Subaqueous Channel-Confined Volcanism within the Chilcotin Group, Bull Canyon Provincial Park (NTS 093B/03), South-Central British Columbia[1]

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INTRODUCTION

The Chilcotin Group (CG) is situated in the Interior Plateau of south-central British Columbia and overlies an area of ~36 500 km^2 (Fig 1; NTS map sheets 092O, P and 093A, B, C, F, G, J and K). The CG mainly comprises flat to shallowly dipping massive to columnar-jointed, olivine-phyric basalt lava with lesser volumes of pillow basalt and hyaloclastite (Mathews, 1989). The basalt ranges in age from 25 to 3 Ma and is broadly coeval with the voluminous Columbia River flood basalt of Oregon and Washington (*e.g.*, Hooper and Conrey, 1989). The CG basalt is typically 5 to <200 m thick and estimates of the total volume are as high as 3 500 km^3; this volume would make the CG a medium-sized igneous province (Seth, *in press*). Previous studies have concentrated on reconnaissance-scale fieldwork and geochemical studies (*e.g.*, Mathews, 1964, 1989; Bevier, 1983; Dostal *et al*., 1996; Anderson *et al.*, 2001).

The work presented here is part of a larger research program for field mapping of the volcanic lithofacies and thicknesses of the CG basalt. The goal of the larger project is to create a 3-D model for facies and thickness variations across the Chilcotin volcanic province that can be used to delineate areas where the CG is thin and exploration drilling for 'blind' metallic deposits becomes feasible. As part of that research program, reports are done on field mapping in and adjacent to Bull Canyon Provincial Park (Fig 1, 2). At this locality, 120 m of CG basalt is exposed, including deposits representing subaqueous and subaerial eruption environments. The intention of this work is to 1) describe and interpret the volcanic stratigraphy and lithofacies exposed at this location; 2) introduce this stratigraphic section as a type section (Bull Canyon-style) for comparing against other sections of CG (*cf*. Andrews and Russell, 2007; Farrell *et al*., 2007); and 3) explore the implications of this stratigraphic succession for eruption style, distribution and thickness of the CG and pre-CG paleotopography.

GEOLOGICAL SETTING AND LOCATION OF THE STUDY AREA

The study area is located in Bull Canyon, approximately 8 km west of Alexis Creek along the Bella Coola – Chilcotin Highway 20 (Alexis Creek map sheet 093B/3; Fig 1, 2). The area was most recently mapped and described by Tipper (1959). In general, the bedrock geology of the south-central Quesnel map area consists of accreted Mesozoic arc terranes (Stikine and Cadwallader terranes; Wheeler and McFeely, 1991), unconformably overlain by early Cenozoic felsic volcaniclastic rocks (*e.g.*, Eocene Kamloops Group), which are themselves unconformably overlain by flat-laying plateau basalt of the Neogene CG.

Lavas of the CG form a series of laterally semicontinuous cliffs along the northern margin of the Chilcotin River where it has incised through the Chilcotin Plateau, from Hanceville (~15 km southeast of Alexis Creek) to the confluence of the Chilcotin and Chilanko Rivers (~20 km west of Alexis Creek). In general, the bluffs comprise basalt lava that dips gently (<5°) to the east and southeast and are at least 15 to 20 m thick. Thicknesses are a minimum because the bases of the cliffs are commonly buried by talus and the upper surfaces have been glaciated and are buried by till. Substantially thicker sections (<150 m) occur along the Chilcotin River valley, where basaltic lava overlies or is interleaved with pillow breccia and hyaloclastite deposits (*e.g.*, Hanceville, Anahim Flats Indian Reserve and Bull Canyon; Andrews and Russell, 2007).

In the area between Alexis Creek and Bull Canyon, basaltic rocks of the CG bury an uneven paleotopographic surface cut into Early Cenozoic (possibly Eocene Kamloops Group) felsic volcaniclastic rocks. The older felsic volcaniclastic rocks rest unconformably on metasedimentary basement. The Bull Canyon is formed where the Chilcotin River is diverted south and east around a paleotopographic high comprising more resistant basement rocks. The diversion produces a 90° bend in the river channel and provides a three-dimensional exposure through the entire succession of CG basalt exposed here (Fig 2, 3, 4). The following section presents a series of stratigraphic sections from the Bull Canyon area based on mapping completed north of the Chilcotin River during the summer of 2006.

