Geological Survey
of Canada

Current Research
2000-A17

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2000

Natural Resources Canada
Ressources naturelles Canada

Canada

Catalogue No. M44-2000/A17E-IN
ISBN 0-660-18009-X

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Volcanic stratigraphy and petrology of the eastern margin of the Kamloops Group near Enderby, British Columbia

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Breitsprecher, K., Thorkelson, D.J., Schwab, D.L., and Thompson, R.I., 2000: Volcanic stratigraphy and petrology of the eastern margin of the Kamloops Group near Enderby, British Columbia; Geological Survey of Canada, Current Research 2000-A17, 7 p. (online; http://www.nrcan.gc.ca/gsc/bookstore)

Abstract: The eastern margin of the Eocene Kamloops Group consists of several outliers extending from the northern Okanagan Valley east to the Shuswap area, in southern British Columbia. Recent field and petrographic investigations on the Enderby Cliffs outlier provide new descriptions of volcanic stratigraphy and petrology. The volcanic succession is underlain by conglomeratic units. The lower and middle parts of the volcanic succession consist of mafic to intermediate, sheet-like, lava of variable thickness and texture. Monomictic diamictite, interpreted as a lahar, and minor finer grained clastic rocks occur at the top of the succession. These lithologies are texturally and compositionally similar to those reported from the main successions of Kamloops Group strata to the west. Differences in volcanic stratigraphy between the Enderby Cliffs and adjacent areas near the Shuswap River suggest a history of synvolcanic faulting. The Eocene successions are fault bounded, and surrounded by Paleozoic rocks.

Résumé : À sa limite orientale, le Groupe de Kamloops de l'Éocène apparaît dans plusieurs lambeaux d'érosion qui s'étendent vers l'est depuis le nord de la vallée de l'Okanagan jusqu'à la région de Shuswap, dans le sud de la Colombie-Britannique. Les récents travaux sur le terrain réalisés dans le lambeau de la falaise Enderby (Enderby Cliffs), ainsi que les études pétrographiques subséquentes ont permis d'obtenir de nouvelles descriptions de la stratigraphie et de la pétrologie volcaniques. La succession volcanique repose sur des unités conglomératiques. Les parties inférieures et médianes de la succession volcanique se composent de coulées en nappes, de composition mafique à intermédiaire, qui montrent des épaisseurs ainsi que des textures variables. Une diamictite monogénique assimilée à un lahar, ainsi que des quantités mineures de roches clastiques à grain fin occupent le sommet de la succession. Ces lithologies présentent des textures et des compositions semblables à celles des unités signalées dans les successions principales du Groupe de Kamloops à l'ouest. Les différences observées dans la stratigraphie volcanique entre la succession du lambeau de la falaise Enderby et celles des régions adjacentes situées à proximité de la rivière Shuswap laissent croire au jeu de failles synvolcaniques. Les successions de l'Éocène sont limitées par des failles et sont entourées de roches du Paléozoïque.

[1] Contribution to the Ancient Pacific Margin NATMAP Project

INTRODUCTION

Eocene volcanic rocks in southern British Columbia have been divided into three groups. The Kamloops Group forms an extensive succession of basalt, andesite, and subordinate felsic rocks with a calc-alkaline (subduction-related) geochemical signature (Ewing, 1981a, b). This group extends from north of Darfield southward to Vernon, and from Cache Creek eastward to Mabel Lake (Fig. 1). The Princeton Group is distinguished from the Kamloops Group by its more felsic character and conspicuous hornblende and biotite phenocrysts. It occurs from Merritt southward to the U.S. border (Monger, 1989a, b) (Fig. 1). The Penticton Group consists of discrete graben-fill successions (Church, 1973, 1982, 1985), and is characterized by rhyolite, phonolite, and other rocks with distinctive alkalic compositions suggestive of a rift or intraplate origin (Church, 1985). Successions belonging to this group extend from Kelowna southward to the Republic Graben in Washington (Fig. 1). Published K-Ar dates range from 54 to 42 Ma for Kamloops Group (Ewing, 1981a; Mathews, 1981), and from 55 to 47 Ma for Penticton Group (Church, 1982), making the groups broadly coeval. Existing dates for Princeton Group between 49 to 48 Ma (Ewing, 1981a; Thorkelson, 1989) place it in the middle of this range. Graben formation for both Penticton and Princeton groups may be linked to dextral strike-slip faulting (Church, 1985; Thorkelson, 1989). Growth faults are reported from all three groups (Church, 1973; Thorkelson, 1989; Read, 1996).

