British Columbia Geological Survey
Geological Fieldwork 1993

PRELIMINARY GEOLOGY OF THE QUATSINO - PORT McNEILL MAP AREAS, NORTHERN VANCOUVER ISLAND (92L/12, 11)

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KEYWORDS: Regional geology, Bonanza Group, Vancouver Group, Karmutsen Formation, Quatsino Formation, Parson Bay Formation, Kyuquot Group, Coal Harbour Group, Island Plutonic Suite, stratigraphy, structure, mineralization, epithermal, acid sulphate alteration

INTRODUCTION

Regional geological mapping at 1:50 000-scale on northern Vancouver Island began in 1992 in the Mahatta Creek area (92L/5; Nixon *et al.*, 1993a and b) and continued in 1993 under the umbrella of a multidisciplinary program to further evaluate the base and precious metal potential of an area of known mineralization and established infrastucture (Panteleyev *et al.*, 1994). The only major operating mine in the area, the Island Copper open-pit operation of BHP Minerals (Canada) Limited, is scheduled to close in 1996 when reserves of copper-molybdenum-gold ore are expected to be exhausted. The area is a prime exploration target for base and precious metals associated with porphyry, epithermal and acid sulphate or high-sulphidation hydrothermal systems (Panteleyev, 1992; Panteleyev and Koyanagi, 1993, 1994). The majority of these systems are associated with the Early to Middle Jurassic Island Plutonic Suite and Early Jurassic Bonanza Group rocks. The regional mapping component of this study focused primarily on potential ties between mineralization and key elements of the Bonanza volcanic stratigraphy. The preliminary findings reported here demonstrate a distinct and regionally persistent relationship between felsic horizons in the volcanic pile and acid sulphate alteration assemblages variably endowed in base and precious metals. These results have an important bearing on applicable mineral deposit models and exploration strategies (Panteleyev and Koyanagi, 1994).

The area mapped (800 km^2) encompasses the Quatsino sheet (92L/12) north and east of Holberg Inlet and the easternmost part of the Port McNeill sheet (92L/11), and extends from the community of Holberg east to Port Hardy and south towards Port Alice (Figure 1). Most of the area is accessible by a well-maintained network of logging roads and by boat in the protected waters of Rupert, Holberg and Neroutsos inlets. The area is covered by the 1988 Regional Geochemical Survey (RGS; Matysek *et al.*, 1989); 1:50 000-scale (Maps 1734G, 9770G) and 1:250 000-scale (Map 7220G) aeromagnetic surveys; a 1:50 000-scale surficial geology map (Kerr, 1992); and drift prospecting studies (Kerr and Sibbick, 1992; Kerr *et al.*, 1992). Follow up of "untested" RGS anomalies in the 92L/102I map sheets is reported by Sibbick (1994) and recent surficial geological studies by Bobrowsky and Meldrum (1994). In addition, work is continuing on the application of *in situ* analysis of naturally acidic stream drainages as an exploration technique (Koyanagi and Panteleyev, 1993, 1994).

TECTONIC SETTING AND REGIONAL GEOLOGY

Northern Vancouver Island lies in the southern part of the Wrangellia tectonostratigraphic terrane which is bounded on the east by plutonic rocks of the Coast Belt and underplated on the west by the Pacific Rim and Crescent accretionary terranes (Wheeler and McFeely, 1991). Amalgamation of Wrangellia to the Alexander Terrane to form the Insular Superterrane appears to have occurred as early as Late Carboniferous time (Gardner *et al.*, 1988). Subsequent accretion of the Insular Superterrane to inboard terranes of the Coast and Intermontane belts may have occurred as late as the mid-Cretaceous (Monger *et al.*, 1982) or as early as the mid-Jurassic when a single superterrane may have been accreted to the North American continental margin (van der Heyden, 1991). There is an accumulating body of geophysical evidence (T. J. Lewis, C. Lowe and T. Hamilton, *personal communications*, 1993) to suggest that since this accretionary event, the northern tip of Vancouver Island may have been involved in the formation of the Queen Charlotte Basin, a Tertiary transtensional province related to oblique convergence of the Pacific and Juan de Fuca plates with the North American plate (Riddihough and Hyndman, 1991). The southern boundary of this extensional regime appears to be marked by the northeasterly trending Brooks Peninsula fault zone which is coincident with Tertiary dike swarms (Nixon *et al.*, 1993a) and young (8 to 2 Ma) calcalkaline lavas of the Alert Bay volcanic belt (Figure 1). The tectonic setting of the Alert Bay suite has been linked to a descending plate-edge effect associated with a stand of

REGIONAL GEOLOGY
NORTHERN VANCOUVER ISLAND

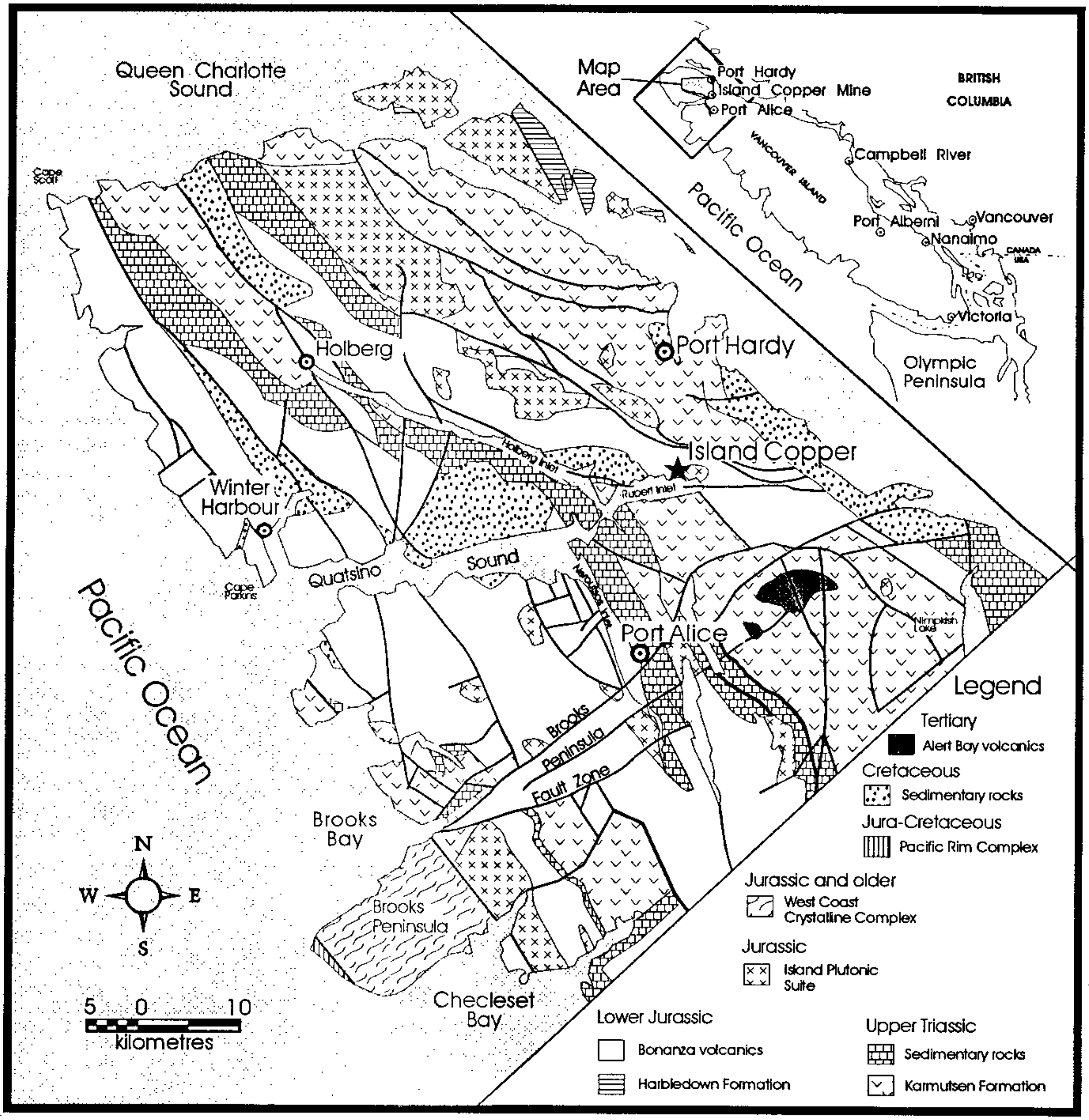

Figure 1. Generalized geology of northern Vancouver Island (modified after Muller *et al.*, 1974). Shaded inset shows location of map area.

the Pacific - Juan de Fuca - North America triple junction off the Brooks Peninsula in the recent past (*i.e.* prior to about 1 Ma; Bevier *et al.*, 1979; Armstrong *et al.*, 1985).

Pertinent aspects of the regional geology of the Quatsino Sound area were summarized by Nixon *et al.* (1993a). The area is largely underlain by fault-bounded blocks of homoclinal strata that belong to the Upper Triassic and Lower Jurassic Vancouver and Bonanza groups, respectively, and that are intruded by Early to Middle Jurassic plutons of the Island Plutonic Suite

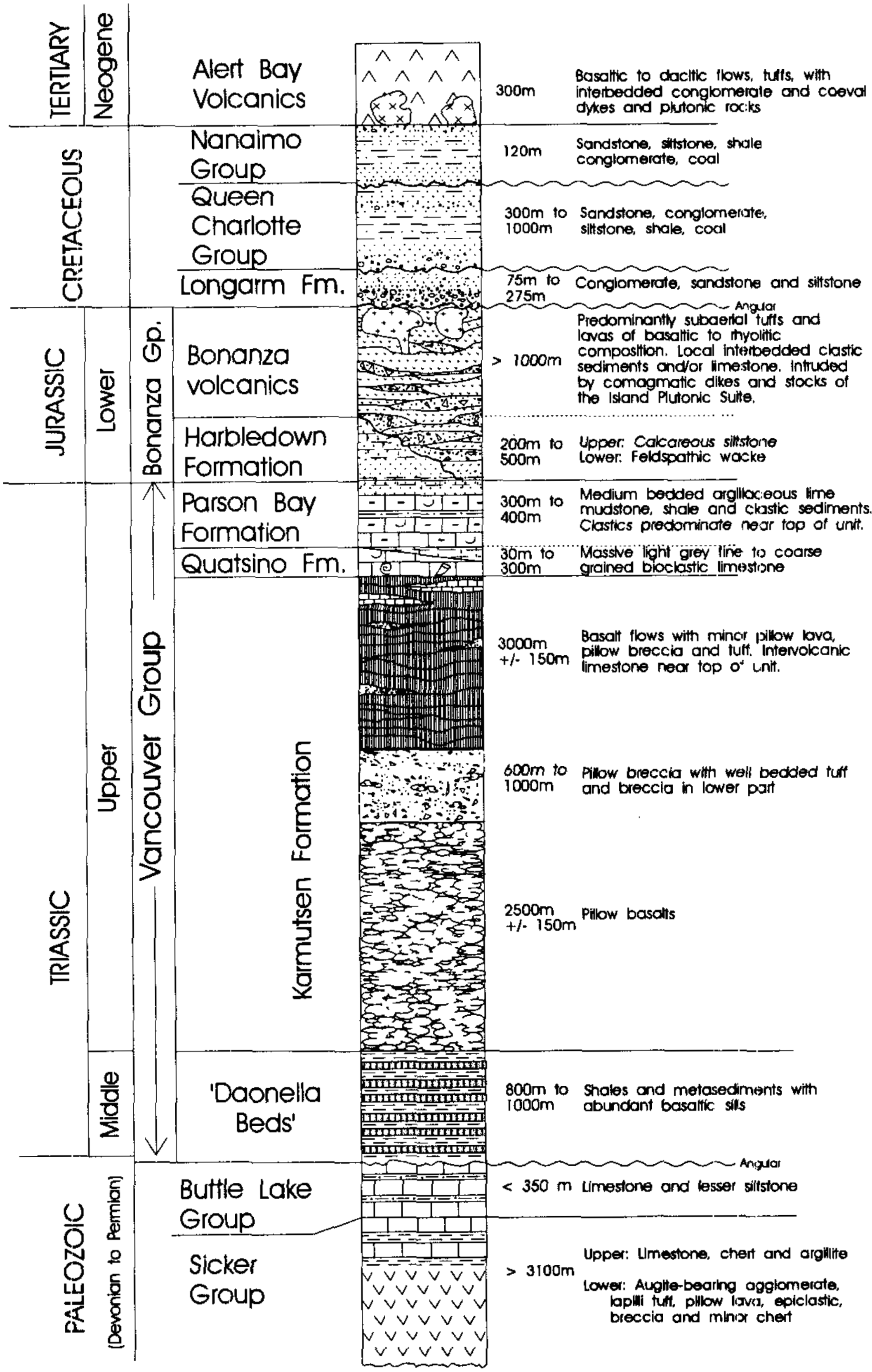

Figure 2. Regional Mesozoic-Cenozoic stratigraphy of northern Vancouver Island (modified after Muller *et al.*, 1974, 1981).

