GEOLOGY OF VANCOUVER ISLAND

by J. E. Muller, 1977

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MARGINAL NOTES

Introduction. Vancouver Island, the largest island in the eastern Pacific Ocean, is 451 km (280 miles) long, a maximum of 126 km (78 miles) wide, and occupies an area of 32,137 sq km (12,408 square miles). Most of its area is occupied by the Island Mountains with peaks of 1,000 to 2,000 m (3,000 to 6,000 foot) elevation. Many central valleys are occupied by finger lakes and the west coast is indented by numerous fiords. The middle part of the east coast, facing Strait of Georgia, is occupied by the Nanaimo Lowlands.

General Geology. The geology of Vancouver Island has been explored mainly by government geologists. Important contributions were made by the following (years of fieldwork in brackets): J. Richardson (1872-1876), G.M. Dawson (1887), C.H. Clapp (1909-1913), H.C. Gunning (1929-1932), A.F. Buckham (1939-1948), J.L. Usher (1945-1948), J.W. Hoadley (1947-1950) and J.A. Jeletzky (1949-1953) of the Geological Survey of Canada, and H. Sargent (1939-1940), J.S. Stevenson (1941-1950), J.T. Fyles (1948-1951), G.E.P. Eastwood (1961-1962), W.J. Jeffery (1960-1964) and K.E. Northcote (1968-1973) of the British Columbia Department of Mines and Petroleum Resources. In addition the work of D. Carlisle, D.J.T. Carson, R. Surdam and R.W. Yole in the period 1960 to 1970 deserves special mention. The work of all these geologists and that of the author since 1963 has been compiled into the present map. The compiler especially acknowledges the invaluable collaboration in field and office of the following colleagues: B.E.B. Cameron, D. Carlisle, D.J.T. Carson, W.G. Jeffery, J.A. Jeletzky, and K.E. Northcote. Fundamental to the work was also isotopic dating by R.K. Wanless and paleontological dating by B.E.B. Cameron, C.A. Ross, H. Frebold J.A. Jeletzky and E.T. Tozer.

The island is the main component of the Insular Belt, the westernmost major tectonic subdivision of the Canadian Cordillera. Narrow strips of land on the west and south coast are newly discovered fragments of the Pacific Belt that is well developed in the western United States and Alaska. The Insular Belt (Island Mountains) contains a middle Paleozoic and a Jurassic volcanic-plutonic complex, both apparently underlain by gneiss-migmatite terranes and overlain respectively by Permo-Pennsylvanian and Cretaceous clastic sediments. A thick shield of Upper Triassic basalt, overlain by carbonate-clastic sediments, separates these two complexes in space and time. Post orogenic Tertiary clastic sediments fringe the west coast.

The Pacific Belt on the western and southern rim of the island contains in its inner (eastern) part an assemblage of late Jurassic to Cretaceous slope and trench deposits, deformed to melange and schist, and an outer part of Eocene oceanic basalt and subjacent basic crystalline rocks.

Wark and Colquitz Gneiss (Pnb, Pns). The names Wark and Colquitz were applied by Clapp (1913) to the mafic and salic parts of the gneiss complex exposed in and near the city of Victoria. The Wark Gneiss consists of fine to medium grained, massive to gneissic biotite-hornblende diorite and quartz diorite. Colquitz Gneiss is lighter coloured, commonly well foliated biotite-hornblende quartz diorite to granodiorite gneiss. Wark and Colquitz gneisses are in places intimately interlayered, but it is possible to map distinct belts where one or the other predominates. The light coloured gneisses are believed to have been derived from clastic sediments, whereas the dioritic rocks are recrystallized basaltic sills or flows. One age determination on zircon from Colquitz Gneiss has yielded discordant ages between 295 and 384 m.y., possibly suggesting early Paleozoic source rocks. K-Argon ages on metamorphic hornblende from Wark diorite are 163 and 182, indicating early Jurassic metamorphism of the Paleozoic parent rock that was perhaps part of the Sicker Group. No stratigraphic contacts with other formations have been found, but volcanic rocks, tentatively correlated with Jurassic Bonanza volcanics may overlie them unconformably.