Detailed mapping of the Penticton Group successions has resulted in a high stratigraphic resolution and petrologic characterization thereof, while the Princeton and Kamloops groups contain outliers for which little information is known. In particular, five outliers constituting the eastern margin of the Kamloops Group (Fig. 1) have not received comprehensive study. Their assignment to the Kamloops Group is based upon their proximity to a large area of Kamloops Group strata to the north and west of Vernon. Previous mapping has divided these outlying successions into a basal unit of conglomerate to sandstone and shale, and a thicker, overlying sequence of volcanic rocks (Okulitch, 1979). Potassium-argon dates from the eastern outliers include one whole-rock date from Enderby Cliffs (42.5 Ma, Ewing, 1981a), and two whole-rock and two biotite dates from Trinity Hills (42.3–48.9 Ma, Mathews, 1981). The three northernmost outliers of Squilax Mountain, Mount Ida, and Enderby Cliffs are reported to be lithologically similar to Kamloops Group, but are placed in a separate structural domain (Ewing, 1995). No published information exists for the Camels Hump outlier. The stratigraphy, geochemistry, and paleogeography have not been previously determined for any of the five outliers. It is possible that one or more of the outliers contains rocks petrologically similar to the Penticton Group.

This paper provides new stratigraphic and petrographic information on the Enderby Cliffs outlier based on mapping and sampling conducted during the summer of 1999. These findings are the first results from a detailed study of the eastern Eocene outliers in the Vernon (82 L) map area, and are part of a broader re-examination of the Eocene volcanic history in southern British Columbia. A principal objective is to determine the spatial and temporal relationships between the Kamloops and Penticton groups, and to identify variations in the tectonic and magmatic regime at the time of volcanism.

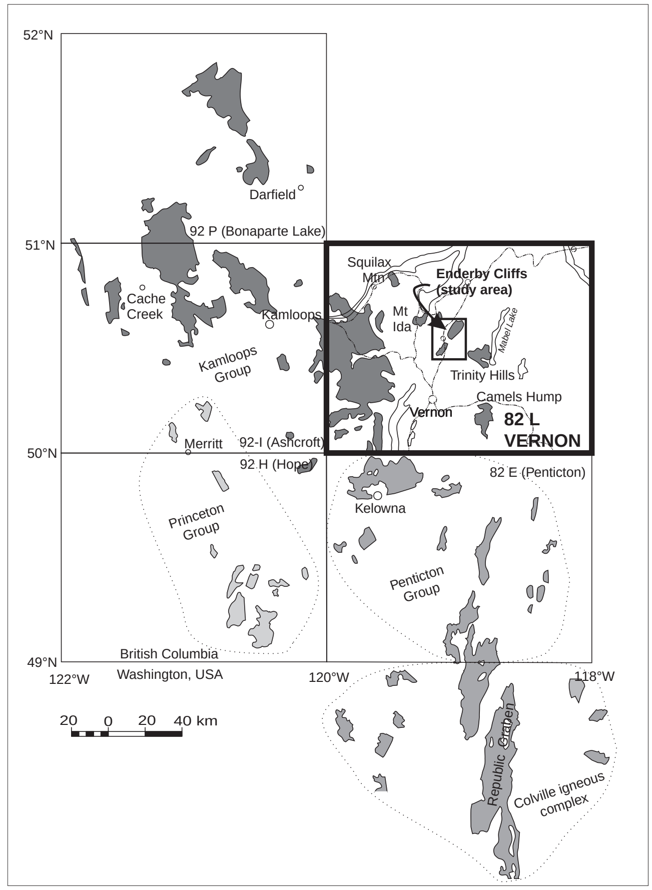

*Figure 1. Location map, Eocene volcanic rocks in south-central British Columbia, Vernon map sheet (82 L) emphasized (*from *Wheeler and McFeely, 1991).*

