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Llangorse volcanic field, British Columbia

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Abstract: The Llangorse volcanic field is located southeast of Atlin, British Columbia, and is part of the larger Atlin volcanic district of the Northern Cordilleran volcanic province. The Llangorse volcanic field comprises seven localities of Neogene to Quaternary volcanic rocks: Hirschfeld Creek–Line Lake, Mount Sanford, Llangorse Mountain (sites 1, 2, 3, and 4), and Chikoida Mountain. The compositions of lava from these centres include olivine nephelinite, basanite, and alkali olivine basalt; all of the Llangorse Mountain sites are basanite. During the summer of 2002, the Llangorse Mountain sites and Chikoida Mountain were mapped in detail as part of the Atlin Targeted Geoscience Initiative, and the results are described in this paper. These exposures of volcanic rocks represent erosional remnants of valley-filling lava flows. Furthermore, many of these volcanic rocks show features that suggest impoundment against or eruption under ice.

Résumé : Le champ volcanique de Llangorse est situé au sud-est d'Atlin, en Colombie-Britannique, et appartient au plus vaste district volcanique d'Atlin de la province volcanique de la Cordillère du Nord. Le champ volcanique compte sept localités de roches volcaniques datant du Néogène au Quaternaire : ruisseau Hirschfield/lac Line, mont Sanford, mont Llangorse (sites 1, 2, 3 et 4) et mont Chikoida. La composition des laves de ces centres révèlent de la néphélinite à olivine, de la basanite et du basalte alcalin à olivine; les laves de tous les sites du mont Llangorse se composent de basanite. Dans le cadre du projet d'Atlin de l'Initiative géoscientifique ciblée, on a procédé à la cartographie détaillée des sites du mont Llangorse et du mont Chikoida au cours de l'été 2002. Les résultats obtenus sont décrits dans le présent rapport. Ces affleurements de roches volcaniques constituent des lambeaux d'érosion de coulées de lave formant le remblayage de vallées. De plus, bon nombre de ces roches volcaniques présentent des caractéristiques qui laissent supposer qu'elles se sont accumulées contre un glacier ou qu'elles ont fait éruption sous des masses de glace.

INTRODUCTION

The Northern Cordilleran volcanic province comprises Neogene to Quaternary volcanic rocks distributed across northwestern British Columbia, the Yukon Territory, and Alaska (Edwards and Russell, 2000). The Atlin volcanic district is part of the Northern Cordilleran volcanic province and consists of several Neogene to Quaternary volcanic centres in the Atlin area (Fig. 1); these include Moose Bay and Anderson Bay (Bultman, 1979), the Llangorse volcanic field, and the Surprise Lake volcanic field (Edwards et al., 2003). The latter field includes Cracker Creek, Ruby Mountain, Ruby Creek, and Volcanic Creek (Edwards and Bye, 2003). The Llangorse volcanic field is situated approximately 55 km southeast of Atlin, British Columbia (Fig. 1), and comprises Neogene to Quaternary volcanic rocks exposed at four localities, including Hirschfeld Creek–Line Lake, Mount Sanford, Llangorse Mountain, and Chikoida Mountain. The

