GEOLOGICAL SETTING AND PALEONTOLOGY OF THE FOSSILIFEROUS EOCENE BEDS NEAR McABEE, SOUTHWESTERN BRITISH COLUMBIA

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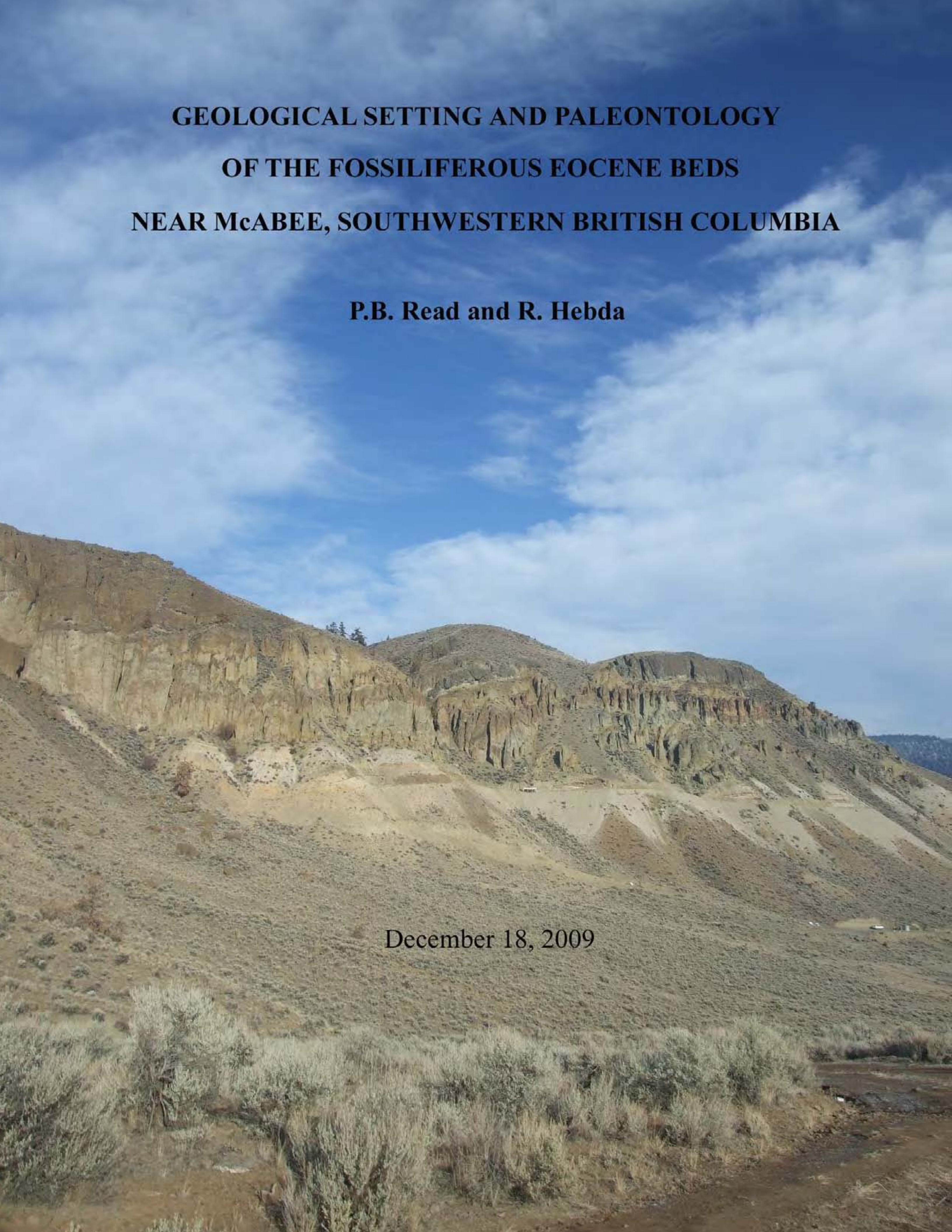

December 18, 2009

Cover: A view to the northeast showing the light-coloured, fossiliferous Zugg beds beneath the castellated cliffs of basalt breccia (**EDvbx**). The access road on Zugg 1 claim runs from the building in the lower right corner along the fossiliferous beds to the shed and beyond in the centre of the picture.