Sicker Group. The Sicker Group comprises all known Paleozoic rocks of Vancouver Island and is subdivided into a lower volcanic formation, a middle greywacke-argillite formation, and an upper limestone formation. The group is exposed in narrow, fault-bounded uplifts. The largest, Horne Lake-Cowichan Lake uplift, is the southernmost, the Buttle Lake uplift lies in the centre, and some smaller outcrop areas occur to the northwest in the Nimpkish region.

The volcanic rocks (CPSv) range from fine grained banded tuffs to breccias with clasts 10 cm or more in size and agglomeratic lava flows. Flows, tuffs and related dykes commonly contain phenocrysts of uralitized pyroxene and albitized plagioclase. A few chemical analyses indicate chemical compositions ranging from basalt to rhyolite. Although internal structure is generally well preserved the rocks are mostly of low greenschist chlorite-actinolite metamorphic rank. Locally they are shear-folded and converted to well foliated chlorite-actinolite schist. The undetermined thickness is estimated to be between 1,000 and 3,000 metres. Only one K-Ar age determination on actinolite in uralite porphyry from Saltspring Island yielded an age of 249 ± 10 m.y. (L.R. Armstrong, pers. comm. 1975). The apparent age of metamorphism is thus Middle Permian and the cooling age must be earlier Permian or older.

The greywacke-argillite sequence (CPSs) occurs in graded beds, a few millimetres to several centimetres thick, of argillite and siltstone, or in beds to several decimetres thick of greywacke sandstone. The greywacke locally contains lenses of detrital limestone. The formation is commonly silicified and like the volcanic rocks its structure varies from almost flat lying bedding to isoclinal folds. Total thickness is estimated to be in the order of 600 metres. Fusulinids and other foraminifera, obtained from the limestones, indicate a Middle Pennsylvanian (Desmoinesian) age.

The Buttle Lake Formation (CPBL), youngest part of the Sicker Group, is exposed in many places along the margins of the uplifts where Paleozoic rocks are overlain by the Karmutsen Formation. Yole (1969) measured a type section in the mountains west of Buttle Lake of 320 m (1050 feet) of interbedded crinoidal limestone and chert. On the basis of brachiopods and a single fusulinid he dated the rocks as Early Permian (Wolfcamp to Leonard) but Sada and Danner (1974) determined a Middle Pennsylvanian age on the basis of fusulinids for the limestone at Horne Lake.

The Sicker Group formations may be a continuous succession, but the possibility of an unconformity between the broadly folded Buttle Lake limestone and the commonly tightly folded greywacke-argillite sequence cannot yet be excluded. Furthermore, as parts of it are invaded by Devonian or older Tyee Intrusions whereas other parts are Pennsylvanian, the group may represent several tectonic units of which the oldest one would appear to be pre Devonian. That question remains to be solved by further structural and isotopic investigation.

Sicker Group rocks are the apparent remnant of a mid-Paleozoic volcanic arc, built on oceanic crust or perhaps on the continental edge. After volcanism ceased the volcanic rocks were covered by clastic and carbonate sediments.

Tyee Intrusions (Pg). Tyee Intrusions were originally mapped by Clapp and Cooke (1917) on Saltspring Island, continuing northwestward to Maple Bay on Vancouver Island. Only recently a pre-Jurassic age was suspected in view of highly altered and partly schistose lithology, entirely distinct from that of Island Intrusions, and has been confirmed by zircon dating, which suggests a minimum age of 360 m.y. They are in part altered granitoid rocks composed mainly of quartz, sericitic albite and microcline-perthite, with minor epidote and chlorite. Commonly the texture is cataclastic. In part they are also sericite schist with elongated quartz eyes to 1 cm length, occurring as sills with schistosity parallel with, but intrusive contacts oblique to the schistosity of the intruded metavolcanics and metagreywacke of the Sicker Group. The apparent early or pre-Devonian age, if confirmed, would indicate that part of the Sicker Group is pre-Devonian.