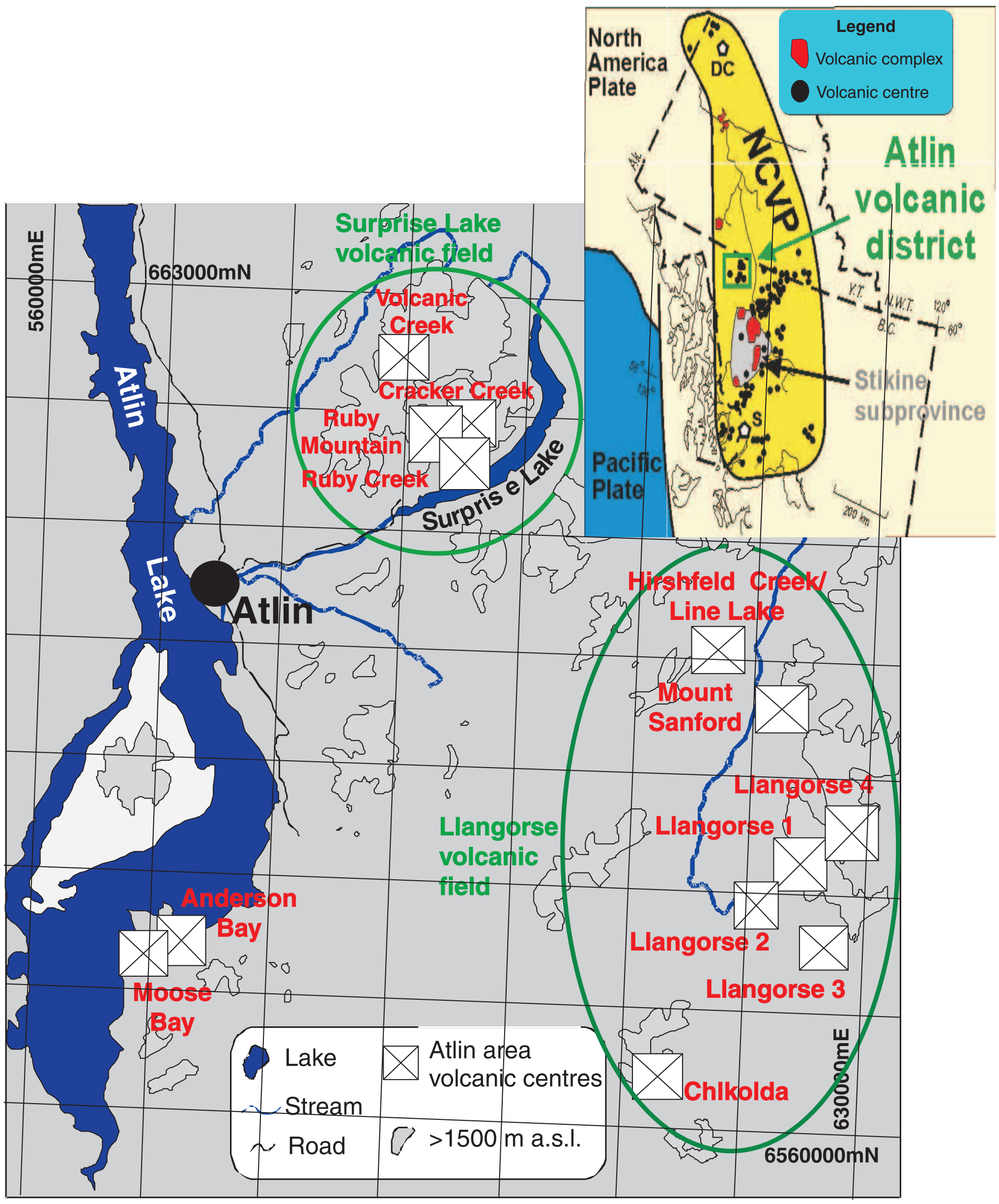

*Figure 1. The Atlin volcanic district, part of the larger Northern Cordilleran volcanic province (NCVP), is composed of Neogene to Quaternary volcanic rocks situated within a 70 km radius of Atlin, British Columbia. The district consists of the Surprise Lake volcanic field, which includes Volcanic Creek, Cracker Creek, Ruby Mountain, and Ruby Creek, and the Llangorse volcanic field, which includes Hirschfeld Creek–Line Lake, Mount Sanford, Llangorse Mountain (sites 1, 2, 3, and 4), and Chikoida (*after *Edwards et al., 2003).*

geographic area included in the Llangorse volcanic field is approximately 144 km^2 and is centred around Llangorse Mountain (Fig. 2).

The regional geology of the Atlin area, which straddles the boundary between the Coast and Intermontane belts, was first mapped by Aitken (1959). The Atlin volcanic district (Fig. 1) lies entirely within the Intermontane Belt and is underlain by Paleozoic sedimentary and volcaniclastic rocks of the Cache Creek Group and by Jurassic and Cretaceous plutons (mostly granitic to granodioritic in composition). The Llangorse volcanic field (Fig. 2), with the exception of Chikoida Mountain, is underlain primarily by the Llangorse