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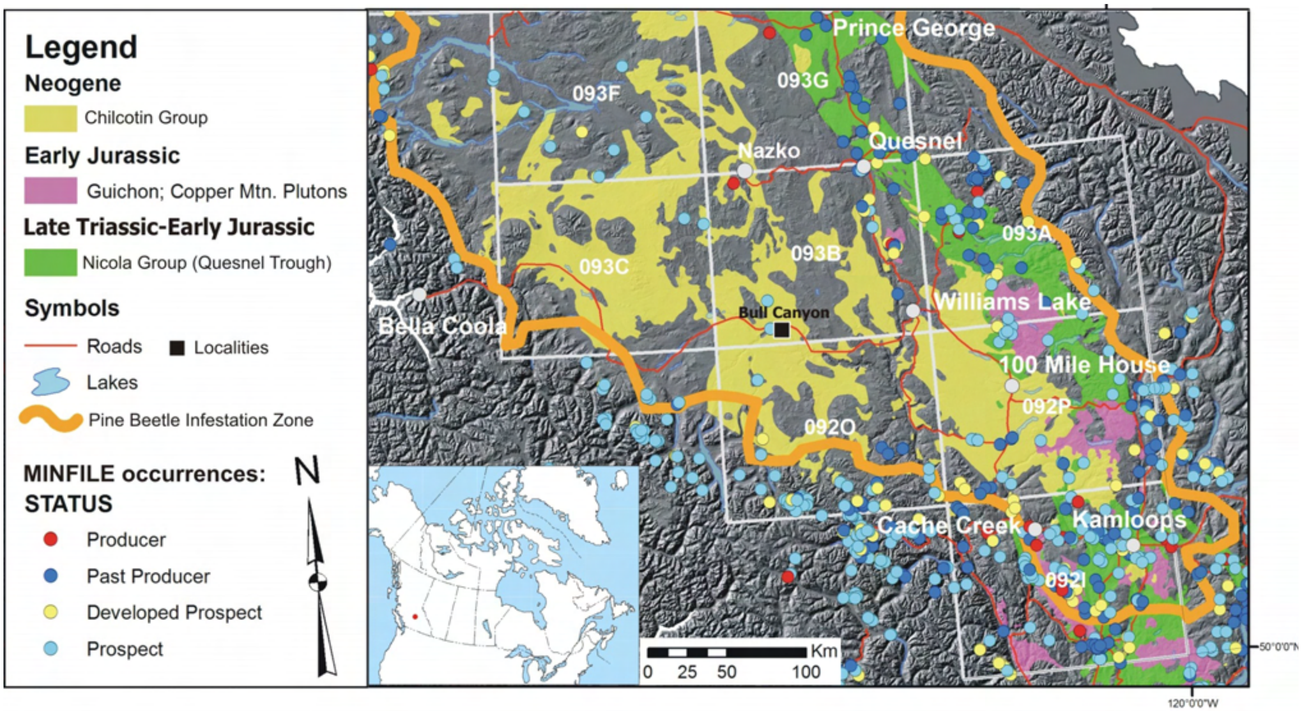


Figure 1. Shaded-relief digital elevation model showing the location of the study area (Bull Canyon) within the Quesnel (093B) 1:250 000 NTS map sheet in west-central BC. The map also shows 1) distributions of geological units (Chilcotin Group basalt and plutonic and metavolcanic rocks of the Quesnel Trough); 2) areal limits of mountain pine beetle infestation; and 3) distributions of mineral occurrences, prospects and mines (MINFILE, 2006). Inset shows the location of the Quesnel map sheet.

LITHOFACIES DESCRIPTIONS, DISTRIBUTIONS AND ASSOCIATIONS

The following lithofacies descriptions are specific to the units illustrated in Figure 3 and to the interpreted facies associations summarized in Figures 4 and 5. The volcanic facies exposed in Bull Canyon have been organized into the following two principal mappable units (Fig 4): 1) a lower pillow-dominated basalt that is the type example of the Bull Canyon–style lithofacies association and 2) an upper coherent basalt. Results of detailed graphic logs are summarized in the schematic stratigraphic columns shown in Figure 5.

