of the uppermost massive limestone, measures approximately 1050 feet. A partial section of the formation, with the base not exposed, was obtained on Marblerock Creek, two miles northeast of the Azure Lake section. At this locality, the thickness measured is 858 feet. Transverse faults crossed in obtaining both of these sections may have increased the apparent thicknesses. Therefore, it is estimated that Formation "B" is about 800 to 1,000 feet in maximum thickness.

It should be noted that for both of these sections, only the thickness of sedimentary rocks is recorded here. Thick sill-like intrusions, within the limestones, are present in both sections; the measured thickness of one of these exceeds 300 feet; another was estimated to be 750 feet. These intrusions of dark green to black, fine to medium garined crystalline rock of basaltic composition, are a prominent feature of the Paleozoic sections of this area. At and near the Azure Lake section of Formation "B," these intrusions are mainly sill-like, with few obvious cross-cutting contacts. To the east, however, on Marble Peak, and its subsidiary ridges, the intrusions appear to be more numerous and more irregular in their outlines, disturbing the continuity of the outcrops of stratified rocks much more severely than to the west.

Gunning, (1931, p. 59) suggested the name "Buttle Lake group or formation" for all or part of the UUper Paleozoic succession in this area. The present writer considers that the sequence of Paleozoic rocks of the Buttle Lake area is equivalent to the Sicker Group (Clapp, 1909, p. 56; Fyles, 1955, p. 19) of southern Vancouver Island, and the latter name has priority. Thus, Gunning's suggested name may most conveniently be applied to a formation within the sequence. In the writer's opinion the most suitable formation to bear the name is that referred to as Formation "B" in this paper. Therefore, when further work has permitted the selection of the best type section, and formal nomenclature is adopted, it is recommended that Formation "B" be called "Buttle Lake Formation."

Formation "B" is well exposed on the east face of Marble Peak, along the north bank of Marblerock Creek, around Azure Lake, and on the narrow ridge extending southward from Mount McBride. Large areas of less precipitous ridge-top exposures are found between Marble Peak and Marblerock Creek. Gunning (1931, p. 60) mentions good exposures of the formation west of Wolf River. Poor exposures, near lake level, occur on the east side of Buttle Lake, two miles north of Ralph River (see Fig. 3). Similar exposures are known on Flower Ridge, south of the Lake. Rocks believed to correlate with Formation "B" occur in several other parts of Vancouver Island, south of Buttle Lake. Upper Paleozoic rocks have not been reported from any area of Vancouver Island north or west of the Buttle Lake area. The general distribution of Upper Paleozoic rocks, and limestone bodies, is indicated by Mathews (1947, Fig. 20) and Mathews and McCammon (1957, Fig. 3).

PALEONTOLOGY

The fauna of Formation "B" is rich and varied (see Plates I, II, and faunal list). The principal groups represented are crinoids (as disarticulated skeletal plates), brachiopods and bryozoans. Less common are foraminifers, gastropods, pelecypods, corals and ostracods. A sparse flora of calcareous algae and vascular plant fragments is represented in the basal unit of the formation.

No fossils have so far been found in Formation "A." The following discussion is based on some of the significant fossils of Formation "B."

Gunning's collection of bryozoans from Formation "B" was identified and described by Dr. M. A. Fritz in 1932. Species of *Stenopora, Rhombopora, Streblascopora, Clausotrypa, Fenestella, Polypora, ?Thamniscus, Acanthocladia, Penniretepora, Goniocladia* and *Protoretepora* were recognised. Most of these species have also been found in the writer's collections, with *Rhabdomeson* sp. and others not reported by Fritz.

Gunning (1931, p. 59) submitted another collection, including brachiopods, to G. H. Girty, who reported on the age, but apparently did not describe the fossils. Brachiopods from limestones at or near Gunning's collecting locality have been identified and described by the present writer; the most abundant fossils belong to species of *Kochiproductus, Neospirifer?, Spiriferella,* and *Echinoconchus.* Less abundant are species of *Horridonia, Laevicamera, Antiquitonia, Hustedia* and other genera.

Foraminifers are not common in Formation "B." *Tetrataxis* sp., a small unidentified fusulinid, and several minute indeterminate forms comprise the small collection of this group from the Buttle Lake area.

PARTIAL FAUNAL LIST FORMATION "B"

Acanthocladia multipora Fritz
Clausotrypa spinosa Fritz
Fenestella basleoensis Bassler
F. parviuscula Bassler
F. cf. *F. pulchradorsalis* Bassler
F. cf. *F. rottiensis* Bassler
Goniocladia intermedia Fritz
Penniretepora grandis (Fritz)
Polypora consanguinea Bassler
P. elongata Fritz
P. cf. *P. macrops* Bassler
P. megastoma (Koninck)
P. sykesi (Koninck)
P. vancouverensis Fritz
Protoretepora cf. *P. haimeana* (Koninck)
Rhabdomeson sp.
Rhomboporea porifera Fritz
Stenopora prolifica (Fritz)
?Thamniscus unilateralis Fritz
Tetrataxis sp.
Fusulinids
Cladochonus? sp.
Caninia? sp.
Antiquitonia sulcata Cooper
Avonia? sp.
Cleiothyridina cf. *C. gerardi* (Diener)
Echinoconchus inexpectatus Cooper
Horridonia sp. A.
H. sp. B.
Hustedia cf. *H. meekana* (Shumard)
Kochiproductus n. sp.
Krotovia? sp.
Laevicamera n. sp.
Muirwoodia? sp.
Neospirifer? n. sp.
N. sp.
Rhyncopora cf. *R. magna* Cooper
"Spirifer" cf. *S. ufensis* (Tschern)
Spiriferella cf. *S. saranae* (deVerneuil)
Sqamularia cf. *S. rostrata* (Kutorga)
Parallelodon? sp.
Aviculopecten? sp.
Gastropods
Ostracods

AGE AND CORRELATION

The bryozoan faunule from the Buttle Lake area was stated by Fritz to be of Permian age, with closest affinities to a Permian fauna of Timor (1932, p. 93). According to Girty (Gunning, 1931, p. 59), the brachiopods indicated Late Pennsylvanian, rather than Permian age.

Of the bryozoan species from the Buttle Lake area described by Fritz as new, none has been reported from other localities, to the present writer's knowledge. A species similar to *Streblascopora pulchra* (Fritz) has been found in Upper Permian rocks of Japan (Sakagami, 1961, p. 11). *Fenestella basleoensis* and *F. parviuscula,* or closely related forms, have been reported from Lower Permian beds of Texas, Russia and Australia, in addition to the original Timor locality and Buttle Lake area (Elias and Condra, 1957, p. 78, p. 108). A species related to *F. parviuscula* has been found in the Upper Permian of Japan (*Sakagami,* 1961). Three of the Buttle Lake bryozoans are Salt Range (Pakistan) species; of these, one (*Polypora megastoma*) has been reported from the Upper Carboniferous, in addition to its Permian occurrences (Branson, 1948, p. 270).

As shown in Table I, many of the brachiopods of Formation "B" are Permian, or Upper Carboniferous and Permian species, or have close affinities with species of such ages. Until the Vancouver Island fauna has been more completely studied and collected, statistical correlation with other faunas of similar age is perhaps not warranted. From the data already available, affinities with the Early Permian fauna of the Coyote Butte Formation of Central Oregon are evident. Relationship with the "Permo-Carboniferous" fauna of the Yukon, the "Arctic Permian" fauna, and the fauna of part of the Cache Creek Group

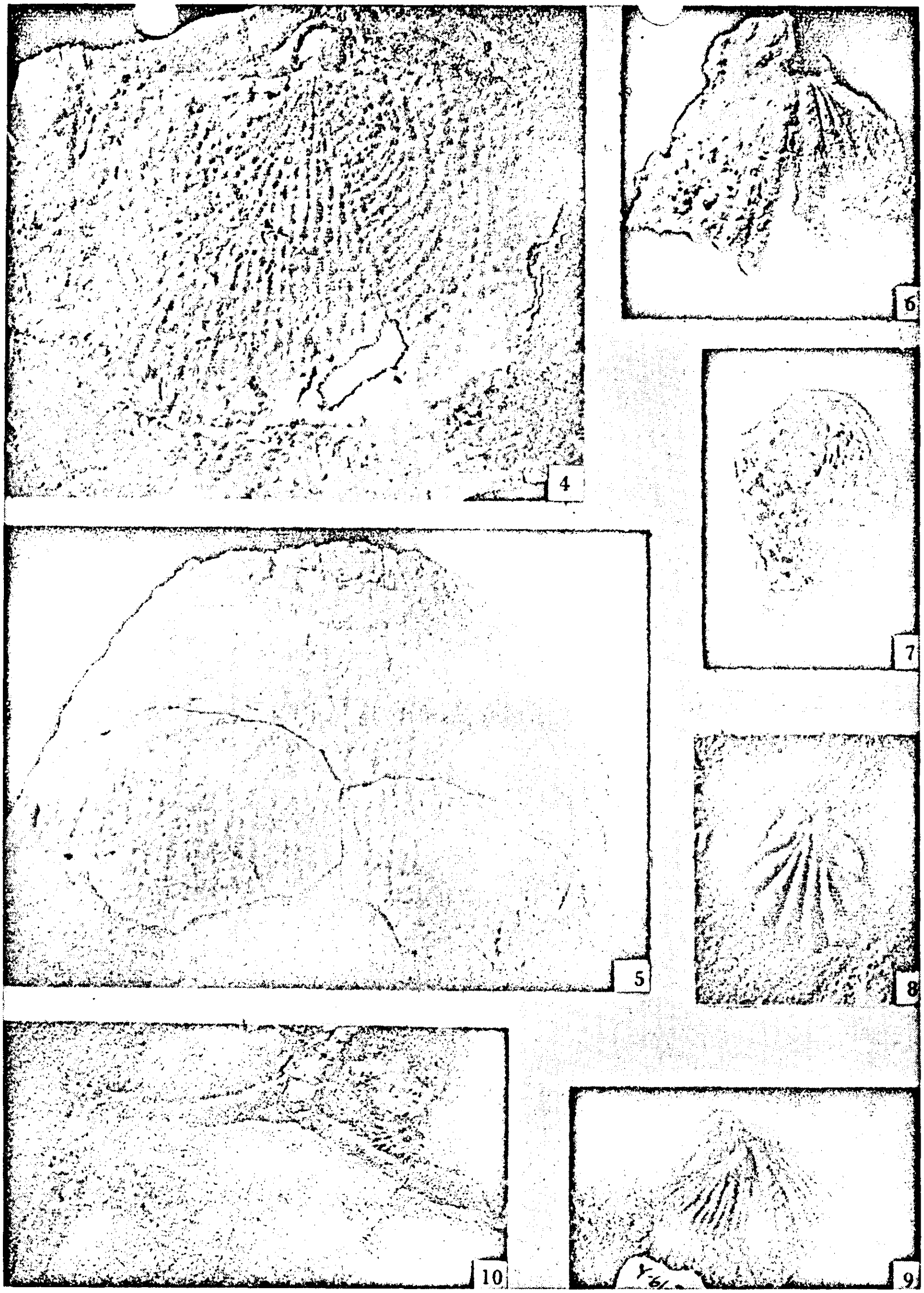

PLATE I.

All figures natural size unless otherwise indicated.

Figs. 4, 5.—*Kochiproductus* n. sp. 4, Brachial view, specimen UBC 20002. 5, Pedicle view, UBC 20001.

Figs. 6, 7.—*Spiriferella* cf. *S. saranae* (de Verneuil). 6, Pedicle view, UBC 20069. 7, Lateral view, same specimen.

Fig. 8.—*Hustedia* cf. *H. meekana* (Shumard), Pedicle view, UBC 20059, x2.

Fig. 9.—*Neospirifer* sp., Pedicle view, UBC 20070.

Fig. 10.—*Stenopora prolifica* (Fritz). External view, UBC 20105.

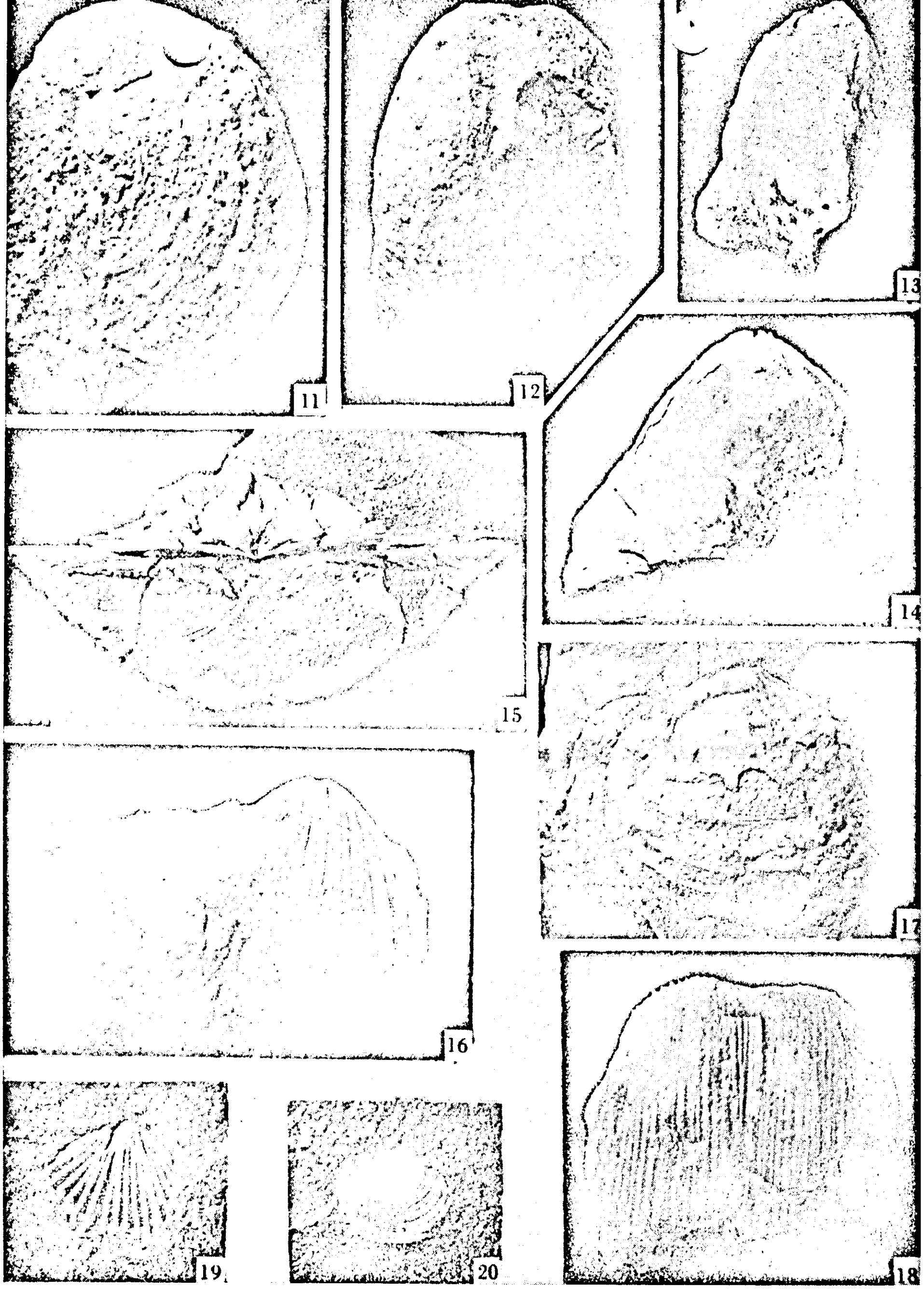

PLATE II.
All figures natural size.