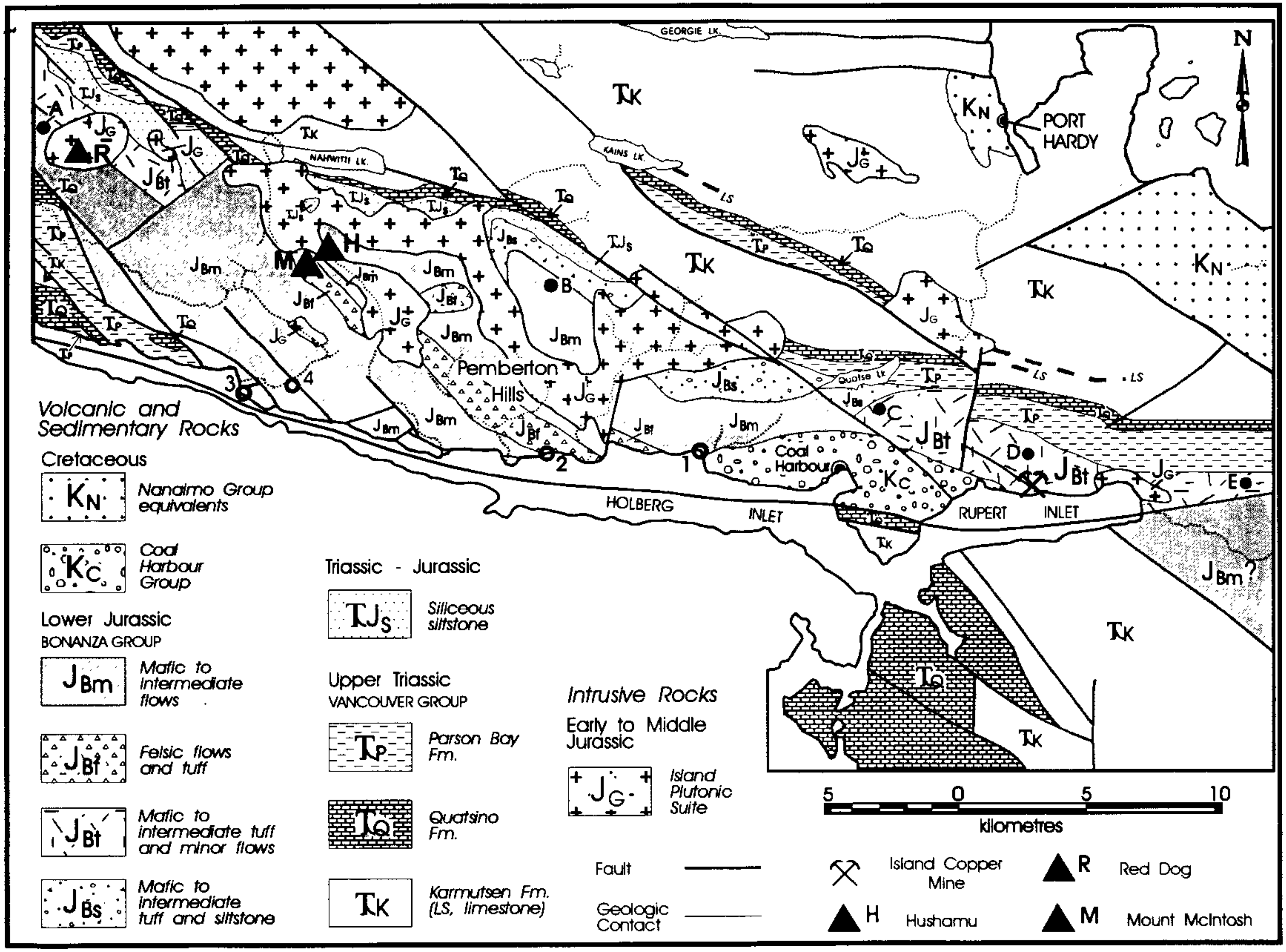

Figure 3. Generalized geology of the Quatsino - Port McNeill map area showing major porphyry deposits and an epithermal prospect (triangles); locations of stratigraphic sections (circles) given in Figure 4, and localities of Cretaceous and Jurassic-Cretaceous strata described in the text.

(Muller *et al.*, 1974, 1981; Figures 1 and 2). Island-arc volcanic and sedimentary rocks of Devonian to Early Permian age and Middle Triassic marine sediments that form the basement of Vancouver Island are not exposed in the project area, and are described elsewhere (*e.g.* Monger *et al.*, 1991). The oldest rocks in the area belong to the Upper Triassic Karmutsen Formation, a thick pile of tholeiitic submarine pillow basalts, breccias and tuffs capped by a subaerial succession of basaltic flows with minor limestone interbeds (Figure 2). The lavas have been interpreted in terms of flood basalt volcanism related to rifting of the older Paleozoic arc sequences, namely the Sicker and Buttle Lake groups (Muller *et al.*, 1974; Jones *et al.*, 1977; Barker *et al.*, 1989). Overlying the Karmutsen Formation is the upper Carnian to middle Norian Quatsino limestone which passes upward into Norian carbonates and clastics of the Parson Bay Formation. The Triassic rocks in turn are overlain by a thick sequence of subaqueous to subaerial arc volcanic and intercalated marine sedimentary rocks of the Lower Jurassic (Sinemurian-Pliensbachian) Bonanza Group. In part, these strata are correlative with non-calcareous "argillites" and greywackes of the Harbledown Formation found farther east across Johnstone Strait and on islands in Queen Charlotte Sound (Figure 1). To date, the Harbledown Formation has not been recognized as a mappable unit on northern Vancouver Island. The lower Mesozoic stratigraphy is intruded by Early to Middle Jurassic granitoids of the Island Plutonic Suite believed to be at least partly comagmatic with Bonanza Group volcanic rocks. Cretaceous marine and nonmarine strata were deposited as clastic wedges on deformed and denuded volcano-plutonic complexes of the Bonanza arc. Felsic to mafic Tertiary dikes and Neogene volcanics of the Alert Bay suite were emplaced in an anomalously near trench, fore-arc environment associated with the Brooks Peninsula fault zone (Armstrong *et al.*, 1985).

STRATIGRAPHIC NOMENCLATURE

Although problems with stratigraphic nomenclature are known to exist (Nixon *et al.*, 1993a), no formal revision of the Lower Mesozoic stratigraphy of northern Vancouver Island is attempted at this time. In general, we have adopted the nomenclature of Muller *et al.* (1974 and 1981). However, new lithostratigraphic units mappable at 1:50 000 scale are described below and underscore the need for more detailed study of strata at the Triassic-Jurassic boundary and within the Bonanza Group. Ongoing studies of conodonts and radiolaria conducted by Michael Orchard (Geological Survey of Canada) and Fabrice Cordey, respectively, are attempting to address these problems.

With regard to the Cretaceous rocks of northern Vancouver Island, Jeletzky (1976) and Muller *et al.* (1974) have used different stratigraphic nomenclature. Although Jeletzky (*ibid.*) recognized similarities between the Cretaceous lithologic and paleontological successions of Quatsino Sound and those of Queen Charlotte Islands (Sutherland Brown, 1968), he preferred to consider the former as distinct. Consequently, he introduced new stratigraphic nomenclature for some rock units in the Quatsino Sound region (*e.g.* Coal Harbour Group). In contrast, Muller *et al.* (1974) and Muller and Roddick (1983) applied Sutherland Brown's nomenclature for the Cretaceous sequences of the Queen Charlotte's to Vancouver Island. However, our preliminary work does appear to substantiate previously proposed differences between the Cretaceous successions in these areas (see also Haggart, 1993), and so we have retained some of Jeletzky's (1976) recommendations, at least until a formal stratigraphic revision of the Cretaceous rocks of northern Vancouver Island is undertaken.

STRATIGRAPHY

The lower Mesozoic stratigraphic units in the Quatsino - Port McNeill map area form a generally westward-dipping, westward-facing homoclinal succession with a conspicuous northwesterly trending structural grain that is shared by major faults and plutons in the region (Figure 3). Outliers of Cretaceous strata occur in the vicinity of Coal Harbour and along the shores of Holberg Inlet. Tertiary dikes are distributed throughout the area but no extrusive equivalents of the Alert Bay volcanics have been identified.

KARMUTSEN FORMATION

The Karmutsen Formation underlies most of the northern and eastern parts of the map area where it forms subdued hummocky terrain (Figure 3). The succession is composed of dark greenish grey to purplish grey and maroon, hematitic basaltic lava flows with minor intercalated pillows, pillow breccias and hyaloclastite deposits, and minor subvolcanic intrusions. It appears that only the predominantly subaerial, uppermost part of the Karmutsen Formation is exposed. The lavas are commonly massive and amygdaloidal with little evidence of internal cooling joints. Flow contacts are observed locally and marked by flow breccias (comparatively rare), a thin zone of hackly jointing at the chilled base of a flow, or textural differences such as phenocryst content or a dense glassy (devitrified) flow base resting on an amygdaloidal flow top. Flow thickness varies from as little as 1 metre to over 6 metres. Two distinct geometries of internal amygdule concentrations have been observed. The most common occurrence is a planar arrangement of amygdules in zones of variable width that are oriented parallel to flow contacts and provide a good indication of paleohorizontal (Plate 1). Pipe amygdules are also locally well developed and intersect these planar horizons at right angles (Plate 2). The latter are usually attributed to vaporization of surface water as hot lavas pass over wet ground, and both sets of features are well known in subaerial flood-basalt provinces. Amygdule infillings include quartz (rarely amethystine varieties) epidote, chlorite, carbonate and zeolite.

Plate 1. Laminar amygdaloidal horizons in Karmutsen basalt, 3.5 kilometres due south of the Island Copper mine across Rupert Inlet (93JHA1-16). These structures provide a good approximation to paleohorizontal. Pen is 16 centimetres long.

The majority of Karmutsen lavas are aphanitic to finely porphyritic (plagioclase <2 mm) with seriate textures; however, medium porphyritic (plagioclase 2-5 mm) lavas are relatively common and coarsely plagioclase-phyric variants (euhedral to subhedral laths measuring 0.5-2 cm) with hiatal textures appear near the top of the succession where they are intercalated with the other lava types as well as interflow limestones. The porphyritic lavas typically exhibit either a trachytoid texture of flow-aligned feldspars or glomeroporphyritic intergrowths in which a radiate or petal-like arrangement of plagioclase laths are ordered about a common nucleus. Local accumulations of plagioclase crystals (up to 40 volume %) are locally evident within individual flows.

Subaqueous basalt sequences occur throughout the map area but form extremely localized accumulations and thus appear to have no regional stratigraphic significance. In pillowed sequences, individual pillows rarely exceed 2 metres in length and at one locality a transition from pillowed basalt to massive flow is evident. Broken pillow fragments (<0.5 m) are distributed chaotically in pillow breccias and finer grained, poorly sorted hyaloclastite deposits. Finely comminuted interpillow material and hyaloclastite debris are locally cemented and veined by white zeolites. Other common vein minerals encountered in the Karmutsen Formation include quartz, epidote, chlorite and carbonate. Disseminated pyrite is widespread and especially common near intrusive contacts; chalcopyrite and native copper have also been observed. The degree of metamorphism of Karmutsen basalts in the map area has yet to be established from thin section studies. Farther west in the Mahatta Creek sheet (Nixon *et al.*, 1993a), prehnite-pumpellyite grade assemblages are widespread, and upper greenschist or lowermost amphibolite-grade facies appear in the thermal aureoles of intrusions of the Island Plutonic Suite.

Plate 2. Pipe amygdules coalescing upward into a planar amygdule-rich horizon in a Karmutsen lava flow, 6 kilometres north-northeast of the eastern end of Rupert Inlet (93JHA10-2). The pipe amygdules form a lineation oriented approximately perpendicular to paleohorizontal.

INTRA-KARMUTSEN LIMESTONE

Two thin (<90 m) horizons of inter-volcanic, pale grey to buff-weathering limestone have been recognized near the top of the Karmutsen Formation. The main exposures form scattered outcrops in the low ground north of the Island Copper mine and roadcuts at the eastern end of Kains Lake (Figure 3). The dominant lithologies comprise thickly to thinly bedded limy mudstone, wackestone with more than 10% oolites set in a micritic matrix, and grain-supported packstone with a calcareous mud matrix. Bedding-parallel stylolites are found in micritic layers and some of the coarser grained beds contain rip-up clasts of black mudstone. Clearly, deposition took place in a shallow, near-shore environment periodically influenced by tidal currents.

QUATSINO FORMATION

The Quatsino Formation generally comprises a pale to medium grey or buff-weathering, thickly bedded or massive lime mudstone, typically medium to dark grey on fresh surfaces. Rarely, the limestone is thinly bedded with undulose bedding surfaces, or laminated, where an argillaceous or silty component is commonly present. Elongate to irregular black chert concretions, usually less than 12 centimetres across, may locally exhibit a preferred orientation with their long dimensions parallel to the layering. Although the limestone is usually unfossiliferous, sparse coral fragments and crinoid stems, and rare ammonites and poorly preserved bivalves, have been observed. Recrystallization of Quatsino limestone is fairly common near faults and at the margins of plutons. In some exposures south of Nahwitti Lake, for example, the limestone has been recrystallized to a pale grey weathering, medium-grained marble with calcite crystals up to 3 millimetres in diameter. Anastomizing veins of calcite, and rarely quartz, are locally abundant near fault zones, and stylolites may be well developed on bedding planes.

The Quatsino - Parson Bay contact is well exposed in the Goodspeed River southwest of the Red Dog porphyry deposit at the boundary of the map area. Here, the top of the Quatsino Formation is a gradation from massive lime mudstone through a layer of oolitic grainstone 2 metres thick into 3 metres of massive algal mats with minor oolitic interbeds. This shallow intertidal to subtidal carbonate sequence is overlain by thin to medium-bedded lime mudstone and argillaceous lime mudstone with thin calcareous mudstone interbeds that define the base of the Parson Bay succession. Although oolitic horizons have been identified elsewhere in the Quatsino Formation, they appear to be relatively rare in the map area, and for the most part a carbonate basin/platform facies appears to be the dominant assemblage (Desrochers, 1989).

