The Cheslatta Lake suite: Miocene mafic, alkaline magmatism in central British Columbia[1]

Robert G. Anderson, Jonah Resnick, James K. Russell, G.J. Woodsworth, Michael E. Villeneuve, and Nancy C. Grainger

Abstract: New mapping, mineralogical, and geochemical studies help characterize late Tertiary primitive, alkaline, sodic basanite, alkali olivine basalt, transitional basalt, and diabase in the Nechako River, Whitesail Lake, and McLeod Lake map areas of central British Columbia and distinguish the Miocene Cheslatta Lake suite. The suite encompasses scattered erosional remnants of topographically distinct, columnar-jointed, olivine-phyric basalt and diabase volcanic necks, dykes, and associated lava flows north of the Anahim volcanic belt and west of the Pinchi Fault. Volcanic centres at Alasla Mountain and at Cutoff Creek, near Cheslatta Lake, are proposed as type areas. Olivine, plagioclase, and pyroxene phenocrysts, megacrysts, and (or) xenocrysts; common ultramafic xenoliths; and rare but significant plutonic and metamorphic xenoliths are characteristic. Basanite, transitional basalt, and alkali olivine basalt groundmass contain plagioclase, clinopyroxene, Fe-Ti oxides, feldspathoid, olivine, and apatite. The Cheslatta Lake suite is characterized by its alkaline character, olivine-rich (>10 wt.%) normative mineralogy, and silica-undersaturated nature (>1 wt.% normative nepheline; hypersthene-normative rocks are uncommon). Mg numbers vary between 72–42. Some samples encompass near-primitive mantle melt compositions. Cheslatta Lake suite rocks in the Nechako River area are distinguished from the underlying Eocene Endako and stratigraphically higher Neogene Chilcotin groups basaltic andesite lavas within the study area, and from the Chilcotin Group basalt in the type area south of the Anahim volcanic belt, by form, preserved thickness, phenocryst–xenocryst mineralogy, amygdule abundance, included xenoliths, isotopic age, and major and incompatible, high field strength, and rare-earth trace element contents.

Résumé : Une nouvelle cartographie et de nouvelles études minéralogiques et géochimiques aident à caractériser la basanite sodique, alcaline et primitive du Tertiaire tardif, le basalte alcalin à olivine, le basalte de transition et la diabase dans les régions cartographiques de la rivière Nechako et des lacs Whitesail et McLeod du centre de la Colombie-Britannique et aident à distinguer la suite de Cheslatta Lake, datant du Miocène. La suite comprend des lambeaux épars de l'érosion de roches topographiquement distinctes et à structure prismée; ces roches comprennent des basaltes à olivine porphyrique, des « necks » de diabase volcanique, des dykes et des coulées de lave associées, au nord de la ceinture volcanique Anahim et à l'ouest de la faille Pinchi. Nous proposons les centres volcaniques du mont Alasla et du ruisseau Cutoff, près du lac Cheslatta, comme régions types. Les roches suivantes sont caractéristiques des phénocristaux, des mégacristaux et (ou) des xénocristaux d'olivine, de plagioclase et de pyroxène; des xénolites ultramafiques communs et de rares mais significatifs xénolites plutoniques et métamorphiques. La matrice rocheuse de basanite, de basalte de transition et de basalte alcalin à olivine comprend du plagioclase, du clinopyroxène, des oxydes de Fe–Ti, des feldspathoïdes, de l'olivine et de l'apatite. La suite de Cheslatta Lake est caractérisée par son caractère alcalin, sa minéralogie normative riche en olivine (>10 % en poids) et sa sous-saturation en silice (les roches à > 1 % en poids de néphéline normative, hypersthène normatif sont peu communes). Les nombres pour le Mg varient entre 72 et 42. Quelques échantillons présentent des compositions du manteau quasi-primitif en fusion. Dans la région de la rivière Nechako, les roches de la suite de Cheslatta Lake se distinguent des roches sous-jacentes Endako, datant de l'Éocène, et des laves basaltiques à andésite des groupes Chilcotin, datant du Néogène, stratigraphiquement plus hautes ainsi que du basalte du Groupe Chilcotin dans la région type au sud de la ceinture volcanique Anahim par les points suivants la forme, la conservation de l'épaisseur, la minéralogie des phénocristaux–xénocristaux, l'abondance d'éléments

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R.G. Anderson[2] and G.J. Woodsworth. Geological Survey of Canada, 101–605 Robson Street, Vancouver, BC V6B 5J3, Canada.
J. Resnick[3] and J.K. Russell. Department of Earth and Ocean Sciences, The University of British Columbia, 6339 Stores Road, Vancouver, BC V6T 1Z4, Canada.
M.E. Villeneuve. Geological Survey of Canada, 601 Booth St., Ottawa, ON K1A 0E8, Canada.
N.C. Grainger. University of Alberta, Edmonton, AB T6G 2E3, Canada.

[1]Geological Survey of Canada Contribution 2000193.
[2]Corresponding author (e-mail: boanders@nrcan.gc.ca).
[3]Present address: Department of Earth and Planetary Sciences, McGill University, 3450 rue University, Montréal, QC H3A 2A7, Canada.

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amygdaloïdes, les xénolites inclus, l'âge isotopique ainsi que, significatif et incompatible, une grande intensité du champ et des contenus trace en éléments des terres rares.

[Traduit par la Rédaction]

Introduction

Neogene–Paleogene plateau basalt flows and intrusions are an important component of the widespread Tertiary igneous rocks that underlie the Interior Plateau in central and south-central British Columbia. They cover an area of 25 000 km^2 from latitude 49°N through 55°N (Fig. 1; Souther and Yorath 1991). The "plateau lavas" were first described by Dawson (1879, 1895) and more accurately delimited and distinguished from Eocene mafic rocks in the more modern maps and reports of Tipper (1957, 1959, 1963, 1969) and Campbell and Tipper (1971). The original informal definition of Chilcotin Group basalt (CGB) of Tipper (1978), for an area south of our study area (Fig. 2), was later refined by Bevier (1983*b*) and Mathews (1989) to encompass basalt and associated pyroclastic and volcaniclastic sedimentary rocks of Late Oligocene to Early Pleistocene age that underlie the Okanagan Highland north to the Nechako Plateau, but exclude the volcanoes of the Anahim volcanic belt and younger Pleistocene to Holocene "valley basalts."

The CGB are plateau basalts underlying a large plateau, likely derived by the overlap of numerous low-profile shield volcanoes (Bevier 1983*b*; Souther and Yorath 1991). Individual vents for CGB volcanism include small cinder cones, volcanic necks, and gabbroic feeders, which locally crosscut lava flows (Farquharson 1973; Woodsworth 1979; Bevier 1983*b*; and Mathews 1989). The CGB is best known and most extensive in the central portion of the volcanic field, south of the Anahim volcanic belt (Fig. 1). Strata include crudely columnar-jointed, paehoehoe basalt flows, minor pillow lava and pillow breccia, and rare silicic tephra layers (Bevier 1983*b*). The stratigraphic thickness of CGB averages 67 m to a maximum of 141 m (Bevier 1983*b*). Estimates of total volume of lava erupted (e.g., 3300 km^3; Bevier 1983*b*) are uncertain due to the effects of Pleistocene glaciation (Bevier 1983*b*). In the south, CGB comprises olivine-bearing transitional basalt with lesser alkali basalt and quartz tholeiite (Bevier 1983*a*; Dostal et al. 1996; Coish et al. 1998). Centres from the northwestern (Poplar Butte; Church and Barakso 1990) and northeastern (Summit Lake Quarry; Brearley et al. 1984) margins of the field are substantially more silica undersaturated (10 wt.% normative nepheline), but were included in the CGB by Mathews (1989).

The northern, western, and southern extents of the CGB distribution are defined by the distribution of numerous erosional remnants of the basalt (Coish et al. 1998; Dostal et al. 1996; Church 1995; Church and Barakso 1990; Woodsworth 1979, 1980). The older K–Ar ages (Middle Miocene to Late Oligocene; Fig. 3 and references therein), relative abundance of more silica-undersaturated rock types, and local occurrences of ultramafic xenoliths (Brearley et al. 1984) suggested that the northern CGB centres (north of the Anahim volcanic belt) were distinct from those in the south.

Nonetheless, the northern component has received comparatively little study. Regional mapping in the study area by Armstrong (1949), Tipper (1963), and Woodsworth (1979, and in Stevens et al. 1982) suggested that ?Miocene mafic lava flows were distinguishable from Eocene rocks by inferred stratigaphic relationships, presence of olivine phenocrysts, and relative lack of alteration and deformation, but it was recognized that the distinction between Eocene and Neogene mafic rocks was inexact.

New data are presented below on the field relationships, age, petrography, and geochemical characteristics of alkaline basaltic rocks in the Nechako River (National Topographic System (NTS) map area 93F), Quanchus Range (Whitesail Lake map area, NTS 93E), and Summit Lake (McLeod Lake map area, NTS 93J) areas. These characteristics are used to (1) define the Cheslatta Lake suite (CLS), a new assemblage of mainly Miocene, olivine-phyric, ultramafic, xenolith-bearing, undersaturated basanite, transitional basalt and alkali olivine basalt lavas and high-level intrusive rocks (see more detailed definition below); (2) distinguish the CLS from Eocene Endako Group mafic rocks within the northern Nechako River map area, with which they were initially correlated (e.g., Tipper 1963; Mathews 1989; Williams 1997); and (3) compare and contrast CLS with lavas and plugs from the type area of mainly younger CGB south of the Anahim volcanic belt and with possible correlatives to the CGB in the eastern part of the Nechako River study area. Preliminary descriptions of individual sites within the CLS are found in Resnick et al. (1999), Resnick (1999), Struik et al. (1999), Church and Barakso (1990), and Woodsworth (1979).

Physiographic and geological setting

The Nechako Plateau is an area of subdued topographic relief as a result of Pleistocene glaciation and is commonly underlain by thick accumulations of glaciogenic materials. The region is almost entirely below tree line. Bedrock is exposed along ridges and small buttes, rivers, and along the numerous logging roads. Volcanic centres that make up CLS were first identified on air photographs by their distinct topographic character. They underlie high points or buttes of 30–150 m in relief (Table 1; Figs. 2, 4; e.g., Tyee and Poplar buttes, Devil's Thumb, Alasla Mountain, and an unnamed feature near Cicuta Lake).

Igneous rocks of the CLS were erupted through Paleozoic (or older) to Tertiary continental crust of a variety of terranes (Stikine, Cache Creek, Quesnel, Slide Mountain, and Kootenay terranes; Fig. 1). The CLS basement is a product of Middle Jurassic and later amalgamation of terranes of island arc and oceanic affinities and subsequent accretion to the ancient North American continental margin. Postaccretionary events included magmatism, metamorphism, and deformation and Eocene extensional tectonism, which encompassed dextral strike-slip faulting along north-trending faults, uplift of the Vanderhoof and Wolverine metamorphic core complexes, development of northeasterly and northwesterly trending block faults, and associated bimodal volcanism (Struik 1993, 1994; Anderson et al. 1998*b*, 2000*a*).

Fig. 1. Locations of Cheslatta Lake suite sites in relation to terrane boundaries; Chilcotin and Ootsa and Endako groups; and the Anahim volcanic belt (modified from Wheeler and McFeely 1991). Approximate terrane boundaries shown by heavy dashed lines and Pinchi fault zone. Terranes: ST, Stikine; CC, Cache Creek; QN, Quesnel; SM, Slide Mountain; NA, pericratonic (Kootenay) and North America. NTS map areas: 93E, Whitesail Lake; 93F, Nechako River; 93J, McLeod Lake. Inset map shows regional distribution of the Chilcotin tectonic assemblage of back-arc volcanic rocks (Wheeler and McFeely 1991) in central and southern British Columbia; grey polygon in inset map shows location of the larger scale part of the figure.

