Geochemistry of Nicola Group Basalt from the Central Quesnel Trough at the Latitude of Mount Polley (NTS 093A/5, 6, 11, 12), Central British Columbia

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INTRODUCTION

Alkaline magmas are important sources of Au and Cu (Muller and Groves, 1993) and are associated with a number of world-class porphyry (Dinkidi, Philippines; Skouries, Greece; Cadia, Australia) and epithermal-style deposits (Porgera and Landolam, Papua New Guinea; Emperor, Fiji; Cripple Creek, United States; see Jensen and Barton, 2000). British Columbia is well endowed with porphyry deposits that formed during two distinct periods in the development of the Cordillera: the first in the Late Triassic to Early Jurassic and the second in the Late Cretaceous to Eocene (McMillan *et al.*, 1995). Alkaline and cospatial calcalkaline Cu-Mo±Au porphyry deposits formed within island-arc settings, represented by the Quesnel and Stikine terranes, located on the fringes of ancestral North America, during Late Triassic to Early Jurassic time. These arcs may have extended for up to 3000 km prior to their collision with ancestral North America, between 185 and 173 Ma (Nixon *et al.*, 1993; Mihalynuk *et al.*, 2004), and they now account for more than half of the accreted crustal material within the BC Cordillera. Late Cretaceous to Eocene porphyry deposits formed in a continental-arc setting after amalgamation of the composite terranes to North America.

Elevated metal prices and recent exploration successes in BC have rekindled interest in Cu-Au porphyry deposits. Key exploration targets are the alkalic Cu-Au porphyry deposits similar to the Galore Creek, Mount Polley and Afton-Ajax deposits (Fig. 1).

Mineralized and unmineralized alkaline intrusions are common throughout the Intermontane Belt, in both Stikine and Quesnel terranes of the Canadian Cordillera (Barr *et al.*, 1976; Lueck and Russell, 1994). Alkaline intrusions associated with porphyry deposits include both silica-saturated and silica-undersaturated types (Lang *et al.*, 1995), but worldwide only the BC deposits are associated with

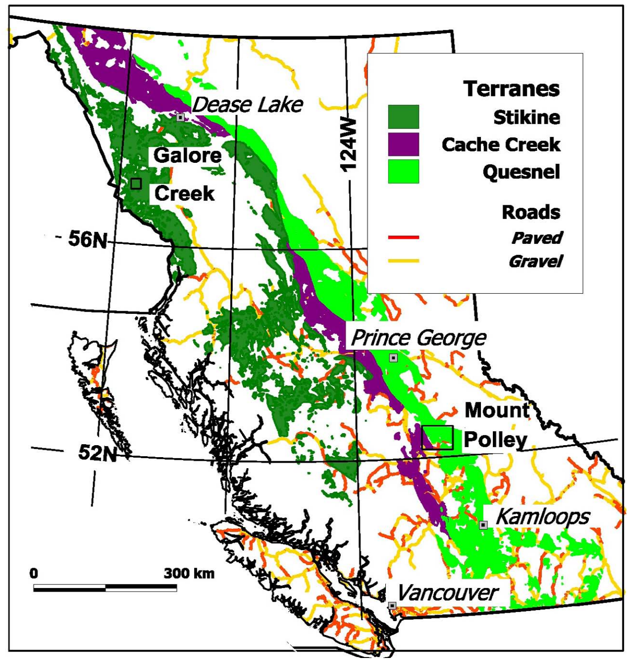

Figure 1. Location of study area, central Quesnel Trough, central British Columbia (modified from Wheeler and McFeely, 1991).

small, complex, either nepheline or leucite normative, silica-undersaturated intrusions, and these contain almost no quartz. Late Triassic British Columbia deposits are unique end-members of a continuum of porphyry deposits associated with calcalkaline, high-K calcalkaline or alkaline systems. Understanding the conditions of alkaline porphyry formation and the distinction between barren and fertile alkaline intrusions is important for the evaluation of arc terranes and their economic potential in BC.

Regional geological mapping and sampling continued at Mount Polley as part of an ongoing study of alkaline Cu-Au porphyry deposits in BC. This report includes the results of mapping and rock geochemical data collected from the eastern side of Quesnel Terrane, in the vicinity of Mount Polley. Key objectives of the project are to complete a lithogeochemical transect across the central Quesnel Terrane at approximately 52.5°N, and to characterize Triassic to Jurassic evolution of the arc, similar to the study of the southern Quesnel by Mortimer (1987). It is also critical to establish the tectonic implications of overlapping calcalkaline and alkaline magmatism and related porphyry mineralization, and to refine the understanding of the petrological evolution of alkaline-arc magmatism that culminated in porphyry mineralization at the Triassic–Jurassic

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boundary. In addition, this study includes a melt – fluid inclusion study on volcanic and intrusive rocks associated with mineralized and barren alkalic centres in the Mount Polley area (Bath and Logan, 2006).

PREVIOUS WORK

The Geological Survey of Canada carried out regional geological studies in the Quesnel River area during the 1950s and 1960s (Tipper, 1959, 1978; Campbell, 1961, 1963, 1978; Campbell and Campbell, 1970), but it was not until the work by Fox (1975) that the alkaline composition of the volcanic rocks was recognized in the Quesnel area. Detailed mapping and mineral deposit studies in the Horsefly area by Morton (1976), and by Bailey (1978) in the area around Morehead Lake, provided the first stratigraphic descriptions of the rocks encompassing the Mount Polley deposit.

Bailey (1988a, b, 1990), Panteleyev (1987, 1988) and Panteleyev and Hancock (1989) carried out regional-scale geological mapping and mineral evaluation in the area located between Quesnel and the Horsefly River as part of the 1985–1990 Canada – British Columbia Mineral Development Agreement. The focus of their studies was to remap and reinterpret the central Quesnel volcanic belt and test the economic potential for Au and Cu deposits along its volcanic-intrusive axis (Panteleyev *et al.*, 1996). Deposit studies at Mount Polley by Hodgson *et al.* (1976), Fraser (1994, 1995) and Fraser *et al.* (1995) recognized three stages of breccia emplacement (pre, syn and postmineralization) and the distinctive alkaline porphyry alteration assemblages that separate the deposit into proximal and distal mineralized zones.

REGIONAL GEOLOGY

The study area lies along the eastern margin of the Intermontane Belt close to its tectonic boundary with the Omineca Belt, in south-central BC. At this latitude, the Intermontane Belt is underlain mainly by Late Paleozoic to Early Mesozoic arc volcanic, plutonic and sedimentary rocks of the Quesnel Terrane. Farther west are coeval rocks of the oceanic Cache Creek Terrane (Fig. 1). The Quesnel Terrane (Quesnellia) consists of a Late Triassic to Early Jurassic magmatic arc complex that formed above an east-dipping subduction zone (Mortimer, 1987). The Cache Creek Terrane, with its Late Triassic to Middle Jurassic (Patterson and Harakal, 1974; Ghent *et al*., 1996) blueschist-facies rocks, represents the remnants of this subduction-accretionary complex (Travers, 1977; Mihalynuk *et al.*, 2004). Quesnellia is fault bounded, juxtaposed on the west with Paleozoic and Mesozoic rocks of the Cache Creek complex, and on the east by Mesozoic to Paleozoic and older metasedimentary, metavolcanic and metaplutonic rocks of the pericratonic Kootenay Terrane. The Barkerville and Cariboo subterranes of the Kootenay Terrane separated Quesnellia from North America until the Middle Jurassic, at which time they were imbricated and thrust eastward onto the North American craton (Nixon *et al.*, 1993). The tectonic boundary between the Kootenay and Quesnel terranes is intruded by the Jurassic–Cretaceous Raft batholith to the south. Tertiary volcanic rocks and feeder dikes of the Chilcotin Group are the youngest rocks in the region (Mathews, 1989).

Quesnel arc magmatism and associated porphyry mineralization migrated eastward with time, beginning in the west *ca.* 212 Ma with development of calcalkaline Cu-Mo±Au deposits at Highland Valley and Gibraltar. East of Gibraltar, submarine to subaerial Na and K-rich lava flows, cogenetic alkaline intrusions and 204 Ma, Cu-Au mineralization occupy the central axis of the arc. Mount Polley is hosted by a high-level, alkaline intrusive complex that is of latest Triassic age (202 Ma; Mortensen *et al*., 1995). A chain of similar deposits extends the length of the Intermontane Belt (Barr *et al*., 1976; Fig. 1). In the south, they are associated with the Iron Mask batholith (Afton, Ajax and Crescent) and Copper Mountain intrusions (Copper Mountain and Ingerbelle) and, to the north, with the Hogem batholith (Lorraine). Uplift and erosion of the fore-arc produced sub-Jurassic unconformities as magmatism shifted east and culminated with intrusion of 195 Ma calcalkaline plutons in the south (Takomkane, Thuya, Wild Horse and Pennask) and deposition of distal volcaniclastic and younger sedimentary rocks across the terrane.

NICOLA GROUP ROCKS

The central Quesnel belt consists of a twofold lithostratigraphic subdivision: a lower fine-grained sedimentary succession and an upper 'alkalic or shoshonitic' sequence of calcalkaline arc volcanic deposits that are gradational with and conformably overlie the sedimentary package. The volcanic succession occupies the central northwest-trending belt and is flanked on the east by 'black phyllite' and on the west by fine-grained volcanic sandstone, siltstone and conglomerate. The opposing regional dips of the Middle to Late Triassic sedimentary units beneath the younger, Upper Triassic volcanic succession provide the geometric definition for the Quesnel Trough (Roddick *et al.*, 1967; Campbell and Tipper, 1970; Panteleyev *et al*., 1996). This twofold sedimentary-volcanic distinction of Quesnellia is recognized in the Mount Milligan and Manson Creek – Germansen Landing areas to the north (Ferri and Melville, 1994; Nelson and Bellefontaine, 1996) and as far south as Little Fort (Schiarizza and Israel, 2001).

Schiarizza *et al.* (2002) subdivided the Nicola Group rocks in the Clearwater – Little Fort area into five informal units: a central (lower) volcanic and (overlying) volcaniclastic package, an eastern sedimentary (Lemieux Creek) and two western sedimentary successions (Meridian and Wavey Lake). They recognized similar rock types and equivalent ages for the sedimentary rocks east and west of the volcanic axis and mapped them as facies-equivalent units. Relevant to the present study are the Anisian, Ladinian and Early Carnian conodont ages from limestone interbedded with grey phyllite, slate and slaty siltstone of their easternmost Lemieux Creek succession, which support correlation with the lithologically similar Middle to Late Triassic basal Nicola rocks of unit 1 (Panteleyev *et al.*, 1996) in the Quesnel Lake area.