PARSON BAY FORMATION

At least two distinct sedimentary facies of the Parson Bay Formation have been recognized in the map area: a predominantly calcareous facies at the western edge; and a weakly calcareous to non-calcareous facies in the northern and eastern parts of the area (Figures 3 and 4).

The western facies of the Parson Bay Formation is well exposed along the Goodspeed River and shores of Holberg Inlet. It consists of a faulted and folded succession of grey to buff-weathering, thin to medium-bedded micritic limestone, argillaceous limestone, calcareous siltstone and mudstone, and fine-grained calcareous sandstone with lesser thin shale interbeds. Lithologies exposed on Holberg Inlet contain abundant fossils including belemnites, bivalves and indeterminate Upper Triassic ammonoids (Arcestids; E. T. Tozer, personal communication, 1993). Similar lithologies in the Goodspeed River section contain graded bedding and crosslaminations. Bivalves identified by E. T. Tozer (personal communication, 1993) as *Halobia* (Carnian to middle Norian) and *Monotis subcircularis* Gabb (upper Norian, Cordilleranus zone) are locally prolific on shaly partings. The latter fossil locality appears to lie about 450 metres above the top of the Quatsino Formation; however, the stratigraphy here is complicated by northwest-trending mesoscopic folds. The contact with underlying massive limestone of the Quatsino Formation is transitional, as already described, and limestone layers at the base of the Parson Bay Formation contain abundant bivalves believed to be *Halobia*.

The northern facies of the Parson Bay Formation crops out along a northwesterly trending belt which extends from Red Dog through the Nahwitti River valley to Quatse Lake and beyond. The unit occupies areas of low relief and outcrops are generally sparse. The apparent stratigraphic setting of this facies at a number of localities along strike is shown in Figure 4. Estimated thicknesses are of the order of 400 to 600 metres except in the Nahwitti River area where structural thinning may have played a significant role. The northern facies may be tentatively subdivided into a lower predominantly calcareous to weakly calcareous sequence, and an upper predominantly non-calcareous succession. The lower part of the sequence consists of intercalated dark grey to black, generally thin to medium-bedded lime mudstone, argillaceous lime mudstone, laminated calcareous siltstone and shale. The upper part comprises thinly laminated, fissile, carbonaceous black shale and lesser dark grey siltstone. In the Red Dog - Nahwitti area, the transition from calcareous to non-calcareous lithologies is not exposed but appears to occur close to the top of the Quatsino Formation. Thin (1 cm) layers of buff-weathering micritic limestone occur sporadically throughout the section but form only a minor component of the stratigraphy. Bivalves identified as *Halobia* (E. T. Tozer, personal communication, 1993) are locally abundant near the transition from carbonate to shale-dominated sedimentation (sections A, B and D, Figure 4). In the east (section E), thickly bedded crystal tuffs or immature volcanic sandstones occur in the upper part of the succession where ammonoids and bivalves, tentatively identified as *Weyla*, are found in non-calcareous black shale interbeds. Although these strata are included here within the Parson Bay Formation, they may represent the base of a predominantly Lower Jurassic tuffaceous succession which is poorly exposed in this area.

SILICEOUS SILTSTONE UNIT

A distinctive unit of siliceous siltstone overlies the Parson Bay Formation in the west and is relatively well exposed in the Red Dog - Nahwitti River area where it has an apparent thickness of 400 to 500 metres (sections A and B, Figure 4). These rocks were previously incorporated within the Parson Bay Formation by Muller *et al.* (1974) and Muller and Roddick (1983). The dominant lithologies are a pale grey to buff-weathering,

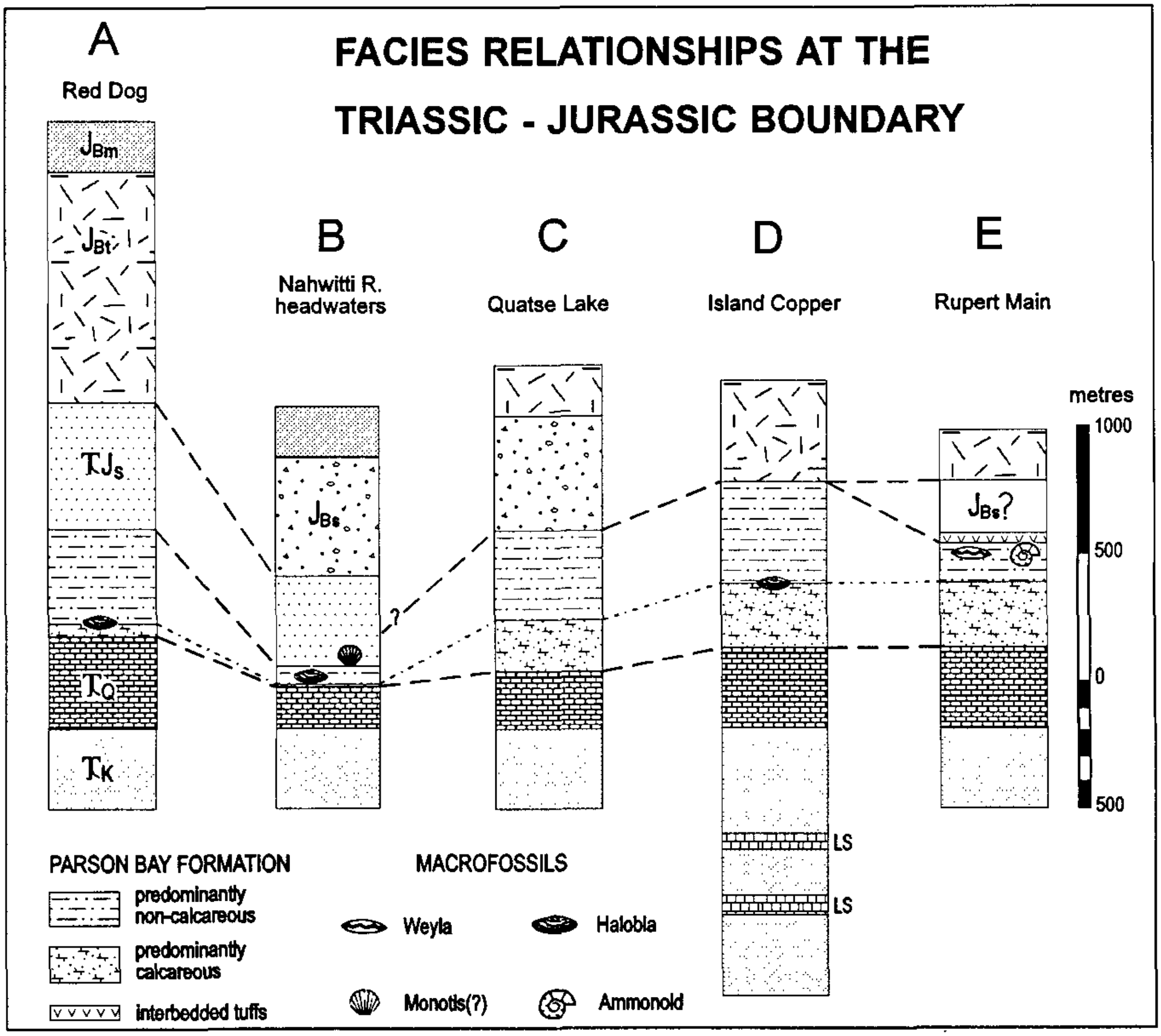

Figure 4. Apparent stratigraphy of Upper Triassic - Lower Jurassic sedimentary and volcaniclastic sequences showing facies variations. Thicknesses were estimated from geological relationships; lithologic patterns and locations of sections A-E are shown on Figure 3.

thinly bedded siliceous siltstone with dark grey shale partings up to 5 millimetres thick, and rare lenticular limestone units several metres in length. The lower part of the section contains rare calcareous mudstone layers (<10 cm thick), and siltstones high in the sequence appear to be more tuffaceous. North of Red Dog, the base of this unit is marked by a heterolithic volcanic conglomerate containing subrounded clasts of aphanitic to plagioclase-porphyritic mafic to intermediate rocks. The latter bed appears to rest conformably on fine-grained clastics at the top of the Parson Bay Formation. South and west of Nahwitti Lake, the siltstones are locally hornfelsed and bleached near the margins of Island Plutonic Suite granitoids, and contain appreciable amounts of pyrite, and locally pyrrhotite, in veins and disseminations associated with white to purple-green skarn alteration. Quatsino limestone in this area has been recrystallized to a medium-grained marble; however, limestone pods within the siltstone unit have retained their micritic character. Despite the effects of alteration, imprints of a bivalve that may be *Monotis* are prolific in certain shale horizons in the lower part of the section. Thus, it is tentatively suggested that the siliceous siltstone unit is uppermost Triassic (upper Norian) to lowermost Jurassic in age.

BONANZA GROUP

The Bonanza Group may be conveniently described in terms of two stratigraphic entities: a predominantly subaqueous epiclastic-pyroclastic succession at the base of the group which can be correlated regionally; and an overlying, predominantly subaerial succession comprising felsic and mafic to intermediate flow and pyroclastic units that may have more restricted significance. In total, the apparent thickness of the Bonanza Group exceeds some 3.5 kilometres, and most of this is subaerial.

LOWER BONANZA STRATIGRAPHY

The base of the Bonanza Group is defined by a mixed succession of epiclastic and pyroclastic rocks which appears to conformably overlie the Parson Bay Formation in the east, and the siliceous siltstone unit in the west. The relative proportions of fine-grained clastics interbedded with coarser epiclastic and pyroclastic rocks locally define a sediment-tuff unit, or a predominantly pyroclastic unit, at or near the base of the Jurassic succession.

Sediment-Tuff Unit

The sediment-tuff unit is exposed at the base of the Bonanza succession between Nahwitti and Quatse lakes (sections B and C, Figure 4). The base of this unit appears to be completely gradational with underlying siliceous siltstones and fine-grained clastics reccur at intervals throughout the succession. However, it is distinguished from underlying siliciclastics by its overall coarser clastic nature and obvious pyroclastic component. The lithologies that are found are quite diverse. Medium grey-green heterolithic volcanic conglomerates contain rounded to subrounded clasts (<20 cm in diameter) of mafic to intermediate volcanic rocks, including plagioclase-phyric and amygdaloidal flows, and rare cobbles of hornblende porphyry. Dark greenish grey, thick to medium-bedded, predominantly monolithic volcanic breccias, tuff-breccias and lithic lapilli tuffs contain largely angular fragments of mafic to intermediate composition measuring up to 20 centimetres in length with most less than 6 centimetres. Accidental lapilli include rare aphanitic siliceous rocks that may be rhyolitic in composition. Clasts in the coarser monolithic deposits tend to be framework supported and may largely represent lag concentrates formed during pyroclastic flow emplacement. Finer grained interbedded clastic materials include thinly bedded to laminated tuffaceous sandstone and siltstone, crystal and crystal-vitric tuff, and siliceous siltstone, and locally exhibit sedimentary structures such as load casts. The volcanic sandstones and crystal tuffs are generally rich in plagioclase; the latter locally contain euhedral augite and possibly hornblende.

Tuff Unit

The tuff unit is a predominantly pyroclastic succession that overlies siliceous siltstones in the Red Dog area and appears to rest on Parson Bay sediments in the vicinity of the Island Copper mine (sections A, C and D, Figure 4). This unit contains similar coarse pyroclastic-epiclastic lithologies as the sediment-tuff unit and may in part be correlative with it. The dominant lithologies are dark greenish grey, massive or thickly bedded heterolithic to monolithic lapilli tuffs, tuff-breccias, volcanic breccias and conglomerates, and minor crystal tuffs and volcanic sandstones. Clasts include aphanitic to amygdaloidal mafic rocks, plagioclase and augite-phyric intermediate rocks, and rare aphanitic felsic volcanics and black shale. The tuff unit is considered to form part of a shoaling-upward succession deposited by submarine pyroclastic flow and epiclastic phenomena operating in a near shore (newly emergent?) environment.

MIDDLE TO UPPER BONANZA STRATIGRAPHY: PEMBERTON HILLS AREA

Mafic to intermediate flows found near the top of the Lower Bonanza succession described above mark the transition from a predominantly submarine to predominantly subaerial island-arc environment. The exact nature of this transition is not well documented at present due to generally poor exposure and the complexities associated with pluton emplacement and faulting. The middle to upper part of the the Bonanza stratigraphy is documented with reference to a type section in the Pemberton Hills region where access is best (Figure 5).

Unit A

The uppermost part of the Bonanza stratigraphy in the Pemberton Hills area (unit A, Figure 5) is represented by a fairly monotonous sequence of dark greenish grey to reddish grey intermediate to mafic lava flows with apparently minor interbedded pyroclastic and sedimentary material. The lavas are predominantly fine (phenocrysts <2 mm) to medium (phenocrysts >2<5 mm) porphyritic varieties containing euhedral to subhedral plagioclase and pyroxene (largely augite); aphanitic and more coarsely porphyritic (phenocrysts <7 mm) flows are less common. The most phenocryst-rich flows contain 30 to 40% plagioclase and up to about 10% pyroxene. Flow breccias are typically well developed at their margins and internal jointing is locally pronounced. The joint pattern appears to correlate with total phenocryst content which may vary conspicuously within the same flow unit. Centimetre-scale platy jointing is well developed in phenocryst-poor flows or flow interiors whereas blocky joint patterns characterize phenocryst-rich flows or parts of flows. The more aphanitic lavas locally exhibit fine amygdaloidal textures with chlorite and hematite infillings. Major element geochemical analyses reported previously by Panteleyev and Koyanagi (1993, Table 2-7-1) and reproduced here (analyses 1-5, Table 1) indicate a rather restricted range of basaltic andesite to andesite compositions.