Gigs. 11, 12.—*Horridonia* sp. A. 11, Lateral view, UBC 20200, from Horne Lake. 12, Pedicle view, same specimen.

Figs. 13, 14.—*Laevicamera* n. sp. 13, Lateral view, UBC 20062. 14, Brachial view, same specimen.

Figs. 15, 16.—*Neospirifer?* n. sj. 15, Internal view, UBC 20013. 16, Pedicle view, UBC 20016.

Fig. 17.—*Echinoconchus inexpectatus* Cooper, Pedicle view, UBC 20039.

Fig. 18.—*Antiquitonia sulcata* Cooper, Pedicle view, UBC 20054.

Fig. 19.—*Rhyncopora* cf. *R. magna* Cooper, Pedicle view, UBC 20084.

Fig. 20.—*Squamularia* cf. *S. rostrata* (Kutorga), External mold, brachial valve, UBC 20095.

TABLE I.

	VI	NWW	CO	CBC	A	Y		GP		NR
						LLs	T	Bc	Ass	
Fenestella basleoensis	O	G		X	G					O(L)
Fenestella parviuscula	O									X(L)
Goniocladia intermedia	O				G					*X*
Polypora megastoma	O	G		G	G		G			O(UC)
Antiquitonia sulcata	O		O	X(L)	X				X	*X*
Cleiothyridina gerardi	X		O		G		G			*X*
Echinoconchus inexpectatus	O		O		X		X			*X*
Horridonia sp. A	O		X		X?	X?	X?			*X?*
Horridonia sp. B	O				X?	X?	X?			X?
Hustedia cf. *H. meekana*	O				X		X			
Kochiproductus n. sp.	O		O		X		X		X	X(L)
Krotovia? sp.	O		X		G		G			
Laevicamera n. sp.	O				X(L?)					*X*
Neospirifer? n. sp.	O			X	X	X?	X?		X?	*X*
Rhyncopora magna	X		O	G	G		X			
"Spirifer" cf. *S. ufensis*	X				X(L?)	O				*X*
Spiriferella saranae	X		X	X	X		X	X	X	O
Squamularia rostrata	X		O	X	G		G		G	O
Tetrataxis	G			G(U)						G
Parafusulina							G	G		
Parafusulina alaskensis					O(L)					X(L)
Parafusulina? calx			O	X(L)						
Parafusulina gracilis			O	O(L)						
Parafusulina? turgida			O	X(L)						
Pseudofusulinella		G						G		
Pseudofusulinella montis			O	X(L)						
Pseudofusulinella occidentalis			O	O(L)						
Schubertella kingi				O(L)				O		G
Schwagerina		G	G	G(L)			G	G		G

LEGEND: O—species present. X—related species; *X*—also in Upper Carboniferous. G—genus present. (L), (U), (UC)—Lower Permian, Upper Permian, Upper Carboniferous occurrence.

COLUMN HEADINGS: VI—Vancouver Island, Buttle Lake Formation. NWW—Northwest Washington, Black Mountain Formation (Wolfcamp?). CO—Central Oregon, Coyote Butte Formation (Wolfcamp-Leonard). CBC—Central B.C., Cache Creek Group (Pennsylvanian? and Permian). A—Alaska, Permian. Y—Yukon and Alaska border, Permo-Carboniferous; LLs—Lower Limestone (Pennsylvanian?), T—Tahkandit Formation (Leonard?). GP—Grinnell Peninsula, Permian; Bc—Belcher Channel Formation (Wolfcamp-Lower Leonard); Ass—Assistance Formation (Upper Leonard). NR—Northwestern Russia, Permian.

SOURCES: Danner, 1957. Cooper, 1957. Dunbar et al, 1960. Aitken, 1959. Armstrong, 1958. Fritz, 1932, 1946. Jones, 1959. Lord, 1948. Trettin, 1961. Buddington and Chapin, 1929. Dunbar, 1946, Moffitt, 1938, 1954. Wright and Wright, 1908. Nelson, 1961a,b; 1962. Mertie, 1930. Harker and Thorsteinsson, 1960. Branson, 1948. Elias and Condra, 1957. Dutro, 1961.

Table I.—Distribution of certain key fossils in Cordilleran, Arctic and Russian regions.

of mainland British Columbia and Permian beds of Alaska is also apparent. Similar faunas also have been reported from eastern parts of the Canadian Cordilleran region (McGugan and Rapson, 1962).

The fusulinids found to date in Formation "B" of the Buttle Lake area are not diagnostic as to horizon or age. However, fusulinids from the Coyote Butte Formation have been identified (Henbest, *in* Dunbar *et al.*, 1960, p. 1781), and are stated to be of Early Permian (Late Wolfcampian-Leonardian) age. *Schwagerina* and *Pseudofusulinella,* two of the genera represented in the Coyote Butte, occur also in the Early Permian Black Mountain Formation of northwestern Washington (Danner, 1957, p. 152). Pitcher (1960, pp. 19, 21, 23) identified several of the Coyote Butte species of *Pseudofusulinella* and *Parafusulina*, together with *Schwagerina,* in the Early Permian part of the Cache Creek Group of the Stikine River area. Early Permian fusulinids have also been reported from the Cache Creek Group of the Fort St. James area (Armstrong, 1949, p. 45) and of the McConnell Creek area (Lord, 1948, pp. 11, 12).

The evidence presented above suggests that Formation "B" of the Buttle Lake area of Vancouver Island is most probably of Early Permian age. It can be correlated, in whole or part, with the Coyote Butte Formation, the Black Mountain Formation, the Early Permian portion of the Cache Creek Group. The Permo-Carboniferous sections of the Yukon, the Permian rocks of the Arctic, and Permian beds of Alaska and other Cordilleran regions, contain faunas with distinct relationships to that of Formation "B," and may also include correlatives of the Vancouver Island formation.

DISCUSSION

Harker and Thorsteinsson (1960, p. 19) have suggested that the Arctic Permian fauna represents a widespread Early Permian (Leonardian; Artinskian-Kungurian or Svalbardian) faunal realm. However, several important problems remain to be resolved before the temporal and geographic limits of this "boreal" (Newell, 1957, p. 426) realm can be accurately defined. Strata associated with deposits of this realm may include also some of Pennsylvanian and earliest Permian (Wolfcampian, Sakmarian) (Harker and Thorsteinsson, 1960, p. 9; Nelson, 1961a, p. 4, etc.), or even Late Permian age (Zechstein, Dunbar, 1955, p. 52, *etc.*; Kamian, Dutro, 1961, p. 226). The brachiopod faunules, especially species of *Horridonia,* appear to have predominantly boreal distribution (Gobbett, 1962). Yet the bryozoans, at least of the Vancouver Island Permian, have distinct Asian and Indo-Pacific affinities. "Middle" and Upper Permian fusulinids of northwestern North America seem to have strong Tethyan affinities (Thompson, Wheeler and Danner, 1950, pp. 46, 47). Thus, at the present stage of investigation, different faunal elements suggest significantly differing interpretations of Cordilleran Permian biogeography. Comprehensive studies of the total faunas of the several regions involved are necessary before such problems may be resolved.

CONCLUSIONS

A formation of dominant limestone lithology is a prominent and persistent unit in the upper part of the Paleozoic succession of the Buttle Lake area of central Vancouver Island. The fauna of the formation indicates a probable Early Permian (Wolfcampian-Leonardian?) age, and is related to a widespread boreal realm. The formation can be correlated with such other Cordilleran formations as the Coyote Butte of central Oregon, the Black Mountain Formation of Washington and part of the Cache Creek Group.

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The Nanaimo Coal Field*

BY A. F. BUCKHAM†

(Annual Western Meeting, Vancouver, B.C.)

INTRODUCTION

SEVERAL basins of the Nanaimo series, a group of coal-bearing sedimentary rocks of Upper Cretaceous age, underlie parts of Vancouver island and the adjacent gulf islands. One, the Nanaimo basin, occurs on the southern half of the west shore of the gulf of Georgia. About fifty square miles at the north end of this basin are known to be underlain by productive coal seams, this area being known as the Nanaimo coal field. Coal has been mined from two horizons—that of the Wellington seam, fairly low in the series, and that of the Newcastle and Douglas seams, about the middle of the series.

Coal has been mined here since the fall of 1852. About fifty million tons have been produced, almost half the total production of British Columbia.

About seventy-two years ago, James Richardson of the Geological Survey made a reconnaissance of the coal measures on Vancouver island, and thirty-five years ago C. H. Clapp(1) mapped and reported on most of the Nanaimo coal field. Twenty-four years ago, J. D. MacKenzie extended the work to those areas not mapped by Clapp. MacKenzie died before the results of his work could be published, but did issue a revised estimate of the *Coal Resources of Southern Vancouver Island*(2). Work by the present writer is a further contribution by the Geological Survey to knowledge of the island coal measures. Having spent more time in the field, and having had more data at his disposal than were available to his predecessors, the writer has been able to throw additional light on the Nanaimo, and other, coal fields on Vancouver island. He is indebted to Canadian Collieries (Dunsmuir), Limited, and to its officials for access to much valuable information in their possession.

GENERAL GEOLOGY

The Upper Cretaceous rocks of Vancouver island occur in five basins: the Nanaimo, Comox, Cowichan, Alberni, and Suquash basins(3). The Nanaimo basin is about eighty miles long, from Nanoose bay on Vancouver island to Orcas island off the state of Washington. Its greatest

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†Geological Survey, Canada.

(1)CLAPP, C. H., *Geology of the Nanaimo Map-Area*; Geol. Surv. Can., Mem. 51, 1914.

(2)MACKENZIE, J. D., *Coal Resources of Southern Vancouver Island*; Geol. Surv. Can., June 1st, 1923 (mimeographed report).

(3)*See* Geol. Surv. Can., Map 196A, Vancouver Sheet.

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width is about twenty miles, average width about nine miles, and its area about 700 square miles.

The Cretaceous of the Nanaimo basin lies on a 'basement' of metamorphosed volcanic and sedimentary, and intrusive igneous, rocks. These are much more resistant to erosion than the coal measures, and form the mountainous 'backbone' of the island, the coal measures forming the coastal lowland. The basement rocks near Nanaimo are chiefly andesitic lavas, commonly referred to as 'trap'. However, considerable amounts of sedimentary rocks—cherts, argillites, quartzites, and limestones—occur with the lavas, the whole assemblage being termed the *Vancouver group*. It is of Permian and Triassic age. All of these rocks were deformed and metamorphosed by the intrusion of a granite of probable late Jurassic or early Cretaceous age. The area now occupied by Vancouver island was at this time uplifted into a range of mountains. At about the same time, the mountains along the mainland coast were built and it is probable that the intervening area, occupied now by the strait of Georgia was, even at that early date, a depression.

A considerable period of erosion followed, as in places the granitic rocks were exposed. From studies of the floor on which the Cretaceous deposits were laid at Nanaimo and Cumberland, it appears that, at the end of this erosion period, the topography was very similar to that of today.

Conditions of Deposition of the Nanaimo Series

There was, then, a range of mountains along the axis of the island, a depression where the strait of Georgia now is, and a coastal lowland between, flat in comparison with the mountain range, but still quite hilly. Both Mackenzie(1) and Charles Graham(2), in papers read before this Institute, give excellent examples of a pre-Upper Cretaceous relief of at least 440 feet at Cumberland. The presence of these pre-Upper Cretaceous hills had a strong influence on the sediments deposited around them, and, in places, caused the cutting out of coal seams low in the series.

As pointed out by Clapp, the lithological character of the sediments of the Nanaimo series indicates very rapid accumulation and deposition. The sandstones are made up of angular to sub-angular fragments and contain a large percentage of easily decomposed minerals. The material composing them evidently did not travel far, and was rapidly buried. There is great variation in the sediments both vertically and laterally. The accompanying section (Figure 1) shows the vertical variation, and the lateral variation is evident both on the outcrops and in bore-holes. Few individual beds persist for any distance. The series is made up of a great pile of overlapping lenses.

Some formations in the series are clearly marine, as is shown by the character of the sediments and the presence of numerous marine fossils. Other parts have the characteristics of near-shore or beach deposits, and others again are of land origin, as is shown by the presence of sun-cracked surfaces and mud-flakes, and in one place imprints of rain drops. This is also borne out by the presence of land plants and coal.