Vancouver Group. The base of the Vancouver Group consists in some places of thin-bedded black argillite, carrying Middle Triassic (Ladinian) Daonella (TRds). The beds, only known from the northeast flank of Mt. Schoen, are about 200 m thick, but are intruded by a greater thickness of diabase sills, bringing total thickness of sediments and sills to about 750 m.

Karmutsen Formation (muTRK) The Karmutsen Formation, named by Gunning (1932), is composed of tholeiitic volcanic rocks, up to 6,000 m thick and underlying a large part of the island. In Carlisle's (1974) standard section the formation is composed of a lower member, about 2,600 m thick, of pillow lava; a middle member, about 800 m thick, of pillow breccia and aquagene tuff; and an upper member, about 2,900 m thick, of massive flows with minor interbedded pillow lava, breccia and sedimentary layers. Except in contact zones with granitic intrusions the volcanics exhibit low-grade metamorphism up to prehnite-pumpellyite grade. Their age is determined by that of the underlying Ladinian unit and by Upper Triassic, Karnian fossils in sediments in the upper member. The basaltic eruptions apparently started with pillow lavas in a deep marine rift basin, continued with aquagene tuff and breccia as the basin became shallower, and terminated with intrusion of subareal basalt flows. Because the volcanics were formed on a rifting oceanic crust they are probably only in some areas underlain by Sicker Group rocks, whereas elsewhere they constitute new oceanic floor.

Quatsino and Parson Bay Formations (uTRQ, uTRPB). Upper Triassic sediments overlie the Karmutsen in the northern and western part of the island but in the east they were mostly eroded before deposition of Upper Cretaceous sediments. The Quatsino Formation consists of limestone, mainly massive to thick-bedded calcilutite, varying from 25 m to 500 m in thickness and containing ammonites and other fossils of late Karnian to early Norian age. The succeeding Parson Bay Formation is in diachronous contact with the Quatsino and in places lies directly on Karmutsen volcanics. It is composed of interbedded calcareous black argillite, calcareous greywacke and sandy to shaly limestone and the proportion and grain size of clastic material generally increases upward. The thickness is between 300 m and 600 m. Fossils are the pelagic pelecypods Halobia in the lower Karnian part and Monotis in the upper Norian part, together with many genera of ammonites. The sediments were formed in near- and off-shore basins in the quiescent Karmutsen rift archipelago.

Bonanza Group (lJB) The Bonanza Group was originally named by Gunning (1932) and at that time included Upper Triassic sediments now known to belong to the Parson Bay Formation. Nomenclatural as well as geological arguments indicate that the group should not be included in the Vancouver Group, as was done by Hoadley (1953) and in previous reports by the writer and others (1969, 1974). The group is mainly represented in the northwest and the southwest of the island and is composed of lava, tuff and breccia, according to available analyses mainly of basaltic and rhyolitic and subordinately of andesitic and dacitic composition. It contains intercalated beds and sequences of marine argillite and greywacke. In the northeast part of the island where only the sedimentary part of the group is present the rocks are referred to the Harbledown Formation (lJH). The Bonanza represents parts of several eruptive centres of a volcanic arc and consequently its stratigraphy varies considerably. A section 2,568 m thick, measured in the northwest at Cape Parkins, contains two sedimentary intercalations 225 and 75 m thick in the lower and upper part of the section. Fossils from Bonanza and Harbledown sediments indicate mainly Lower Jurassic Sinemurian age for the northwest and northeast and Pliensbachian age for the southwest.

