Preliminary Geology of the Nimpkish Map Area (NTS 092L/07), Northern Vancouver Island, British Columbia

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INTRODUCTION

Northern Vancouver Island is richly endowed in a variety of base and precious-metal deposits. For example, the Cu-Mo-Au porphyry deposit at the former Island Copper mine (1971–1994) produced approximately 345 million tonnes of ore with average head grades of 0.41 wt% Cu, 0.017% Mo, 0.19 g/t Au and 1.4 g/t Ag (Perello *et al.*, 1995). Other porphyry deposits are known to exist in the region (*e.g.*, Hushamu [MINFILE occurrence 92L 240] and Red Dog [92L 200]; MINFILE, 2005) and, thanks to a recent surge in metal prices, the potential for bringing these and future discoveries into production is currently high.

In order to improve understanding of the geological setting of mineral occurrences and the exploration potential of northern Vancouver Island, a regional mapping project (1:50 000 scale) was initiated this past summer in the Nimpkish map area (Fig. 1). The project encompasses the region between Nimpkish and Bonanza lakes, and extends northeast to Robson Bight and south to the Nimpkish River. The area is contiguous with regional mapping at the same scale completed more than a decade ago in the Quatsino Sound region (discussed below). This paper presents the preliminary results of the 2005 field season. Further details on the mapping and geological setting of the mineral occurrences are presented by Nixon *et al*. (in press).

The Nimpkish sheet covers an area of more than 1000 km^2 with moderate to rugged relief and heavy forest cover except for the higher ridges. Access is provided by an extensive system of active and decommissioned logging roads; however, road coverage is poor in the northeastern part of the project area. Outcrop is generally sparse. Thick deposits of glacial till and outwash typically occupy the main valley bottoms and form veneers on valley slopes. The best exposures are found in roadcuts, along ridge crests and forming bluffs on valley sides, and where streams have incised narrow canyons.

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PREVIOUS WORK

The earliest recorded geological investigations of northern Vancouver Island were made by G.M. Dawson during his pioneering voyage (Dawson, 1887). Early mineral deposit studies were conducted by Dolmage (1919) and Gunning (1930), who carried out the first systematic mapping of the Nimpkish area (Gunning, 1930, 1932, 1938a, b). Hoadley (1953) incorporated much of Gunning's earlier work in his study of the geology and mineral deposits of the Zeballos-Nimpkish area. The most comprehensive reports dealing specifically with the geology and mineral deposits of northern Vancouver Island are those of Muller *et al*. (1974), Jeletsky (1976) and Muller and Roddick (1983). More recently, the results of 1:50 000-scale mapping combined with geochronological and biostratigraphic studies in the Quatsino Sound region have been published in a series of preliminary reports by Nixon and coworkers (Nixon *et al.*, 1993a, b, 1994a, b, 1995a, b; Friedman and Nixon, 1995; Archibald and Nixon, 1995). The lithostratigraphic nomenclature applied to the Nimpkish area (discussed below) draws upon this existing knowledge base.

TECTONIC SETTING AND REGIONAL GEOLOGY

The geology of Vancouver Island is characterized principally by Upper Paleozoic to Lower Mesozoic rocks of the Wrangell tectonostratigraphic terrane, which extends north through the Queen Charlotte Islands into southern Alaska (Fig. 1; Wheeler and McFeely, 1991). Wrangellia was amalgamated with the Alexander Terrane in the Alaska panhandle to form the Insular Superterrane as early as the Late Carboniferous time (Gardner *et al*., 1988), and was accreted to inboard terranes of the Coast and Intermontane belts as late as the mid-Cretaceous (Monger *et al*., 1982) or as early as the Middle Jurassic (van der Heyden, 1991).

At the latitude of the project area, Wrangellia is intruded to the east by granitoid rocks of the Coast Plutonic Complex and fault bounded to the west by the Westcoast Crystalline Complex, part of the basement to Wrangellia, and Pacific Rim Terrane (Wheeler and McFeely, 1991). The relatively low relief and high heat flow of northernmost Vancouver Island reflect tectonism associated with the development 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; Lewis *et al*.,

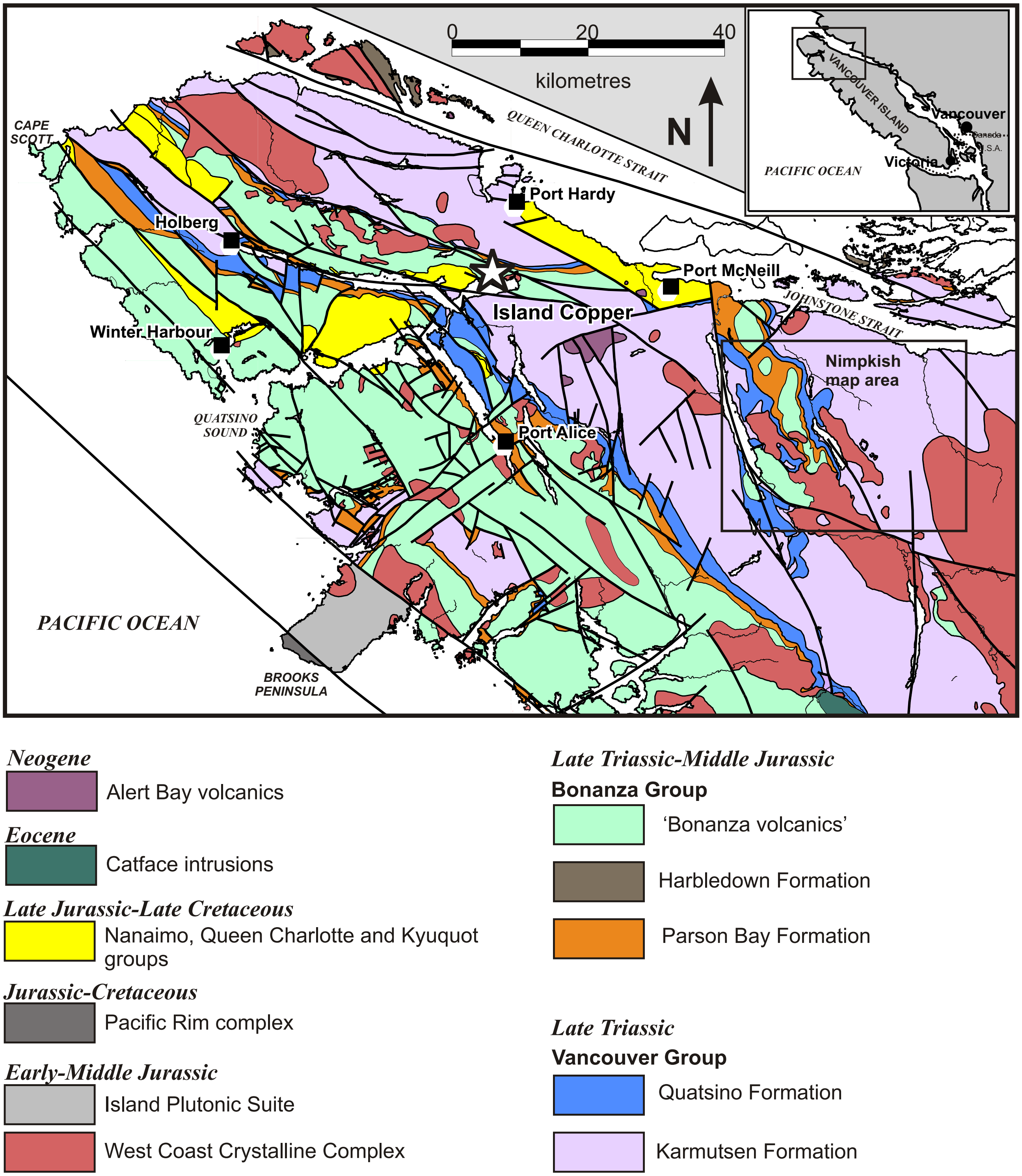

Figure 1. Regional geology of northern Vancouver Island (after Massey *et al*., 2005), showing the location of the Nimpkish map area.

1997). This geological history has resulted in the present crustal architecture: a dominant northwest-trending structural grain manifested by the distribution of major stratigraphic units, faults and granitoid batholiths (Fig. 1). Numerous fault-bounded blocks of homoclinal Early Mesozoic strata generally dip westward (Muller *et al*., 1974). The northeasterly-trending Brooks Peninsula fault zone delineates the southern boundary of the Tertiary extensional regime in the Queen Charlotte Basin. This zone of tectonism also coincides with the southern limit of Tertiary (Neogene) dikes and remnants of effusive volcanism in the region (Armstrong *et al*., 1985; Lewis *et al*., 1997).

STRATIGRAPHIC NOMENCLATURE AND AGE RELATIONSHIPS

The stratigraphic nomenclature proposed for the Alert Bay – Cape Scott map sheet (NTS 092L) by Muller *et al.* (1974), as revised by Muller *et al.* (1981), is shown in Figure 2. Revisions to the Triassic–Jurassic lithostratigraphic nomenclature proposed in this study, shown in Figure 3, are based on previously published and unpublished geochronological and biostratigraphic data for the Quatsino Sound area (Nixon *et al.*, 1993a, b, 1994a, b, 1995a, b; Friedman and Nixon, 1995; Archibald and Nixon, 1995). The age ranges are based on recent improvements to the geological time scale (Palfy *et al*., 2000; Gradstein *et al*., 2004). The preliminary results of recent mapping in the Nimpkish area appear consistent with this new time-stratigraphic framework.