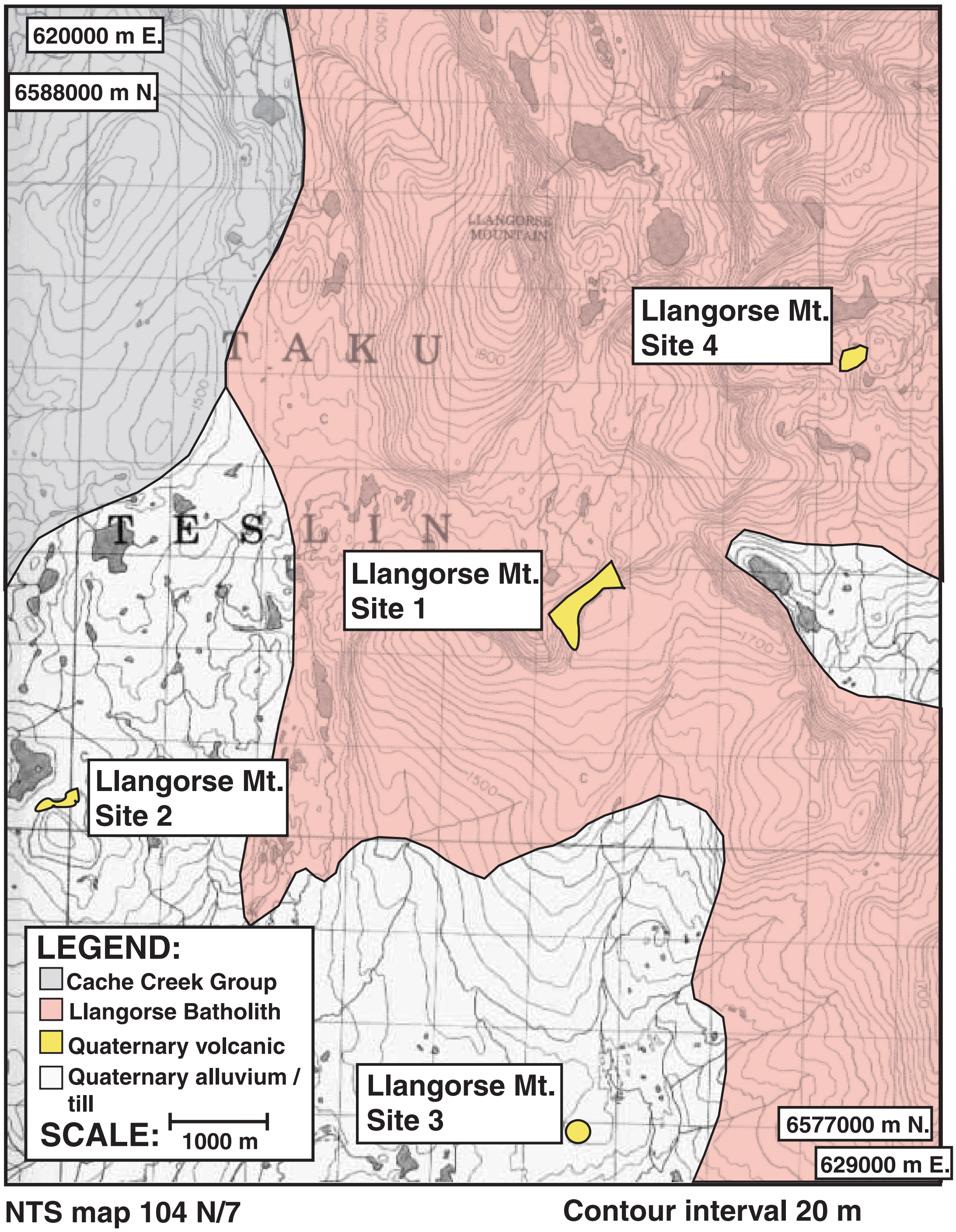

Figure 2. Geology of the area near Llangorse Mountain (after *Aitken, 1959), showing the Llangorse Mountain sites 1, 2, 3, and 4, and the distributions of volcanic deposits mapped in the 2002 field season. These exposures of Neogene to Quaternary volcanic rocks are erosional remnants of lava flows.*

Mountain batholith, a Jurassic granodiorite intrusion, and possibly by chert from the Cache Creek Group. The Chikoida volcanic rocks are underlain by a Jurassic granitic intrusion.

Mapping and sample collection in the Llangorse volcanic field were undertaken during the summer of 2002, as part of the Atlin Targeted Geoscience Initiative, to:

1. provide an inventory of Neogene volcanic rocks within the Llangorse volcanic field and establish their composition, volume, and age;
2. study the volcanology of the individual deposits and determine the style of eruption and the environmental conditions into which the lavas were erupted (e.g. glaciovolcanic, subaerial); and
3. collect xenoliths entrained in these lavas, with particular emphasis on those with a mantle affinity. Subsequent chemical analysis of these samples can help characterize the nature of the lithospheric mantle underlying the Stikinie and Cache Creek terranes and constrain its origins (e.g. autochthonous versus allochthonous relative to the overlying terranes).

LLANGORSE VOLCANIC FIELD

Volcanic rocks of the Llangorse volcanic field (summarized in Tables 1, 2) were mapped at a scale of 1:20 000 during the summer of 2002 . The occurrences nearest Llangorse Mountain have been divided into sites 1, 2, 3, and 4 (Fig. 1, 2). The volcanic rocks exposed nearest to Llangorse Mountain have been previously studied by Nicholls et al. (1982), Higgins and Allen (1985), Carignan et al. (1994), Francis and Ludden (1995), Edwards et al. (1996), J. Nicholls (unpub. data, 1999), Peslier et al. (2000), and Abraham et al. (2001); these centres have been interpreted as hypabyssal feeder pipes or valley-filling lava flows. The Chikoida Mountain volcanic rocks were not mapped by Aitken (1959), but were subsequently described by Mihalynuk and Smith (1992) and by Edwards et al. (1996), who interpreted them as hypabyssal feeder pipes (Edwards et al., 1996). The Llangorse volcanic field also includes the Hirschfeld Creek–Line Lake (described by Aitken, 1959; Francis and Ludden, 1995) and Mount Sanford (described by Higgins and Allen, 1985) centres. Although all of the the volcanic rocks are Neogene to Quaternary in age, their relative ages and relationships to one another are unclear. Volcanic rocks in the Llangorse volcanic field (*see* Fig. 3, Table 3) are basanite (Nicholls et al., 1982; J. Nicholls, unpub. data, 1999).

Table 1. Locations and volumes of volcanic rock occurrences in the Llangorse Mountain area. Localities keyed by number to Figures 1 and 2.

Site / Name	[UTM[1]] Northing	Easting	Latitude / Longitude	Volume (x 10^6 m^3)
1) Site 1	6582950	625950	59°22'5.8"N / 132°47'1.9"W	21.4
2) Site 2	6580122	619838	59°20'40.9"N / 132°53'34.4"W	3
3) Site 3	6577850	625600	59°19'21.4"N / 132°47'34.7"W	3
4) Site 4	6585401	628415	59°23'22.3"N / 132°44'20.6"W	2.0
5) OC #1[2]	6580271	630526	59°20'34.3"N / 132°42'18.1"W	<10 m^3
6) OC #2[2]	6588961	627398	59°25'18.4"N / 132°45'17.4"W	<10 m^3

[1] northing and easting in metres UTM relative to North American Datum 1927
[2] isolated outcrops that are too small to portray on Figures 1 and 2

Table 2. Descriptions and petrological characteristics of basanitic volcanic rocks (*see* Fig. 3) and deposits located in the Llangorse volcanic field. Localities keyed by number to Figures 1 and 2.

