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Chasm and Dog Creek lithofacies, Chilcotin Group basalt, Bonaparte Lake map area, British Columbia

R.E. Farrell, G.D.M. Andrews, J.K. Russell, and R.G. Anderson

Abstract: A diverse range of lithofacies occur within the Neogene Chilcotin Group in south-central British Columbia. Stratigraphic sections at Chasm Park and Dog Creek are dominated by subaerial, flat-lying basaltic lavas on top of, or interstratified with, minor pillow basalt and hyaloclastite units. The stratigraphic successions show depositional environments consistent with lava emplacement into mature paleochannels containing rivers and lakes. The nature of deposits observed in the Chasm and Dog Creek sequences show pronounced differences in the style of subaerial lava emplacement related to the differences in effusion rates, proximity to the vent, and paleotopography. A fundamental conclusion is that the complex stratigraphy of the subaerial lavas of the Chilcotin Group define a variety of lithofacies; the Chasm and Dog Creek lithofacies are defined in this paper.

Résumé : Le Groupe de Chilcotin du Néogène, dans le centre sud de la Colombie-Britannique, renferme une gamme diversifiée de lithofaciès. Les profils stratigraphiques établis au parc provincial Chasm et à Dog Creek sont dominés par des laves basaltiques subaériennes subhorizontales qui reposent sur des quantités mineures de basalte en coussins et de hyaloclastite ou qui y sont interstratifiées. Les successions stratigraphiques témoignent de milieux de dépôt qui sont compatibles avec une mise en place des laves dans des paléochenaux à maturité renfermant des cours d'eau et des lacs. La nature des dépôts observés dans les séquences au parc Chasm et à Dog Creek révèle des différences marquées de styles de mise en place subaérienne des laves associées à des différences de taux d'effusion, de proximité des cheminées et de paléotopographie. L'une des conclusions fondamentales qui peut être tirée est que la stratigraphie complexe des laves subaériennes du Groupe de Chilcotin définit toute une gamme de lithofaciès; les lithofaciès de Chasm et de Dog Creek sont définis dans le présent article.

INTRODUCTION

Basalt of the Chilcotin Group constitutes a Neogene (28–1 Ma) (Anderson, 2001), volcanic field situated in the Intermontane Belt of south-central British Columbia (Fig. 1). The Chilcotin Group is expressed physiographically as a series of areally extensive plateaus (e.g. Cariboo, Chilcotin, and Fraser) that are incised by large rivers, and surrounded by higher topography underlain by basement. The Chilcotin Group typically comprises subhorizontal basalt lavas and minor volumes of intercalated volcaniclastic deposits less than 200 m thick (Bevier, 1983; Mathews, 1989). Chilcotin Group rocks cover an area of approximately 36 500 km^2 and overlie Paleozoic-Mesozoic basement rocks. Commonly the basement rocks include volcanic (Nicola Group) and plutonic (Copper Mountain suite) rocks of the Triassic-Jurassic Nicola Arc in the Quesnel Trough. Farther north, the Chilcotin Group overlies Cretaceous-Eocene sedimentary rocks of the Nechako Basin, which is prospective for hydrocarbons. Directly beneath the Chilcotin Group, the nature of bedrock geology is unknown except for small-scale basement windows. The Chilcotin Group is typically overlain by thick (>15 m) Pleistocene glacial deposits and are best exposed along valleys and canyons walls such as found at Chasm and Dog Creek (Fig. 1).

This report summarizes results from the 2006 summer field mapping program in the Bonaparte Lake area (NTS map area 92 P). The field program was undertaken in support of the Geological Survey of Canada's TGI-3 Southern Cordillera projects. Previous studies have concentrated on regional-scale mapping, geochemical sampling, paleo-ecology, and K-Ar isotopic dating (Bevier, 1983; Mathews and Rouse, 1986; Mathews, 1989; Read, 1989; Dostal, 1996). The authors' focus is to identify and characterize lithofacies variations within the subaerial facies of the Chilcotin Group. Results to date include detailed lithostratigraphic descriptions for two sections of Chilcotin Group basalt exposed in cliff sections in Chasm Park and along Dog Creek valley. Ultimately, results from these stratigraphic studies, including lithofacies studies on Bull Canyon subaqueous lavas (Gordee et al., 2006), will form the basis for three-dimensional modelling of lithofacies architecture and thickness variations of this volcanic province. The models will provide a fundamental contribution to estimating the economic resource potential of south-central British Columbia (Andrews and Russell, 2007).