Intercalated clastic horizons in unit A provide valuable structural markers but outcrops are sparse. Thickly bedded tuff-breccias and lithic lapilli-tuffs contain angular to subrounded, variably oxidized and altered clasts (<20 cm in diameter) of the lavas which host them, and rare accidental fragments of hornblende porphyry. Their finely comminuted matrices usually carry euhedral to broken crystals of plagioclase and/or pyroxene. Thinly bedded to laminated, crystal-rich volcanic sandstones locally exhibit crossbedding and soft-sediment deformation features.

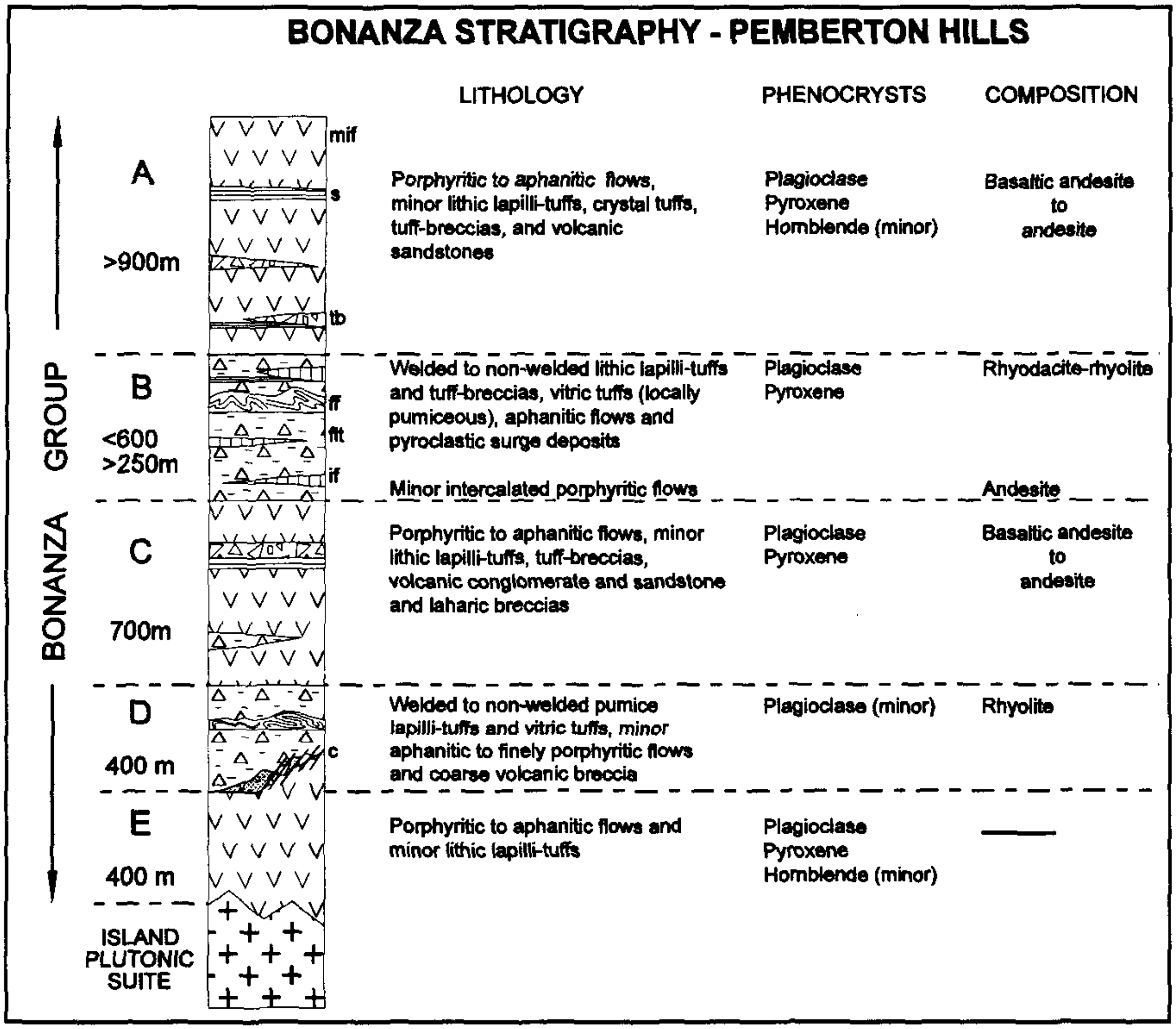

Figure 5. Schematic stratigraphy of the Bonanza Group in the Pemberton Hills area (see Figure 3). Key to lithologic patterns: mif, mafic to intermediate flows; s, volcanic sandstones; tb, tuff-breccias; ff, felsic flows; flt, felsic lapilli tuffs; if, intermediate flows; c, caldera margin.

Unit B

The upper felsic volcanic package (unit B, Figure 5) has a strike length of at least 25 kilometres and forms a southwesterly trending line of resistant knolls and ridges extending from Mount McIntosh to Holberg Inlet (Figure 3). The dominant lithologies are pale grey to white or buff-weathering ash-flow tuffs and viscous flows with minor proportions of intermediate lavas. The felsic rocks are variably altered rhyolites and rhyodacites (analyses 6-17, Table 1); intercalated porphyritic flows are basaltic andesite in composition (analyses 18 and 19, Table 1).

The lapilli tuffs are characterized by abundant angular to subangular clasts of aphanitic rhyolite, some with pronounced flow laminations, and a minor proportion of aphanitic to porphyritic mafic-intermediate volcanic rocks set in a finely comminuted vitroclastic matrix. These rocks locally grade downward, probably within the same flow unit, into texturally similar tuff-breccias where accessory rhyolitic blocks measure up to 15 centimetres in diameter. The lithic population generally constitutes 15 to 25% by volume of the deposit with clasts ranging from 2 to 6 centimetres. Welding is usually not obvious in outcrop. However, flattened grey-green pumice lapilli are a conpicuous component of ash-flow tuffs exposed near the southwestern end of the unit (Wanokana Creek). At one locality in the Pemberton Hills (headwaters of Youghpan Creek), lithic lapilli-tuff grades upward into welded vitric tuff which in turn is overlain by a thin (0-12 cm) layer of bedded tuff followed by another ash-flow unit of welded vitric tuff. Locally, the latter unit has eroded through the layered horizon into the unit below. Internally, the layered vitric horizon is very thinly bedded to laminated and locally exhibits trough cross-stratification. Welding in the enveloping ash-flow tuff units is bedding parallel and continues without break where the stratified layer is missing. The

TABLE 1

WHOLE-ROCK MAJOR ELEMENT COMPOSITIONS, BONANZA GROUP

No.	Sample	Unit[1]	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	SiO_2*
1	92AP01/1-1	A	51.90	0.83	17.67	8.17	0.18	2.96	7.89	3.24	1.36	0.24	4.77	99.21	54.96
2	92AP01/2-2	A	50.79	1.01	17.09	9.54	0.19	2.91	9.47	2.75	0.22	0.20	5.25	99.42	53.93
3	92AP11/5-53	A	51.47	0.80	17.50	9.12	0.19	4.50	7.74	3.05	1.04	0.20	3.69	99.30	53.83
4	92AP01/5-5	A	54.14	0.86	16.60	8.13	0.16	2.60	5.01	3.42	1.25	0.17	7.16	99.50	58.63
5	92AP13/10-68	A	55.28	0.86	18.74	6.80	0.27	2.44	7.52	3.15	1.13	0.19	3.07	99.45	57.36
6	91AP41a	B	73.80	0.83	18.67	0.08	0.00	0.00	0.08	0.00	0.01	0.12	6.05	99.64	78.85
7	91AP20/6-95	B	96.34	1.67	0.95	0.17	0.00	0.00	0.01	0.00	0.00	0.01	0.59	99.74	97.17
8	93GNX14-2-6	B	78.62	0.87	6.59	2.22	0.01	0.05	0.32	0.38	1.17	0.19	9.02	99.45	86.94
9	93GNX15-4	B	70.07	0.56	9.92	9.47	0.01	0.06	0.12	0.14	0.14	0.10	9.35	99.96	77.33
10†	92AP19/1-109	B	60.54	1.11	15.49	10.63	0.00	0.00	0.17	0.00	0.01	0.23	11.22	99.40	68.66
11†	92AP19/1-110	B	70.16	1.45	18.65	1.34	0.00	0.02	0.16	0.00	0.01	0.20	7.42	99.41	76.27
12†	92AP19/1-111	B	86.24	2.04	2.03	7.94	0.00	0.00	0.03	0.00	0.00	0.04	2.53	100.85	87.71
13†	92AP19/1-112	B	93.90	2.81	2.13	0.74	0.00	0.00	0.03	0.00	0.00	0.03	1.12	100.76	94.24
14†	92AP19/1-113	B	63.66	0.84	17.06	7.09	0.00	0.25	0.16	0.00	1.36	0.20	9.06	99.68	70.25
15†	92AP19/1-114	B	66.68	0.67	12.92	8.55	0.00	0.21	0.14	0.00	1.51	0.21	8.38	99.27	73.36
16†	92AP19/1-115	B	63.38	1.05	6.95	7.47	0.13	2.46	6.11	0.30	0.36	0.11	10.81	99.13	71.76
17	93GNX10-1	B	70.93	0.69	19.64	0.27	0.01	0.05	0.10	0.06	0.04	0.10	7.88	99.77	77.19
18	92AP19/2-119	B	49.23	0.90	19.21	9.01	0.19	3.05	10.03	2.63	0.44	0.20	4.45	99.34	51.88
19	92AP19/2-120	B	48.34	0.86	17.76	9.22	0.26	3.26	6.09	5.24	0.31	0.19	7.94	99.47	52.81
20	92VKO8-1	C	54.46	0.77	17.49	8.60	0.20	3.57	7.61	2.84	1.32	0.23	2.64	99.73	56.09
21	92AP16/1-77	C	55.64	0.83	17.54	8.52	0.16	3.01	7.31	3.05	1.72	0.23	1.76	99.77	56.77
22	92AP20/8-128	C	54.36	0.81	15.97	8.05	0.19	4.94	3.65	3.04	1.95	0.15	6.22	99.33	58.38
23†	92AP19/1-116	C	54.59	0.94	15.51	7.46	0.11	5.78	3.36	1.01	1.13	0.21	9.11	99.21	60.59
24†	92AP19/1-117	C	56.74	0.83	16.02	8.44	0.17	4.48	3.56	2.62	2.60	0.17	3.60	99.23	59.33
25†	92AP19/1-118	C	55.84	0.83	15.84	8.38	0.08	4.30	4.54	2.29	1.07	0.17	5.92	99.26	59.63
26	92AP21/7-132	C	53.48	0.78	15.95	8.36	0.25	5.88	6.63	2.66	1.80	0.15	3.55	99.49	55.74
27	92VKO8-4	D	74.22	0.27	13.05	2.09	0.11	0.86	1.72	3.27	1.87	0.08	1.84	99.38	76.09
28	92AP16/7-83	D	69.80	0.30	14.60	2.52	0.12	1.34	2.40	3.32	2.86	0.07	2.05	99.38	71.71

[1] See Figure 5

Data from Panteleyev and Koyanagi (1993).

* Recalculated to 100% anhydrous with total Fe as Fe_2O_3.

† Borehole samples labelled according to increasing depth from 10 to 16 and 23 to 25.

textural and stratigraphic relationships of the bedded tuff horizon are consistent with features found in pyroclastic surge deposits.

The pyroclastic flow deposits pass laterally along strike, and are locally overlain or interbedded with, aphanitic rhyolite flows (and dikes) with locally well-preserved flow laminations and flow folds. Flow breccias are relatively common and contain rounded to angular blocks of dense aphanitic flow material; some of these breccias carry pumiceous blocks with partially preserved tube vesicles.

The andesitic lavas are a minor but distinctive component of this unit. They are dark greenish grey, strongly porphyritic flows carrying blocky to lath-like plagioclase (<7 mm) and pyroxene (<2 mm) phenocrysts that form up to 15 and 10 modal percent respectively. Platy jointing oriented parallel to the flow foliation is locally quite pronounced.

Unit C

The upper rhyolitic sequence is underlain by a succession of dark grey-green to maroon mafic to intermediate lavas interbedded with relatively minor proportions of epiclastic and pyroclastic rocks of similar composition. Most of the volcanic rocks range from andesite to basaltic andesite in composition (analyses 20-26, Table 1). The lavas are usually porphyritic with plagioclase (<5 mm) and pyroxene (<3 mm) phenocrysts typically forming up to 35% by volume of the rock. Flow breccias are observed locally and the more porphyritic varieties exhibit flow laminations and well-developed flow folds due to their high apparent viscosity (Plate 3). A thickly bedded conglomerate with well-rounded cobbles of volcanic rocks occurs near the middle of the succession and thinly bedded tuffaceous sandstones are found near the base. Lithic lapilli-tuffs and tuff-breccias contain matrix-supported, angular to subrounded clasts of porphyritic to aphanitic lavas. Rare laharic breccias contain a similar population of clasts up to 0.5 metre in diameter, supported by a brick-red clay-rich matrix.

Unit D

The only known outcrops of the lower rhyolitic unit occur north of the Pemberton Hills at the northern

Plate 3. Flow fold in porphyritic andesite flow, Bonanza Group (unit C, Figure 5); quarry 0.4 kilometre northeast of the Wann Knobs, Pemberton main logging road (93GNX10-2). The high apparent viscosity of this flow is due to its crystal-rich nature.

extremity of the logging road system (H600 road). The sequence is dominated by pale grey to buff-weathering ash-flow tuffs with minor airfall deposits and rhyolitic flows or dikes that are variably propylitized and clay-altered. Analytical data for two fairly fresh samples indicate rhyolitic compositions (analyses 27 and 28, Table 1).