Devonian to Early Permian island-arc volcanic, volcaniclastic and sedimentary rocks that form the basement of Wrangellia (Sicker and Buttle Lake groups; Massey, 1995a, b, c) are not exposed on northernmost Vancouver Island. Lithostratigraphic units diagnostic of Wrangellian stratigraphy form the Triassic tripartite succession of the Karmutsen, Quatsino and Parson Bay formations (Jones *et al*., 1977), which Muller *et al*. (1974, 1981) placed in the Vancouver Group (Fig. 2). The Karmutsen tholeiitic flood basalts are currently interpreted to represent a thick (~6000 m) oceanic plateau formed by the activity of a mantle plume (Greene *et al.*, 2006). The overlying Quatsino limestone represents shallow-water carbonate deposition accompanying subsidence during the waning stages of Karmutsen volcanism (Carlisle and Suzuki, 1974; Muller *et al*., 1974). Sedimentation continued with the deposition of deeper water, impure limestone and siliciclastic rocks of the Parson Bay Formation. The volcanic, volcaniclastic and epiclastic strata of the Bonanza Group, and coeval intrusions of the Island Plutonic Suite, mark a renewed phase of island-arc magmatism and sedimentation (Carson, 1973; Muller *et al*., 1974; Woodsworth *et al*., 1991; Debari *et al*., 1999, 2000).

Lithostratigraphic evidence for including the Parson Bay Formation within the Bonanza Group is based on the occurrence of coarse volcaniclastic deposits, and rarely lavas, of basaltic to rhyolitic composition, intercalated with typical Parson Bay rocks. To the west, for example, in the adjoining Alice Lake map sheet (NTS 092L/06), basaltic lapilli tuff deposits, interpreted as the products of phreatomagmatic eruptions, are found close to the undisturbed contact with the Quatsino Formation and contain angular fragments of the limestone. In a measured section in the same area near Kathleen Lake, volcaniclastic debris flows and juvenile augite, hornblende and plagioclase-bearing crystal tuffs (partly reworked) are constrained by biostratigraphic evidence (conodont faunas and bivalves, including the Late Triassic fauna *Monotis subcircularis* Gabb; Nixon *et al*., 2000) to lie within the uppermost Middle to Upper Norian part of the Parson Bay section. Hornblende in these deposits has provided an Ar^{40}/Ar^{39} plateau age of 199.4 ±3.4 Ma (95% confidence limit; Nixon *et al*., 2000). According to recent time scales (Fig. 3), this date is essentially coincident with the Triassic–Jurassic boundary, and within error of the recommended age for the Norian–Rhaetian stage boundary (Gradstein *et al*., 2004). Some previous workers have also recognized that certain volcanic lithostratigraphic units of the Bonanza Group may be Upper Triassic (Rhaetian?) in age (*e.g*., Hecate Cove Formation; Jeletzky, 1976). Thus, recent biostratigraphic and geochronological evidence favours an Upper Triassic age for the initiation of volcanism in the Bonanza arc. As described below, volcanic breccias and lavas are also observed within typical Parson Bay rocks in the Nimpkish area. Accordingly, the authors have provisionally placed the entire Parson Bay Formation in the Bonanza Group (Fig. 3). Sedimentary strata of the Harbledown Formation, which are partly correlative with the Bonanza Group (Lower Jurassic; Carlisle, 1972; Muller *et al*., 1974), have not been recognized as a separate map unit within the Nimpkish area. Relationships between the Harbledown and Parson Bay formations in the Quatsino Sound area are currently under review.

The youngest isotopic ages for the Bonanza Group have been obtained on subaerial rhyolite lava and ash-flow tuff sequences exposed about 20 km west of the former Island Copper mine (described in Nixon *et al*., 1994a). These rocks have yielded U-Pb zircon dates of *ca*. 169 Ma or Middle Jurassic (mid-Bajocian; dates revised since originally reported by Friedman and Nixon, 1995). Currently, the oldest U-Pb zircon dates are 199–202 Ma (R.M. Friedman and G.T. Nixon, unpublished data, 1992-1996) from rhyolitic lavas on the west coast near Le Mare Lake (Nixon *et al*., 1993a) and south of Winter Harbour near Nose Peak (Nixon *et al*., 1995a). According to the time scale shown in Figure 3, these dates straddle the Triassic–Jurassic boundary. From previous work in the Quatsino Sound region, the authors consider it probable that the earliest juvenile volcanic components of the Bonanza arc may date back at least to the Early Norian, and that earlier (Carnian) fine-grained siliciclastic deposits in the Parson Bay Formation may have a distal arc-derived component.

Age relationships between the Bonanza Group and the Island Plutonic Suite were recently evaluated by Archibald and Nixon (1995) and DeBari *et al*. (1999, 2000), who concluded that the available geochronological and biostratigraphic data favour a comagmatic relationship. Previous dating studies of U-Pb zircon and Ar^{40}/Ar^{39} mineral separates (mainly hornblende and biotite) in granitoid rocks on northern Vancouver Island indicate crystallization ages of 197–167 Ma for the Island Plutonic Suite (Friedman and Nixon, 1995; Archibald and Nixon, 1995 and unpublished data 1992-1996). Thus, the oldest granitoid rocks are earliest Jurassic in age and lie within *ca.* 5 Ma of the oldest isotopic dates (latest Triassic) on volcanic rocks of the Bonanza Group.

STRATIFIED ROCKS

The main lithostratigraphic units in the Nimpkish map area belong to the Upper Triassic Karmutsen and Quatsino formations of the Vancouver Group and Parson Bay Formation of the Upper Triassic–Middle Jurassic Bonanza Group (Fig. 3 and 4). The youngest map units are volcanic and minor intercalated sedimentary rocks exposed in the core of a broad, northerly-trending syncline between Nimpkish and Bonanza lakes (Fig. 4). The latter rocks are tentatively assigned to the informally named, submarine to subaerial 'Bonanza volcanics' of the Bonanza Group (Muller *et al*., 1974, 1981). Younger, Upper Jurassic (?) to Cretaceous strata and Tertiary rocks of the Alert Bay volcanic belt that are exposed further north appear to be absent in the Nimpkish area.

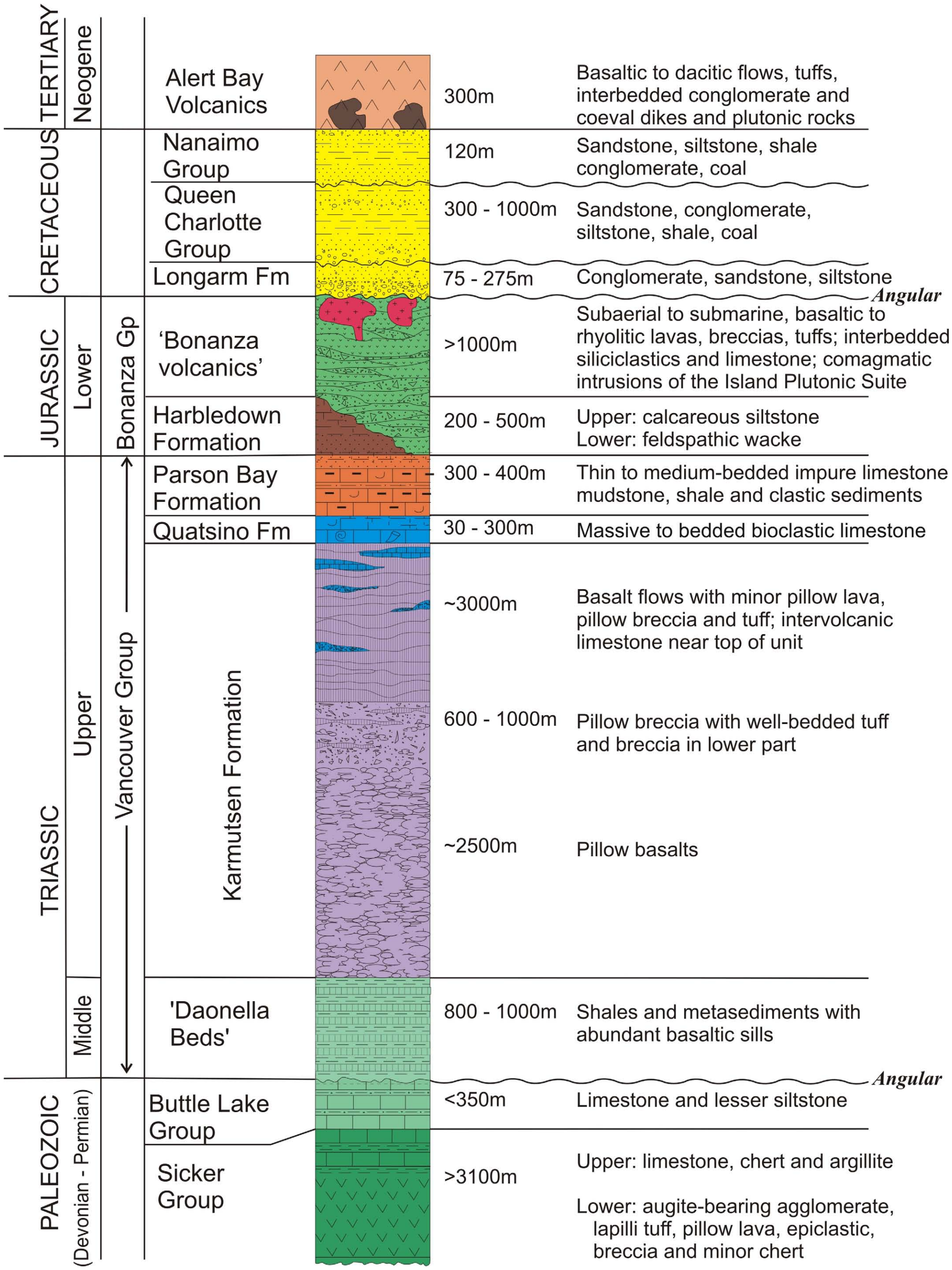

Figure 2. Stratigraphic nomenclature for northern Vancouver Island used by Muller *et al*. (1974, 1981).

Vancouver Group

Only the Upper Triassic Karmutsen and Quatsino formations of the Vancouver Group are exposed in the Nimpkish area.