The study area occurs within the pine beetle infestation zone, shown on Figure 1, which is one estimate of the extent of pine forests infested with the mountain pine bark beetle, currently decimating the pine forests of southern British Columbia.
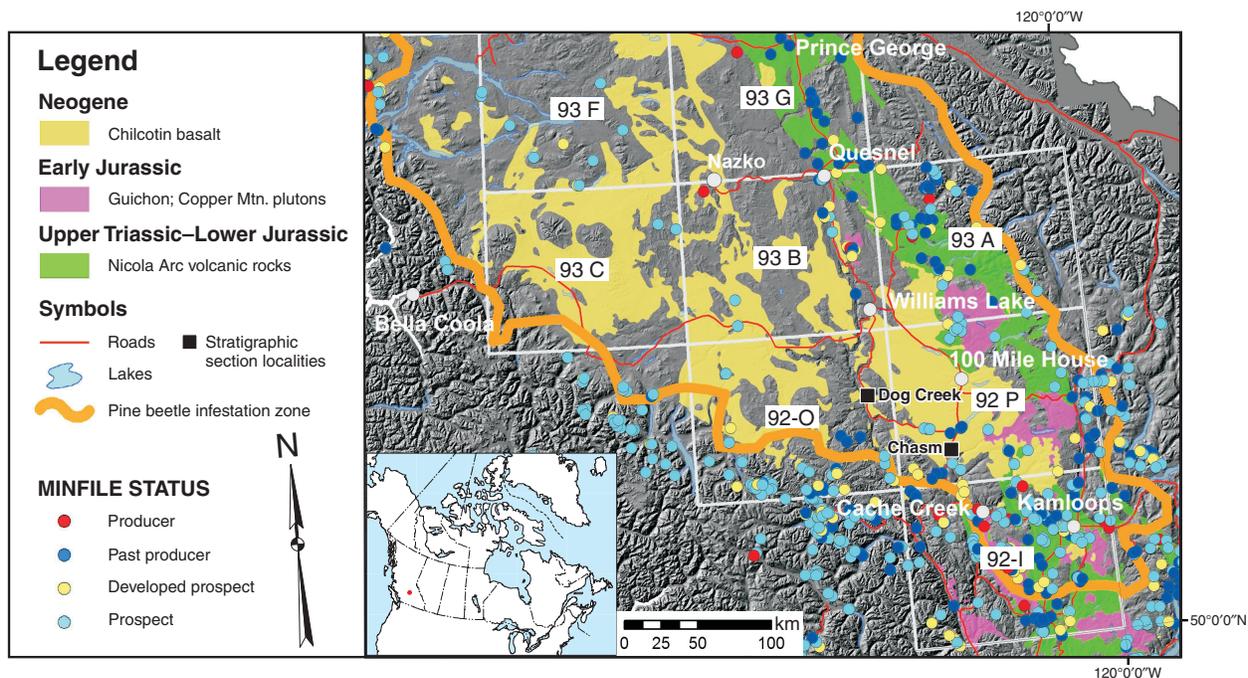

Figure 1. Shaded relief, digital elevation model as map showing distribution of Chilcotin Group basalt (yellow) in south-central British Columbia. Black squares mark the locations of the Chasm Park and Dog Creek stratigraphic sections of Chilcotin Group basalt described herein. Economically important tectonostratigraphic units are represented in green and pink.

LITHOFACIES DESCRIPTIONS

Chilcotin Group basalt exposed at Chasm and Dog Creek (Fig. 1) is divided into two subaerial units, Chasm and Dog Creek lithofacies; detailed descriptions of stratigraphy, geophysical characteristics, thickness, and interpretations of depositional environments are presented.

The Chasm lithofacies

Location

The Chasm lithofacies of the Chilcotin Group is defined at its type area in Chasm Park, British Columbia (51°10′N, 121°26′W; Fig. 1) and on the adjoining property called the 'RR Bar Ranch'. A continuous 7 km long canyon (The Chasm) features walls that expose approximately 120 m of subhorizontal basalt lavas (Fig. 2a) overlying a 30 m thickness of Miocene basement rocks and Eocene sedimentary rocks, and limestone of the Cache Creek Group. The canyon has been significantly widened by rotational slumping of layers of basalt towards the canyon axis, allowing access to the otherwise precipitous cliff exposures.

Stratigraphy

The exposed base of the Chilcotin Group is about 25 m above outcrops of Early Miocene Deadman Formation (Read, 1989); the Miocene deposits infill a paleochannel cut into older clastic sedimentary rocks (Eocene (?) Kamloops Group), which in turn appear to infill a paleochannel cut into Lower Paleozoic limestone of the Cache Creek Terrane. The lowest Chilcotin Group exposures comprise an approximately 20 m thick succession of massive to crudely bedded, hyaloclastite pillow breccia with intercalated basalt pillows that are conformably overlain by massive, laterally extensive basalt lavas (Fig. 2b).