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EXECUTIVE SUMMARY

Near McAbee in southwestern British Columbia, richly fossiliferous beds of early Eocene age (48.6 to 55.8 million years ago) have attracted the conflictive interests of amateur and professional paleontologists and the mineral industry. The B.C. Ministry of Agriculture and Lands financed this study to obtain scientific data to assist it in developing strategies and setting policies for the best management and protection of fossils at McAbee.

To a maximum thickness, the fossiliferous beds form the uppermost hundred metre of shallow-water sediments deposited in an ancient lake. Erosion has removed most of the lake sediments except for three remnants ranging from 0.5 to 3.5 kilometres in length, which lie on the north side of the Thompson River between six and thirteen kilometres east of the village of Cache Creek and within two kilometres of the Trans Canada Highway.

Contouring of the rugged, ancient topography at the base of the Eocene deposits shows that the first Eocene rocks were deposited in at least three deeply incised, ancient rivers with a confluence near the present mouth of Battle Creek. The lower part of the Eocene rocks consists of coarse conglomerate (gravel) and debris flows (lahars) with up to four different episodes of volcanic flows partly filling the ancient valleys, but never crossing or damming the valleys. As the ancient valleys filled, the stream gradients decreased and the clast size of the sediments diminished to form pebble conglomerate.

Finally, beyond the area mapped, the ancient river system was dammed, possibly by lava flows or a land slide, and for a short period of geological time an ancient lake formed within the ancient drainage system near McAbee. During this interval, a diverse and abundant warm temperate flora and fauna of modern aspect flourished in and around the ancient lake. Remains of these animals and plants fell or were washed into the near-shore lake waters settled to the bottom and were buried and preserved as compression fossils within the lake sediments. The fossil flora consists of delicately preserved leaves, twigs, cones, nuts, flowers, pollen and spores. The fossil fauna includes an exceptionally diverse assemblage of well-preserved insects, a few species of fish and crayfish, and rare occurrences of birds including their feathers. The fossils lie flattened on the bedding of the enclosing rock which splits easily along this surface to display the fossils. The rich abundance, wide diversity and excellent preservation of fossils in fissile rock make the easily accessible fossiliferous beds near McAbee a unique site for Eocene fossils in Canada and North America.

Later in the Eocene, a massive outpouring of basalt flows and breccia ended the deposition of lake sediments and completely buried the ancient topography under hundreds to possibly thousands of metres of volcanic rocks. More recently erosion and glaciation have removed much of the Eocene rock, but preserved three remnants on the north side of the Thompson River composed of Eocene volcanic and fossiliferous sedimentary rocks. These three remnants, the Zugg, Perry Ranch and Battle Creek, contain fossiliferous beds with a length of 2.7 km, 1.3 km and 0.4 km and thicknesses ranging up to 100 m, 30 m and 15 m respectively.

Field inspection of selected exposures and review of representative collections and published literature demonstrate that exposures on the Zugg 1 claim are superior to all others with respect to access, quality, diversity and abundance of fossils.

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INTRODUCTION

Within the province of British Columbia, the Ministry of Agriculture and Lands is leading the development of a Fossil Management Framework, which aims to provide stewardship of the fossil resources in order to protect their scientific, natural heritage and educational values. Near McAbee in southwestern British Columbia, some of the Eocene sedimentary rocks are richly fossiliferous and also contain occurrences of industrial minerals of sub-economic grade and quantity. While the fossiliferous rocks near McAbee have been identified as an important scientific and heritage resource (Wilson, 2008), commercial activities at the main known site continue under legal mineral tenures. As a result, the objectives of the amateur and professional paleontologists and the industrial mineral users have collided: the amateurs wishing to either keep or sell the fossils they find, the professional desiring to study and protect the fossil heritage and the industrial mineral user wanting to mine, treat and sell the fossiliferous rocks. With this backdrop of conflicting interests, the British Columbia Ministry of Agriculture and Lands, under Contract CCLAL09013, has funded this study of the geological setting and paleontology of the fossiliferous Eocene beds near McAbee, southwestern British Columbia. The intention is to provide a background of scientific information to assist the Ministry in the resolution and management of these conflicting interests not only at McAbee but elsewhere in the province.