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(1)MACKENZIE, J. D., *The Coal Measures of Cumberland and Vicinity, Vancouver Island*; C.I.M. Trans., Vol. XXV, 1922, pp. 382-409.

(2)GRAHAM, Charles, *The Problems of the Vancouver Island Coal Industry;* C.I.M. Trans., Vol. XXVII, 1924, pp. 456-477.

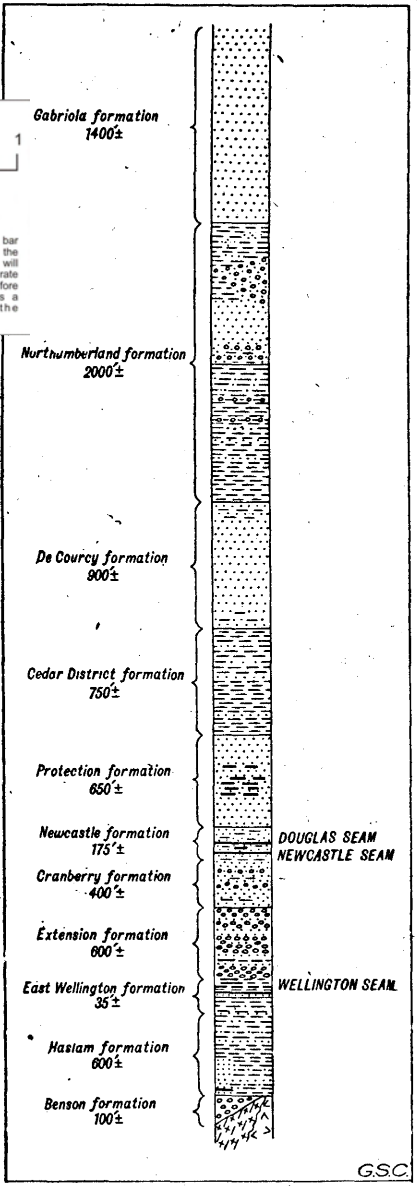


Figure 1.—Generalized stratigraphic section, Nanaimo coal field.

The total thickness of the Nanaimo series in the Nanaimo area averages about 7,600 feet, while to he southeast it is more than 10,000 feet. This is taken to indicate that the deepest parts of the basin were to the southeast. The succession at Nanaimo is indicated in Figure 1. All of the formations of the Nanaimo series are known in the Nanaimo basin. In the Comox basin, the four lowest formations, totalling 1,300 feet, were only formed from Nanoose bay southward, and none of the six lowest, totalling 1,900 feet, were formed north of Qualicum river. The five uppermost formations were probably continuous from the International boundary to Campbell river. This indicates a progressive overlap, a northward migration of the north shore of the Cretaceous seas as deposition continued.

Here, then, are the conditions under which the Nanaimo series was deposited: To begin with, there was a depression lying between two mountain ranges, but separated from the range on the southwest by a bench or coastal lowland. Rapid erosion in the mountains was supplying a large volume of material which was being carried down and spread over the lowland and the depression. At the same time, however, the 'depression' area was sinking in relation to sea level. The amount of elevation, through deposition of new sediments, and of lowering, through sinking, did not maintain a constant balance, so that at some times the sediments were being deposited by the action of streams above sea level, and at other times by wave and current action below sea level. Coal seams could form, but only at those special times when sinking balanced up-building and the shore line at a given place remained stationary for a considerable period, to give seams time to attain workable thickness.

STRUCTURAL GEOLOGY

The dominating feature of the structure of the Nanaimo coal field is the occurrence of numerous, strong faults (Figure 2). These dislocations cross the entire field, and their extensions to the north and to the south show them to be part of a major fault zone which extends along the east coast of Vancouver island for at least seventy miles.

The presence of the faults in the Nanaimo coal field was proved in two ways. In the areas where mining and prospecting have been extensive, they were shown by contours carefully drawn on the floors of the various coal seams, based upon mine and borehole elevations. In the area to the west of Nanaimo, as the map shows, it happens that the distribution of the Cretaceous formations is admirably suited to bring out their presence. Particularly in the area to the west, the continuation of the faults between places where they were known by the above means was greatly aided by the stereoscopic examination of vertical aerial photographs. Well-defined, straight 'breaks' or linear depressions were observed to join such places, and their continuity could thus be plotted with confidence.

The faults, where they can be observed in the Cretaceous sediments, are for the most part thrusts. Figure 3, giving a section taken along the

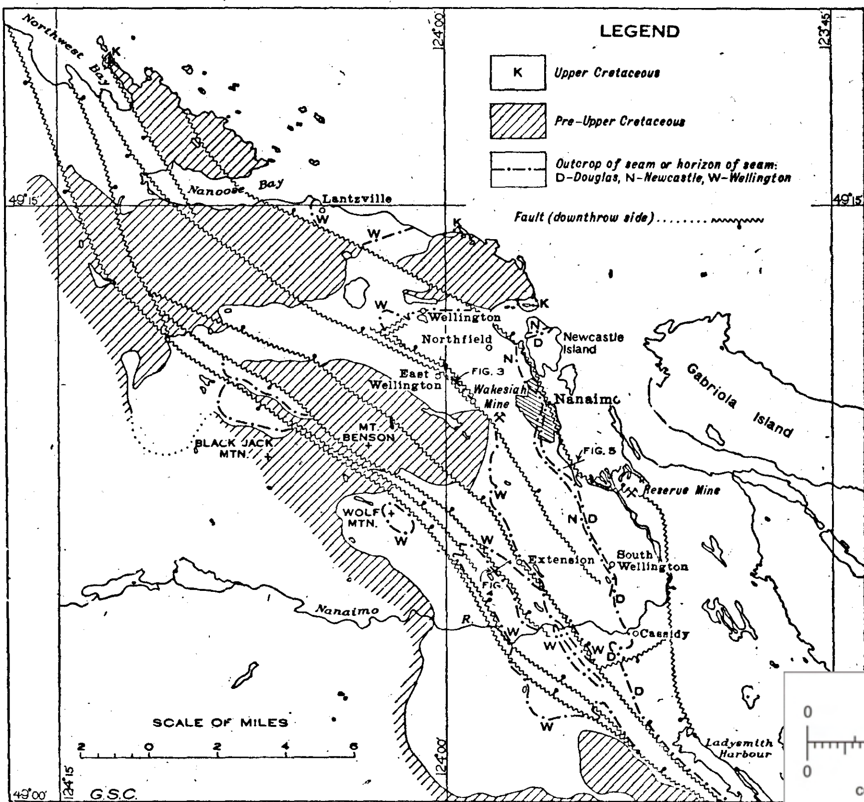
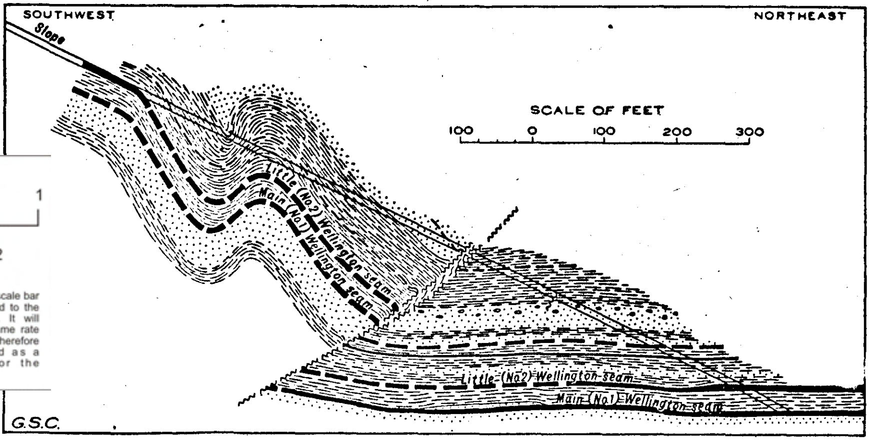


Figure 2.—Geological sketch-map of the Nanaimo coal field.



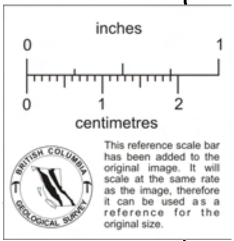


Figure 3.—Section on main slope, East Wellington Coal Company's mine, showing thrust fault.

main slope of the East Wellington Coal Company's mine, is a good example of such a fault. Figure 4A shows a similar fault between the No. 1 and the Nos. 2 and 3 mines of the Extension colliery. Both figures show faults displacing the Wellington seam, the seam low in the section.

Faults in the strict sense of the term, that is, clean breaks in the measures with complete separation of parts that formerly were continuous, occur in the lower part of the section. In the Nanaimo area, their presence has not been established in rocks above the Extension formation. Instead, very sharp overturned folds are found. Figure 4B shows a dislocation of the Douglas seam as displayed in the main slope of the New Douglas mine and the South Side workings of No. 1 mine. The effect of such a roll is the same as that of the faults of Figures 3 and 4A, namely, the seam is heavily downthrown to the east; but actual rupture of the measures is lacking.

Tracing the faults along the strike indicates that most are probably of the rotational, or hinge, type. For example, the fault which runs nearest to the southwest side of mount Benson (Figure 2), is the same as that shown in Figure 4A. At the Extension tunnel it has a downthrow or vertical displacement to the northeast of about 390 feet. About four miles north of this, on the southern flank of mount Benson, the downthrow is still to the northeast, although it is much less, and about six miles north the downthrow is the other way, to the northwest. Similarly, the second fault to the northeast of this has its downthrow to the northeast in the Nanaimo area, and to the northwest at Northwest bay. On the other hand, the fault between these two apparently has a downthrow to the southeast throughout its entire length.

In the Nanaimo area, all the faults have their downthrow side on the northeast. The westernmost fault has a downthrow of perhaps 1,000 feet, certainly more than 600 feet. The next, going northeast, has a maximum downthrow of about 150 feet, but pinches out to the southwest. The next, that described above, has a downthrow of about 390 feet, and the next about 300 feet. The fault that passes through East Wellington has a downthrow

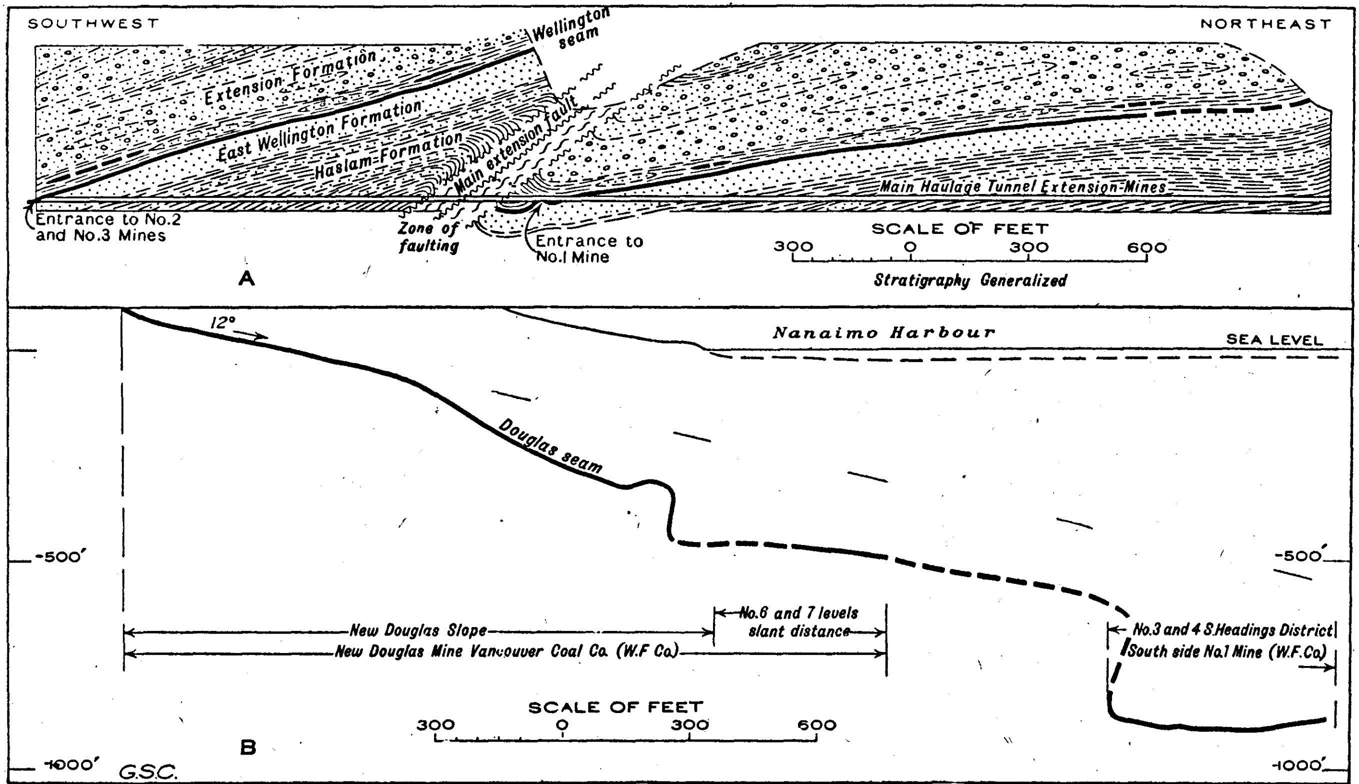


Figure 4.—(A) Section on main haulage tunnel, Extension Mines, showing thrust fault.
(B) Section on line of New Douglas Slope, showing Harbour 'downthrow'.

in excess of 200 feet for most of its length. The Harbour downthrow or sharp roll, that illustrated in Figure 4B, has, at No. 1 mine, caused a vertical displacement equivalent to a downthrow of 400 to 500 feet.

Origin of the Faults

In a study of the British Columbia coastline, Professor Peacock(1), formerly of the University of British Columbia, concluded that a fracture pattern, to which the Nanaimo faults belong, is a feature of the whole coast, formed in connection with the pre-Upper Cretaceous mountain-building. He also concluded that movement on the fractures was renewed after the deposition of the Cretaceous sediments. The latter conclusion is well supported in the Nanaimo area. No evidence proving the pre-Upper Cretaceous movement has been found, but the conclusion is in accord with the facts now known.