KARMUTSEN FORMATION

The oldest rocks exposed in the area belong to the Karmutsen Formation, which underlies the northeastern half of the map sheet and the western shore of Nimpkish Lake. The Karmutsen basalts typically form terrain ranging from knobby hills to rugged mountains. The three major subdivisions described to the southeast in the Bute Inlet – Schoen Lake area comprise a lower pillow lava sequence overlain by pillow breccia and 'aquagene' tuff and breccia, in turn overlain by subaerial flows (Carlisle, 1972; Fig. 2). These subdivisions have not been delineated in the Nimpkish area due to limited access and disruption by faults. Layered flow sequences belonging to the youngest Karmutsen subdivision predominate, except in the extreme southwestern corner of the map area and possibly in the poorly accessible northeastern sector toward Robson Bight.

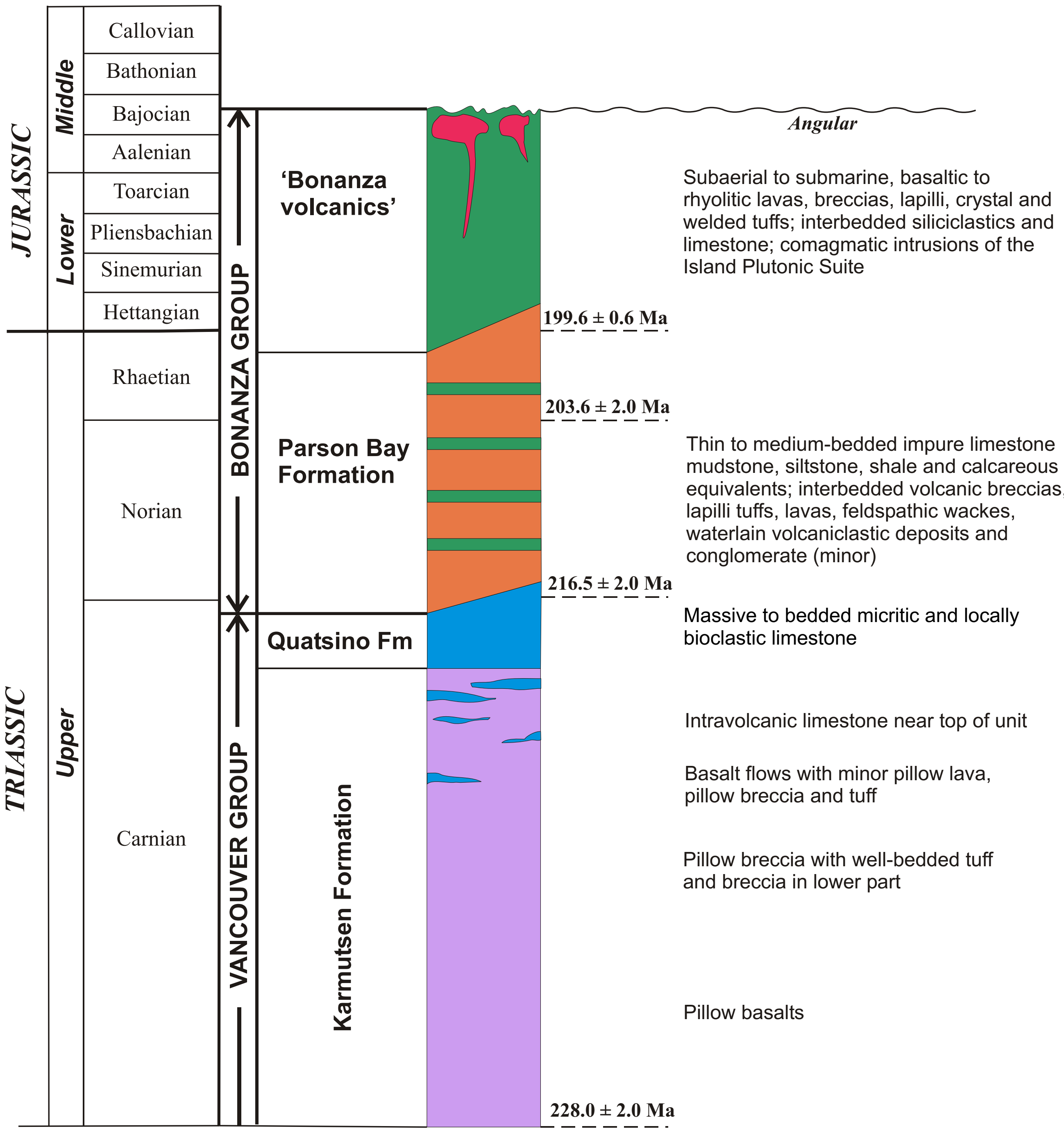

Figure 3. Revised stratigraphic nomenclature for Triassic–Jurassic lithostratigraphic units proposed in this study. The geological time scale is that of Gradstein *et al*. (2004).

Typical Karmutsen basalts are dark grey-green to almost black, aphanitic to plagioclase phyric and locally amygdaloidal. At least two varieties of plagioclase-phyric flows can be recognized: lavas that carry subequant to prismatic plagioclase phenocrysts that are generally 1–5 mm in length and 5–15% by volume; and megacrystic varieties containing blocky to lath-shaped plagioclase crystals 1–2 cm in length and up to 50% by volume (Fig. 5). The plagioclase-rich megacrystic flows generally weather medium to pale grey and locally exhibit strong trachytoid textures. They are confined to the uppermost part of the Karmutsen Formation and therefore serve as useful stratigraphic markers where intra-Karmutsen limestone or the Quatsino Formation is missing (Fig. 4).

The contacts between individual flows are typically sharp and unbrecciated, and there is no evidence for significant erosion or paleosol formation. Primary columnar jointing has not been observed. Certain lavas exhibit a pronounced flow foliation defined by a zone of stretched and flattened amygdules, or by centimetre-scale layering (1–

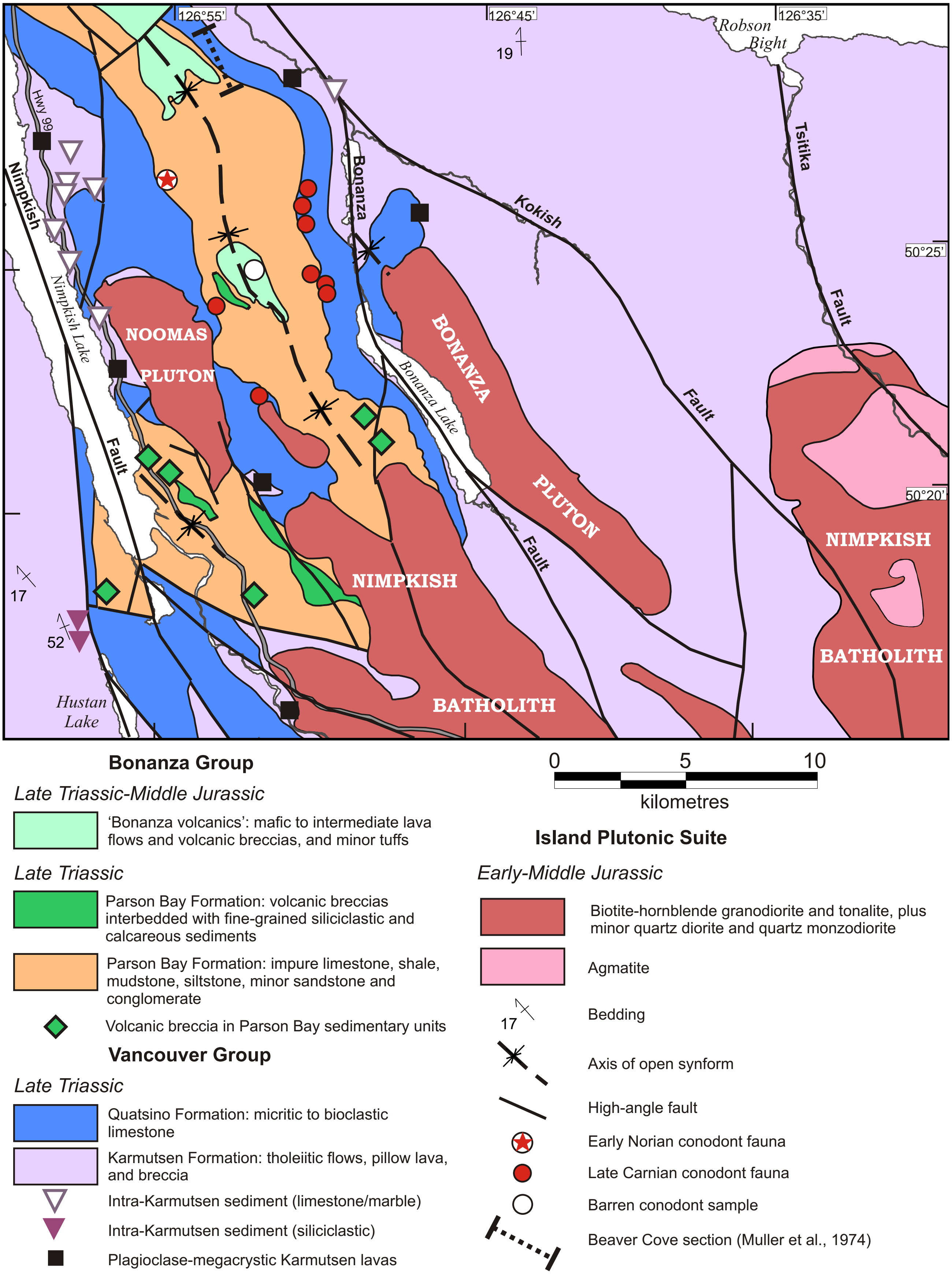

Figure 4. Generalized geology of the Nimpkish map area, northern Vancouver Island.

20 cm thick) of amygdule-rich and amygdule-free lava (Fig. 6).

