Geological Survey of Canada

CURRENT RESEARCH
2003-A8

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2003

CURRENT RESEARCH

Natural Resources Canada Ressources naturelles Canada

Canada

ISSN 1701-4387
Catalogue No. M44-2003/A8E-IN
ISBN 0-662-33303-9

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Publication approved by GSC Pacific, Vancouver

Overview of Neogene to Recent volcanism in the Atlin volcanic district, Northern Cordilleran volcanic province, northwestern British Columbia

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Edwards, B.R., Russell, J.K., Anderson, R.G., and Harder, M., 2003: Overview of Neogene to Recent volcanism in the Atlin volcanic district, Northern Cordilleran volcanic province, northwestern British Columbia; Geological Survey of Canada, Current Research 2003-A8, 6 p.

Abstract: We present an overview and summary of recent field and geochemical studies on Neogene to Recent mafic alkaline volcanic rocks in the Atlin volcanic district, one of the major subdivisions within the Northern Cordilleran volcanic province. The volcanic deposits in this district are subdivided into two spatially separated volcanic fields, Surprise Lake and Llangorse. Both comprise mafic alkaline rocks, which range in composition from alkaline basalt to nephelinite, contain abundant populations of felsic and peridotitic xenoliths, and locally directly overlie deposits of late Tertiary–Quaternary gravels. In two locations, Ruby Creek and Volcanic Creek, the Au-bearing gravels are being actively mined (Ruby Creek) or explored (Volcanic Creek). Field relationships suggest that many volcanic features in the Atlin district formed during the Quaternary.

Résumé : Nous présentons un aperçu et un condensé d'études géochimiques et de travaux sur le terrain qui ont été réalisés récemment en relation avec les roches volcaniques mafiques aux affinités alcalines du Néogène à l'Holocène du district volcanique d'Atlin, l'une des principales subdivisions de la province volcanique de la Cordillère du Nord. On subdivise les dépôts volcaniques de ce district en deux champs volcaniques distincts sur le plan spatial : les champs volcaniques de Surprise Lake et de Llangorse. Ces deux champs sont constitués de roches mafiques aux affinités alcalines, dont la composition varie du basalte alcalin à la néphélinite. Ces roches contiennent de grandes quantités de xénolites felsiques et péridotitiques et, par endroits, surmontent en contact direct des dépôts de gravier du Tertiaire tardif et du Quaternaire. À deux endroits, aux ruisseaux Ruby et Volcanic, les graviers aurifères font l'objet présentement d'une exploitation minière (ruisseau Ruby) ou de travaux d'exploration (ruisseau Volcanic). Les relations observées sur le terrain laissent croire que bon nombre d'entités volcaniques du district d'Atlin se sont formées au cours du Quaternaire.

[1] Contribution to the Targeted Geoscience Initiative (TGI) 2000–2003.

INTRODUCTION

The Northern Cordilleran volcanic province (Fig. 1, inset) includes Neogene to Recent volcanic rocks located in northwestern British Columbia, the western Yukon Territory, and extreme eastern Alaska (Edwards and Russell, 2000). It is a distinctive petrographic province comprising mafic alkaline to felsic peralkaline volcanic rocks. Volcanic deposits in the province were erupted across several well defined terrane boundaries within the northern Canadian Cordillera, as well as at least two major fault systems (Edwards and Russell, 2000; Abraham et al., 2001). The Atlin volcanic district in northwestern British Columbia is a subprovince within the north-central part of the Northern Cordilleran volcanic province (Fig. 1, inset).