This report on the investigation of the McAbee area starts with the development of the paleo-valleys that underlie the Eocene volcano-sedimentary rocks and controlled the types of Eocene deposition and their distribution. Although Pleistocene and Recent erosion and glaciation have removed most of the Eocene rocks, three volcano-sedimentary remnants remain composed of fluvial and lacustrine sediments and intercalated basalt flows. They are the Zugg, Perry Ranch and Battle Creek remnants. A description of the Eocene paleo-valley fillings preserved in these remnants follows together with that of the underlying rocks and the nearby overlying Eocene basalt. Of the paleo-valley units, the lacustrine units named the Zugg, Perry Ranch and Battle Creek beds are richly fossiliferous and a discussion of their fossil content forms the section on paleontology. In the McAbee area, the known and potential fossil localities and their attributes are compared. An assessment of the industrial mineral potential of the area concludes the investigative portion of the report.

1. LOCATION AND ACCESS

The fossiliferous beds in the McAbee area lie between six and thirteen kilometres east of the village of Cache Creek and up to two kilometres north of the Trans Canada Highway on the lower grass-covered, south-facing slopes of the Cache Creek Hills. A network of powerline, farm and mining roads from the highway provides access near or to the fossiliferous beds. The roads also serve the surrounding area of geological investigation, which is up to two kilometres wide and extends eight kilometres west-northwesterly from the east side of Battle Creek (Map 1). Most of the side road gates are locked at the highway and permission for access is required from the nearby ranch owners.

2. PURPOSE OF STUDY

The purpose of this study is to determine the extent of the fossiliferous beds near McAbee and their geological setting with a view to identifying locations containing fossils of similar quality, diversity and quantity, which may support educational and research opportunities. In addition, by providing opportunities for comparison, the information will support paleontological oversight of the amateur fossil collecting activities at the claim site (Zugg 1), which will help to ensure that fossils of significant scientific value are made available to the scientific community for research and education.

3. PAST WORK

In addition to the regional geological mapping (1:250 000-scale) of Monger and McMillan (1989), who revised the earlier work of Duffell and McTaggart (1952), the detailed work by Ewing (1981) included the McAbee area as did that by Read (1988) at 1:50 000-scale. At 1:25 000-scale, McMillan (1978) investigated the Eocene and older rocks immediately south of the McAbee area.

Starting with Hills (1965), the fossiliferous beds near McAbee have been the focus of extensive paleontological research of macro- and micro-flora, insects, fish, and rare birds. Wilson (2008) in his McAbee Fossil Site Assessment report lists 40 scientific publications which refer to or examine various aspects of the paleontology of the fossiliferous beds near McAbee (Appendix A). Half of these investigations have been published since 2000 and many unpublished studies are in progress, such as the insect investigations of Archibald.

4. PRESENT WORK

This study, which covers an area of approximately 12 square kilometres, consists of geological and paleontological components. At 1:5,000-scale, the mapping defined the geological map units of the lower part of the Kamloops Group of Eocene age, traced their distribution and determined their mutual contact relations and those with the overlying Eocene volcanic rocks and underlying Mesozoic stratified and plutonic units. This mapping, accomplished by P.B. Read in 16 field days between November 20 and December 11, 2008, provides the stratigraphic framework and geological setting for the paleontology of the area (Map 2).

The paleontological portion of this study results from five days of field investigations by R. Ludvigsen in mid-November 2008 and a further five days by R. Hebda in the summer of 2009. The latter was accompanied by J. Leahy for two days at the Perry Ranch Beds and by B. Madu and J. Mosterd for a few hours at the Kitty Litter Quarry. Both R. Ludvigsen and R. Hebda visited the Zugg 1 claim several times to collect fossils and, for the latter, to observe the use of the site by customers.