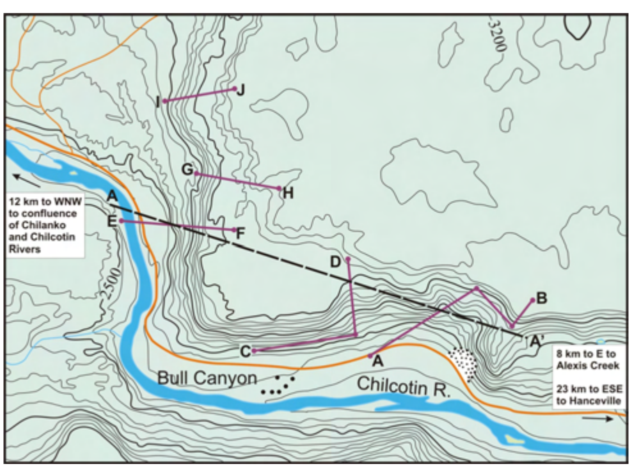


Figure 2. Topography (elevations in feet) of the Bull Canyon area showing, the distribution of exposures of CG basalt within Bull Canyon (black circles), locations and orientations of stratigraphic sections used for graphic logs and cross-sections and the locations of geographic features discussed in the text.

Bull Canyon–Type Lithofacies: Pillow-Dominated Basalt (unit pB)

The pillow-dominated basalt unit is best exposed along the tallest and steepest southwest-facing wall of the Bull Canyon massif (Fig 3), where it unconformably overlies older felsic volcaniclastic rocks that may belong to the Kamloops Group. Unit pB constitutes much of the cliff, whereas exposures to the north and east are thinner and less continuous. The pB unit contains several subaqueous volcanic and volcaniclastic lithofacies (Fig 5) including, from most to least volumetrically abundant 1) close-packed basaltic pillow facies (cpB), 2) basaltic pillow-fragment breccia and basalt breccia facies (bpB), 3) hyaloclastite (HpB), and 4) a peperitic facies (PpB).

CLOSE-PACKED BASALTIC PILLOW FACIES (cpB)

This facies is, volumetrically, the most abundant in the pB unit and consists of repeated successions of close-packed basaltic pillows (Fig 6a, 6b). Individual pillowed facies are lensoid in shape, range from about 2 to 10 m in thickness, are apparently thin and become increasingly discontinuous at progressively higher stratigraphic intervals of the pB unit. The pillows are spherical to elongate where sections along the main Bull Canyon cliff face are oriented roughly parallel to the elongation direction of interconnected lava lobes (*cf*. McPhie *et al*., 1993). The pillows are moulded around mutual contacts and display a wide variety of textures common to pillowed lava formations (Fig 6b, 6c), including (but not limited to) multiple rind structures, spreading cracks, gas cavities, concentric vesicle trains and radial pipe vesicles. Prismatic joints are common. Interpillow sediment comprises a mixture of massive to thinly-laminated mudstone or pillow fragments.

Several localities along the main Bull Canyon cliff face display basaltic pillows surrounding more massive zones of basaltic lava with radial columnar jointing (Fig 3, 6a). This association is possible evidence of the propagation of lava tubes within the cpB facies (McPhie *et al.*, 1993). Highly vesicular domains within individual pillows and abundant multiple rind structures of this facies suggest that basaltic lava was deposited in very shallow water (*e.g.*, Kano, 1991).

Figure 3. Field photograph showing a panorama of the west-southwest face of the main Bull Canyon massif, north of Highway 20. The bluff is approximately 500 m high.

BASALTIC PILLOW FRAGMENT BRECCIA AND BASALT BRECCIA FACIES (bpB)

The cpB facies in the main Bull Canyon section grades laterally over ≤50 m into pillow breccia and reworked pillow basalt breccia (bpB), respectively (Fig 6c, 6e). Individual exposures of these facies are thin (<3 m) and lensoid in shape. The components of the bpB facies are identical to the interpillow fragmental matrix found in the close-packed pillow facies, except that the bpB facies becomes progressively and proportionally enriched in the matrix relative to coherent pillows.

