British Columbia Geological Survey
Geological Fieldwork 1988

GEOLOGY OF THE ALBERNI — NANAIMO LAKES AREA, VANCOUVER ISLAND* (92F/1W, 92F/2E and part of 92F/7)

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KEYWORDS: Vancouver Island, Sicker Group, Duck Lake Formation, Cowichan uplift, thrusts, massive sulphide, gold.

INTRODUCTION

A 4-year program of 1:50 000-scale regional mapping was initiated by the Geological Survey Branch in southern Vancouver Island in 1986, under the Canada/British Columbia Mineral Development Agreement. The program was planned to cover three 1:50 000 NTS sheets centred on the main Sicker Group outcrop area within the Cowichan uplift (Figure 1-8-1). The 1988 field season saw the completion of the field component of this project. Previous mapping in the Cowichan Lake (92C/16) and Duncan (92B/13) areas has been reported on (Massey and Friday, 1987, 1988) and released as Open Files (Massey *et al.*, 1987, 1988).

During 1988, fieldwork was concentrated in the area around Fourth Lake (92/F1W) and west to Alberni Inlet (92F/2E), extending northwards to Horne Lake (92F/7). Road access is good with Highway 4 passing through the northern part of the area and the Bamfield road running along the western margin. An extensive network of logging roads, in various states of upkeep, provides access along most of the valleys and adjacent slopes.

PREVIOUS WORK

The Sicker Group was first defined as the Mount Sicker Series by Clapp (Clapp, 1912; Clapp and Cooke, 1917) within the Duncan area, although erroneously interpreted as younger than the Karmutsen Formation (Vancouver Series). Later workers in the Buttle Lake and Cowichan Lake areas recognized that the Sicker Group is indeed older (Gunning, 1931; Fyles, 1955). Muller and colleagues mapped large portions of Vancouver Island including the Alberni area (Muller and Carson, 1969). Detailed investigations of the China Creek area were reported on by Stevenson (1945).

Stratigraphic studies of the Sicker Group were conducted by Yole (1963, 1964, 1969) and Muller (1980). A major revision of the stratigraphy of the Sicker Group of the Cowichan uplift has been suggested by Sutherland Brown, based on 1:50 000 mapping in the Alberni-Bamfield corridor undertaken by the Geological Survey of Canada in support of the LITHOPROBE 1 Project (Sutherland Brown and Yorath, in preparation; Sutherland Brown *et al.*, 1986). A similar revision has also been made independently by Juras in the Buttle Lake uplift (Juras, 1987). Biostratigraphic and radiometric dating of the rocks of southern Vancouver Island has been summarized by Muller and Jeletzky (1970), Brandon *et al.*, (1986), and Armstrong *et al.*, (unpublished preprint).

REGIONAL SETTING

The Alberni–Nanaimo Lakes area is situated at the northwestern end of the Cowichan uplift, one of a series of major geanticlines constituting the structural fabric of southern Vancouver Island (Figure 1-8-1). The area lies within the Wrangellia terrane, which on Vancouver Island comprises three thick volcano-sedimentary cycles (Paleozoic Sicker Group, Upper Triassic Vancouver Group and the Jurassic Bonanza Group) overlapped by late Cretaceous sediments of the Nanaimo Group. The geology and structure of the area are summarized in Figures 1-8-2 and 1-8-3.

STRATIGRAPHY

The oldest rocks in the area belong to the Paleozoic Sicker Group (Figure 1-8-2) which contains volcanic and sedimentary units ranging in age from Middle Devonian(?) to Early Permian. These are intruded by mafic sills and dykes coeval with overlying basaltic volcanics of the Late Triassic Karmutsen Formation. Micritic limestone of the Quatsino Formation and volcanic rocks of the Early Jurassic Bonanza Group overlie the Karmutsen Formation. All these sequences have been subsequently intruded by granodioritic stocks of the Middle Jurassic Island intrusions. Late Cretaceous sediments of the Nanaimo Group lie unconformably on the older sequences and are the principal host to Late(?) Eocene porphyry sills.

SICKER GROUP

Since the initial work of Clapp (1912) there have been several attempts to formally subdivide the Sicker Group. Muller (1980) proposed four subdivisions which, in ascending stratigraphic order, are the Nitinat Formation, the Myra Formation, an informal sediment-sill unit and the Buttle Lake Formation. Recent paleontological and radiochronological studies (Brandon *et al.*, 1986), coupled with newer mapping (Sutherland Brown *et al.*, 1986; Sutherland Brown and Yorath, 1985; Juras, 1987), have thrown some doubt on these subdivisions and their universal applicability. New stratigraphic subdivisions have been proposed by Sutherland Brown for the Cowichan uplift, based on work in the Alberni area (Sutherland Brown and Yorath, in preparation). Apart from one major change outlined below, these formational subdivisions have also proven to be applicable in the Cowichan Lake and Duncan areas and have been adopted for this project (Massey and Friday, 1988; Massey *et al.*, 1987, 1988). A composite stratigraphic section for the Sicker Group in the Alberni–Nanaimo Lakes area is illustrated in Figure 1-8-4.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

Sutherland Brown has also suggested that the Sicker Group be redefined to include only the lower volcanic-volcaniclastic rocks, with the younger epiclastic sediments and limestones comprising a new Buttle Lake Group. There is great merit in this suggestion although, for convenience, the older, broader usage of "Sicker Group" has been retained here.

Duck Lake Formation

This is a newly defined stratigraphic unit within the Sicker Group, comprising a dominantly pillowed basalt sequence. Amygdaloidal basalts within the Sicker Group of the Cowichan uplift were first described by Fyles (1955) but were not formally separated as a stratigraphic unit. The pillow lavas were ascribed by Muller and Carson (1969) to the Karmutsen Formation and to either the Sicker Group or Karmutsen Formation by Laanela (1966). Sutherland Brown (1986, and Sutherland Brown and Yorath, in preparation) recognized that these pillows were of Sicker Group age but included them within the McLaughlin Ridge Formation.

Detailed mapping on behalf of Westmin Resources Limited on the Debbie property in the early 1980s documented a package of pillowed basalts that passed up through a discontinuous unit of cherts and felsic tuffs into pyroxene-plagioclase-phyric flows and volcaniclastics (R. Walker, personal communication, 1988). The whole package was thought to be part of the Myra Formation, using Muller's terminology, and younger than the Nitinat Formation. The results of mapping on a more regional scale by the authors