5. ACKNOWLEDGEMENTS

L. Coward and G. Webber Atkins of the B.C. Ministry of Agriculture and Lands, Crown Lands Administration Division, with much care and attention, guided this contract through all governmental hurdles. N. Massey of the B.C. Geological Survey and R. Hebda of the Royal British Columbia Museum provided scientific and editorial advice. A number of ranch owners, Perry Ranch in particular, kindly allowed access to and through their lands during the field mapping and fossil collecting. J. Leahy, D. Langevin, B. Madu and J. Mosterd were of great assistance in the field. P. Cassadio provided advice about accessing the Perry Ranch beds. B. Archibald provided access to his published and unpublished work on the fossil insects at McAbee. K. and P. Kikegawa, Geodrafting Services Ltd., Vancouver provided their skilled production of the geological map.

Without the kindness and cooperation of these individuals, this study would not have been completed within the allotted time. However, any errors and omissions in the report are the authors' responsibilities and we would appreciate the readers bringing them to our attention.

PALEOTOPOGRAPHIC SETTING AND STRATIGRAPHIC FRAMEWORK OF THE EOCENE FOSSILIFEROUS BEDS

1. INTRODUCTION

The paleotopographic setting of the Eocene volcano-sedimentary sections near McAbee is so important to an understanding of the rocks that it precedes a discussion of the detailed stratigraphy. The setting principally affects the type of sedimentation and the distribution of all of the volcano-sedimentary units in the lower part of the Eocene succession.

2. PALEOTOPOGRAPHY OF THE BASE OF THE EOCENE

Between Cache Creek and Deadman River, some thirty kilometres to the east, the Eocene succession forms a very open, upright syncline with limbs dipping ten degrees or less (Read, 1989). This gentle deformation of post-late early Eocene age contrasts sharply with the rugged paleotopography of the basal Eocene unconformity. The detailed geological mapping of McMillan (1978) on the south side of the Thompson River and by Read (1988) north of the Thompson permits structure contouring of the base of the Eocene (Map 1). As the McAbee area lies on the southwestern limb of the syncline near the hinge, the basal Eocene unconformity has a slight northeastward tilt at McAbee.

On the basal Eocene unconformity, structure contours between 1500 and 3000’, with an interval of 500’, outline the junction among three paleo-valleys. The longest, well-defined paleo-valley, named Eo-Semlin Valley, trends east-southeastward along the present Semlin valley. A south trending paleo-valley, called Eo-Battle valley, is centred on the present south-flowing Battle Creek. The third paleo-valley, designated Eo-Thompson valley, trends west-northwest and lies close to the present course of the west-flowing Thompson River. The confluence of these paleo-valleys lies near the present mouth of Battle Creek. South of their junction, two paleotopographic possibilities exist. The preferred one is a two-kilometre wide, steep-walled canyon, which is more than 500 m deep and runs initially to the southeast. According to the regional distribution of the Eocene rocks (Monger and McMillan, 1989), it then veered to the east towards Mount Savona and ends against a proposed unmapped post-early Eocene fault in Durand Creek. The other alternative is that only an embayment exists to the southeast and that the main paleo-channel draining the area runs either to the west along the Eo-Semlin valley where a post-late Eocene fault cuts it, or to the east along the Eo-Thompson. Both the Eo-Semlin and Eo-Thompson paleo-valleys would correspond in direction, but only the Eo-Semlin in paleo-drainage direction to Tribe’s (2005, p. 221) proposed Eocene paleo-channel from Kamloops to Ashcroft.

The fill of these paleo-valleys is mainly conglomerate and lahar with the greatest thickness at the confluence of the paleo-valleys, near the abandoned McAbee railway station (Figure 1). Here 260 m of conglomerate and lahar with intercalated lava flows form the lower part of the paleo-valley filling. The angular to subangular clasts are mainly Eocene volcanic rocks indicating that some Eocene volcanism preceded the development of the paleo-valleys eroded mainly

LEGEND

	(Preferred Alternative						
Structure contours on the base of the Eocene	(Inferred						
(500' contour interval)	(Other Alternative						
Post-early Eocene fault							
Fossiliferous shale beds (**Eptf**)							
Paleo-valley		***EO-BATTLE***					

Scale 1:50,000

Map 1: Structure contour map of the basal Eocene unconformity showing the junction of the three Eocene paleo-valleys and the preferred and other alternative (dotted contours) for the arrangement of the structure contours near the south edge of the map.