Site	Volcanological features	Petrographic features	Xenoliths[1]
1	Valley-filling lava flow overlying debris flow sediments	Olivine porphyritic (5 modal %); lath-like plagioclase; fine to medium grained	M >> C
2	Small remnant of massive lava	Pyroxene xenocrysts with reaction rims; plagioclase xenocrysts	M >> C; P
3	Remnants of lava flows and associated hyaloclastite breccia	Pyroxene xenocrysts with reaction rims	M >> C; P
4	Valley-filling flow, lava underlain by debris-flow sediments	Olivine porphyritic (5 modal %); lath-like plagioclase; fine to medium grained	M >> C

[1] Lavas commonly contain mantle-derived (M) xenoliths of peridotite, crust-derived xenoliths (C), and megacrysts of pyroxene (P)

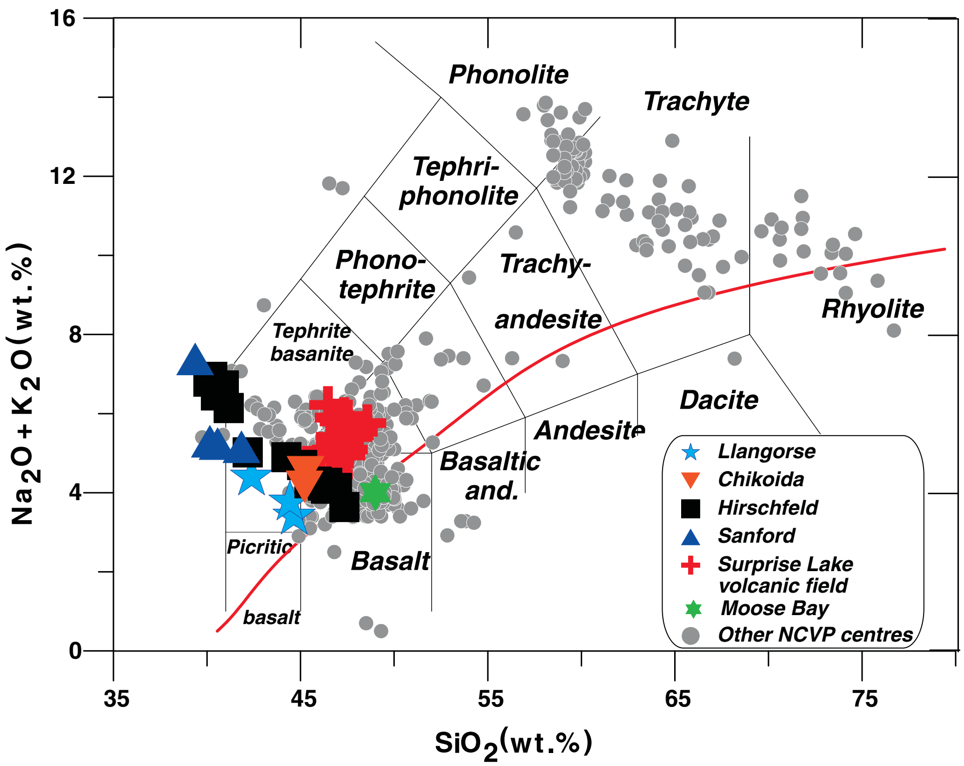

Figure 3.

Chemical composition of volcanic rocks from the Llangorse volcanic field, expressed as weight per cent alkalis versus silica, are compared to similar rocks from the Surprise Lake volcanic field and other Northern Cordilleran volcanic province (NCVP) centres (Edwards and Russell, 1999). Data are from samples analyzed by Russell and Edwards in 1997, and are compared with data from Abraham, et al. (2001) and Francis and Ludden (1995).

Table 3. Major-element chemical compositions (in wt.%) of volcanic rocks in the Llangorse volcanic field from samples analyzed by Russell and Edwards in 1997. Figure 3 compares these samples with those in Abraham et al. (2001) and Francis and Ludden (1995).

Sample	SiO_2	TiO2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
95-CM[1]	45.21	2.70	11.84	0.00	12.03	0.19	12.18	8.77	2.97	1.18	0.69
95-CM[1]	45.26	2.74	11.95	0.00	12.16	0.20	12.03	8.82	3.20	1.32	0.70
95-LM[2]	44.65	1.95	12.76	0.00	12.13	0.20	12.72	10.32	2.49	0.91	0.32
95-LM[2]	44.43	2.03	12.41	0.00	12.24	0.21	12.69	10.38	2.71	1.05	0.42

[1] Chikoida Mountain samples: basanite from UTM 6565200N 612450E, (lat. 59°12'46.1"N, long. 133°1'19.6"W)

[2] Llangorse Mountain site 1: basanite from UTM 6582950N, 625950E (lat. 59°22'5.8"N, long. 132°47'1.9"W)

The three sites nearest Llangorse Mountain (sites 1, 2, and 3) were originally identified by Aitken (1959). During field mapping in the summer of 2002, we discovered a new lava flow (site 4, Fig. 2), as well as two small (less than 5 m^2) outcrops of lava that are too small to show on the map.