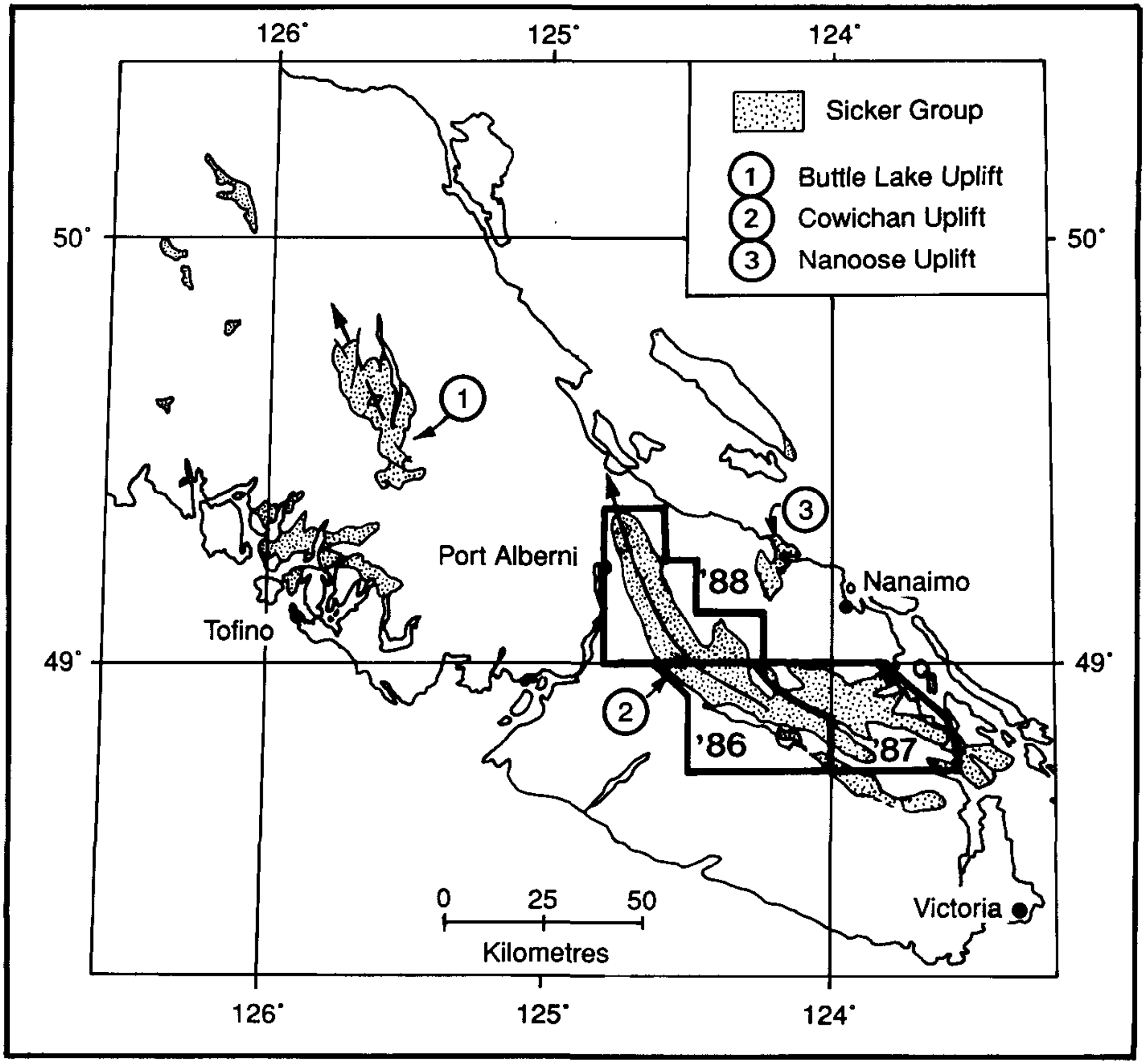

Figure 1-8-1: Location of the Sicker Project area, southern Vancouver Island, in relation to the three major geanticlinal uplifts cored by Sicker Group rocks (after Brandon *et al.*, 1986). 1986-88 field seasons are indicated.

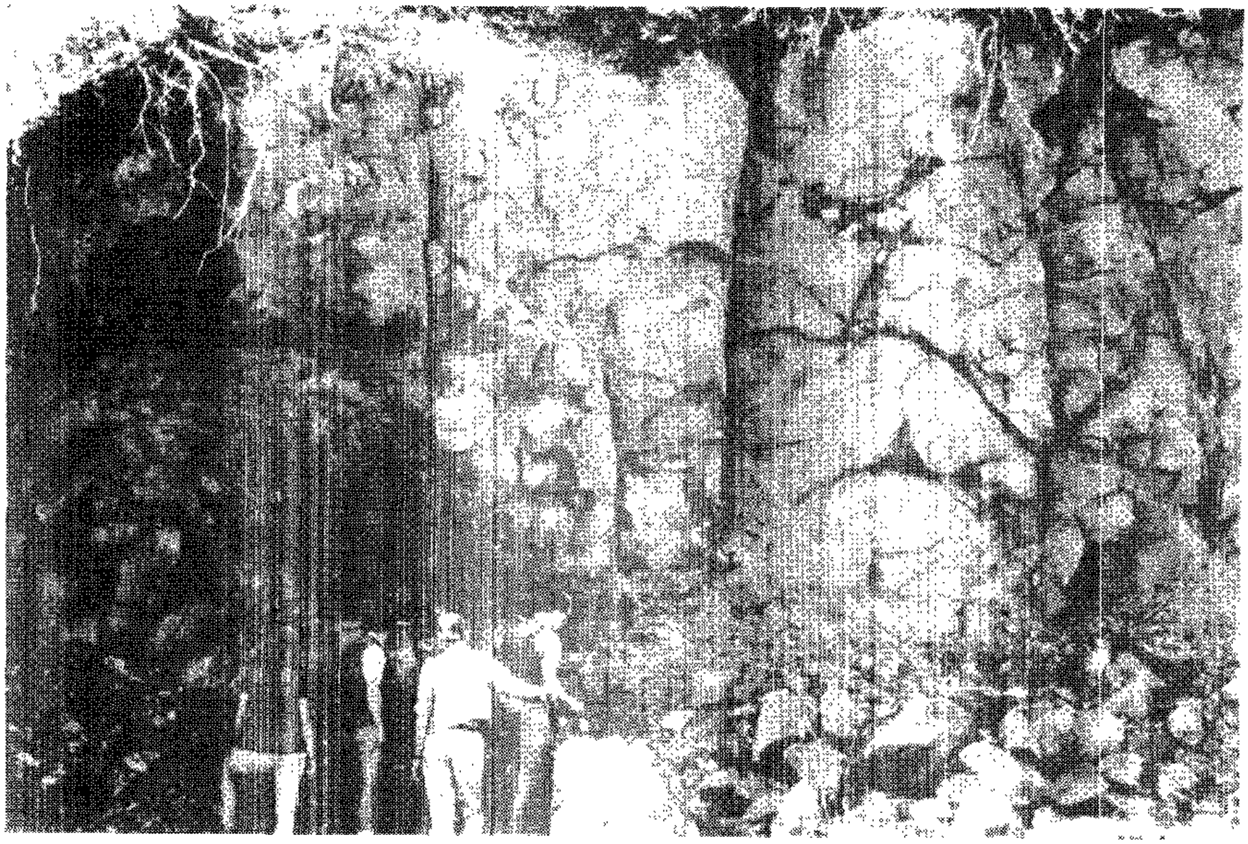

Plate 1-8-1: Pillow lavas of the Duck Lake Formation, Sicker Group, Duck Main.

confirm the relationships found by Westmin but correlate the overlying pyroxene-phyric volcanics with the Nitinat Formation.

The pillow lavas are thus considered to be older and significant enough to define a new formational unit. The proposed name Duck Lake Formation is taken from the Duck Lake road leading south from China Creek, along which Sutherland Brown measured and described a reconnaissance type-section (Sutherland Brown and Yorath, in preparation). A lower stratigraphic limit to the formation has not yet been recognized and the Duck Lake Formation is the oldest known exposed unit on Vancouver Island. Small patches of pillowed and massive aphyric basalt were mapped in the Cowichan Lake and Duncan areas in previous years and included in the Nitinat Formation (Massey and Friday, 1987, 1988). These may more correctly belong to the Duck Lake Formation.

The Duck Lake Formation consists dominantly of grey to maroon pillowed and massive basaltic flows (Plate 1-8-1). They show significant lithological differences to the younger Karmutsen Formation pillow lavas (Table 1-8-1). Typically the Duck Lake flows are aphyric and amygdaloidal, although variolitic and feldspar-phyric varieties are common. Pillows, although usually uniform in size within a particular flow, range from 30 centimetres to 3 metres in diameter. Shapes vary from spherical to ellipsoidal and elongate. Amygdules often form concentric zones which are thicker in the curved tops of pillows and are infilled with calcite, chlorite, epidote and quartz. Veins of quartz and epidote are also common. Epidote alteration patches may occur within some pillows and along selvages. Variolitic zones are coincident with or inside the amygdaloidal zones. Pillow selvages are thin, 50 to 100 millimetres, and chloritic. The pillows are usually tightly packed with very little space between them. Where present, the space is infilled with chert, jasper, tuff, or rarely hyaloclastite.

Monolithic basaltic breccias and pillow breccias occur as interbeds within the flows (Plate 1-8-2). Like the flows, clasts in the breccias are aphyric, amygdaloidal basalt. The matrix is usually chloritic and tuffaceous, but occasional hyaloclastite is present. Chert, jasper and cherty tuff interbeds are also found, particularly near the top of the sequence. These are usually well bedded and laminated with occasional magnetite and hematite laminae. Well-bedded felsic tuffs (Plate 1-8-3) and lapilli tuffs are sometimes seen associated with cherts and jaspers at the top of the Duck Lake Formation, for example, at the "900 Zone" on Mineral Creek and the Microwave Tower north of Summit Lake. This horizon is potentially of major significance for gold and base metal exploration in the area.

Massive dacite-rhyolite bodies are found in several places associated with the pillow lavas. They appear in the most part to be dykes and sills. The dacite is fine grained, aphyric and cherty in appearance. It is dark to medium grey in colour, weathering white with some red stains on fracture surfaces. Similar-looking dacite dykes, though rare, also intrude the Nitinat Formation.