The airfall deposits are thinly bedded vitric and crystal tuffs with some normally graded interbeds that consistently face and dip to the southwest. Flow or dike material is commonly flow laminated and aphanitic or finely porphyritic (<2 mm) with several percent feldspar phenocrysts. The lapilli tuffs are conspicuously pumiceous with dark grey-green, variably flattened pumice lapilli defining non-welded to welded textures. Their lithic population rarely exceeds 5% by volume of finely crystalline to porphyritic intermediate to felsic volcanic rocks.

Complex stratigraphic and structural relationships are exposed in roadcuts along the southeastern edge of the main outcrop area. A distinctively coarse heterolithic breccia at the base of the succession contains angular to subrounded blocks up to 3 metres across set in a finely comminuted dark greyish green matrix. This framework-supported breccia contains clasts of aphanitic and plagioclase-phyric basaltic to intermediate rocks, some of which were clay-altered or propylitized prior to brecciation, and sparse fragments of flow-banded rhyolite. This layer represents a debris flow or landslide deposit most likely associated with a vent-forming eruption. This deposit is overlain by, and in gradational contact with, non-welded pumiceous tuff that grades upward into partially welded lapilli tuff. Further south and a little higher in the section, welded vitric tuff, a pumice-poor horizon within the lapilli tuff sequence, overlies aphanitic intermediate volcanic rocks of unit E. The contact is sharp and depositional with no break in welding. The lack of a flow-top breccia at this contact implies that either a period of erosion preceeded deposition of the pyroclastic flows or that deposition occurred on the surface of a rotated block. At the northeastern limit of exposure, these intermediate flows are faulted against the lapilli tuffs and underlying volcanic breccia by one of a series of en echelon east-northeasterly trending faults (and subparallel mafic dikes). These faults are no doubt responsible for the rotation of welded fabrics in the lapilli tuffs at this locality which strike at high angles to regional bedding trends and dip moderately to steeply (30-60°) west and north.This fault-controlled margin with local evidence for (catastrophic?) deposition of coarse volcanic breccias immediately preceding ash-flow deposition is consistent with relationships typical of caldera margins. A partially exhumed caldera source-region in which the felsic pyroclastic rocks of unit E are preserved as an intracaldera facies would also explain the restricted extent of pyroclastic deposition. This interpretation requires a disconformity between units C and E along strike.

Unit E

Stratigraphically beneath the lower rhyolitic package, and best exposed in roadcuts north and east of the Hushamu porphyry (Figure 3), is a sequence of dark grey-green and medium grey to pinkish grey intermediate to mafic flows and flow breccias. The more altered rocks near intrusive contacts are buff to rusty weathering due to disseminated pyrite. Plagioclase-phyric lavas of andesitic composition appear to be the dominant lithology; no analyses of these rocks are currently available. Some of these rocks carry phenocrysts of hornblende (< 3mm) and xenoliths of hornblende diorite. At this time, it is not clear whether the latter lithologies are indeed part of the stratigraphy or a porphyritic phase of the Island Plutonic Suite.

BONANZA VOLCANISM: A PREDOMINANTLY SUBAERIAL SETTING

The onset of Bonanza volcanism is marked by a coarsening-upward sequence of intercalated marine, epiclastic and pyroclastic deposits which marks the gradual emergence of a volcanic island arc in the Early Jurassic. In the Quatsino - Port McNeill map area, this sequence is marked by the siliceous siltstone unit which overlies Parson Bay lithologies in the northwestern part of the map area, the overlying tuff-siltstone unit which we have tentatively assigned to the lowermost Jurassic, and the tuff unit which is well developed in the east. The persistence of oxidized massive flows and flow breccias at intervals throughout the Bonanza stratigraphy, the occurrence of welded tuffs within felsic pyroclastic sequences, the apparent lack of pillowed sequences and hyaloclastite deposits, and dearth of marine incursions within the volcanic pile indicate that Bonanza volcanism occurred in a predominantly subaerial setting. This contrasts little with the Mahatta Creek area where intra-Bonanza marine sedimentary rocks and pillow breccias have been documented but are nevertheless scarce (Nixon *et al.*, 1993a). In the present map area, large volumes of porphyritic lavas, predominantly andesite and basaltic andesite, are the main component of the Bonanza succession. Of the two felsic volcanic packages identified in the Pemberton Hills area, the upper unit is the most widespread and marks a significant episode of rhyolitic volcanism. Both felsic horizons represent the products of flow-dome and caldera complexes associated with what appear to be relatively small volumes of pyroclastic flow material. They are also important from a mineral potential standpoint as discussed later.

CRETACEOUS ROCKS

Lower Cretaceous strata equivalent in part to the Longarm Formation, as well as the younger Coal Harbour Group, are exposed principally on the shoreline along Holberg and Rupert inlets, and for short distances inland where outcrops are sparse (Figure 3). Additional exposures of Upper Cretaceous strata (Nanaimo Group equivalents) are found on the east coast in Port Hardy and vicinity. Throughout the Quatsino - Port McNeill map area, it is evident that both nonmarine and marine facies are represented in the Cretaceous succession.

STRATA EQUIVALENT TO THE LONGARM FORMATION

Lower Cretaceous strata of approximately Hauterivian-Barremian age crop out at various localities around Holberg Inlet. The strata were noted by Jeletzky (1976), who studied small exposures in Apple Bay, and they were subsequently correlated with the Longarm Formation of the Queen Charlotte Islands by Muller *et al.* (1974) based on age relationships. Although Valanginian-Barremian strata near the entrance to Quatsino Sound (Winter Harbour area; Figure 1) are indeed similar to typical Longarm Formation rocks of the Queen Charlotte Islands, those in Holberg Inlet are lithologically distinct. For this reason, we treat the latter as "Longarm Formation equivalents".

Longarm Formation equivalent strata in Holberg Inlet consist of sandstone, pebble conglomerate, siltstone and, locally, coal seams up to approximately 10 centimetres in thickness. The strata are best displayed along the shoreline of Holberg Inlet in exposures some 5 and 10 kilometres west of Coal Harbour at Apple Bay and near Henriksen Point (localities 1 and 2 respectively, Figure 3), and appear to form an overall fining-upward sequence. The base of the Longarm Formation equivalent strata has not been observed but, based on facies and structural relationships, the succession is inferred to rest unconformably on volcanic rocks of the Bonanza Group.

The stratigraphically lowest units of this package consist of massive, medium to thinly bedded sandstone, locally pebble rich, with interstratified coal seams and abundant plant debris. These rocks grade upward into medium-bedded, trough cross-stratified to massive sandstone, and finally into hummocky cross-stratified, medium to fine-grained sandstone. Measurements of trough cross-stratification in the coarser sandstone bodies indicate southeasterly to southwesterly directed paleocurrents. Resistant, hummocky cross-stratified sandstone beds in the upper part of the sequence at Apple Bay are interstratified with less resistant and poorly exposed marine siltstone and mudstone units, giving the appearance of a sandstone-rich succession; in fact, the fine-grained facies predominate and reflect a continuation of the trend towards increasing water depth seen throughout the Cretaceous section. Thus, the exposures of Longarm Formation equivalent strata in Holberg Inlet appear to comprise a single overall fining-upward sequence. The Hauterivian-Barremian age of Longarm Formation equivalent strata recognized to date in Holberg Inlet is based on ammonite faunas, and inoceramid and trigoniid bivalves (summarized in Muller *et al.*, 1974).

COAL HARBOUR GROUP

The base of the Coal Harbour Group has not been observed at Coal Harbour, but is inferred to rest unconformably on volcanic rocks of the Bonanza Group (see summary in Jeletzky, 1976). The lowest strata consist of massive conglomerate with minor lenses of coarse-grained channel sandstone (*i.e.* Blumberg Formation of Jeletzky, 1976; the 'coarse arenite unit', which Jeletzky believed to underlie the Blumberg Formation, is here interpreted as sandstone lenses within the Blumberg Formation conglomeratic succession). Earlier mapping by staff at the Island Copper mine identified a basal contact of Blumberg Formation conglomerate resting on the Bonanza Group (J. Fleming and A. Reeves, unpublished data), but this exposure has subsequently been paved over. The conglomerate is succeeded up-section by trough cross-stratified sandstone intercalated with siltstone, minor conglomerate and minor coal.

The overall fining-upward facies trend noted in Jeletzky's (1976) measured section of the Blumberg Formation southwest of the Island Copper minesite is duplicated on the shore at Coal Harbour. Measurements of trough cross-stratified sandstone of the Blumberg Formation in both these sections indicate southeasterly to southwesterly paleocurrent trends, similar to those determined for the Longarm equivalent strata.

The age of the Coal Harbour Group is poorly constrained and relies on the identification of palynomorphs of late Early Cretaceous (Albian) age made by Hopkins (in Jeletzky, 1976) and collected from the section southwest of the Island Copper mine.

STRATA EQUIVALENT TO THE NANAIMO GROUP

Strata equivalent in age to the Nanaimo Group of southern Vancouver Island (Muller and Jeletzky, 1970) crop out in the northeastern part of the map area (Figure 3). The strata were studied previously by Jeletzky (1969) and Muller and Jeletzky (1970). Most exposures are found in recent roadcuts in the town of Port Hardy, and along the shoreline southeast of the town. The strata comprise gently dipping, shallow-marine to nonmarine facies, and include medium to coarse-grained sandstone and pebble conglomerate, siltstone and minor coal. Although no contact with older rocks has been seen, structural relationships suggest that the succession rests with angular unconformity on Karmutsen Formation volcanic rocks. The age of Nanaimo Group equivalent rocks in the map area is late Upper Cretaceous (approximately Campanian), as determined from marine molluscs (Jeletzky in Muller and Jeletzky, 1970).

SEDIMENTARY ROCKS OF UNCERTAIN AFFINITY (JURASSIC-CRETACEOUS)

Sedimentary rocks previously mapped as Lower Cretaceous Longarm Formation by Muller *et al.* (1974) along the north shore of Holberg Inlet just east of the mouth of Clesklagh Creek (locality 3, Figure 3) consist of vertically dipping, southward-younging, interstratified tuffaceous sandstone and volcanic conglomerate, flow breccias of andesitic composition, and minor thin coal seams. The age of these rocks is presently unknown but given the predominance of volcaniclastic debris and their compositional immaturity, they appear more likely to belong to the Bonanza Group.

A faulted, northeasterly dipping stratigraphic section exposed along logging roads above, and east of, Clesklagh Creek (locality 4, Figure 3) consists of a basal unit of coarse-grained pebbly volcanic sandstone, locally containing rhynchonelliform brachiopods and apparently interstratified with andesitic volcanic rocks. These strata appear to be overlain by several tens of metres of silty mudstone containing belemnite fragments. The mudstone section is in turn overlain by a thick sequence of marine to nonmarine(?), cross-stratified sandstone and siltstone which forms the top of the section. The age of the brachiopods found at the base of the section is presently unknown but brachiopods of this general type are common in Lower to Middle Jurassic rocks of the Insular Belt (H.W. Tipper, personal communication, 1993). It is therefore possible that the Klesklagh Creek strata may also belong to the Bonanza Group.

INTRUSIVE ROCKS

Intrusive rocks in the map area comprise stocks and batholiths of the Island Plutonic Suite and their associated porphyritic phases, and mafic to felsic dikes and sills of Karmutsen, Bonanza and Tertiary age. Potassium-argon isotopic determinations summarized by Muller *et al.* (1974) on hornblende and biotite from intrusions of the Island Plutonic Suite in the map area yield dates between 145 and 169 Ma [Middle Jurassic (Bathonian) to the Jurassic-Cretaceous boundary according to the time scale of Harland *et al.*, 1990]. These dates are generally considered to be too young and reflect minimum (cooling) ages only. Rubidium-strontium isochron dates of 177±10 Ma (Muller, 1977) and approximately 180 Ma (dated by R. L. Armstrong; J. Fleming, personal communication, 1992) provide better estimates of actual intrusion ages (*i.e.* latest Early to earliest Middle Jurassic).

ISLAND PLUTONIC SUITE

Granitoid rocks of the Island Plutonic Suite underlie sizeable areas of subdued relief in the central and northwestern parts of the map area The principal rock types are pale grey to buff-weathering, generally medium-grained and equigranular, hornblende-bearing diorite or monzodiorite and quartz monzodiorite to granodiorite (nomenclature after Le Maitre, 1989). Propylitic and argillic alteration assemblages and skarning are locally well developed at their margins. Crosscutting fractures and veins are commonly filled with chlorite, hematite, epidote, quartz, kaolin, zeolites and, rarely, potassium feldspar.

The southern margin of the Nahwitti batholith north of Nahwitti Lake (Figure 3) is composed of coarse to medium-grained (2-6 mm) equigranular biotite-bearing hornblende quartz diorite to monzodiorite containing about 5% modal quartz and up to 20% hornblende. A marginal zone about a kilometre wide contains subequal proportions of biotite and hornblende and sparse xenoliths of feldspathic amphibolite. The granitoid rocks are extremely fresh and have been sampled for Ar-Ar dating. Conventional K-Ar dates on hornblende and biotite separates taken from the southern margin of the batholith range from 154 to 169 (±8) Ma (summarized in Muller *et al.*, 1974).