Llangorse Mountain: site 1

The sequence of lavas at site 1 (Fig. 1, 2) is volumetrically the second largest Neogene basanite centre in the Llangorse volcanic field after Hirschfeld Creek (Francis and Ludden, 1995; Tables 1, 2). The outcrop is a large, cliff-forming bluff approximately 80 m high and 100 m wide. Vertical columnar joints extend throughout the flow; the columns are generally smaller at the top of the flow (approx. 1 m) than at the base (approx. 2 m). The lavas contain abundant xenoliths and xenocrysts in an aphanitic groundmass. A layer of highly vesicular, quenched basanite about 30 cm thick occurs at the base of the lava flow. Mantle-derived xenoliths are common; they are mostly concentrated in the base of the lava flow (1–5% by volume) and are rare (much less than 1% by volume) in the upper part. The peridotite xenoliths are mostly spinel lherzolite and are typically 1 to 2 cm in size, but xenoliths greater than 20 cm in size are not uncommon. Crustal xenoliths are rare (much less than 1% by volume) and are generally less than 5 cm in size at this locality; most of these appear to be derived from the Llangorse Mountain batholith and may represent surficial fragments entrained during flow of the lavas.

Quenched basanite directly overlies volcaniclastic debris-flow sedimentary deposits along the west side of the massif (Fig. 4). These sedimentary deposits are not present beneath the flow on the eastern side of the massif. At the eastern contact, the lava flow is in direct contact with *grus* derived from weathering of the Llangorse Mountain batholith. The volcaniclastic debris-flow sedimentary deposits are poorly sorted, crudely stratified, and contain subangular to subrounded fragments. They are primarily matrix supported, with minor clast-supported layers. The dominant clast type is granodiorite, which derives from the underlying Llangorse Mountain batholith. Granodiorite clasts vary from 2 cm to 5 m in diameter. Clasts of basanitic lava are also common and vary in size from 2 to 50 cm. Larger boulders, up to 1 to 2 m in size, are concentrated toward the bottom of the depositional sequence. An unusual feature of these volcaniclastic sedimentary deposits is the occurrence of peridotite clasts, which range from a few millimetres to more than 20 cm in diameter and represent mantle xenoliths originally entrained in the basanite lava.

The debris-flow matrix has a grain size of 2 to 4 mm and comprises clasts of granodiorite, vesicular basanite, peridotite, and palagonitized basanite (Fig. 5D). The deposit is partly consolidated but still friable. Crude layering at the base of the deposit dips approximately 25° to the northwest and is only visible at the southwest margin of the flow. The juxtaposition of rounded granitoid clasts and subangular basanitic clasts in a poorly sorted, matrix-supported deposit is consistent with a water-saturated debris flow. The presence of large, subangular clasts of fresh vesicular basanite and peridotite xenoliths supports the hypothesis that these sedimentary deposits are syneruptive with the overlying lava flow.

Llangorse Mountain: sites 2 and 3

The columnar-jointed basanite lavas at sites 2 and 3 (Fig. 1, 2) are mound shaped and approximately 200 m in diameter (Tables 1, 2). Lavas at site 2 show moderately well developed columns, oriented vertically and ranging in size from 1 to 2 m. At site 3, development of columnar jointing varies. Well developed columns, 10 to 30 cm in diameter, show highly variable fanning orientations on the east and west faces of the outcrop. The north face features larger (approx. 30 cm), poorly formed, vertical joints.

Peridotite xenoliths are common (1–5% by volume) at both localities and range in size from 5 to 10 cm. At site 2, crustal xenoliths are rare (much less than 1% by volume) and appear to derive from the Llangorse Mountain batholith; crustal xenoliths at site 3 are also rare (much less than 1% by volume) but appear to be chert and are therefore possibly derived from the Cache Creek Terrane. Lavas at both sites contain clinopyroxene xenocrysts characterized by 1 to 2 mm reaction rims.