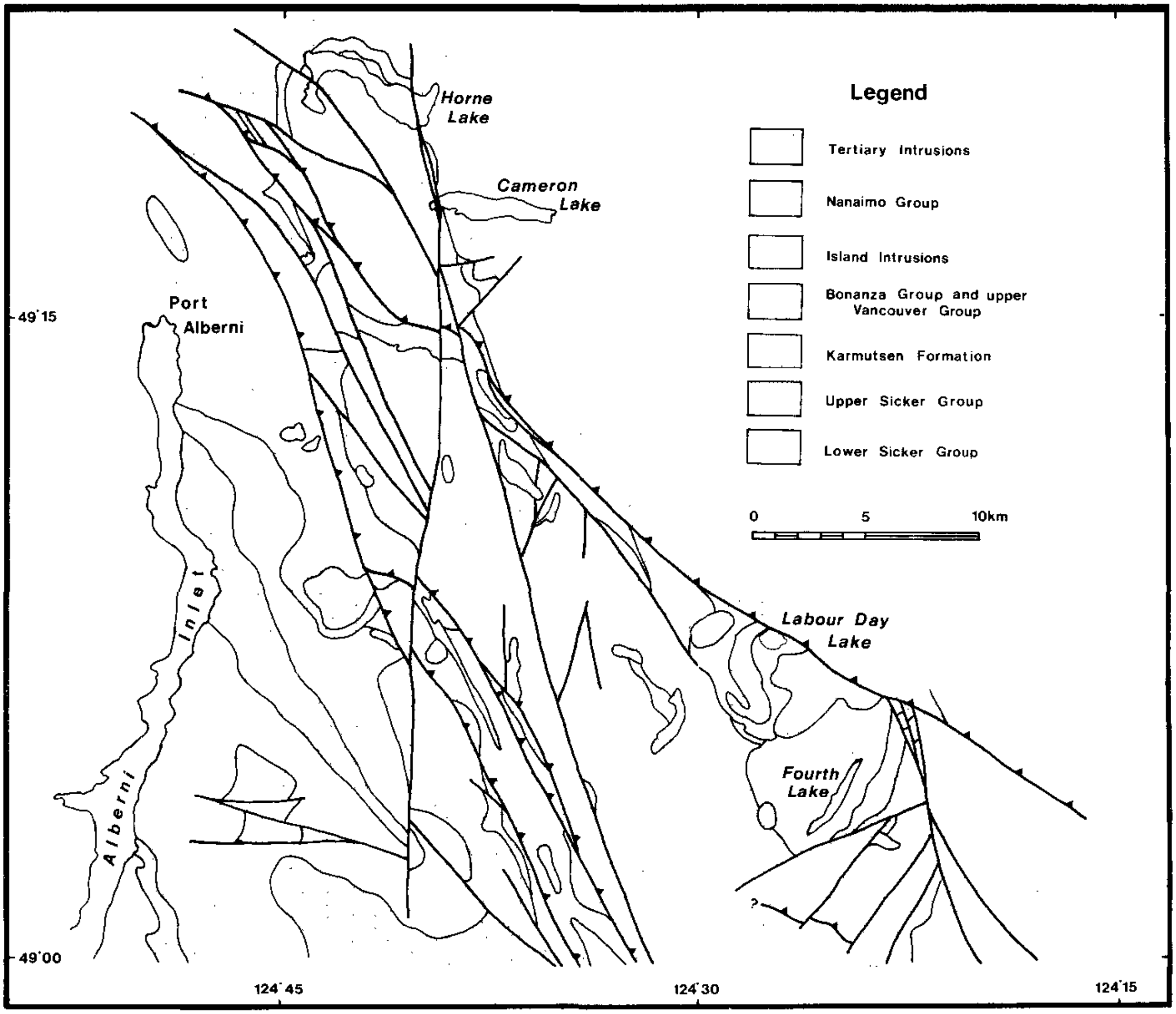

Figure 1-8-2: Geology of the Alberni–Nanaimo Lakes area.

Nitinat Formation

Overlying the Duck Lake Formation is the Nitinat Formation, a volcanic package characterized by pyroxene-feldspar-porphyritic basaltic andesites, typically occurring as agglomerates, breccias, lapilli tuffs and crystal tuffs. However, pyroxene-phyric, amygdaloidal, pillowed and massive flows are developed in several areas, for example Nitinat Pass and the West Fork of the Nitinat River. Pyroxenes may be large, up to 1 centimetre in diameter, euhedral to subhedral, and comprise 5 to 20 per cent of the rock. They are variably uralitized. Plagioclase is often as abundant as pyroxene, but phenocrysts are usually smaller, ranging up to 5 millimetres in diameter. Amygdules present in flows and clasts in coarser pyroclastics are infilled with chlorite, quartz, epidote or calcite. Non-pyroxene-phyric breccia, tuffaceous sandstone and laminated tuff are also found locally, interbedded with the pyroxene-phyric rocks.

This volcanic unit is equivalent to the Nitinat Formation of Muller (1980).

McLaughlin Ridge Formation

The Nitinat Formation passes upwards transitionally into the McLaughlin Ridge Formation, a sequence of volcaniclastic sediments dominated by thickly bedded, massive tuffites and lithic tuffites with interbedded laminated tuffaceous sandstone, siltstone and argillite (Figure 1-8-4). Associated breccias and lapilli tuffs are usually heterolithic and include aphyric and porphyritic (feldspar, pyroxene, hornblende) lithologies, commonly mafic to intermediate in composition. Felsic tuffs are rare.

The McLaughlin Ridge Formation is equivalent to the lower parts of the Myra Formation of Muller (1980).

Cameron River Formation

The upper part of the Sicker Group is made up of a dominantly epiclastic and bioclastic sedimentary sequence comprising the Cameron River, Mount Mark and St Mary's

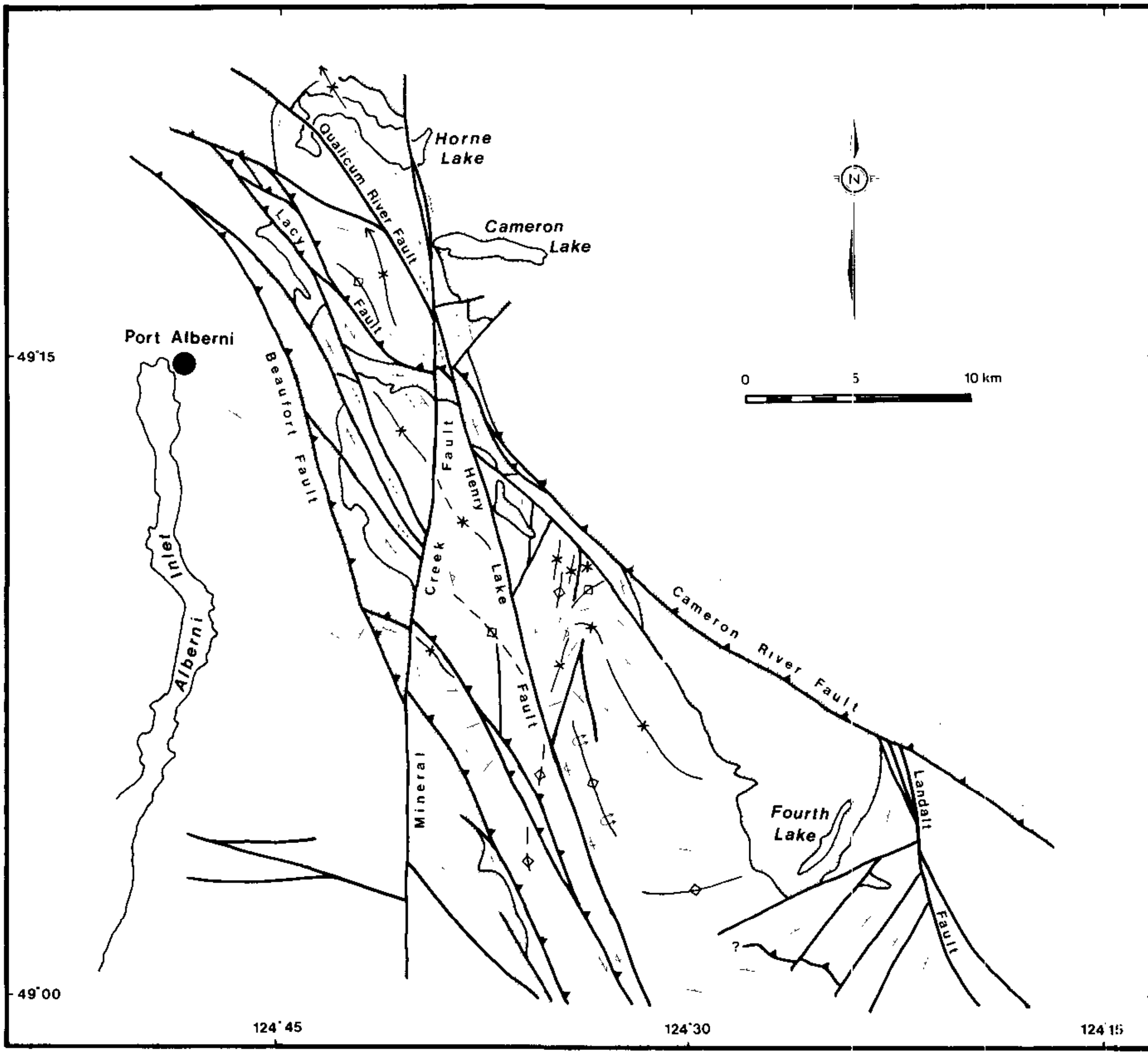

Figure 1-8-3: Major structural elements of the Alberni–Nanaimo Lakes area. Post-Sicker Group rocks indicated by shading.