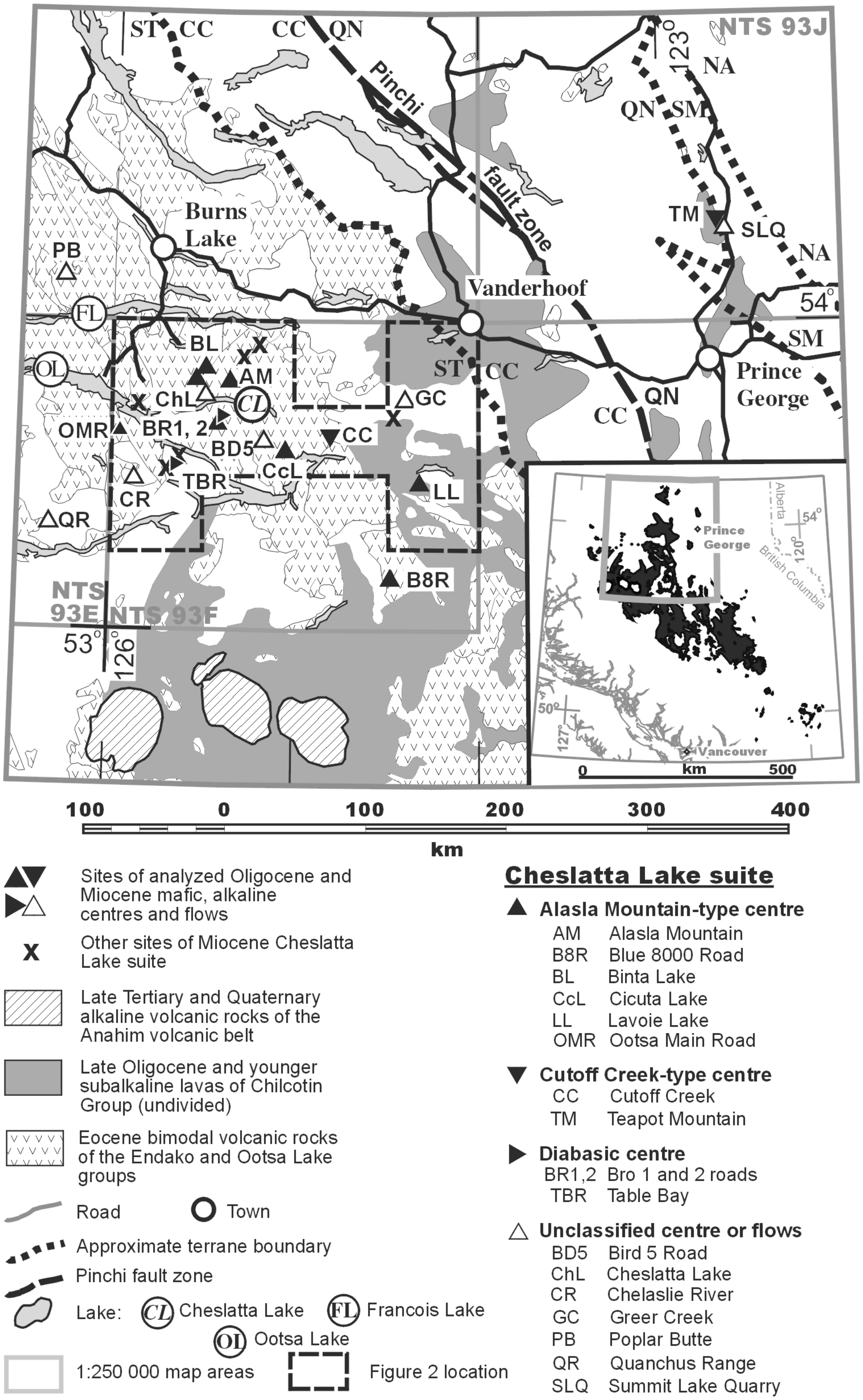


Table 1. Field properties and ages of volcanic and gabbroic rocks, northern Nechako River, Summit Lake, and Whitesail Lake map areas.

Location	Fig. 1 and Table 2 label	NTS map area	UTM easting (zone 10)[a]	UTM northing (zone 10)[a]	Form	Chemical rock name[b]
Bird Road No. 5, locality 1	BD5	93F/11	361258	5943268	Basaltic dyke and lava flow	Basanite[c]
Bird Road No. 5 locality 2,	BD5	93F/11	360954	5943601	Basaltic lava flow	Basanite[c]
Cicuta Lake	CcL	93F/11	364328	5939695	Basaltic volcanic plug	Basanite[c]
Binta Lake	BL	93F/14	336325	5968537	Basaltic volcanic plug	Basanite[c]
Blue 8000	B8R	93F/01	401271	5892467	Basaltic volcanic plug	Basanite
Summit Lake Quarry	SLQ	93J/07	523613	6017530	Basaltic lava flow	Basanite?[c]
Ootsa Main Road	OMR	93F/12	303790	5948008	Basaltic plug	Transitional basalt[c]
Table Bay Road	TBR	93F/12	325580	5934149	Gabbro plug (diabase)	Transitional basalt
Alasla Mountain	AM	93F/14	344931	5964890	Basaltic volcanic plug	Transitional basalt?[c]
Lavoie Lake	LL	93F/08	412379	5926478	Basaltic volcanic plug	Transitional?[c] basalt
Chelaslie River	CR	93F/05	313264	5928315	Basaltic lava flow	Alkali ol basalt[c]
Cheslatta Lake	ChL	93F/14	337083	5958682	Basaltic lava flow	Alkali ol basalt
Bro 2 Road	BR1, BR2	93F/11	342370	5954724	Gabbro plug (diabase)	Alkali ol basalt
Cutoff Creek	CC	93F/10	380505	5944585	Basaltic volcanic plug	Alkali ol basalt
Teapot Mountain	TM	93J/07	520858	6019898	Basaltic lava flow	Alkali ol basalt
Coffeepot Mountain		93J/07	516300	6030200	Basaltic? lava flow	
Greer Creek (Wetherup 1998)	GC	93F/16	409615	5958118	Lava flows	
Quanchus Range 78WV-397	QR	93E/09	669200 (zone 9)	5940850 (zone 9)	Basaltic volcanic plug(?)	Alkali ol basalt
Quanchus Range 78WV-399	QR	93E/09	673950 (zone 9)	5944450 (zone 9)	Basaltic lava flow	Alkali ol basalt
Quanchus Range 78WV-401	QR	93E/09	679600 (zone 9)	5944500 (zone 9)	Basaltic lava flow	Alkali ol basalt
Quanchus Range 78WV-403	QR	93E/08	685050 (zone 9)	5928900 (zone 9)	Basaltic lava flow	Basanite
Quanchus Range 78WV-406	QR	93E/07	662130 (zone 9)	5923650 (zone 9)	Basaltic lava flow	Alkali ol basalt

Note: NA, Not applicable.
[a]All UTM northing and easting coordinates given for samples listed in Table 2 are for UTM zone 10, except Quanchus Range samples, which are for UTM zone 9 (all in NAD 27).
[b]After LeBas et al. 1986. ol, olivine.
[c]Groundmass nepheline identified; ? indicates that nepheline identity uncertain or nepheline or alkali feldspar in groundmass.
[d]M.E. Villeneuve and N.C. Grainger, unpublished data, 1999.

Geology

The Cheslatta Lake suite is a previously undivided assemblage of Miocene mafic alkaline intrusive and extrusive - igneous rocks in northern Nechako River map area, characterized by outcrop characteristics, structural setting, abundance and nature of xenocrysts and phenocrysts, and petrographic textures (summarized in Table 1). The CLS is similar to older centres and lavas to the west and east of the reference area.

Outcrop characteristics and structural setting of the CLS

Neogene alkaline rocks of the CLS in central British Columbia occur as scattered erosional remnants of volcanic and diabasic necks (Figs. 1, 2, and 4), lava flows, and dykes. The volcanic and diabasic plugs typically exhibit continuous columnar jointing on the outcrop scale (e.g., Fig. 4) and range in area between 200 m^2 and 3 km^2. Diabasic, Alasla Mountain-type and Cutoff Creek-type volcanic centres (Figs. 1, 2) were distinguished by columnar-joint thickness; relative abundance of xenolith, megacryst, and phenocryst populations; and petrographic textures (Resnick et al. 1999; Resnick 1999). Diabasic centres have fine to medium grain size, thick columnar joints (1–3 m), ophitic and diabasic textures, but generally lack megacrysts and xenoliths. Alasla Mountain-type and Cutoff Creek-type volcanic centres are comparatively higher level intrusions, marking the location of former volcanoes, and have thinner columnar jointing (≥1 m), suggesting more rapid cooling; contain common megacrysts and xenoliths; and have aphanitic groundmasses.

The Alasla Mountain-type igneous centres contain abundant ultramafic xenoliths (>3% by volume) and lack plagioclase and pyroxene megacrysts. The Cutoff Creek-type volcanic centres contain rare ultramafic xenoliths, abundant plagioclase and pyroxene megacrysts, and have a vitreous groundmass.

The total stratigraphic thickness of flows within CLS in Nechako River map area is uncertain, because exposure is discontinuous and there are no thick stratigraphic sections. In the southwestern part of the Nechako River map area, three successive basalt flows were observed (L.C. Struik, personal communication, 1999). At individual localities, lava flows reach a maximum thickness of 10–15 m. Within 100 m of some plugs, basement is typically well exposed, structurally below the volcanic neck, suggesting that lava flows that erupted from these centres were not of significant thickness, post-Miocene erosion was significant enough to remove a substantial amount of material, and (or) that the flows filled paleo-valleys and did not spread out.

The exposures of thick sequences of lavas in the Quanchus Range (Figs. 1, 4; Woodsworth 1979, 1980), tentatively included in the CLS, are an important exception. There, about 150 km^2 of flat-lying, columnar-jointed basalt flows are exposed at an elevation of about 1700 m (Fig. 4*b*). The flows were erupted onto a surface having moderate topographic relief. No basalt is found above 1700 m elevation, suggesting

Type of centre	Shape	Dimension (plug)(m x m)	Relief (m)	Texture	Age[d]
NA	NA	NA	NA	Vesicular	Middle Miocene
NA	NA	NA	NA	Aphanitic	
Alasla	Oval	400 x 200	100	Rarely vesicular	
Alasla	Oval	200 x 100	40	Uncommonly amygdaloidal	
Unknown	Easterly elongate	2000 x 1500	150	Aphanitic	
NA	NA	NA	30	Dense	Late Oligocene
Alasla	Sub-circular	400 x 300	70	Dense	Middle Miocene
Diabasic	Circular	1000 x 1000	120	Diabasic (ophitic)	
Alasla	Sub-circular	500 x 450	165	Uncommonly amygdaloidal	Middle Miocene
Alasla	Sub-circular	350 x 325	100	Dense, vesicular	Middle Miocene
NA	NA	NA	NA	Dense	
NA	NA	NA	15	Uncommonly amygdaloidal	
Diabasic	Circular	1000 x 1000	60	Diabasic (ophitic)	
Cutoff	Sub-circular	300 x 250	90	Porphyritic, vitreous	
Cutoff	Oval	420 x 335	120	Dense	
Unknown	Sub-circular	825 x 600	160		
NA					
	Circular	200 x 200	ca. 100		Middle Miocene
			ca. 120		Early Miocene (Stevens et al. 1982)

that the sources of eruption were at or below that elevation and that the basalts ponded against the higher hills in the area. Locally, the flows are cut by basalt plugs that extend up to 20 m above the flat plateau surface formed by the flows (Fig. 4*b*). Locally, weakly consolidated to unconsolidated sand and gravel form a unit a few centimentres to a metre thick beneath the basal flow. Individual flows have a thickness of about 5–15 m, and the total thickness of the unit is about 100 m. Whereas the Endako Group basalts are tilted (and folded?), overlying Cheslatta Lake suite lavas in the Quanchus Range are undeformed and flat lying, indicating that block faulting in this area ceased before eruption of the Cheslatta Lake basalts.

The occurrence of the volcanic centres along extensional fault systems (Fig. 2; Struik 1994; Anderson et al. 1998*a*; Resnick et al. 1999; Anderson et al. 1999, 2000*b*) that experienced syn- and post-Eocene movement suggests that ascending Neogene magmas exploited preexisting structural weaknesses in the crust. In addition, a well-developed penetrative fracture cleavage observed locally within the Neogene rocks (Resnick et al. 1999) suggests possible further reactivation of preexisting Eocene fault systems and a close relationship between Neogene magmatism and faulting.

Xenoliths and megacrysts

Ultramafic, mantle-derived xenoliths are a dominant macroscopic feature of the CLS. Crustal-derived (plutonic and metamorphic rock) xenoliths are present in most volcanic centres. A database of 300 xenoliths collected in the study area is presented in Resnick (1999). Mineral chemistry and petrography of spinel lherzolite from three volcanic centres and one dyke in the Nechako River map area are described by Suh (1999). Mineral chemistry of the ultramafic xenoliths from the Summit Lake locality are described by Ross (1983), Brearley et al. (1984) and Peslier (1998).

Ultramafic xenoliths are spinel peridotite (dominantly lherzolite, harzburgite, dunite, and wehrlite) and range in size from finely disaggregated, millimetre-sized xenocrysts to xenoliths up to 25 cm in size. Some ultramafic xenoliths show that partial melting occurred at the xenolith–host contact (Suh 1999).