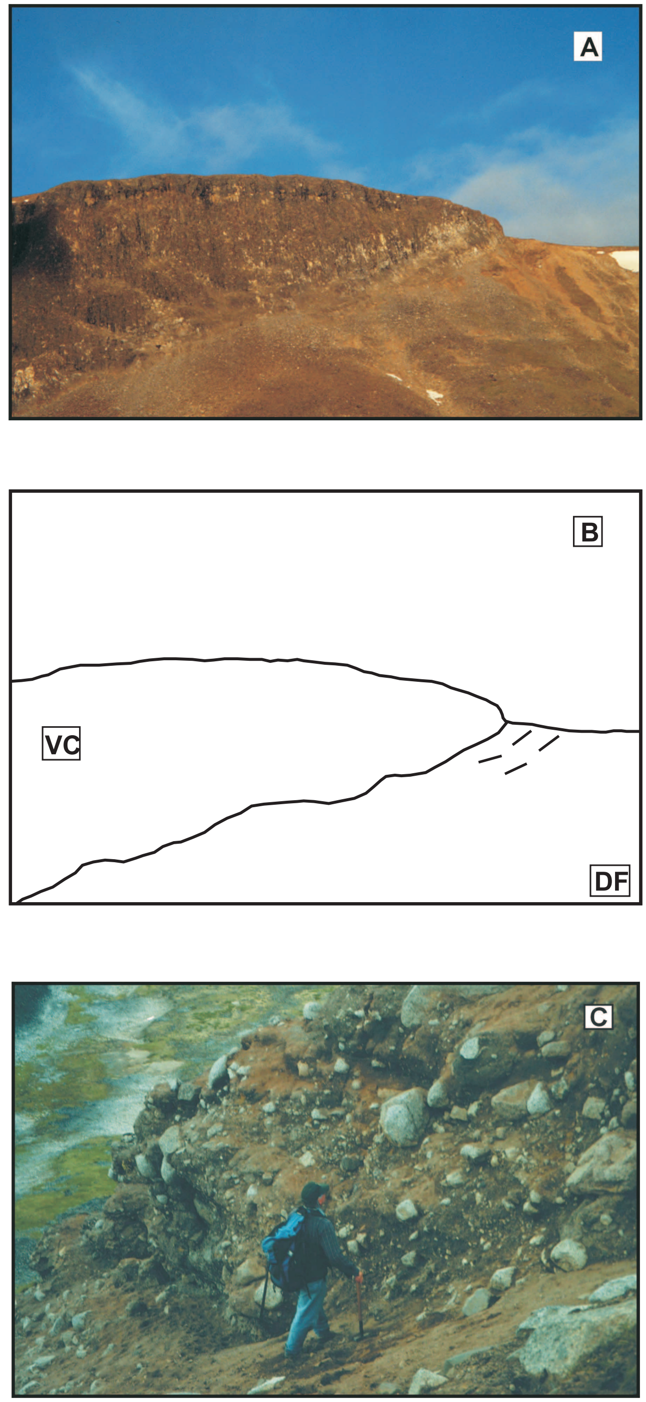

Figure 4. *Llangorse Mountain site 1:* ***A)*** *western side of the bluff defined by the lava flow;* ***B)*** *diagrammatic sketch of part A, showing contact between lava (VC) and volcaniclastic debris-flow deposit (DF); short line segments indicate apparent dip direction of crude bedding in debris-flow deposit;* ***C)*** *nature of bedding and sorting in debris-flow sediments underlying the valley-filling massive lava flow.*