PREVIOUS WORK

Numerous workers have contributed to our understanding of Eocene volcanism in southern British Columbia. In particular, this work has led to the identification of the problem presented by differing tectonic affinity between adjacent and temporally equivalent magmatic bodies. Jones (1959) separated the previously recognized Kamloops Group from adjacent basement lithologies, and further recognized the major north-south fault system in the Okanagan Valley. Okulitch (1979) refined the basement-to-Eocene contact and mapped the sedimentary-to-volcanic rock contacts of these successions, as well as adding significantly to the regional structural pattern. Church (1973, 1979, 1980a, b, c, 1981) provided detailed stratigraphic, petrologic, and geochemical characterization of the Penticton Group successions. Ewing (1981a, b, 1982) conducted mapping and sampling of the main

Kamloops Group succession, and established its regional stratigraphic, petrologic, and geochemical character. He further noted occurrence of Penticton Group-like chemical trends found in some Kamloops Group rocks. Monger (1989a) followed previous workers (e.g. Ewing, 1981a) and separated the lithologically distinctive rocks of the Princeton Group from the Kamloops Group during regional mapping in the Ashcroft and Hope map areas. Most recently, Read (1996) conducted geological mapping that included the Kamloops–Penticton Group transition area and suggested that within that area, division of rocks into two groups was unnecessary.

RESULTS

Unit descriptions

Eight stratigraphic units were recognized at the Enderby Cliffs outlier: two basal sedimentary units: EKmc and EKc, four nonclastic units: EKja, EKma, EKfa and EKmb, all succeeded by two volcaniclastic units: EKvx and EKvd (Fig. 2, 3). A third basal sedimentary unit consisting of sandstone and coal beds exists, but has not been defined in this report. In the early 1900s, coal was mined from the northwest part of the outlier. The old mine site was not accessed and so the stratigraphic position of the unit (above or below EKc) was not determined. Unit descriptions are based on both field data and preliminary petrographic observations. Geochemical analysis is in progress.

Unit EKmc is a dark-grey-weathering, light grey, monomict conglomerate derived from tonalitic intrusions hosted by gneiss that outcrops to the north and east of the Eocene succession. The unit is massive, clast supported, poorly sorted, shows no grading or imbrication, and has approximately 8% matrix content. Clasts are angular to subrounded, and range from 1 cm to over 3 m in size. The unit could not be mapped to any great extent, but locally has a thickness of up to 100 m.

Unit EKc is a dark-brown-weathering, medium grey, polymict conglomerate. The deposit is massive and ungraded, and ranges from matrix to clast supported. Clast compositions reflect adjacent basement lithologies, including granitoid, phyllite, and hornblende-biotite schist. Clasts range from 1 to 120 cm in size, are rounded to subrounded, and lack imbrication. Clast lithology and size suggest a proximal source area. Matrix content averages 10%; its composition is greywacke. The unit is approximately 550 m thick and is weakly to moderately lithified. It was not possible to discriminate between bedding and several prominent fracture sets.

Unit EKja is a dark-grey-weathering, medium grey, aphyric, mafic to intermediate lava. The unit displays crude columnar jointing, and only three flows of 7 to 8 m thickness were observed. Total stratigraphic thickness of the unit is approximately 25 m. Preliminary petrography shows mesostasis and groundmass to occur in approximately equal proportions. Groundmass is dominated by euhedral plagioclase laths, with minor augite and trace amounts of orthopyroxene and opaque minerals. A representative thin section from this unit has a whole-rock mode of 55% groundmass and 45% mesostasis. Groundmass mode consists of 85% plagioclase laths, 10% augite, 3% orthopyroxene, and 2% opaques. Maximum grain size of groundmass is 0.35 mm.

Unit EKma is a medium-grey-weathering, medium greenish-grey, aphyric, intermediate lava. Vesicles are typically filled with calcite or zeolite, range in size from 0.5 to 3 mm, and are generally spherical to slightly ellipsoidal. Flow folding at 1 to 10 m scales is common. Curviplanar fractures are controlled by flow folding (Fig. 4) which is often observable from a distance. The unit has a relatively constant thickness of approximately 80 m. A representative thin section from this unit has a whole-rock mode of 80% groundmass and 20% mesostasis. Groundmass consists of 95% plagioclase and 5% opaques. Maximum grain size of groundmass is 0.6 mm.