Locally, significant volumes of volcanic breccia, possibly water-laid, contain matrix-supported clasts (1–10 cm across) of the adjacent lava in a very fine grained, grey-green, comminuted matrix. Where pillows occur, the interpillow material is dark grey to almost black, fine grained and commonly silicified, and coarse pillow fragments are very rare.

Relatively thick sequences of Karmutsen pillow basalt are exposed west of Hustan Lake and the southern tip of Nimpkish Lake in the southwestern corner of the map area. The pillows comprise slightly flattened ellipsoids averaging 0.5–1 m across (Fig. 7). Pillow-fragment breccia deposits occur locally but constitute only a small fraction of the total volume. The breccia comprises pillow fragments up to 0.4 m across in a finer grained hyaloclastite matrix. Rarely, these pillow lavas and breccia units enclose well-bedded, thin (3 m or less) sedimentary horizons consisting of black (fresh) to orange (weathered), thickly laminated to medium-bedded mudstone, shale and, rarely, fine sandstone, all of which can be calcareous and contain thin limestone interbeds. Similar sedimentary rocks were described by Carlisle and Suzuki (1974) intercalated within the upper part of the Karmutsen succession. However, the most common sedimentary units encountered near the top of the flow sequence are concentrated along the west shore of Nimpkish Lake. Here, small pods of pale to medium grey, massive to thinly bedded, micritic intra-Karmutsen limestone up to 4 m thick mark a transition to the overlying Quatsino Formation (Fig. 4).

In thin section, phenocrysts of calcic plagioclase in Karmutsen basalt are partly replaced by sericite, epidote and clay minerals, and fine-grained chlorite – opaque mineral products generally replace former glass inclusions. Clinopyroxene forms either intergranular subhedral crystals or anhedral subophitic–ophitic grains, rarely up to 2 mm in length, enclosing plagioclase laths in the groundmass. Certain flows are distinctly enriched in clinopyroxene and, in some cases, basalt with coarsely ophitic textures may represent high-level sills. Euhedral to granular Fe-Ti oxides are a common primary accessory phase and account for the strongly magnetic character of many lavas. Amygdaloidal zones tend to be concentrated close to flow tops and near the chilled margins of pillows.

The effects of low-grade metamorphism, ranging from zeolite to prehnite-pumpellyite facies, are well documented in the Karmutsen Formation (*e.g.*, Surdam, 1973; Greenwood *et al*., 1991). Numerous veins and amygdules are commonly filled with quartz, potassium feldspar, epidote, chlorite, carbonate, clay minerals and zeolites. Interpillow material may be almost totally replaced by one or more of these minerals, and pillow-fragment breccias locally contain replacement pods of coarse calcite crystals (up to 2 cm). Veins and diffuse zones of secondary silicate-carbonate may contain finely crystalline pyrite, which may form layers up to 1 mm thick within rare interbedded sedimentary rocks. Some joints and fractures are coated with acicular actinolite, which may reflect localized greenschist-facies conditions due to elevated temperatures of hydrothermal fluids influenced by granitoid emplacement. Strong alteration of Karmutsen basalt to epidote-amphibolite assemblages is usually found close to intrusive contacts with the Island Plutonic Suite, as documented elsewhere (Kuniyoshi and Liou, 1976).

Figure 5. Prismatic and subequant plagioclase megacrysts in a Karmutsen Formation flow, Kinman Creek (locality 05GNX-6-8-1); pencil magnet is 12 cm in length.

QUATSINO FORMATION

The Quatsino Formation is well exposed east and south of Nimpkish Lake, where it is intruded by granitoid rocks of the Island Plutonic Suite, and in the higher ground border-

Figure 6. Amygdaloidal layering in Karmutsen Formation basalt flow just below the base of the Quatsino Formation limestone, northeastern shore of Nimpkish Lake (locality 05MEL-1-7-1).

ing Bonanza Lake, where it forms high cliffs. Around Bonanza Lake, Quatsino limestone reaches a thickness of about 350 m, comparable to that estimated by Muller and Rahmani (1970) in the Beaver Cove section (~320 m) near the northern edge of the map area (Fig. 4). This unit is much thicker to the west in the vicinity of Alice Lake (~750 m) but thins dramatically farther west on the coast around Klaskino Inlet (approx. 30–40 m; Muller *et al*., 1974; Nixon *et al*., 1993a).

The Karmutsen-Quatsino contact is exposed in roadcuts just north of Bonanza Lake near kilometre 18 on the main logging road. Here, massive grey limestone rests directly on dark grey-green, aphanitic to sparsely plagioclase-phyric, amygdaloidal basalt. The contact is sharp and appears conformable, but likely represents a nondepositional unconformity (paraconformity). A 1 m thick zone of epidote alteration is coincident with the contact. Local lenses and pods of intra-Karmutsen limestone, lithologically similar to the Quatsino, are found within flow sequences just below the basal contact and mark a transition to shallow-marine conditions.

Figure 7. Karmutsen Formation pillow lavas with interpillow quartz, west of Hustan Lake in the southwestern corner of the map area (locality 05GNX-20-3-1); hammer is 35 cm in length.

The lower part of the Quatsino Formation is typically a dark to medium grey, predominantly massive, fetid micritic limestone that weathers pale grey to white where recrystallized to marble. Stylolites are extremely common and, in many cases, are the only structure present. Ammonites have been collected at several localities but are too poorly preserved to be identified.

The uppermost part of the Quatsino Formation is generally composed of thinly laminated to medium or thickly bedded micrite to (rarely) calcarenite sequences that locally contain laminae enriched in bioclastic debris. Normally graded beds are observed locally and attest to deposition by the action of turbidity currents. Transported shell fragments, largely gastropods up to 1 cm across and thin-shelled pelecypods up to several centimetres across (predominantly *Halobia* sp.), occur in both the more massive and the well-bedded horizons but are more common near the top of the unit. Locally, dark grey to black chert concretions are present and some sequences exhibit pervasive silicification.

The Quatsino Formation in the Nimpkish area has undergone extensive reconstitution to a predominantly white and pale grey marble and, locally, dark grey and green varieties, due to the action of hydrothermal fluids apparently driven by heat from the granitoid bodies. In the vicinity of intrusive contacts, a dark grey and white layering, subparallel to bedding in some cases, is conspicuous in areas of skarn development (discussed below). Finely disseminated sulphide minerals and thin (<1 mm) stringers of pyrite are also found in these zones.

Bonanza Group

Lithostratigraphic units of the Bonanza Group in the Nimpkish area, as defined earlier in this report, include the Upper Triassic Parson Bay Formation and the informally named Upper Triassic to Middle Jurassic 'Bonanza volcanics'. As described below, volcanic rocks occur as both individual beds and mappable units within the mixed carbonate-siliciclastic Parson Bay sedimentary sequences. It is clear from the textures and mineralogy of the volcanic constituents that most, if not all, of these deposits represent the products of renewed volcanic activity and therefore record the encroachment and initial phases of Bonanza arc volcanism.

PARSON BAY FORMATION

The Parson Bay Formation is exposed in the core of a northerly-trending syncline in the high ground between Nimpkish and Bonanza lakes, and at the south end of Nimpkish Lake in a region of low to moderate relief. The thickness of this unit is difficult to estimate due to poor exposure combined with localized internal structural disruption and a plethora of hypabyssal dikes and sills that invade these rocks. In the Alice Lake area to the west, Muller *et al*. (1974) estimated a true stratigraphic thickness of about 600 m, whereas only the basal 50 m of Parson Bay strata are recorded in their Beaver Cove section (Fig. 4).

QUATSINO – PARSON BAY TRANSITION

The contact with the underlying Quatsino Formation limestone is conformable and sharply gradational to transitional over widths of 0.5–5 m. This thinly bedded interval is generally marked by intercalations of pale grey–weathering Quatsino limestone and dark grey, impure (siliceous to sandy) limestone, calcareous mudstone and siltstone, and minor, locally fossiliferous (*Halobia* sp.) black shale.

The age of the Parson Bay – Quatsino contact in the Nimpkish area has been established from collections of conodont fauna identified by M.J. Orchard, Geological Survey of Canada. Sample locations are plotted in Figure 4 where their age assignments are indicated. Most of the samples were collected in the northwestern part of the map area on both flanks of the major syncline. Micritic and impure limestone beds from the uppermost Quatsino and lowermost Parson Bay formations, including strata at several localities within 3–20 m of the contact, yield Late Carnian conodont faunas. A single site in the northeast, where Parson Bay rocks are tightly folded and faulted, has produced an Early Norian fauna. Thus, the Quatsino – Parson Bay transition in the Nimpkish area may confidently be placed within the Late Carnian, possibly close to the Carnian–Norian boundary. This contact is regionally diachronous because, to the west in the Alice-Kathleen lakes area, it is straddled by late Early Norian conodont faunas (Nixon *et al*., 2000), and on the west coast is restricted once more to the Carnian, according to ammonite collections summarized by Muller *et al*. (1974).

SEDIMENTARY STRATA

Typical Parson Bay sedimentary rocks include grey to black, thinly laminated to thickly bedded, impure micritic limestone, mudstone, siltstone, shale, and grey-brown to pale buff, fine to coarse-grained feldspathic sandstone. Locally, thin (<5 cm), ochre to pale grey–weathering clay-rich beds may reflect layers rich in tuffaceous (vitric?) material. Clastic beds are commonly calcareous and shale beds may be distinctly carbonaceous; graphite commonly occurs where the latter rocks are cut by faults. Bedding is predominantly planar, and rare wavy laminations in limestone possibly represent the vestiges of algal mats. Certain beds are strongly silicified and pyritic, or impregnated by finely disseminated hematite, and finely disseminated diagenetic pyrite is widespread. Localized bleaching and recrystallization of impure limestone to marble occurs near intrusive contacts with the Island Plutonic Suite.