Crustal xenoliths are less common than ultramafic xenoliths and include gabbro, granite, anorthosite, and granulite in the Nechako River area; gneiss is an additional crustal-xenolith rock type in the McLeod Lake map area locality (Resnick 1999). Partially melted, leucocratic plutonic xenoliths are observed infrequently at many localities. The groundmass of rocks at the Lavoie Lake, Summit Lake Quarry, and Cutoff Creek localities contain xenocrystic plagioclase.

Megacrysts (crystals greater than 2 mm in size) include olivine, clinopyroxene, plagioclase, and magnetite. Megacrysts are rare, except in the Cutoff Creek type volcanic centres (see above), where clinopyroxene and feldspar megacrysts are common. Some megacrysts display reaction rims, reaction

Table 1 (*concluded*).

Location	Phenocrysts–xenocrysts[e]			
Bird Road No. 5, locality 1	ol: xn (< 1%; 4 mm; an)	pl: xn (< 1%; 1 mm; an)		
Bird Road No. 5 locality 2,	ol: ph, xn (ph = 10%; xn < 1%; 1 mm: an)	pl: xn (< 1%; 1 mm; an)		
Cicuta Lake	ol: ph, mg (ph = 9%; xn < 2%; 1–5 mm; sub)	pl: ph (1%)	px: ph (< 1%)	
Binta Lake	ol: ph, xn (ph: 5%; xn = < 1%; 1–5 mm; sub-an)			
Blue 8000	ol: ph–xn? (1–2%; 2–4 mm; sub)	pl: ph (< 1%; 2–4 mm; eu)	px: ph (< < 1%; 1–10 mm; eu)	mt: ph (< < 1%; 1–10 mm; eu)
Summit Lake Quarry	ol: ph (5%; 0.5–1 mm; sub)	pl: xn (2%; 1–5 mm, an)	px: xn <2%	
Ootsa Main Road	ol: ph, xn (ph = 7%; xn = 1%; 1–5 mm; sub)	pl: xn (< 1%; 1 mm; eu)		
Table Bay Road	pl: ph (35–60%; 1–2 mm; eu)	px: ph (10–40%; 1–2 mm; eu)	ol: ph (1%; 1 mm; sub)	
Alasla Mountain	ol: ph, xn (ph = 5%; xn = 2%; 1–5 mm; sub-an)	mt: mg (1%; 5 mm; sub)	px: mg (< 1%)	
Lavoie Lake	ol: ph, xn (ph = 12%; xn = 1%; 1–2 mm; an)	px: ph, mg (ph = 1%; mg = 1%; 1–2 mm; eu)	pl: xn (< 1%; 10–15 mm; an)	mt: mg (< < 1%; 5 mm; an)
Chelaslie River	pl: xn (1%; 3 mm; an)	ol: ph, mg (ph = 5%; mg = 1%; 1–2 mm; an-sub)	px: xn (2%: 3 mm; an)	
Cheslatta Lake	pl: ph (35%; 1–7 mm; eu)	ol: ph, xn? (ph = 20%; xn = < 1%; 1–4 mm; sub)	px: xn (< 1%; 4 mm)	
Bro 2 Road	ol: ph (10%; 1mm; sub)	px: ph (40%; 2–10 mm; oph)	pl: ph (45%; 1–2 mm; eu)	
Cutoff Creek	pl: xn (15%; 10 mm; sub)	ol: ph (4%; 2 mm; sub)	px: xn (2%; 0.5–2 mm; an-sub)	mt: mg (< < 1%; 12 mm; sub)
Teapot Mountain	pl: xn (1–2%; 1–2 mm; an)	ol: ph, xn (ph = 10%; xn = 1 %; 1–4 mm; sub-an)		

[e]%, percentage of rock by volume; an, anhedral; eu, euhedral; mg, megacryst; mm, length of crystal longest dimension in millimeters; mt, magnetite; ol, olivine; oph, ophitic; ph, phenocryst; pl, plagioclase; px, clinopyroxene; sub, subhedral; xn, xenocryst.

coronas, and (or) sieve textures indicative of disequilibrium with the host basalt. Others lack any evidence of reaction with the host melt.

Petrography

Samples of the CLS encompass basanite (BASAN), transitional basalt (TRANS), and alkali olivine basalt (AOB) compositions. Petrographic description and modal abundance estimates were complemented by scanning electron microscopy at The University of British Columbia, Vancouver, using a PHILIPS XL30 scanning electron microscope and the PGT IMIX energy dispersive spectroscopy (EDS) – image analysis system to confirm the petrographic identification of minerals.

Forsteritic olivine is the principal phenocryst phase in the igneous rocks (Table 1) constituting up to 1–12% and is rarely zoned. Clinopyroxene, plagioclase, and magnetite occur as rare phenocrysts at a few localities.

Vesicles or amygdules are scarce in the volcanic rocks. Their groundmass is black to dark grey in colour, typically aphanitic, fine grained, holocrystalline, and typically intersertal, containing rare microlites of plagioclase. At the Lavoie Lake locality, groundmass feldspar is strongly trachytic. The groundmass comprises plagioclase (40–60%), clinopyroxene (augite or diopside; 3–35%), Fe–Ti oxides (magnetite > > ilmenite; 5–20%), feldspathoid (nepheline and (or) leucite; 2–20%), olivine (2–15%), and trace apatite.

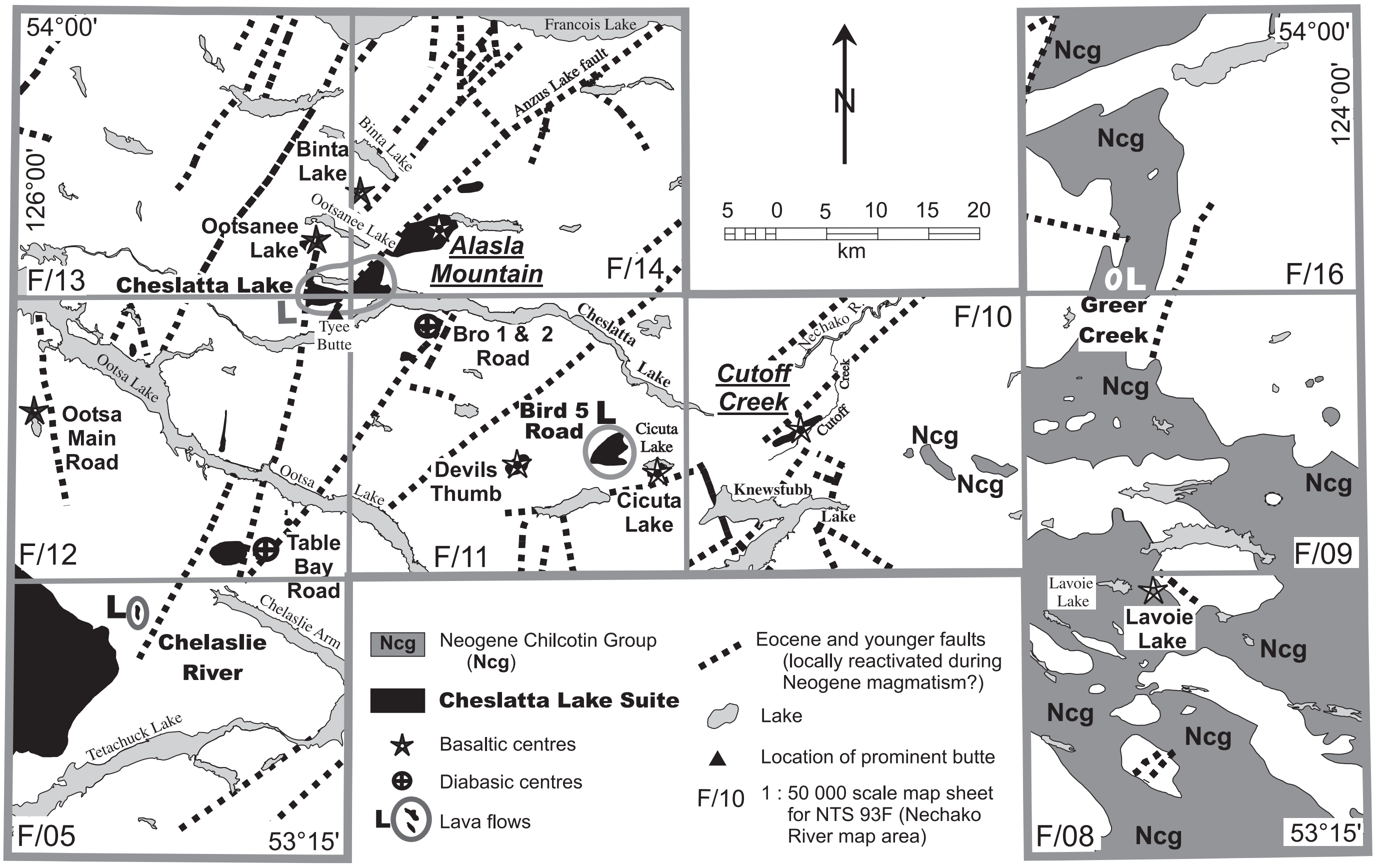
Feldspathoid commonly occurs as late-stage, anhedral, poikilitic grains, up to 2 cm in size and up to 20% in the groundmass. The irregular habit and extremely fine-grained nature of the feldspathoid hinder precise estimates of the modal abundance and the optical discrimination between nepheline and leucite. Basanite contains more than 5% feldspathoid; alkali olivine basalt contains less than 5% feldspathoid, and transitional basalt contains no visible feldspathoid.

Alteration is minor and constitutes typically less than 1% of the total rock. Iddingsite locally occurs after olivine. Calcite, chalcedony, and zeolites are rare, but occur as linings in vesicles or as microveinlets (<250 μm in width).

Definition and type localities for the Cheslatta Lake suite

The Cheslatta Lake suite is informally defined as an assemblage of columnar-jointed, mafic, olivine-phyric volcanic necks, lesser associated lavas, and rare dykes. The suite is best known in the northern Nechako River map area (NTS 93F), but rocks of similar character to the west in the Quanchus Range (Woodsworth 1979, 1980; and in Stevens et al. 1982)

Fig. 2. Distribution of volcanic and diabasic centres and associated lavas of the Cheslatta Lake suite and Chilcotin Group and their association with Eocene and younger faults in the northern Nechako River map area (see Fig. 1). The reference localities for the Cheslatta Lake suite at Alasla Mountain and Cutoff Creek are shown.



and Poplar Butte (Church 1973; Church and Barakso 1990) and to the east at the Summit Lake quarry and Teapot Mountain localities (e.g., Ross 1983; Brearley et al. 1984; Peslier 1998; Struik 1994) may be part of the suite. The volcanic rocks have groundmasses of basanite, transitional basalt, and alkali olivine basalt compositions comprising plagioclase, clinopyroxene, Fe–Ti oxides, feldspathoid, olivine, and apatite. They contain phenocryst, megacryst, and (or) xenocryst assemblages of olivine, plagioclase, pyroxene, and rare magnetite. Ultramafic mantle xenoliths and rare, but significant plutonic and metamorphic rock xenoliths are characteristic.