The Red Dog stock is a crowded feldspar porphyry with a finer grained, less porphyritic phase along its eastern margin and an equigranular quartz diorite phase whose contact relationships have not been observed. Blocky to lath-shaped feldspars averaging 3 to 5 millimetres in length and reaching 15 millimetres comprise up to 35 modal % of the rock together with chloritized hornblende (10%) and sparse quartz (1-2%). The finely crystallized mesostasis is grey to black. Three small stocks of diorite and "quartz-eye" granodiorite occur east of Red Dog (only one is shown on Figure 3); extensive hornfelsing of their hostrocks suggests that these bodies are more extensive at depth although not necessarily connected.

The large plutonic body south of Nahwitti Lake, referred to here as the Wanokana batholith, apparently extends from Hepler Creek in the west through Hushamu to Wanokana Creek in the east where it is disrupted by faulting (Figures 3 and 6). The Wanokana intrusion and its wallrocks are much more propylitized and clay-altered than the southern margin of the Nahwitti batholith. In the vicinity of Hepler Creek, the rock is a medium to coarse-grained (<7mm), equigranular hornblende quartz

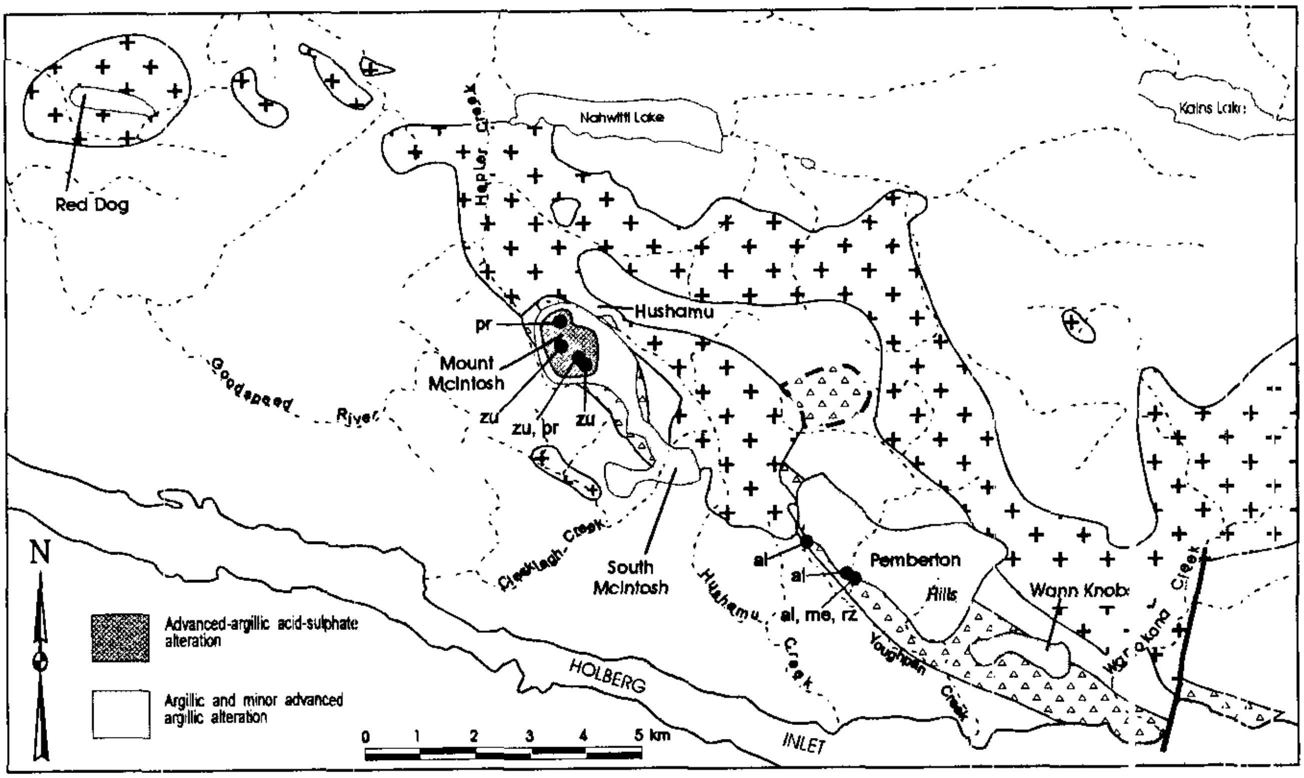

Figure 6. Geologic setting of acid sulphate alteration assemblages and X-ray diffraction sample sites.

monzodiorite to quartz diorite containing variable proportions of quartz (5-20 modal %) and partially chloritized hornblende (<15 modal %), with a plagioclase:potassium feldspar ratio approaching 2:1. These relatively quartz-rich rocks are also found along the northern margin of the pluton in outcrops east of Nahwitti Lake. On ridges north and east of the Hushamu deposit, dark grey-green, fine to medium-grained diorites and andesitic country rocks are extensively pyritized (2-10 volume % pyrite), and are difficult to tell apart in areas of more intense alteration. A similar fine-grained marginal phase is also exposed farther south in streams draining the northern flank of South McIntosh and high on the eastern flank of the lower Hushamu Creek valley (Figure 6). In these areas, a chloritic fine-grained marginal diorite grades into a medium-grained hornblende diorite with increasing distance from the contact. These rocks contain abundant disseminated pyrite (up to 10 volume %) and are partially altered to clay minerals. Exposures near Wanokana Creek are largely medium-grained (<5 mm) equigranular hornblende monzodiorite or diorite that may be weakly porphyritic with plagioclase reaching 8 millimetres. Minor leucocratic monzodiorite with less than 10% modal hornblende and rare medium-grained syenite with up to 70% potassium feldspar, 15% plagioclase and 15% hornblende ± biotite are also observed. A dark greenish grey fine to medium-grained hornblende-bearing dioritic phase again occurs along the northern contact with pyritic and propylitized andesitic volcanics several kilometres due north of the Wann Knobs (Figure 6). Two K-Ar determinations on biotite from Hepler Creek and the northern margin of the batholith southwest of Nahwitti Lake yield dates of 145±5 and 159±5 Ma, respectively (Muller *et al.*, 1974).

Two small plutons farther east intrude the Karmutsen Formation. The Quatse stock northeast of Quatse Lake (Coal Harbour intrusion of Muller *et al.*, 1974) is a medium-grained hornblende monzodiorite or diorite with as much as 20 to 25% modal amphibole and less than 15% potassium feldspar. The southeastern margin of the intrusion is appreciably propylitized with thin anastomizing late-stage veins of kaolin cored with quartz. The Glenlion stock, exposed in roadcuts along the Holberg - Port Hardy road and in the headwaters of Glenlion Creek for which it is named, is a medium to coarse-grained, equigranular to weakly porphyritic (<7 mm) hornblende diorite. Intrusion breccias (agmatites) and concentrations of angular to subangular xenoliths of Karmutsen lavas occur at its margins; these mafic wallrocks are generally pyritized and locally silicified. Rare centimetre-scale modal layering of hornblende and feldspar is developed within zones up to several metres wide that parallel the ductily sheared margins of younger dikes.

The Island Copper intrusion is a west-northwest-trending, northerly dipping dike-like body in the order of 100 to 150 metres wide that is probably an offshoot of the stock at the eastern end of Rupert Inlet. The dike is a quartz feldspar porphyry with phenocrysts of rounded to partially embayed quartz (<1 cm; 5-15 modal %), subhedral, locally glomerophyric, plagioclase (<4 mm; <30%) and minor altered mafic phenocrysts set in a fine-grained quartzofeldspathic groundmass. The Rupert stock is a medium to coarse-grained, equigranular to porphyritic granodiorite containing up to 30% modal quartz, 60% feldspar and about 10% chloritized hornblende. Outcrops in the eastern part of the intrusion locally exhibit intense argillic alteration. Detailed descriptions of the geology of these intrusions are given by Cargill *et al.* (1976). A K-Ar date on biotite from the Rupert stock yielded an apparent crystallization age of 154±6 Ma (Muller *et al.*, 1974).

MINOR INTRUSIONS

The majority of dikes and sills in the map area are microdiorite or aphanitic to plagioclase ± pyroxene-porphyritic mafic to felsic equivalents of Bonanza Group volcanic rocks. Intrusions of Karmutsen age have only rarely been identified; a fine-grained basaltic sill with well-developed columnar jointing is exposed in a roadcut about 1.4 kilometres east of Georgie Lake. Dikes and sills of fine to medium-grained diorite to quartz monzodiorite or granodiorite are associated with intrusions of the Island Plutonic Suite. Hornblende-bearing porphyritic intrusions are widespread in the Bonanza Group and Upper Triassic sedimentary succession and commonly occur as marginal phases of granitoid plutons or crosscutting dikes. Pale grey weathering, coarsely porphyritic dikes of quartz (<1.5 cm) and plagioclase (<1 cm), rarely accompanied by hornblende (<1.5 cm) with hiatal to seriate textures are found southwest of Quatse Lake and on Rupert Main logging road southeast of Rupert stock, and represent apophyses of nearby granitoids of the Island Plutonic Suite. Hornblende plagioclase porphyries are generally medium porphyritic (<5 mm) with euhedral hornblende (<15%) and plagioclase (<20%) phenocrysts. Coarse hornblende (± plagioclase) porphyries have hiatal textures with large (<2 cm) euhedral amphibole phenocrysts set in a quartzofeldspathic microcrystalline to fine-grained groundmass. Soft-sediment deformation features have been observed at the base of sills intruding thinly bedded Bonanza sediments and within intrusion breccias cutting Parson Bay clastics north of Island Copper. These breccias comprise angular to subrounded clasts (<20 cm) of hornblende porphyry and xenoliths of siltstone and limestone derived from the underlying Quatsino Formation. A well-chilled, sparsely hornblende-phyric groundmass in the core of the intrusion is replaced by a black shaly matrix at the margin. Locally, contorted xenoliths of thinly bedded sediment are also observed. These textures imply that intrusion began in Early Jurassic time before Upper Triassic sediments were completely consolidated. In fact, angular xenoliths of hornblende porphyry and medium-grained diorite have been found in the basal Bonanza flow and tuff unit exposed along the Coal Harbour - Port Hardy road.

TERTIARY DIKES

Some dozen or so mafic dikes of presumed Tertiary age are distributed throughout the map area. They appear to be less prolific here than farther south in the vicinity of the Brooks Peninsula fault zone (Nixon *et al.*, 1993a), although this observation may be more apparent than real. The dikes are up to 3 metres wide and are distinguished by their fresh appearance, blocky jointing and dark rusty brown, spheroidal weathering. Fresh surfaces are dark grey, and there are both aphanitic and plagioclase-phyric (<15% phenocrysts) varieties. Amygdules may be filled with carbonate and pyrite, and flow-laminated margins are common. Dikes of rhyolitic as well as basaltic composition cut the Cretaceous rocks at several localities in Apple Bay and Coal Harbour. Most of these dikes dip steeply to moderately (90-60°) and strike 015 to 070 or 315. A whole-rock K-Ar determination for a basaltic dike on East Straggling Island in Holberg Inlet yielded an Early Oligocene date of 32.3±1.6 Ma (Muller *et al.*, 1974).

STRUCTURE

The structural style in the Quatsino - Port McNeill area is dominated by block faulting. Strata within individual fault blocks typically have a consistent dip and facing direction toward the south to southwest, describing a northwesterly trending homocline. On a regional scale, the area makes up part of the western flank of the Victoria arch, a northwesterly trending anticlinorium which is known to culminate east of Nimpkish Lake, southeast of the study area (Muller *et al.*, 1974). The northwesterly structural grain is further emphasized by prominent northwesterly trending transpressional faults. In all, three phases of deformation have been recognized in the map area, but have not yet been analyzed in detail. Comments on the main events are offered below.

PHASE 1: POST-EARLY JURASSIC TO PRE-CRETACEOUS DEFORMATION

The earliest phase of deformation is related to an east to northeast-directed compressional event which resulted in regional tilting of the Lower Jurassic and older strata to form the Victoria arch. This was accompanied by flexural-slip folding and the development of northwesterly trending thrust faults. Early northeast-directed compression is indicated by the presence of a locally well-developed, northwesterly striking, stylolitic cleavage in Quatsino limestone.

PHASE 2: POST-MID TO (?)PRE-LATE CRETACEOUS DEFORMATION

A second deformational episode postdates deposition of mid-Cretaceous Coal Harbour Group sediments and may predate deposition of the Upper Cretaceous Nanaimo Group. This episode was caused by a period of intense strike-slip faulting and lesser thrusting, which resulted from northerly directed compression. Faults formed during this episode are the dominant northwesterly trending structures in the area and, in many cases, have produced significant drag folding, particularly where adjacent units are well bedded. The most obvious of these are northwesterly striking, high-angle oblique-slip faults which have a right-lateral and south-up sense of motion. The faults cause most of the stratigraphic repetitions that occur in the map area. The Holberg fault, a curvilinear south-side-up thrust, for the most part hidden beneath Holberg Inlet except near Coal Harbour (Figure 3), formed during this phase of deformation in response to northward-directed stresses. This important structure places Upper Triassic strata on the south side of the inlet adjacent to mid-Cretaceous and older strata on the north side of the inlet. The most convincing kinematic indicator for movement on the Holberg fault is the presence of many northerly verging, gently plunging drag folds in its footwall. This sense of motion is also demonstrated by minor coaxial thrust faults and a well-developed stylolitic cleavage in limestones in the footwall. Some of the major northwesterly trending, right-lateral oblique-slip faults in the area are splays off the Holberg fault; for example, faults near the western limit of mapping. Other major faults with a similar sense of motion include the Kains Lake and Nahwitti Lake faults.