In the lower part of the Parson Bay Formation, thin-shelled pelecypods, tentatively identified as *Halobia* sp. (Carnian to Middle Norian), are commonly found in the fine-grained siliciclastic beds and are especially abundant in certain shaly horizons. Higher in the stratigraphy, bivalves, tentatively identified as *Monotis* sp. (Late Norian), are locally abundant in black fissile shale. Most of these strata probably represent a low-energy, shallow-marine environment, although mudstone at one locality exhibits desiccation cracks, which is indicative of intertidal conditions.

Volcanogenic rocks, including feldspathic wacke, breccia and rare conglomeratic beds, are a distinctive though subordinate component of the Parson Bay succession in the Nimpkish area (Fig. 4). These deposits are intercalated with typical, and locally fossiliferous, Parson Bay strata, and were obviously deposited in the same shallow-marine environment.

VOLCANIC ROCKS

A variety of bedded volcaniclastic deposits, including volcanic wacke and lithologically diverse breccia and minor lavas, is found at widely dispersed localities within the Parson Bay Formation. Some are mappable units of volcanic breccia, lava and interbedded sedimentary strata; others form more localized deposits at the scale of a bed, or thin sequence of beds, within the stratigraphic succession (Fig. 4).

Two northwesterly-trending volcanic sequences occur near the southern end of Nimpkish Lake and appear to sit conformably within the Parson Bay succession. The western sequence contains thickly bedded volcanic breccia, medium-bedded feldspathic wacke, laminated siltstone and massive lavas. The dark grey-green breccia contains poorly sorted, angular to subangular andesitic clasts (<1.5 cm) in a fine-grained plagioclase-bearing matrix. The clasts show similar textures: plagioclase microlites are set in a clay-sericite-altered and devitrified volcanic glass. Their matrix-supported character and preferred orientation suggests deposition by turbidites. The associated lavas are finely amygdaloidal, plagioclase-phyric andesite. Euhedral to subhedral plagioclase phenocrysts and glomerocrysts (<4 mm across and up to 15 vol%) are set in a devitrified and clay-sericite-altered glassy groundmass containing microlitic plagioclase. Irregular amygdules are lined with quartz and infilled with chlorite. Thin beds of water-laid volcanic breccia along strike to the northwest (Fig. 4) contain two basaltic clast types: angular to subangular lithic clasts with large (<5 mm) euhedral–subhedral plagioclase phenocrysts, and clasts enclosing euhedral clinopyroxene (<2 mm) that shows pronounced normal zoning. These deposits are also associated with feldspar-bearing and lithic-rich volcanic wacke.

The eastern volcanic sequence is partly fault bounded, and its exact stratigraphic position is uncertain. Although placed in the Parson Bay Formation, it may locally represent the base of the ‘Bonanza volcanics’. The dominant rock types are variably reworked, dusky red to dark grey-green volcanic wacke and breccia. Two end-member types of monolithic breccia have been identified, both containing angular to subrounded volcanic clasts typically less than 1 cm across. Felsic volcanic breccia contains fragments with euhedral to subhedral phenocrysts (<3 mm) of plagioclase, minor euhedral mafic microphenocrysts (<0.5 mm) pseudomorphed by chlorite, and trace amounts of resorbed to subhedral quartz set in a devitrified glassy groundmass free of plagioclase microlites. Their mafic counterparts have clasts that are generally crowded with plagioclase microlites enclosed in a nearly opaque, oxide-charged groundmass. In one sample, these clasts contain subhedral phenocrysts of clinopyroxene with few feldspar microlites. The volcanic wacke is coarse to medium grained, thickly bedded to laminated, enriched in lithic fragments and plagioclase, and contains detritus of mixed parentage. Well-bedded sequences may be normally graded and locally contain worm burrows. Minor intercalated sedimentary strata include calcareous mudstone, siltstone and limestone.

Small outcrops of mafic volcanic breccia occur close to the contact with Quatsino limestone between Hustan and Nimpkish lakes (Fig. 4). Angular to subrounded, lapilli-size basaltic clasts are enclosed in a poorly sorted, massive deposit. The clasts are weakly amygdaloidal and sparsely feldspar porphyritic. Plagioclase microlites in the groundmass are set in an altered and recrystallized volcanic glass studded with granular secondary sphene. The fine-grained clastic matrix is cemented and partly replaced by carbonate, potassium feldspar, quartz, epidote, minor prehnite and opaque oxides. The clasts may represent formerly palagonitized hyaloclastite material redeposited in the shallow-marine environment.

West of Bonanza Lake, virtually monolithic volcanic breccia contains clasts of strongly amygdaloidal basalt with euhedral and sector-zoned clinopyroxene phenocrysts (<1 mm) and glomerocrysts (<2 mm) set in a devitrified glass rich in flow-aligned plagioclase microlites. The clastic matrix contains similar basaltic material, opaque oxides, trace subhedral hornblende and devitrified glass shards. Clinopyroxene phenocrysts are locally intergrown with a mafic mineral (olivine?) pseudomorphed by opaque oxide, carbonate, and cryptocrystalline serpentine-actinolite (?). These massive beds are overlain by thin to medium-bedded pyritic siltstone and lithic-crystal tuffaceous wacke.

Thin volcaniclastic sequences are interbedded with typical Parson Bay rocks on the western flank of the northerly-trending syncline east of Nimpkish Lake, and lie stratigraphically below the base of the central outlier of 'Bonanza volcanics' (Fig. 4). Dark grey-green, bedded volcanic breccia and buff-weathering feldspathic-lithic wacke are intercalated with dark grey calcareous mudstone and siltstone. Locally, dewatering structures are well developed in the sandstone and mudstone (Fig. 8). The volcanic breccia contains angular to subrounded basaltic clasts mineralogically and texturally similar to those observed in the overlying 'Bonanza volcanics' (described below). The transition from marine sedimentary strata to predominantly volcaniclastic deposits, which defines the base of the 'Bonanza volcanics' at this locality, appears conformable.

Figure 8. Well-developed load casts with ball and flame structures in calcareous mudstone – feldspathic lithic wacke sequence near top of Parson Bay Formation and just below the 'Bonanza volcanics' unit, central part of core of major syncline (locality 05MEL-22-21-1); hammer is 35 cm in length.

'BONANZA VOLCANICS'

In the Nimpkish area, the 'Bonanza volcanics' conformably overlie shallow-marine sedimentary strata of the Parson Bay Formation. The base of this map unit is taken as that point in the stratigraphic column at which volcanic rocks, either clastic or lavas, become dominant. Due to the rapidly changing nature of volcanic environments, particularly those straddling the land-water interface, lateral facies variations are expected to be diverse and abrupt. Thus, the base of this predominantly volcanic succession is anticipated to be diachronous and likely to be defined by different volcanic rocks in different areas. Furthermore, where sedimentary and volcanic rocks are interbedded and exposure is limited, as in the study area, this contact may be difficult to define precisely. This problem is further compounded by the superabundance of subvolcanic dikes and sills that intrude the Parson Bay succession.

The aerial extent of 'Bonanza volcanics' in the Nimpkish map sheet has been significantly reduced in comparison to earlier mapping (Muller *et al*., 1974; Muller and Roddick, 1983). This appears to be a direct consequence of adopting the above definition for the 'Bonanza volcanics', since Muller *et al*. (1974) placed the base of this unit where they encountered the first occurrence of volcanic breccia or lava in the stratigraphic succession. Since only the lowermost part of the 'Bonanza volcanics' appears to be preserved, their thickness in the Nimpkish area cannot be meaningfully estimated. However, based on a measured section near Cape Parkins at the entrance to Quatsino Sound, the average thickness of the volcanic succession is estimated to be 2600 m (Muller *et al*., 1974).

The 'Bonanza volcanics' in the study area are preserved in the northern and central sectors of the northerly-trending syncline between Nimpkish and Bonanza lakes (Fig. 4). Similar volcanic rocks exposed farther south in a structurally complex area near the western margin of the Nimpkish Batholith have tentatively been assigned to the Parson Bay Formation (discussed above). Lava flows predominate in the north and volcanic breccia units in the south; intercalated sedimentary strata are a minor component of both packages.

The northern outlier of 'Bonanza volcanics' is composed of pale grey to buff-weathering, massive, aphanitic to porphyritic basaltic lavas and minor fine-grained sedimentary rocks. The basalts are dark green-grey to reddish grey or maroon lavas that generally carry phenocrysts of pyroxene and rarely plagioclase, and commonly exhibit amygdaloidal textures. In thin section, subhedral phenocrysts (<1 mm) and monomineralic intergrowths (<4 mm) of clinopyroxene are set in a fine-grained groundmass of plagioclase, granular pyroxene and opaque oxides partially altered to clay and sericite. Some lavas contain mafic phenocrysts (olivine or orthopyroxene) completely pseudomorphed by microcrystalline oxides, chlorite and serpentine (?). Amygdules are commonly filled with chlorite, epidote, quartz, carbonate and zeolite.

The associated sedimentary rocks are dark grey to black fissile shale and thinly laminated to medium-bedded mudstone with poorly preserved bivalve fragments. Multiple thin basaltic dikes (<2 m in width) intrude the sedimentary strata but commonly cannot be seen to cut the overlying basalt. At one locality, the dense, bulbous base of the overlying lava clearly transects underlying shale without significant deformation. Rare internal flow structures have been observed, but no definitive flow contacts with surrounding sedimentary strata were found. The textures are clearly indicative of high-level emplacement, and these rocks may represent the roots of a small volcanic complex that preserves both intrusive and extrusive facies. The authors have therefore tentatively included this complex as a stratigraphic component of the 'Bonanza volcanics'.