The bpB facies contains a small proportion (1–2%) of *in situ* pillows, isolated pillows and pillow fragments, presumably derived from the cpB facies. The bpB facies also contains 'rag-shaped' vesicular clasts of basalt that have large gas cavities. These clasts possibly formed on the margins of a subaqueous, pillow-forming lava. Poorly formed pillows and lava rags could have been torn from its margins and fed immediately into a rapidly moving and depositing current. The basalt breccia facies is massive to crudely medium to thickly bedded and crudely normally graded. The facies is monomictic, clast supported, lacks a fine matrix and clasts are blocky and angular. These characteristics, together with the association with the aforementioned facies, support the interpretation that this facies derives from a single source: the progressive disintegration of basaltic pillows in a subaqueous environment.

HYALOCLASTITE FACIES (HpB)

Discontinuous lenses of hyaloclastite facies are very common in association with successions of pillow basalt. Apparently regular, columnar-jointed lava, upon closer inspection, comprises a clast-supported, matrix-free, jigsaw-fit, monomict basalt volcaniclastic deposit. Clasts range from ~2 mm to ~20 mm in size and have curviplanar margins. A significant proportion of angular basalt clasts within the basalt breccia facies (bpB) probably derive from this facies.

PEPERITE FACIES (PpB)

The peperitic facies (PpB) is well developed within the pillow basalt unit in horizons where there is significant mudstone. The PpB facies consists of jigsaw-fit, monomict basalt clasts with curviplanar margins and an evenly distributed mudstone matrix (Fig 6d). Some interstitial mudstone is hornfelsed. The PpB facies occurs at the base of single basalt units and is interpreted to have formed where basaltic lava flows interacted and were quench-fragmented by wet, unconsolidated mud overlying earlier flows. This facies commonly grades vertically and laterally into columnar-jointed basalt or close-packed basalt pillows.

Coherent Basalt (unit cB)

The uppermost mappable unit comprises a relatively thin (≤30 m) and laterally continuous aphyric basalt lava (cB) that features well-developed, widely-spaced columnar joints. The cB unit outcrops along the northern margin of the Chilcotin River valley and is best exposed in the areas north and east of the main Bull Canyon locality. This unit is the equivalent of the Chasm-style lithofacies (Farrell *et al.*, 2007) typical of subaerial lavas throughout the CG (Andrews and Russell, 2007).

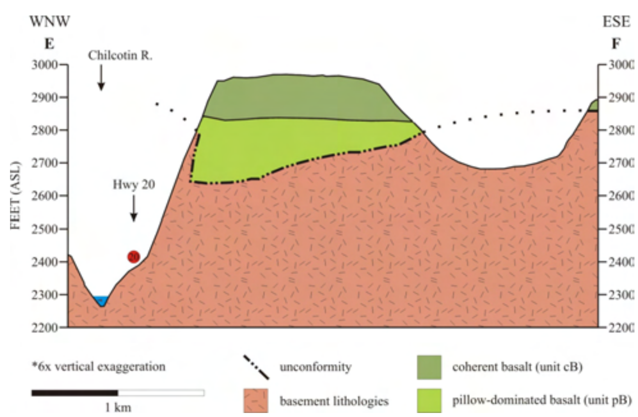


Figure 4. Cross-section illustrating the general stratigraphic relationships between Chilcotin Group basalt and the basement rocks (*e.g.*, Kamloops Group (?)) in the Bull Canyon study area. The location of the cross-section is shown as E-F in Figure 2. The cross-section orientation was chosen to emphasize the relief on the contact due to the original paleochannel filled in by Chilcotin Group basalt.