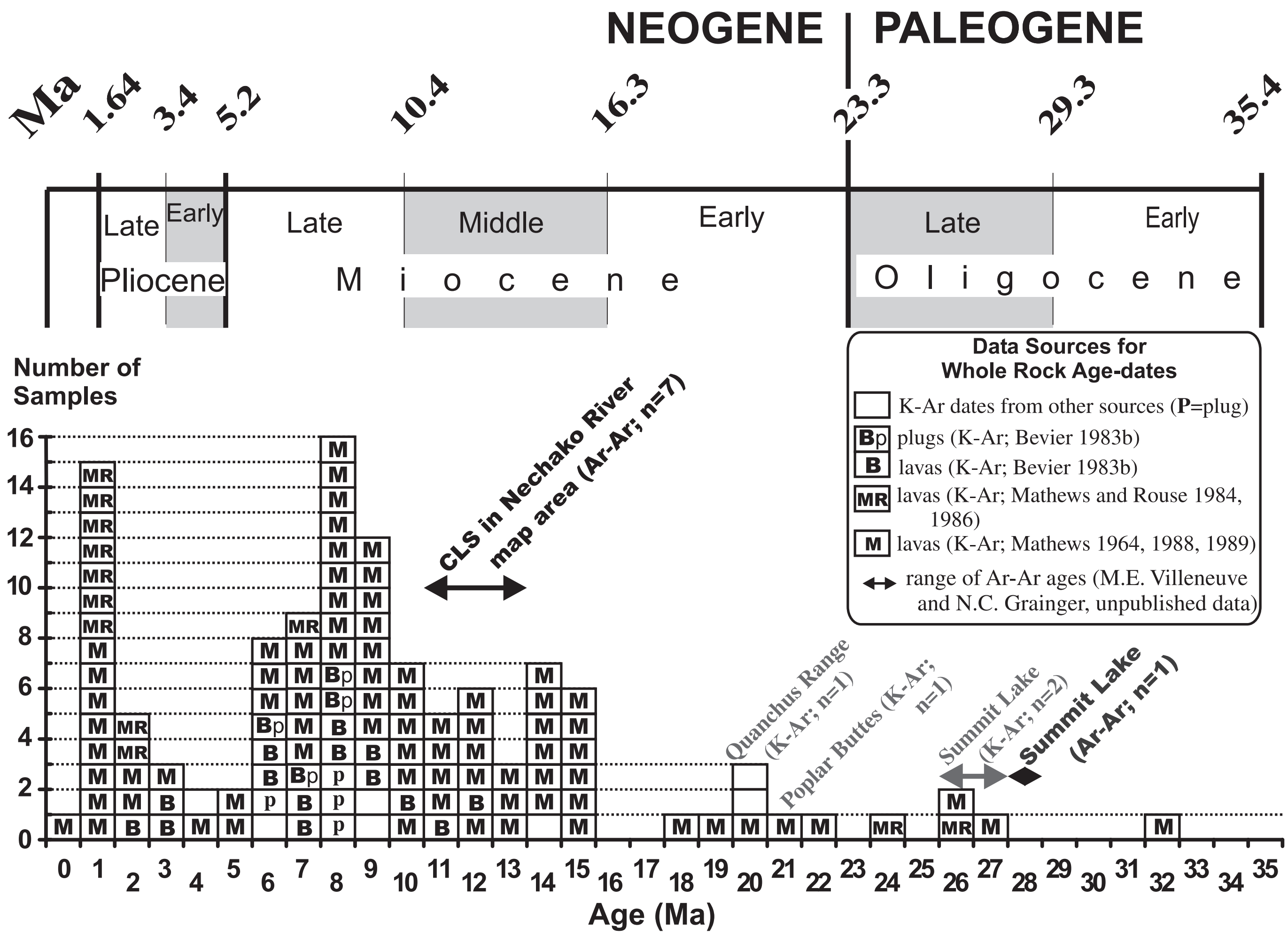
Type areas (Figs. 1, 2) include volcanic centres north and east of Cheslatta Lake at Alasla Mountain (NTS 93F/14; Universal Transverse Mercator (UTM) coordinates E344931, N 5964890, zone 10, North America Datum (NAD) 27) and Cutoff Creek (NTS 93F/10; UTM coordinates E 380505, N5944585, zone 10, NAD 27). These areas encompass the range of features that characterizes the volcanic centres.

Alasla Mountain (Figs.1, 2, 4a) is among the largest basaltic volcanic necks in the northern Nechako River map area and extends along an Eocene northeast-trending brittle fault system (Anderson et al. 1999). The centre features well developed, subvertical columnar joints that locally dip radially towards the centre. Common olivine and minor magnetite phenocrysts, glomerocrysts, and megacrysts (reaching sizes of 30 mm) are set in a dense, black, aphanitic groundmass, which contains uncommon (10–15%), local and small (1–6 mm in size) amygdules. Round mantle xenoliths (1% and 2–5 cm in size) are most commonly coarse- to medium-grained lherzolite and minor dunite, containing olivine, orthopyroxene, and chromian diopside. Millimetre- to centimetre-scale layering of chromian diopside, orthopyroxene, and olivine is rarely observed in the xenoliths.

North of Cutoff Creek (Figs. 1, 2, 4*c*), a subcircular, locally highly weathered basaltic neck is separated from the Endako Group basaltic andesite rocks by a brittle, northeast-trending fault subparallel with other faults of the Eocene Nechako graben (Anderson et al. 1998*a*). The centre contains well-developed columnar joints that become more vertical and narrower upwards (Fig. 4*c*). Megacrysts of black pyroxene, plagioclase, and magnetite (1–3%) are set in a vitreous and dominantly aphanitic groundmass with rare plagioclase microphenocrysts. Mantle xenoliths are rare, round (1–5 cm in size), medium-grained lherzolite, containing olivine, chromian diopside, and orthopyroxene. Crustal xenoliths, many of which exhibit compositional layering, are also rare.

Diabasic centres are rare; one located 1 km east of a spur road (485 road) of Table Bay Road (Figs. 1, 2; NTS 93F/12; UTM coordinates E325580, N5934149, zone 10, NAD 27) is typical. It is a circular (1 km diameter) diabasic centre that crosscuts Mesozoic volcanic rocks, but contains no xenoliths. The diabase displays well-developed, vertical columnar

Fig. 3. Histogram of K–Ar isotopic ages for Paleogene and Neogene mafic volcanic and intrusive rocks in central and southern British Columbia (time scale from Harland et al. 1990). Data from the principal sources (Bevier (1983*b*), Mathews (1964, 1988, 1989), and Mathews and Rouse (1984, 1986)) are identified; other data sources include Farquharson and Stipp (1969), Bevier et al. (1979), Rouse and Mathews (1979), Wanless et al. (1979), and Stevens et al. (1982). The range of $^{40}Ar–^{39}Ar$ (Ar–Ar) isotopic ages for newly dated Cheslatta Lake suite (CLS) and Summit Lake samples (M.E. Villeneuve and N.C. Grainger, unpublished data, 2000) are shown.



jointing. The rock is relatively unaltered, has an ophitic texture, and contains phenocrysts of plagioclase (locally altered to epidote), pyroxene, and olivine.

Age

Conventional K–Ar dating of CGB whole rocks (e.g., Mathews 1989; Fig. 3 and references therein) suggested that volcanism spanned about 25 million years, from Late Oligocene through Early Pleistocene, and occurred in three main magmatic episodes: 15–13 Ma, 9–6 Ma, and 3–1 Ma. New $^{40}Ar–^{39}Ar$ dating of samples was carried out on hand-picked, xenolith- and xenocryst-free whole-rock material as part of this study and on whole rocks in other studies following methods outlined in Villeneuve et al. (1997) and Villeneuve et al. (2001). The dates suggest a middle Miocene age for seven samples in the Nechako River map area and a late Oligocene age for a sample from the Summit Lake locality (M.E. Villeneuve and N.C. Grainger, unpublished data, 1999); the data and detailed interpretations will be published elsewhere. The CLS magmatism occurred between the major magmatic pulses of CGB magmatism identified by Mathews (1989); however, it is consistent with his observation that the oldest magmatism occurs around the peripheries of the plateaux. The age for the Summit Lake quarry centre is slightly older than the earlier determined K–Ar dates, but is concordant within the uncertainties in the K–Ar dates.

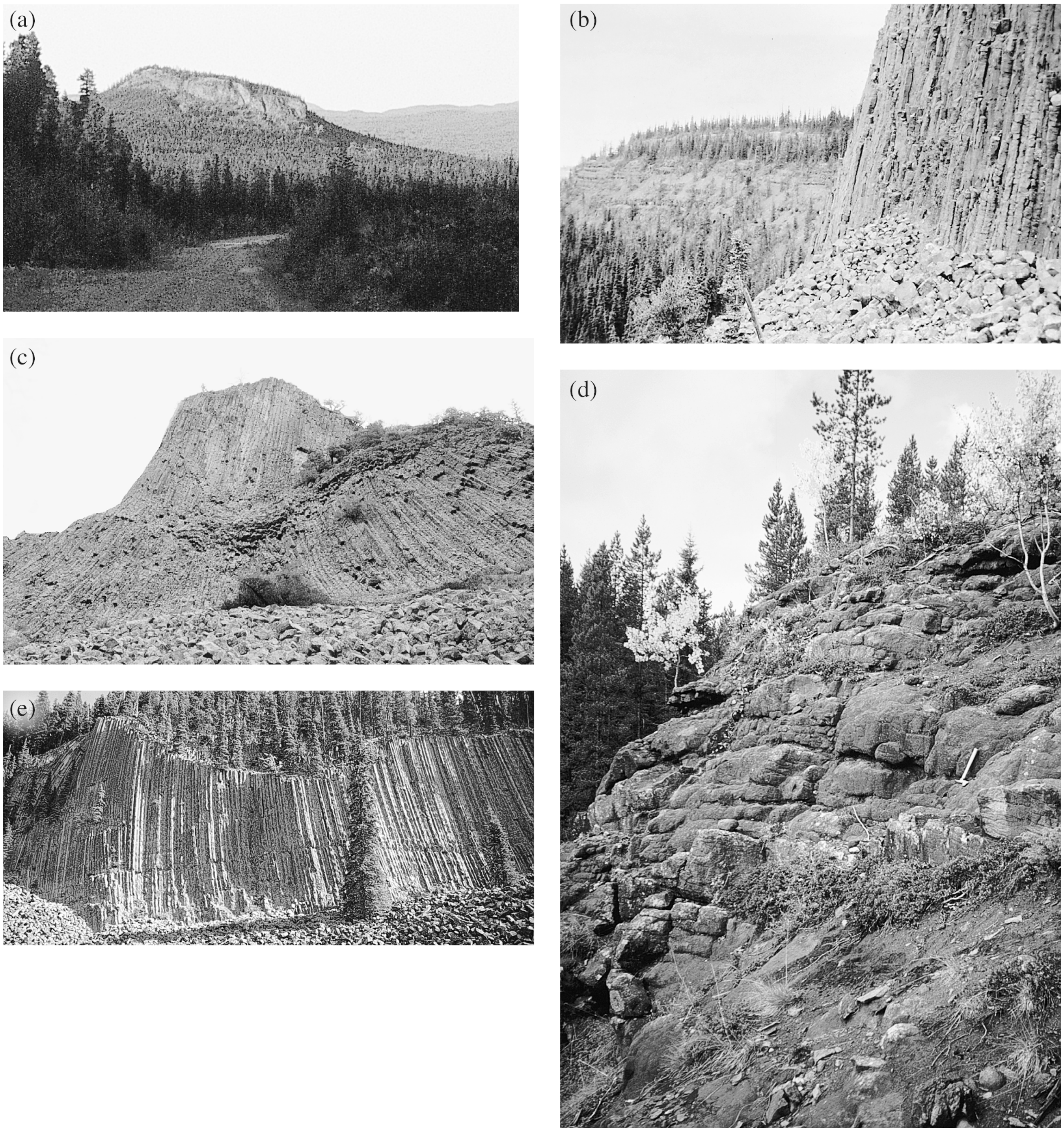
To the northwest of the study area, samples from the Quanchus Range and Poplar Butte localities yielded Early Miocene ages (19.6 and 21.5 Ma) via conventional K–Ar dating on whole rocks (Mathews 1989). To the northeast of the study area, samples yielded Miocene ages (ca. 11.5 Ma, K–Ar dating, Mathews 1989), similar to the newly determined Ar–Ar dates for localities in the northern Nechako River area.

Geochemical characteristics

Sample preparation and analytical procedures

Twenty-two samples for geochemical analysis were

Fig. 4. Photographs of mafic volcanic and diabasic centres and associated lavas of the Cheslatta Lake suite and Chilcotin Group in the Nechako River map area. (*a*) View north to Alasla Mountain volcanic centre. Alasla Mountain has about 165 m relief and is one of the largest volcanic plugs in the study area. (*b*) Flat-lying undeformed lava flows of the Cheslatta Lake suite in the Quanchus Range form a conspicuous escarpment east of St. Thomas River in the Whitesail Lake map area. The plateau basalts are crosscut by a columnar-jointed basalt plug (foreground). (*c*) View east to convergent columnar joints in the volcanic plug at Cutoff Creek. Columns are subhorizontal at margins of photograph and subvertical in the centre horizon. Relief above talus pile is approximately 70 m. (*d*) Thin, flat-lying basalt flows of the Chilcotin Group at Suscha Falls in southeastern Nechako River map area. Hammer is 30 cm long. (*e*) View southeast to undeformed, columnar-jointed basalt flow, approximately 35 m thick, of the Cheslatta Lake suite near Natuza Lake in southwestern Nechako River map area (photograph by L.C. Struik).



crushed to 1 cm rock chips using a steel jaw crusher. Rock chips were hand picked to remove visible xenolith and megacryst fragments, weathered surfaces, and amygdaloidal material. The chips were then ground in a tungsten-carbide ring mill. Samples were analyzed at the analytical chemistry laboratory of the Geological Survey of Canada, Ottawa, On-

Table 2. Major-, minor-, and trace-element analyses of Oligocene–Miocene mafic rocks, including Cheslatta Lake suite.