The base of the Nicola, unit 1 (Fig. 2), forms a northwest-trending belt exposed east of Quesnel Lake. It has been estimated to constitute at least 2500 m (Rees, 1987), to locally 4000 m (Bloodgood, 1990), of fine-grained graphitic and quartzose sedimentary rocks that grade upward into (Carnian to Norian) basal units of the upper volcanic unit. Missing from the Lemieux Creek succession but well described by Bloodgood (1987), Rees (1987) and

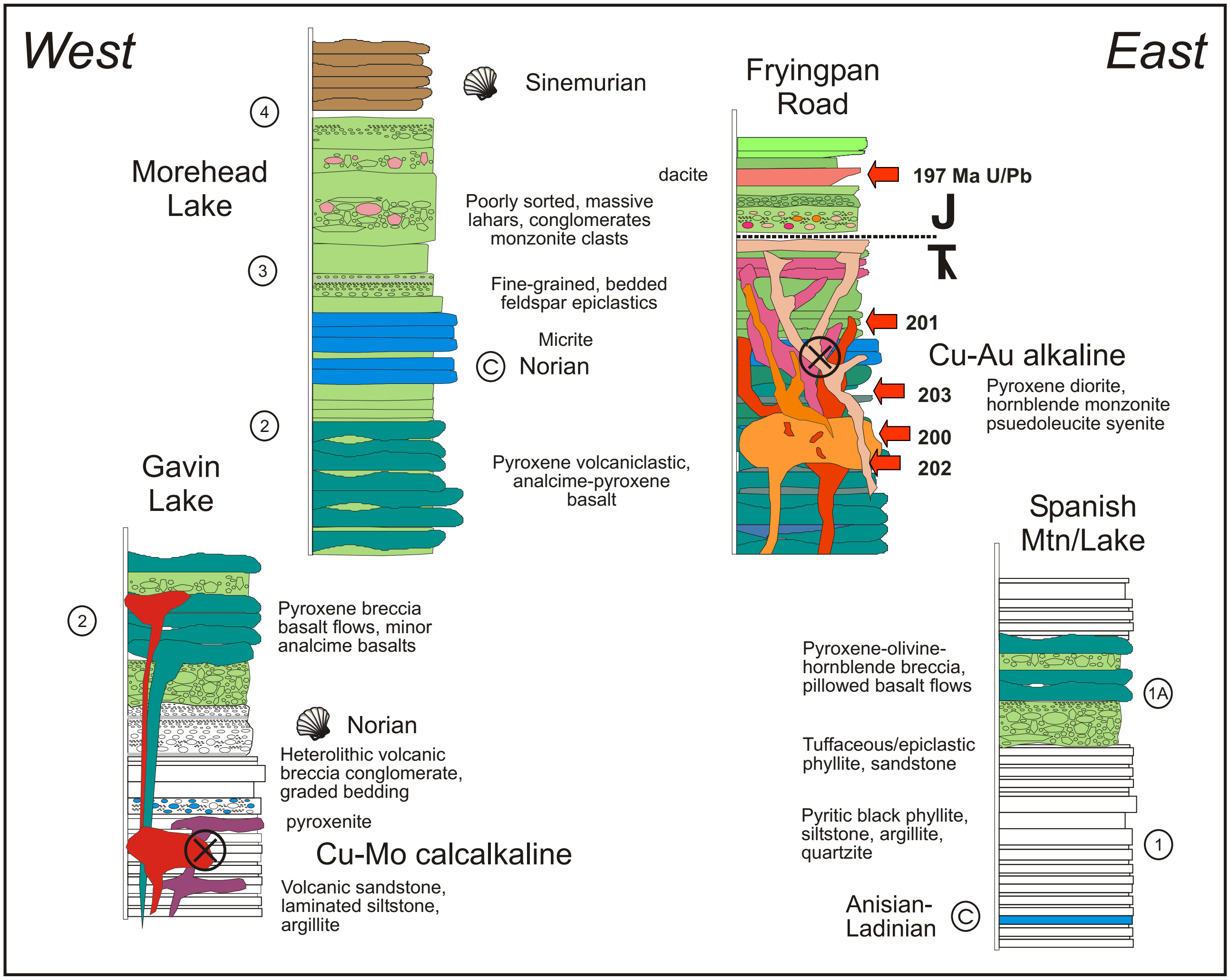

Figure 2. Stratigraphic sections for Nicola Group volcanic and sedimentary rocks in the Spanish Mountain, Fryingpan Road, Morehead Lake and Gavin Lake areas.

Panteleyev *et al.* (1996, unit 1A) in the Eureka Peak and Quesnel Lake areas are mafic hornblende, pyroxene volcanic breccia, conglomerate and tuffaceous argillite, which occur near the top of the sedimentary sequence (MLƮNv).

Augite porphyritic flow, breccia and volcaniclastic units define a northwest-trending belt, up to 20 km wide, of subaqueous and subordinate subaerial volcanic rocks with an estimated thickness on the order of 5–6.5 km (Rees, 1987; Panteleyev *et al.*, 1996). Thickest accumulations of volcanic rocks and coeval subvolcanic intrusions define the magmatic axis of the Quesnel arc and show remarkable similarity in chemical affinity and geochronological correlations along the length of the arc, as well as with other Late Triassic arcs in the Cordillera (Mortimer, 1987; Mihalynuk et al., 1994, Nelson and Bellefontaine, 1996; Panteleyev *et al.*, 1996; this study). Green or maroon, clinopyroxene (augite)–phyric basalt to basaltic andesite (LƮNpv) is the dominant and identifying rock type, but augite-olivine±plagioclase, augite-plagioclase-analcime (LƮNav) and hornblende-plagioclase-augite (LƮNhv) basalt compositions occur across the study area. Volumetrically, fine to medium-grained volcaniclastic deposits far exceed tuff and breccia units, and coherent lava and flow breccia units form the least abundant components of the arc within the study area.

West of the magmatic axis is a second package of fine-grained sedimentary and volcaniclastic rocks, the Gavin Lake succession, which underlies pyroxene volcanic breccia and flow rocks of the main volcanic facies (Fig. 2). It crops out north of Beaver Creek valley and extends about 20 km in a northwest-trending belt between Antoine and Gavin lakes. Panteleyev *et al.* (1996) mapped these as equivalent to their eastern sedimentary assemblage (unit 1). On its northern side, the contact between the Gavin Lake succession and overlying volcanic rocks trends northwest, orthogonal to the regional bedding in the lower sedimentary succession. At outcrop scale, however, the contact is gradational and conformable. The southern contact is poorly exposed and unconformably overlain and/or faulted against unnamed Jurassic sedimentary and Tertiary basalt units (units 6 and 11 of Panteleyev *et al.*, 1996).

The Gavin Lake succession is dominated by fine-grained, well-stratified, 25–30 mm thick beds of light and dark grey, wavy laminated siltstone, normal graded sandstone and cherty shale. Interbedded, massive or thick bedded pyroxene and plagioclase-rich crystal sandstone occurs locally or forms the matrix of thick-bedded debris flows.

The thin-bedded rocks are dark grey, black and rusty-weathering slate and dense cherty argillite that breaks with a conchoidal fracture. Interlayered with these are medium-bedded, pale and dark green, grey and brown cherty volcanic siltstone, brown medium-grained feldspathic sandstone with shale and siltstone rip-up clasts, and rare polylithic volcanic conglomerate. Also present, west of Antoine Lake, are coarse polymictic volcanic conglomerate, normal-graded beds of limestone, clast-dominated debris flows and finer grained laminar crossbedded sandstone-siltstone couplets. The conglomerate includes angular to subrounded pebbles of siltstone, green and maroon pyroxene-phyric basalt and pink hornblende–phyric subvolcanic monzonite supported by a silty or crystal-rich wacke matrix. Panteleyev *et al.* (1996) reported a Late Triassic (probably lower Norian) age for a suite of conodonts (GSC locality No. C-117644; Orchard, 1995). The colour alteration index (CAI) of 3.5 – 4.5 is slightly lower than the 5.0–5.5 CAI for Middle Triassic conodonts collected from the eastern sedimentary package of black phyllite.

North of Gavin Lake, the fine-grained sedimentary rocks are overlain conformably by bedded polymictic volcanic breccia and matrix-supported granule to pebble conglomerate, graded sandstone and cherty volcanic siltstone. Normal-graded beds and load structures indicate upright-facing, immature volcaniclastic units that contain pyroxene and plagioclase crystal-rich horizons and angular lithic fragments. Analcime and pyroxene flow breccias conformably cap the section (Fig. 2).

BASALT STRATIGRAPHY

The authors agree with the general stratigraphy of Bailey (1978) and Panteleyev *et al.* (1996), who recognized four main volcanic units in the study area (unit 1A and units 2, 3 and 4; see Fig. 2). Volcanic and epiclastic rocks of unit 1a were separated from the upper, dominantly volcanic sequence because they occur entirely within the Middle to Upper Triassic sedimentary unit 1, albeit near the top of the succession (Fig. 2), and on the basis of their petrochemical differences (Panteleyev *et al.*, 1996). They are interpreted to represent initiation of arc magmatism in a marginal-basin setting Bloodgood (1987). In the present study, these are referred to as Eastern arc basalt (MLTRNv).

Units 2, 3 and 4 record the evolution of magmatism and the main construction period of the arc during the Late Triassic. These define the central axis of the arc and are referred to as Central arc basalt (LTRNv). In general, the volcanic stratigraphy consists of a subaqueous pyroxene-phyric basalt unit, consisting mainly of flows and breccias; pyroclastic and lahar deposits of more evolved 'felsic' compositions; and an upper, subaerial, analcime-bearing olivine basalt unit (Logan and Mihalynuk, 2005). Ages of these three units were interpreted to span the Upper Triassic to Early Jurassic boundary. Subsequent U-Pb isotopic age dating of the various intrusive phases of the Polley and Bootjack stocks indicates that these intrusions are Late Triassic (Palfy *et al.*, 2000); therefore, they cannot intrude rocks younger than 200 Ma (Fig. 2).

Evidence for isolated Early Jurassic calcalkaline volcanism and plutonism is recognized in the area: for example, the 197 Ma (Logan *et al.*, in press) quartz-phyric dacite unit located immediately north of Mount Polley mine (Logan and Mihalynuk, 2005) and the 195 Ma quartz syenite dike at Shiko Lake. However, the majority of Early Jurassic strata within the study area are well-bedded sedimentary units that contain Early Sinemurian, Canadensis Zone fossils (GSC locality No. 93215b, 93960, 93961; Poulton and Tipper, 1991; Tipper, 1992) and mature, well-bedded, polylithic, monzonite-bearing conglomerate (Logan and Mihalynuk, 2005; Fig. 2). Provenance studies of Early Jurassic sedimentary sequences in the study area indicate immature arc-derived sandstone containing Late Triassic to Early Jurassic detrital zircons that suggest local sources dominated, or diluted and masked, any evolved North American continental sedimentary influence (Petersen *et al.,* 2004).