Unit EKfa is a succession of grey- and-red-weathering, medium grey, aphyric to augite-plagioclase-phyric, mafic to intermediate lava flows. Individual flows range from 2–12 m in thickness, are sheet-like, and have red oxidized vesicular or amygdaloidal flow-top breccia ranging from 1.5 to 5 m thickness, and dense grey flow bases. This contrast produces a bedded appearance from a distance (Fig. 5). A minimum of 16 separate flows are thus identified on the exposed portion of this unit at the main cliff face. Vesicles developed in flow tops are substantially larger than those in EKma below, and are typically deformed into flattened ellipsoids. Vesicles may be open, but are more typically partially or wholly filled with quartz, chalcedony, or black oxides. The maximum observed vesicle long-axis length was 10 cm, with mean length of 2 cm. Tuff interbeds are scarce to absent within this unit, and do not exceed 2 cm thickness where found. The total thickness of the unit is approximately 200 m. Preliminary petrography shows little compositional variation from the preceding units. Textural differences include the development of a weak to moderate trachytic texture in groundmass and development of phenocrysts. Quartz xenocrysts with reaction rims of augite were observed in one sample. Some plagioclase phenocrysts display oscillatory zonation. A representative thin section from this unit has a whole-rock mode of 50% groundmass, 45% mesostasis, and 5% phenocrysts. Phenocryst mode is 75% augite and 25% augite. Groundmass consists of 90% plagioclase, 3% augite, and 7% opaques. Maximum phenocryst size is 1.5 mm and maximum grain size of groundmass is 0.25 mm.

Unit EKmb is a dark-grey-weathering, aphyric, nonvesicular, mafic lava flow. It is massive, displays crude columnar jointing, and has a maximum thickness of about 30 m. The unit is discontinuous and has an irregular surface (Fig. 4) possibly representing deposition of lava flows in a channeled morphology. A representative thin section from this unit shows 95% groundmass and 5% mesostasis. Groundmass mode consists of 95% plagioclase laths and 5% opaques. Maximum grain size of groundmass is 0.05 mm.

Unit EKvx consists of interbedded clastic deposits of varied lithologies and lava flows. This unit contains the only volumetrically significant (approximately 5%) pyroclastic deposits found at this outlier. These occur as both tuff and lapilli-tuff beds ranging from 5 to 30 cm in thickness. The