Lake formations (Figure 1-8-4). This sedimentary package is apparently conformable on the underlying volcanics along the northeastern limb of the Cowichan uplift, for example, in the upper Cameron River valley and the Chemainus valley, but is unconformable along the southwestern limb both in the Alberni and Cowichan areas.

The Cameron River Formation comprises mostly thin-bedded, often cherty sediments. These vary from green and red ribbon cherts, black cherty argillites, green and white cherty tuffs, grey and green siltstones and argillites, to thicker bedded green volcanic sandstones. Chert breccias with a sandy matrix occur near the base of the formation; intercalated argillite and calcarenite beds up to 1 metre thick, dominate the upper part.

The Cameron River Formation is equivalent to the upper parts of Muller's Myra Formation together with the sediments of the informal sediment-sill unit (Muller, 1980). Chronologically, it is correlative, in part, with the volcanics of the Thelwood and Flower Ridge formations of the Buttle Lake upift (Juras, 1987) and probably with units PSc and PSd of the Nanoose uplift (Sutherland Brown and Yorath, 1985).

Mount Mark Formation

The Mount Mark Formation conformably overlies and laterally interfingers with the Cameron River Formation. However, in places along the southwest limb of the uplift, for example west of Rift Creek and on the south slopes of Douglas Peak, it lies directly and unconformably on the lower Sicker Group volcanics.

The formation consists of massive limestone beds with minor argillite and chert interbeds. The limestones are well bedded, varying from about 15 centimetres up to about 5 metres thick (Plate 1-8-4). They are predominantly bioclastic calcarenites and calcirudites, rich in broken crinoid stems ranging up to 2 centimetres in diameter. Bryozoa, brachipods, pelecypods, corals and trilobites have also been reported from these rocks (Yole, 1963, 1965). Fossil clasts are often replaced by silica and weather positively. Some limestone outcrops contain many thin chert beds developed by siliceous replacement of limestone. Thin black argillite and shale beds are developed in places, and maroon tuffaceous shales are seen in the basal part of the sequence in the Horne Lake area.

The Mount Mark Formation is the equivalent of the Buttle Lake Formation of Muller (1980) and other authors (for example, Yole, 1969).

St Mary's Lake Formation

The St Mary's Lake Formation conformably overlies the Mount Mark limestones. It is, however, only extensively preserved in three localities – St Mary's Lake, the west branch of the Cameron River, and the southwest slopes of Douglas Peak. It is cut out elsewhere by the unconformity beneath the Karmutsen Formation.

The formation comprises brownish weathering, grey sandstone and black argillite graded beds, volcanic sandstones and pebble conglomerates, black cherty argillite, greenish chert and minor jasper. Conglomerates contain volcanic and flat angular cherty argillite clasts. Scouring, load structures, normal and inverse grading, slumping and disrupted bedding are all observed in these sediments.

The St Mary's Lake Formation is probably equivalent to supra-limestone pillowed volcanics and minor sediments seen in the Nanoose uplift (Sutherland Brown and Yorath, 1985, and in preparation) and possibly to the Henshaw Formation of the Buttle Lake uplift (Jeffrey 1967).

VANCOUVER GROUP

Karmutsen Formation

Basaltic volcanics of the Karmutsen Formation underlie large parts of the map area, particularly around Mount Arrowsmith in the northeast, Mount Mark in the northwest and the Museum Creek area in the southwest. They comprise orange-brown-weathering pillowed flows, pillow breccias and hyaloclastite breccias interbedded with massive flows and sills. Typically the basalts are feldspar phyric, often with ragged or glomeroporphyritic feldspars in a fine-grained groundmass. Pillows are usually large, 1 to 2 metres in diameter, with thick chloritic selvages and abundant intrapillow hyaloclastite and quartz. Amygdules are common and are infilled with chlorite, calcite or epidote.

Plate 1-8-2: Pillow breccia, Duck Lake Formation, Sicker Group, Rift Creek area.

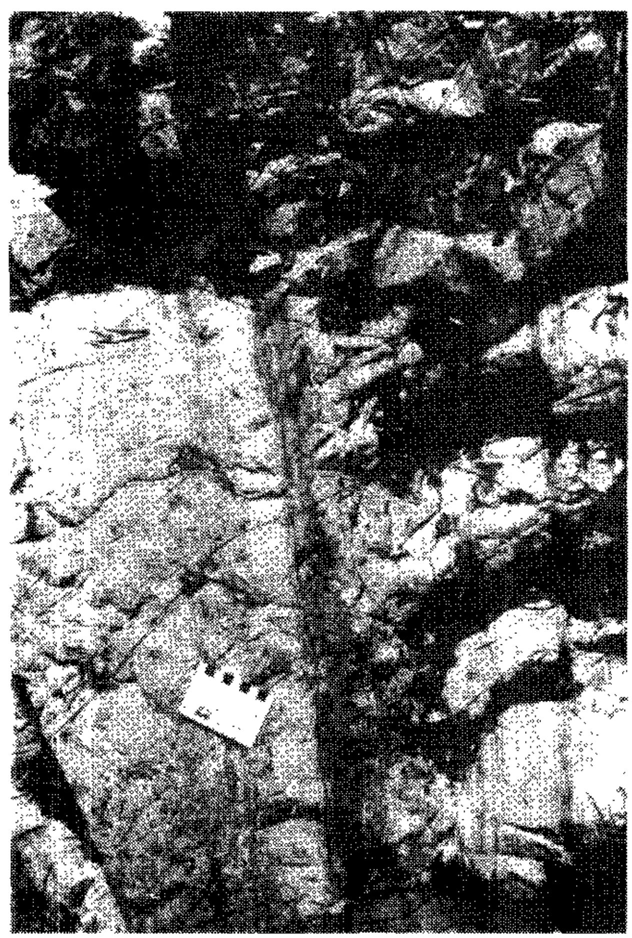

Plate 1-8-3: Well-bedded felsic tuffs, Duck Lake Formation, Sicker Group, Microwave Tower.

Diabase and gabbro dykes of probable Triassic age are widespread in the area, intruding Sicker Group rocks of all types. They are medium to coarse-grained diabase, gabbro, and leucogabbro with minor diorite, equigranular to porphyritic with feldspar phenocrysts. The glomeroporphyritic clusters typical of gabbros in the Duncan area (Massey and Friday, 1988) are rare in the Alberni area. Mafic phenocrysts are absent.

UPPER VANCOUVER GROUP

Outcrops of the Quatsino, Parson Bay and Sutton formations are restricted in the map area. Massive, pale-weathering, dark grey micrite of the Quatsino Formation outcrops along the Bamfield road south of Parsons Creek. A massive, poorly bedded limestone, with abundant silicified corals and other fossils along bedding planes, is associated with medium-grained, grey, limey sandstone on the south side of Mount Spencer. These rocks probably belong to the Parson Bay and Sutton formations. Cobbles of Parson Bay Formation(?) black calcareous argillite with ammonite remains are also found in the creeks draining this area.

BONANZA GROUP

Bonanza Group volcanic rocks overlie the Upper Vancouver Group sediments and are similarly restricted in outcrop. On Mount Spencer, basal, pale green feldspar-crystal tuffs and maroon tuffs and lapilli tuffs are overlain by pyroxene-feldspar crystal and crystal lapilli tuffs.

NANAIMO GROUP

Clastic sediments of the Nanaimo Group unconformably overlie older volcanic units and the Island intrusions. They are most thickly developed in the Alberni valley, although poorly exposed, except around the margin, due to Quaternary cover. Other major outcrop areas are around Labour Day Lake and the Cameron River–Summit Lake area. The sediments of the Nanaimo Group constitute major fining-upward cycles (Muller and Jeletzky 1970), of which the first, the Comox-Haslam, is developed in the map area.

COMOX FORMATION

The basal Benson member of the Comox Formation is a coarse, poorly bedded pebble and boulder conglomerate which is absent in many places. The conglomerates have rounded clasts which consist of a variety of volcanic and intrusive lithologies of immediate local origin; larger boulders are often angular. Minor red hematitic siltstone interbeds are occasionally seen.

Overlying sandstones are medium to coarse grained, grey with rusty weathered surfaces. They contain feldspar crystals and abundant lithic fragments, mostly volcanic rocks of local provenance. Black plant-fragments are characteristic of many beds. Calcareous cement is common. A few granule and pebble conglomerate beds are interbedded with the sandstones. Several sandstone beds yielded abundant fossil faunas, including gastropods, pelecypods and possible broken ammonites and nautiloids.