Middle to Late Triassic Metavolcanic Rocks (unit 1A)

Nine samples of metavolcanic rocks representing rocks from unit 1A (Panteleyev *et al.*, 1996) were collected from Spanish Mountain (n = 2), east of Spanish Lake (n = 3) and east of Horsefly in the vicinity of Viewland Mountain (n = 5). The rocks in the area of Spanish Mountain include plagioclase crystal tuffaceous siltstone, volcanic conglomerate and hornblende-plagioclase porphyritic breccia. Northeast of Spanish Lake, pale green foliated tuffaceous phyllite, massive greenstone and breccia dominate, with rare, thin pillowed flows of pyroxene porphyry basalt. Sections containing pyroxene basalt appear identical to the younger volcanic stratigraphy in the main Quesnel volcanic belt farther west. However, thin-section investigation reveals substantial recrystallization and low-grade metamorphism. Analcime basalt identified in the field is, in fact, metabasalt with secondary albite porphyroblasts filling vesicles. Panteleyev *et al*. (1996) showed a 1–2 km wide, northwest-trending belt of volcanic rocks extending between Horsefly and Quesnel lakes, centred on Viewland peak. Reconnaissance along the length of this belt collected representative samples of intermediate to mafic metavolcanic breccia and flow units. Deformation and lower greenschist metamorphism have also variably affected the massive breccia flow and tuffaceous units.

The volcanic rocks from the vicinity of Eureka peak (Bloodgood, 1987) comprise coarse porphyritic flows, breccia and fine-grained tuff. Phenocryst assemblages consist of pyroxene, hornblende and plagioclase. The volcanic rocks have been metamorphosed to lower greenschist facies. Metamorphic minerals include actinolite, albite, epidote, chlorite, quartz and calcite. Conodonts from limestone-bearing rocks southwest of Spanish Mountain have yielded Middle Triassic ages ranging from Anisian to Ladinian (Orchard, 1995), with conodont alteration indices (CAI) of 5.0–5.5. Bloodgood (1987) concluded that the chemistry suggested an island-arc origin with possible back-arc or marginal-basin affinities.

Late Triassic Augite-Phyric Volcanic Rocks

Maroon, green and grey pyroxene-phyric flow, breccia and pyroxene crystal–rich volcaniclastic units form the majority of the central volcanic belt. They are interfingered with augite-olivine, analcime and hornblende-bearing basalt units throughout the stratigraphic column (Panteleyev *et al.*, 1996; Logan and Mihalynuk, 2005) and near the top by limestone and felsic crystal tuffs (Fig. 2). Normal graded-bedding, crossbedding and load features are common in the sedimentary rocks; all indicate upright facing beds and a subaqueous environment of deposition.

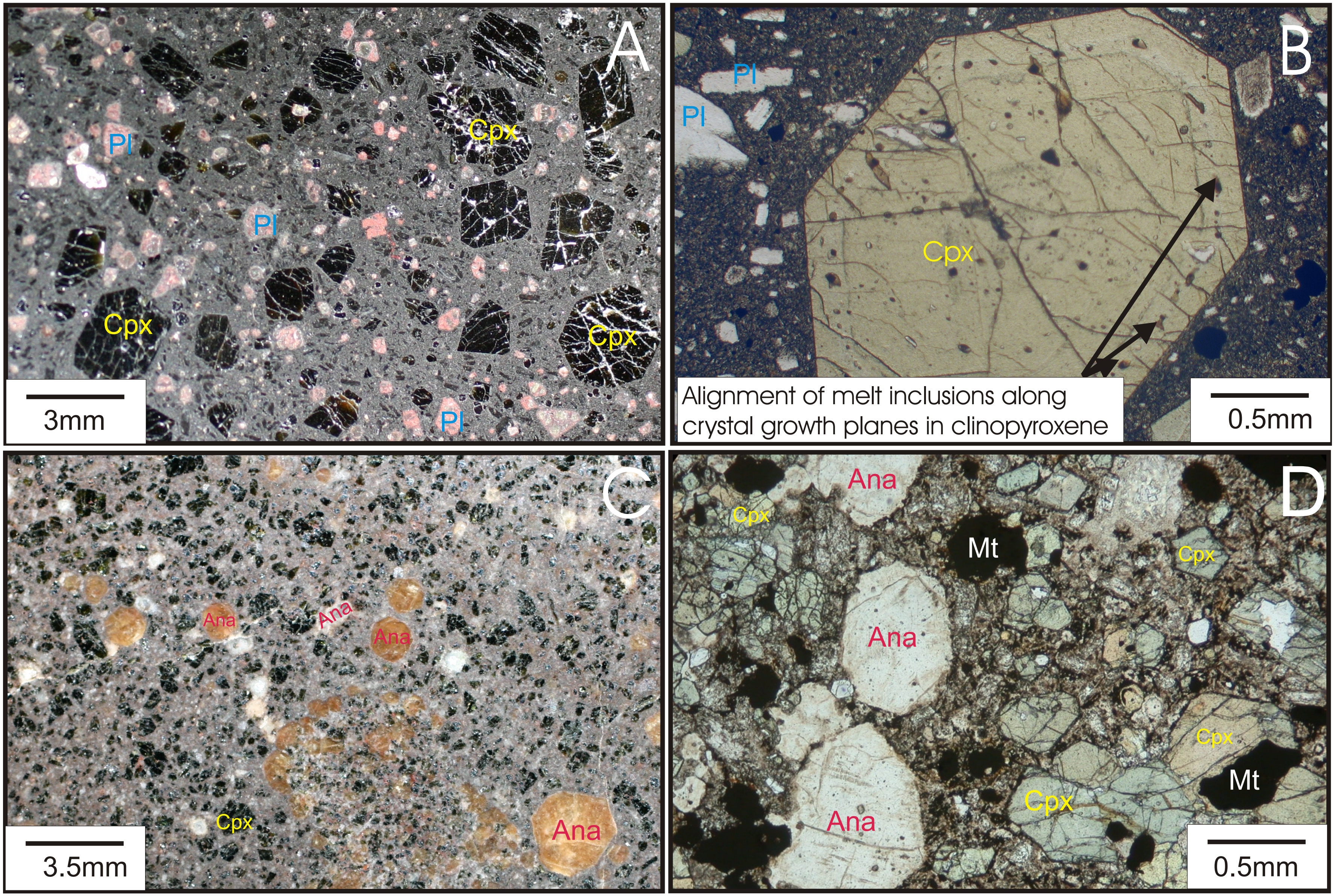

Figure 3. Hand samples (A and C) and thin sections (B and D) of typical alkaline basalt. Photomicrographs A and B are augite-plagioclase–phyric basalt; C and D are analcime-augite–phyric basalt with magnetite. Abbreviations: Ana, analcime; Cpx, augite; Mt, magnetite; Pl, plagioclase.

Coherent flows comprise 30% (to a maximum of 50%) medium to coarse-grained euhedral pyroxene (Fig. 3A, B), 20% subhedral plagioclase phenocrysts in a fine-grained felted seriate groundmass of plagioclase, pyroxene, ±olivine, magnetite and apatite. Euhedral coarse pyroxene crystals up to 5 mm in diameter are well zoned and often show alignment of melt inclusions along growth planes. Porphyritic augite flow breccia and flow tops are commonly amygdaloidal and exhibit trachytic alignment of plagioclase laths in a chloritic vitrophyric matrix.

Late Triassic Analcime-Phyric Volcanic Rocks

Analcime-bearing mafic flows crop out near Trio Lake, Mount Polley, west of Morehead Lake (Logan and Mihalynuk, 2005) and south of Antoine and Shiko lakes. South of Jacobie Lake, analcime-bearing basalt forms the basal flow unit that overlies the Gavin Lake succession. Excellent exposures are found along the highway north of Prior Lake within an ~260 m thick volcanic section dominated by dark grey-green to maroon, vesicular augite porphyry flows. Analcime content varies from one flow to the next, as do pyroxene and olivine contents.

Typical flows comprise 30% medium to coarse-grained euhedral pyroxene (up to 60%); 20–50% fine to coarse plagioclase, locally including coarse, trachytically aligned, bladed phenocrysts; 2–10% medium-grained olivine, commonly replaced by bright red iddingsite; up to 10% amygdules, mostly filled with calcite and chlorite; and 0–20% euhedral, salmon pink analcime up to 3 cm diameter (Fig. 3C, D).

Analcime occurs as euhedral phenocrysts, as irregular interstitial matrix material and as amygdule fillings in coherent basalt flows. In addition, it is present as euhedral grains in juvenile crystal lithic tuff and epiclastic units, which would support a primary origin for this phenocryst. The debate whether analcime is primary or secondary in similar Nicola lavas (Coates, 1960; Mortimer, 1987) or the younger Crowsnest Formation (Peterson and Currie, 1993) is inconclusive. Karlsson and Clayton (1991) presented strong isotopic and microprobe data to support low-temperature replacement of early leucite and a secondary origin for pristine analcime crystals.

Late Triassic to Early Jurassic (?) Hornblende-Phyric Volcanic Rocks

Hornblende-phyric basalt flows, dikes and breccia units form a subordinate but distinctive sequence exposed along the eastern side of the central volcanic belt at the QR deposit (Fox and Cameron, 1995) and north of Shiko Lake. Panteleyev *et al.* (1996) correlated these rocks (their unit 2d) with units 2a and 2b, which occupy a lower position in the Upper Triassic stratigraphy. Fossil or isotopic age constraints are lacking. From observations during the present study, similar hornblende-phyric flows and dikes are associated with sedimentary units high in the stratigraphy. These units are quartz poor and different from the Early Jurassic quartz-phyric hornblende dacite.

Hornblende-plagioclase porphyry dikes and diorite sills north of the Quesnel River at QR and Shiko Lake crosscut black and grey, thin laminated argillite and siltstone. The dikes are commonly rusty and contain 1–2% pyrite.

The rocks contain 3–5 mm euhedral grains of conspicuous hornblende, smaller euhedral pyroxene and plagioclase within a fine-grained seriate groundmass of the same minerals. Accessory minerals include magnetite, apatite, pyrite and the alteration minerals chlorite and carbonate. A white zeolite, possibly laumontite, occupies amygdules.

Intrusive Bodies

Dark green, 10–20 m wide pyroxenite bodies intrude fine-grained volcaniclastic rocks in two locales west of Gavin Lake. The pyroxenite occupies sill-like (conformable with bedding) bodies and dikes that crosscut bedding at high angles. The pyroxenite consists of coarse-grained, euhedral zoned pyroxene phenocrysts, altered subhedral olivine pseudomorphed by serpentine and talc, and plagioclase laths within a fine-grained, altered, opaque-rich (magnetite and pyrite) matrix of plagioclase, pyroxene and alteration minerals, including chlorite, talc and calcite. These intrusions are relatively rich in MgO (10.26 wt%; Table 1), represent a less fractionated magma, and contain similar major-element abundances as the pyroxenite at Mount Polley (*see* Bath and Logan, 2006; Fraser, 1994). They are likely feeder dikes to some of the early pyroxene-phyric basalt flows that stratigraphically overlie the western volcaniclastic sequence. Younger, texturally similar augite porphyry (AP) dikes that intrude the mine stratigraphy at Mont Polley have much lower MgO contents (5.26 wt% MgO; Fraser, 1994).