The regional geology of the Paleozoic and Mesozoic units overlain by the Atlin volcanic district deposits has been well described over the past five decades, beginning with the pioneering work of Aitken (1959) and followed by the work of Bultman (1979), Bloodgood et al. (1989), Bloodgood and Bellefontaine (1990), Ash and Arksey (1990), Mihalynuk and Smith (1992), and Mihalynuk et al. (1992). The volcanic centres within the Atlin volcanic district have been described in a number of studies, including general field descriptions by

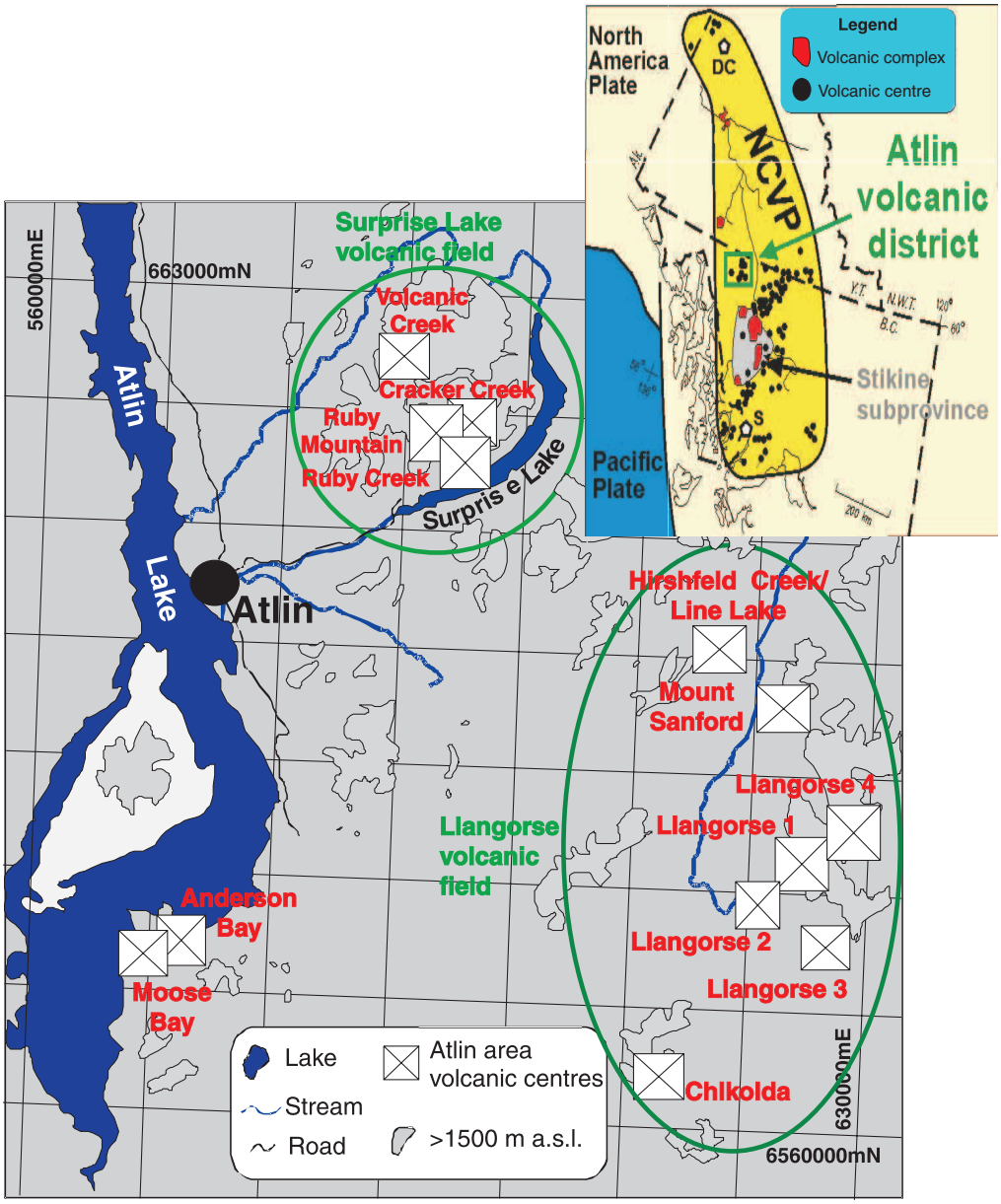

Figure 1. *Regional location map for the Atlin volcanic district. The map base is modified from NTS 104 N. Inset map shows the location of the Atlin volcanic district within the Northern Cordilleran volcanic province (NCVP).*

Aitken (1959), Levson (1992), and Edwards et al. (1996), detailed petrological and geochemical studies of specific centres (Francis and Ludden, 1995; Nicholls and Stout, 1998, 1999), and as part of regional geochemical studies (Nicholls et al., 1982; Abraham et al., 2001) (Table 1).