HASLAM FORMATION

The Haslam Formation consists of characteristic rusty weathering, black argillite and siltstone. It is fine to silty, often poorly bedded and friable, fracturing to pencil-shaped pieces. Interbeds of fine to medium-grained, grey silty sandstone up to 1 metre thick may occur within the argillites. Calcareous concretions may be found and replacement was extensive enough in one outcrop southwest of Mount Patlicant to result in a massive limestone that grades laterally into argillite. Fossils are present within the Haslam Formation, though poorly preserved due to the ubiquitous pencil-and-rod fracturing, and include gastropods, pelecypods, ammonites and plant material.

INTRUSIONS

ISLAND INTRUSIONS

Several granodioritic plutons and stocks of Middle Jurassic age occur in the area. These bodies are usually elongate in shape, although the Fourth Lake stock is roughly circular. The intrusions show considerable lithological varia-

TABLE 1-8-1
COMPARISON OF PILLOW LAVAS IN THE DUCK LAKE AND KARMUTSEN FORMATIONS

		Duck Lake Formation	Karmutsen Formation
Lithology		Green-grey to maroon, mostly aphyric basalt, variolites common, feldspar basalt less abundant.	Black-weathering orange-brown, feldspar basalts (feldspars ragged) dominate, aphyric basalts common. Variolites rare.
Pillows—shape		Tightly packed, rounded.	More loosely packed, rounded to irregular.
—size		30 cm–2 m; uniform within a flow	Average 1 m; some variability within flow units.
—selvages		Thin, 1 cm.	Thick chloritic, 2–3 cm.
—intra-pillow		Poorly developed, jasper, chert or quartz infillings, hyaloclastite rare.	Very common, hyaloclastite, "dallasite" chlorite or quartz infillings.
Associated lithologies	i	Monolithic basaltic breccia, pillow breccia common. Hyalclastite rare.	Pillow breccia, hyaloclastite clastite breccia and isolated pillow hyaloclastite clastite breccia common.
	ii	Massive flows, sills common	Massive flows and sills common.
	iii	Well-bedded cherts, jasper, magnetite-hematite-chert, cherty tuff, common in upper parts of formation.	Cherty tuffs rare.
	iv	Felsic volcanics sporadic at top of unit; dacite-rhyolite dykes common.	Felsic material absent.

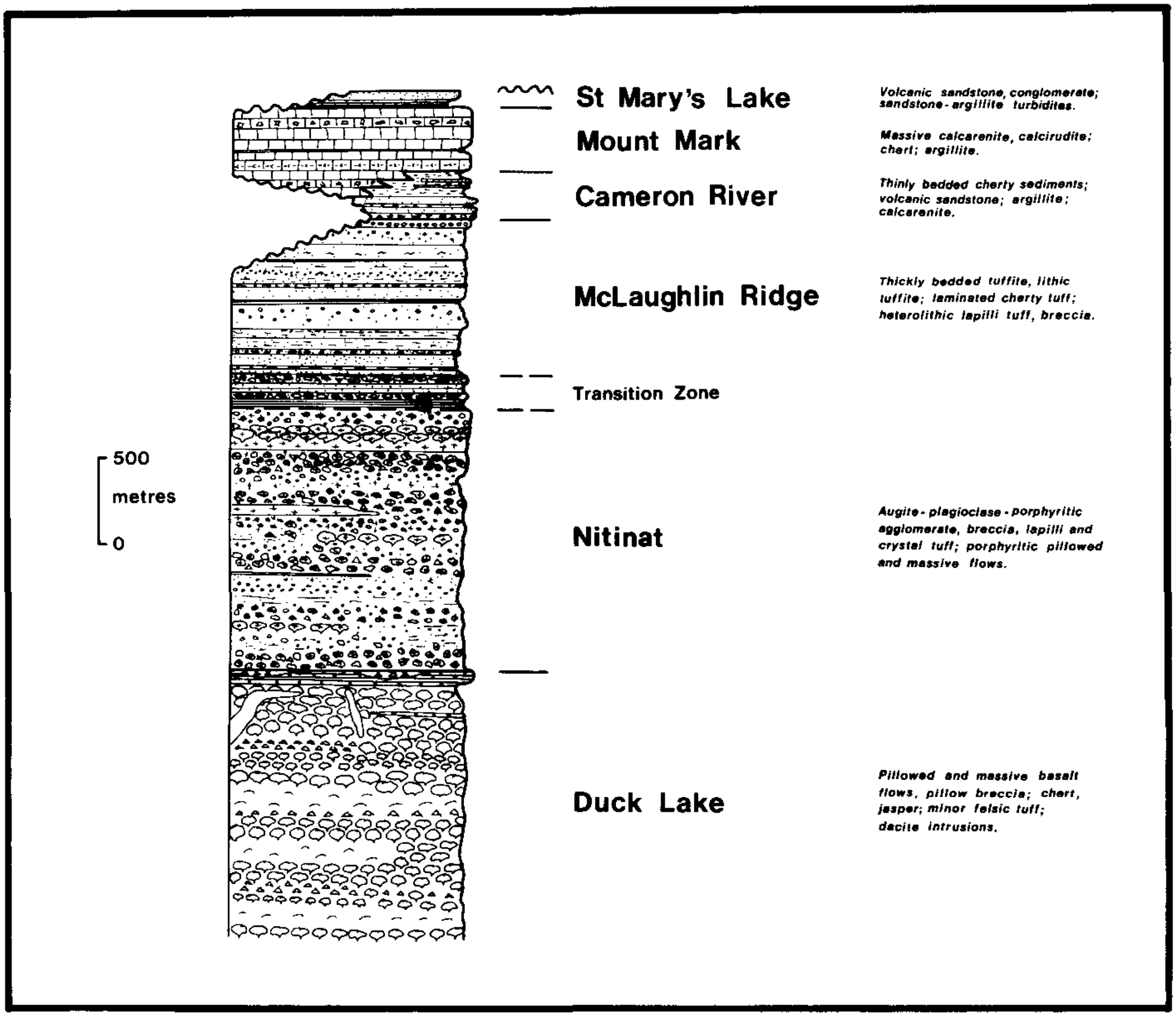

Figure 1-8-4: Composite stratigraphic section of the Sicker Group (scale approximate). Lithographic symbols are schematic.

tion. The Port Alberni pluton is fairly uniform throughout, comprising granodiorite and quartz diorite. The Fourth Lake stock is also apparently uniform in outcrop, but displays a gradual compositional variation from diorite and monzonite in the north to quartz diorite and granite in the south. The Corrigan pluton, in contrast, is heterogeneous and composite, comprising a mix of diorite, quartz diorite, granodiorite and monzogranite phases with abundant minor intrusive dykes.

The dominant lithology in most bodies is a medium to coarse-grained, equigranular granodiorite to quartz diorite with a characteristic "salt-and-pepper" texture. Quartz is usually irregular in shape, often interstitial to the feldspars. Feldspars are white, though some pink staining is seen on weathered surfaces, and usually form subhedral laths. Hornblende is the principal mafic mineral. It is tabular to acicular, black to greenish black in colour and may be slightly larger in size than the feldspars. Where present, black to brown biotite books are subordinate to hornblende. Chlorite replaces hornblende and biotite in altered rocks. Colour index varies from 10 to 20 in the granodiorites, but may range up to 40 in diorites. White fine-grained aplite dykelets and veins cut the granodiorites.

Most of the intrusive bodies are rich in inclusions, particularly in marginal zones where agmatitic intrusive breccias are developed. The angular to subrounded xenoliths are of local country rock lithologies showing a range of amphibolitization and assimilation features. The xenoliths are normally randomly oriented.

A variety of dykes and small irregular intrusions occur throughout the area. They are probably coeval with the Island intrusions with which they are spatially related. Lithologically, they include intermediate feldspar porphyry, hornblende-feldspar porphyry and minor diabase.