Sample:	78WV-403	ATR98-0203	ATR98-0204	ATR98-3703	ATR98-0501	AT98-3603a	ATR98-0402	ATR98-3303
Locality:	QR	Bird 5 Rd 1	Bird 5 Rd 2	Cicuta Lake	Binta Lake	Blue 8000 Rd	SLQ	OMR
Eastings:	685050	361258	360954	364328	336325	401271	523613	303790
Northings:	5928900	5943268	5943601	5939695	5968347	5892467	6017530	5948008
NTS map:	93E/08	93F/11	93F/11	93F/11	93F/14	93F/01	93J/07	93F/12
Unit; Rock type:	CLS?; BASAN	CLS; BASAN	CLS; BASAN	CLS; BASAN	CLS; BASAN	CLS; BASAN	CLS?; BASAN	CLS; TRANS
SiO_2 (wt.%)	43.1	44.0	46.3	45.0	45.8	44.1	46.2	45.2
TiO_2	2.47	2.76	2.35	2.65	2.33	3.20	1.67	2.03
Al_2O_3	13.9	13.9	13.9	13.4	14.1	13.9	15.4	12.7
Fe_2O_3	5.6	3.4	4.5	3.5	4.4	5.1	3.2	4.3
FeO	7.2	7.7	7.0	8.4	7.4	8.6	6.0	7.3
MnO	0.22	0.17	0.17	0.18	0.20	0.18	0.16	0.18
MgO	5.79	5.69	8.37	8.83	8.07	8.84	9.90	12.99
CaO	7.93	6.59	7.30	7.00	6.96	8.64	10.25	7.59
Na_2O	5.7	5.3	4.1	4.4	4.7	4.7	2.9	3.4
K_2O	2.88	2.00	2.06	3.37	2.77	2.05	2.99	1.61
H_2OT	3.6	1.8	2.3	2.1	2.4	0.3	0.9	2.2
CO_2T	0.2	5.3	0.8	0.1	0.1	0.1	0.2	0.1
P_2O_5	1.48	1.56	1.15	1.35	1.23	0.80	0.60	0.79
TOTAL	100.1	100.2	100.3	100.3	100.5	100.5	100.4	100.4
Fe_2O_3 (total)	13.60	11.90	12.30	12.80	12.60	14.60	9.80	12.40
Ag (ppm)	0.5	1.3	1.2	1.2	0.5	0.3	0.5	0.8
Ba	1200	580	410	550	560	450	1600	580
Be	4.4	4.4	3.7	3.9	4.0	2.5	1.4	2.4
Bi	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
Cd	0.5	0.3	b.d. (< 0.2)	b.d. (< 0.2)	0.8	b.d. (< 0.2)	0.4	1.7
Cl	1067	446	687	171	164	580	134	169
Co	46	40	45	47	42	61	43	57
Cr	86	94	275	319	264	164	262	560
Cs	1.1	1.0	0.46	0.39	0.58	0.34	1.9	0.51
Cu	25	23	31	25	26	42	53	37
F	1192	917	865	912	848	807	715	656
Ga	24	26	23	26	23	25	16	20
Hf	9.4	12.0	11.0	11.0	9.5	7.1	3.8	6.2
In	0.07	0.17	0.06	b.d. (< 0.05)	0.06	0.08	0.05	b.d. (< 0.05)
Mo	6.1	5.5	4.2	2.9	3.0	5.2	1.0	0.8
Nb	120	100	85	120	100	69	76	74
Ni	82	87	199	253	203	170	180	449
Pb	8	7	7	5	7	4	2	4
Rb	79	29	34	47	40	35	88	42
S	356	308	67	80	174	127	114	b.d. (< 50)
Sb	b.d. (< 0.2)	0.5	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
Sc	7.1	11	14	12	13	15	26	16
Sn	3.3	4.0	3.0	2.8	2.5	2.3	1.4	1.7
Sr	1900	1800	1400	1600	1500	950	720	1000
Ta	7.2	6.2	6.0	6.7	5.6	4.8	4.9	5.0
Te	b.d. (< 0.2)	b.d. (< 0.2)	0.2	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
Th	11.0	7.2	6.3	6.3	7.4	4.9	4.3	4.9
Tl	0.05	0.11	0.05	0.05	0.06	b.d. (< 0.02)	0.05	0.05
U	3.0	2.4	2.0	1.9	2.1	1.6	1.0	1.3
V	139	117	132	130	127	199	214	153
Zn	140	138	125	138	114	123	47	88
Zr	450	510	450	510	460	300	160	270
Ce	210	180	140	160	170	120	80	100
Dy	6.3	7.3	6.5	6.5	5.9	5.6	4.0	4.8
Er	2.1	2.8	2.6	2.5	2.6	2.0	2.1	2.1
Eu	3.9	4.5	3.7	4.3	3.6	3.2	1.9	2.6
Gd	9.5	11.0	9.1	9.7	8.8	8.5	5.1	6.6
Ho	1.00	1.1	1.0	0.96	1.0	0.94	0.75	0.79
La	116	81	66	76	84	57	39	52
Lu	0.21	0.28	0.27	0.25	0.31	0.20	0.31	0.23
Nd	89	92	71	84	76	53	36	51
Pr	24.0	23.0	18.0	20.0	21.0	14	9.9	13
Sm	14.0	15.0	12.0	15.0	12.0	10	6.3	8.9
Tb	1.30	1.5	1.3	1.5	1.1	1.1	0.72	0.99
Tm	0.24	0.34	0.31	0.30	0.35	0.25	0.30	0.28
Y	29	34	29	34	32	26	25	26
Yb	1.3	1.8	1.8	1.6	2.2	1.4	2.1	1.6

Table 2 (*continued*).

ATR98-3001A	ATR98-0302	ATR98-0202	78WV-397	78WV-399	78WV-401	78WV-406	ATR98-3308
TBR	Alasla Mtn.	Lavoie Lake	QR	QR	QR	QR	Chelasli R.
325580	344931	412379	669200	673950	679600	662130	313264
5934149	5964890	5926478	5940850	5944450	5944500	5923650	5928315
93F/12	93F/14	93F/08	93E/09	93E/09	93E/09	93 E/ 07	93F12
CLS; TRANS–DIAB	CLS; TRANS	CLS; TRANS	CLS?; AOB	CLS?; AOB	CLS?; AOB	CLS?; AOB	CLS; AOB
45.7	45.4	49.0	46.7	45.3	46.0	48.4	43.9
2.38	1.99	2.43	2.15	2.48	2.06	1.93	2.04
14.7	13.5	14.0	14.3	13.9	14.2	14.6	12.6
3.5	3.5	5.6	3.5	4.6	4.7	5.7	3.9
6.9	8.1	6.5	8.3	9.1	8.6	6.5	8.2
0.15	0.18	0.15	0.18	0.18	0.18	0.17	0.19
7.81	11.16	8.17	9.13	8.60	8.82	6.98	11.46
8.86	8.10	7.99	9.02	8.93	8.85	9.18	8.91
3.8	3.3	3.8	3.0	2.9	2.9	3.3	3.2
1.98	2.11	1.55	1.59	1.42	1.18	0.82	1.17
3.4	1.9	0.6	1.8	2.1	2.6	2.2	3.6
0.1	0.1	0.1	0.2	0.3	0.2	0.3	0.1
1.14	1.04	0.59	0.57	0.54	0.43	0.35	0.88
100.4	100.4	100.5	100.4	100.4	100.7	100.4	100.2
11.20	12.50	12.80	12.70	14.80	14.30	12.90	13.00
0.6	0.7	b.d. (< 0.1)	0.2	0.3	0.2	0.2	0.7
760	460	320	540	460	420	270	690
2.3	2.8	1.7	1.4	1.4	1.1	0.9	2.2
b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	0.4	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
0.2	0.2	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
b.d. (< 100)	492	159	243	113	b.d. (< 100)	b.d. (< 100)	130
41	51	52	48	58	54	44	54
249	429	246	301	206	219	235	460
0.48	0.39	0.12	0.24	0.22	0.32	0.17	0.46
54	39	49	48	58	56	30	45
985	599	505	710	560	513	500	725
22	20	19	17	18	22	19	19
5.4	7.0	3.0	3.7	4.0	4.1	3.3	6.0
0.06	0.06	b.d. (< 0.05)	0.07	0.07	0.08	0.06	0.06
2.5	1.9	0.9	1.6	1.8	1.3	1.1	2.2
61	74	16	38	40	40	26	73
178	295	211	175	181	143	47	327
4	5	1	2	3	2	2	4
45	32	12	24	26	28	19	43
b.d. (< 50)	65	57	136	b.d. (< 50)	68	92	139
b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
17	18	15	20	17	19	23	17
2.2	1.9	1.1	1.5	1.5	1.5	1.7	1.5
1200	1200	540	870	830	650	540	980
3.5	4.4	1.3	2.4	2.6	2.5	1.7	4.2
b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
4.1	5.7	1.1	2.8	2.8	2.6	1.8	4.8
0.05	0.05	b.d. (< 0.02)	0.16	0.03	b.d. (< 0.02)	b.d. (< 0.02)	0.05
1.2	1.6	0.37	0.85	0.88	0.87	0.59	1.4
216	147	168	198	192	192	204	167
91	91	107	74	116	106	94	90
220	320	200	170	180	140	120	250
110	120	33	60	64	58	43	100
5.1	5.1	4.2	4.4	4.5	4.3	4.0	5.0
2.1	2.3	2.0	2.2	2.2	1.8	1.8	2.1
2.7	2.8	1.6	1.8	1.9	2.1	1.7	2.7
7.2	7.2	4.9	5.4	5.5	5.8	5.1	7.2
0.80	0.86	0.82	0.86	0.88	0.79	0.76	0.78
53	60	15	28	30	27	20	52
0.26	0.28	0.27	0.29	0.30	0.22	0.24	0.22
56	53	21	31	31	31	24	52
13.0	15.0	4.5	7.3	7.9	7.4	5.5	12.0
9.4	9.0	4.7	5.8	6.2	6.2	5.2	9.2
1.0	0.93	0.72	0.80	0.81	0.84	0.73	1.0
0.28	0.31	0.29	0.30	0.31	0.23	0.25	0.26
28	28	22	23	23	21	21	25
1.6	1.9	1.9	2.0	2.0	1.5	1.6	1.4

Table 2 (*continued*).

Sample:	ATR98-0803	ATR98-3501	ATR98-0301	ATR98-0401	AT98-3301A	AT98-3305A	AT98-3703A
Locality:	Cheslatt L.	Bro 2 Rd	Cutoff Ck.	Teapot Mtn.	NW of Suscha Ck.	N of Blackwater R.	S bank, Suscha Ck.
Eastings:	337083	342370	380505	520858	415990	424546	408705
Northings:	5958682	5954724	5944585	6019898	5896724	5898997	5897320
NTS map:	93F/14	93F/11	93F/10	93J/07	93F/01	93F/01	93F/01
Unit:	CLS	CLS	CLS	CLS?	Chilcotin Gp.	Chilcotin Gp.	Chilcotin Gp.
Rock Type	AOB	AOB–DIAB	AOB	AOB	basaltic andesite	basaltic andesite	basaltic andesite
SiO_2 (wt.%)	47.4	48.3	46.2	47.7	50.90	48.50	50.40
TiO_2	1.85	1.21	2.75	1.23	1.96	2.34	2.27
Al_2O_3	14.0	15.3	16.1	15.5	14.1	13.5	14.2
Fe_2O_3	2.8	3.2	3.2	3.2	5.3	4.6	2.4
FeO	9.0	7.6	8.8	6.3	7.5	7.8	9.8
MnO	0.17	0.17	0.19	0.17	0.16	0.17	0.16
MgO	9.78	10.20	6.48	9.07	7.14	7.36	7.33
CaO	9.31	9.28	9.24	10.30	8.33	7.95	8.39
Na_2O	3.0	2.8	3.7	3.1	3.1	3.3	3.4
K_2O	1.12	0.53	1.19	1.67	0.53	1.14	0.97
H_2O T	1.3	1.5	0.7	1.0	2.5	3.1	0.7
CO_2T	0.1	0.1	1.2	0.2	0.2	0.1	0.1
P_2O_5	0.53	0.27	0.61	0.68	0.21	0.56	0.40
TOTAL	100.4	100.5	100.4	100.1	101.9	100.4	100.5
Fe_2O_3 (total)	12.80	11.60	12.90	10.20	13.60	13.30	13.30
Ag (ppm)	0.2	0.2	0.6	0.4	0.1	0.1	0.1
Ba	420	300	350	1700	170	380	300
Be	1.3	0.5	1.4	1.1	0.6	1.3	1.1
Bi	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
Cd	b.d. (< 0.2)	b.d. (< 0.2)	0.3	0.2	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
C	133	b.d. (< 100)	305	163	b.d. (< 100)	108	190
Co	52	52	49	39	40	37	37
Cr	316	216	109	422	241	226	220
Cs	0.24	0.49	0.26	1.2	0.16	0.14	0.22
Cu	57	45	41	61	56	49	35
F	465	301	573	865	197	570	411
Ga	20	17	19	15	22	23	23
Hf	3.8	2.5	4.8	3.5	2.7	4.1	3.5
In	b.d. (< 0.05)	0.06	0.05	b.d. (< 0.05)	b.d. (< 0.05)	0.07	0.13
Mo	1.6	0.8	2.0	0.9	0.9	1.5	1.3
Nb	34	6	43	60	9.1	26	21
Ni	218	164	68	169	150	132	154
Pb	2	1	1	5	b.d. (< 1)	2	2
Rb	20	12	22	40	9.9	20	15
S	66	356	332	128	69	b.d. (< 50)	61
Sb	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
Sc	21	25	21	25	20	18	18
Sn	1.1	1.0	1.6	1.4	1.2	1.7	1.8
Sr	690	350	530	880	410	480	510
Ta	2.8	0.95	4.1	3.6	0.69	1.5	1.6
Te	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)	b.d. (< 0.2)
Th	2.7	1.1	2.9	5.4	0.77	1.70	1.40
Tl	0.03	0.06	0.04	0.05	0.03	0.03	0.03
U	0.72	0.33	0.90	1.3	0.32	0.64	0.50
V	188	190	217	204	172	202	176
Zn	85	73	76	47	128	134	129
Zr	150	97	200	160	94	170	140
Ce	61	26	59	97	16	41	30
Dy	3.9	4.1	5.8	4.0	4.2	5.9	5.1
Er	1.8	2.3	2.7	2.2	1.9	2.7	2.3
Eu	1.9	1.3	2.3	2.0	1.8	2.5	2.2
Gd	5.1	4.3	6.6	5.2	5.1	7.6	6.5
Ho	0.70	0.77	1.0	0.78	0.74	1.0	0.89
La	31	13	26	48	6.7	18	14
Lu	0.25	0.34	0.34	0.33	0.23	0.34	0.27
Nd	29	17	33	43	12	26	19
Pr	7.8	3.6	7.8	12.0	2.5	5.8	4.3
Sm	5.7	4.2	7.1	6.8	4.4	7.4	6.0
Tb	0.70	0.74	1.1	0.71	0.73	1.0	0.90