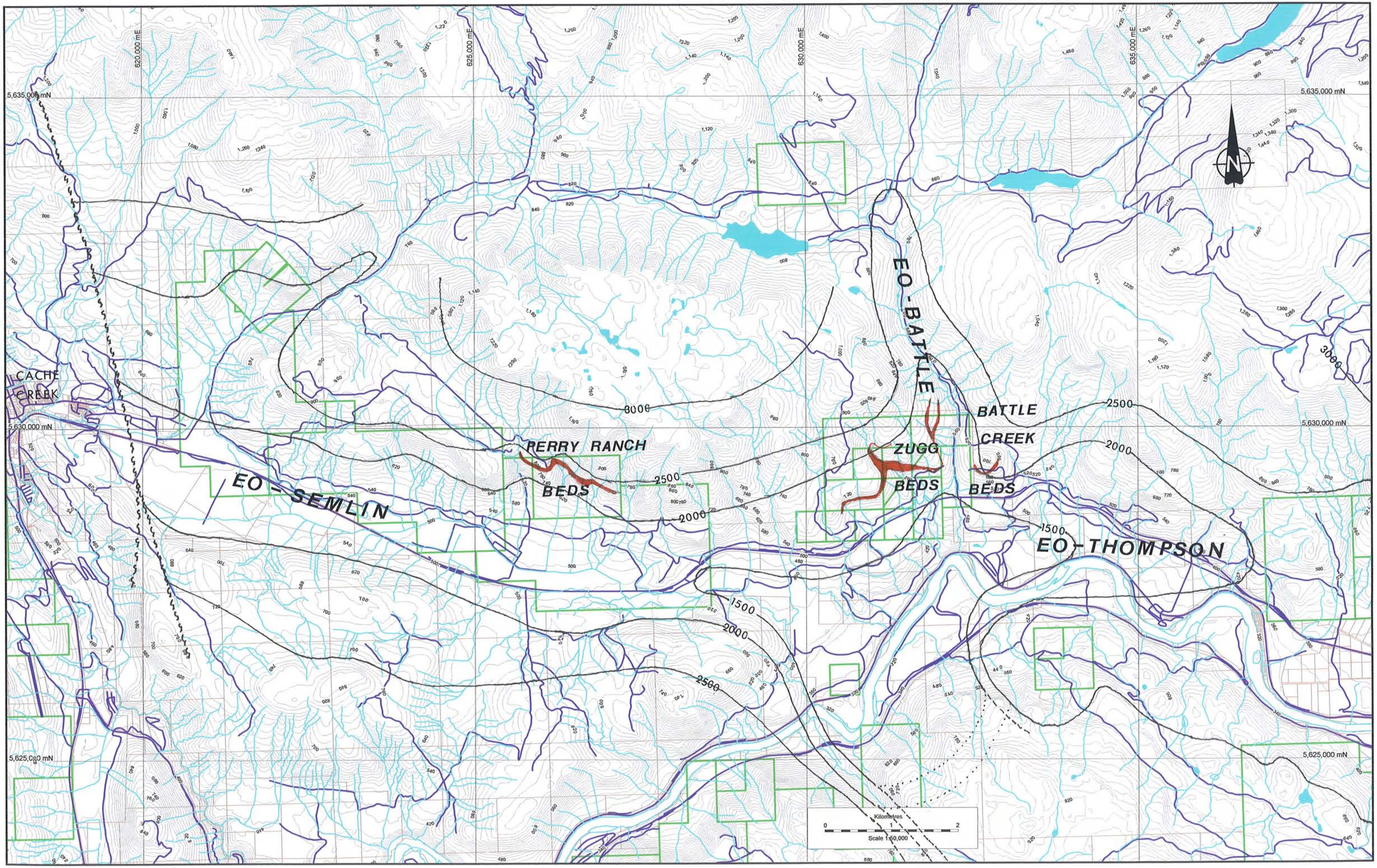
EO-BATTLE
BATTLE CREEK BEDS
ZUGG BEDS
PERRY RANCH BEDS
EO-SEMLIN
EO-THOMPSON
CACHE CREEK
3000
2500
2000
1500
620,000 mE
625,000 mE
630,000 mE
635,000 mE
5,635,000 mN
5,630,000 mN
5,625,000 mN
Kilometres
0
2
Scale 1:50,000