Volcanic rocks from the Atlin volcanic district are important regionally because they are distinctly alkaline in character compared to mafic lava from the central Northern Cordilleran volcanic province (Fig. 2), they contain abundant xenoliths of basement rocks mapped as part of the Cache Creek terrane, and they bear important stratigraphic relationships to Au-bearing gravels that are currently mined in the Ruby Creek drainage.

The Atlin volcanic district may also be the site of the youngest historic eruption in Canada. An article published in *The Klondike Nugget* on January 28, 1899, reported that miners in the Atlin mining camps "...were working nights, gladly profiting by the mellow twilight caused by the volcano's glare, which turned night into day…" (Anonymous, 1899, p.4). Obviously, if the report was accurate, it would have important implications for the possibility of future eruptions within the Atlin volcanic district.

Fieldwork completed during July 1995, July 2000, and July 2002 included mapping and sample collecting at 9 of the 13 volcanic deposits in the Atlin volcanic district. Despite extensive fieldwork at the youngest volcanic features, we did not discover any signs of Late Holocene or historic volcanic activity. Specifically, none of the 13 volcanic deposits in the Atlin volcanic district appears to host tephra deposits younger than several thousand years old. Thus, the article in *The Klondike Nugget* cannot be substantiated. However, given the location of the placer operations from which the eruption was supposedly visible (Pine, Birch, Discovery, and McKee creeks) and the reported location of the volcano approximately 50 miles (80.45 km) south of Gladys Lake, the vent might possibly be in the very rugged and inaccessible Coast Mountains south or southwest of Atlin Lake.

The purpose of this paper is to provide a brief summary of recent studies of centres in the Atlin volcanic district and to establish the regional importance of centre-specific studies reported by Edwards and Bye (2003) and Harder et al. (2003).

OVERVIEW OF THE ATLIN VOLCANIC DISTRICT

The Atlin volcanic district is part of the Northern Cordilleran volcanic province and includes 13 spatially distinct volcanic deposits that range from small, isolated remnants of lava flows (e.g. Llangorse and Chikoida), to shallow-level intrusions (Hirschfeld Creek), and to partly preserved volcanic cones (e.g. Ruby Mountain) (Table 1). Eleven of the thirteen deposits are grouped into two spatially separated volcanic fields, the Surprise Lake and Llangorse volcanic fields (Fig. 2, Table 1). The other two deposits, Anderson Bay and Moose Bay, are about 40 km away from the two more extensive volcanic fields.

Surprise Lake volcanic field

The Surprise Lake volcanic field comprises cinder cones and lava flows from the Ruby Mountain, Cracker Creek, and Volcanic Creek centres and from Ruby Creek. Surprise Lake is a major physiographic feature that bounds the southern and eastern edges of the known volcanic rocks within the field (Fig. 1). The volcanic centres in this volcanic field are unique for the Atlin district because the vents and vent deposits are relatively well preserved. The primary volcanic deposits within the field include lava flows, consolidated and