Field relationships show that the faults in the Nanaimo area are caused by more or less vertical movements of large blocks of the basement rocks. These movements took place along pre-existing breaks, and were probably the result of the area being subjected to stresses which caused compression in a northeast-southwest direction, normal to the faults.

A north-south break in a body of rocks, in which the west side has moved upward relative to the east, would place any body of material lying above the break under shearing stress, and it may be shown by the theory of mechanics of materials that any resultant rupture would be along a plane which dips west, the west side moving over the east in a thrust. This is exactly the situation in the lower part of the section. The writer believes that both the faults and the sharp rolls described above are parts of the same occurrence. As the stress proceeds farther from the point of application, it tends to be felt in a zone rather than along a line. A part of it will be taken up in slippage between the beds, and the result is that what was a fault below becomes a sharp roll above (Figure 5).

The economic consequences of this are great. Where there is a clean break, relieving the stress, slippage between the beds will be much less than where there is a roll, and, consequently, shearing of individual beds, such as coal seams, will be less. Moreover, where there is a roll, the stress may not wholly have been relieved, some remaining pent-up in the rocks. These conclusions will be applied when discussing the coal seams.

Besides being disturbed by faults and sharp rolls, the rocks of the Nanaimo coal field have been bent into a series of broad, open folds. Especially in the western part of the area, the folds are associated with the faults. It may be shown that the kind of stress that caused the faults could also have caused the folding observed, and it is probable that all of the faults and folds were formed at the same time and in response to the same set of stresses.

GEOLOGY OF THE COAL DEPOSITS

There are two main horizons in the Nanaimo series, that of the Wellington and that of the Newcastle-Douglas seams. The lowest seam, the Wellington, occurs about 700 feet above the base of the Nanaimo series, overlying 600 feet of sandy shale of marine origin, the Haslam formation. The

(1)PEACOCK, M. A., *Fiord-Land of British Columbia*, Geol. Soc. Am., Bull., Vol. 46, 1935, pp. 633-696.

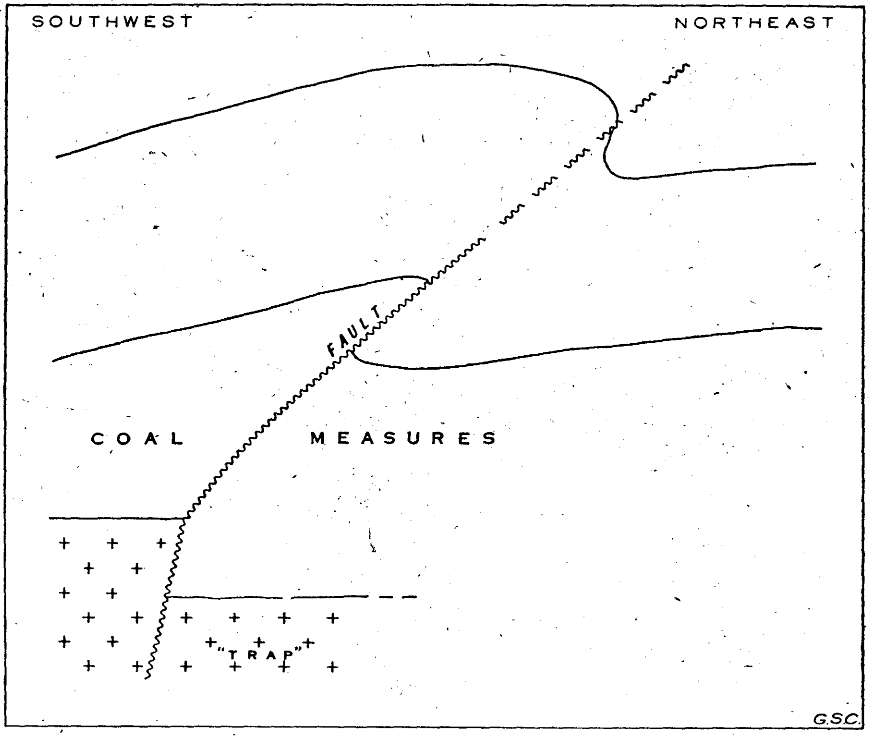


Figure 5.—Sketch showing probable structure on faults, Nanaimo area.

Newcastle and Douglas seams are from 25 to 100 feet apart, averaging 60 feet, the Newcastle being the lower. They overlie the Wellington by about 1,000 feet, and are separated from it by the Extension formation, averaging 600 feet of conglomerate, and the Cranberry formation, averaging 400 feet of shaly sandstone and shales. From these three seams—the Wellington, Newcastle, and Douglas—has come over 90 per cent of the field's production.

In the extreme northwestern part of the field, in what is termed the Black Jack area, the lower part of the Haslam formation, elsewhere chiefly shale, is made up of sandstone, and at the base of this occurs a horizon carrying coal. None has been mined, and the crops thus far known are thin and dirty. This is the only place on Vancouver island where coal is known to occur at this horizon.

Above the Haslam formation is the horizon of the Wellington seams. The main seam, that referred to above, and the one from which by far the greatest Wellington production has been made, is the lowest. Above this are, in places, several seams. It has been the custom to state that a seam known as the Little Wellington lies from 20 to 60 feet, averaging 35 feet, above the Wellington. In the northern part of the area, this statement covers at least three seams. These may be designated from the bottom upward. The Wellington No. 1 is the Main Wellington seam, the Wellington No. 2 is that commonly referred to as the Little Wellington, and the others are Nos. 3 and 4. The three upper seams lie above the main Wellington at intervals of approximately 35 feet, 60 feet, and 75 feet, floor to floor. The main Wellington seam has been mined at Wellington, Northfield, East Wellington, Wakesiah, and Extension mines. The No. 2 or Little Wellington seam has been mined at No. 9 mine, Wellington, East Wellington, Harewood, and No. 4 Extension mines. The Nos. 3 and 4 seams were worked in the Northfield mine when it was re-opened in 1936. Excepting at the Harewood and No. 4 Extension mines, these upper seams seldom exceed two feet in thickness, and workings in them have not been extensive.

Another small seam occurs from 200 to 250 feet above the main Wellington, in the middle of the Extension formation. It is known only in bore holes, and although it reaches 2 ft. 4 in. in thickness at one place, its occurrence is very patchy.

The Newcastle seam occurs at the base of the Newcastle formation. Between it and the Douglas above are, in places, several seams of coal, whose occurrence, also, is very patchy. The Newcastle has the most limited distribution of any of the Nanaimo seams, having only proved workable in the No. 1 and Brechin mines. Elsewhere in the district, it is known through prospects and boreholes, and is thin and dirty.

The Douglas seam occurs in the Newcastle formation and is, on the average, 60 feet above the Newcastle seam. It has been worked in several old Hudson's Bay mines; in the Douglas and New Douglas, No. 1, and Reserve mines; in the various Southfield mines of the Vancouver Coal Company; in No. 1, No. 2, and Morden mines of the Pacific Coast Coal Mining Company; in No. 5 and No. 10 mines of Canadian Collieries (Dunsmuir); and in the Cassidy mine of the Granby Consolidated Mining, Smelting and Power Company.

Above the Newcastle is the Protection formation, chiefly white sandstone. This formation is the equivalent of that which contains the seams at Cumberland, but at Nanaimo it does not contain workable seams. Boreholes which have sectioned the Protection formation at Nanaimo have revealed as many as five seams between six and nine inches thick. These do not correspond in stratigraphic position with those at Cumberland.

Detailed Description of Seams

The main *Wellington* seam has been found to have a workable area twelve miles long and an average of one mile in width. It varies in thickness from nothing to nearly thirty feet, and averages from four to seven feet. Its floor is almost everywhere the hard East Wellington sandstone, although a foot or so of shale may intervene. The roof is most commonly shale or sandy shale, but in many places is sandstone or conglomerate. The most conspicuous feature of the seam is its variability in thickness, caused chiefly by minor faults, folds, or bands, usually in the roof, the floor being fairly regular although occasionally showing sharp rolls. Excellent illustrations of typical roof rolls are to be found in Clapp's report on the area(1). Partings of 'rash', a dirty, sheared coal, and of shale, are common in the seam.

The *Newcastle* is the most restricted in distribution of the productive seams, having proved workable only in an area some two miles long by a mile and a half wide underlying Newcastle and Protection islands. Its

(1)*Op. cit.*, pp. 112-3.

average thickness is 3 ft. 4 in. to 3 ft. 10 in., and its extremes, where worked, 1 ft. 8 in. to 6 ft. to 8 ft. Its floor is usually flaggy or shaly sandstone and its roof varies from sandy shale to fine conglomerate. Except in the vicinity of faults or rolls, the seam does not contain partings. The Newcastle seam is by far the most regular of the three.

The *Douglas* seam has been found workable over an area about nine and a half miles long by a mile and three-quarters wide. It is as variable in thickness as the Wellington, in places more so, with range from *nil* to thirty feet and an average of over five feet. Both the floor and roof are quite variable in character, from fine conglomerate to sandy shale. Commonly, the variations in thickness are caused by undulations in the floor, although the roof may roll as well. They are most marked in the southern part of the area, say from Old Southfield mine south. Here, a face may be in twelve to fourteen feet of coal one day and in rock a day or two later. In many places, especially to the south, the seam is highly sheared and made up of sheared dirty coal or 'rash'. Partings of rock in the seam are often found to be extremely contorted. Barren areas occur in which, although the regular floor and roof persist, the intervening material is rock. Many fantastic examples of these variations are illustrated in a paper by C. M. Campbell(1) on the Cassidy mine at the extreme southern end of the workable area. Perhaps a classic example of the difficulties of operating a mine in such a seam is one given by Charles Graham(2) in a paper on the Vancouver Island coal industry. A bore hole had shown eight feet of coal. A slope passed nearby the bore in barren ground. Levels were driven to both the rise and dip sides of the bore, also in barren ground. A cross-cut between the levels, inbye from the bore, was again in barren ground. The mine manager then had a square pillar, 100 feet on a side, all the sides of which were barren of coal, but within which was a bore hole reported to have cut eight feet of coal. This was too much, so a cross-cut was driven to the bore on sights. It was found the bore had cut a pocket of coal, and that, had it been moved twenty feet away in any direction, it would have been in barren ground.

The foregoing descriptions of the seams have given the areas in which the seams have proved workable. The results of ninety-four years of mining and prospecting have defined these fairly accurately, and, while it is not intended to imply that, within these areas, the seams will everywhere be found workable, it is not likely that, outside of them, bodies of coal of workable size and seam thickness will be found. It might be mentioned that, in addition to all the mines and prospects, over 330 bore holes have been drilled in the Nanaimo area.

Origin and Geological History of the Coal Seams

It has been pointed out that the sediments of the Nanaimo series were deposited on a coastal plain, a bench between the mountains on the west and the sea on the east. It has also been seen that the coal measures were deposited under rapidly varying marine and terrestrial conditions. There are very few places in the area where the floor of the seams might be considered an underclay. Nowhere, so far as the writer has been able to ascertain, is there any place where roots and stumps were found in their original

(1)CAMPBELL, C. M., *Cassidy and the Douglas Seam;* C.I.M., Trans., Vol. XXVII, 1924, pp. 478-483.

(2)*Op. cit.*, pp. 456-477.

position. Both the floors and roofs of the seams are quite variable, being shale, sandstone, or conglomerate. At one place in No. 1 mine, a lens of fossil shells occurred in the roof, appearing similar to natural shell accumulations occurring on present-day beaches. The seams, where relatively undisturbed and hence presumably much as when laid down, are in places dirty. The dirty coal alternates with the clean—in places the seams are composed entirely of dirty coal or carbonaceous shale. Evidently, at these places, silt was deposited along with the carbonaceous matter, giving rise to the 'wants'.

These conditions do not fit the picture of coal formed as the result of accumulation of vegetable matter in large coastal-plain swamps, with standing timber and luxuriant undergrowth. Whether the material forming the seams grew in place, in peat bogs, as Clapp suggested, or whether it is transported vegetable matter, cannot be stated. The field evidence for this is not easy to interpret, and determination of the question is perhaps best left to the Cumberland area, where the original structure of the beds has not been obscured by later deformation. In any case, it seems most probable that the coal originated very close to the sea level, in large lagoon-like areas, separated from the outer sea by sand bars. Streams would discharge sediments into such lagoons and in places erode the deposits forming in them. Really violent storms would cut through the barrier bars and permit the waters of the outer basin, laden with roiled-up mud and sand, to enter. The resulting coal seams would contain partings of dirty coal or of shale, and in places shale or sandstone would entirely replace the seams.

It is evident that the position of the lagoons, and of silted or dirty areas in them, is what governs the location of the productive areas of coal as found today. Their location can be predicted if the geography at the time of deposition of the coal seams can be reconstructed. Thus lagoons would likely form where bays formerly existed, but one would not expect them along what were formerly straight, featureless stretches of coast. Near former hills or headlands, the seams would not be good, since streams probably discharged sediments from the hills, and since wave action would be strong about headlands, preventing the formation of bars or lagoons. At the same time, the shelter they would provide might well give rise to productive areas in their lee. An example of this occurs to the northeast of the Wakesiah mine. Here, a bore hole encountered trap twenty-three feet above the projected horizon of the main Wellington seam, that is between 600 and 700 feet above the usual base of the Cretaceous. The potential seam area actually occupied by the trap is small, yet, for about one square mile on the north, the seam is both thin and dirty, no doubt because of the presence of this former headland. To the southwest, however, very productive areas of coal were formed, presumably in the lee of this headland, and they have been worked in the Wakesiah and Jingle Pot mines.