Island Intrusions and Westcoast Complex (Jg, PMns, PMnb). The Island Intrusions are batholiths and stocks of granitoid rocks ranging from quartz diorite (potash feldspar <10% of total feldspar quartz 5-20%) to granite (potash feldspar >1/3 of total feldspar; quartz >20%). They underlie about one quarter of the island's surface and intrude Sicker, Vancouver and Bonanza Group rocks. Within the Bonanza Group they form high-level stocks and dykes of hornblende-quartz-feldspar porphyry and there is an apparent comagmatic relationship between intrusions and volcanics. About 40 K-Argon determinations have yielded dates of 141 to 181 m.y. for the intrusions and a few determinations on the volcanics are in the same age range. Preliminary results of Sb/Sr dating of Island Intrusions and also Bonanza volcanics have yielded respectively 174 m.y. and 184 m.y. isochron-ages (R.L. Armstrong and Krista Scott, pers. comm.).

The Westcoast Complex is also genetically related to the Island Intrusions. It is a heterogeneous assemblage of hornblende-plagioclase gneiss, amphibolite, agmatite and quartz diorite or tonalite, exposed in western coastal areas from Barkley Sound to Brooks Peninsula. One age determination on zircon from the complex has yielded near-concordant U/Pb dates of 264 m.y. and two K-Argon dates on hornblende from Westcoast rocks are 192 and 163 m.y. The complex is considered to be derived from Sicker and Vancouver Group rocks, migmatized in Early Jurassic time. Its mobilized granitoid part is considered to be the source of Island Intrusions and, indirectly, Bonanza volcanics. Available dating suggest that the plutonic-volcanic arc that formed these interrelated crystalline formations became extinct in Middle Jurassic time. A period of uplift and erosion followed.

Upper Jurassic Sediments (uJS). Upper Jurassic siltstone, greywacke and conglomerate, bearing volcanic subvolcanic and sedimentary, but no plutonic clasts are exposed in a small coastal area south of Kyuquot Sound. They contain fossils of Middle Jurassic Callovian to Late Jurassic Tithonian age and indicate the beginning of deposition of a clastic wedge on the eroded volcanic-plutonic complex.

Longarm Formation and Queen Charlotte Group (lKQC, lKQP). Lower Cretaceous formations are only present in the Quatsino Sound region. They are greywacke, siltstone and conglomerate, mainly derived from volcanic and older sedimentary rocks. A very thick boulder conglomerate of the Queen Charlotte Group carries some clasts of high-level plutonic rocks. The formations overlap eastward onto the pre-Cretaceous erosion surface and nowhere is a complete section of Lower Cretaceous rocks exposed. The total thickness probably does not exceed 1,400 m. Marine fossils indicate Early Cretaceous Valanginian to Barremian age for the Longarm Format cn and Aptian to Cenomanian age for the Queen Charlotte Group.

Nanaimo Group (uKC to uKGA) Upper Cretaceous sediments are, in contrast to the Lower Cretaceous, exposed exclusively on the east side of the island and on adjacent Gulf Islands. They consist of cyclical, upward fining sequences of conglomerate, sandstone, shale and coal of non-marine or near-shore deltaic origin, succeeded by marine sandstone, shale and thin-bedded graded shale-siltstone sequences. Five major cycles are distinguished of which the first four have been divided into two formations each, a lower fluvial to deltaic and an upper marine formation. Coal seams in the lowest cycle of the Comox basin and in the second cycle of the Nanaimo Basin were mined from 1850 to about 1950. Macrofossils and microfossils indicate Late Cretaceous Santonian to Maestrichtian age. The Nanaimo Group was deposited in a fore-arc basin between the Coast Plutonic Belt (then an active volcanic arc) and the Insular Belt.