Figure 1: An eastward view north of McAbee railway station of cliffs of volcanic boulder conglomerate and lahar of unit **ETbcg**.

into the basement rocks of the Eocene succession. The only pre-erosion remnant of Eocene volcanic rocks identified during this study lies on the eastern edge of mapping south of the Trans Canada Highway. Near the top of the conglomerate fill, clasts from the Nicola Group, Ashcroft Formation and Guichon Batholith compose up to 25% of the subangular to subrounded detritus reflecting that the level of erosion had reached the basement rocks underlying the Eocene. The common occurrence of cobbles and boulders reflects the high gradients of the streams occupying Eo-Battle and Eo-Thompson valleys.

During deposition of the conglomerate, volcanic eruptions produced at least four volcanic successions which flowed into but not across the paleo-valleys near their confluence. A fifth period of volcanic flows may have spanned the paleo-valleys, but did not dam them. The lavas are aphanitic, almost vitreous, indicating their quick chilling in an aqueous environment.

The upper portion of the paleo-valley fill now comprises remnants of formerly much more extensive lacustrine deposits. They consist of bentonitic sandstone and white-weathering, thin-bedded shale with thin bentonitic ash and rhyolite crystal-lithic ash-tuff lenses and thin beds. The thin-bedded lacustrine shale hosts an abundant and highly diverse assemblage of well preserved Eocene flora and fauna. The lacustrine deposits range in elevation from 700 to 820 m above sea level on the north side of the Thompson, where they are known to be richly fossiliferous. On the south side of the Thompson River, they lie between 900 and 1065 m above sea level, where their fossil content is unknown

(McMillan, 1978). The presence of the lacustrine deposits suggests that landslide development of a short-lived lacustrine environment.

The onset of voluminous basaltic eruptions heralded the sudden end of the fluvial and lacustrine environments and produced a local intra-Eocene unconformity as depicted on Maps 2 and 3 and most easily seen in the field at the top of the lacustrine deposits. Elsewhere, this unconformity has volcanic rocks on both sides and requires close attention to define.

TABLE 1: Cretaceous to Recent Time-Event Table for McAbee and Nearby

Geologic Time	Age in Ma	Rock Unit			Event
Pleistocene to Recent			Qs		Erosion, glaciation and development of present topography
mid-Miocene	~12-13	Chilcotin Group	Chasm Formation		Eruption of Miocene plateau basalt
					Local lacustrine sedimentation (diatomite)
			Deadman River Formation		Damming of paleo-valley system
					Rhyolite volcanism blanketed paleo-topography Mio-paleo-valleys and forming paleo-lakes
					Development of basal Miocene unconformity with Mio-paleo-valleys
early mid-Eocene	~50-55	Kamloops Group	Dewdrop Flats Formation		Main Eocene volcanism (units **EDvb**, **EDvbx** etc.)
					Development of intra-Eocene disconformity
late early Eocene	~55-58		Tranquille Formation		Lacustrine sedimentation (unit **ETptf) FOSSILS**
					Damming of paleo-valley system
					Fluvial and volcanic deposition of paleo-valley fill (units **ETrtf** to **ETpcg)**
					Development of intra-Eocene unconformity with Eo-paleo-valleys
					Uplift and erosion
					Initial Eocene volcanism (unit **ETrd)**
					Development of basal Eocene unconformity with paleo-valleys
					Uplift, erosion and gentle folding
Cenomanian	~94-100		Unnamed unit		Terrestrial sedimentation: fluvial and swamp
					Uplift and erosion

STRATIFIED AND PLUTONIC ROCKS

1. INTRODUCTION

In the vicinity of McAbee, the Eocene stratigraphy consists of a locally developed volcano-sedimentary succession underlying a thick sequence of flows and tephra. Two locally developed intra-Eocene unconformities and the regionally developed basal Eocene unconformity bound a paleo-valley fill that forms the volcano-sedimentary succession.