The central outlier of 'Bonanza volcanics' is composed of basaltic volcanic breccia and interbedded marine sedimentary rocks. The breccia is yellowish to purplish brown or very pale grey weathering and dark grey-green on fresh surfaces. Angular to subrounded lapilli-size clasts in the massive to crudely bedded coarser breccia may reach 8 cm across; angular blocks up to 1 m in length are rarely observed. Maximum clast size in the finer grained deposits rarely exceeds ~1 cm and grades down into sub-millimetresize fragments. The breccia ranges from framework to matrix-supported types and is monolithic to weakly heterolithic with sparse, angular to subangular fragments of mudstone, wacke and limestone. The finely comminuted matrix is commonly cemented by carbonate and prehnite, and locally silicified. Most outcrops of coarse volcanic breccia show little sorting or bedding. However, thin intervals of finer grained, variably sorted volcanic breccia are generally well bedded, and locally exhibit trough-shaped bedding (Fig. 9). Intercalated with the volcanic breccia are pale grey to buff-weathering, dark grey to black, thinly laminated to medium-bedded mudstone, shale and limestone, and subordinate feldspar-lithic sandstone. Some clastic beds are calcareous or silicified, and locally yield poorly preserved fossils.

In thin section, basaltic clasts in the breccia commonly show amygdaloidal textures with carbonate and prehnite infillings, and contain abundant flow-aligned plagioclase microlites (<0.5 mm) and sparse clinopyroxene set in a groundmass of finely crystalline plagioclase, opaque oxides and grey-brown, clay-carbonate-altered devitrified glass. The interbedded sandstone is moderately to poorly sorted volcanic wacke rich in euhedral to anhedral and broken plagioclase and small (<2 mm) basaltic clasts mineralogically similar to their host volcanic breccia.

Although the carbonate and siliciclastic beds intercalated with the volcanic breccia are lithologically similar to the Parson Bay strata, these rocks have been provisionally placed within the 'Bonanza volcanics'. This assignment was influenced by the predominance of volcanic rocks and, though by no means definitive, the lack of conodont fauna in a single sample of interbedded limestone (Fig. 4).

The textural features of basaltic clasts in the breccia, specifically their amygdaloidal character, former glassy groundmass and hyalopilitic fabric displayed by plagioclase microlites, indicate that they formed by fragmentation of lavas flows and were deposited in a near-vent environment. Certain matrix-supported deposits were clearly emplaced by mass flowage. The clast-supported breccia is more difficult to interpret, but possible emplacement mechanisms include deposition by normal epiclastic processes and explosive hydromagmatic activity.

INTRUSIVE ROCKS

All the major intrusions in the Nimpkish area belong to the Island Plutonic Suite; the vast majority of the minor intrusive bodies in the Nimpkish area are apophyses of these granitoid rocks or high-level basaltic to rhyolitic dikes and sills related to Bonanza volcanism.

Island Plutonic Suite

Granitoid intrusions of the Island Plutonic Suite underlie significant tracts of terrain in the southern half of the map area and form the northern termination of the northwesterly-trending Nimpkish batholith and its satellite plutons (Carson, 1973; Muller *et al*., 1974). Conventional K-Ar dates on hornblende and biotite from granitoid rocks in the Nimpkish map sheet have yielded isotopic ages of *ca.* 147–173 Ma (Wanless *et al.*, 1967, 1968, 1974; Breitsprecher and Mortensen, 2004). However, the reliability of these older K-Ar dates and their significance in terms of constraining the age of crystallization have been questioned (Archibald and Nixon, 1995; DeBari *et al.*, 1999, 2000). A more recent U-Pb zircon date of 168.6 ±5.6 Ma (95% confidence level) was reported by DeBari *et al.* (1999) for a sample of hornblende-biotite quartz diorite from the Nimpkish Batholith collected in a roadcut on Highway 19 approximately 5 km beyond the southeastern corner of the Nimpkish map sheet. This date is comparable to U-Pb and Ar^{40}/Ar^{39} dates on zircon and hornblende, respectively, which have been obtained for some of the youngest members of the Island Plutonic Suite on northern Vancouver Island (Friedman and Nixon, 1995; Archibald and Nixon, 1995).

In the Nimpkish area, intrusions of the Island Plutonic Suite are buff to pale grey or grey-green-weathering, medium to coarse-grained, heterogeneous granitoid bodies with equigranular to inequigranular or weakly porphyritic textures. According to the IUGS modal classification (LeMaitre, 1989), the principal rock types (estimated visually) are hornblende and biotite-bearing granodiorite and tonalite, with minor quartz diorite, diorite, granite and quartz-feldspar and potassium feldspar-megacrystic porphyry. Quartz forms anhedral, interstitial grains in the granitoid and rounded to subhedral phenocrysts in the porphyry. Euhedral megacrysts of subequant potassium feldspar (<2 cm) characterize a minor granite phase located near the southwestern margin of the eastern Nimpkish Batholith. Weakly chloritized mafic minerals, hornblende and biotite, generally occur in subequal proportions and constitute 5–15 vol% of the granodiorite-tonalite suite and up to 25 vol% of the dioritic rocks. Anhedral to euhedral bi-

Figure 9. Lenticular bedding in mafic, moderately sorted, water-laid volcanic breccia (cemented by calcite and zeolite) near the base of the 'Bonanza volcanics' unit in central part of core of major syncline (locality 05MEL-21-3-1); hammer is 35 cm in length.

otite crystals locally occur as well-developed books (<6 mm), and hornblende is generally prismatic and more abundant in the dioritic rocks. Locally, the Noomas pluton contains subhedral hornblende crystals up to 1 cm; and biotite is the dominant mafic constituent in the Bonanza pluton. A few samples of the latter intrusion exhibit poorly developed micrographic to granophyric textures. Colourless clinopyroxene crystals are rare and usually occur as resorbed relict grains within hornblende. Accessory minerals include Fe-Ti oxides, apatite and zircon. Alteration assemblages involve chlorite, epidote, sericite, carbonate, hematite, sphene and clay minerals, and minor disseminated pyrite.

Contacts with the country rock are generally sharp and steeply inclined to vertical. Locally, planar to irregular vein networks are well developed in hostrocks and some contacts are defined by faults. Dark grey-green, rounded to elongate dioritic xenoliths, typically less than 10 cm across and rarely reaching 1 m, are a common though generally sparse constituent of all plutons. Locally, xenolith-rich zones exhibit a pronounced magmatic flow foliation. In the eastern part of the Nimpkish batholith, extensive zones of agmatite are developed in Karmutsen wallrocks (Fig. 4). The agmatite involves subrounded to angular blocks (>1 m) of dark green-grey, aphanitic Karmutsen basalt set in a net-veined granitoid mesostasis. Although the xenoliths are amphibolitized and hornfelsed, original amygdaloidal textures are locally preserved. The occurrence of agmatite zones well within the batholith most likely indicates proximity to the roof.

Minor Intrusions

Dikes and sills (approx. 0.1–20 m in width) associated with the emplacement of volcanic sequences in the Bonanza Group cut older rocks of the Vancouver Group. They are typically fine grained and range in composition from basalt to rhyolite. The basaltic to andesitic intrusions are by far the most abundant. Some dikes branch repeatedly to form complex geometries without any deformation of adjacent bedding. Sill-like intrusive geometries are preferentially developed in the Parson Bay rather than the Quatsino and Karmutsen formations, presumably reflecting the well-bedded nature and lower lithostatic pressure of this part of the Bonanza Group at the time of intrusion.

The basaltic to andesitic intrusive rocks are dark grey-green to black, buff to pale green-grey-weathering rocks with aphanitic to porphyritic textures. These intrusions have well-developed chilled margins and commonly exhibit amygdaloidal interiors where amygdules are locally elongated to define a pronounced flow fabric parallel to their contacts. The porphyritic dikes generally carry euhedral to subhedral phenocrysts of plagioclase (<4 mm) that form up to 15 vol% of the rock. Subhedral clinopyroxene phenocrysts (up to 8 mm in size and 5 vol%) may coexist with feldspar, or represent the sole phenocryst phase, in which case glomeroporphyritic textures are common. The groundmass is typically very fine grained and usually carries devitrified and altered glass impregnated with opaque oxides.

The felsic intrusions are aphanitic to rarely feldspar phyric and may exhibit a marked flow lamination adjacent to their contacts. Dike interiors generally lack this fabric. Porphyritic intrusions contain sparse subequant plagioclase up to 3 mm in length and constituting up to 2 vol% of the rock. Many felsic dikes are intensely weathered and altered to assemblages of quartz, epidote, chlorite, carbonate, hematite, limonite and zeolite (?); pyrite may form up to 5 vol% of the rock.

Many of the dikes exploit fault zones where postemplacement motion has resulted in the growth of slickenfibres of secondary minerals, commonly epidote and quartz. These minerals, together with carbonate, zeolite, albite (?) and potassium feldspar (rare) are the most common vein minerals.

Minor apophyses of the Island Plutonic Suite are medium to coarse grained, equigranular to porphyritic, and dioritic to tonalitic. These dikes and sills range in thickness from less than 10 m to greater than 100 m. Most of the intrusions are hornblende diorite (locally clinopyroxene-bearing) or quartz diorite, leucocratic tonalite and quartz-plagioclase (±potassium feldspar) porphyries. Biotite and hornblende are the principal ferromagnesian minerals and typically constitute less than 5 vol% of the more leucocratic rock types and 15 vol% or more of the dioritic intrusions. Alteration minerals include chlorite, sericite, epidote, chlorite, sericite, actinolite and clay minerals. Silicification is locally pervasive and usually accompanied by minor disseminated pyrite.

The porphyritic rocks carry phenocrysts (<5 mm) of subequant plagioclase and resorbed quartz set in a microcrystalline quartzofeldspathic groundmass. Some display prominent macroscopic quartz-eye textures. A rare variety of granitic dike contains euhedral blocky megacrysts (1–2 cm in length) of potassium feldspar. Pale grey tonalite dikes at the southwestern margin of the Noomas pluton, just south of a large screen of Quatsino limestone, exhibit large (<10 cm in length) elongate gas cavities (miarolitic) infilled with coarsely crystalline dark green epidote, clearly indicative of high-level emplacement (Fig. 10).