Carmanah and Escalante Formations (eoTC, eoTE). Tertiary clastic sediments overlie bevelled Island Mountain rocks in a narrow strip of land along the west coast and are also exposed on most of the continental shelf west of the island. The Escalante Formation is the basal conglomerate of Eocene age about 300 m thick, and is overlain by the Carmanah Formation of mainly siltstone and sandstone, about 1,200 m thick. The contained microfauna of the Carmanah is mainly correlative to the Refugian stage of the western United States (late Eocene to early Oligocene) but younger beds are of Zemorrian (middle to late Oligocene) age (B.E.B. Cameron and W.W. Rau, personal communications, 1973). The beds overlie Insular Belt rocks as well as the Leech River Formation of the Pacific Belt with clear angular unconformity. They were deposited on the upper part of a coastal shelf area, but many beds are sedimentary melanges that were redeposited by massive slumping. The formations may have extended much farther eastward but were removed from the land-area by late Tertiary and Pleistocene massive erosion.

Pacific Rim Complex and Leech River Formation (JKP, JKL). The Pacific Rim Complex is exposed mainly in the western coastal area between Ucluelet and Tofino that includes Pacific Rim National Park. It is composed mainly of greywacke and argillite with minor ribbon chert, basic volcanic rocks, limestone and conglomerate. The rocks are generally highly faulted and sheared and in many places are tectonic melanges. Locally the cherts contain radiolarians indicating Tithonian age (A.E. Pessagno, in Muller, 1976) and the greywacke has yielded Buchia's of Valanginian age (J.A. Jeletzky, pers. comm., 1972). The rocks are therefore in part coeval to Upper Jurassic sediments and the Longarm Formation. Granitoid clasts in the conglomerate indicate probable correlation with the Aptian conglomerate of the Queen Charlotte Group.

The Leech River Formation is exposed in a belt, 2 to 12 km wide, between San Juan and Leech River Faults on southern Vancouver Island. Like the Pacific Rim Complex the rocks are greywacke, argillite and minor chert and volcanic rocks but they are largely metamorphosed to schist. Metamorphic grades increase from phyllite in the north to garnet-biotite schist with andalusite porphyroblasts near Leech River Fault in the south. There muscovite gneiss and pegmatite with large muscovite and tourmaline crystals is also present. The age of metamorphism according to several K-Argon determinations is 40 m.y.

The Pacific Rim Complex and Leech River Formation are interpreted as a tectonized assemblage of slope and trench sediments and their metamorphic equivalents, formed in a late Jurassic to Cretaceous trench off the continental margin. They are equivalent in age and facies to the Franciscan Terrane of California although the metamorphic facies is apparently different. It is postulated that the volcanic arc, paired to this trench, is the Coast Plutonic complex and that Upper Jurassic and Cretaceous clastic sediments of the Insular Belt were deposited in the arc-trench gap.

Metchosin Volcanics and Sooke Intrusions (eTM, Tgb, Tg) Metchosin Volcanics underlie most of the south tip of Vancouver Island, south of Leech River Fault. They are pillow lavas, aquagene tuff and breccia and amygdaloidal flows of tholeiitic composition very similar to Karmutsen volcanics in lithology and sequence, but of lesser thickness, estimated at about 4,000 m. Dyke complexes of basalt and diabase intrude and underlie the volcanics. On the basis of Turritella within intercalated volcanic sandstone at Albert Head, in the middle part of the sequence, the volcanics are apparently of early Eocene age.

Chlorite schist and hornblende-plagioclase gneiss (TMn), exposed mainly in the area west of Jordan River, are interpreted as highly deformed and metamorphosed equivalents of Metchosin Volcanics. Hornblende from hornblende-plagioclase gneiss yielded a K-Argon date of 47 m.y.

The Sooke Intrusions are in part gabbro, commonly coarse grained, and with minor anorthosite (Tgb), apparently underlying the Eocene volcanics. Also present are gneissic amphibolite, hornblende gabbro, angular agmatite and small stocks of tonalite (Tg), presumably formed by migmatization, mobilization and intrusion into the volcanic sequence. Metchosin Volcanics and Sooke Intrusions could be interpreted as the upper and lower parts of new oceanic crust formed in early Tertiary time.