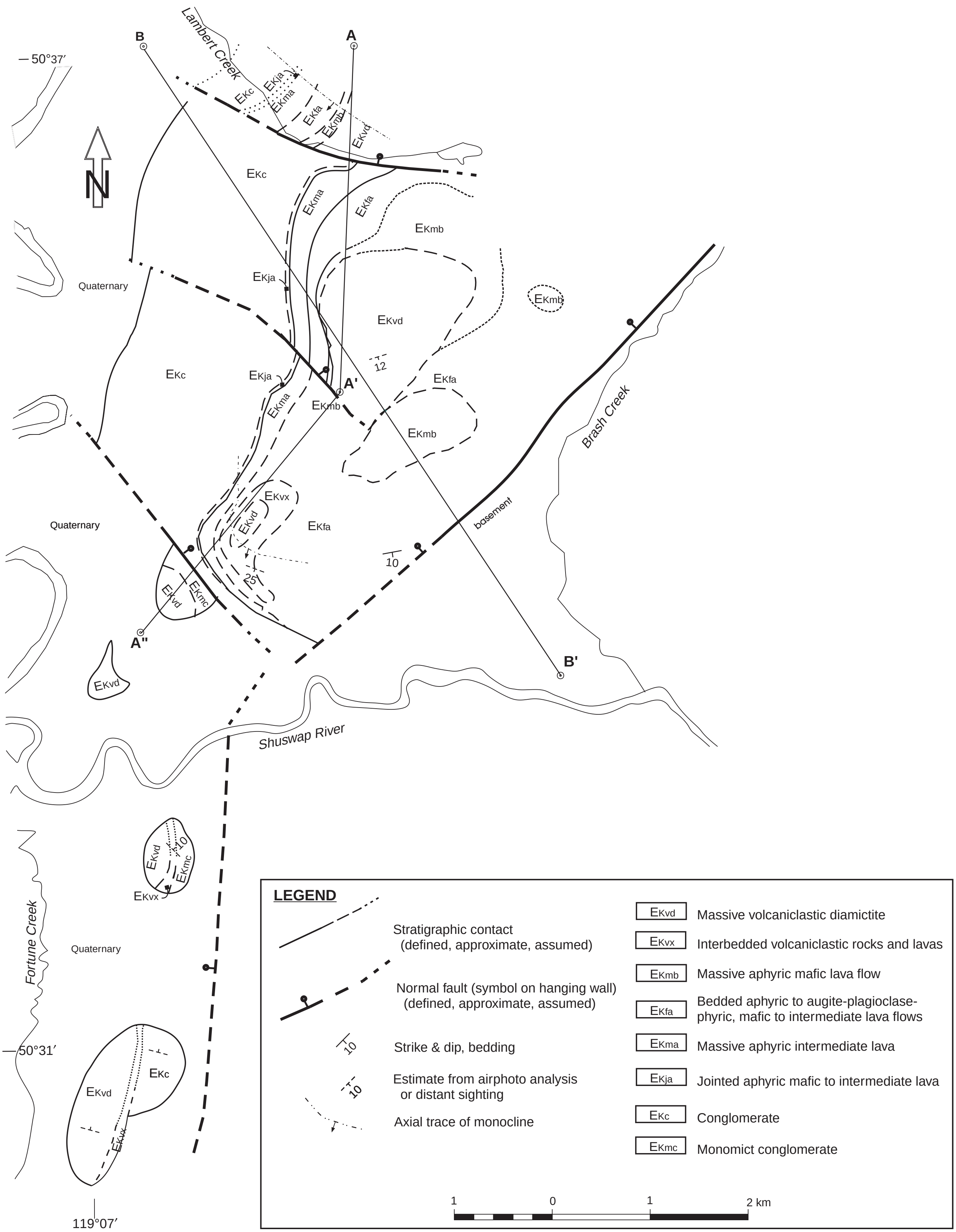

Figure 2. *Geology of the southern portion of the Enderby Cliffs outlier (*modified from *Okulitch, 1979).*

lava flows are account for approximately 25% of the unit volumetrically, and are petrologically and morphologically similar to those of unit EKfa. Clastic beds make up approximately 70% of the unit. Clastic beds include a poorly sorted breccia consisting of angular volcanic clasts in a sandy matrix, a tan-weathering, medium- to coarse-grained arkosic sandstone, and a conglomeratic bed with rounded nonvolcanic clasts. The unit is found at the southern end of the main outlier, where it interfingers with overlying EKvd. The unit has a maximum thickness of 60 m.

Unit EKvd, a massive volcaniclastic diamictite, forms the uppermost unit of the Eocene succession at Enderby. Maximum thickness of this unit is approximately 200 m. The unit is both matrix and clast supported. Clasts are dominated by poorly sorted, very angular, vitric lava clasts, ranging in size from 1 to 100 cm. The matrix is composed of mud to sandy mud, and occupies from 8 to 15% of rock volume. As with basal EKc, bedding is not discernable; however, it may be obscured by thoroughgoing, regularly spaced (2 to 4 m) fractures. The clast lithology is dissimilar to any of the locally deposited lava-flow units. A representative thin section of a clast from this unit shows a whole-rock mode of 45%