The task of reconstructing the ancient geography at Nanaimo has been complicated by the faulting. Thus, with a low-angle thrust fault, the horizontal displacement is much greater than the vertical. A thrust dipping at 30° and causing a 600-foot downthrow has had a horizontal displacement of 1,040 feet, nearly a quarter of a mile. Parts of seams that are now close together, or even overlapping, may originally have been some distance apart. Moreover, the original location and elevation of trap ridges is not the same as that observed today. Thus, at present, mount Benson is about 3,400 feet high. Yet behind it, on an isolated upthrown block, are the Wolf Mountain outcroppings of the Wellington seam at about 2,000 feet elevation. Mount Benson is, therefore, more of an eminence today than it was when the coal seams formed. It is clear that nothing will be gained by making plans showing the areas of good coal and areas of 'wants', and endeavouring to deduce therefrom the pattern on which the seams were deposited, *until* the structures have been rectified or brought back to what they were before the folding and faulting.

As described under *Structural Geology*, the measures, particularly in the upper part of the section, have undergone considerable slippage of bed over bed because of the folding and faulting. Since, amongst rocks, coal is especially easy to shear, much of this shearing would be concentrated in the seams themselves. It has been observed both in the Douglas and Wellington seams that, in the disturbed areas of variable seam thickness where high coal occurs, somewhere nearby there is a corresponding area of low coal. One result of the folding and shearing of the seams has thus been to cause the coal to migrate locally and for short distances from areas where pressure was locally high to areas where it was less, since it is often not possible to account for these variations on a basis of original deposition. In general, it may be stated that the broader variations in the coal seams are due to the conditions existing when they were laid down, but that local variations are frequently due to the deformation of the measures.

A consideration of the distribution of the faults provides a key to certain variations in the Douglas seam observed in the Nanaimo field. In the extreme southern part of the area, at Nos. 5 and 10 mines, South Wellington, and at the Cassidy mine of the Granby Company, the Douglas seam is highly sheared and disturbed. At No. 10 and Cassidy mines, blowouts or outbursts of coal and gas were common and greatly interfered with the operation of the mines. The geological map shows that the faults converge toward this area from the north. In the west-centre of the area, the most western outcrop of the Wellington seam is more than four miles from the outcrop of the Douglas, while in the southern part of the area the two outcrops are less than a mile apart. The downthrow has been concentrated in the southern part of the area, and here slippage of bed over bed will reach a maximum. Here, too, the Douglas seam and associated measures have been more tightly folded than elsewhere in the area. The only other place in the area where blowouts occurred was in the deepest part of the Reserve mine, on a steep roll which is part of the Harbour downthrow. There is evidently a relationship between this tight folding and blowouts, and the writer is inclined to believe that this relationship arises from the residual stress pent up in the folds, although it is also possible that the increased heat and pressure that must have existed in the vicinity of these folds caused some chemical or physical change in the properties of the coal that is responsible for the blowouts.

The recognition of the faulting at Nanaimo has answered a question that has bothered everyone who has studied both the Nanaimo and Cumberland fields, namely, why, in two coal fields so similar in origin and occurrence as these, do the Nanaimo seams show such disturbance, rapid variation in thickness, and large amounts of 'rash' or sheared dirty coal, whereas the Cumberland seams exhibit none of these features. The previous version of the structure of the Nanaimo field did not imply sufficiently intense deformation to account for the difference in the two fields, but that here advanced does.

After the faulting, the Nanaimo area stood above—and at least in its western part, high above—sea-level, and since that time much erosion has taken place. This removed considerable amounts of good coal, for, if the coal accumulated in lagoon-like areas as postulated, the deposits would lens out, become dirty, and finally disappear on both the landward and seaward sides. That this occurs down the pitch, or seaward, has been established, the Wellington seam becoming unworkable about a mile from its extreme western outcrop, and the Douglas about a mile and a half. The experience of mining both at Nanaimo and Cumberland bears out the statement that, on Vancouver island, the best coal is found on the crop. If one assumes that the coal would be best at the centre of the lagoons and would deteriorate at the same rate both landward and seaward, at least half of the original coal deposits of the Nanaimo area have been removed by erosion. The nearness of the range of mountains to the west shows that the amount could not be much greater, and it may have been less if the rate of deterioration were greater landward than seaward.

CONCLUSIONS

(1) The Nanaimo series was deposited in a sinking depression between two mountain ranges from which sediments were being carried and deposited in the dpression. The character of the sediments formed—land, near-shore, or marine—was determined by the balance of sinking *versus* sedimentation. An especially steady set of conditions was required for the deposition of coal seams.

(2) The surface on which the sediments were deposited was one of considerable local relief, and the topography at the time of deposition had a strong influence on the character of the seams.

(3) The seams were originally deposited in low coastal swamps or lagoons protected from the outer sea by barrier bars, and, because of this: (*a*) the seams, as originally deposited, were in places dirty and their broad variations into areas of good, thick coal and thin, dirty coal are due to original deposition; and (*b*) natural limits are set on the field. These have been determined by prospecting.

(4) The area as a whole has been subjected to strong stresses which produced both faulting and folding. The faulting has chiefly determined the attitude and position of the seams, and has caused many of the local variations in them.

(5) Approximately half the coal of the Nanaimo coal field was removed by erosion.

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UPPER CRETACEOUS FORAMINIFERAL ZONES, VANCOUVER ISLAND, BRITISH COLUMBIA, CANADA[1]

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ABSTRACT

Previous geological work is summarized by Usher (1951). The Cretaceous rocks lie in two basins, the Comox Basin in the north and the Nanaimo Basin in the south, separated by a pre-Cretaceous ridge. The succession consists of alternating marine shales and marine and non-marine sandstones. From bottom to top, the shales of the Nanaimo Basin are named the Haslam, Cedar District, and Northumberland formations. Those of the Comox Basin are the Qualicum, Trent River, Lambert and Spray formations.

The foraminifera represent restricted and open marine biofacies; the former is not considered here. The lower parts of the Haslam, Qualicum and Trent River formations are typified by large Lagenids, *Gaudryina austinana* and *Rugoglobigerina* cf. *rugosa;* this fauna is probably Campanian in age. The Cedar District, Northumberland, Upper Trent River, and low Upper Lambert formations contain *Cibicides voltziana, Globotruncana arca* and many other genera; this fauna is late Campanian in age; it corresponds to faunas of Taylor and early Navarro age in California. The uppermost part of the Lambert formation and the Spray formation contain *Bolivina incrassata, Bulimina petroleana, Globorotalites spinea,* and other species; this fauna is early Maestrichtian in age, and corresponds to P. P. Goudkoff's D1 and D2 zones in the Navarro of California. The Campanian-Maestrichtian boundary is thus placed within the Upper Lambert formation, slightly higher than the level used by Usher.

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INTRODUCTION

The material upon which this paper is based was collected by the writer in 1958 and 1959 from the Upper Cretaceous succession which outcrops on the east coast of Vancouver Island and on adjacent islands in the Strait of Georgia (Fig. 1).

No previous work has been published on the foraminifera, but considerable interest in the Upper Cretaceous rocks of the area has continued since 1849 due to the presence of coal seams near Nanaimo and Comox. Recently several oil companies have carried out surface investigations to explore the possibility of oil accumulation in the many sandstones which are developed in the succession. Usher (1952) effectively summarizes previous geological work, provides a useful description of the stratigraphy and introduces the extensive ammonite faunas which occur at certain levels in the Upper Cretaceous sequence. Usher's fossil localities were all visited and completely sampled by the writer, in addition to other localities not recorded by Usher.

ACKNOWLEDGMENTS

Mr. and Mrs. W. Padgham of the University of British Columbia assisted with the field work in the Nanaimo Basin; Miss J. E. Rapson, University of Alberta, Calgary, and consultant, assisted with the field work in the Comox Basin. Mr. B. Carr-Brown assisted with part of the laboratory work and preliminary taxonomy as a graduate thesis project at Queen's University, Kingston, Ontario. The field collecting in the Nanaimo area was supported by a grant from the Geological Survey of Canada. Assistance with drafting and illustration was given by the Geological Department, University of Alberta, Edmonton.

STRATIGRAPHY

The Cretaceous rocks of the Nanaimo group consist of a thick succession of alternating sandstone and shale units which have been given formational status (Usher, 1952). The sandstones often include conglomerates and in places coals, and are usually of somewhat limited lateral extent, particularly across strike. The regional dip of the Nanaimo Group is to the east, so that basal Cretaceous beds rest on older rocks along the east coast of Vancouver Island, while younger Cretaceous rocks form the elongate offshore islands in the Strait of Georgia. Marine faunas and microfaunas are almost exclusively restricted to the shale formations, most of which are, unfortunately, to a considerable extent covered by the sea. It is convenient to consider the area in terms of two basins of deposition, since the stratigraphic and faunal sequence in each is somewhat different. These are (1) the Nanaimo Basin in the south and (2) the Comox Basin in the north. The Nanaimo Basin extends from Nanaimo in the northwest to Sucia Island (U.S.A.) in the southeast. The Comox Basin extends from the vicinity of Comox in the north to Nanoose Bay in the south. The shale formations of the Nanaimo Basin are named, from bottom to top, the Haslam, Cedar District and Northumberland formations. Those of the Comox Basin are the Qualicum, Trent River, Lambert and Spray formations. Sandstone and conglomerate formations, which occur between the above mentioned shales, also carry local names, but are not considered here.

A coarse clastic basal Cretaceous concentrate rests on pre-Cretaceous rocks just north of Nanaimo (Locality 27), indicating an area of high pre-Cretaceous relief which may have formed a natural barrier between the basins. However, the Cretaceous succession probably rests on a rather irregular surface throughout the area, and other pre-Cretaceous "highs" no doubt existed, giving rise

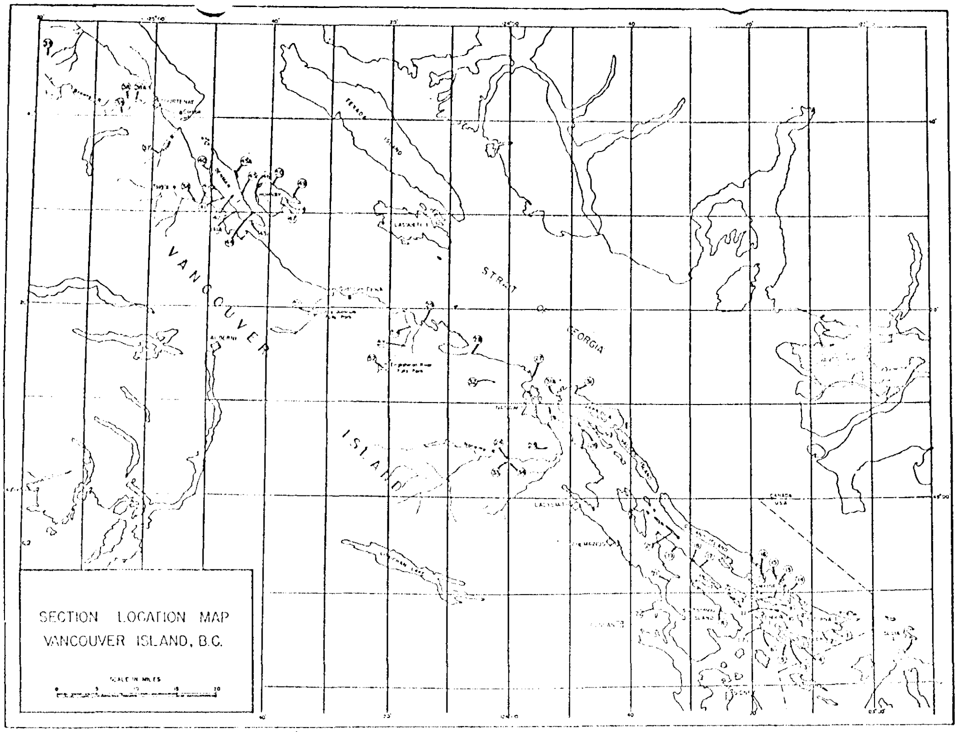

Fig. 1.—Section location map, Vancouver Island, B.C.

to restricted areas of sedimentation and controlling the nature of the basal Cretaceous beds. In Figure 2 (after Usher, 1952), broken lines show the conventional lithologic correlation between the formations of the Nanaimo and Comox Basins. In this interpretation, the lower beds of the Nanaimo Basin are not represented in the Comox Basin. The oblique lines "F" show age relationships postulated as a result of the study of the foraminifera. It is interesting to note that Usher (1952, p. 35, para. 2) also found diachronous relationships from his study of the ammonite faunas but nevertheless attempted to make faunal zones, which carried the names of *lithologic* formations, fit into the standard lithologic correlation. The present paper demonstrates that each shale unit (or formation) does not necessarily coincide with the natural faunal zones based on foraminifera.

SAMPLING AND SAMPLE PROCESSING

The microfauna occurs exclusively in gray shale which is often considerably silty and sandy. Usually, a high arenaceous content corresponds with a high proportion of agglutinated foraminifera in the population, combined with a decrease in the total numbers present. Sandstones and siltstones are usually unfossiliferous.