The approximately west to east exposure of the Zugg, Battle Creek and Perry Ranch beds and enveloping strata allows construction of stratigraphic columns taken directly from the field mapping. Map 3 shows these stratigraphic columns constructed at 100 m NAD 83 UTM easting intervals. The top of the Zugg Battle Creek and Perry Ranch beds is used as a reference datum and designated as 0 m with thicknesses measured above and below it. To take into account the northward stepping of the exposures, the NAD83 UTM northing of the position of the stratigraphic columns appears in the Map 3. The justification for using the top of these beds as a reference datum is the common development of waterlain tuffaceous beds at and near the top of the unit, which probably represents a single short-lived volcanic event.

Because the Eocene stratigraphy, particularly its fossil content, is the main focus of this study, the descriptions of the underlying rock units are brief.

2. NICOLA GROUP (unit uЂNV)

Grey-green aphanitic to plagiophyric meta-andesite flows form a part of the east valley wall of Battle Creek about two kilometres upstream from its confluence with the Thompson River. On the forestry access road up Battle Creek, roadcuts yield the best exposures of this complexly jointed, chlorite-altered unit. The contact across the basal Eocene unconformity is not exposed.

3. GUICHON BATHOLITH (unit ЂJqd)

The most accessible exposures of the outliers of the Guichon Batholith are on the Trans Canada Highway at the east end of Semlin Valley. By far the best exposures are the quarry walls at Canadian National Railway’s McAbee Quarry on the north bank of the Thompson River just east of the mouth of Battle Creek. The plutonic rock ranges from a medium-grained (1- 3 mm) fresh to chloritized biotite-hornblende quartz diorite and granodiorite to a diorite. Its contact with the nearby Nicola Group and Ashcroft Formation is not exposed, but an exposure of the nonconformity with the overlying Eocene conglomerate forms the anchor point for a wooden power pole 80 m west of the second to last hairpin from the bottom of the McAbee Quarry access road (Figure 2). Here, subangular to subrounded Guichon cobbles in the basal Eocene conglomerate overlie the steep northerly dipping nonconformity.

4. ASHCROFT FORMATION (unit lmJA)

Dark grey fissile shale forms a few grey rounded hillocks beneath the lens of Eocene sediments north of the Perry Ranch. The unconformity against the overlying Eocene rhyolite ash-tuff is unexposed.

5. KAMLOOPS GROUP

The Kamloops Group of Eocene age is widespread in southern British Columbia, where it extends for over a 130 kilometres in a broad east-west belt from east of Kamloops to the Fraser River. Stratigraphically it is characterized by a lenticular volcano-sedimentary unit at its base and an overlying thick sequence of flows and tephra. In the McAbee area, the upper of the intra-Eocene unconformities permits a subdivision of the rocks of the Kamloops Group into a lower volcano-sedimentary unit and an upper volcanic unit. This subdivision of the Kamloops Group corresponds to Ewing's (1982) subdivision of the group into the lower volcano-sedimentary Tranquille Formation and upper volcanic-rich Dewdrop Flats Formation in the type area. This subdivision is accepted here and used to subdivide the Eocene stratigraphy.

Figure 2: The basal Eocene unconformity 80 m west of the second from last hairpin from the bottom of the McAbee Quarry road. The nonconformity between the grey Guichon quartz diorite **ЂJqd** (lower left corner) and overlying conglomerate **ETbcg** (upper right half) trends at 285/63NE.