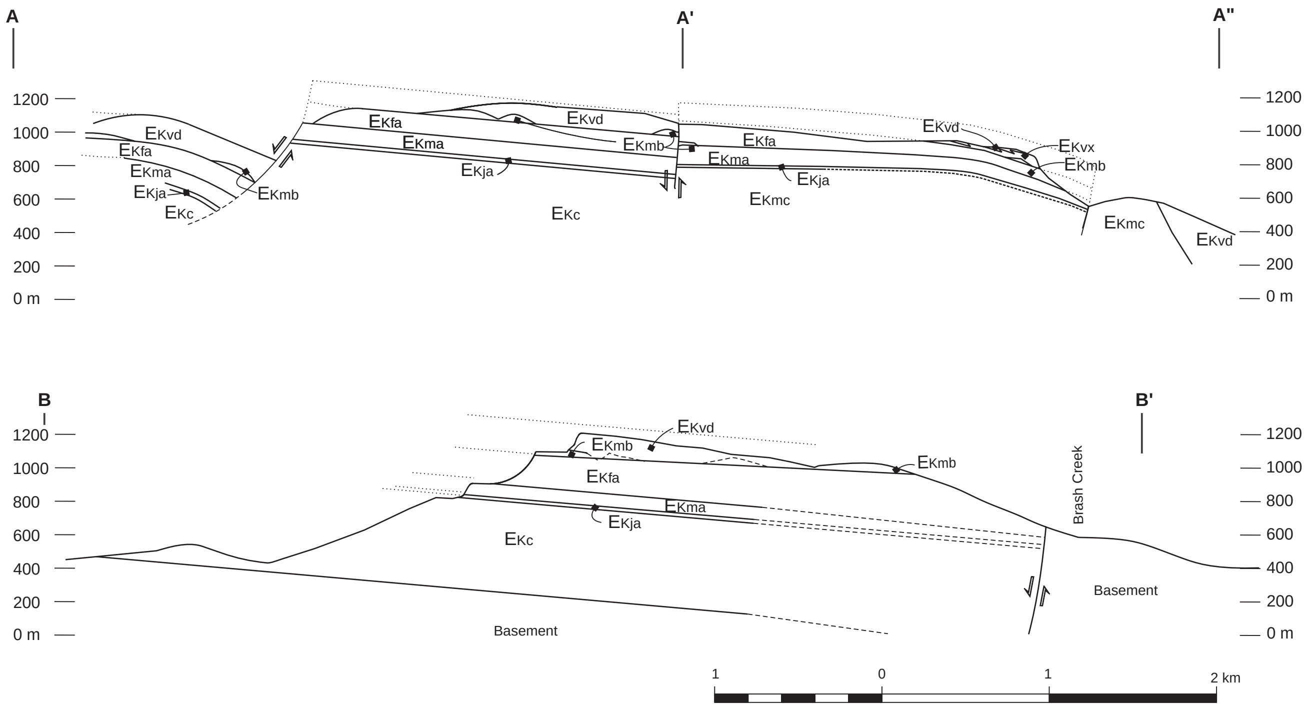

Figure 3. *Preliminary cross-sections, Enderby Cliffs.* See *Figure 2 for legend and location of cross-sections.*

Figure 4. *Curviplanar fractures developed along flow-fold planes.*

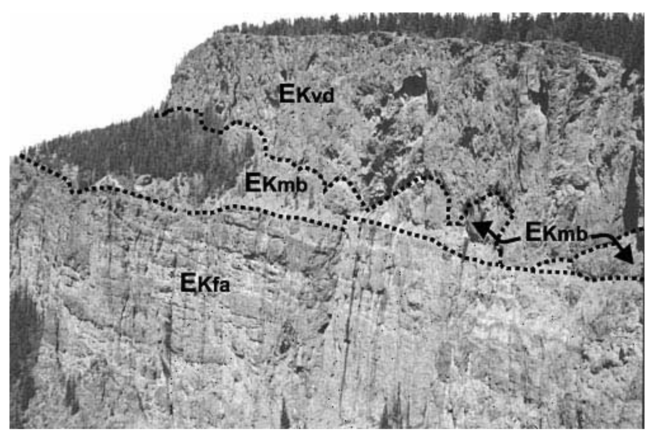

Figure 5. *Lateral continuity of bedding in* EKfa *is well exposed in the main, west-facing, upper cliff face of the central block.*

groundmass, 45% mesostasis, and 10% phenocrysts. Groundmass consists of 65% plagioclase, 20% orthopyroxene, and 15% augite. Phenocrysts are 90% plagioclase laths and 10% olivine. Phenocrysts size is approximately 0.5 mm and grain size of groundmass is 0.1 mm.

Stratigraphy and structure

Results of mapping in the Enderby Cliffs outlier are presented in the form of a generalized geological sketch map (Fig. 2) and cross-sections (Fig. 3). Generalized stratigraphy of Enderby Cliffs is presented in cross-section B-BN (Fig. 3) oriented perpendicular to the estimated dip slope. The cumulative thickness of the Eocene succession at Enderby is approximately 1000 m. This is consistent with reported thicknesses of up to 2 km for other portions of the Kamloops Group (Ewing, 1981a; Read, 1996).