The type section is located on the eastern margin of The Chasm (Fig. 3) and exposes 96.5 m of subaerial basalt lavas (nine individual flows) and intercalated paleosols. The individual flows exceed 10 m thick, can typically be traced laterally for up to 2 km, and lava tops and bases are generally bounded by distinctive, 0.5 m thick red-orange paleosol horizons (Fig. 2a, c). Single lava sheets (e.g. lava 2) are more common at the base of the section, but towards the top of the section (e.g. lava 8) are formed by overlapping lava lobes ('lobate' lavas; Fig. 3).

Lavas 1, 2, and 3 are thick, sheet-like, massive, and columnar jointed (Fig. 3); characteristically, they include significant thicknesses (≤8 m) of basalt pillows with ropey rinds at their bases (Fig. 3, 4a, b), that grade upward into massive lava. The massive lavas exhibit an internal three-part zonation typical of all the lavas in the Chasm lithofacies: an amygdaloidal base of zeolite-filled vesicles and pipe vesicles (Fig. 3c, 4a); a massive, columnar jointed, nonvesicular centre; and a vesicular or amygdaloidal upper margin that is typically oxidized, eroded, brecciated, and partly infilled by paleosol material, sediment, or tongues of lava from the overlying unit (Fig. 4d, e). Sediment found in some infilled cracks appears fused (hornfelsed), suggesting that crack propagation and sediment filling occurred soon after lava emplacement when the interior remained hot.

Massive lava 4 is 2 m thick or less, but appears to have a highly weathered and oxidized, and substantially eroded upper surface. Only the highly vesicular base and a portion of the massive interior centre is preserved (Fig. 2c, 3).

Lavas 5, 6, 7, and 8 are typically thick, lobate, massive, and columnar jointed (Fig. 3) and characteristically do not exhibit many pillows. They typically exhibit the same internal zonation as the underlying lavas; however, the zonation is repeated within each individual lobe, rather than in the compound sheet itself. Lavas 7 and 8 are plagioclase porphyritic (~2 mm in length) and feature vertical and horizontal vesicle 'chimneys' (Fig. 4f) which appear to form three-dimensional vesicle networks.

Lava 9 is the only unit that is demonstrably laterally continuous across the entire type area at Chasm Park, extending approximately 7 km in length. It is at least 9 m thick (top eroded and buried by glacial till) and is composed of at least six tiers of low-aspect-ratio lobes (≤3 m thick; Fig. 3); the authors describe the shape of these lobes as lenticular to distinguish them from 'fatter' lobes in lavas 5, 6, 7, and 8. Each lenticular lobe is generally highly vesicular; with an internal zonation similar to that preserved in the underlying lavas; some lenticular lobes are vesicular throughout. Lava 9 is discontinuously exposed beneath at least two thin (0 to <5 m), lobate lavas that are highly discontinuous below the glacial erosion surface; both tend to thicken and become more continuous northwards towards the Chasm Park rest area, where one of them (at nearby Fiftyseven Creek) has been dated to 9.2 ± 0.4 Ma (K/Ar whole-rock analysis, Mathews, (1989)).

Interpretation

The section described above defines characteristics of the Chasm lithofacies. The most important characteristics are: thick lavas (≥10 m thick); massive, nonvesicular interiors of lava flows; and eroded and oxidized lava tops with well developed paleosols. Chasm lithofacies lavas are similar in thickness and internal zonation to lavas commonly observed in 'compound lavas' in flood-basalt provinces (e.g. the Columbia River, U.S.A.; Hooper and Conrey (1989); and the Deccan Traps, India; Seth (2006)). Compound lavas are typically interpreted to form by inflation (the SWELL hypothesis, Self et al. (1998)) of initially thin, vesicular pahoehoe lava to produce a massive, nonvesicular interior that cools slowly, producing columnar joints. The present authors interpret the presence of thick paleosols and thick oxidized zones to record prolonged hiatuses between lava emplacements, allowing significant erosion, weathering, and soil formation to occur.
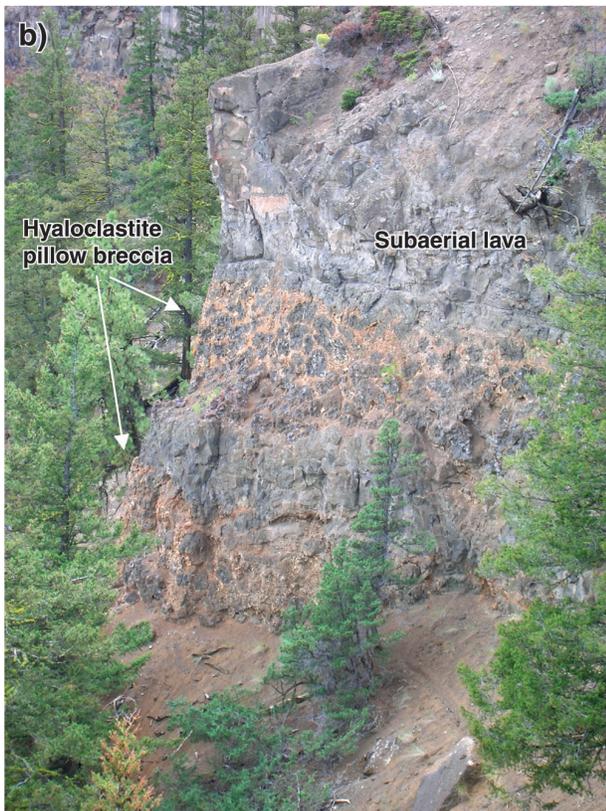
Figure 2. Large-scale field relations in Chasm Park. **a)** Nine lavas (~55 m thick) separated by baked red paleosols; west side of The Chasm. **b)** Hyaloclastite pillow breccia overlain by a subaerial lava; the characteristic orange (probably palagonitized) matrix is obvious. Individual pillows are up to 1 m across; viewed looking south. **c)** Oblique view of the type section (~30 m) in the east side of The Chasm, including lavas 3 to 6. Note the prominent orange paleosols with very irregular margins.