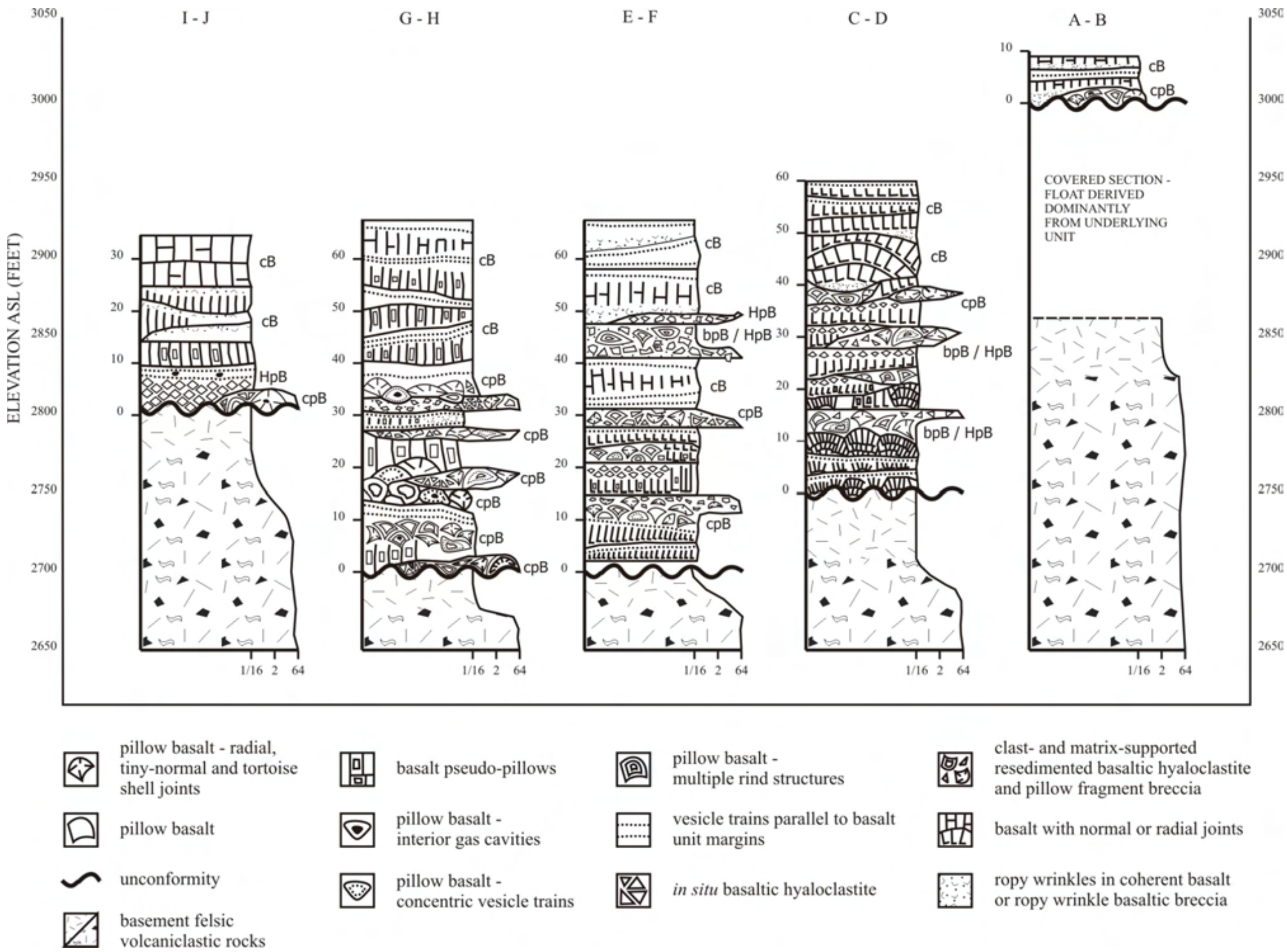


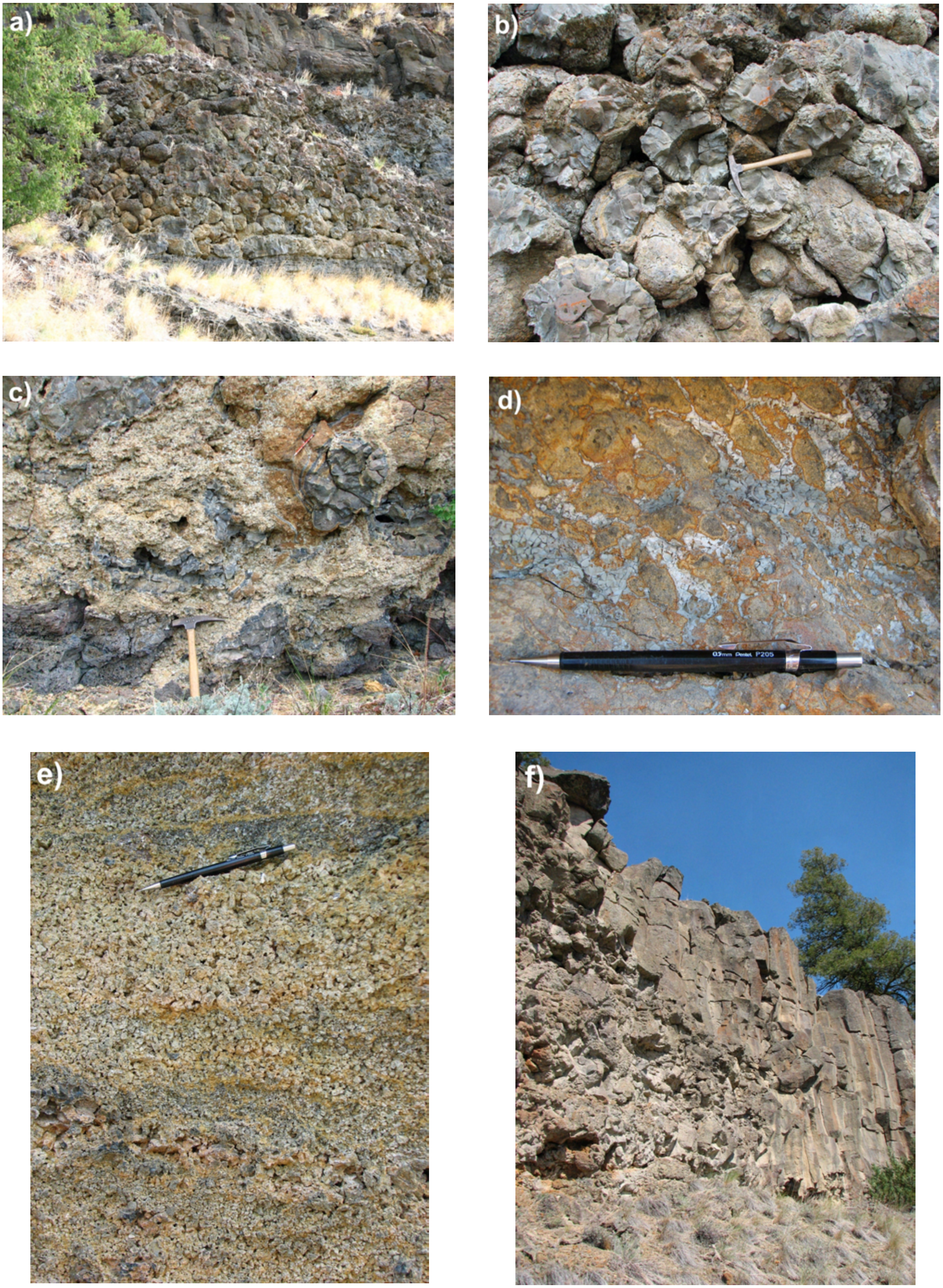
Figure 5. Stratigraphic sections of Chilcotin Basalt sequences summarizing graphic logs of the section exposed in Bull Canyon, west-central BC. Locations of stratigraphic sections are shown in Figure 2. The upper limit of each stratigraphic column corresponds to the highest elevation of continuous rock exposure but does not necessarily represent the top of the stratigraphic section, which is locally found at an elevation of 3200 ft (975 m).