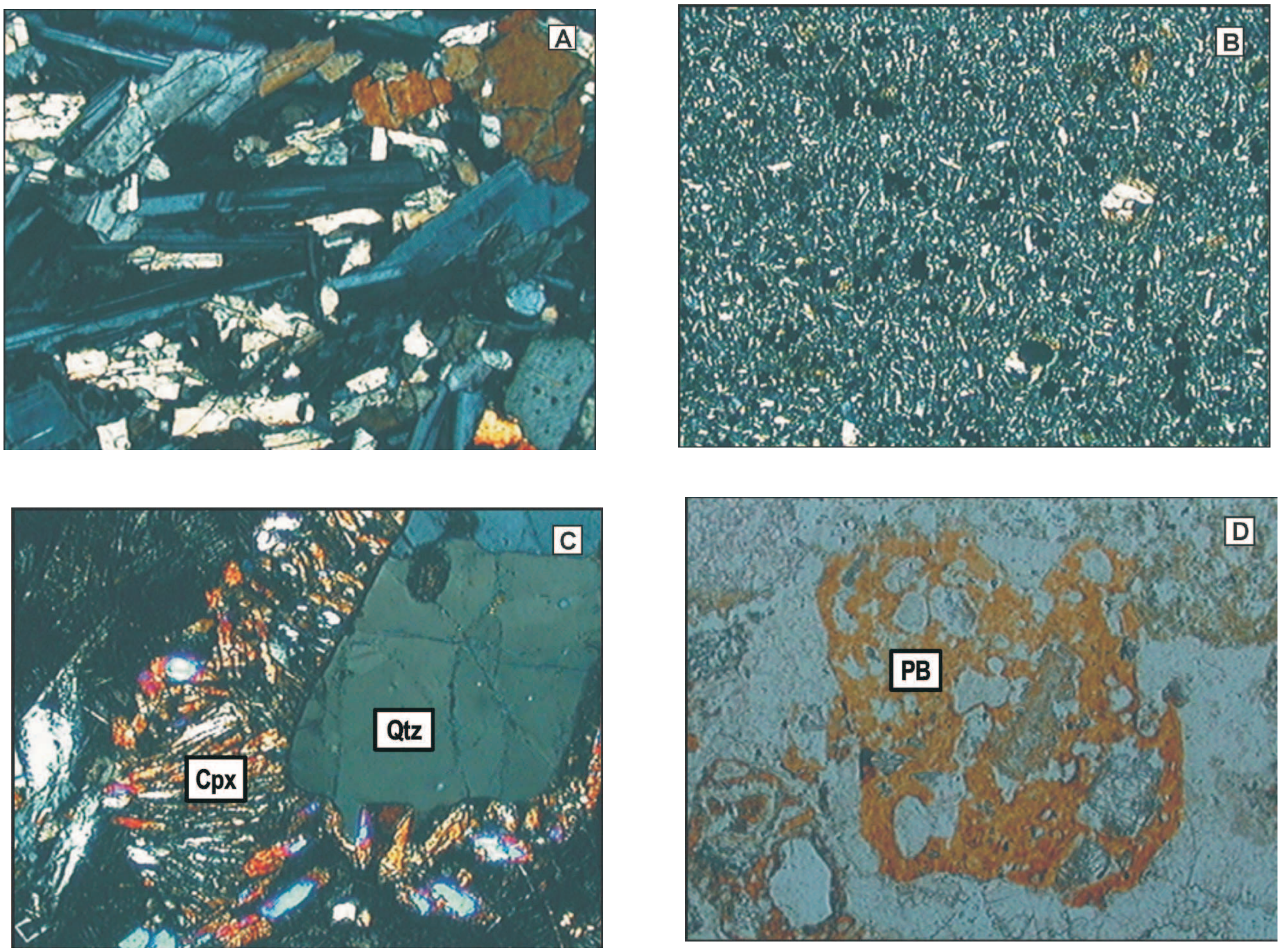

Figure 5. *Photomicrographs of volcanic rocks from Llangorse volcanic field:* ***A)*** *medium-grained feldspar-rich basanite from lavas filling paleovalley at site 1;* ***B)*** *fine-grained to aphanitic basanite lava from site 2;* ***C)*** *xenocryst of quartz (Qtz) with clinopyroxene reaction rim (Cpx) from lava at site 4; and* ***D)*** *palagonite altered basanite clast (PB) from volcaniclastic debris-flow deposit, site 1. Field of view is 1.65 mm for all photomicrographs.*

Llangorse Mountain: site 4

The lava at site 4 (Fig. 1, 2) is newly discovered and not shown on Aitken's (1959) map. The outcrop is approximat ely 350 m by 300 m, less than 50 m high, and forms two main ridges (east and west ridges; Tables 1, 2). Columnar joints are well developed in some areas and, in particular, on the west ridge. The columnar jointing exposed on the west ridge forms an A-shaped structure, with joints on the flanks plunging away from the centre of the ridge. The volcanic rocks are aphanitic basanite containing abundant xenoliths, similar to those exposed at site 1. The contact between the lava and the granodiorite basement rock (the Llangorse Mountain batholith) is exposed, and the basanite appears to 'coat' the granodiorite. Xenocrysts of plagioclase, quartz, and amphi bole, generally 1 to 2 cm in size, within the basanite suggest that some melting of the granodiorite occurred during emplacement of the lava (Fig. 5C).

Volcaniclastic debris-flow sedimentary deposits, very similar in composition to those found at site 1, occur directly beneath the lava flow. They are indurated but break easily, and contain clasts of granodiorite, vesicular basanite, palagonitized basanite, and rare (less than 1% by volume) millimetre-size peridotite, as well as a matrix of smaller clasts and sand, silt, and clay. The volcaniclastic sedimentary deposits are, in most areas, clast supported and poorly sorted, with subangular to subrounded clasts. Very crude bedding is present, with the largest boulders (up to several metres) con centrated at the bottom of the unit. The volcaniclastic sedi mentary deposits dip down-valley to the northeast and define the shape of a narrow valley that is partially filled by the lava flow. As at site 1, the presence of vesicular basanite and small peridotite clasts strongly supports the idea that these high energy debris-flow sedimentary deposits are also syneruptive.

Peridotite xenoliths are common (1–5% by volume) and are dominantly 1 to 10 mm in size, although some range up to 15 cm. Large peridotite xenoliths are more common on the east ridge than the west ridge, and lava in one area in particular is extremely rich in xenoliths, with boulders of it containing up to 70% xenoliths. Crustal xenoliths are rare, except in areas near the contact with the basement and in some float boulders. These xenoliths are likely derived from the Llangorse Mountain batholith, and many are quite porous, indicating that they were partially melted. Unlike sites 2 and 3, no clinopyroxene xenocrysts were found at site 4.

The granodiorite (Llangorse Mountain batholith) appears to form a mound in the middle of the occurrence and is surrounded by basanite and volcaniclastic sedimentary deposits. Basanite lava also occurs in depressions across the granodiorite outcrop; the contact morphology suggests that granodiorite basement formed an irregular surface in the valley before eruption of the basanite.

Chikoida Mountain

The Neogene to Quaternary volcanic rocks at Chikoida Mountain (Fig. 1, 2) were described by Mihalynuk and Smith (1992) and by Edwards et al. (1996), and were interpreted to represent hypabyssal feeder pipes to a volcanic centre subsequently removed by glaciation. The locality features several small (less than 15 m^2), highly weathered outcrops of basanite. Columnar joints in two outcrops dip slightly (less than 15°) toward the centre of the outcrop. Crustal and mantle xenoliths are present in the lava. Peridotite xenoliths are rare (much less than 1% by volume) and less than 5 mm in size. Crustal granitic xenoliths are common (1–5% by volume), most likely derived from the surrounding intrusion. They are up to 50 cm in size and, in some places, appear partly melted and even deformed by flow.

Volcaniclastic sedimentary deposits underlie the lava flow. The sedimentary deposits are matrix supported and, in most places, contain less than 15% clasts, which are generally small (less than 10 cm in size) and composed of granite and basanite. Peridotite xenoliths are rare and are all less than 3 mm in size. The association of volcaniclastic sedimentary deposits with the lava suggests that the Chikoida volcanic rocks were subaerially erupted as a valley-filling flow. The matrix-rich nature of the volcaniclastic sedimentary deposits and absence of large clasts suggests that these deposits may be a substantial distance from their source. The volcaniclastic sedimentary deposits and lava are present at a high elevation (1850 m), indicating that the source was considerably higher and has been eroded.