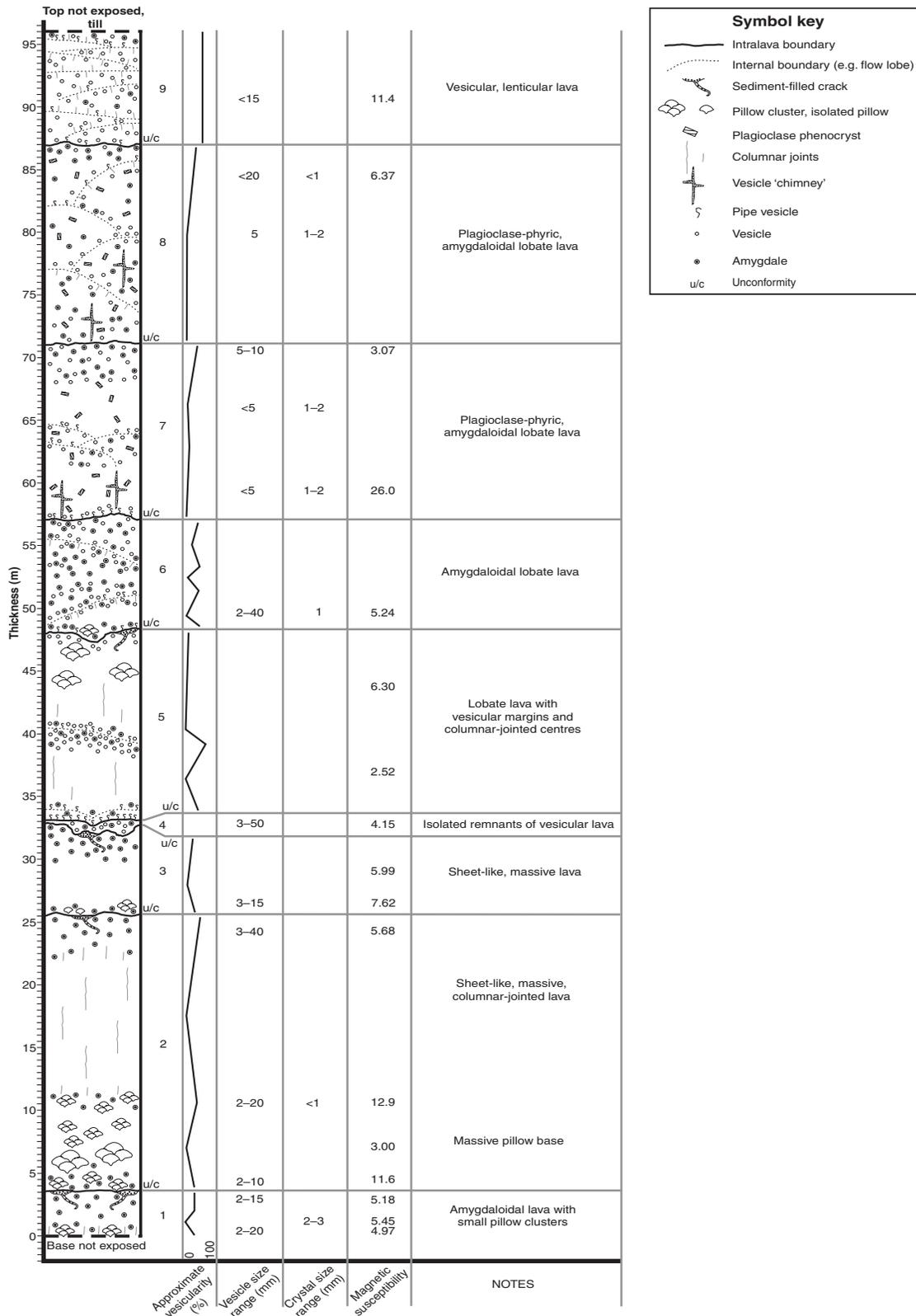**Figure 3.** Graphic log of nine lavas and intercalated paleosols from the type section of the Chasm lithofacies at Chasm Park, British Columbia. Vesicle, phenocryst, and magnetic susceptibility data (10^{-3} SI units) are provided for reference.