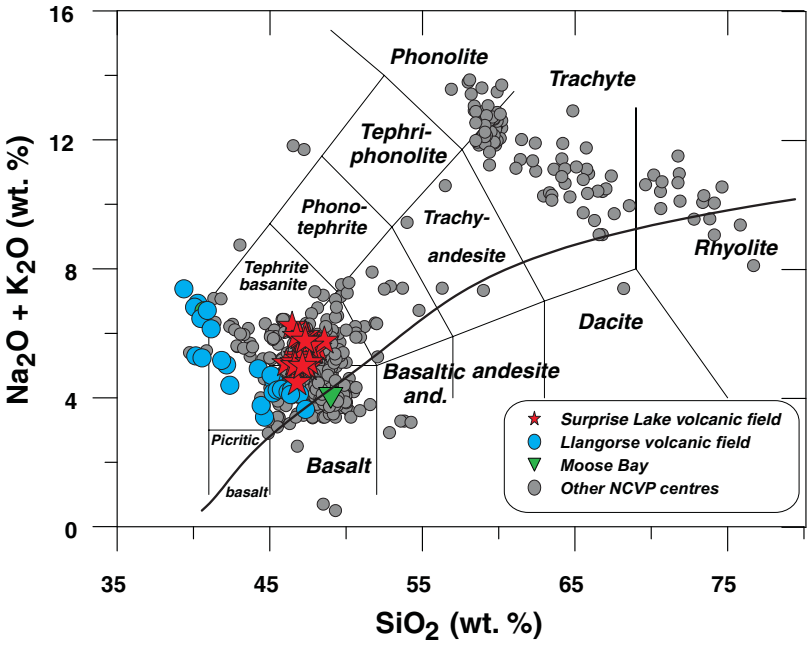

Figure 2.

Total-alkalis-versus-silica classification diagram showing the chemical composition of Atlin volcanic district rocks compared to volcanic rocks from the rest of the Northern Cordilleran volcanic province. Fields are after *LeBas et al. (1986). The alkaline-subalkaline division of Irvine and Baragar (1974) is also shown (orange line).*

Table 1. Summary of locations, ages, volcanic features, and estimated volumes for Neogene to Recent volcanic centres within the Atlin volcanic district, Northern Cordilleran volcanic province (*after* Edwards and Russell, 2000).

Volcanic field / centre*	Location (lat; long.)	Volcanic feature	Volume (km^3)	Age[1]	Notes
Anderson / Moose Bay	59.30°N, 133.75°W	flows	<0.1	27.5 ± 4.3 to 16.2 ± 2 Ma	Dates reported by Bultman (1979)
Surprise Lake volcanic field					
Volcanic Creek	59.77°N, 133.40°W	cone(s) and flows	0.02	Late Quaternary	Granite xenoliths and orthopyroxene and olivine megacrysts present[2,3]; westernmost flow overlies gravel deposits; ACTIVE PLACER EXPLORATION
Ruby Mountain	59.70°N, 133.38°W	cone and flows	~1	Mid- to Late Quaternary	Spinel lherzolite and granite xenoliths, orthopyroxene and olivine megacrysts present[2,3,4]; volcanic deposits on south flank overlie gravel deposits
Cracker Creek	59.70°N, 133.29°W	cone	0.003	Late Quaternary	Granite xenoliths present[2]
Ruby Creek	59.65°N, 133.36°W	flow	<0.01	0.54 ± 0.2 Ma	Granite xenoliths present[2,5]; overlies gravel deposits; ACTIVE PLACER MINING
Mount Llangorse volcanic field					
Hirschfeld Creek/Line Lake	59.53°N, 132.92°W	neck	<0.1	T-Q	Spinel lherzolite xenoliths present[6]
Fire Mountain (Mount Sanford)	59.45°N, 132.78°W	intrusions / dykes	<0.001	T-Q	spinel lherzolite, harzburgite, websterite, orthopyroxenite, gabbro, and chert xenoliths present[7]
Llangorse Mountain					
1	59.37°N, 132.78°W	neck / flow	<0.1	Q	lherzolite, dunite [2,8]; overlies bedded, coarse boulder gravel [2, 8]
2	59.35°N, 132.90°W	flow	<0.001	T-Q	peridotite and crustal xenoliths, pyroxene xenocrysts present[8]
3	59.32°N, 132.90°W	flow	<0.001	T-Q	peridotite and crustal xenoliths, pyroxene xenocrysts present[8]
4	59.38°N, 132.73°W	flow	<0.001	T-Q	peridotite and crustal xenoliths present[8]
Lone Point	59.03°N, 132.78°W	plug	<0.001?	T-Q	spinel lherzolite[6]
Chikoida Mountain	59.20°N, 133.04°W	eroded flow remnants	<0.001	T-Q	lherzolite, dunite, granite, clinopyroxene[2]