DISCUSSION

All four sites near Llangorse Mountain are Neogene to Quaternary in age. However, there are some petrological differences (Fig. 5A, B). Lavas at sites 2 and 3 are fine grained with large pyroxene xenocrysts surrounded by prominent reaction rims (Fig. 5B), compared to the lavas at sites 1 and 4, which are fine to medium grained, have little groundmass feldspar, and lack pyroxene xenocrysts (Fig. 5A). This observation leads us to postulate that there were at least two different eruptive events in the area. However, each site provides some evidence that eruption coincided with the presence of large ice masses.

Several mound-shaped lava outcrops within the Llangorse volcanic field show large variations in the size and orientation of columnar joints. Strong variations in size and orientation of cooling joints can be indicative of interactions between lava and ice (Walker and Blake, 1966), suggesting that some of the Llangorse volcanic field lava was erupted under or against ice. Furthermore, the lava flow at site 1 is substantially overthickened, beyond the aspect ratio expected of low-viscosity basanite lava flows. As well, layering in the lava flow changes from inclined at the base of the flow (concordant with the underlying volcaniclastic sedimentary deposits) to subhorizontal at the top. These observations suggest that the lava ponded against a barrier in the valley, causing the flow to become overthickened and wedge shaped. However, such a barrier is no longer present and, considering the young age of the lava, it is unlikely that there has been sufficient erosion to completely remove a barrier of this magnitude (at least 80 m high). We suggest that the lava may have ponded against a valley-filling ice sheet that subsequently retreated, thereby exposing the leading edge of the ponded lava. The nearly vertical cliff of lava and absence of horizontal columnar joints at site 1 suggest that the leading edge of the lava flow has been removed by one or more catastrophic mass-wasting events (e.g. landslides).

Several lava flows exposed in the Llangorse volcanic field were erupted subaerially. These flows overlie debris-flow sedimentary deposits containing clasts of country rock, basanite, peridotite, and palagonitized basanite. The volcanic rocks at these localities are interpreted as valley-filling lava flows. The presence of clasts of vesicular basanite and peridotite xenoliths indicate that the debris flows originated on or near the volcano that erupted the overriding lava flows. Poor sorting, large clast size, and the angularity of clasts suggest rapid deposition by high-energy currents. The debris-flow deposits are interpreted to have been deposited by *jökulhlaups*, sudden cataclysmic releases of water ponded over or around the volcano as a result of the large-scale melting that attends subglacial eruptions (Nielsen, 1936; Einarsson et al., 1997). Debris flows can also originate by other mechanisms, such as rapid melting of a snow pack, torrential rain, or failure of natural dams. There are, however, several factors that strongly link these debris flows to a flood event related to volcanism: 1) clasts of volcanic rock fragments are monolithological, comprising only vesicular to glassy (sometimes partly palagonitized) basanite; 2) peridotite xenoliths, which are highly friable and break down rapidly in transport, are found throughout the volcaniclastic sedimentary deposits; and 3) the overlying lava flow is identical to the fresh, friable clasts of lava in the volcaniclastic sedimentary deposits.

An unusual feature of the debris-flow sedimentary deposits occurring in the Llangorse volcanic field is the presence of palagonitized clasts of basanite. Palagonite forms via the hydration and breakdown of basaltic glass in water-saturated environments. Palagonitization rates are extremely low for meteoric alteration, and palagonite is therefore not considered to be a normal product of weathering (Friedman and Smith, 1960; Moore, 1966). Palagonite commonly occurs in hyaloclastite deposits and is an indication of glassy material in association with water; heated water (greater than 100°C) is required for rapid palagonitization (Friedman and Smith, 1960; Moore, 1966). The debris-flow currents clearly sampled glassy tephra up-slope. The presence of palagonitized basanite clasts in these young, partly indurated, volcaniclastic sedimentary deposits is a reasonable indication that the debris flows were water saturated and warm to hot (100–300°C). The debris flows may have been hot at the time of deposition, consisting of a mixture of hot volcanic particles and warm water derived from melting of ice. Another possibility is that the debris flows may have been initially cool and water saturated but were subsequently heated to 100 to 300°C by the overthickened (greater than 70 m) lava flow that immediately covered them.

The presence of peridotite xenoliths in lavas and debris-flow sedimentary deposits provides a window into the lithospheric mantle underlying the northern Canadian Cordillera. The Stikinie and Cache Creek terranes are allochthonous and were added to North America by latest Jurassic time (Gabrielse and Yorath, 1991). It is unknown, however, if the lithospheric mantle that now underlies these terranes was transported along with them, or if it has a North American affinity. This is a major question that will be addressed by petrological and geochemical study of the xenoliths within these young basanite lava flows. The Llangorse Mountain site 1 locality is particularly rich in mantle xenoliths, and was extensively sampled during the summer of 2002 for future studies.

CONCLUSIONS

The Llangorse volcanic field consists of seven localities of Neogene to Quaternary volcanic rocks: Hirschfeld Creek–Line Lake, Mount Sanford, Llangorse Mountain (sites 1, 2, 3, and 4), and Chikoida Mountain. The Llangorse Mountain sites and Chikoida Mountain were mapped in detail during the summer of 2002 as part of the Atlin TGI project, and we provide new interpretations for these localities. Previous interpretations have suggested that these localities are feeder dykes to volcanic centres that were subsequently eroded (Francis and Ludden, 1995; Nicholls and Stout, 1998). We interpret these exposures of volcanic rocks to represent erosional remnants of valley-filling lava flows that may have been impounded against or erupted under ice sheets.

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