The western portion of the study area is intruded by metre to decimetre-wide quartz porphyritic monzonite dikes. The dikes consist of a fine-grained leucocratic matrix, variable amounts of finely disseminated pyrite and sparse to 10% euhedral quartz phenocrysts. Biotite (up to several percent) and rarely hornblende are present, but both are often completely replaced by sericite and carbonate. Weathering produces a distinctive limonitic-pinkish, fine-grained massive rock with conspicuous (2–8 mm) quartz phenocrysts. The largest concentration of these intrusive rocks occurs at Gavin Lake, where a coalescing swarm of east-trending dikes and small quartz monzonite porphyry plugs intrude an area approximately 0.5 km by 3 km immediately north of the lake. Chalcopyrite and molybdenite mineralization is associated with quartz and K-feldspar stockwork veining in the dikes. North-trending quartz veins, in places up to 5 m wide, cut the fine-grained volcaniclastic sequence. Mineralization includes chalcopyrite and galena with Au and Ag values reported (Hodgson, 1970). Bailey (1978) and Panteleyev *et al.* (1996) correlated these quartz-bearing calcalkaline intrusions with hornblende-biotite monzogranite of the Nyland Lake stock and included them in the Cretaceous Naver plutonic suite (Woodsworth *et al.,* 1991). A sample of quartz porphyritic monzogranite was collected for U-Pb geochronology; results are pending.

WHOLE-ROCK GEOCHEMISTRY

More than 100 representative samples were collected during the regional mapping of the Quesnel Lake area. These included samples of all major phases of the Mount Polley igneous complex, phases of equivalent (?) regional intrusive centres and a suite of the surrounding host lavas. Weathered surfaces or altered samples were screened by

TABLE 1. MAJOR-OXIDE AND SELECT TRACE-ELEMENT GEOCHEMISTRY FOR VOLCANIC AND INTRUSIVE ROCKS FROM THE QUESNEL LAKE AREA. ALL ANALYSES AT COMINCO LABS, VANCOUVER. ROCK AND MINERAL ABBREVIATIONS: pxnt, PYROXENITE; bslt, BASALT; brecc, BRECCIA; PX, PYROXENE; DORT, DIORITE; anal, ANALCIME; hnbl, HORNBLENDE; PO, PORPHYRY; epid, EPIDOTE; ALT, ALTERED; META, METAMORPHOSED; vlc, VOLCANIC. ANALYTICAL METHOD ABBREVIATIONS: XRF1, FUSED DISC – X-RAY FLUORESCENCE; TIT, HF DIGESTION – TITRATION; XRF2, PRESSED PELLET – XRF

			Element	SiO2	TiO2	Al2O3	Fe2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Ba*	LOI	Total	Nb	Rb	Sr	Y	Zr
			Units	%	%	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm
			Method	XRF1	XRF1	XRF1	XRF1	TIT	XRF1	XRF1	XRF1	XRF1	XRF1	XRF1	XRF1	FUS	SUM	XRF2	XRF2	XRF2	XRF2	XRF2
Field Number			Detection limit	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	3	3	3	3	3
Western feeder dikes	Easting	Northing	Rock Type																			
L05-7-35	583391	5815847	pxnt	46.25	0.43	9.43	7.59	2.74	0.11	13.85	9.15	0.62	3.74	0.34	0.08	4.51	98.84	bd	108	420	7	26
L05-8-56	584508	5814773	pxnt	48.9	0.75	14.68	8.29	2.14	0.15	6.07	8.65	2.94	2.72	0.38	0.06	3.77	99.5	3	66	836	13	44
B05-38-309	581957	5816505	pxnt	46.74	0.5	11.6	3.75	6.5	0.14	10.86	8.53	1.11	4.26	0.37	0.08	4.62	99.06	bd	85	525	8	10
Eastern volcanics (MLTNv)																						
L05-31-242 B	617366	5815976	bslt	48.27	1.09	13.88	0.82	7.72	0.18	7.84	8.26	3.2	2.16	0.25	0.07	3.08	96.82	10	80	621	16	32
L05-31-244	624988	5812571	bslt-brecc	49.81	0.7	17.5	3.16	3.61	0.11	4.78	11.44	2.22	1.21	0.15	0.05	4.45	99.19	4	27	594	17	41
L05-31-245	627005	5809512	bslt	50.41	0.74	17.62	2.44	4.62	0.12	5.46	8	3.73	2.4	0.27	0.07	3.52	99.4	bd	38	964	22	44
L05-12-103	611942	5828360	bslt-brecc	48.91	0.75	14.01	1.77	5.99	0.11	11.27	7.69	2.1	2.04	0.23	0.11	4.42	99.4	7	96	197	19	127
L05-12-104	611789	5827866	bslt-brecc	55.5	0.73	14.23	0.99	4.19	0.09	5.71	6.78	5.09	2.09	0.57	0.12	3.35	99.44	10	56	352	32	127
L05-12-104-2	611789	5827866	bslt-brecc	51.22	1.01	16.79	1.36	5.85	0.1	6.92	4.59	3.95	3.27	0.43	0.17	3.94	99.6	14	143	273	30	180
L05-12-100	610588	5825008	plw-brecc	52.15	1.15	14.43	2.27	4.91	0.1	4.42	9.52	3.64	0.01	0.2	0.01	6.81	99.62	3	<3	243	32	84
Central volcanics (LTNv)																						
B05-13-105	586016	5819125	px bslt	47.43	0.63	13.35	6.31	3.97	0.17	8.14	11.32	1.82	2.78	0.31	0.06	2.73	99.02	bd	49	833	11	27
B05-17-137	598544	5831704	bslt brecc	48.56	0.69	13.85	0.07	9.4	0.18	8.4	10.69	2.31	1.54	0.23	0.05	3.6	99.57	4	42	578	17	35
L05-6-23	587770	5817263	bslt brecc	47.56	0.6	12.34	5.39	4.47	0.15	9.92	10.96	1.86	2.38	0.28	0.05	3.68	99.64	4	54	677	15	29
L05-9-69	592733	5831979	bslt brecc	47.97	0.63	13.01	3.94	4.62	0.15	8.42	13.06	1.96	1.6	0.2	0.07	3.95	99.58	4	50	495	16	43
L05-18-140	575825	5832707	bslt brecc	48.15	0.6	12.65	4.87	4.84	0.18	7.42	11.14	2.77	2.55	0.28	0.09	3.96	99.5	bd	51	614	12	31
L05-28-204	591320	5815000	px bslt	47.75	0.63	13.06	5.94	4.19	0.17	9.19	10.67	1.76	2.89	0.31	0.06	2.69	99.31	9	79	773	9	23
L05-29-210	592193	5808835	dort	48.18	0.66	14.97	5.82	3.97	0.18	7.23	8.97	2.11	3.46	0.33	0.08	3.2	99.16	7	84	1061	9	32
L04-14-24	594012	5820043	px dort	47	0.76	14.14	7.55	3.96	0.18	7.42	11.75	2.34	2.5	0.33	0.14	0.99	99.51	6	35	832	16	36
M04-19-6	594010	5820050	px dort	49	0.63	14.46	7.18	3.07	0.18	6.65	10.17	2.5	3.67	0.34	0.17	0.99	99.36	5	56	1263	17	40
L04-18-50	593810	5820137	px dort	48.7	0.76	18.01	5.58	4.32	0.17	4.51	9.89	3.06	2.65	0.28	0.13	1	99.55	-3	34	614	20	55
M04-21-1b	591861	5825326	bslt	49.13	0.62	16.37	5.09	3.61	0.15	5.17	7.13	2.57	5.15	0.44	0.2	3.23	99.27	6	88	1000	13	53
M04-22-4	605148	5812440	bslt brecc	49.79	0.67	14.71	4.63	4.13	0.15	7.75	9.55	2.24	2.48	0.41	0.15	2.54	99.66	3	34	773	17	71
M04-27-1	585709	5821580	bslt brecc	45.88	0.81	15.23	8.36	3.1	0.2	5.51	10.57	4.01	1.65	0.62	0.08	2.92	99.29	5	20	1207	19	57
L05-32-248	604402	5809833	px-po bslt	47.4	0.62	12.82	6.81	3.25	0.17	7.46	12.89	2.07	2.05	0.36	0.07	3.39	99.36	bd	50	1022	8	22
L04-12-10	582114	5826062	anal px bslt	45.75	0.81	12.13	7.83	4.48	0.2	7.71	12.85	3.44	0.93	0.64	0.06	2.48	99.81	7	8	912	14	53
L04-18-52	592046	5820432	anal px bslt	48.81	0.56	15.01	6.13	3.61	0.2	5.28	9.27	2.75	5	0.46	0.15	1.62	99.26	6	78	1764	9	41
L05-5-20	596421	5822497	anal px bslt	48.93	0.51	16.43	6.43	1.88	0.17	5.55	7.42	6.32	0.92	0.62	0.12	4.42	99.72	bd	17	1040	16	38
L05-13-109	603307	5811794	breccia	46.68	0.74	11.31	6.54	4.47	0.15	8.78	11.56	2.13	2.27	0.4	0.06	4.38	99.47	7	57	833	15	33
L05-29-216	602006	5804767	anal px bslt	47.72	0.66	14.52	7.5	2.38	0.15	6.03	9.25	4.34	1.66	0.34	0.15	4.64	99.34	bd	24	573	14	43
L05-32-246-2	600846	5804521	anal px bslt	46.47	1.04	13.81	9.62	2.45	0.28	5.53	10.63	3	2.74	0.75	0.11	3.27	99.7	bd	159	898	9	44
L05-17-133	602475	5815074	hnbl bslt	47.81	1.25	13.48	3.05	7.36	0.17	7.15	9.69	2.85	1.78	0.31	0.07	4.46	99.43	7	73	409	18	73
L05-26-194	589271	5815117	hnbl bslt	48.36	0.8	14.77	3.86	5.12	0.15	8.3	10.43	3.64	0.68	0.2	0.03	2.98	99.32	bd	17	862	18	55
L05-30-222	581841	5836202	hnbl bslt	51.27	0.91	17.12	3.65	3.75	0.1	3.44	8.06	2.81	4.94	0.4	0.2	2.71	99.36	4	105	530	19	83
B05-35-280	580735	5835899	hnbl dort	49.38	0.85	17.2	2.16	7.07	0.15	4.42	8.35	2.86	3.61	0.37	0.14	3.29	99.85	bd	106	802	19	37
L05-30-223	580758	5835905	hnbl dort	50.38	0.83	15.86	1.87	6.06	0.12	4.75	9.05	2.74	3.75	0.4	0.21	3.21	99.23	3	93	647	20	57
Early Jurassic Dacite																						
B05-28-230	591796	5826577	hnbl dacite	57.15	0.43	17.79	4.12	1.15	0.15	1.46	5	4.98	2.71	0.17	0.22	4.08	99.41	bd	50	514	15	66
M04-26-18	592800	5826580	dacite	57.91	0.43	17.81	4.06	1.13	0.14	1.48	4.59	4.82	2.76	0.18	0.22	3.95	99.61	7	27	487	17	67
Q/C																						
CANMET SY4				49.69	0.28	20.59	3.11	2.69	0.10	0.51	7.98	7.03	1.60	0.11	0.03	5.41	99.10	10	54	1212	114	508
CANMET SY4	**Recommended**			49.9	0.287	20.69	3.35	2.86	0.108	0.54	8.05	7.1	1.66	0.131	0.034	4.56		13	55	1191	119	517
L05 5-20				48.93	0.51	16.43	6.43	1.88	0.17	5.55	7.42	6.32	0.92	0.62	0.12	4.42	99.72	bd	17	1040	16	38
L05-20rep				48.81	0.51	16.37	6.49	1.85	0.17	5.55	7.44	6.4	0.92	0.58	0.12	4.46	99.67	bd	11	1039	16	34
% Difference				0.25	0.00	0.37	0.93	1.61	0.00	0.00	0.27	1.26	0.00	6.67	0.00	0.90	0.05	0.00	42.86	0.10	0.00	11.11

careful inspection of hand samples, and 75 were selected for analysis. Samples were milled in chrome steel (trace elements) and tungsten carbide (major oxides) at the BC Geological Survey laboratory in Victoria. Replicate samples and standards were included and the splits were shipped for analyses to Teck Cominco Laboratories, Vancouver for major-element and trace-element abundances (Ba, Rb, Sr, Nb, Zr and Y) by X-ray fluorescence (XRF); Acme Analytical Laboratories Ltd., Vancouver for trace-element analyses using inductively coupled plasma – emission spectrometry (ICP-ES); and Activation Laboratories Ltd., Ancaster, Ontario for trace-element analyses using instrumental neutron activation analysis (INAA). A subset of the samples was sent to Memorial University, Newfoundland (MUN) for trace-element analyses using inductively coupled plasma – mass spectrometry (ICP-MS). Detection limits, precision and accuracy are discussed in a companion paper (Bath and Logan, 2006).