STRUCTURE

The Nimpkish map area is underlain by a southwesterly to westerly-facing, moderately dipping, homoclinal succession cut by major high-angle faults trending northerly to northwesterly. This succession lies on the western flank of a major, northerly-trending anticlinal structure, the ‘Victoria arch’ (Muller *et al*., 1974), cored by Paleozoic basement rocks. This structure continues south as the Buttle Lake anticlinorium (Monger and Journeay, 1994).

The major faults are generally hidden by lakes and till-covered valleys but marked by strong lineaments. The Nimpkish-Hustan and Bonanza faults bound a down-thrown block containing the youngest stratigraphic units (‘Nimpkish block’ of Muller *et al*., 1974). The amount of displacement by faulting is not well constrained. However, judging from the prevalence of shallowly dipping slickenfibres on fault planes throughout the area, the sense of motion was oblique slip.

The ‘Nimpkish block’ contains the axis of a major north-northwesterly-trending synform that preserves the Parson Bay Formation and the lowermost part of the ‘Bonanza volcanics’. The strata on the flanks of this open fold dip moderately (20–30°) toward the core. Superimposed on this synclinal structure, and preferentially developed in the well-bedded sequences of the Parson Bay Formation, are tight, locally chevron-style folds, one to several metres in amplitude with upright to recumbent or overturned attitudes. In outcrops with adequate exposure, these folds form discrete packages bounded by low-angle fault surfaces (with apparent thrust motion) oriented subparallel to the attitude of the bedding outside the zone of compressional deformation. Minor fold axes may be oriented at high angles to the trend of the major syncline. These structures appear to have a complex history and their origin is not well understood. They may have been formed during flexural-slip folding and compression in the cores of the larger structures, or generated by transpressional strike-slip faulting, or both.

The timing of regional, east to northeast-directed compressional deformation on northern Vancouver Island is constrained to be younger than Middle Jurassic (post-Bajocian, the age of the youngest volcanic rocks in the Bonanza Group; Friedman and Nixon, 1995) and older than the Early Cretaceous (Hauterivian–Valanginian) strata that rest with angular unconformity on the Bonanza Group (Nixon *et al*., 1993a, 1994a, 1995a). This episode of deformation may be further constrained to be late Middle to early Late Jurassic, since clastic strata ('White Point Beds') of Upper Jurassic age (late Oxfordian to Tithonian) underlie Lower Cretaceous sequences in the Queen Charlotte Islands (Gamba, 1993; Haggart and Carter, 1993). This contractional event was followed by uplift and erosion prior to deposition of Jurassic–Cretaceous sedimentary strata.

The history of faulting on northern Vancouver Island is complex and embodies Cretaceous transpression and Tertiary extension. Extensional faulting and diking evidently occurred early during Bonanza volcanism. Major northwesterly-trending faults displace (in a right-lateral sense), and locally fold, Early to early Late Cretaceous sedimentary sequences exposed in the Quatsino Sound area (Muller *et al*., 1974; Nixon *et al*., 1993a. 1994a, 1995a). In the Nimpkish area, the Kokish fault and northwesterly-trending structures that cut the Nimpkish batholith at the southern margin of the map area may well share a similar history. Northerly-trending structures, such as the Nimpkish-Hustan and Bonanza faults, may record Tertiary block-faulting near the southern margin of the Queen Charlotte Basin. Faulting appears to have continued through to the end of Neogene volcanism (Muller *et al*., 1974).

MINERAL OCCURRENCES

The Nimpkish area hosts a variety of base and precious-metal deposits, and is perceived as a region of future mineral potential (Massey, 1995d). The map area contains some 34 mineral occurrences (MINFILE, 2005), including skarn and manto deposits, Cu-Au-Mo porphyry, volcanic redbed Cu, and Au, magnetite and sulphide-bearing vein and stockwork systems (Fig. 11). The area also has a prior history of extraction of industrial minerals, notably limestone and marble.

The major metalliferous deposit types in the Nimpkish area are intrusion-related skarns and mantos clustered about the margins of the Island Plutonic Suite and hosted by Quatsino limestone and calcareous strata of the Parson Bay Formation. Mineralization is particularly extensive at the margins of the Noomas pluton and western part of the Nimpkish batholith. New skarns and a manto occurrence were also investigated during the 2005 field season

Figure 10. Flow-aligned miarolitic cavities filled with radiating epidote crystals in tonalitic dike at southwestern margin of Noomas pluton near Storey Creek (locality 05GNX-4-3-1); pencil magnet is 12 cm in length.

(Fig. 11). Lithogeochemical assays of selected known and new occurrences are given in Tables 1 and 2.

One of the largest Fe and Pb-Zn-Cu skarn systems is hosted by an enclave of Quatsino limestone at the southwestern margin of the Noomas Pluton (Fig. 11). The Smith Copper deposits (MINFILE 92L 037/208) have drill-indicated reserves of approximately 84 000 t grading 12.5 wt% Zn, 3.7% Pb, 1.69% Cu and 64.4 g/t Ag. The mineralization contains sphalerite, galena, pyrrhotite, chalcopyrite, pyrite and magnetite set in a gangue assemblage of pyroxene, garnet, epidote, chlorite, quartz and carbonate. Some of the thin (<2 m) calcsilicate skarns also contain subhedral to rounded crystals of chondrodite (?) up to 1 cm in size and coarsely prismatic diopside up to 3 cm. The main zone of mineralization trends ~340° and dips to the southwest, locally coincident with the attitude of the major lithostratigraphic units. Extensive calcsilicate skarn assemblages were also discovered at the northern margin of this pluton, although sulphide mineralization does not appear to be as common. A well-mineralized Fe-Zn skarn containing sphalerite, pyrite, malachite and magnetite from the eastern margin of this pluton, and close to the Wolf occurrence (MINFILE 92L 121), gave 2.3% Zn, 0.27% Cu, 7.5 g/t Ag and anomalous gold (50 ppb Au; Tables 1 and 2).

At the northwestern termination of the Nimpkish batholith, a Cu-Mo prospect (92L 207) and Fe-Cu-Au-Zn skarns (Nimpkish Copper; MINFILE 092L 036, plus 118–120) occur at the contact with Quatsino limestone (Fig. 11). Assays of drillcore reach 0.29% Cu and 85 g/t Au over

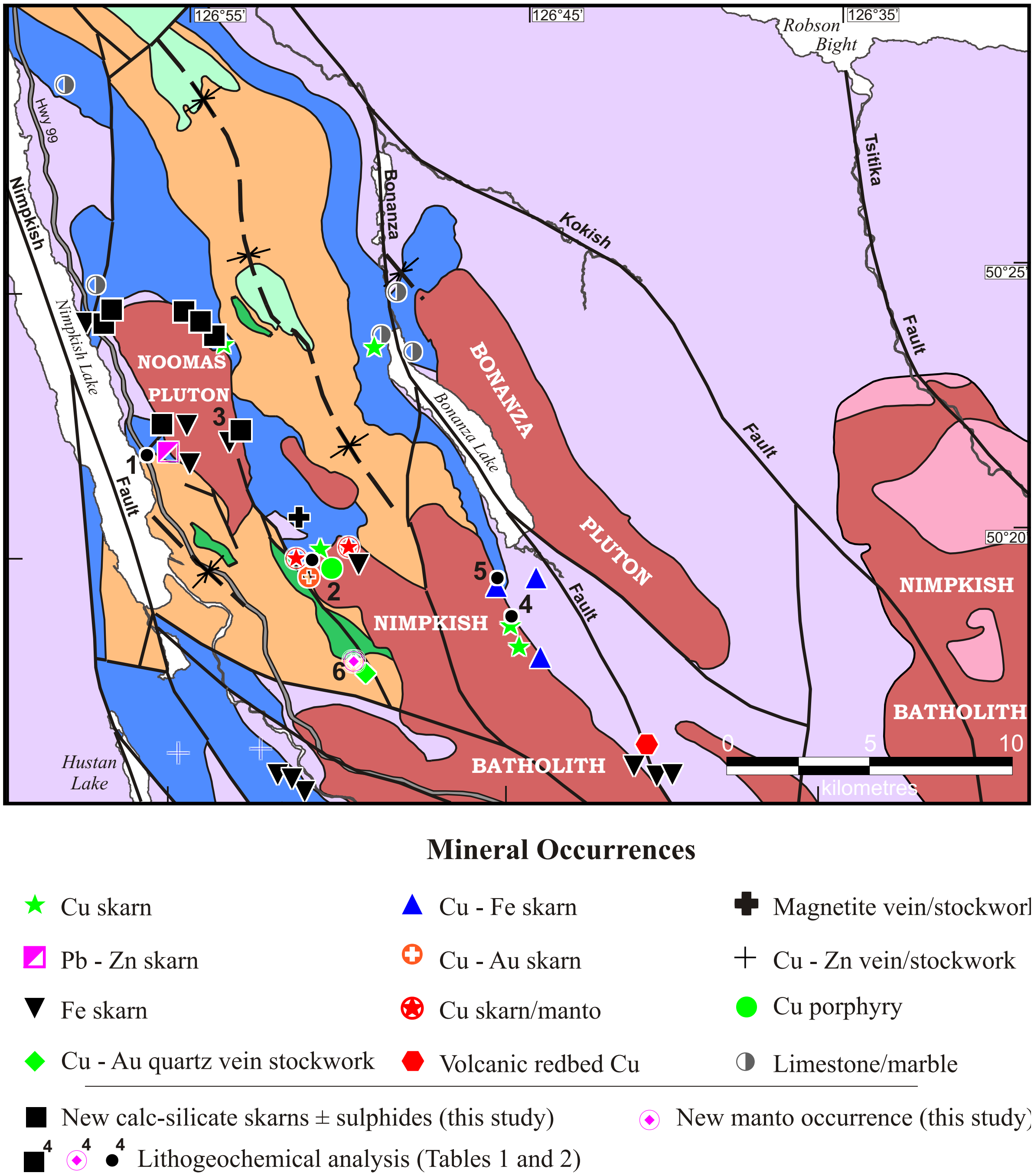

Figure 11. Geological setting of metallic and industrial mineral occurrences (MINFILE, 2005) and new showings (this study) in the Nimpkish area.

small widths (0.7 m), and a nearby trench has assayed 17.6% Zn and 0.73% Cu over 0.5 m. The mineralization occurs in small lensoid bodies (6 m long by 0.5 m thick) in Quatsino limestone that contain covellite, sphalerite, pyrrhotite, pyrite, malachite, molybdenite and bornite. A grab sample of massive pyrrhotite-pyrite ore in calcsilicate skarn collected during this study returned 0.18% Cu, 900 ppb Ag and 230 ppm Co (Table 1). The Cu-Mo porphyry-style mineralization is hosted by a shear zone where a quartz stockwork carries chalcopyrite and pyrite.