At each locality visited, the section was continuously sampled by taking about 100 grams of representative sample per twenty feet of section. Holes and trenches were excavated to ensure fresh, unweathered, uncontaminated material. Exceptions to this routine were made when obviously fossiliferous levels were encountered. In this case, 100 grams of sample were taken from the bed containing the megafauna. Also, when sandstones and siltstones

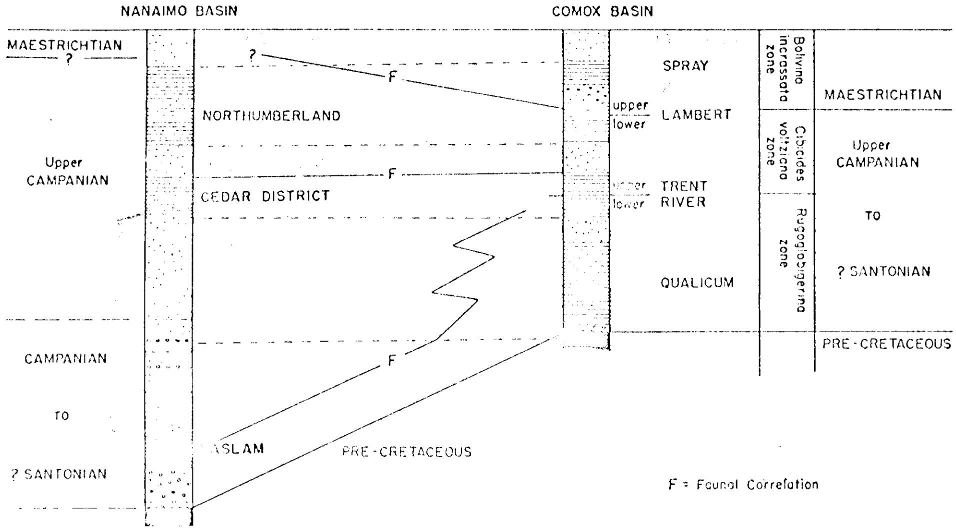

Fig. 2. Correlation diagram.

occurred, they were not included with the microfossil samples, since experience has shown that sandy material is unsuitable. However, in this case separate samples were taken, and are being examined petrographically by Miss June E. Rapson, University of Alberta, and Consultant, Calgary.

The microfossil samples, numbering about 600, were crushed to one-eighth inch maximum size and soaked in detergent solution for several weeks. They were then rolled in jars with weighted rubber slugs, on a roller mill for periods up to three hours, depending on the hardness of the sample. Following this disintegration process, the samples were washed through sieves where further gentle abrasion was applied with a flexible rubbed pad. The residues were dried, bottled and picked in the usual way using a binocular microscope. Since the microfauna is relatively sparse, a total of approximately 1800 man-hours of picking was necessary to obtain approximately 7,000 specimens in the present collection.

STRATIGRAPHIC MICROPALAEONTOLOGY

The Succession of the Comox Basin, (Type Section for the area).

Figure 3 shows the stratigraphic ranges of selected diagnostic foraminifera in the Comox Basin.

Bolivina incrassata zone

(Maestrichtian)

The most striking faunal break in the entire succession occurs in the middle of the Upper Lambert formation on the north shore of Hornby Island; this is undoubtedly the Campanian-Maestrichtian boundary. The following foraminifera occur only above this level: *Bolivina incrassata, Bulimina petroleana, Planulina* cf. *nacatochensis, Eponides* cf. *umbonella, Allomorphina cretacea, Arenobulimina* sp. and, in the Spray formation, *Spiroplectammina navarroana.* Restricted to the Upper Lambert formation are: *Globorotalites spinea, Anomalina* cf. *pseudoexcolata, Epistomina supracretacea* and *Gyroidina* cf. *globosa.*

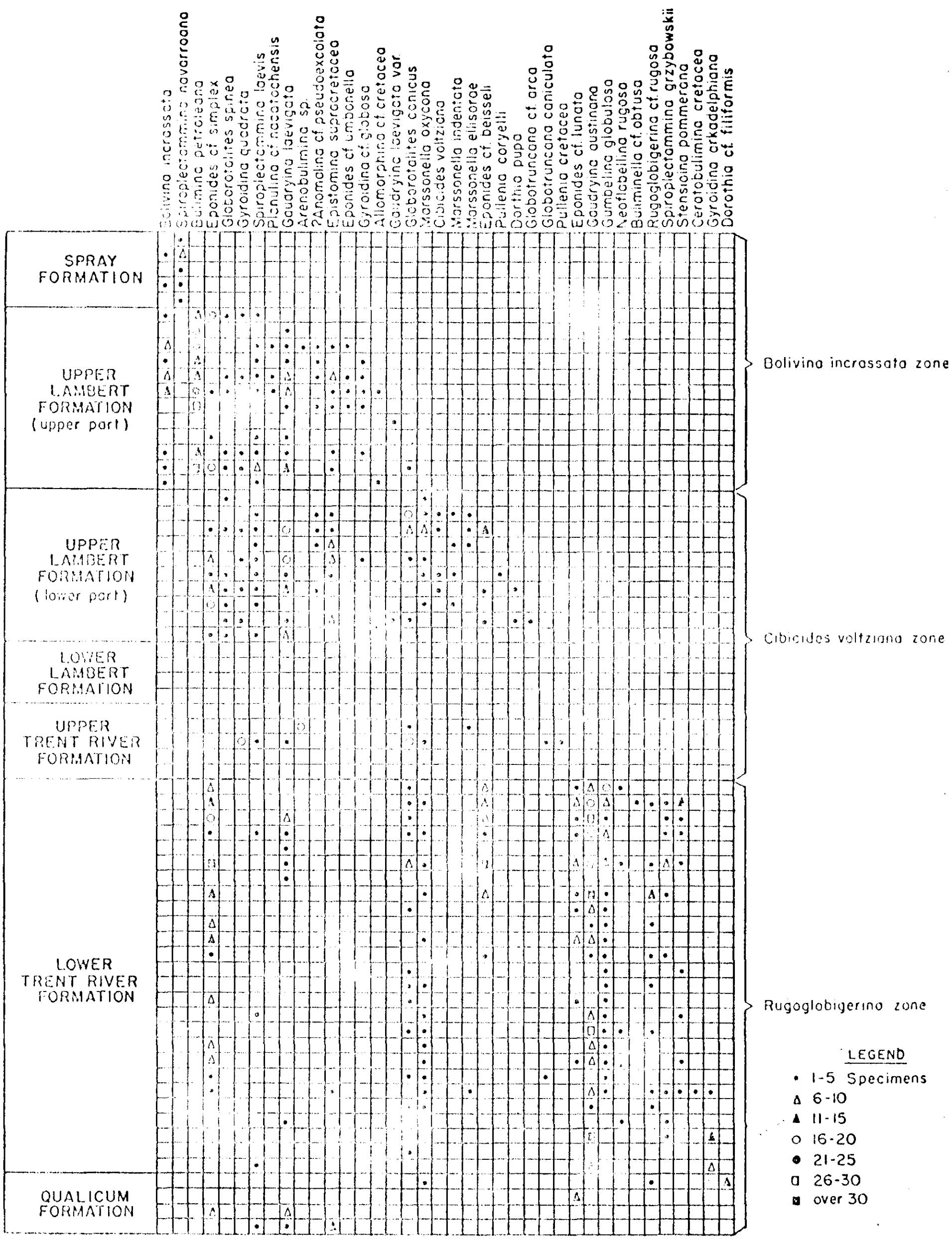

Fig. 3.—Range chart, Comox Basin, B.C.

Cibicides voltziana zone
(Upper Campanian)

The following species have their upper limit at the Campanian-Maestrichtian boundary in the middle of the Upper Lambert formation: *Cibicides voltziana*, *Marssonella oxycona*, *M. indentata*, *M. ellisorae*, and *Eponides* cf. *beisseli*. Also in the *C. voltziana* zone *Pullenia coryelli*, *Dorothia pupa*, *Globotruncana* cf. *arca*, *Globotruncana caniculata* and *Pullenia cretacea* occur, while the Lower Lambert formation contains only agglutinated forms which are not considered here.

Rugoglobigerina zone
(Campanian and ?Santonian)

The following species do not occur above the top of the lower Trent River formation which outcrops on the east coast of Vancouver Island: *Eponides* cf. *lunata*, *Gaudryina austinana*, *Gumbelina globulosa*, *Neoflabellina rugosa*, *Buliminella obtusa*, *Rugoglobigerina* cf. *rugosa*, *Spiroplectammina grzybowskii*, *Stensiöina pommerana*, *Ceratobulimina cretacea*, *Gyroidina arkadelphiana*, and *Dorothia* cf. *filiformis*. The basal beds of the Trent River formation and some levels low in the Qualicum formation are also typified by an abundance of *Gaudryina austinana* and large lagenids including *Lenticulina pseudocultratus*, *L. modestus*, *Saracenaria navicula*, *Nodosaria* sp., *Dentalina* sp., and *Marginulina* sp. The latter three genera at this and other levels are usually fragmentary. Because of poor outcrop control, the exact stratigraphic position of the Qualicum formation must be considered doubtful at the moment. At least part of this formation may be the age equivalent of at least part of the Lower Trent River formation.

The above microfaunal sequence corresponds well with that recorded from the Gulf Coast of the U.S.A., the European Upper Cretaceous, and other Upper Cretaceous marine sequences, but few species occur in rocks of this age in Alberta.

Goudkoff (1945) subdivided the Cretaceous in Great Valley, California, using foraminifera, and a number of Vancouver Island species are common to both areas. Goudkoff's C to D2 zones of Navarro (Maestrichtian) age, are typified by *Planulina nacatochensis*, *Bulimina petroleana*, *Gyroidina globosa*, and *Bolivina incrassata*, which also occur in the *Bolivina incrassata* zone of the Comox Basin. Goudkoff's E zone (Taylor age, U. Campanian), contains *Anomalina henbesti* among other species common to both areas. This species appears identical with *Cibicides voltziana* from Vancouver. The pelagic index foraminifer *Globotruncana arca* occurs in Goudkoff's D2 zone (somewhat higher than a comparable form from Vancouver), while *Globotruncana caniculata* occurs lower down in the F zone (Campanian) as it does in the Vancouver sequence. Thus the Vancouver *Bolivina incrassata* zone is correlated with Goudkoff's C to D2 zones, while the *Cibicides voltziana* zone corresponds to Goudkoff's F zone. The Vancouver *Rugoglobigerina* cf. *rugosa* fauna is apparently not recognisable in Goudkoff's sequence, although the microfaunal assemblage is Campanian in age, as evidenced particularly by the presence of *Neoflabellina rugosa*, *Gaudryina austinana*, and *Ventilabrella austinana*.

THE SUCCESSION OF THE NANAIMO BASIN

The Nanaimo Basin contains a somewhat lower proportion of calcareous foraminifera than the Comox Basin, but quite reliable correlation can nevertheless be made.

Firstly, as shown by Figure 4, the Maestrichtian *Bolivina incrassata* zone is not represented in the Nanaimo Basin. Levels high in the Northumberland formation contain *Cibicides voltziana*, *Globorotalites conicus*, *Eponides* cf. *beisseli*, *Marssonella oxycona*, and other species typical of the Upper Campanian *Cibicides voltziana* zone. Although a few longer ranging species recorded from the *Bolivina incrassata* zone do occur in the Northumberland formation (*e.g.* *Anomalina* cf. *pseudoexcolata*, *Epistomina supracretacea*), the presence of the *Cibicides voltziana* fauna and the absence of the abundant and diagnostic fauna *Bolivina incrassata, Bulimina petroleana, Globorotalities spinea, Planulina nacatochensis,* and *Allomorphina* cf. *cretacea,* definitely dates the highest Northumberland formation as older than *B. incrassata* zone.

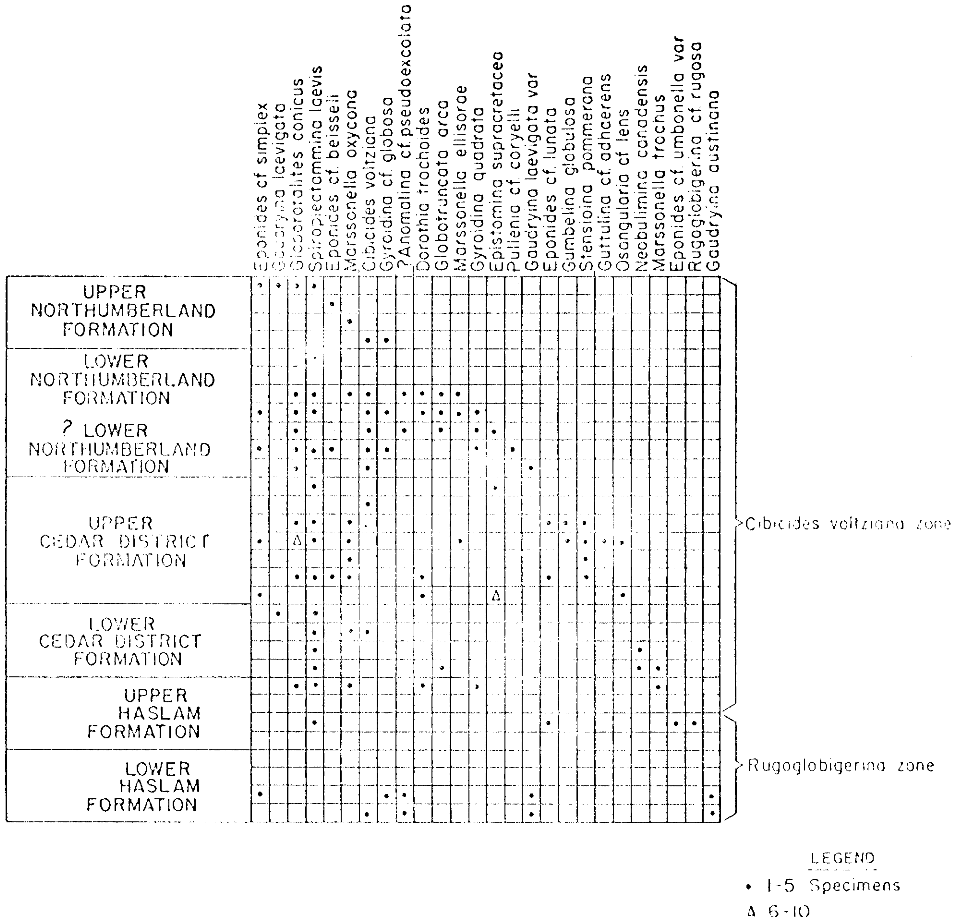

Fig. 4.—Range chart, Nanaimo Basin, B.C.

The Cedar District formation contains the *Cibicides voltziana* fauna, and *Eponides* cf. *lunata, Gumbelina globulosa,* and *Stensiöina pommerana* also occur. These three latter species are also common in the uppermost part of the Lower Trent River formation (Locality 36A).