This report focuses on the geochemical characterization of the Triassic basalt stratigraphy across the axis of the Quesnel arc at the latitude of Quesnel Lake, in the vicinity of the alkalic Cu-Au porphyry deposit at Mount Polley. Thirty-seven basalt samples are discussed in this report. Samples of the volcanic units have moderate to high loss-on-ignition values (0.99–4% LOI). This data set was complemented by whole-rock analyses from published sources (Bloodgood, 1987; Panteleyev *et al*., 1996; Fraser, 1995).

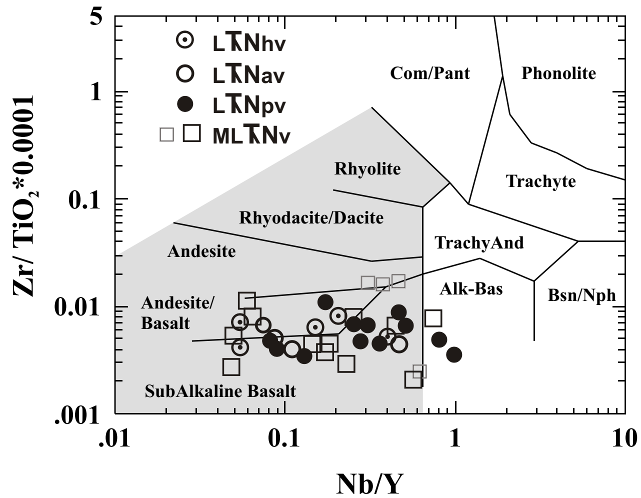

Figure 4. Zr/TiO2 *vs.* Nb/Y plot of Triassic Nicola Group volcanic rocks showing compositional range and classification for Mount Polley area (after Winchester and Floyd, 1977). Rock type codes: LT̄Nhv, hornblende phyric basalt; LT̄Nv, analcime-phyric basalt; LT̄Nvpv, pyroxene-phyric basalt; MLT̄Nv, hornblende-pyroxene metabasalt; small square, this study; large square, data from Bloodgood (1987).

RESULTS

Major Oxides

Major and trace-element compositions of representative volcanic rocks from the Nicola Group are provided in Table 1. Normative calculations, discriminant and bivariant plots use chemical data that are recalculated to 100% volatile free. Overall, the rock compositions are comparable to Nicola lavas from the southern (Mortimer, 1987), central (Barrie, 1993) and northern (Takla; Dostal *et al.*, 1999) Quesnel Terrane (Souther, 1977). The silica content varies between 45 and 52 wt%. The rocks have a moderately high content of alkalis (5–7 wt% Na_2O+K_2O) and plot as transitional to alkaline on the total alkali *versus* silica diagram (Irvine and Baragar, 1971) and as subalkaline basalt and andesitic basalt on the Zr/TiO_2 *versus* Nb/Y immobile element plot (Fig. 4) of Winchester and Floyd (1977), a result of the relatively depleted Nb and lower high field strength elements (HFSE; *e.g.*, <1.1 wt% TiO_2) that characterize volcanic arc rocks. Intraplate rifts and continental alkalic suites are enriched in Nb and TiO_2 relative to volcanic rocks formed at destructive plate boundaries, and plot to the right of the shaded area in the alkali basalt field.

An AFM plot (Fig. 5) shows a calcalkaline trend for the majority of the sample suite. Basalt from the Eureka peak area (Bloodgood, 1987) and stratigraphically equivalent lavas from the eastern side of the arc at Spanish Mountain (SM), east of Spanish Lake (SL) and in the Viewland Peak area (VP) straddle the tholeiitic-calcalkaline trend. These basalts are interlayered with Middle to Upper Triassic sedimentary rocks, and are older than the main arc and may therefore represent early volcanism and initiation of arc magmatism (Bloodgood, 1987; Panteleyev *et al.,* 1996). The typically high MgO contents (mean values of 7–10 wt%; Table 1) indicate that these volcanic rocks represent a primary magma that has not under gone substantial fractionation (see Fig. 6).

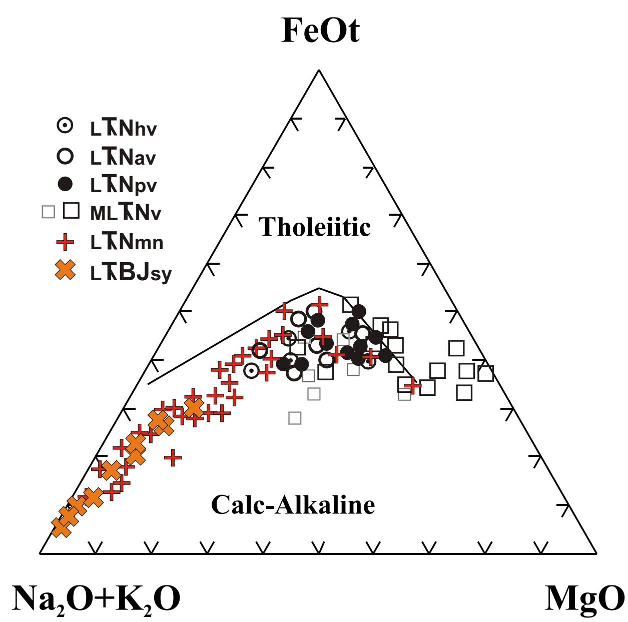

Figure 5. AFM ternary diagram showing calcalkaline nature of Mount Polley igneous rocks. Rock type codes as in Figure 4 plus LT̄Nmn, Late Triassic regional intrusive rocks (diorite to monzonite) and LT̄BJsy, Bootjack stock syenite.

When plotted against an index of fractionation such as wt% MgO (Fig. 6), the major-element abundances can be used to determine the cogenetic relationships between different rock units. With the exception of a subset of the most primitive Eureka Peak basalt (Bloodgood, 1987; Panteleyev *et al.,* 1996, unit 1A), the smooth linear trends for the remaining samples suggest they can all be related by simple fractional crystallization. The FeO_T, TiO_2, P_2O_5,

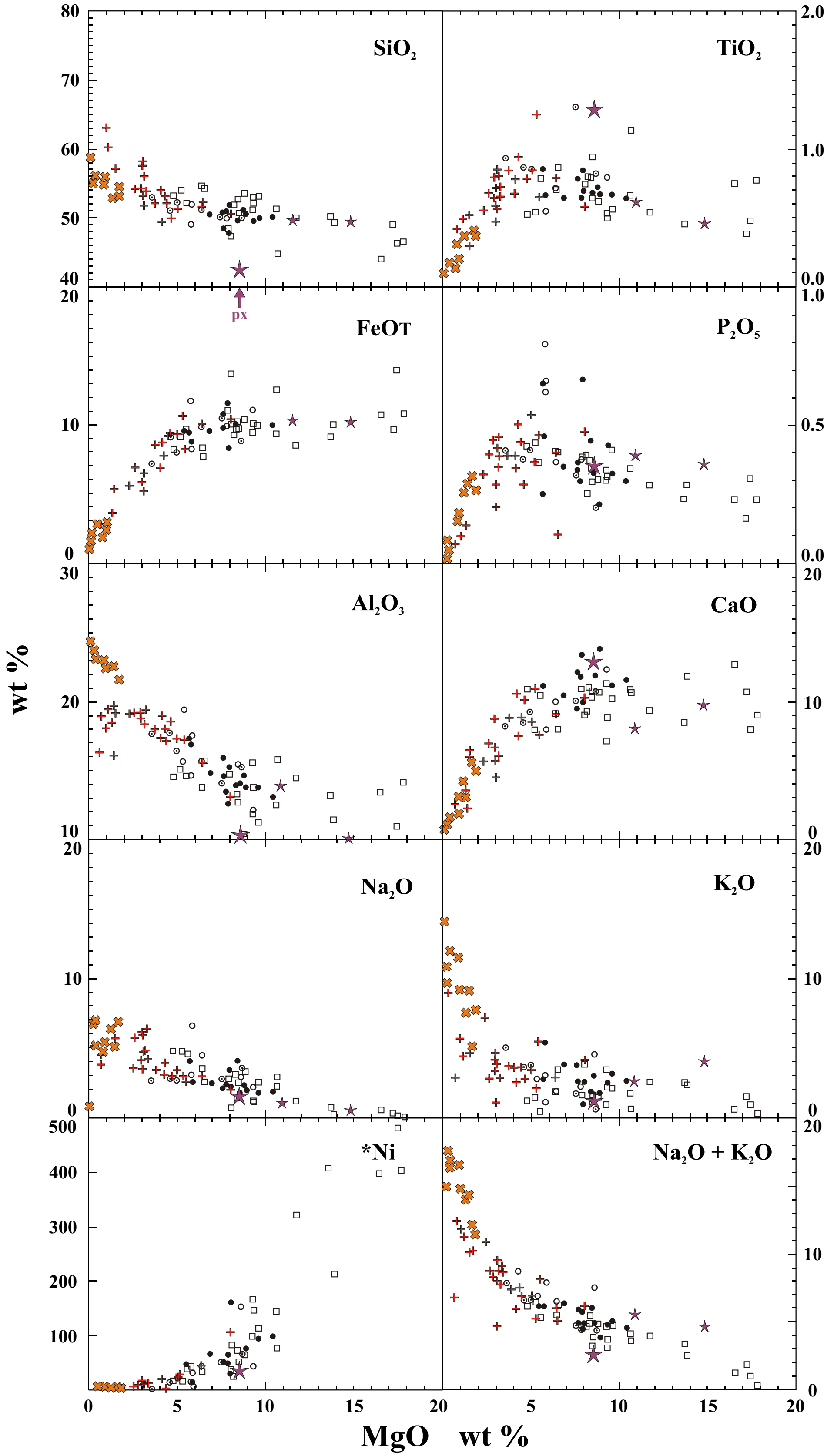

Figure 6. Major-element and trace-element bivariant diagrams for Nicola basalt, Eureka peak basalt (Bloodgood, 1987), pyroxenite (Fraser, 1994), regional intrusive units and Bootjack stock syenite. Symbols as in Figure 4 plus star, pyroxenite; large star, Fraser (1994). All analyses recalculated 100% volatile free. * Ni values in ppm.