Table 2 (*concluded*).

Sample:	ATR98-0803	ATR98-3501	ATR98-0301	ATR98-0401	AT98-3301A	AT98-3305A	AT98-3703A
Locality:	Cheslatt L.	Bro 2 Rd	Cutoff Ck.	Teapot Mtn.	NW of Suscha Ck.	N of Blackwater R.	S bank, Suscha Ck.
Eastings:	337083	342370	380505	520858	415990	424546	408705
Northings:	5958682	5954724	5944585	6019898	5896724	5898997	5897320
NTS map:	93F/14	93F/11	93F/10	93J/07	93F/01	93F/01	93F/01
Unit:	CLS	CLS	CLS	CLS?	Chilcotin Gp.	Chilcotin Gp.	Chilcotin Gp.
Rock Type	AOB	AOB–DIAB	AOB	AOB	basaltic andesite	basaltic andesite	basaltic andesite
Tm	0.26	0.32	0.35	0.32	0.26	0.36	0.30
Y	23	28	29	25	23.0	31.0	27.0
Yb	1.7	2.0	2.1	2.3	1.7	2.5	2.0

Note: Compositions below detection limits (b.d.) and detection limits (in parentheses) shown. The chemical rock names follow the conventions of Le Bas et al. (1986). Universal Transverse Mercator easting and northing coordinates (NAD 27) are for zone 10 for all samples, except for those from the Quanchus Range (zone 9). BASAN, basanite; TRANS, transitional basalt; DIAB, diabase; AOB, alkali olivine basalt. Unit indicates the site or group. Locality abbreviations from Fig. 1.

tario. Analyses of the samples (Table 2) include the major elements and trace elements Ba, Nb, Rb, Sr, and Zr, which were analyzed by X-ray fluorescence on fused beads prepared from ignited samples of rock powder. FeO was determined by titration. H_2O and CO_2 were analyzed by combustion followed by infrared spectrometry. The rare-earth element (REE) and Y concentrations were determined by inductively coupled plasma – mass spectrometry (ICP-MS). A sub-suite of replicate powders were also analyzed for major and trace elements by X-ray fluorescence at the Geochemical Laboratory at McGill University, Montréal, Quebec.

Geochemical composition and classification

The rocks analyzed in this study (Table 2) are sodic-alkaline basalt (Na:K = 2:1) with SiO_2 from 43 to 49 wt.%. All but one diabase plot in the alkaline field of Irving and Baragar (1971), and most are strongly alkaline, silica-undersaturated (normative nepheline = 0.1–18 wt.%; normative olivine > 10 wt.%) and high potash (Figs. 5*a*, 5*b*). The Miocene CLS samples share a high-potash, within-plate alkali basalt affinity with the older Eocene Endako Group basaltic andesite samples (Anderson et al. 2000*a*). However, the CLS rocks are clearly more alkaline, less silicic (and silica-saturated), relatively enriched in FeO* and MgO relative to $Na_2O + K_2O$ in an total alkalies – Fe0*–Mg0 (AFM) ternary plot (Fig. 5*c*) than Endako Group samples (Anderson et al. 2000*a*; R.G. Anderson, unpublished data, 1999). The CLS samples also contain less Zr and have lower Zr/TiO_2 and Zr/Y ratios compared to the Endako Group.

Three distinct groups of alkaline rocks (Fig. 5) are distinguished based on decreasing weight percent abundance of normative nepheline (ne): (1) basanite (BASAN: most contain > 9% ne and modally abundant groundmass nepheline), (2) transitional basalt (TRANS (or trachybasalt in Fig. 5*a*): most contain ca. 4–6% ne), and (*c*) alkali olivine basalt (AOB) compositions (most contain 0–1% ne). Normative nepheline abundance may be a superior indicator of relative silica undersaturation than estimates of modal feldspathoid abundance, because of the difficulty in identifying the groundmass feldspathoid phases and an assumption that the geochemical samples reflect a larger bulk sample of the rock. BASAN samples have high normative orthoclase content (12–20%), which may be indicative of unidentified groundmass leucite.

There is a strong, positive covariance among compatible elements Cr and Ni and MgO, with significant variations at intermediate MgO values (Fig. 6). The linear trend may reflect olivine fractionation, but differences in source region or degree of partial melting may account for the scatter in Cr and Ni contents. A subset of the TRANS and AOB samples are distinguished as the most mafic in the principal field of mafic igneous rocks of this study by their greater content of compatible elements (MgO, Ni, Cr, Co). Only four BASAN, TRANS, and AOB samples exhibit the range of Ni:MgO ratio values (e.g., 23–39) typical of primitive magmas (BSVP 1981).

The BASAN samples exhibit highly fractionated REE profiles (compared to typical chondrite; Fig. 7), characterized by enriched light REE (LREE) and lesser heavy REE (HREE) contents. LREE abundance and LREE and HREE fractionations decrease with increasing degree of silica saturation (Fig. 7*a*–7*c*; e.g., La_N/Sm_N for BASAN, 3.1–5; for TRANS, 2–4; and for AOB, most are 2–3.3). HREE profiles of the eastern samples in the McLeod Lake area (Figs. 7*a*, 7*c*) are also somewhat distinguished from samples from CLS in the Nechako River area by their flat patterns. One diabase sample exhibits chondrite-normalized REE patterns similar to the highly fractionated REE profiles of TRANS samples (Fig. 7*b*), but the other exhibits only a weakly fractionated REE profile (Fig. 7*c*). REE compositions for Quanchus Range samples overlap those for CLS in the Nechako River area. Chilcotin Group samples near the study area and to the south generally have smaller abundances and weaker fractionation of the LREE, but overlap in their HREE compositions (Figs. 7*d*, 7*e*). Eocene basaltic andesite of the Endako Group in the Nechako and Fort Fraser areas is clearly distinguished from CLS by marked Eu anomalies and significantly greater HREE content (Fig. 7*d*).

In terms of incompatible element (Rb, Ba, K, P, Ti, Rb, Zr) abundances, CLS samples resemble typical alkaline mafic volcanic rocks. BASAN samples have the highest concentrations (Fig. 8*a*–8*c*). The abundance of Pb, Ba, Ti, Nb, Zr, and Na increases with decreasing MgO.

Variations in major, minor, and trace-element concentrations and high field strength element (HFSE) ratios for CLS samples along a 300 km east-northeast-trending transect across the centres in central British Columbia shown in Fig. 1 exhibit differences from west to east. These differences exist irrespective of rock type (i.e., BASAN and AOB rock types both exhibit systematic differences). The

McLeod Lake samples have distinctively higher CaO and Al_2O_3 and lower TiO_2, P_2O_5, and Fe_2O_3 relative to CLS samples from the Nechako River map area to the west. There is an enrichment in Cs, Rb, Ba, Yb, Lu, and Sc and a depletion in La, Ce, Sr, Nd, Hf, Zr, Sm, Eu Ti, Gd, Dy, and Y in the eastern samples relative to rocks of comparable compositions in the western part of the study area (e.g., Fig. 8*a*). The AOB sample from the McLeod Lake map area is distinct in its comparative enrichment in Cs and Ba (Fig. 8*c*). As in the REE plots, the TRANS sample ATR98–0202 (Lavoie Lake) and the AOB diabase sample are distinguishable in a multielement plot (Figs. 8*b*, 8*c*). Chilcotin Group samples near and south of the study area have smaller incompatible and HFSE contents for similar compositions compared with CLS in the Nechako River area. Eocene basaltic andesite of the Endako Group in the Nechako and Fort Fraser areas is compositionally similar in incompatible and HFSE content to CLS, but differs from CLS by its marked Ba, Nb, and Ti anomalies (Fig. 8*d*).

Discussion

Oligocene–Miocene magmatism in south-central British Columbia was the result of back-arc partial melting of the upper mantle in the asthenosphere inboard of the Pemberton volcanic belt (Bevier 1983*a*, 1983*b*). Magmatism responsible for the CLS was also inboard of that recorded in the Miocene part of the Masset Formation on Queen Charlotte Islands (e.g., Hickson 1991) and occurred in Stikine, Cache Creek, Quesnel, Slide Mountain, and Kootenay terranes. Melting may have occurred in an extensional tectonic regime and magmas emplaced along preexisting Eocene faults. The geological, petrographic, and geochemical data allow for correlations among Neogene volcanic centres and define regional variations in Miocene magmatism.

CLS rocks from this study share some traits with, but also significantly differ from, the CGB extensively studied to the south (e.g., Bevier 1983*a*, 1983*b*; Mathews 1989), in abundance and nature of xenoliths and megacrysts, petrographic textures, age, and chemical composition. The suite is clearly distinguished from the Eocene Endako Group. These characteristics lead to the definition of a new suite of Neogene mafic alkaline intrusive and extrusive rocks.

Xenoliths and megacrysts

Volcanic and diabasic rocks of the CLS contain common ultramafic, plutonic, and metamorphic xenoliths and megacrysts. The CGB lavas, as described by Bevier (1983*a*, 1983*b*) do not contain ultramafic xenoliths or mafic megacrysts. However, ultramafic xenolith-bearing lava flows or volcanic necks of pre-Pleistocene age are reported in south-central British Columbia (Littlejohn and Greenwood 1974; Ross 1983; Canil et al. 1987; Peslier 1998), including pre-Pleistocene alkaline, xenolith-bearing basalt flows within the formally defined distribution of the Chilcotin Group basalt of Bevier (1983*a*) (e.g., near Rayfield River (Canil et al. 1987; Peslier 1998)). Endako Group lavas and related diabasic intrusions are inclusion- and megacryst-free.

Petrographic textures

The CGB is phenocryst-poor and contains olivine as the sole phenocryst phase (Bevier (1983*a*, 1983*b*). Rocks of this study contain dominantly olivine phenocrysts, as well as uncommon plagioclase, clinopyroxene, and, rarely, magnetite. Endako Group basaltic andesite are seriate (microphenocrysts of plagioclase, orthopyroxene and clinopyroxene) and more commonly amygdaloidal compared to CLS.