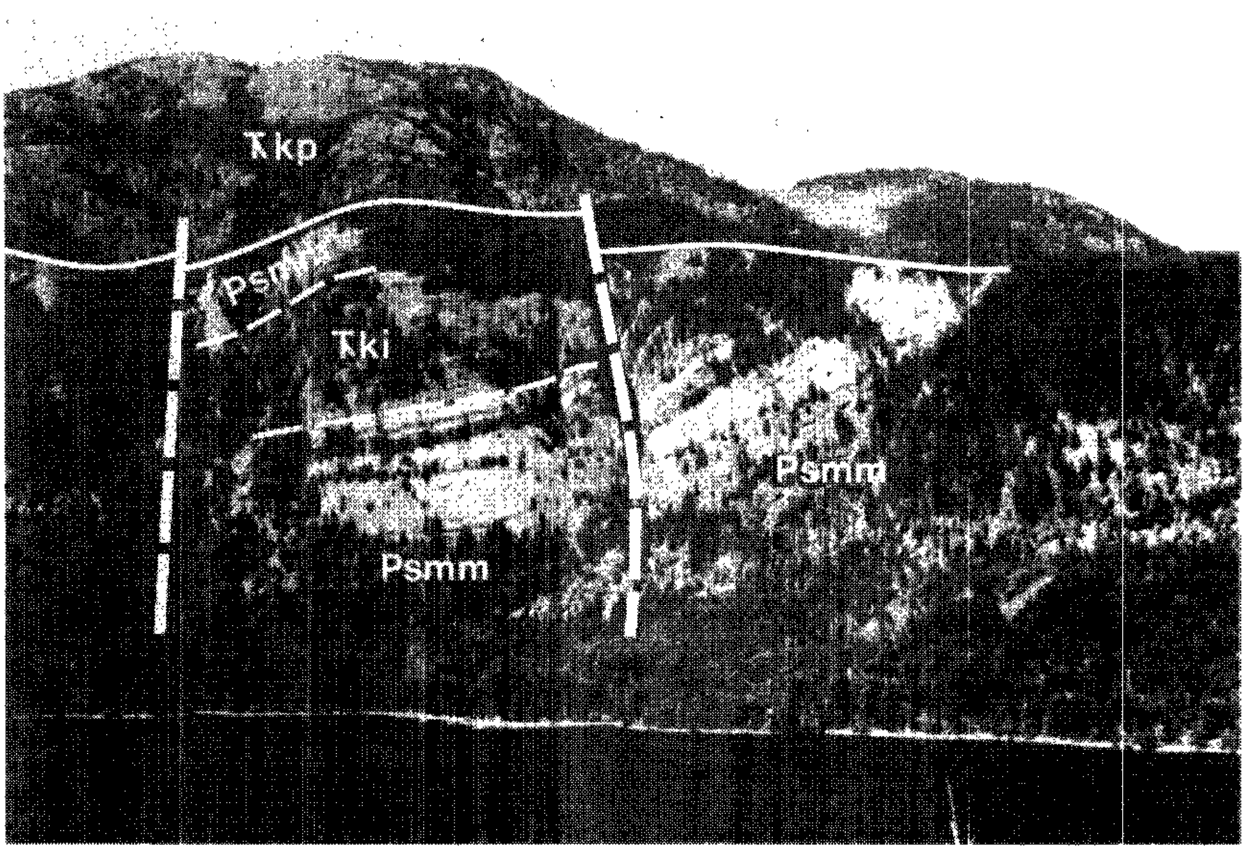

Plate 1-8-4: View northwards across Horne Lake to Mount Mark. Mount Mark Formation (PSmm) in east limb of Horne Lake syncline is intruded by gabbro sills (TrKi) and unconformably overlain by Karmutsen Formation pillow lavas (TrKp).

TERTIARY INTRUSIONS

Porphyritic dacite sills and dykes occur throughout the map area (Plate 1-8-5). Though no geochronometric ages are yet available for these intrusions, they are comparable to "Catface intrusions" seen elsewhere on Vancouver Island and thus probably of late Eocene to early Oligocene age. The prophyries contain varying proportions of feldspar and hornblende phenocrysts in a fine-grained, light to medium grey groundmass (Plate 1-8-6). Feldspar is white plagioclase typically forming subhedral to euhedral laths up to 1 centimetre long but averaging 1 to 2 millimetres. Hornblende occurs as elongate laths or needles up to 1.5 centimetres long. Phenocrysts vary in both absolute proportions (from about 10 to 30 per cent of the rock) and in relative proportions of hornblende to feldspar. Aphyric dacite is uncommon.

The Tertiary intrusions occur as dykes up to 3 metres wide, intruding most older lithologies. Dykes are also found intruding major fault zones, which appear to have acted as passage ways for the magmas. Where the porphyries have penetrated the Nanaimo Group sediments, they have spread out as thick sills, for example, at Patlicant Mountain and Labour Day Lake.

STRUCTURE AND TECTONICS

The Alberni–Nanaimo Lakes area has a complex tectonic history involving at least five major deformational events. These events have often rejuvenated previous structures rendering specific analysis of their effects difficult. The present map pattern is dominated by the effects of Tertiary(?) faulting, though older events are important in establishing relationships within fault blocks (Figure 1-8-3).

PHASE 1 — LATE DEVONIAN

The unconformity between the upper Sicker Group sediments and the underlying volcanics, along the southwestern limb of the Cowichan uplift, points to a major deformational

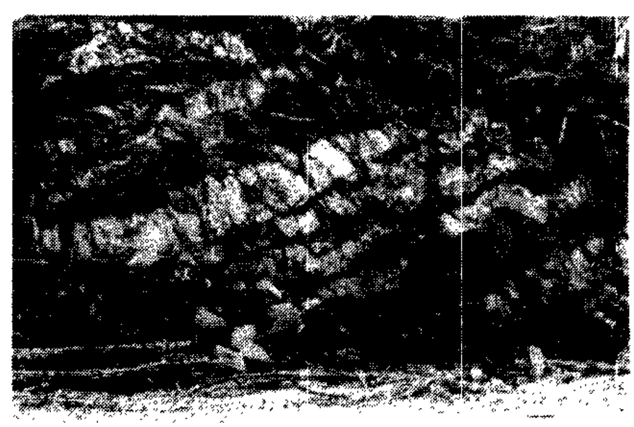

Plate 1-8-5: Tertiary hornblende-feldspar porphyry sills intruding Comox Formation sandstones and siltstones, southwest of Labour Day Lake.

event taking place in late Devonian to earliest Mississippian times. Specific effects of this deformation are difficult to document with any certainty in the map area. In the Peak Lake area of McLaughlin Ridge, a fan-shaped array of north-northeast-trending folds with steep to overturned limbs runs contrary to, and appears to be deformed by, later southeast-trending structures. These north-northeast-trending folds may be of Late Devonian age.

PHASE 2 — MIDDLE PERMIAN — PRE-MIDDLE TRIASSIC

All Sicker Group rocks have been affected by a series of southeast-trending, upright to overturned, southwest-verging folds with abundant parasitic minor folds. Major fold axes are often difficult to locate in the field but can be estimated from regional map patterns. Overturning of beds is seen locally in minor folds throughout the area and on the southern limb of a regional anticlinal fold in the Nitinat River area (see Fig 1-8-3). The folds are truncated by the overlying Karmutsen Formation (Plate 1-8-4).

Penetrative axial planar foliation is generally absent throughout most of the area. However, Sicker Group volcanics to the west of the Mineral Creek fault and south of the Lacy fault have a well-developed north-northwest-trending schistosity with generally steep northeasterly dips. Rare chlorite crenulation lineations and elongation of pillows are subhorizontal to shallow dipping.

Faulting accompanied or postdated folding. On McLaughlin Ridge several north to northeast-trending faults crosscut the folds, but are themselves truncated by Tertiary(?) faults. Their age is unknown but may be pre-Triassic. On the east side of the West Cameron River valley, small-scale faults offset Sicker Group sediments but do not affect the unconformably overlying Karmutsen Formation.

PHASE 3 — LATE TRIASSIC

Extensive crustal dilation accompanied the evolution of Karmutsen Formation lavas and intrusions. However, deformation specifically associated with this event has not yet been documented within the Alberni area.

PHASE 4 — MIDDLE JURASSIC

Regional-scale warping of Vancouver Island produced the three major geanticlinal uplifts cored by Sicker Group rocks (Figure 1-8-1), including the Cowichan uplift. Plutons and stocks of the Middle Jurassic Island intrusions are often elongate parallel to the uplifts, although they apparently show little or no affects of the deformation themselves, suggesting the intrusions were syntectonic to postdeformation. Uplift and erosion followed sometime in the Late Jurassic to Middle Cretaceous, establishing the pre-Nanaimo Group topography.

PHASE 5 — TERTIARY(?)

Large-scale northwesterly trending thrusts cut the map area into several slices (Figure 1-8-3). Two major fault zones are recognized. The Cameron River fault runs southeast along the Cameron River valley, north of Labour Day Lake, past Third Lake and down Dunsmuir Creek to join the Fulton fault. To the northwest, the fault splits. A northern splay (Qualicum River fault) continues to the west of Horne Mountain and along the Qualicum River valley, and a southern splay (Lacy fault) runs west near Summit Lake and northwest to Lacy Lake and Esary Lake. The Beaufort fault zone trends southeast along the Beaufort Ranges, passes just east of Bainbridge Lake and Patlicant Mountain and down Rift Creek valley, continuing to the southwest as the Cowichan fault. This fault zone contains several splays.