TABLE 2. TRACE-ELEMENT DATA FOR VOLCANIC ROCKS FROM THE QUESNEL LAKE AREA. ELEMENTS ON LEFT SIDE OF TABLE (Au TO W) WERE ANALYZED AT ACME ANALYTICAL LABORATORIES, VANCOUVER; ELEMENTS ON RIGHT SIDE OF TABLE (Y TO Th) WERE ANALYZED AT MEMORIAL UNIVERSITY, NEWFOUNDLAND (MUN). ANALYTICAL METHOD ABBREVIATIONS: FAI, LEAD-COLLECTION FIRE ASSAY – ICP-ES FINISH; TICP, FOUR-ACID DIGESTION – INDUCTIVELY COUPLED PLASMA–EMISSION/MASS SPECTROMETRY ANALYSIS; PIMS, PEROXIDE FUSION – ICP-MS. HIDDEN STANDARDS (GSB TILL 99/GRX1 AND CANMET SY4) AND REPEAT ANALYSES (MMI04 21-1 AND ABA05 32-259-1) WERE USED TO EVALUATE ANALYTICAL ACCURACY FOR THE SUITE OF ELEMENTS ANALYZED AT ACME LABS AND AT MUN (GREY BACKGROUND)

Element	Au	Mo	Cu	Pb	Zn	Ag	Ni	Co	As	U	Bi	W
Unit	ppb	ppm	ppm	ppm	ppm	ppb	ppm	ppm	ppm	ppm	ppm	ppm
Method	FAI	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP
Detection Limit	1	0.05	0.02	0.02	0.02	20	0.1	0.2	0.2	0.1	0.04	0.1
Field Number												
Eastern volcanics (MLTNv)												
L05-31-244	10	0.43	67.55	3.43	78.6	54	27.6	23.3	0.6	0.4	bd	0.1
L05-31-245	2	0.35	125.54	3.5	76.4	70	33.8	24.5	1.1	0.5	bd	0.1
JLO 12-100	6	0.11	312.25	1.76	61.3	144	89.5	32.7	33.2	0.1	-0	0.5
L05-12-104	4	0.22	234.01	66.52	50.7	259	58.2	20.5	5	1.7	0.34	1.5
Central volcanics (LTNv)												
L05-6-23	3	0.37	141.68	5.86	86.6	90	94.8	47.6	1.7	0.4	0.04	0.2
L05-9-69	6	0.53	101.23	3.8	67	74	73.6	37	1.3	0.5	bd	0.2
L05-18-140	11	0.28	144	5.45	86.1	86	45.1	38.7	3	0.4	bd	0.1
L05-28-204	5	0.48	150.12	5.09	89.8	83	92.8	44.8	1.4	0.4	bd	0.2
L05-29-210	7	0.49	158.7	6.37	91.1	95	57.1	38.8	2.1	0.6	bd	0.2
L04-14-24	2	0.62	204.43	5.82	98.1	77	57.1	41.7	3.5	0.5	bd	0.2
M04-19-6	5	1.63	42.69	5.21	82.8	37	62.8	35.4	2.2	0.7	bd	0.6
L04-18-50	5	1.16	99.86	4.08	104.3	64	8.9	32.5	2.4	0.7	bd	0.4
M04-21-1b	8	1.17	150.98	8.68	85.3	104	47.4	29.9	32.9	1	bd	0.7
M04-22-4	5	0.66	135.96	7.57	74.6	83	158	36.7	3.4	1.2	bd	0.3
M04-27-1	5	1.96	289.07	8.32	118.8	206	13.6	46.4	2.7	1.1	bd	0.5
L05-32-248	bd	0.69	204.19	5.67	87.1	79	56.8	41.4	1.9	0.7	bd	0.2
L04-12-10	13	1.28	169.8	6.66	101.5	98	26.3	51.3	1.7	0.9	bd	0.3
L04-18-52	6	0.6	172.07	9	104.8	87	26.9	36.2	4.8	0.5	bd	0.5
L05-5-20	8	0.35	232.27	9.83	93.1	111	24.6	28.7	1.6	1.8	0.07	0.2
L05-13-109	4	0.77	132.41	4.44	92.1	38	45.9	50	7.1	0.8	bd	0.5
L05-29-216	9	0.74	54.28	5.8	121	40	38.1	37.1	2.9	0.7	bd	0.5
L05-32-246-2	3	0.71	208.93	6.56	125.3	140	12.6	45.9	4.2	1.1	bd	0.2
L05-17-133	bd	1.47	123.36	1.29	86.5	71	54.7	41	4.2	0.7	bd	0.2
L05-26-194	5	0.73	102.72	5.34	86.1	55	66.3	39.3	2.2	0.6	bd	0.1
L05-30-222	11	2.41	13.92	3.62	43.8	45	4.3	11.4	6.8	1.2	0.04	3.3
B05-35-280	bd	1.62	163.46	4.15	67.5	241	16	37.5	2.3	1.3	bd	0.5
L05-30-223	3	2.27	48.24	5.03	53.8	101	22.1	21.9	1.2	1.9	bd	1.6
Early Jurassic Dacite												
M04-26-18	2	1.16	57.71	5.79	77.9	113	1.6	10.5	2.6	0.8	bd	0.7
Q/C												
Standard	35	19.04	1289.10	830.98	899.5	38425	38.9	8.7	473.3	36.2	1701	200
Recommended	36	18.00	1110.00	720.00	760.0	31000	41.0		401.0	33.0	1380	164
Sample	25	0.74	99.23	47.56	104.1	343	3.3	16.6	12.2	1.8	0.15	1.6
Sample (rep)	24	0.84	99.56	47.37	110.5	363	3.3	16.7	12.1	2.0	0.14	1.6
% Difference	4	12.66	0.33	0.40	6.0	6	0.0	0.6	0.8	10.5	6.90	0.0

Element	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Th
Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Method	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN	MUN
Detection Limit	0.004	0.042	0.028	0.077	0.006	0.008	0.003	0.030	0.014	0.006	0.017	0.004	0.026	0.002	0.010	0.003	0.012	0.003	0.021	0.042	0.008
Field Number																					
Eastern volcanics (MLTNv)																					
L05-31-244																					
L05-31-245	15.54	50.29	2.23	927.80	7.18	14.17	1.94	8.97	2.44	0.83	2.90	0.47	2.98	0.62	1.80	0.27	1.80	0.26	1.52	0.10	0.83
JLO 12-100	28.28	88.90	2.14	37.96	3.42	8.74	1.82	9.86	3.26	1.31	4.68	0.78	5.14	1.09	3.17	0.46	3.00	0.42	2.30	#####	#####
L05-12-104	23.84	133.24	15.51	1688.75	47.21	76.74	9.51	36.03	5.88	1.31	4.96	0.67	4.01	0.83	2.44	0.36	2.41	0.38	3.24	0.67	14.31
Central volcanics (LTNv)																					
L05-6-23	12.23	38.41	1.64	643.91	5.57	11.40	1.62	7.80	2.05	0.71	2.40	0.39	2.47	0.50	1.44	0.21	1.35	0.20	1.15	0.07	0.64
L05-9-69	14.67	51.58	2.10	1040.24	5.51	12.37	1.78	8.68	2.45	0.79	2.93	0.47	2.97	0.59	1.74	0.25	1.58	0.23	1.48	0.11	0.97
L05-18-140	12.29	41.25	1.55	1289.30	6.56	12.76	1.76	8.04	2.08	0.70	2.50	0.39	2.41	0.49	1.47	0.21	1.42	0.21	1.24	0.08	0.84
L05-28-204	13.57	43.88	1.98	882.05	6.37	12.94	1.79	8.39	2.19	0.75	2.54	0.41	2.54	0.52	1.51	0.22	1.48	0.22	1.28	0.09	0.75
L05-29-210	14.60	49.72	2.70	1164.59	7.51	14.97	2.05	9.40	2.43	0.82	2.73	0.44	2.78	0.58	1.68	0.24	1.64	0.25	1.23	0.12	1.04
L04-14-24	13.63	34.05	1.59	1687.44	5.61	11.70	1.71	8.27	2.14	0.75	2.73	0.44	2.82	0.54	1.56	0.22	1.48	0.21	1.07	0.08	0.63
M04-19-6	12.42	39.56	4.62	2092.92	6.26	12.54	1.75	8.16	1.99	0.68	2.42	0.38	2.43	0.50	1.44	0.21	1.39	0.20	1.12	0.12	0.92
L04-18-50	16.65	56.91	2.48	1443.90	6.45	13.47	1.90	9.19	2.32	0.82	2.99	0.50	3.25	0.65	1.91	0.28	1.85	0.26	1.55	0.12	0.92
M04-21-1b	12.40	52.10	4.77	2495.53	8.05	15.45	2.06	9.06	2.13	0.70	2.37	0.38	2.38	0.48	1.42	0.21	1.42	0.20	1.35	0.16	1.34
M04-22-4	12.60	75.76	4.57	2068.57	10.78	21.41	2.84	12.22	2.66	0.81	2.73	0.42	2.46	0.49	1.43	0.21	1.40	0.20	1.87	0.16	2.11
M04-27-1	16.22	68.62	3.75	1080.19	16.50	31.37	4.10	17.49	3.74	1.16	3.77	0.56	3.31	0.64	1.82	0.26	1.64	0.23	1.83	0.17	2.28
L05-32-248	12.98	40.66	1.70	897.37	8.42	16.75	2.29	10.38	2.41	0.80	2.70	0.41	2.58	0.52	1.51	0.21	1.39	0.20	1.21	0.07	0.94
L04-12-10	13.84	55.28	3.24	764.32	13.54	26.84	3.56	15.69	3.40	1.04	3.57	0.52	3.02	0.55	1.49	0.21	1.34	0.19	1.55	0.14	1.72
L04-18-52	11.47	44.97	2.73	1707.68	8.23	16.06	2.14	9.78	2.23	0.72	2.44	0.37	2.24	0.44	1.29	0.19	1.22	0.18	1.24	0.13	1.19
L05-5-20	11.40	54.54	3.83	1626.08	15.09	24.82	3.01	11.89	2.38	0.75	2.40	0.36	2.20	0.44	1.27	0.18	1.23	0.18	1.29	0.14	2.28
L05-13-109	14.75	55.71	3.04	885.21	11.27	21.93	2.88	12.90	2.97	0.96	3.26	0.50	3.06	0.59	1.69	0.24	1.54	0.23	1.58	0.14	1.47
L05-29-216	14.46	49.72	2.64	2172.05	7.47	14.81	2.04	9.43	2.39	0.78	2.65	0.43	2.75	0.56	1.63	0.24	1.56	0.23	1.35	0.12	1.12
L05-32-246-2	15.46	55.10	3.63	1489.70	13.28	26.39	3.62	16.17	3.72	1.16	3.87	0.57	3.34	0.63	1.73	0.24	1.56	0.23	1.75	0.20	1.56
L05-17-133	22.10	80.70	4.21	1002.50	7.34	16.50	2.50	12.03	3.33	1.15	4.25	0.68	4.41	0.91	2.61	0.37	2.43	0.36	2.17	0.22	1.28
L05-26-194	18.69	69.53	3.40	372.34	6.94	14.66	2.09	9.92	2.60	0.92	3.19	0.54	3.53	0.72	2.11	0.31	2.04	0.32	1.84	0.17	0.99
L05-30-222	21.57	98.48	4.31	2838.67	12.50	26.78	3.80	17.45	4.21	1.25	4.26	0.68	4.16	0.86	2.42	0.36	2.33	0.35	2.49	0.21	2.91
B05-35-280	17.73	72.02	3.05	1922.88	10.10	20.95	2.94	13.51	3.20	0.99	3.56	0.56	3.48	0.72	2.02	0.29	1.97	0.28	1.99	0.16	2.35
L05-30-223	18.69	75.06	4.02	2966.24	13.82	27.91	3.83	17.22	3.99	1.33	3.92	0.59	3.62	0.75	2.12	0.31	1.99	0.30	1.96	0.17	3.66
Early Jurassic Dacite																					
M04-26-18	10.72	68.15	2.24	2727.23	6.83	13.81	1.91	8.54	1.97	0.68	2.05	0.33	2.00	0.41	1.24	0.19	1.31	0.19	1.63	0.13	1.38
Q/C																					
Standard	107.54	612.00	17.95	410.03	57.31	118.97	14.75	57.77	12.47	1.89	14.12	2.63	18.91	4.31	14.21	2.26	14.91	2.06	11.06	0.82	1.28
Recommended	119.00	517.00	13.00	340.00	58.00	122.00	15.00	57.00	12.70	2.00	14.00	2.60	18.20	4.30	14.20	2.30	14.80	2.10	10.60	0.90	1.40
Sample	9.63	57.96	4.49	2990.90	11.23	19.02	2.28	9.07	1.80	0.65	1.75	0.27	1.74	0.36	1.10	0.18	1.22	0.18	1.36	0.20	1.61
Sample (rep)	9.46	56.56	4.49	3005.14	11.00	18.74	2.27	8.85	1.79	0.64	1.71	0.27	1.70	0.36	1.11	0.17	1.17	0.17	1.30	0.20	1.67
% Difference	1.83	2.45	0.03	0.48	2.07	1.46	0.44	2.53	0.32	0.70	2.36	1.83	2.00	1.46	0.69	3.89	4.85	5.80	4.11	0.31	3.91