[1] All radiometric ages are K-Ar, except where (*) denotes Ar/Ar; T-Q, Q, denotes estimated ages as Tertiary to Quaternary or Quaternary, respectively
[2] Edwards et al. (1996)
[3] Nicholls and Stout (1999)
[4] Nicholls et al. (1982)
[5] Edwards and Bye (2003)
[6] Francis and Ludden (1995)
[7] Higgins and Allen (1985)
[8] Harder et al. (2003)

unconsolidated volcanic breccia, slightly welded lapillistone, and poorly consolidated lapilli- to ash-sized tephra. Secondary deposits include a rock glacier and landslide deposits at Ruby Mountain (Aitken, 1959; Levson, 1992; Edwards et al., 1996; Edwards and Bye, 2003).

Detailed descriptions of field relationships, distribution and character of deposits, and major-element geochemistry for the Ruby Mountain, Cracker Creek, and Ruby Creek centres are given by Edwards and Bye (2003). Work continues on the Volcanic Creek centre (A. McCarthy and B.R. Edwards, work in progress, 2003). Specific rock types include alkaline basalt, hawaiite, and basanite from the TAS classification (LeBas et al., 1986). Compared to rocks from the Llangorse volcanic field, rocks from the Surprise Lake volcanic field have a more restricted range in SiO_2 (45–49 wt. %) and higher average values of Na_2O and K_2O for comparable values of SiO_2 (Fig. 2). Lava and tephra from all three centres and from Ruby Creek show signs of interaction with basement materials including abundant white felsic xenoliths and rare small peridotitic xenoliths.

Although quantitative age constraints for the Surprise Lake volcanic field are limited to a single K-Ar age of 540 ka for the Ruby Creek lava flow (Mortensen, 1992), field relationships are consistent with all features in the field being

Quaternary in age (Aitken, 1959; Levson, 1992; Edwards et al., 1996). The tephra cone that forms the bulk of Ruby Mountain appears to have erupted on the eastern side of a ridge that was part of a glaciated valley. The Cracker Creek cone has been only slighted modified by glacial action and is one of the youngest volcanic features in the Atlin district (Aitken, 1959; Edwards et al., 1996). Field observations are consistent with the cone having formed since the last major period of regional glaciation, and possibly even since the last advance of the alpine glaciers. This would give it a maximum age of 10 000 BP (Clague, 1991). Volcanic Creek hosts nested cones that also appear to be from the Latest Quaternary. The scoria cones have been little modified by erosion or mass wasting, possibly because of their location at the junction of two U-shaped valleys, where they were protected from glacial erosion by Mount Barham. However, the scoria cones are unlikely to have survived repeated episodes of regional glaciation.

Volcanic deposits from Ruby Mountain, Ruby Creek, and Volcanic Creek directly overlie deposits of late Tertiary–Quaternary gravels. At Ruby Creek and Volcanic Creek, the Au-bearing gravels were apparently armoured primarily by overlying lava flows, which protected them from erosion by regional glaciation. Both locations have had historic placer mining activity, and placer mining at Ruby Creek is ongoing (Wojdak, 2002).