Where exposed, these thrusts are high-angle reverse faults which dip between 45 and 90 degrees to the east or north-northeast. Slip planes may be relatively sharp and narrow, but wide schistose zones have formed in receptive lithologies and splays and imbricate zones are well developed. The thrusts generally place older rocks over younger and become listric at mid-crustal depths (Sutherland Brown and Yorath, 1985). Displacements along fault planes are undetermined. Lithological and stratigraphical comparison along the Cameron River fault suggests that offsets are probably in the order of 5 to 10 kilometres horizontally and 1 to 2 kilometres vertically. Other faults are not expected to differ markedly from this. Direction of motion is suspected to be westwards; slickensides on fault planes indicate latest movement was horizontal and northwesterly directed.

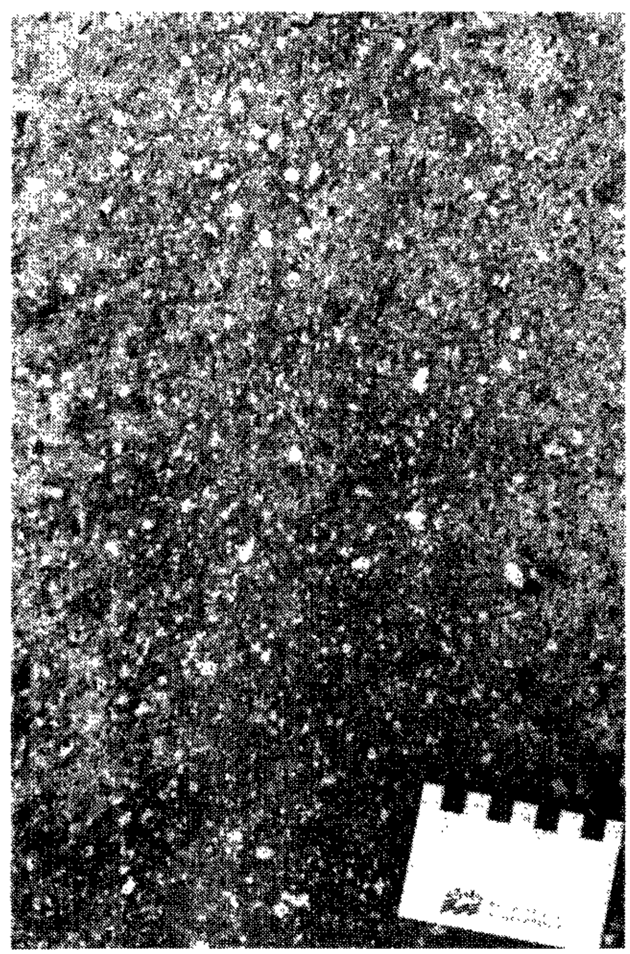

Plate 1-8-6: Tertiary hornblende-feldspar porphyry, Labour Day Lake.

The Henry Lake fault connects the Cameron River and Beaufort fault zones, and may have a similar reverse fault geometry although this is speculative at this time. The north-trending Mineral Creek fault offsets the Cameron River and Beaufort faults. It is a subvertical shear zone with apparent sinistral displacements of less than 1 kilometre. Vertical displacements are undetermined.

The age of faulting is unknown at this time. The faulting involves sediments of the Nanaimo Group as young as the Cedar District Formation. However, the faults are intruded by Tertiary porphyry dykes which show only minor late-stage brittle fracturing. It is suspected that most of the faulting took place during the Tertiary (pre-Oligocene), possibly during crustal shortening accompanying the accretion of the Pacific Rim and Crescent terranes to the south and west of the project area.

METAMORPHISM

The metamorphic grade in the area is generally quite low, but increases with the age and structural position of the rocks. Nanaimo Group sediments are essentially unmetamorphosed showing only diagenetic alteration in detrital iron oxides and calcareous cements. Basalts of the Karmutsen Formation show amygdule infillings and veins of chlorite, calcite, epidote and quartz, and alteration assemblages typical of the prehnite-pumpellyite facies. Intrusive rocks are unaltered except in chloritic shear zones.

Sediments of the Sicker Group are essentially unmetamorphosed except where involved in intense shearing where chlorite and sericite have developed along foliation planes. Sicker Group volcanic rocks, however, show the effects of greenschist metamorphism. Intermediate to mafic rocks have chloritic schistose matrixes with epidote alteration of feldspars and variable uralitization of pyroxenes. Secondary quartz, calcite, chlorite and epidote are common in veins and amygdules.

Jurassic granodiorite stocks and plutons in the map area show only sporadic development of contact metamorphic aureoles around their perimeters. The effects of this are most vividly illustrated in the skarning of limestone of the Mount Mark Formation around the Fourth Lake stock. Minor hornfelsing of volcanics and sediments is apparent around some smaller stocks, for example in the upper Franklin River valley, and amphibolitization of xenoliths is common.

MINERAL DEPOSITS

Exploration and mining in the Alberni–Nanaimo Lakes area started as early as 1862 with small-scale placer-gold mining on China Creek. Activity increased in the 1890s, principally along Alberni Inlet, China Creek, Mineral Creek and in King Solomon Basin. Several gold veins were staked and modest production was acheived from the Victoria property. A lull in exploration ensued until the 1930s when prospecting for gold was renewed, resulting in limited production from the Victoria, Havilah, Thistle, WWW and Black Panther claims (see Table 1-8-2). Activity declined again after World War II. The 1960s witnessed another round of exploration, focused on the search for porphyry copper and iron-copper skarn deposits, and the regional evaluation of the Esquimalt and Nanaimo Railway Land Grant. No production resulted, however. The present cycle of exploration followed the discovery of the HW polymetallic massive sulphide orebody at Buttle Lake. All areas of Sicker Group outcrop in the Alberni–Nanaimo Lakes area have since been staked and numerous exploration targets defined by mining companies and local prospectors. Extensive drilling has been carried out on many properties and Westmin Resources Limited collared a 2-kilometre exploration adit on the Mineral Creek zone in 1988.

TABLE 1-8-2
MINERAL PRODUCTION IN THE ALBERNI AREA

Property	Production Years	Tonnes	Au g	Ag g	Cu kg	Pb kg
Victoria	1898, 1934–36	365	9,425	1,679	88	
Havilah	1936 & 1939	949	8,056	43,669	1,925	5.750
Thistle	1938–42	6,283	85,874	65,969	309,088	
Black Panther	1947–48, 1950	[illegible],715	15,832	29,642	226	5 588
WWW	1899, 1935, 1940–41	106	14,650	15,552	244	1 100
B D Q	1940	1	62	156	11	
Kitchener	1929	168	124	653	5,366	

Unrecorded production of marble has also taken place from the Horne Lake property.

Several types of mineral deposit are present in the Alberni–Nanaimo Lakes area.

Volcanogenic, polymetallic massive sulphides and exhalative oxides: Polymetallic massive sulphide deposits have been a major target within the Sicker Group since the successful development of the Westmin Resources Limited mine in the Buttle Lake area in the late 1960s. Within the Cowichan uplift, deposits have been found associated with felsic volcanics in the McLaughlin Ridge Formation (for example, Lara, Mount Sicker). However, in the Alberni area the McLaughlin Ridge Formation is dominated by mafic to intermeditate volcaniclastic sediments and appears barren of syngenetic mineralization.

Cherts, jaspers, manganiferous cherts and massive sulphides of probable exhalative origin are found within the map area, occurring interbedded with and overlying pillowed basalts of the Duck Lake Formation. Minor felsic tuffs may overlie them. The most important showing so far discovered in this unit is the "900 Zone" on Westmin Resource's Debbie property. A lean iron formation with a magnetite-rich base is locally isoclinally folded with fold axes plunging south-southeast. Beneath and crosscutting the chert horizon is a quartz-vein stockwork which may be younger (Tertiary ?) in age. Native gold, pyrite, magnetite and arsenopyrite occur in quartz veinlets in the chert and jasper and also in narrow carbonate veinlets that crosscut the quartz veinlets. Similar iron amd manganese-rich cherts have been prospected in the Summit–Horne Lake area, for example, Lacy Lake, and occur at many other localities, for example, upper China Creek and the Butler Peak-Green Mountain area (Mountain/Jubilee property).