Age

Dated CLS rocks are Early to Middle Miocene (ca. 21–11 Ma and Middle Miocene on average for $^{40}Ar–^{39}Ar$ dates); mafic alkaline rocks to the east are Late Oligocene (Fig. 3) and geochemically distinct. Most CLS magmatism is correlative with the earliest and apparently longest lived voluminous episode (27–14 Ma) of the Late Oligocene – Pliocene plateau basalt magmatism defined by Mathews (1989) and significantly older than the 9–6 Ma and 3–1 Ma magmatic events principally recognized by him in the southern CGB. Endako Group lavas are well characterized as middle Eocene in age (e.g., Anderson et al. 1998*b*; Anderson et al. 2000*a*).

Chemical Composition

CLS basaltic necks and flows of this study are more silica undersaturated and more alkaline (e.g., common basanite compositions) than the CGB (Bevier 1983*a*, 1983*b*). The differences may partly result from a sampling bias (i.e., volcanic necks in the CLS versus lava flows in the CGB) or from the reconnaissance nature of this study. Systematic sampling across individual volcanic plugs for geochemical analysis might corroborate the geochemical evidence for variations between alkali olivine basalt, transitional, and basanite compositions observed at some CLS localities (e.g., Quanchus Range).

Nonetheless, the area north of the Anahim volcanic belt is characterized not only by older centres (e.g., Mathews 1989), but also by nepheline-normative compositions (Fig. 9A) compared to hypersthene-normative rocks to the south. This may indicate differences in the degree of source region melting; the northern field representing smaller fraction partial mantle melts versus larger fractions in the southern field.

The Mg numbers for the CLS (72–42) reveal a broader and commonly less evolved range of compositions than CGB, but overlap the larger Mg numbers for CGB (between 60–65, e.g., Fig. 9B) and its range of Ni compositions (Fig. 6). The trace-element data for rocks to the south are comprehensive enough to allow for some comparisons with the CLS (e.g., Figs. 7, 8). REE data for some samples of AOB and TRANS from the southern CGB do overlap with the least undersaturated rock types of this study (Fig. 7*e*), but few have the flat HREE patterns typical of the Oligocene alkaline mafic rocks in the McLeod Lake area to the east (which suggest that the latter samples likely did not originate from a garnet-bearing source). Finally, significant compositional overlap exists between alkaline basaltic rocks of the CLS and Anahim volcanic belt (Fig. 5), but the significance of the similarities remains unresolved. Eocene Endako Group basaltic andesite are less alkaline, more siliceous, invariably hypersthene-normative, and contrast with CLS in incompatible, HFSE and REE contents.

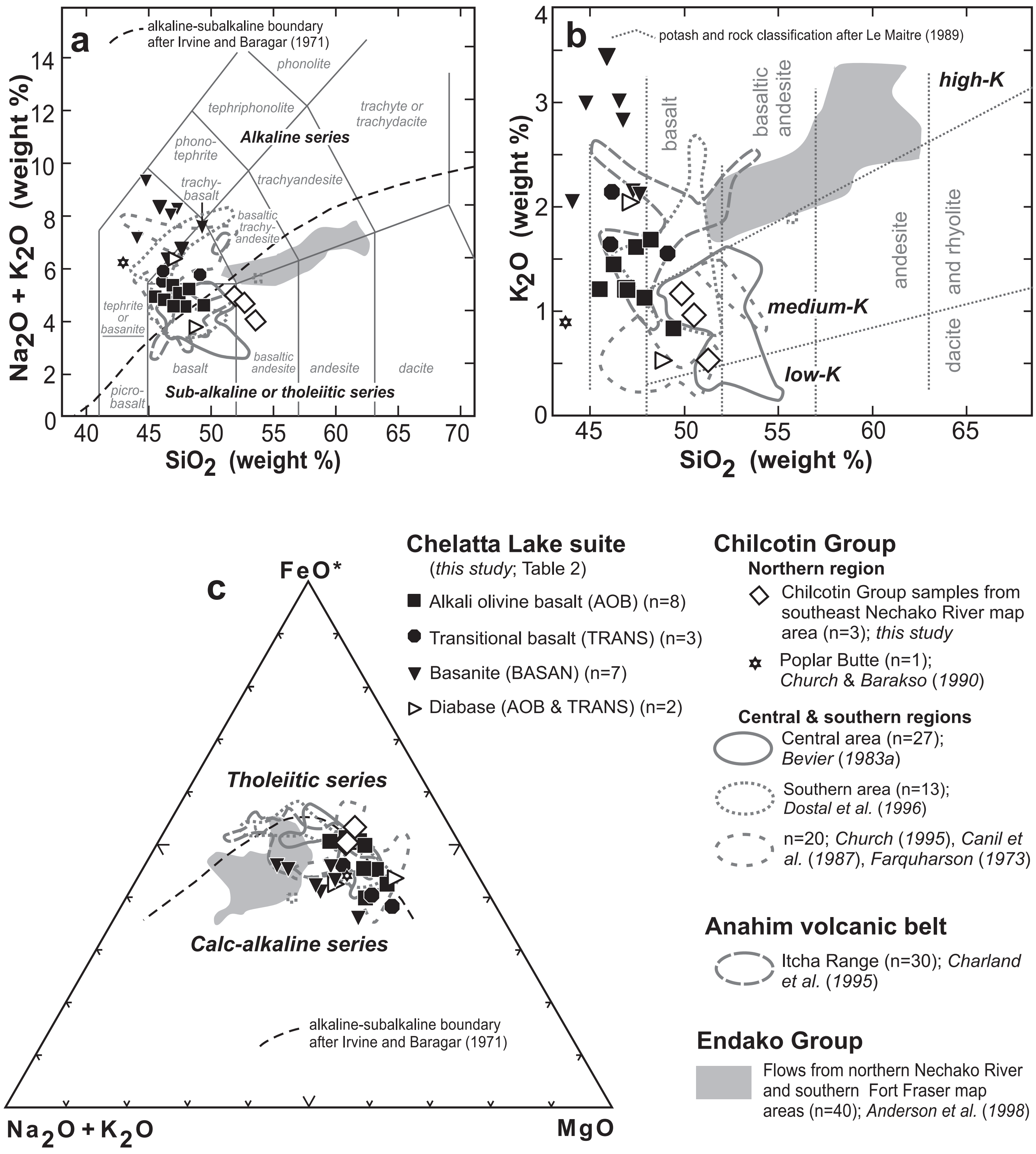
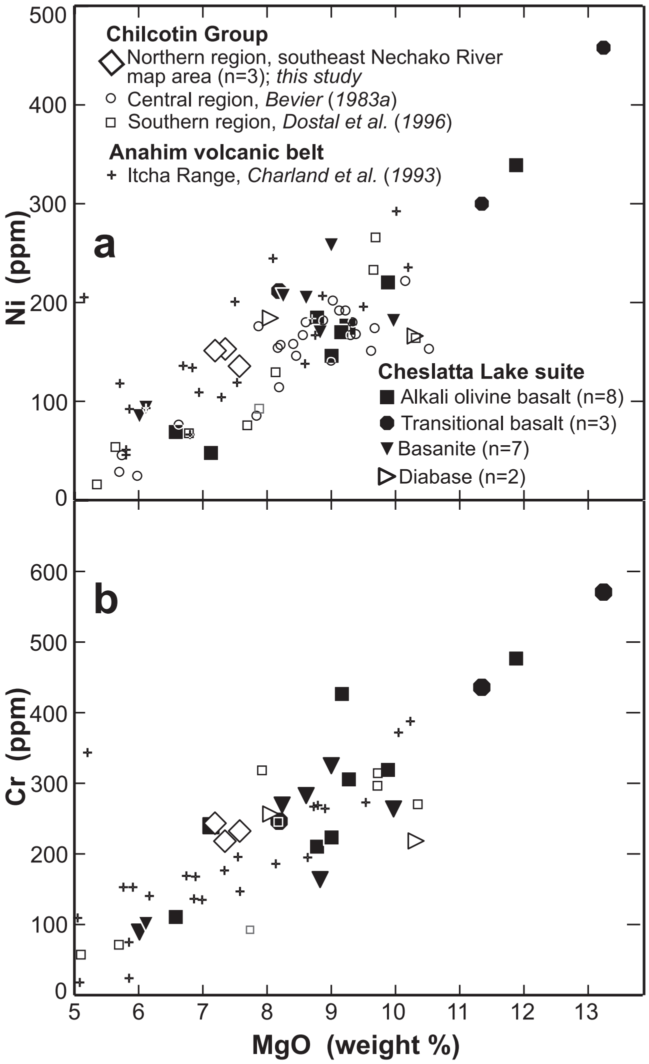


Fig. 5. Compositional fields for samples from the volcanic and diabasic centres and associated lavas of the Cheslatta Lake suite and Chilcotin Group in the southeastern Nechako River map area compared with compositions for samples from (data sources given in legend) the southern and central exposures of the Chilcotin Group and associated plugs; Anahim volcanic belt; and the mafic volcanic rocks of the Eocene Endako Group in southern Fort Fraser and northeastern Nechako River map areas. (*a*) Total alkali–silica diagram and classification fields from Le Bas et al. (1986), (*b*) Potash–silica variation and classification fields from Le Maitre (1989), and (*c*) AFM variation diagram and tholeiitic–calc-alkaline classification from Irvine and Baragar (1971).

Fig. 6. Variation of Ni and Cr with MgO for samples from the volcanic and diabasic centres and associated lavas of the Cheslatta Lake suite and Chilcotin Group in the Nechako River map area.



Definition of CLS and correlations

We propose the term Cheslatta Lake suite for Miocene mafic volcanic and igneous rocks north of the Anahim volcanic belt and west of the Pinchi Fault in central British Columbia (Fig. 1). The definition includes centres in Nechako River map area, as well as the compositionally similar but somewhat older Poplar Butte and Quanchus Range sites. The CLS centres commonly occurred along preexisting fault structures and are commonly xenolith- and megacryst-bearing. Rocks are (clinopyroxene–plagioclase) olivine-phyric, nepheline-normative, alkaline to transitional basalt in composition. The suite encompasses the numerous intrusive volcanic necks and plugs and the extrusive plateau lavas that constitute volcanic centres in this extensive volcanic field. The CLS rocks differ from the CGB, as defined by Bevier (1983*a*, 1983*b*), in their abundance of ultramafic xenoliths, porphyritic nature, and more common silica-undersaturated and primitive magma compositions.

The broadly compositionally similar centres at Summit Lake and Teapot Mountain (Fig. 1) share the structural setting and xenolith, megacryst and phenocryst abundance and composition, but differ significantly in terrane setting, greater xenolith variety and abundance, older age, and HFSE and REE compositions with the CLS centres in Stikine Terrane to the west. The anomalous major- and trace-element compositions and older age, which characterize the Summit Lake and Teapot Mountain magmas, suggest that they may have been derived from a different mantle source than that for basalt to the west. The eastern centres are tentatively excluded from the CLS based on these differences.

Miocene, ultramafic xenolith-bearing lavas and plugs are known within the CGB field to the south (e.g., Canil et al. 1987; Peslier 1998), but are not as well studied as CLS. The informal status of the CLS definition permits extension of the definition of the CLS, based on the compositional, areal, and (or) temporal continuum between alkaline and transitional basaltic magmatism to compositionally similar and coeval units, which may be revealed upon further mapping, mineralogical, and geochemical studies of the southern CGB.

Conclusions

Paleogene–Neogene mafic, alkaline magmatism in south-central British Columbia is the result of back-arc partial melting of the upper mantle in the asthenosphere, inboard of the Pemberton volcanic belt (e.g., Bevier 1983*a*, 1983*b*) and Miocene Masset Formation (Hickson 1991). Late Tertiary volcanic rocks in this study constitute a primitive, sodic alkaline suite of basanite, alkali olivine basalt, transitional basalt, and diabase. The term CLS is introduced for the mainly Miocene assemblage of fault-bounded, olivine-phyric, mantle nodule-bearing, undersaturated basanite, transitional basalt, and alkali olivine basalt lavas and high-level intrusive rocks occurring north of the Anahim volcanic belt and east of the Pinchi Fault. Regionally, a systematic difference in the major-, minor-, and trace-element concentrations in the Miocene–Oligocene mafic alkaline rocks of the CLS may be correlated to differences in source region composition between the western and eastern parts of the study area, and to changes in the continental asthenosphere with time. Centres east of the Pinchi Fault are tentatively not included in CLS based on these temporal, xenolith compositional, and abundance and geochemical differences.

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Fig. 7. Chondrite-normalized rare-earth element plots for the Cheslatta Lake suite (CLS) (chondrite REE compositions of Sun (1982) used) for samples of (*a*) basanite; (*b*) transitional basalt; (*c*) alkali olivine basalt compositions and diabase shown. Comparisons of CLS compositional range with (*d*) Eocene Endako Group in southern Fort Fraser and northeastern Nechako River map areas (Anderson et al. 1998*b*) and Chilcotin Group in the southeastern Nechako River map area, and (*e*) selected samples from the southern part of the Chilcotin Group.