a) Amygdaloidal pillows

b) Ropey pillow rinds

c) Pipe vesicles

d) Regolith breccia

Sediment and/or paleosol material-filled cracks

e) Tongues of basalt descended into crack in underlying lava

Upper regolith breccia

f) 5 m long vesicle 'chimneys'
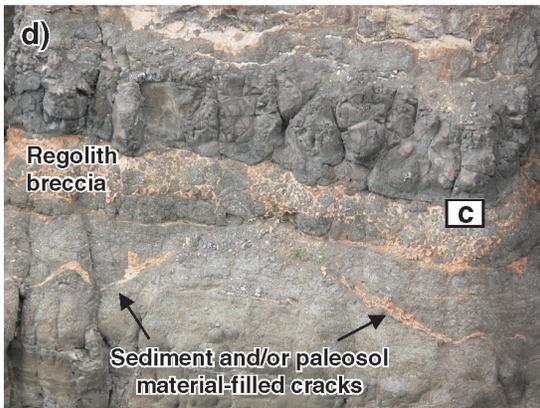
The authors infer that the lavas at Chasm Park fill and bury a long-lived paleochannel because the lavas were emplaced onto a laterally confined hyaloclastite deposit, filled a paleochannel cut into Early Miocene Deadman Formation, which itself filled a paleochannel cut into the pre-Miocene basement rocks. As well, the Chilcotin Group is laterally confined to a broad valley between basement highs to the east and west. Therefore, the authors conclude that there is a persistent drainage system in the Chasm Park area that has been able to re-establish itself several times in the past 15 Ma.

Source vents for the lavas at Chasm Park have not been identified: inflated pahoehoe lavas are thought to be capable of flowing for tens of kilometres during emplacement, and it is possible that vent areas may be a considerable distance away. The absence of proximal features such as spatter deposits, volcanic bombs, or volcanic edifices is consistent with Chasm flows distal from their source; however, a series of enigmatic gabbroic stocks have been identified approximately 30 km to the north (e.g. Mount Begbie; Farquharson and Stipp (1969)); these have been inferred to be the eroded remnants of conduits that fed the Chilcotin Group (Farquharson and Stipp, 1969; Bevier, 1983; Mathews, 1989). The present authors have no conclusive evidence to associate the stocks farther north to the lavas at and around the Chasm locality, but further geochemical and geochronological studies will test the hypothesis.

Dog Creek lithofacies

Location

Rocks of the Dog Creek lithofacies of the Chilcotin Group occur along a 15 km long valley and canyon adjacent to Dog Creek, British Columbia (Fig. 1). The spectacular cliff exposures along the western end of the Dog Creek (e.g. Fig. 5a), are underlain by as much as 100 m thickness of Chilcotin Group basalt and intercalated sedimentary rocks. The Chilcotin Group is not seen in contact with the basement in Dog Creek; however, the authors infer the contact to be highly irregular because of: the significant basement relief evident now (e.g. the Dog Creek Dome) is a limestone hill about 150 m above

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Figure 4 (opposite). Small-scale field relations and structures from the Chasm lithofacies. **a)** Basal, closely packed, open-framework, pillow basalt on top of a red paleosol; view looking east. Scale arrow is 10 cm long. **b)** Ropey textures developed on the outer margins of basalt pillows; view looking east. Scale arrow is 10 cm long. **c)** Pipe vesicles in amygdaloidal lava (lava 6) overlying a baked red paleosol; view looking east. Scale arrow is 10 cm long. **d**) Strongly eroded, weathered, and oxidized upper contact (1 m thick) of lava 5. Note the relative position of photograph 4c, labelled 'c'; view looking north. **e)** Tongues of lava 3 emplaced into cracks in the upper contact of lava 2. Scale arrow is 10 cm long. **f)** Vesicle chimneys (5 m high) in lava 7; view looking east.

the highest basalt outcrops and the Chilcotin Group cannot be significantly thicker in the valley bottom than what is presently exposed (inferred maximum thickness ≤150 m).

Stratigraphy

The type section (51°35′N, 122°14′W) includes 75 m of subaerial basalt lavas (>40 individual lavas) and 15 m of sediments (inferred to be a proglacial succession) and till (Mathews and Rouse (1986); Fig. 6). Two types of basalt lava are observed: widespread and thin (≤5 m thick), lenticular, highly vesicular lavas that dominate (Fig. 5a, b); and minor volumes of channel-confined, thick (≤25 m thick), nonvesicular lavas with characteristic colonnade and entablature jointing (Fig. 5c).