Lava of mafic to intermediate composition dominates the succession. Pyroclastic beds are scarce to absent for the majority of the succession. Rare, thin (1–2 cm) tuff beds occur within the bedded lava flows of EKfa, and beds of tuff and lapilli tuff occur within EKvx. Neither dykes nor vents were found, although the northern block of the outlier remains unmapped.

Stratigraphic omissions are evident in four small outliers to the south of the Enderby Cliffs succession. The northernmost of these is the knoll abutting the southwest side of the main outlier, with the remaining three occurring in a southward progression adjacent to Fortune Creek. At these outliers, most of the volcanic units of the Enderby Cliffs succession are absent, and the succession consists of only the basal prevolcanic sedimentary units and the uppermost volcanic strata, volcaniclastic units EKvx and EKvd. The only nonclastic component consists of interbedded lava flows in unit EKvx. Relative to the Enderby Cliffs succession, approximately 350 m of lava is missing between the basal conglomerate and the upper volcaniclastic units.

Two sets of faults control the distribution of Eocene volcanic rocks in the Enderby area. One of these consists of three west- to northwest-trending, steep faults spaced approximately 2 km apart. Two faults in this set, at Lambert Creek and at the southern end of the cliffs, are flanked to the north by east-trending monoclines. These folds may be roll-over anticlines, and the faults to the south of them may be north-dipping listric normal faults. North-side-down offset is estimated at 550 m for the fault along Lambert Creek, and 120 m for the northwest-trending fault approximately 2 km to the south. The contrast in volcanic stratigraphy across the southern fault, at the south end of the Enderby Cliffs, complicates estimates of displacement and will be further investigated.

A second set of faults, striking north to northeast, juxtaposes the Eocene succession against Paleozoic to Jurassic basement rocks (Okulitch, 1979). The prevalent attitude of the outlier is a southeast dip towards a northeast-oriented normal fault at Brash Creek. This fault has been previously reported as a growth fault (Read, 1996). South of the Shuswap River, the Eocene succession is bounded to the east by a north-south-oriented, steep, west-side-down fault.

CONCLUSIONS

The Enderby Cliffs outlier consists of Eocene basal conglomeratic deposits and overlying volcanic strata typical of the Kamloops Group. The outlier has been divided into eight lithologic units. The basal conglomerates are interpreted as large-scale, coalescing alluvial fans or debris-flow deposits (EKc) and talus-cone deposits (EKmc). The thin basal volcanic unit (EKja) is mafic to intermediate in composition, and is overlain by extrusions of similar composition, but varying thickness and texture, (EKma and EKfa), resulting in variation of depositional morphology. Current data indicate that these units are of fairly uniform thickness and of sheet-like morphology. The extraordinarily thick, massive nature of the volcaniclastic diamictite (EKvd) and its apparent lack of a correlative local source lends support to its preliminary interpretation as one or more lahar deposits possibly derived from the larger Kamloops Group body to the west. Deposition of this unit occurred towards the end of, or after, cessation of magmatic activity at the outlier. This interpretation requires further analysis. Marked differences in volcanic stratigraphy between the main Enderby Cliffs succession and the outlying hills to the south implies a history of synvolcanic faulting.

FURTHER WORK

Details of the stratigraphic and structural history in the Enderby Cliffs area will be completed. Stratigraphy and structural interpretation resulting from detailed mapping at the Trinity Hills outlier is underway. Full petrologic descriptions for all units defined at these two outliers will follow based on detailed petrography and on results of geochemical analysis of samples collected during mapping. Major, minor, and trace-element ratios of samples collected from throughout the southern British Columbia Eocene volcanic belt will be modelled with the goal of determining the nature of source differences between Kamloops and Penticton groups.

ACKNOWLEDGMENTS

The Geological Survey of Canada is thanked for logistical support. Ken Daughtry and Discovery Consultants provided information and stimulating discussion. Neil Church kindly provided guidance and samples from other Eocene volcanic successions. Henry Marsden provided valuable advice in the field. Catherine Hickson is thanked for numerous helpful suggestions.

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