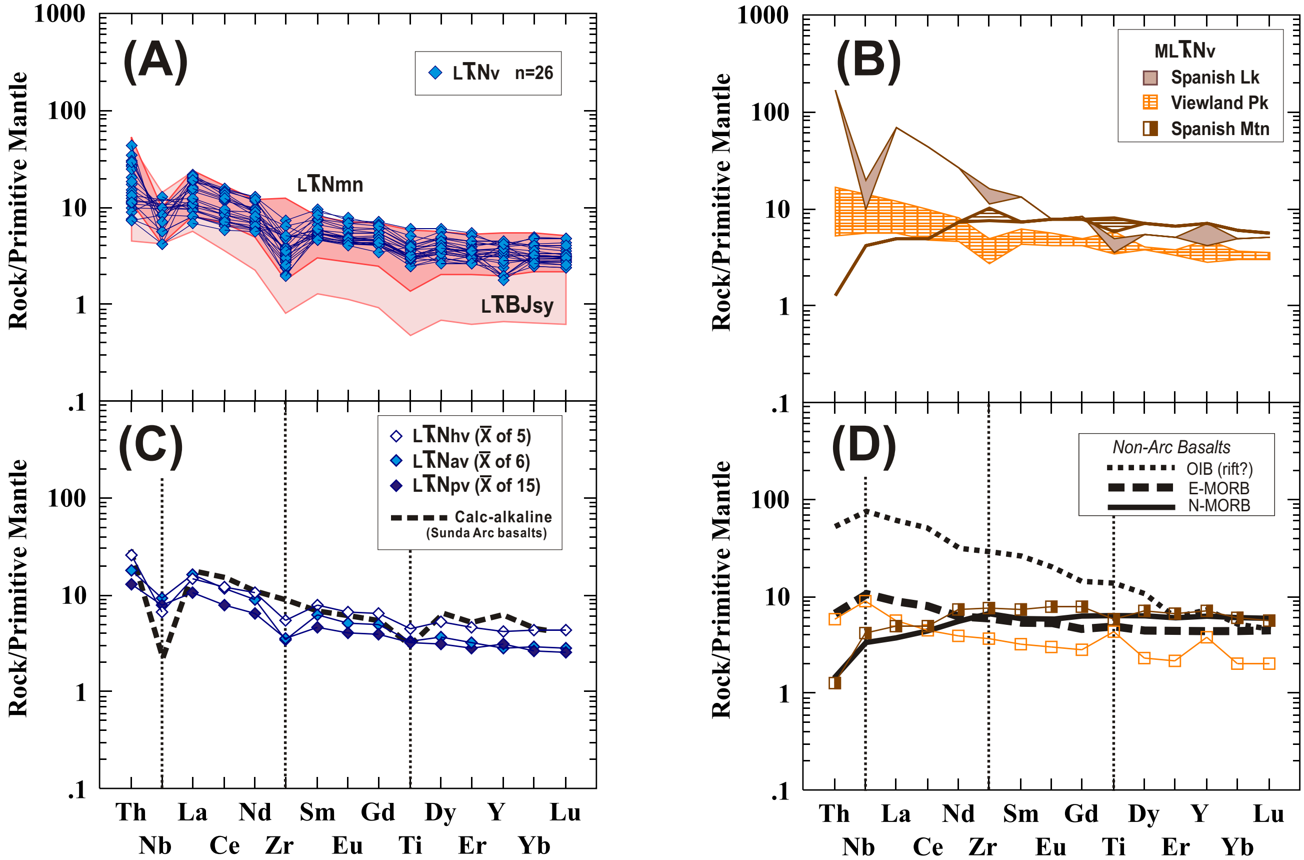

Figure 7. Primitive mantle–normalized (Sun and McDonough, 1989) multielement plots for Late Triassic Nicola Group basalt and basaltic andesite (LTNv) from the central part of the arc (A and C) and Middle to Late Triassic 'black phyllite'–hosted volcanic rocks (MLTNv) from the eastern side of the arc (B and D). Shaded areas in A correspond to the range of values for Late Triassic regional diorite to monzonite intrusive rocks (dark) and syenite of the Bootjack stock (light). Plot C compares average pattern of pyroxene, analcime and hornblende-phyric basalts with a typical calcalkaline island-arc basalt from the Sunda Arc (Jenner, 1996). Plot D compares average pattern of Viewland Peak metabasalt and pillowed basalt (L05-12-100) from Spanish Mountain with OIB, E-MORB and N-MORB from Sun and McDonough (1989).

CaO and Ni values display positive correlations, whereas Al_2O_3, Na_2O and SiO_2 and Na_2O+K_2O correlate negatively. The major-oxide trends show the least differentiated (*i.e.*, highest wt% MgO) to be the oldest basalt of unit 1A, and show progressive evolution and differentiation from pyroxene to analcime and finally hornblende-bearing basalt and the coeval/cogenetic intrusive suites of diorite-monzodiorite-syenite (Panteleyev *et al.*, 1996; this study). The pyroxenite that intrudes the Gavin Lake sedimentary succession is more primitive and shows better overall positive correlation with differentiation trends than the Mount Polley pyroxenite (Fraser, 1994). In fact, the Mount Polley pyroxenite sample has an intermediate MgO value relative to the most primitive basalt and the most fractionated syenite samples from the Bootjack stock (Bath and Logan, 2006). Overall, the differentiation trends are normal and consistent with fractional crystallization of olivine, clinopyroxene, Fe-Ti oxides, plagioclase and apatite. The increase in Al_2O_3 and SiO_2 and the sharp decrease in CaO and MgO beginning at approximately 9 wt% MgO probably reflect fractional crystallization (removal) of clinopyroxene. The sharp decline in Ni (and Cr) supports an early fractionation of olivine and clinopyroxene, and the general increase in P_2O_5 and TiO_2 contents with decreasing MgO reflects early suppression and subsequent crystal fractionation of apatite and sphene (Fig. 6).

The K_2O values show no correlation, whereas Na_2O shows a strong negative correlation, as does Na_2O+K_2O with the exception of the highly differentiated and potassic Bootjack stock syenite.

Trace Elements and Rare Earth Elements

Trace and rare earth element (REE) abundances of representative volcanic rocks from the Nicola Group are given in Table 2.

Mafic rocks from the central belt are basalt and basaltic andesite. They have TiO_2 contents of 0.7–0.85 wt% and low Nb contents ranging from <3 to 7 ppm (Table 1). The chondrite-normalized REE patterns for the basalt from the central belt are characterized by mean light rare earth element (LREE) enrichments (La/Yb_{CN} = 3.4, 3.9 and 5.6) and a downward sloping pattern toward the heavy rare earth elements (HREE). The HREE are essentially flat, (<10 times chondrite, not shown). Primitive mantle–normalized trace-element patterns of the Central arc basalt suite (LTNpv, LTNav and LTNhv) have broadly similar patterns (Fig. 7A, C). All are characterized by moderate negative Nb anomalies relative to Th and La, and all possess negative Ti anomalies and a generally downward sloping profile from LREE to HREE. The geochemical patterns for the basalt, and a suite of Late Triassic diorite-monzonite-syenite intrusive rocks collected from the study area, are similar and suggest that they are cogenetic. Also shown is the trace-element pattern of the Late Triassic Bootjack syenite stock, with its higher concentrations of incompatible elements (left side of diagram) and lower concentrations of compatible elements (right side of diagram) compared to the regional diorite and basalt, which is consistent with fractionation from a dioritic parent magma (Bath and Logan, 2006). Primitive mantle–normalized mean trace-element values of the hornblende, analcime and pyroxene-phyric basalts (Fig. 7C) are variably depleted but closely parallel the pattern for calcalkaline-arc basalt from the Sunda arc (Jenner, 1996), which supports the field relationships (*i.e.*, interlayered breccia flows and coarse to fine tuff, polylithic breccia and epiclastic deposits).