The thin, lenticular lavas are characterized by highly vesicular, coherent margins and vesicular autobreccia units (Fig. 5d); typically these margins are fresh (i.e. not oxidized), and there is no evidence of paleosols. Some surfaces between thin, lenticular lavas host volcanic bombs that deform the underlying lava lobes (Fig. 5e), suggesting that they are proximal to the source (i.e. within range of ballistic bombs ejected from the source vent). The thick lavas are strongly channellized in contrast to the laterally extensive thin lavas. They fill channels cut into thin lavas, and are only exposed as narrow lenses (<20 m across) when viewed perpendicular to the paleochannel. Erosion surfaces associated with the channels do not exhibit paleosols. The thick lavas exhibit well developed colonnade and entablature jointing that is usually interpreted to be the result of water infiltration into, and water flow over, hot lava (Long and Wood, 1986). Other narrow paleochannels are filled by lenses of hyaloclastite, hyaloclastite pillow breccia, and closely packed pillow lava (Fig. 6).

Interpretation

The authors infer that the Dog Creek succession is confined within a paleochannel cut into the limestone basement, parallel to the present-day Dog Creek valley; based on the limited distribution of Dog Creek lithofacies basalt; the abundance of small, infilled paleochannels within the succession that suggests that there was a persistent fluvial drainage system; and the presence of a spatially restricted proglacial and glacial succession suggests the proximity of a mountain-valley glacier (Mathews and Rouse, 1986). The present authors interpret the lavas of the Dog Creek lithofacies to be proximal to their source because