Small plutons a few km in diameter intrude various pre-Tertiary rocks of the Insular Belt in many places (Tg) They also form sills in flat lying Upper Cretaceous sediments, in the instance of Constitution Hill about 300 m thick. They also intrude the Pacific Rim Complex near Tofino. They are composed of quartz diorite and quartz diorite porphyry with hornblende and plagioclase phenocrysts, and of breccia that may have formed in a diatreme. K-Argon determinations have yielded dates between 32 and 59 m.y. The intrusions may be sub-volcanic eruption centres, aligned on three subcrustal fracture zones, radiating from the Tofino area respectively towards Zeballos, Mt. Washington and the upper Nanaimo River. However, no fractures or faults clearly related to the intrusions have been identified (Carson, 1973).

Sooke Bay Formation (mpTSB). The Sooke Bay Formation (modified from "Sooke Formation" to allow distinction from "Sooke Intrusions") occurs in depressions on the erosion surface of Metchosin Volcanics and Sooke Intrusions. It is probably less than 200 m thick and does not extend north of Leech River Fault. It contains locally coquina's of shallow water pelecypods indicating Miocene age, but the microflora may indicate early Pliocene age as well (Shouldice, 1971). The formation is of fluvial to deltaic origin.

Late Tertiary volcanic rocks (TvS) are exposed in small areas south of Port McNeill. They are basalt, almost unconsolidated tuff and breccia, volcanic boulder conglomerate and light coloured dacite tuff. Whole-rock K-Argon determinations yielded dates of 7.6 and 7.9 m.y.

Structure. The structure of the island is almost entirely dominated by steep faults. Only the flysch-type Pennsylvanian and Jura-Cretaceous sediments and associated thin-bedded tuffs show isoclinal shear-folding. Faulting and rifting probably occurred during the outflow of Karmutsen lavas in Late Triassic time, establishing the northerly and westerly directed fault systems affecting Sicker and Vancouver Group rocks. Faulting in northwest direction, accompanied by southwestward tilting in the west, and later by northeastward tilting in the east (the latter affecting Upper Cretaceous sediments) occurred in late Mesozoic to early Tertiary time. Faulting in a northeasterly direction affected younger Mesozoic and early Tertiary rocks. The important San Juan and Leech River Faults were active respectively in late Mesozoic and early Tertiary time and may be structures associated with subduction zones.

Mineral Deposits. Much of the coal in the Nanaimo Group, worked since 1850, has been depleted, especially in the Nanaimo Basin. In the Comox Basin there are still some doubtfully economic reserves of high volatile bituminous coal. The most important metallic ore deposits are: (1) massive sulphides of Zn, Cu, Pb, Au, Ag in Sicker volcanics (Western Mines), (2) skarn deposits of Cu and Fe in Quatsino limestone (Argonaut, Texada, Coast Copper, etc.;(3) porphyry copper deposits surrounding and within high level Island Intrusions (Island Copper) or in the Sooke Intrusions (Mt. Washington, Catface) (4) Cu in shearzones in amphibolized Sooke gabbro (Jordan River).

Glaciation. The entire island was glaciated during the Pleistocene. During an older glaciation, perhaps early Wisconsin, the entire island was covered by an ice-sheet, continuous across the Georgia Depression and generally flowing southwestward. Peaks with ice margins at present 1,000 to 1,500 m levels formed monadnocks and are readily recognized in the landscape. In one or more later glacial events ice probably accumulated in a northern, a middle and a southern centre, formed piedmont glaciers in Nimpkish, Alberni and Cowichan Valleys and flowed out from these with ice tongues into many valleys now occupied by finger lakes. The Strait of Georgia was also occupied by ice that flowed south across the Gulf Islands and the Victoria-Sooke region. Marine transgression during deglaciation attained elevations of 150 m along the east coast and 50 m along the west coast. The complex history of glaciation of the island is still awaiting detailed analysis.

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