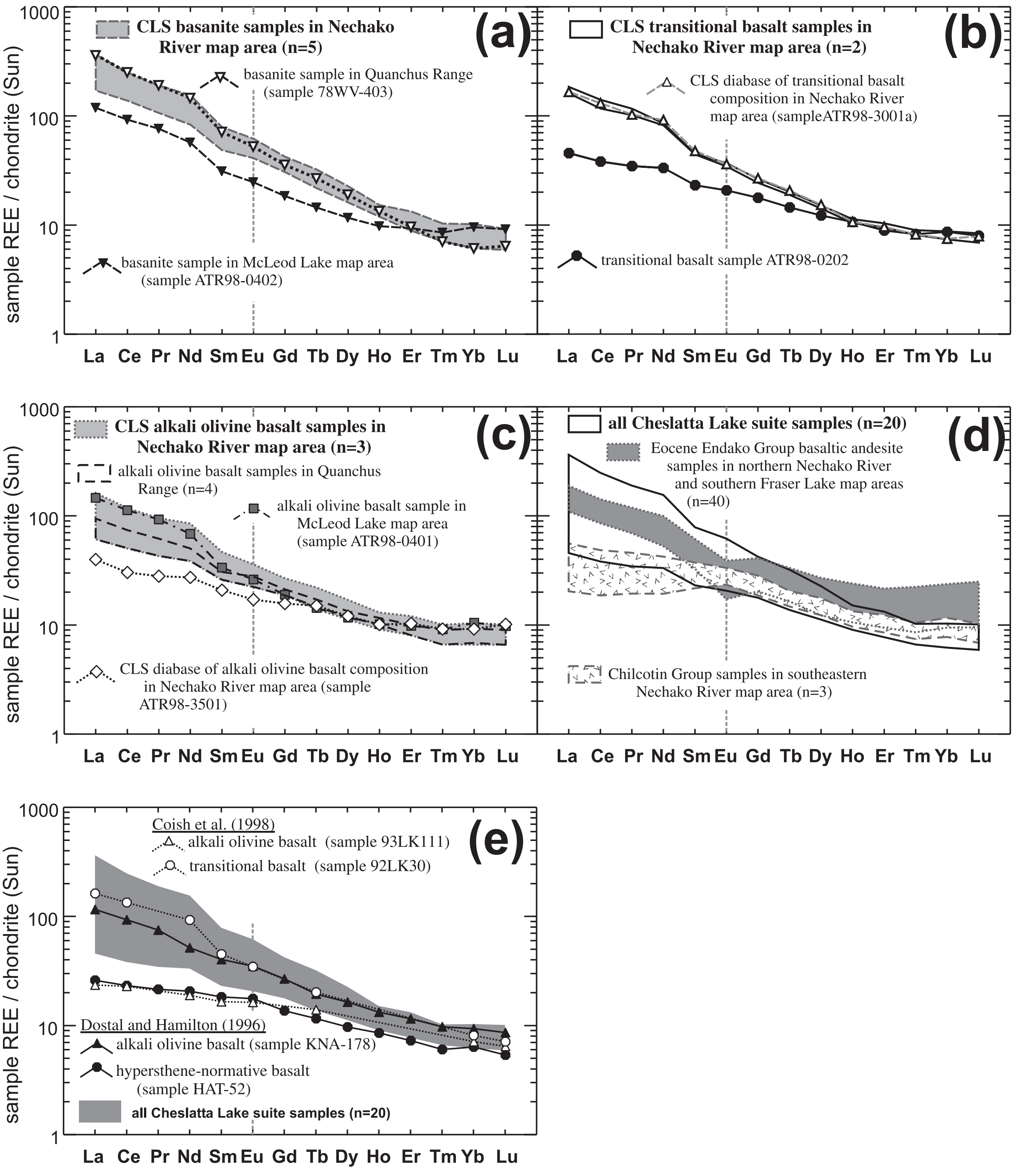


Fig. 8. Trace-element multielement diagram (normalized to primitive mantle compositions of G.A. Jenner, unpublished data, in NewPet program, 1994) for the Cheslatta Lake suite (CLS) for samples of (*a*) basanite; (*b*) transitional basalt; (*c*) alkali olivine basalt compositions and diabase shown. Comparisons of CLS compositional range with (*d*) Eocene Endako Group in southern Fort Fraser and northeastern Nechako River map areas (Anderson et al. 1998) and Chilcotin Group in the southeastern Nechako River map area, and (*e*) selected samples from the southern part of the Chilcotin Group.

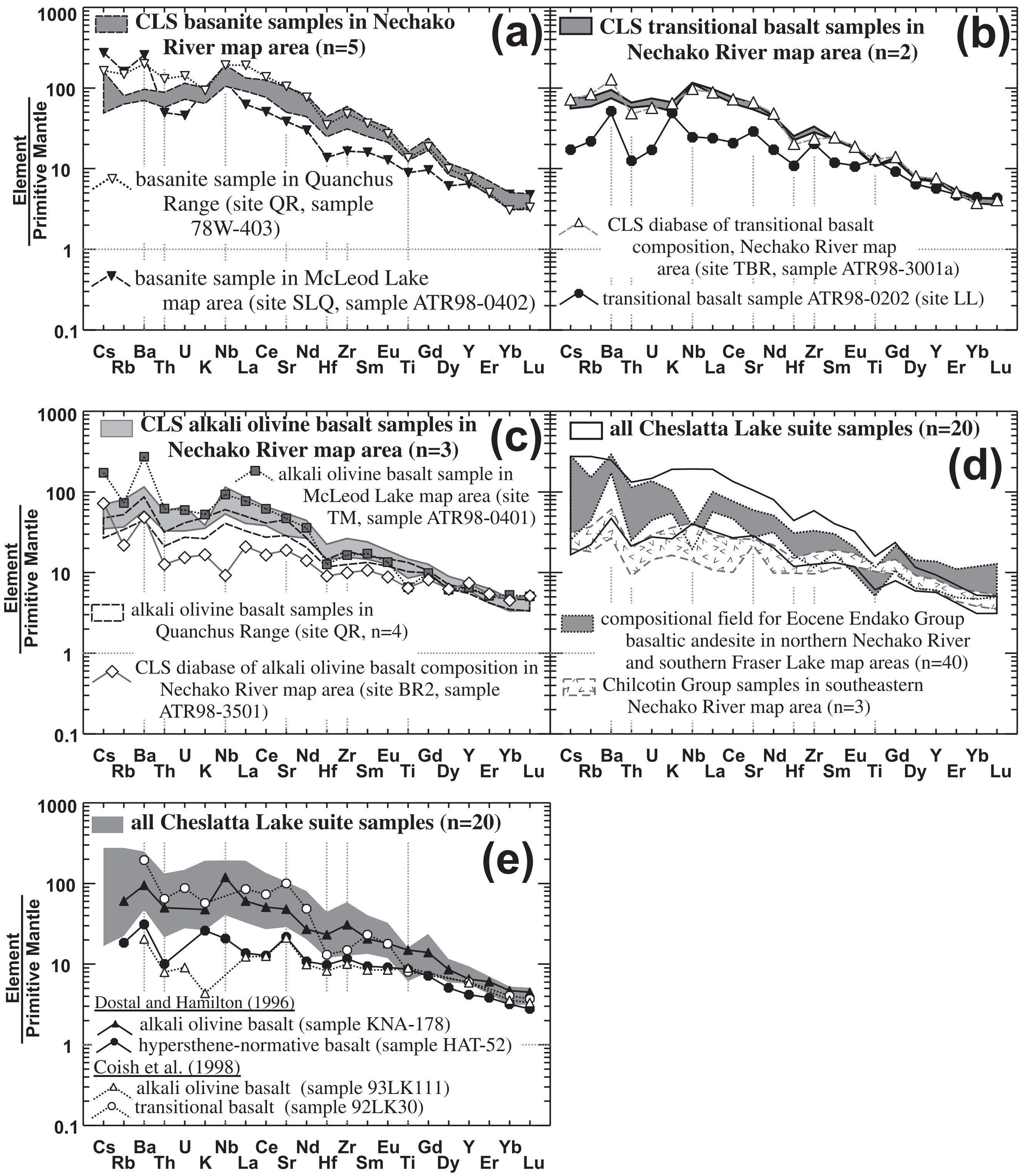
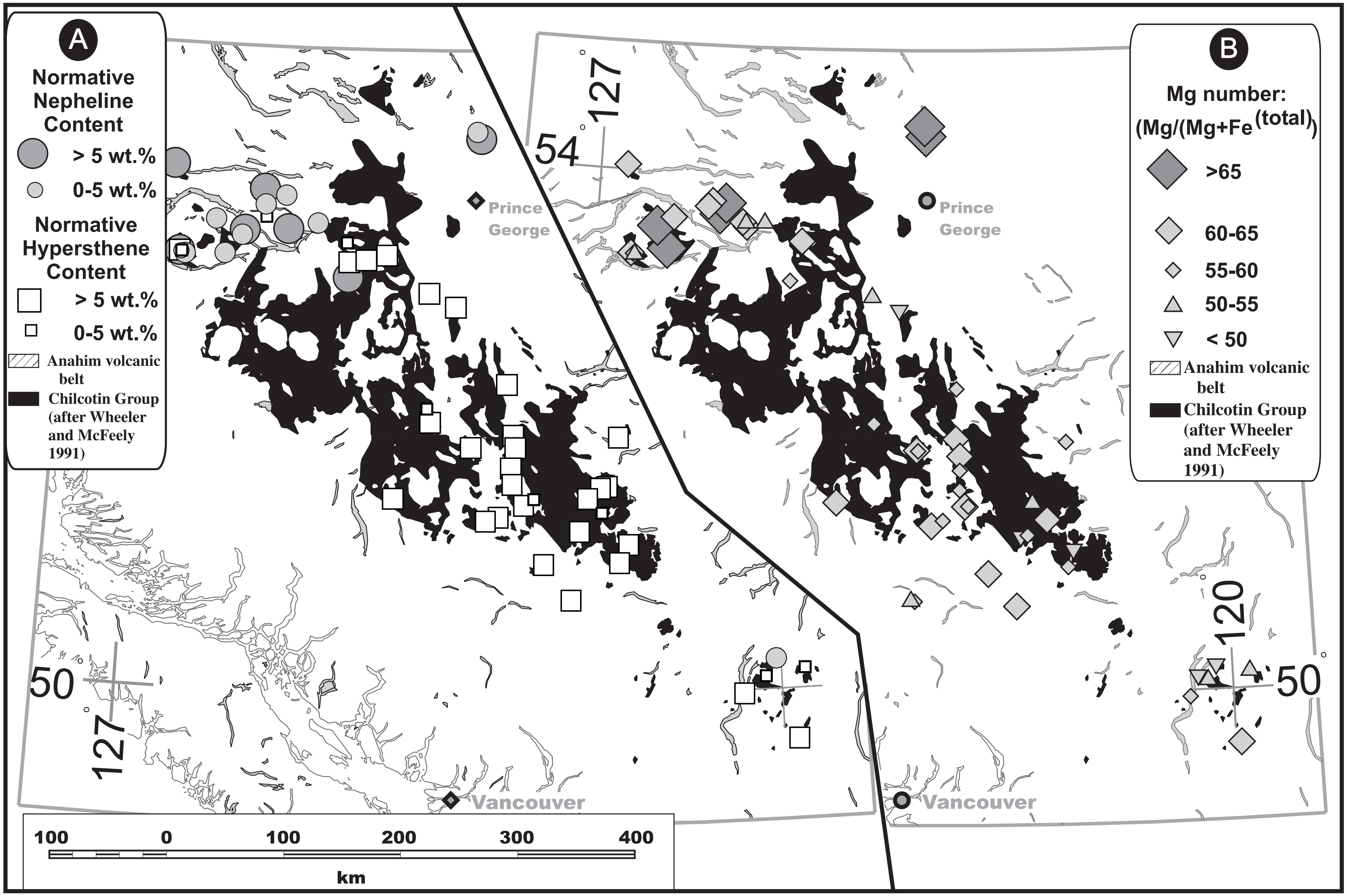


Fig. 9. Regional compilation of geochemical parameters of the Cheslatta Lake suite (see Fig. 1) and southern distribution of Chilcotin Group. The data set for basaltic rocks in south central British Columbia excludes the Anahim volcanic belt (hachured units) and Pleistocene–Recent valley-filling lavas of the Wells-Grey Clearwater area. (A) Normative nepheline and hypersthene compositions calculated on a weight percent basis. (B) Mg number (Mg# = Mg/(Mg + Fe$^{(total)}$)).



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