of: the presence of volcanic bombs (e.g. Fig. 5e); and the highly inflated nature of the thin lavas that suggests they have not travelled far (and not significantly degassed) before becoming too cold to advance by ductile flow. The present authors infer that the thin lavas were rapidly emplaced as proximal, pahoehoe sheets (e.g. Kilauea-style eruptions; Seth (2006)) that infilled the earlier Dog Creek topography. Contemporaneous fluvial erosion produced channels that were infilled by hyaloclastite and
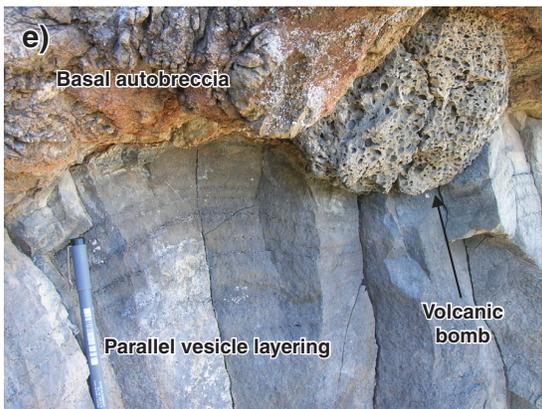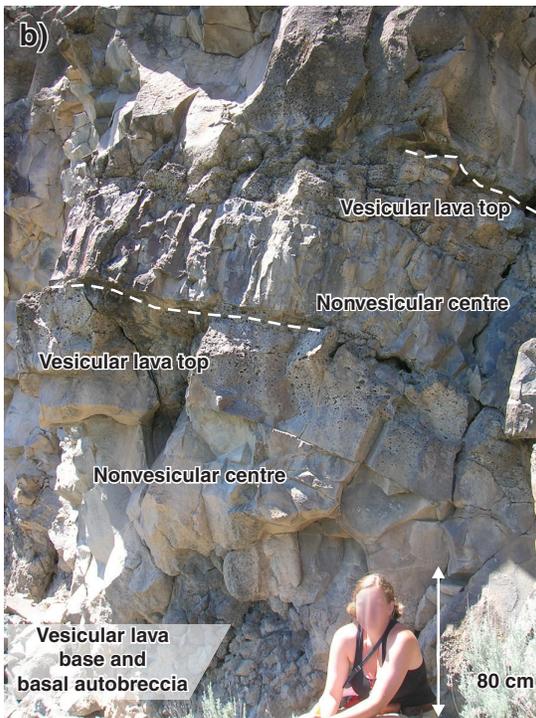
Figure 5. Field relations within the Dog Creek lithofacies. **a)** Multiple thin (≤3 m thick), lenticular pahoehoe lavas in cliffs at the mouth of the Dog Creek valley; view looking east. **b)** Thin (≤3 m), inflated pahoehoe lavas, exhibiting highly vesicular basal and upper contacts, and relatively nonvesicular interiors. Note the crudely developed columnar jointing on the margins of each lava; view looking northeast. **c)** View of a thick (~30 m), channellized lava with colonnade and entablature jointing, viewed perpendicular to channel; view looking north. **d)** Vesicular top of a pahoehoe lava; the hand, for scale, is 20 cm across; view looking north. **e)** Volcanic bomb preserved at the contact between two pahoehoe lavas. Note how the parallel vesicular layering is gently deformed around the bomb. Pen is 12 cm long. View looking north.
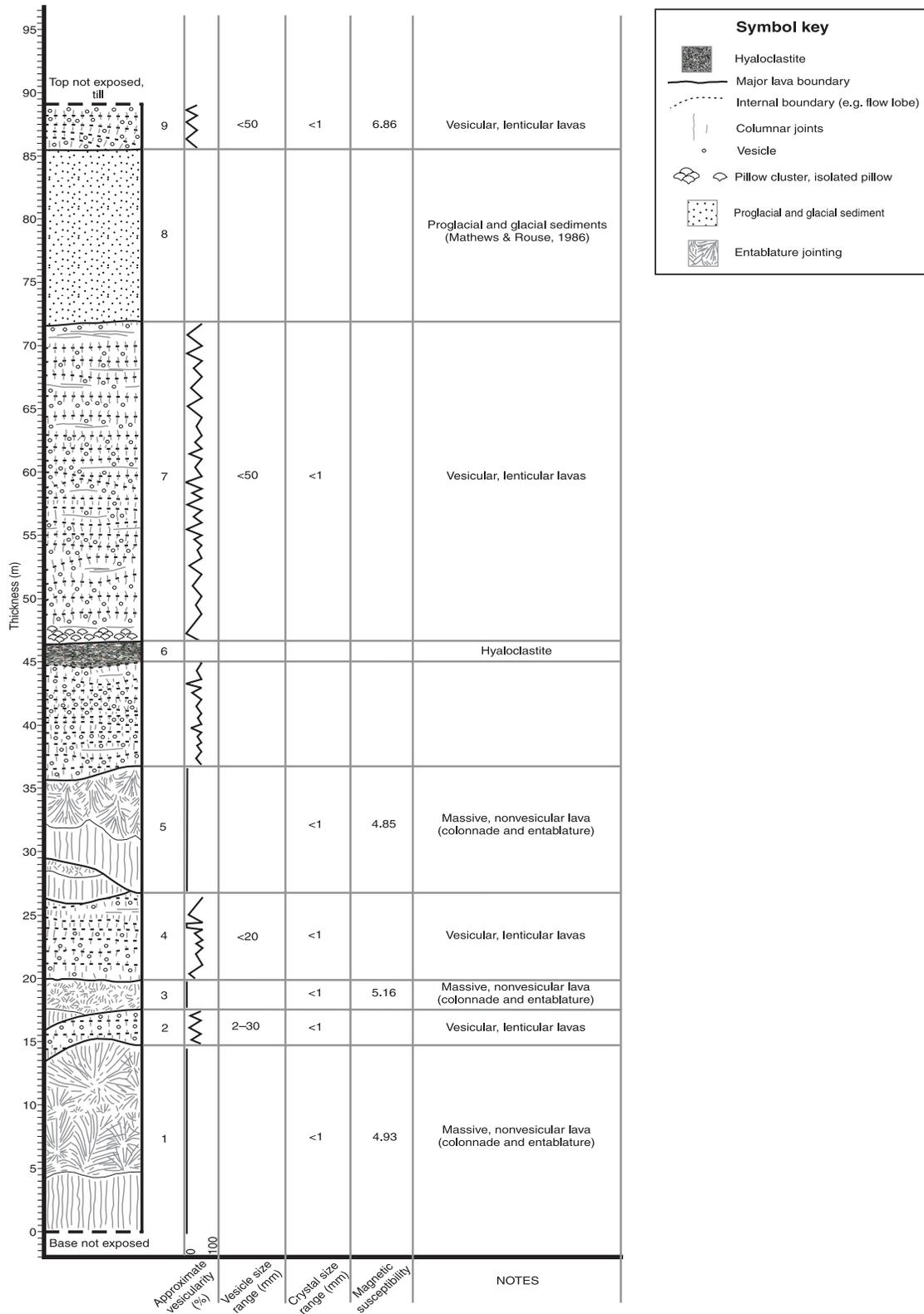
Figure 6. Graphic log of nine lavas and intercalated paleosols from the type section of the Dog Creek lithofacies in Dog Creek, British Columbia. Vesicle, phenocryst, and magnetic susceptibility data (10^3 SI units) are provided for reference.