DISCUSSION

Careful examination of the specific elevations of the basal unconformity between the Chilcotin Group and underlying basement felsic volcaniclastic rocks in Bull Canyon delineates an uneven paleotopographic surface (Fig 4, 5). More specifically, in three dimensions, the morphology of the feature is that of a paleochannel with a moderately steep north paleowall and very steep east paleowall. The southern wall of the paleochannel appears to coincide with the present-day southern bank of the Chilcotin River (Fig 4) and was apparently steep as well. The paleochannel is greater than 1 km wide and has an approximate northeast orientation (Fig 2, 4). Outside of the paleocanyon, outcrops of thin (<15 m thick), coherent basalt lava rest unconformably on top of pre-Chilcotin Group rocks. This relationship defines the margins of the paleochannel and constrains its width to ≤1.5 km.

The pillow basalt unit (pB) is concentrated within this paleodepression and is interpreted to record the emplacement of basalt lava flows into a locally deep and water-filled channel. The flows probably dammed up the local paleodrainage system, which periodically ruptured, generating the currents necessary to rapidly erode pillow basalt (cpB), peperite (PpB) and hyaloclastite (HpB) facies, and transport and deposit material to form pillow fragments and basalt breccia facies (bpB). Widespread, thin, coherent and sheet-like lava flows (cB) of the upper basalt unit cap the infilled paleochannel, having apparently been emplaced over a relatively flat, subaerial paleotopographic surface.

Figure 6. Field photographs of volcanic units exposed in the walls of Bull Canyon: a) outcrop (~10 m across) comprising pillowed basalt (pB) underlain by lava tubes and overlain by massive basalt (cB); b) detailed image of closely packed pillows (cpB) featuring small-scale (centimetre) radial columnar joints and concentric structure parallel to the outer surface, defined by banding; hammer is 35 cm long; c) pillow fragment breccia (bpB) within a more coherent pillow basalt unit; grey domains are more-or-less intact basaltic pillows; orange-brown patches comprise clast-supported, monomict, basalt breccia resulting from the disintegration of basaltic pillows and pseudopillows (HpB); d) peperitic basalt breccia (PpB) formed by the entrainment of wet, poorly consolidated mudstone (grey) into massive to pillowed basalt; pencil is 15 cm long; e) moderately well-bedded, clast-supported, monomict, angular volcaniclastic deposit of palagonitized hyaloclastite; pencil is 15 cm long; f) vertical exposure (5 m) of massive basalt stratigraphically above pillow basalt and hyaloclastite (partly obscured by grass); the unit grades downward and laterally from coherent basalt with well-developed, regularly oriented columnar joints (right) into a less-coherent, irregular, fragmented breccia (left and centre).


a)
b)
c)
d)
e)
f)

CONCLUSIONS

Similar subaqueous-subaerial facies associations have been observed elsewhere in the Chilcotin and Fraser plateaus (Bevier, 1983; Mathews, 1989; Farrell *et al*., 2007; Andrews and Russell, 2007): 1) along the Fraser Canyon from Soda Creek south to Canoe Creek (NTS 092O, 093A and 093B); 2) elsewhere along the Chilcotin, Chilco, Chilanko and Taseko Rivers (092N, 092O and 093B); 3) at Chasm Provincial Park (092P); and 4) along Upper Deadman Creek (092P). The authors consider the section exposed at Bull Canyon to be the type locality for the subaqueous Bull Canyon–style lithofacies in the CG. These initial observations, together with those in the Bull Canyon area, potentially have major implications for the emplacement of the CG: 1) subaqueous-subaerial facies transitions over a wide area indicate that the early stages of volcanism were strongly controlled by significant paleotopography; 2) within paleochannels, the CG is the thickest (≤150 m); away from paleochannels, however, the Chilcotin Group lavas are typically much thinner (≤20 m); 3) paleodrainages were long-lived, as suggested by the gradual transition from subaqueous to subaerial lithofacies; and 4) the lack of major paleosol horizons or erosion surfaces within many sections, including at Bull Canyon, suggests a short duration of volcanism in individual areas.

This study provides some of the primary evidence used by Andrews and Russell (2007), to support their assertion that the exploration potential of the Chilcotin Group should be re-evaluated in light of an improved understanding of the three-dimensional architecture of the CG. Specifically, the recognition of the Bull Canyon–style lithofacies highlights the importance of pre-CG paleotopography (paleochannels) on the overall architecture of the CG, and the thickness distribution that is key to interpreting geophysical exploration data.

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