Llangorse volcanic field

The Llangorse volcanic field includes remnants of lava flows south of Llangorse Mountain, a possible vent plug at Hirschfeld Creek (Francis and Ludden, 1995; also referred to as 'Line Lake' by Aiken, 1959), dykes at Mount Sanford (Higgins and Allen, 1985; also referred to 'Fire Mountain' by Francis and Ludden, 1995), and vent and lava flow remnants at Chikoida Mountain (Edwards et al., 1996) (Fig. 1; Table 1). The Hirschfeld Creek occurrence was interpreted as a shallow-level plug by Francis and Ludden (1995). They showed that rocks at Hirschfeld Creek range from hypersthene-normative basalt to nephelinite. Higgins and Allen (1985) described samples from nephelinite dykes near Mount Sanford. The scattered lava remnants at Chikoida Mountain were originally described as possible vent conduits (Edwards et al., 1996), but alternatively could be small lava-flow remnants (Harder et al., 2003); the outcrops are limited to a few metres in diameter. The field and geochemical characteristics for deposits from the Llangorse Mountain area are described in greater detail by Harder et al. (2003).

The samples from the Llangorse volcanic field have a greater range in SiO_2 (40–47 wt. %) and generally lower values of Na_2O and K_2O (for samples with comparable SiO_2) than those from the rest of the Atlin district (Fig. 2). Rock types include alkaline basalt, basanite, and nephelinite. Xenoliths are also ubiquitous at deposits in the Llangorse field; however, peridotitic xenoliths are volumetrically dominant at most locations, with the exception of Chikoida Mountain.

Age constraints for the Llangorse volcanic field are presently limited to field observations with respect to glacial features. Aitken (1959) suggested that the volcanic rocks in the Llangorse area were decidedly older than those in the Surprise Lake area, and we concur with his observations. However, at least one deposit immediately west of the summit of Llangorse Mountain (labelled Llangorse 1 on Fig. 1) appears to have partly filled a glaciated valley, suggesting that the deposit is Quaternary in age.

Occurrences of rocks at Anderson Bay and Moose Bay

Occurrences of volcanic rocks at Anderson Bay and Moose Bay on the southeastern shores of Atlin Lake (Fig. 1) are remnants of columnar-jointed lava flows (Bultman, 1979). The two flow remnants have been described briefly by Bultman (1979) and Bloodgood and Bellefontaine (1990), and one sample was chemically analyzed by Erdman (1985) (Table 1). The sample is geochemically unique for the Atlin district and the Northern Cordilleran volcanic province as a whole (Fig. 2). It is basaltic, but has distinctly lower values of Na_2O and K_2O for a comparable value of SiO_2 and plots within the subalkaline division of Irvine and Baragar (1974).

Bultman (1979) reported two Miocene K-Ar ages for the lava flows: 27.5 ± 4.3 Ma and 16.2 ± 2 Ma. If the reported ages are accurate, then these lava flows may represent the oldest events in the Northern Cordilleran volcanic province. However, their distinctive chemical characteristics compared to the other Atlin district volcanic rocks and the apparent large age difference could also be interpreted to indicate that these rocks are not part of the Northern Cordilleran volcanic province suite.

ONGOING STUDIES OF ROCKS IN THE ATLIN VOLCANIC DISTRICT

At least three different research groups continue to investigate samples from the Atlin volcanic district. Workers at the University of Calgary are studying samples from Volcanic Creek and Mount Llangorse (J. Nicholls, pers. comm., 2002). Progress reports on studies by other workers are included in other papers (Harder et al., 2003; Edwards and Bye, 2003; A. McCarthy and B.R. Edwards, work in progress, 2003). The ongoing studies within the Atlin volcanic district are important for understanding several regional-scale problems with implications for the following: 1) the character of the lithosphere beneath the Cache Creek terrane; 2) the timing of glaciation in northwestern British Columbia; and 3) the timing and preservation of economically important placer Au deposits.

ACKNOWLEDGMENTS

We wish to acknowledge M. Mihalynuk for providing background information on the geology of the Atlin area and informing us about the Chikoida Mountain and Atlin Lake

locations. The fieldwork for the ongoing studies of volcanic deposits in the Atlin area has been generously funded by the Atlin TGI project (project number 000024-03-01), LITHOPROBE, NSERC, the Michigan Space Grant Consortium, and Grand Valley State University. We also thanks K. Simpson for helpful suggestions about the text and figures and B. Vanlier for her patience and editorial assistance.

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