Symbol key

Hyaloclastite
Major lava boundary
Internal boundary (e.g. flow lobe)
Columnar joints
Vesicle
Pillow cluster, isolated pillow
Proglacial and glacial sediment
Entablature jointing

Thickness (m)

Top not exposed, till

Unit	Approximate vesicularity (%)	Vesicle size range (mm)	Crystal size range (mm)	Magnetic susceptibility	NOTES
9		<50	<1	6.86	Vesicular, lenticular lavas
8					Proglacial and glacial sediments (Mathews & Rouse, 1986)
7		<50	<1		Vesicular, lenticular lavas
6					Hyaloclastite
5			<1	4.85	Massive, nonvesicular lava (colonnade and entablature)
4		<20	<1		Vesicular, lenticular lavas
3			<1	5.16	Massive, nonvesicular lava (colonnade and entablature)
2		2–30	<1		Vesicular, lenticular lavas
1			<1	4.93	Massive, nonvesicular lava (colonnade and entablature)

Base not exposed

Table 1: Summary of the characteristic features of the Chasm and Dog Creek lithofacies.

	Chasm lithofacies	Dog Creek lithofacies
Deposition environment; basement topography	Subaerial; broad valley	Subaerial; narrow valley
Volume of individual lavas	Large (km^3)	Small (tens of m^3)
Proximity to vent	Distal	Proximal
Depositional breaks	Yes - significant	No
Lava type	Inflated pahoehoe (SWELL)	Kilauea-style pahoehoe
Lava morphology	Extensive sheets, and compound sheets composed of lobes	Extensive compound sheets composed of lenticular lobes, and single, channellized lavas
Duration of emplacement	Long (many Ma)	Short (<< 2 Ma)
Hyaloclastite	Only at base	Small lenses throughout

pillows when the water-lava volume ratio was high, and were infilled by thick lavas with colonnade and entablature jointing when the water-lava volume ratio was small.

DISCUSSION: LAVA MORPHOLOGY AND TYPE

The authors have recognized two end-member lithofacies of subaerial Chilcotin Group basalt based on their size, morphology, internal structure, and contact relations at type sections at Chasm Park and Dog Creek (Fig. 1). Together with an accompanying subaqueous lithofacies (Bull Canyon lithofacies; Gordee et al. (2006)), they summarize the volume regimes of this part of the Chilcotin Group. The Chasm and Dog Creek lithofacies, though both subaerial, are distinctly different and regionally recognizable (Table 1).

So far, the authors have only mapped the Dog Creek lithofacies rocks within a 10 km radius of the type area among coeval young Chilcotin Group basalt. The limited regional distribution of the Dog Creek lithofacies and its proximal nature, predict it is only likely to be found close to vents, and that erosion or burial by later, more voluminous distal basalt would easily obscure it. In contrast, the authors have identified the Chasm lithofacies throughout the Chilcotin Group, including where it is seen in relation to the Bull Canyon lithofacies (Gordee et al., 2006; Andrews and Russell, 2007).

Both lithofacies are strongly influenced by paleotopography. The Chasm lithofacies rocks are typical of large volume 'plateau basalts' (e.g. Bevier, 1983) that appear to blanket the topography by filling in paleochannels and burying paleoridges. They typically exhibit significant thickness variations and are not, as often assumed, thick, planar sheets. Identification and measurement of the thickness variations within the Chasm lithofacies is likely to lead to a more optimistic assessment of the exploration potential of the basement underlying the Chilcotin Group (Andrews and Russell, 2007). Similarly, the Dog Creek lithofacies is strongly influenced by paleotopography; everywhere it occurs it is strictly confined to narrow tributary valleys of the Fraser River valley.

FUTURE WORK

Ongoing studies of the Chilcotin Group will include further fieldwork in 2007 to improve and expand field constraints on stratigraphy and thickness, and to supplement the existing sample suites, which will contribute to a comprehensive geochronological and geochemical study of the Chilcotin Group in order to establish a rigorous chrono- and chemo-stratigraphy. The physical properties (e.g. porosity, density, magnetic susceptibility, electrical conductivity, etc.) of samples will provide a four-dimensional, georeferenced physical-property database for use in geological and geophysical interpretations by other researchers.

CONCLUSION

Two distinctive, subaerial lithofacies are identified and defined within the Chilcotin Group basalt within and adjacent to the Bonaparte Lake map area (NTS 92 P): the Chasm lithofacies and the Dog Creek lithofacies. The two lithofacies differ considerably in lava volume, distribution, morphology, and the inferred duration of volcanism and regional extent. The Chasm lithofacies appears to be ubiquitous throughout the Chilcotin Group in contrast to the areally restricted Dog Creek lithofacies. The authors infer the Chasm lithofacies to be composed of large-volume, inflated lavas typical of flood-basalt provinces, whereas lavas of the Dog Creek lithofacies are typical of proximal, small-volume pahoehoe lavas, confined to paleovalleys, as might be emplaced during the present-day on Hawaii.

ACKNOWLEDGMENTS

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