The mafic volcanic rocks from the eastern volcanic belt (Spanish Lake, Spanish Mountain and Viewland Peak suites) are subalkaline basalt and andesite. They have similar TiO_2 contents of 0.7–1.0 wt% and low Nb contents of 3–14 ppm (Table 1), but show different trace-element abundances and multielement patterns when compared. Chondrite-normalized REE patterns for the basalt from the Viewland Peak suite are characterized by mean LREE enrichments ($La/Yb_{CN} = 2.8$) and a downward sloping pattern toward the HREE, but the basalt from Spanish Mountain is characterized by an upward sloping pattern toward the HREE. The HREE are essentially flat (~10 times chondrite for VP and 20 times chondrite for SM, not shown). The primitive mantle–normalized trace element patterns of the Viewland Peak and Spanish Mountain basalts (Fig. 7B, D) are characterized by depletions in the LREE (La, Ce) and most incompatible elements (Th, Nb), and therefore reflect typical depleted-mantle sources. Both have a positive Nb anomaly relative to Th and La, and positive Zr and Ti anomalies. They have flat or slightly negative slopes that closely overlap the global compilation patterns (Sun and McDonough, 1989) for enriched mid-ocean ridge basalt (E-MORB) and normal mid-ocean ridge basalt (N-MORB), respectively. The primitive mantle–normalized trace-element patterns for the Spanish Lake basalt are similar to patterns for subduction-generated arc basalt, but show elevated incompatible elements (Th, Nb) in comparison to central belt alkaline basalt.

On the Zr-Y-Ti tectonic discrimination diagram (after Pearce and Cann, 1973; Fig. 8), which is used to distinguish non-arc basalt (high Ti/Y ratios) from other magma types, all of the basalt from the central volcanic belt plots in arc-basalt fields, specifically fields A (tholeiitic volcanic-arc basalt, VAB) and B (MORB and calcalkaline VAB), with three metabasalt samples (MLTRNv) from the eastern side of the arc (Viewland Peak area) plotting in field C (calcalkaline VAB). The distinction between fields A and B and field C can be modelled by upper crustal assimilation, which changes the composition from the average N-MORB mantle toward average upper crustal compositions (higher Zr values; Pearce, 1996). All of the basalt from the central volcanic belt has high-field-strength element (HFSE) abundances that are characteristic of VAB (high Th/Y ratios and Nb depletion) and plot in the calcalkaline (Hf/Th ratios <3) portion of the arc-basalt field on Figure 9 (after Wood, 1980). A single sample of pillowed basalt from Spanish Mountain falls into the MORB field (A).

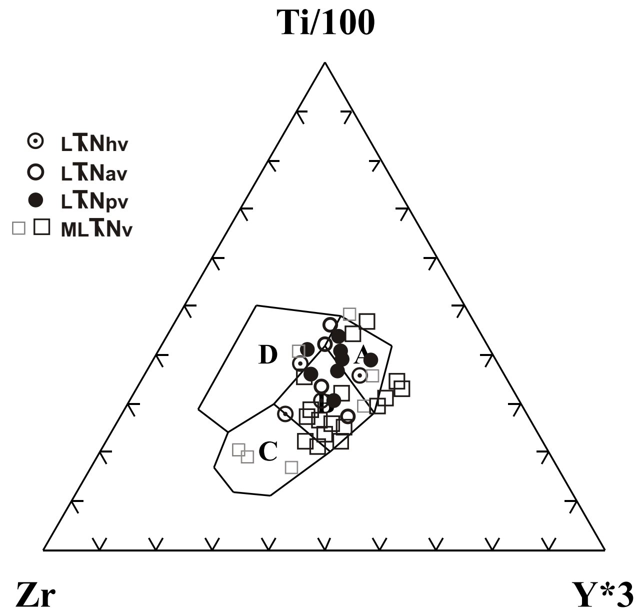

Figure 8. Tectonic discrimination diagram based on Zr, Ti, Y (after Pearce and Cann, 1973), used to distinguish non-arc basalt (high Ti/Y ratios) from other magma types and a partial separation of MORB and VAB. MORB plot in field B, calcalkaline VAB plot in fields B and C, tholeiitic VAB plot in field A and C, and non-arc within-plate basalt (WPB) plot in field D. Symbols as for Figure 3. All basalt and basaltic andesite from the central volcanic belt plot within fields A and B, with the exception of three basalt samples (MLTRNv) from the eastern side of the arc (Viewland Peak area), which occupy field C.

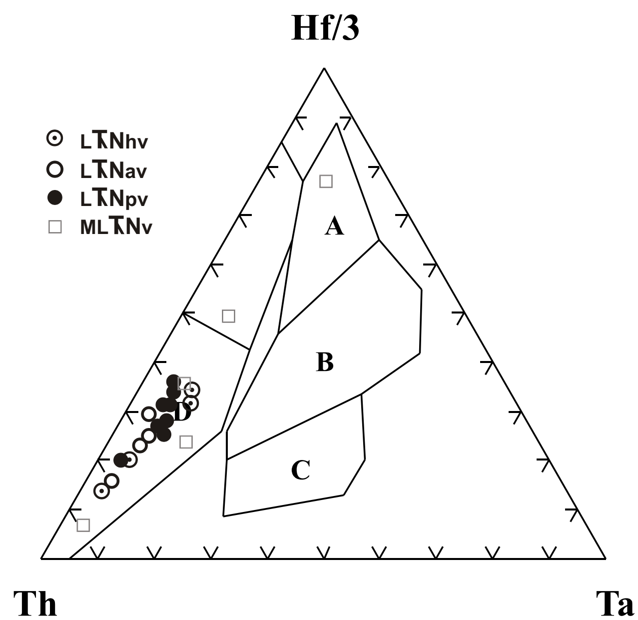

Figure 9. Tectonic discrimination diagram based on Th, Hf, Ta (after Wood, 1980), used to distinguish arc basalt (high Th/Ta) and theoretically between calcalkaline basalt, tholeiitic-arc basalt and non-arc basalt. Basalt and basaltic andesite from the central volcanic belt fall within the calcalkaline-arc basalt field (D). A single pillowed basalt sample from Spanish Mountain plots within the MORB field (A).

DISCUSSION

The Late Triassic Takla and Nicola rocks of Quesnellia have features of shoshonitic rocks derived from island arcs (de Rosen-Spence, 1985; Mortimer, 1987; Barrie, 1993; Pantelyev *et al.*, 1996; Nelson and Bellefontaine 1996), similar to the Late Triassic Stuhini rocks of Stikinia (Logan and Koyanagi, 1994; Logan, unpublished data, 2005). Low initial Sr ratios and εNd values (Preto *et al.,* 1979; Smith *et al.*, 1995; Lang *et al.*, 1995) indicate a primitive intraoceanic setting that was not underlain by continental (enriched-mantle) material.

Arc basalt is derived from essentially two sources; the subarc mantle wedge and an aqueous fluid and/or melt (adakitic lavas; Kay, 1981; Peacock *et al.,* 1994) derived from the subducted slab (Davies and Stevenson, 1992; Kerrich and Wyman, 1996). Dehydration of the slab at depths of approximately 100 km releases fluids that metasomatize the overlying subarc mantle wedge (MORB-like; Pearce and Peate, 1995), enriching it in the volatiles, S, SiO_2 and large-ion lithophile elements (LILE) such as Rb, K, Cs, Ba and Sr (Tatsumi *et al.*, 1986; de Hoog *et al.*, 2001). Certain high-field-strength elements (HFSE), such as Ti, Nb and Ta, are not mobilized (conservative elements; Pearce and Peate, 1995) but are retained in the downgoing slab. Melting of the subarc mantle wedge produces primary basaltic magmas that are distinguished from MORB by their higher H_2O and LILE and anomalously low Ti, Nb and Ta contents (Richards, 2003). These magmas rise to the base of the crust where they undergo a multistage process involving crustal **m**elting, **a**ssimilation, **s**torage and magma **h**omogenization (‘MASH’ model of Hildreth and Moorbath, 1988).

In southern BC, the Quesnel Terrane is an isotopic and geochemically primitive arc complex that formed above an east-dipping subduction zone (Cache Creek Terrane). Early Mesozoic magmatism responsible for construction of the arc is characterized by calcalkaline and alkaline stages of development. Arc magmatism migrated eastward with time, beginning in the west, *ca.* 212 Ma, with development of Cu-Mo±Au deposits at Highland Valley and Gibraltar that are related to calcalkaline intrusions of the Guichon plutonic suite (Woodsworth *et al.*, 1991). At the latitude of Mount Polley (east of Gibraltar), the majority of the arc consists of Na and K-rich, submarine to subaerial lava flows and cogenetic alkaline intrusions that represent ~20 m.y. (Norian stage) of alkaline magmatism. The chemical trends of the basaltic rocks change over time (up stratigraphy) from primitive eastern basalt (MLTRNv) and pyroxenite to more evolved/felsic central basalt (LTRNv). They overlap and parallel the chemical evolution of the Late Triassic intrusions and are likely cogenetic. Magmatism culminated between 204 and 200 Ma (Copper Mountain plutonic suite of Woodsworth *et al.*, 1991) with the intrusion of evolved monzonitic to syenitic bodies and Cu-Au porphyry mineralization. The causative magma in a mineralized porphyry system provides the heat, H_2O, S and metals to the system. These elements are exsolved from the magma and produce the brecciation, alteration and Cu mineralization. Bath and Logan (2006) present chemistry and petrography that favours the Late Triassic Bootjack stock (Bailey and Archibald, 1990) as a late fractionate/component of the causative magma responsible for mineralization at Mount Polley.

Uplift and erosion of the fore-arc produced sub-Jurassic unconformities as magmatism shifted east and culminated with intrusion of calcalkaline plutons at 195 Ma and deposition of distal volcaniclastic and younger sedimentary rocks across the terrane. In the study area, only small, high-level, quartz-bearing calcalkaline intrusions represent the voluminous Early Jurassic calcalkaline magmatism that is preserved in the southern and northern Quesnel Terrane. To the south, this magmatism is represented by an arc-parallel belt of 195 Ma calcalkaline batholiths (Takomkane, Thuya, Wild Horse, Pennask) in the eastern part of the Quesnel Terrane that represent the roots of this Early Jurassic magmatic arc.

CONCLUSIONS

The basalt and trachyte of the Nicola Group have well-developed high-field-strength element (Nb, Ta, Zr, Hf, Ti) depletions, and Th, U, and large-ion lithophile element (Rb, Ba, K, Sr) enrichment, which is typical of subduction-zone magmas in the central belt. They have REE concentrations similar to those of the Mount Polley igneous complex, consistent with a similar melt source and a cogenetic relationship through fractional crystallization.

The eastern volcanic belt contains metavolcanic units with geochemical characteristics of non-arc basalt that represent initiation of volcanism either in a back-arc basin or transitional volcanic arc-marginal basin setting. The latter model is supported by geochemistry and Nd isotope characteristics of Upper Triassic sedimentary rocks in the southern Quesnel Terrane (Unterschutz et al., 2002).

An interpretation that the rocks in the Quesnel Lake area may have been erupted within mature island-arc settings is consistent with the dominance of alkaline basaltic over intermediate andesitic compositions, the shoaling of the arc, and shallow-water deposition of limestone and reworked, locally derived volcaniclastic rocks.

The intrusive complex at Mount Polley represents one of a number of Cu-Au-mineralized magmatic centres that define the culmination of alkaline magmatism (Copper Mountain plutonic suite of Woodsworth *et al.*, 1991) in the Latest Triassic development of the Quesnel Terrane. An eastward shift of magmatism in the Early Jurassic and the return to mainly calcalkaline volcanism is marked by the appearance of a quartz-bearing dacite and Early Jurassic fossiliferous sedimentary rocks.

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