While the Haslam formation is usually poorly fossiliferous, at a number of localities it contains *Rugoglobigerina* cf. *rugosa, Gaudryina austinana* and an abundance of lagenids similar to those found in the lowest Trent River and Qualicum formations. The Haslam formation thus corresponds at least to part of the *Rugoglobigerina* zone. The basal beds of the Haslam, Trent River and Qualicum formations, with their *Gaudryina* and *Lenticulina* fauna, either belong to a lower zone of possible Santonian age, or else the microfauna is primarily a facies fauna controlled by similar conditions, as the Cretaceous sea encroached on the irregular pre-Cretaceous surface.

The Cedar District and Northumberland formations thus apparently correspond in time to the interval comprising the Upper Trent River formation up to and including the lower part of the Upper Lambert formation. The microfauna of the upper part of the Upper Lambert formation and the overlying Spray formation, is unique and these formations are the youngest in the area.

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Geology and mineral deposits of the major islands on the British Columbia coast*

By W. G. JEFFERY and A. SUTHERLAND BROWN**

THIS PAPER DESCRIBES BRIEFLY the mineral development of the most westerly part of southern Canada. The islands of the Queen Charlottes, Vancouver, and Texada Islands lie west of the Coast Range Mountains and form a distinct geological unit (Fig. 1).

The rugged deeply indented coastline and the interior mountains make the islands a difficult area for mineral exploration although they are readily accessible by aeroplane and boat.

In the Queen Charlotte Islands, mountains form the southwestern part of Graham Island and the whole of Moresby Island. The peaks attain their greatest height of 4,000 feet in the central part of Moresby Island, and decrease in elevation to the north and south.

Apart from a narrow eastern coastal plain averaging about 8 miles wide south of Johnstone Strait, the whole of Vancouver Island is mountainous.. The most rugged and highest parts are in the centre of the island where peaks rise to over 7,000 feet.

The climate is mild and wet. Up to 300 inches of rain per year can fall at the heads of west coast fiords but an average figure for the islands is about 100 inches except for the east coast. This mostly falls in winter. The summers are good for exploration work with temperatures averaging about 60 degrees Fahrenheit.

Forest cover is thick up to elevations of about 3,500 feet, above which the country is alpine in character. The undergrowth density varies greatly depending upon location, elevation, and forest maturity.

History

The coalfields of eastern Vancouver Island were one of the mineral features which first attracted attention, and mining commenced in 1852.

Selwyn of the Geological Survey of Canada started mapping in 1871 followed by Dawson in 1878 and 1885. McKenzie published some studies about parts of the Queen Charlotte Islands in 1916. On Vancouver Island a succession of workers starting with Clapp in 1912* mapped the southern portion of the island. The interior of the northern portion of the island was investigated by Gunning in the late 1920's, followed by Hoadley in the post-war period. Texada Island was mapped by McConnell in 1914. In 1926 Young and Uglow published a review of the iron deposits of the west coast that included a considerable amount of information on local geology.

The many mineral occurrences of the islands are described in the Bulletins and Annual Reports of the British Columbia Minister of Mines and Petroleum Resources. In recent years

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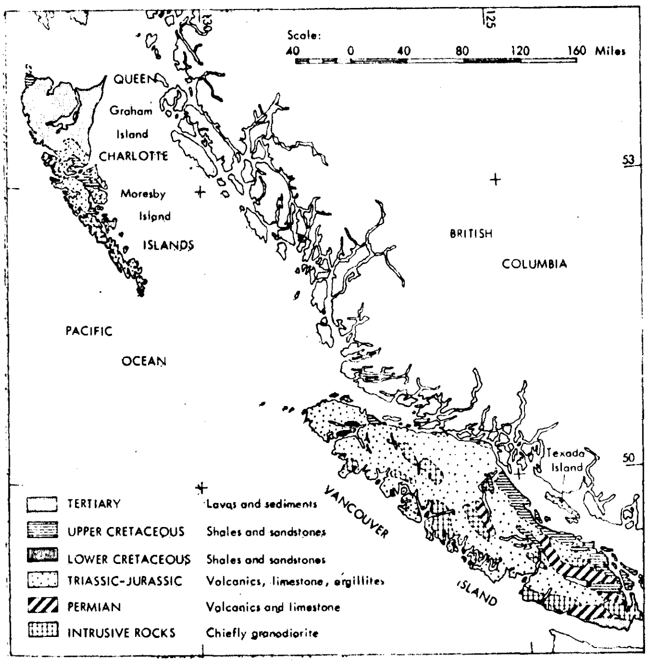


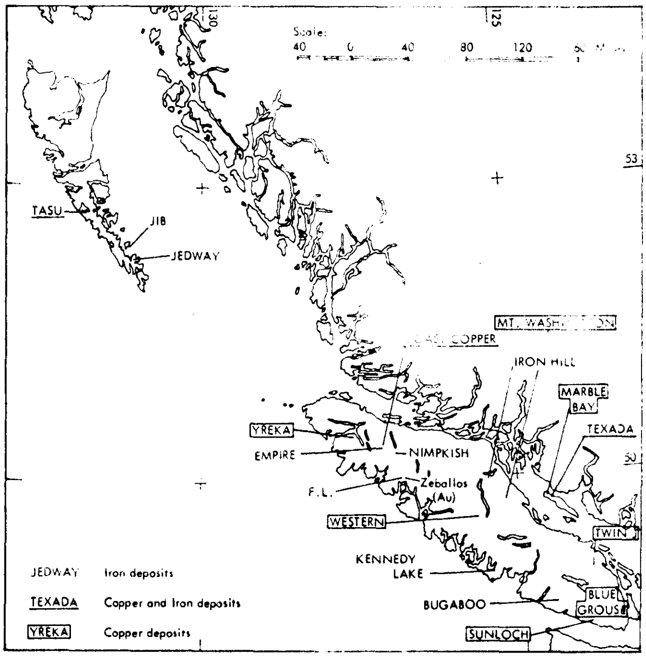


Figure 1. (Left) Geology of the Coast Islands of British Columbia. Figure 2. (Right) Major mineralized deposits of the Coastal Islands of British Columbia.

the work of the Department has expanded due to the development of several mines in the islands and a considerable amount of mapping has been done.

Geology

The Queen Charlotte Islands and Texada Island have been mapped completely. There are gaps in the geological mapping of Vancouver Island, and the correlations between various parts of the island are not certain. Also, although the rocks are similar in character there has been only partial correlation between the Queen Charlotte Islands and Vancouver Island. However, for the purposes of this paper some geological correlations will be assumed.

Two limestone units, one Lower Permian and one Upper Triassic, form the key to the Palaeozoic and Mesozoic stratigraphy of the islands. The oldest rocks underlie the Lower Permian limestone and occur in the southern part of Vancouver Island. These rocks are named the Sicker Group. The total thickness is unknown but is indicated to be at least 8,000 feet in the region of Cowichan Lake. The rocks are dominantly of volcanic origin and pyroclastic in nature. They include thin-bedded, cherty, argillaceous, and feldspathic tuffs, coarse and fine volcanic breccias, greenstones, and limestone. Along strike the character and facies change rapidly, and continuous markers or uniform stratigraphic sequences within the Sicker Group have been determined only for relatively small areas. At the top of the group crinoidal limestone and calcareous sediments contain Early Permian fossils and this unit is as much as 1,000 feet thick.

The limestone formation of the Sicker Group is overlain by the Vancouver Group, composed of volcanic rocks with an intercalated limestone unit. The lower suite of volcanic rocks is termed the Franklin Creek volcanics in the southern part of Vancouver Island, the Texada Formation on Texada Island, and the Karmutsen Group in the northern part of Vancouver Island and in the Queen Charlotte Islands. These rocks are fairly uniform throughout the entire region and consist of basaltic flows and pillow lavas with interbedded pillow breccias and some tuffs. Thin limestone horizons near the top of this sequence and the thick overlying limestone bed have been determined as Upper Triassic in age, so that the underlying volcanic rocks are usually regarded as Triassic. The thickness of the Karmutsen rocks is uncertain but appears to be not less than 10,000 feet.

The overlying Triassic limestone is termed the Sutton limestone in southern Vancouver Island, the Quatsino Formation in the centre and north, the Marble Bay Formation on Texada Island, and the Kunga Formation on the Queen Charlotte Islands. The limestone in places grades upward into thin-bedded carbonaceous limestones and argillites. The total thickness of these units varies from 1,000 to 4,000 feet.

Above the limestone there is a thick sequence of volcanic breccias, agglomerates, and tuffs together with flows all of which are dominantly andesitic in character. On Vancouver Island they are referred to as the Bonanza Group and are Early and Middle Jurassic in age. The equivalent rocks in the Queen Charlotte Islands are Middle Jurassic and are named the Yakoun Formation. The thickness has great variation from place to place but is nowhere less than about 3,000 feet and may be of the order of 10,000 feet thick. Sedimentary rocks composed mainly of volcanic material occur at the base of the Bonanza Group; in the Queen Charlotte Islands they are distributed variably throughout the Yakoun Formation.

All these rocks were affected by the Coast Range orogeny extending through the Late Jurassic and Early Cretaceous. This involved regional folding and faulting, metamorphism, and a succession of igneous intrusions. Lower Cretaceous rocks in northern Vancouver Island overlie intrusive rocks unconformably and a major number of intrusions on the islands are Late Jurassic in age. The composition of the intrusions range from granite to gabbro but is mainly quartz diorite and granodiorite.

The Cretaceous sediments of Vancouver Island consist of conglomerate, sandstone, and shale with coal seams. In the Queen Charlotte Islands there are beds of similar character, the Queen Charlotte Group, approximately 8,000 to 10,000 feet thick, which are tectonically equivalent although somewhat older than those on Vancouver Island.

Tertiary rocks occur within a small area of Vancouver Island. They comprise some thin sediments, some Early Tertiary volcanic flows, and small intrusive stocks. In the Queen Charlotte Islands the Masset Volcanic Formation is extensive and is composed of pyroclastic breccias, rhyolitic ash flow tuffs, dacitic flows, columnar basaltic flows, and some minor volcanic sandstones. Individual facies can be up to 6,000 feet thick and in places there can be a great thickness of volcanic rocks.

In summary the stratigraphy shows that the coastal islands are largely underlain by volcanic rocks with lesser amounts of granitic rocks and small areas of sediments.

The rocks in general have suffered only moderate deformation and the regional folds are open and moderate in intensity. There are some tight folds and severely deformed structures which, although local in extent, are important as mineralization controls.

Faults are important and the many linear topographic features such as fiords, coastlines, and river valleys represent a fracture system.

Field evidence indicates that there are major strike faults concordant with the geological grain of the country. In addition there are east-west and north-south faults that in places offset the strike faults. The widespread distribution of volcanic rocks of uniform nature and the heavy vegetation cover are factors that make faulting inconspicuous, but the fault pattern is important if problems of the mineral distribution are to be solved.

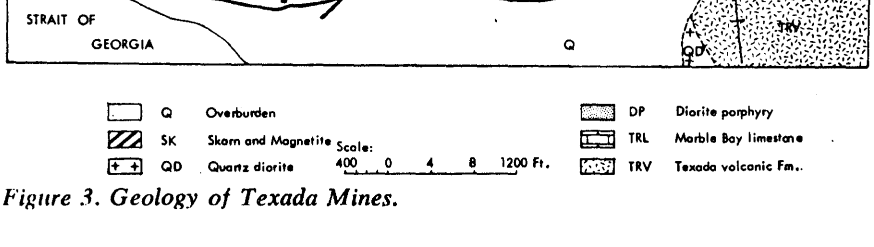


Figure 3. Geology of Texada Mines.

Mineral Deposits

There are scores of mineral prospects

in the region, and a rough classification must be made in order to present the information of mineral wealth and potential. Probably the most convenient division for the metalliferous occurrences is iron, base metal, and gold deposits although there is some overlap between them (Fig. 2).

Iron Deposits

From 1951 to the end of 1963, 11,546,083 short tons of iron concentrates with a value of $94,681,569 have been produced from the magnetite deposits in British Columbia. To obtain an idea of the nature of these deposits some examples are briefly described.

All the main deposits are associated with the Upper Triassic limestone of the coastal islands, and are close to intrusive rocks. The magnetite orebodies may occur within the limestone, or on contacts with igneous intrusions, or partly or wholly in the volcanic rocks above and below the limestone. Always they occur where the three rock types are in close association.

Texada Mines is one of the oldest iron producers on the coast. The present operation commenced in 1951. Four magnetite orebodies have been developed as open pits and these are named the Prescott, Yellow Kid, Paxton, and Lake (Fig. 3).

A small salient of a larger quartz diorite body divides the orebodies. On the east side the Paxton and Lake orebodies are at the contact of the limestone and the underlying volcanic rocks along the keels of sharp overturned folds in the limestone and adjacent to the intrusive rock. The relationships of the other two orebodies are not as definite. Mushoom-shaped structures in the quartz diorite appear to have had some control over ore deposition. Texada Mines has now partially converted to underground operations and development is taking place from a shaft equipped with the first friction hoist installed in British Columbia.

The Jedway deposit in the southern Queen Charlottes went into production as an open-pit operation on the basis of nearly 4,000,000 tons of 42 per cent iron. Ore occurs as tabular bodies in volcanic rocks underlying limestone that are cut by a diorite pluton in the immediate vicinity. The limestone, greatly crumpled locally, forms a broad west trending anticline and the deposit occurs on the north flank of this structure. The rocks are cut by a series of northwest shears. Ore in part extends along the fault zones and also concentrates around the keels of local folds in the limestone.