PHASE 3: TERTIARY DEFORMATION

The most recent phase of deformation in the area is represented by northwesterly to north-northwesterly directed extension which postdates the deposition of Upper Cretaceous Nanaimo Group sediments. This phase is represented by minor northeasterly to east-northeasterly striking normal faults which affect Upper Cretaceous and older strata. Reactivation of pre-existing strike-slip faults occurred, but appears to be rare. Tertiary dikes intruded during this phase of deformation commonly strike toward the northeast, although this is not the only observed orientation.

LITHOLOGIC CONTROLS ON STRUCTURAL STYLE

The Karmutsen volcanic rocks form a rigid coherent mass that has deformed by strictly brittle mechanisms; faults and shear fractures are common. Bedding-parallel slip is rare due to an apparently high degree of cohesion along flow contacts. Beds were tilted during the earliest phase of deformation described above, but later faulting does not appear to have caused significant rotation of bedding. This has resulted in a bedding orientation which is remarkably consistent throughout the map area (Figure 7).

Limestone of the Quatsino Formation has accommodated strain by both brittle and ductile mechanisms. This unit typically dips moderately to the southwest or south except where the beds have been dragged into flexural-slip folds in response to faulting (Figure 7). Pressure solution to form stylolite seams is common in most limestone outcrops and, together with associated calcite veins, has probably resulted from tectonic thickening. Quatsino limestone reaches extreme apparent thicknesses in the region east of Neroutsos Inlet and Quatsino Narrows. These anomalous thicknesses are at least partly due to folding and thrust fault repetitions in this area.

Shale, siltstone and limestone of the Parson Bay Formation have largely accommodated strain by bedding-parallel shear. This has resulted in the development of mesoscopic folds which are particularly evident adjacent to fault zones (Figure 7). The shale facies of the Parson Bay Formation, which crops out in the northwest part of the map area, may have controlled faulting locally to some degree as this facies is found in the footwall of several megascopic faults.

Volcanic rocks of the Bonanza Group have deformed predominantly by shear. This unit is characterized by very broad zones of intensely sheared rock adjacent to megascopic faults. Commonly these rocks dip moderately to the south or southwest but they are locally dragged adjacent to faults giving bedding attitudes a more random orientation (Figure 7). Part of this pattern may well reflect syn-Bonanza structural complexities such as caldera formation.

ECONOMIC GEOLOGY

The Quatsino - Port McNeill map area contains economically important porphyry copper-molybdenum-gold deposits, including the Island Copper mine, and base and precious metal skarns in addition to mineralization associated with epithermal acid sulphate alteration zones which are the current focus of exploration. In all, a total of 83 mineral occurrences are listed in the MINFILE database, which is the principal source of grade and tonnage information given below.

SKARNS

Most of the 18 or so mineral occurrences in the area that are classified as skarns, largely lead-zinc and copper skarns (G. E. Ray, personal communication, 1993), are developed at the margins of plutons that intrude Quatsino limestone or limestone interbeds near the top of the Karmutsen Formation. The most significant of these is the Caledonia deposit, situated at the eastern extremity of the Wanokana batholith northwest of Quatse Lake, where chalcopyrite occurs in an epidote-garnet-actinolite skarn in Quatsino limestone. Based on underground development, inferred reserves total some 68 000 tonnes grading 704 grams per tonne silver, 6.1% copper, 7.45% zinc and 0.6% lead. Several other skarn occurrences are also enriched in silver and a few contain gold assaying up to 0.3 gram per tonne in grab samples. A skarn occurrence within intra-Karmutsen limestones at the southeastern end of the Quatse stock has also been noted. The limestones here have been recrystallized and

Figure 7. Poles to bedding for Karmutsen Formation; Quatsino Formation; Parson Bay Formation; and Bonanza Group. Contoured using the Schmidt method (3% points per 1% area).

replaced by a coarse-grained diopside-garnet-magnetite exoskarn with minor epidote, tremolite? and calcite, and disseminated chalcopyrite, pyrite and malachite. Locally, centimetre-scale magnetite-rich zones are interlayered with garnet-diopside zones.

PORPHYRY DEPOSITS

Porphyry deposits have been, and continue to be, one of the main exploration targets in the region. The Island Copper mine of BHP Minerals (Canada) Limited is an arc-related porphyry copper-molybdenum-gold deposit hosted by a quartz feldspar porphyry dike of the Island Plutonic Suite and andesitic flows and pyroclastic rocks near the base of the Bonanza Group. The geology and mineralization are described in detail by Cargill *et al.* (1976) and summarized by Perello *et al.* (1989) and Panteleyev and Koyanagi (1993). Briefly, three main stages of alteration and mineralization have been recognized. An early stage represented by a stockworked core of quartz-magnetite-amphibole-sodic plagioclase that grades outward into a biotite-magnetite zone followed by a chlorite zone and an outermost epidote zone; a superimposed, structurally controlled intermediate stage related to the formation of a quartz stockwork and sericite-chlorite-kaolinite alteration assemblages; and a late stage involving generation of hydrothermal breccias under extreme base-leaching conditions resulting in a pyrophyllite-dumortierite-sericite-kaolinite alteration assemblage. The main copper mineralization occurred during the early stage, and was closely followed by the main episode of molybdenum mineralization. The ore minerals, chiefly chalcopyrite and molybdenite with sparse bornite, sphalerite and galena, occur in fractures and locally as disseminations. Pyrite is two to three times as abundant as chalcopyrite, and magnetite is the most abundant oxide mineral. Rhenium is recovered from molybdenite concentrates in reported concentrations of up to 2400 ppm. Reserves were initially estimated at 257 million tonnes grading 0.52% copper, 0.017% molybdenum and 0.22 gram per tonne gold (Perello *et al.*, 1989). Mining began in 1971 and up to the end of June 1993 over 319 million tonnes of ore had been mined with the recovery of over 1 billion kilograms of copper, 25 million kilograms of molybdenum, 32.5 million grams of gold and 262 million grams of silver. The mine is tentatively scheduled to close in 1996.

Large zones of argillic and advanced argillic alteration are associated with porphyry deposits in the western part of the area. The Red Dog stock (described above) is host to a small porphyry copper-molybdenum-gold deposit concentrated in a quartz-magnetite breccia, the remnants of an acid-leached pyrophyllite-kaolinite-quartz "cap", in the central part of the intrusion (Figure 6). Economic minerals include chalcopyrite, molybdenite, bornite and traces of covellite. The deposit

TABLE 2

SOME CHARACTERISTIC ACID-SULPHATE ALTERATION MINERALS IDENTIFIED IN THE BONANZA GROUP BY X-RAY DIFFRACTION*

Mineral	Ideal Formula
Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$
Alunite	$KAl_3(SO_4)_2(OH)_6$
Natroalunite	$(Na>K)Al_3(SO_4)_2(OH)_6$
Zunyite	$Al_{13}Si_5O_{20}(OH,F)_{18}Cl$
Diaspore	$AlO(OH)$
Kaolinite/dickite	$Al_4Si_4O_{10}(OH)_8$
Jarosite	$KFe_3(SO_4)_2(OH)_6$
Rozenite	$FeSO_4{\cdot}4H_2O$
Melanterite	$FeSO_4{\cdot}7H_2O$

* A. Panteleyev, unpublished data

has a drill-indicated reserve of 31.2 million tonnes grading 0.313% copper, 0.446 gram per tonne gold and 0.007% molybdenum (Crew Natural Resources Limited, Prospectus). The Hep and Hushamu porphyry deposits are situated at the margin of the Wanokana batholith (Figure 6). Geological reserves at the Hushamu are reported to be 172.5 million tonnes grading 0.28% copper, 0.34 gram per tonne gold and 0.009% molybdenum. The Hep deposit is reportedly located at the intersection of two shear zones estimated to contain 45 350 tonnes of material with an average grade of 0.80% copper.

ACID SULPHATE ALTERATION AND MINERALIZATION

Hydrothermal alteration and mineralization of the acid sulphate or high-sulphidation type in the Quatsino map area has been described previously by Panteleyev and Koyanagi (1993, 1994). They pointed out that these mineralized systems are entirely hosted by Bonanza volcanic rocks. Their argillic and advanced argillic alteration zones, as modified here, are shown in Figure 6, together with preliminary results of X-ray diffraction studies (Panteleyev, unpublished data). It is clear that the distribution of acid sulphate alteration coincides precisely with the trend of the upper rhyolitic unit of the Bonanza Group. This alteration certainly affects underlying basaltic andesite and andesite flows (unit C, Figure 5) but not the overlying lavas (unit A), with the apparent exception of one locality due west of South McIntosh where a rhyolite dike is exposed. It therefore seems likely that there is a fundamental genetic relationship between the felsic volcanic rocks and the development of acid sulphate alteration assemblages in the Bonanza Group.

The nature and origin of the hydrothermal fluids and the economic and gangue minerals that characterize these systems have recently been summarized by Panteleyev (1992) and placed in the context of specific deposit types that may exist on Northern Vancouver Island. It is evident that magmatic fluids play an important role in generating the extreme base-leaching conditions that characterize these copper-gold-silver mineralizing systems, some of which may have genetic, spatial and temporal relationships to subvolcanic porphyry copper deposits at depth. Alteration minerals commonly found in acid sulphate assemblages and that have been identified in the map area include pyrophyllite, alunite/natroalunite, zunyite, kaolinite, dickite, rozenite, jarosite, melanterite, sericite, illite, paragonite and native sulphur (Table 2; Figure 6). In addition, Panteleyev and Koyanagi (1993) sampled a vein occurrence overlooking Youghpan Creek that contained native gold coexisting with alunite (possibly schlossmacherite, an arsenian variety of alunite). A characteristic feature of this style of alteration is the relatively high abundance of pyrite which is largely responsible for the high acidity of natural drainages in the area (Koyanagi and Panteleyev, 1993, 1994). Felsic flow and pyroclastic rocks containing some 5 to 20% finely disseminated pyrite/marcasite are fairly common, and locally, more massive layers with up to 80% sulphides have been observed.

There is clear textural evidence for the felsic nature of the volcanic protolith at localities scattered throughout the argillically altered upper rhyolitic unit, with the notable exception of Mount McIntosh, where the advanced argillic overprint is strongest. Relict flow laminations and, rarely, flow folds, and pyroclastic textures, including welding, can readily be identified within the widespread argillic alteration at the Wann Knobs and in the Pemberton Hills, as detailed earlier.

Plate 4. Thin, clay-altered rhyolite dike cutting more intensely altered and locally brecciated rhyolite host. Note irregular dike margins and dispersed inclusions of brecciated and altered wallrock. Upper rhyolite (unit B), Bonanza Group, Mount McIntosh (93GNX22-3).

Where primary textures have been obliterated, the rock is reduced to a white-weathering, compact homogeneous microcrystalline mass or a vuggy porous siliceous rock locally infilled with secondary silica and clay minerals.

At Mount McIntosh, destruction of primary volcanic textures is much more complete in a widespread zone of advanced-argillic acid sulphate alteration. Here, pyrophyllite coexists with alunite, zunyite, diaspore and kaolinite, and metallic minerals include abundant pyrite, local enargite and traces of chalcopyrite, covellite, chalcocite and bornite (Figure 6; Panteleyev and Koyanagi, 1993, 1994). A compact to vuggy, microcrystalline silica-clay mottled rock forms extensive outcrops along the drill-road system high on the east side of the ridge. Locally, hydrothermal alteration breccias form at least two generations of narrow (<1 m wide) irregular dike-like bodies that crosscut the mottled siliceous rocks. Relict primary textures, including aphanitic flow breccias and flow laminations, are rarely preserved west of the roads along the crest of the ridge. The variably altered siliceous rocks are intruded locally by thin (<25 cm wide) rhyolitic dikes, some of which

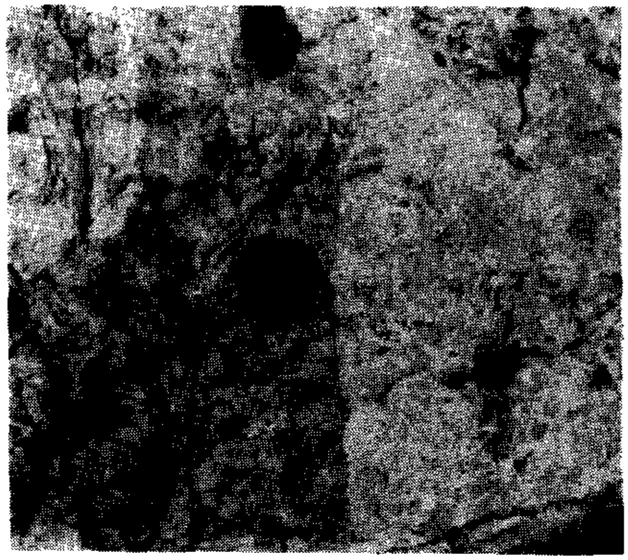

Plate 5. Rhyolite dike with relict flow laminations (left) cut by altered hydrothermal breccia (right), South McIntosh (93GNX21-4).

carry rounded phenocrysts of quartz. Most of these dikes have sharp planar contacts; however, one has an irregular contact and a well-developed flow lamination, and incorporates screens and xenoliths of intensely altered wallrock (Plate 4). These dikes clearly postdate the advanced argillic alteration but appear to have been affected by late-stage argillic alteration, particularly at their margins. Other features of note include small restricted zones of intense quartz stockworking, and open-space fillings incompletely sealed by thinly layered, crustiform silica-hematite precipitates that contour these irregular channelways.