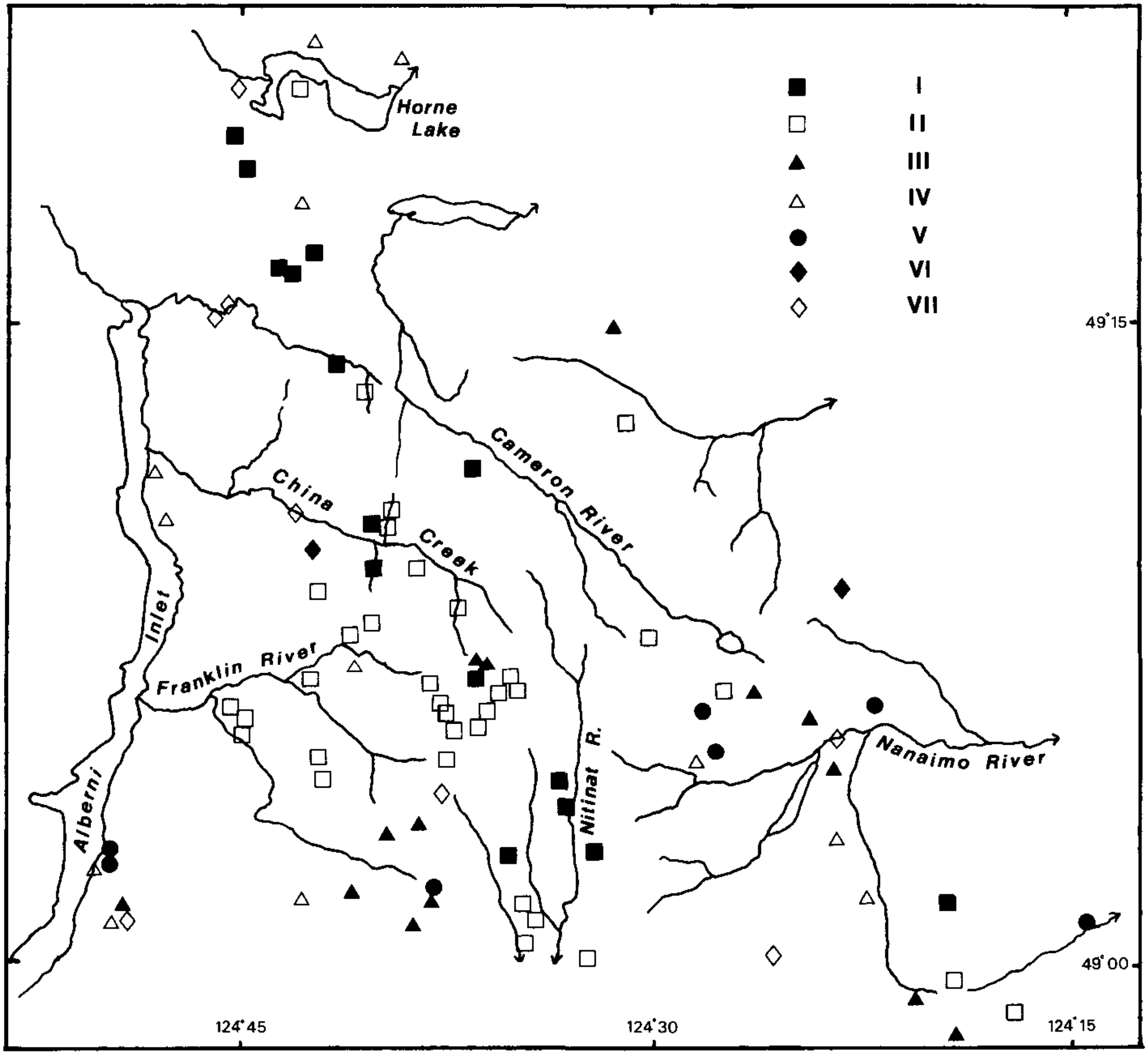

Figure 1-8-5: Distribution of mineral deposits in the Alberni–Nanaimo Lakes area. I Volcanogenic polymetallic massive sulphides and exhalative oxides; II Gold-bearing quartz-carbonate veins along shears; III Copper-molybdenum veins and stockworks: IV Other base-metal veins; V Iron-copper skarns; VI Epigenetic quartz-arsenic(-antimony) veins; VII Other mineral deposits.

Massive sulphides also occur at this stratigraphic level, although they may have been remobilized during later shearing. The major areas of development are on McLaughlin Ridge (Regina, Cop Creek) and in the Nitinat River – Raft Creek area (Kitkat, Raft). Sulphides are also reported in felsic volcanics on the Main/Railway showing north of Stokes. None of these occurrences has yet proven economic.

Gold-bearing pyrite-chalcopyrite-quartz-carbonate veins along shears: As in the Cowichan Lake and Duncan areas, many of the faults and shears cutting the Alberni–Nanaimo Lakes map area are veined by rusty orange-weathering quartz-carbonate. The more economically important veins are localized along the Tertiary(?) thrusts and crossfaults, for example, the Victoria vein on the Mineral Creek fault and the Black Panther vein on the Beaufort fault zone. The quartz veins are variable in strike length and range up to about 1 metre wide. Carbonate alteration zones up to several metres wide border the veins and may extend into the hangingwall and footwall. Mineralization has taken place episodically during motion on the faults, with earlier veins and alteration being disrupted and reveined. Unaltered porphyry dykes often crosscut veins, suggesting mineralization is pre-Late Tertiary in age. Commonly reported sulphides are pyrite, pyrrhotite, chalcopyrite and arsenopyrite. Sphalerite and galena are less common. The carbonate is principally ankerite and calcite. Clots of dark green fuchsite or mariposite occur occasionally with the carbonate. Gold is found both in the discrete quartz veins and in the alteration haloes where it appears to be associated with the sulphides.

Most of the mineral production in the area has been from these quartz-carbonate shear-zone deposits and they are presently the targets of much exploration activity, for example, the Debbie (Mineral Creek zone), Thistle, Black Panther and Lizard Lake properties.

Copper-molybdenum quartz veins and stockworks: Sulphide-bearing quartz veins occur in granodiorite and adjacent country rock on several properties in the map area. Most of these are associated with the Corrigan Creek pluton (for example, Andy and WWW), but other showings have been found in the Mount McQuillan stock (Sol and Havilah), the Fourth Lake stock (Surprise and WO 7), the Nanaimo Lakes batholith (Louishman-Maureenah) and the Mount Buttle stock (Allies and Close). Most of the showings are veins but well developed stockwork features are seen on the Andy property and disseminated sulphides on the Starlight. The quartz veins generally contain pyrite or pyrrhotite with chalcopyrite and lesser molybdenite.

Other base-metal veins: Several chalcopyrite-pyrite-quartz vein deposits are hosted in Sicker Group (Rush and Nan), Karmutsen Formation (Lofstrom and Qualicum) or Bonanza Group (Union Jack and MOR) lithologies. Although poorly documented, these veins appear to be related to shears but lack the ankeritic alteration associated with the Late Eocene(?) gold-copper veins, and are not obviously related to Jurassic stocks. The PD showing consists of sphalerite-arsenopyrite-bearing veins in Mount Mark Formation limestone. Undoubtedly, several ages and styles of mineralization are grouped together here and more documentation is needed to separate them.

Skarns: Jurassic Island intrusion granodiorites often produce skarns when they intrude limey rocks and skarning may be associated with some of the copper-molybdenum vein deposits (Mary), and with the mined ore at the Thistle mine (Stevenson 1945). Iron-copper skarns, similar to those in the Cowichan area (Blue Grouse) are also found in the Alberni–Nanaimo Lakes area. These received some attention in the past for their copper potential but are now undergoing re-evaluation for gold (Ettlinger and Ray, 1987). The host rocks include limestones from both the Mount Mark Formation (Skarn and Tangle 1) and the Quatsino Formation (Kitchener) as well as limey units within the upper part of the Karmutsen Formation. Sulphides (pyrite, chalcopyrite) and iron oxides (magnetite) occur as irregular pods, lenses and veins within the calc-silicate skarn. Gangue minerals include yellow to brown garnet, dark green pyroxene, epidote, calcite, quartz and chlorite.

On the Villalta property, the main exploration target is a stratiform aurifeous hematitic cap developed on the skarn. This subhorizontal cap unconformably overlies post-skarn karstic collapse breccias, although hematite veins crosscut the skarn and hematite also replaces garnet. The cap is overlain by Nanaimo Group conglomerate and may be of middle Cretaceous age.

Epigenetic quartz-arsenic(-antimony) veins: Realgar, stibnite and pyrite are variably developed in Tertiary sills and Haslam Formation argillites on at least two properties (Coal and Grizzly) in the area. Strong to moderate clay-carbonate alteration and silicification accompany the mineralization and affect the porphyry sills and the argillites. Mineralization on the Coal claims is probably spatially related to the Moriarty fault. These veins, although slightly younger, are probably genetically related to the quartz-ankerite shear veins of Group 2 above.

Other deposits: Various nonmetallic deposits have been exploited in the area, particularly Quaternary gravels for aggregate. Marble was quarried on the Horne Lake property. Subeconomic grades of clay, shale, rhodonite and limestone have been reported from various localities in the area.

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