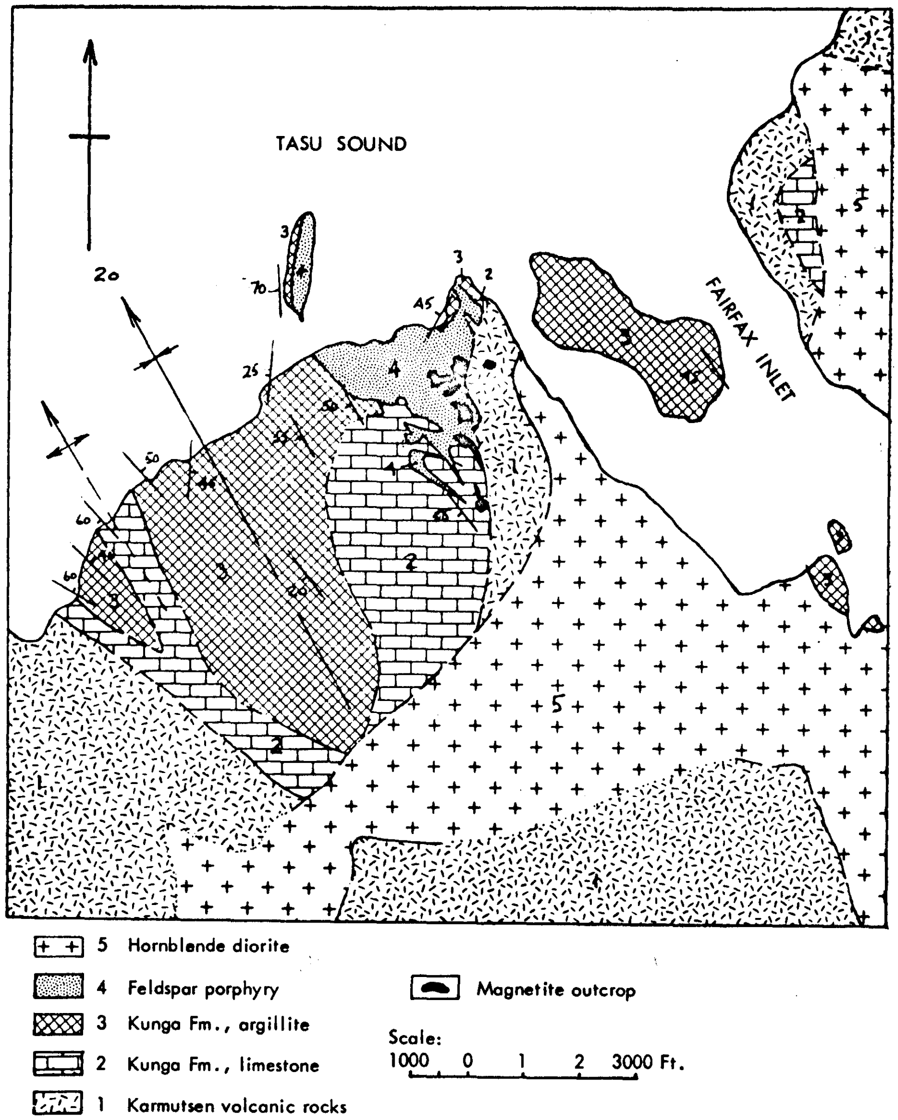


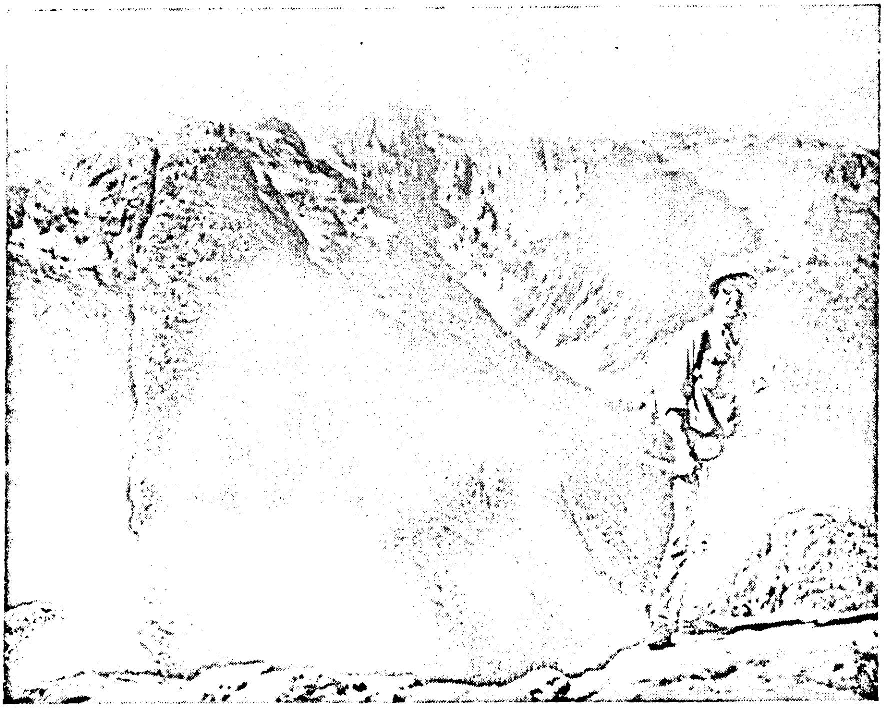
Figure 4. Geology of Tasu deposit.

The deposit at Tasu Sound, west coast of the Queen Charlotte Islands, is still being explored but it promises to be the biggest so far found on the coast. The ore indicated is in the order of 40 million tons of approximately 37 per cent iron and this would appear to be a conservative figure of the eventual available tonnage. Between a quarter and a third of this amount is also copper ore (Fig. 4).

The orebody is on the east limb of a north plunging syncline formed by limestone overlying volcanic rocks. A laccolith-like porphyry mass lies at the limestone-greenstone contact. Ore occurs as tabular bodies parallel to bedding, replacing the basal limestone, porphyry, and to a lesser extent the volcanic rocks. There may be a relationship with northwest faults. A diorite pluton of the coast intrusions occurs very close to the orebodies.

At the Empire mine on Vancouver Island tabular bodies of magnetite and skarn in the Merry Widow orebody lie sub-parallel to the steep easterly dipping contact of a diorite-gabbro stock and are enclosed mostly within metamorphosed volcanic rocks overlying local folds in the limestone. Prominent northeast faulting through the orebodies has been a major control. Along one of these faults there are also two pipes of high-grade magnetite wholly enclosed in limestone and cutting upward through the bedding. These pipes formed the Kingfisher deposits. This is another iron property that has passed from the open-pit stage to underground operations.

The other iron deposits of the coast (Fig. 2) are important but the foregoing examples from each of the major islands, together with the apparently largest deposit so far found, serve as illustrations. In essence the features of the mineralization and



Geological mapping in central Vancouver Island.

their relation to the regional geology are well known. Local structures are important as ore controls although they are often not recognized until development takes place.

These iron deposits may be small compared with the normal economic unit of iron mining, but they play a valuable part in the economy of the west coast. They were the first mining interest of Japanese industry, an interest that has subsequently expanded to all phases of mining in British Columbia.

Base Metals

The iron deposits have varying amounts of sulphides associated with the magnetite. In places there is sufficient chalcopyrite to produce a copper concentrate. This is the case of Texada Island; it will be the case in some parts of the Tasu orebody; at the Coast Copper mine a copper-gold concentrate is the primary product and a magnetite concentrate is secondary.

The Coast Copper deposit has features similar to the iron orebodies, except that it is more distant from intrusive rocks. The ore minerals, magnetite, chalcopyrite, and bornite, are confined to a thin zone on the sharp contact of a limestone bed with underlying volcanic rocks, that dips 37 degrees westward toward the same diorite-gabbro stock associated with the magnetite ore of the Empire mine. The mineralization forms raking oreshoots within the stratigraphic horizon.

Another mine that will produce copper is the zinc, copper, lead, gold, and silver deposit of Western Mines Limited on central Vancouver Island. The orebodies occur within volcanic rocks that underlie the Lower Permian limestone formation. Recent mapping has shown that these rocks are gently folded and extensively faulted. The sulphide occurs as replacement bodies within a broad northwest trending sheer zone.

An area with a similar ore and gangue mineral assemblage to Western Mines lies on Mount Sicker in southern Vancouver Island. This small producer closed in 1909, apart from a period of operation from 1943 to 1947 when it was known as the Twin J. Sulphide ore occurred within a sheared zone in pre-Permian schists and tuffs and was controlled by dragfolds.

Yet another copper deposit on the island is that of the Sunloch and Gabbro mine situated about 50 miles from Victoria. This consists of several orebodies of chalcopyrite-pyrrhotite mineralization occurring in fracture zones and sheared rocks in Eocene basaltic flows and Oligocene gabbroic sills.

Some copper deposits have been mined to deep levels on Texada Island. Wholly contained within limestone, they were high-grade bornite-chalcopyrite orebodies with appreciable gold and silver. The mineralization was related to fault zones close to intrusive contacts of quartz diorite and granodiorite. The orebodies were small but persistent in a vertical sense and the Marble Bay mine extended to 1,500 feet in depth. The ore carried over thirty mineral species, most of them in minor amounts.

The Yreka deposit remains a dormant copper prospect with features similar to the magnetite properties on the islands.

There are indications of other types of base metal occurrences. Plans have been announced for the erection of a mill at the Mount Washington copper deposit, where chalcopyrite, bornite, pyrite, arsenopyrite, and molybdenite occur in gently dipping quartz veins enclosed by volcanic breccias and dacite porphyries of possible Tertiary age. At Catface Mountain on the west coast of Vancouver Island chalcopyrite and bornite mineralization has been found in quartz monzonite intruded by quartz diorite and andesite sheets.

Gold Deposits

The Zeballos gold mining camp was prominent in its production period from 1935 to about 1948 but is now dormant. Several mines produced gold and silver from quartz-sulphide fillings in well-defined fault fissures rarely more than a foot wide that maintained a fairly uniform strike and dip for considerable distances. Tension fractures are the most favourable locations for ore.

Petroleum, Natural Gas, and Coal

The petroleum and natural gas potential of the various basins between the islands and the mainland, and the offshore area of the continental shelf west of Vancouver Island is not well known but exploration is continuing.

The coal deposits of the Cretaceous rocks of the east coast of Vancouver Island have been worked for over 100 years but their output is now negligible.

Conclusion

From evidence of the producing, dormant, and prospective mining properties on the islands it is clear that there are varied types of deposit within a fairly small area. An important feature is that mineralization can occur throughout the entire stratigraphic range of rocks exposed in the region.

The magnetite-chalcopyrite deposits appear to be solely associated with the Upper Triassic limestone member. Prospecting for this type of iron deposit has been fairly widespread in the last few years, but in many cases the methods have not been those which would have detected magnetite-poor and copper-rich members of this class of mineral deposit.

At Western Mines the surface showings have been known for almost fifty years but only now is the ore being developed. For the time being exploration for these replacement sulphide bodies will be guided to areas underlain by the older rocks on Vancouver Island in which these ores have been found.

The most recent development is the discovery of low-grade base metal mineralization in breccia-type structures.

Prospecting on the islands in the past has been widespread though erratic in its intensity and enthusiasm. The mild wet climate allows prospecting operations through the summer but it is a discouraging climate in the winter, and above fairly low elevations heavy snowfall prohibits exploration. The thick forest cover creates its own difficulties for exploration operations, and a large part of the coastal islands is rough and rugged country. However the area is accessible in that no place is far removed from the sea or large lakes, or from settled areas in the case of Vancouver Island.

There is no doubt that the two features of rugged mountain topography and heavy forest cover make some of the modern exploration techniques difficult to use. Airborne geophysics remains plagued by difficulties of location, ground clearance, and interpretation. Research is still required in the use of geophysics and geochemistry in such areas. Thus it is an area of Canada where ground prospecting by the single prospector willing to crack rocks and look under tree roots can still have a fair chance of making a strike.

Paper presented at the Annual Meeting, Prospectors and Developers Association, Toronto, 1964.

Individual air conditioning for hot plant workers

A NEW AND EFFECTIVE ANSWER to hot plants and overheated workers whose efficiency declines as the temperature goes up, has been developed by the medical and engineering departments of Kaiser Aluminum & Chemical Corporation's plant at Chalmette, Louisiana.

Culminating a six-year research and development programme, the doctors and engineers have come up with an individual air conditioning system which weighs only three pounds and delivers cool clean air directly to the worker through equipment he wears. The personal air conditioner makes it possible for a man to move freely about and work comfortably even in a hot, humid environment.

The heart of the new system is a 33-year-old laboratory curiosity — a vortex tube — which has no moving parts and is operated by compressed air. Fed by a lightweight air hose connected to a standard industrial compressed air supply system, the vortex tube emits a stream of cool air from one end and warm air from the other. A control valve provides air to the worker at between 65 deg. F. and 80 deg. F., with a flow of 20 cfm.

The vortex tube is worn on a belt at the waist, and delivers the cool air through a simple air-harness of flexible perforated tubing worn under the regular workshirt and inside a fabric hood.

Dr. W. F. Leinhard, medical consultant at the Chalmette plant, and T. A. Brassette of the plant's engineering department, are credited with development of the individual air conditioning system for plant use. It proved successful in various plant operations on a trial basis through the summer months of 1962 and 1963, and its use is to be extended further this summer.

'Successful attainment of practical personal air conditioning represents a significant breakthrough in providing greater comfort to workers in plants or other locations where it is not possible to air condition the entire work area," said Dr. J. P. Hughs, Kaiser Aluminum's medical director.

Conditioning of only the air space adjacent to the skin surface has long been recognized as a theoretically sound approach. However, past efforts to provide an adequate supply of cool air have usually required large refrigeration units that lacked mobility and flexibility, and were costly to install and maintain. Even greater difficulties were encountered in attempting to transport cool air through a length of hose to the worker.

The vortex tube, however, makes cool air available directly to the man. Great mobility is provided by a standard, half-inch diameter air hose connected to lines leading from a central air compressor station, such as is common in many industrial plants. Hoses up to 150 feet in length have been used successfully. A safety coupling also has been designed which provides for quick uncoupling of the hose connection.

The vortex tube was invented in 1931 by George Ranque, a French metallurgist, who was granted a United States patent for his invention in 1934. In 1946, the vortex tube was further developed by Rudolph Hilsch, a German physicist. Until recent years it has remained essentially an experimental device, but the vortex tube used in the main air conditioning system is now available from commercial suppliers.