Some of the alteration features described above are also observed in a rhyolite dike intruding andesitic flows west of South McIntosh, and this outcrop provides an instructive record of protolith destruction. The aphanitic dike is 10 metres wide and offset across a high-angle (Tertiary?) fault trending 070. Pervasive hydrothermal alteration and devitrification have preferentially affected the pale greyish green margins of the dike. Flow laminations parallel to the contact are preserved locally in the less altered, darker grey core of the intrusion. These laminar flowage structures are crosscut by breccias with sharp to gradational contacts and angular fragments (<20 cm) of variably rotated rhyolite (Plate 5). Some flow-laminated rhyolite clasts at the margins of these breccias can be pieced back together and into their hostrock, providing clear evidence that brecciation and alteration took place after consolidation and cooling as opposed to during emplacement. These hydrothermal breccias bear a striking resemblance to the late crosscutting breccia dikes at Mount McIntosh.

CHEMICAL EFFECTS: PRELIMINARY OBSERVATIONS

Analytical data for hydrothermally altered rhyolitic protoliths given in Table 1 show variable leaching of base, alkali, and other metals depending on the specific nature and degree of the alteration. Assuming a starting composition of relatively fresh Bonanza rhyolite (*e.g.* analysis 27, Table 1), felsic protoliths at Mount McIntosh exhibit: extreme leaching of sodium, potassium, calcium, magnesium and manganese, and, in this example, iron, with concomitant gains in aluminum, titanium and volatiles (analysis 6, Table 1); and extreme depletion of all metals except titanium which has been added to the rock (analysis 7). Note that in the latter case, and in similarly altered samples near the top of a drill hole in the Pemberton Hills (analyses 18c and d, Table 1), the balance of gains and losses of major element oxides does not require significant introduction of silica into the rock, and the process appears to be one in which leaching of all components takes place with the notable exception of titanium and residual silica. As titanium is clearly mobile in the fluids that generate these acid sulphate alteration assemblages, this constituent cannot be used as a conserved element in attempts to reconstruct the composition of the protolith.

AGE OF THE MINERALIZATION AND ALTERATION: A LOWER JURASSIC EPITHERMAL SYSTEM

There is some evidence to suggest that the acid sulphate alteration and mineralization occurred contemporaneous or penecontemporaneous with extrusion of Bonanza rhyolites. The most direct evidence occurs at Mount McIntosh where rhyolite dikes postdate the advanced argillic overprint. The recognition of flow breccias and flow laminations in the rhyolitic rocks and the presence of open-space fillings indicate that Mount McIntosh most likely represents a rhyolitic flow-dome complex. Rhyolite dikes intruded after the initial phases of dome extrusion represent a renewed period of internal inflation as a new pulse of magma ascended from depth. As noted above, these dikes postdate an episode of epithermal mineralization associated with advanced argillic acid sulphate alteration. As the bulk of the acid sulphate alteration is restricted to the upper Bonanza rhyolite unit, epithermal fluids were either particularly active during this period of felsic subaerial volcanism, or this is simply a reflection of the overall proximity of these rhyolitic rocks to their source vents. If the acid sulphate epithermal systems are indeed linked with porphyry copper mineralization at depth, as the presumed coeval nature of intrusions of the Island Plutonic Suite might suggest, then precious metal deposits transitional between the porphyry and epithermal environments ought to be hosted by rocks stratigraphically beneath the upper rhyolitic unit. In the overall context of Bonanza stratigraphy, as defined here (Figure 5), units C through E would be prime exploration targets for these "transitional" types of deposit. It is also intriguing to note that the two most significant porphyry copper-molybdenum-gold deposits in the area, at Island Copper and Red Dog, have intruded similar stratigraphic levels near the base of the Bonanza Group. Significant mineralization at the Red Dog deposit is intimately associated with a silicified and brecciated host that exibits advanced argillic alteration (pyrophyllite-quartz-kaolinite). Perhaps this siliceous rock represents a residue of extreme acid leaching formed in a "transitional" or epithermal environment that has since been partially engulfed and overprinted by higher level porphyry emplacement and mineralization.

ACKNOWLEDGMENTS

We owe a great debt of gratitude to all those who offered advice and assistance in the field, and participated in informative (sometimes downright lively!) discussions on the geology. John Fleming and Alan Reeves of BHP Minerals (Canada) Limited kindly made available geological compilations and docking facilities at the Island Copper mine; Peter Dasler (Daiwan Engineering Limited) shared his knowledge of the region; Mike Orchard (Geological Survey of Canada) made conodont collections (we hope!); Fabrice Cordey collected radiolaria (or at least "features"); Doug Archibald (Department of Geological Sciences, Queen's University) collected samples for Ar-Ar dating; and Tim Tozer (Geological Survey of Canada) made fossil identifications. We would also like to thank Western Forest Products Limited and Tribune Bay Logging Limited for safe access to the area; Donna Blackwell, Alan Gilmore and Bill Newman (Government Agent in Port Hardy) for logistics and expediting services; and John Newell and Brian Grant for editorial comments. Our sincere appreciation is extended to all those who attended the end-of-season workshop in Port Hardy for stimulating geological discussions, particularly those that took place on the field trip.

REFERENCES

Armstrong, R. L., Muller, J. E., Harakal, J. E. and Muehlenbachs, K. (1985): The Neogene Alert Bay Volcanic Belt of Northern Vancouver Island, Canada: Descending-plate-edge Volcanism in the Arc-trench Gap; *Journal of Volcanology and Geothermal Research*, Volume 26, pages 75-97.

Barker, F., Sutherland Brown, A., Budahn, J. R. and Plafker, G. (1989): Back-arc with Frontal Arc Component Origin of Triassic Karmutsen Basalt, British Columbia, Canada; *Chemical Geology*, Volume 75, pages 81-102.

Bevier, M. L., Armstrong, R. L. and Souther, J. G. (1979): Miocene Peralkaline Volcanism in West Central British Columbia - Its Temporal and Plate Tectonics Setting; *Geology*, Volume 7, pages 389-392.

Bobrowsky, P. T. and Meldrum, D. (1994): Preliminary Drift Exploration Studies, Northern Vancouver Island (92L/6 and 11); *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Cargill, D. G., Lamb, J., Young, M. J. and Rugg, E. S. (1976): Island Copper; *in* Porphyry Deposits of the Canadian

Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 206-218.

Desrochers, A. (1989): Depositional History of Upper Triassic Carbonate Platforms on Wrangellia Terrane, Western British Columbia, Canada; *American Association of Petroleum Geologists*, Bulletin 73, pages 349-350.

Gardner, M. C., Bergman, S. C., Cushing, G. W., MacKevett, E. M. Jr., Plafker, G., Campell, R. B., Dodds, C. J., McClelland, W. C. and Mueller, P. A. (1988): Pennsylvanian Pluton Stitching of Wrangellia and the Alexander Terrane, Wrangell Mountains, Alaska; *Geology*, Volume 16, pages 967-971.

Haggart, J. W. (1993): Latest Jurassic and Cretaceous Paleogeography of the Northern Insular Belt, British Columbia; *in* Mesozoic Paleogeography of the Western United States II, Dunne, G. C. and McDougall, K. A., Editors, *Society of Economic Paleontologists and Mineralogists (Pacific Section)*, Book 71, pages 463-475.

Harland, W. B., Armstrong, R. L., Cox, A. V., Craig, L. E., Smith, A. G. and Smith, D. G. (1990): A Geologic Time Scale 1989; *Cambridge University Press*, Cambridge, England.

Jeletzky, J. A. (1969): Mesozoic and Tertiary Stratigraphy of Northern Vancouver Island, British Columbia (92E, 92L, 102I); *Geological Survey of Canada*, Paper 69-1A, pages 126-134.

Jeletzky, J. A. (1976): Mesozoic and ?Tertiary Rocks of Quatsino Sound, Vancouver Island, British Columbia; *Geological Survey of Canada*, Bulletin 242.

Jones, D. L., Silberling, N. J. and Hillhouse, J. (1977): Wrangellia - A Displaced Terrane in Northwestern North America; *Canadian Journal of Earth Sciences*, Volume 14, pages 2565-2577.

Kerr, D. E. (1992): Surficial Geology of the Quatsino Area (92L/12); *B. C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1992-6, scale 1:50 000.

Kerr, D. E. and Sibbick, S. J. (1992): Preliminary Results of Drift Exploration Studies in the Quatsino (92L/12) and the Mount Milligan (93N/1E, 93O/4W) Areas; *in* Geological Fieldwork 1991, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources,*, Paper 1992-1, pages 341-347.

Kerr, D. E., Sibbick, S. J. and Jackaman, W. (1992): Till Geochemistry of the Quatsino Map Area (92L/12); *B. C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1992-21, scale 1:50 000.

Koyanagi, V. M. and Panteleyev, A. (1993): Natural Acid-drainage in the Mount McIntosh/Pemberton Hills Area, Northern Vancouver Island (92L/12); *in* Geological Fieldwork 1992, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 445-449.

Koyanagi, V. M. and Panteleyev, A. (1994): Natural Acid-drainage in the Red Dog - Hushamu - Pemberton Hills Area, Northern Vancouver Island (92L/12); *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Le Maitre, R. W. (Editor) (1989): A Classification of Igneous Rocks and Glossary of Terms; *Blackwell Scientific Publications*.

Matysek, P. F., Gravel, J. L. and Jackaman, W. (1989): 1988 British Columbia Geochemical Survey, Stream Sediment and Water Geochemical Data, NTS 92L/102I - Alert Bay/Cape Scott; *B. C. Ministry of Energy, Mines and Petroleum Resources*, RGS 23.

Monger, J. W. H., Price, R. A. and Tempelman-Kluit, D. J. (1982): Tectonic Accretion and the Origin of the Two Major Metamorphic and Plutonic Welts in the Canadian Cordillera.; *Geology*, Volume 10, pages 70-75.

Monger, J. W. H., Wheeler, J. O., Tipper, H. W., Gabrielse, H., Harms, T., Struik, L. C., Campbell, R. B., Dodds, C. J., Gehrels, G. E. and O'Brien, J. (1991): Cordilleran Terranes *in* Upper Devonian to Middle Jurassic Assemblages; *in* Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C. J., Editors, *Geological Survey of Canada*, Geology of Canada, Number 4, pages 281-327.

Muller, J. E. (1977): Evolution of the Pacific Margin, Vancouver Island, and Adjacent Regions; *Canadian Journal of Earth Sciences*, Volume 14, pages 2062-2085.

Muller, J. E. and Jeletzky, J. A., (1970): Geology of the Upper Cretaceous Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia; *Geological Survey of Canada*, Paper 69-25.

Muller, J. E. and Roddick, J. A. (1983): Geology Alert Bay - Cape Scott, British Columbia; *Geological Survey of Canada*, Map, 1552A, scale 1:250 000.

Muller, J. E., Cameron, B. E. B. and Northcote, K. E. (1981): Geology and Mineral Deposits of Nootka Sound Map Area (92E), Vancouver Island, British Columbia; *Geological Survey of Canada*, Paper 80-16.

Muller, J. E., Northcote, K. E. and Carlisle, D. (1974): Geology and Mineral Deposits of Alert Bay - Cape Scott Map Area, Vancouver Island, British Columbia; *Geological Survey of Canada*, Paper 74-8.

Nixon, G. T., Hammack, J. L., Hamilton J. V. and Jennings, H. (1993a): Preliminary Geology of the Mahatta Creek Area, Northern Vancouver Island (92L/5); *in* Geological Fieldwork 1992, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 17-35.

Nixon, G. T., Hammack, J. L., Hamilton J. V. and Jennings, H. (1993b): Preliminary Geology of the Mahatta Creek Area (92L/5); *B. C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1993-10, scale 1:50 000.

Panteleyev, A. (1992): Copper-gold-silver Deposits Transitional Between Subvolcanic Porphyry and Epithermal Environments; *in* Geological Fieldwork 1991, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1992-1, pages 231-234.

Panteleyev, A., Bobrowsky, P. T., Nixon, G. T. and Sibbick, S. J. (1994): Northern Vancouver Island Integrated Project; *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Panteleyev, A. and Koyanagi, V. M. (1993): Advanced Argillic Alteration in Bonanza Volcanic Rocks, Northern Vancouver Island - Transitions Between Porphyry Copper and Epithermal Environments (92L/12); *in* Geological Fieldwork 1992, Grant, B. and Newell, J. M., Editors, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 287-293.

Panteleyev, A. and Koyanagi, V. M. (1994): Advanced Argillic Alteration in Bonanza Volcanic Rocks, Northern Vancouver Island - Lithologic Associations and Permeability Controls (92L/12); *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Perello, A., Arancibia, O., Burt, P., Clark, A. H., Clarke, C., Fleming, J., Himes, M. D., Leitch, C. and Reeves, A. (1989): Porphyry Cu-Mo-Au Mineralization at Island Copper, Vancouver Island, B. C.; *Geological Association of Canada, Cordilleran Section*, Porphyry Copper Workshop, Vancouver, April (Abstract).

Riddihough, R. P. and Hyndman, R. D. (1991): Modern Plate Tectonic Regime of the Continental Margin of Western Canada; *in* Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C. J., Editors, *Geological Survey of Canada*, Geology of Canada Number 4, pages 435-455.

Sibbick, S. J. (1994): Preliminary Report on the Application of Catchment Basin Analysis to Regional Geochemical Survey Data, Northern Vancouver Island (92L/SW); *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Sutherland Brown, A. (1968): Geology of the Queen Charlotte Islands, British Columbia; *B. C. Ministry of Energy Mines and Petroleum Resources*, Bulletin 54.

van der Heyden, P. (1991): A Middle Jurassic to Early Tertiary Andean-Sierran Arc Model for the Coast Belt of British Columbia; *Tectonics*, Volume 11, pages 82-97.

Wheeler, J. O. and McFeely, P. (Compilers) (1991): Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America; *Geological Survey of Canada*, Map 1712A, scale 1:2 000 000.

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