Copper-iron skarn deposits at the eastern margin of the Nimpkish batholith south of Bonanza Lake are hosted by Quatsino and intra-Karmutsen limestone (Fig. 11). The former Steele Creek open pit mine (MINFILE 92L 164) produced 4718 t of 2.48% Cu and 8.7 g/t Ag in 1968–1971. Drillcore samples taken in 1994 returned up to 0.38% Cu and 2.8 g/t Ag. The mineralization contains chalcopyrite, pyrite, malachite, and magnetite in a calcsilicate gangue. A high-grade grab sample collected during this study gave 23.3% Cu, 170 g/t Ag and 1330 ppm Co (Tables 1 and 2). Copper-iron skarn mineralization further north (MINFILE

TABLE 1. LITHOGEOCHEMISTRY OF MINERALIZED SAMPLES, NIMPKISH AREA

Map ID		1	2	3	4	5	6	6			
Sample		05GNX-2-8-1	05GNX-7-17-3	05DSV-4-1-1	05DSV-5-6-1	05DSV-6-2-1	05DSV-5-7-1	05DSV-5-7-1[1]	GSB Till 99	GSB Till 99	Difference (%)[2]
NAD83	Easting	646997	652808	650237	659796	654312	659273	659273	Internal	Mean of	
(Zone 9)	Northing	5581282	5577604	5582166	5575629	5574048	5577002	5577002	standard	10	
Ti	(wt%)	0.53	0.01	0.04	0.02	0.03	<0.001	0.001	0.54	1.13	71.1
Al	(wt%)	7.03	0.05	0.51	0.23	0.43	0.77	0.78	6.85	6.40	6.8
Fe	(wt%)	7.92	59.19	42.92	34.72	15.93	24.80	24.94	8.31	9.20	10.2
Mg	(wt%)	8.23	0.04	1.20	0.67	0.98	0.03	0.04	3.45	3.61	4.5
Ca	(wt%)	8.12	0.10	8.27	6.05	15.34	1.97	1.57	1.00	1.00	0.0
Na	(wt%)	0.97	0.01	0.05	0.01	0.03	0.01	0.01	1.90	1.85	2.6
K	(wt%)	0.04	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	0.83	1.57	61.6
P	(wt%)	0.03	0.03	0.02	0.02	0.02	0.00	<0.001	0.12	0.12	0.9
S	(wt%)	0.11	>10	5.25	>10	3.46	>10	>10	0.01	0.01	0.0
Mo	(ppm)	0.3	2.1	1.3	0.7	0.4	19.6	18.9	0.9	0.8	11.8
Cu	(ppm)	63	1798	2733	>10000	208	>10000	>10000	190	186	2.2
Pb	(ppm)	0.8	3.7	4.3	174	4.7	574	656	236	241	2.1
Zn	(ppm)	63	34	>10000	768	>10000	>10000	>10000	438	388	12.2
Ag	(ppb)	50	919	7511	>200000	487	>200000	>200000	1366	1575	14.2
Au[3]	(ppb)	6	17	51	375	3	170	95	30	36	18.2
Li	(ppm)	2.7	0.2	0.8	0.1	1.2	0.4	0.4	35		
Cs	(ppm)	0.2	0.1	0.4	0.1	0.1	0.1	0.1	1.5	1.9	23.5
Ba	(ppm)	23	2	17	1	20	2	2	784	846	7.6
Rb	(ppm)	0.9	0.3	0.8	0.1	0.2	0.2	0.2	26	48	57.7
Sr	(ppm)	200	3	38	1	44	257	266	104		
Sc	(ppm)	38	0.1	1.7	0.6	1.1	<0.1	<0.1	28.2	13	73.8
V	(ppm)	261	<1	8	12	10	2	4	197	107	59.2
Cr	(ppm)	448	6	9	6	5	1	1	323	398	20.8
Ni	(ppm)	370	5	2	314	2	112	128	220	261	17.0
Co	(ppm)	67	234	37	1332	300	557	604	50	53	5.0
Mn	(ppm)	1520	117	17598	726	26017	671	600	1394	1516	8.4
Hf	(ppm)	0.83	0.02	0.33	0.15	0.10	0.02	<0.02	0.79	3.64	128.7
Zr	(ppm)	17	0.4	7	4	3	0.6	1	23	108	130.3
Nb	(ppm)	<1	<1	<1	<1	<1	<1	<1	9		
Y	(ppm)	18.2	0.2	2.9	1.1	2.8	1.2	1.5	16.7	27	47.1
U	(ppm)	0.1	10.8	1.8	1.3	0.9	0.2	0.3	0.9	1.4	43.5
Ce	(ppm)	4.46	0.35	2.67	2.13	1	0.48	0.58	37.74	52.73	33.1
Ga	(ppm)	13.98	1.11	3.8	4.49	1.63	2.74	2.69	17.69		
Cd	(ppm)	0.07	0.63	166	81.34	601	2164	2091	1.11	0.74	40.0
As	(ppm)	2.1	<0.2	11.8	77.4	22	5	5	64.3	70	8.5
Sb	(ppm)	0.08	0.08	3.21	0.2	1.5	0.52	0.53	13.66	15.28	11.2
Bi	(ppm)	<0.04	5.87	1.63	16.15	1.36	97.91	118.68	0.22	0.13	51.4
Sn	(ppm)	0.4	<0.1	0.6	13	0.1	0.5	0.6	1		
W	(ppm)	<0.1	0.6	58.5	4.8	0.4	8.4	4.3	0.5	0.1	133.3

Sample descriptions: 1, volcanic wacke with diseminations and veins of pyrite+chlorite; 2, massive pyrrhotite-pyrite ore in calcsilicate skarn; 3, pyrite-sphalerite-magnetite-malachite in calcsilicate skarn; 4, pyrite-chalcopyrite-malachite-magnetite in calcsilicate skarn; 5, massive stratiform sphalerite-greenockite-chalcopyrite-pyrrhotite manto; 6, chalcopyrite-pyrite-malachite-bornite-Native Cu in calcsilicate skarn

Samples jaw crushed at the BC Geological Survey (Victoria), then pulverized in a steel mill at Acme Analytical Laboratories Ltd. (Vancouver); glass wash between each sample; all analyses performed by four-acid digestion inductively coupled plasma emission/mass spectrometry

[1]hidden duplicate

[2]percent difference calculated as the difference between analyzed value of GSB Till 99 and the mean of ten previous analyses

[3]analysis by lead-collection fire-assay with ICP-ES finish

92L 134), near the Quatsino-Karmutsen contact, carries chalcopyrite, pyrite, bornite, sphalerite, malachite, native copper and magnetite. A high-grade grab sample gave 18.6% Cu, 17.5% Zn, 200 g/t Ag, 95–170 ppb Au, 600 ppm Co, 2100 ppm Cd and 100 ppm Bi (Tables 1 and 2).

A new mineral showing was discovered at the end of a short spur off a new logging road system near the western margin of the Nimpkish batholith. The mineralization is hosted by dark grey to black, medium to thinly bedded limestone, calcareous mudstone, siltstone and shale of the

TABLE 2. ASSAYS OF ORE-GRADE SAMPLES, NIMPKISH AREA

Map ID	3	4	5	6	6
Sample	05DSV-4-1-1	05DSV-5-6-1	05DSV-6-2-1	05DSV-5-7-1	05DSV-5-7-1[1]
Fe (wt%)	39.48	30.95	16.32	22.09	22.13
Mn (wt%)	1.72	0.07	2.60	0.06	0.06
Cu (wt%)	0.24	23.27	0.05	18.62	18.58
Pb (wt%)	<0.02	<0.02	<0.02	0.05	0.05
Zn (wt%)	2.27	0.06	8.06	17.52	17.11
Cd (wt%)	0.015	0.007	0.055	0.183	0.175
Ag (ppm)	9	170	<2	189	201

Sample locations and descriptions given in Table 1

Samples jaw crushed and pulverized in a steel mill at Acme Analytical Laboratories Ltd.; glass wash between each sample; all analyses (0.5 g sample) performed by four-acid digestion inductively coupled plasma emission spectrometry

[1]hidden duplicate

Parson Bay Formation near the contact with interbedded, mafic volcanic breccia (Fig. 11). The mineralization forms a thin (~0.5 m) stratiform horizon composed mainly of sphalerite with minor greenockite bloom and malachite staining. A grab sample assayed 8.1% Zn, 200 ppm Cu, 600 ppm Cd and 500 ppb Ag (Tables 1 and 2). The showing appears to represent a manto deposit associated with intrusion of the Nimpkish batholith. Interestingly, this occurrence lies about 600 m northwest of the Engl Cu-Ag showing (MINFILE 92L 296), where quartz-Ag veins are hosted by a 1 m wide fault zone. The latter mineralization also contains sphalerite and it is possible that the two systems are related.

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