(a) Tranquille Formation

This formation includes all the sedimentary and intercalated volcanic rocks that form the paleo-valley fill. They are preserved as three erosional remnants, which are from west to east the Perry Ranch, Zugg and Battle Creek remnants. The Perry Ranch and Zugg remnants are three kilometres apart, whereas only half a kilometre separates the Zugg and Battle Creek remnants. The formation consists of an erosional remnant of Eocene rhyodacite flows (**ETrd**), thought to predate the paleo-valley, and then the units of the paleo-valley fill. In the Zugg and Battle Creek remnants, these include widespread conglomerates (units **ETbcg** and **ETpcg**), which host five volcanic units starting with two sequences of aphyric basalt flows (**ETvb1 and ETvb2**), then a porphyritic hornblende-augite basalt (**ETvbm**), a rhyolite tephra (**ETra**) and an upper aphyric basalt flow and breccia unit (**ETvb3**). Above the conglomerate units is a sequence of fossiliferous lacustrine sediments composed of shale and minor crystal-lithic tuff and ash (unit **ETptf**). In the Perry Ranch remnant, the paleo-valley fill consists of a tuffaceous sandstone and siltstone (**ETss**) with two intercalated basalt flows (**ETvb**) topped by the same fossiliferous lacustrine beds (**ETptf**).

1. Rhyodacite Flows (unit ETrd)

At the eastern edge of mapping, east of the access road to McAbee Quarry, is a bluff of buff weathering, aphanitic, microvesicular rhyodacite flows. Although contacts with the surrounding rock units are unexposed, the conglomerate of the paleo-valley fill appears to lap onto the flows, which form part of the east paleo-valley wall of Eo-Battle creek (Map 2). Although these flows belong to the Kamloops Group, they appear to be an erosional remnant of Eocene flows remaining after the erosion forming the paleo-valleys.

2. Zugg and Battle Creek Remnants

The Zugg remnant contains a complete section of the paleo-valley fill topped by lacustrine sedimentation, yielding a total thickness of at least 380 m. Within this fill, the remnant contains two conglomerate units with five intercalations of volcanic rocks topped by a maximum thickness of 100 m of fossiliferous lacustrine sediments. The boulder conglomerate unit is the host rock for the volcanic rocks, which are described in ascending stratigraphic order.

The valley of Battle Creek separates the Battle Creek remnant lying east of the creek from the Zugg remnant to the west. The lower portion of the paleo-valley fill connects across the creek, but the upper lacustrine portion does not.

(a) Volcanic Boulder Conglomerate (unit **ETbcg***)*

This widespread unit extends for up to 5.3 kilometres long from its eastern exposures on the McAbee Quarry road through its western exposures on the Trans Canada Highway 2.5 kilometres west of Battle Creek to a gully at 590 m elevation and 150 m east of the power pylon road. Exposures occur from 340 metres elevation close to the Thompson River to immediately beneath the lacustrine beds in the roadcuts on the Zugg claim at 600 m or to 540 m on the road to the Kitty Litter Quarry. The best and most accessible exposures of the lower part of the unit are on the McAbee Quarry road (Figure 3) and the cliffs behind the abandoned McAbee railway station (Figure 1) and for the upper part of the unit, the roadcuts on the Zugg 1 claim (Figure 4).

The clast composition and roundness changes from monomictic angular Eocene basalt clasts, some up to 2 m in diameter, in the lower part of the unit to subangular and subrounded polymictic Eocene volcanic clasts with up to 25% of the clasts derived from the Guichon Batholith in the upper part of the unit (Figure 5). Lahars with angular clasts floating in a matrix of fine clasts of the same composition are common in the lower part of the unit and gradually pass upward to polymictic conglomerate. This upward variation in clast composition reflects the erosion of the initially deposited Eocene volcanic rocks and then continued downcutting into the pre-Eocene basement composed of Nicola Group volcanic and Guichon plutonic rocks. The fissile shale of the Ashcroft Formation is so friable that it does not form cobbles or boulders. The lower part of the unit yields distinctive brown weathering outcrops whereas in the upper part the outcrops tend to grey-buff. Throughout the unit, the clast size ranges from minor pebbles to dominant boulders and bedding is absent to very crudely developed (Figure 3). On both walls of the lower part of Battle valley, the upper part of the unit grades laterally from a volcanic conglomerate to a volcanic breccia.

The unit nonconformably overlies an outlier of the Guichon Batholith with the exposed contact in a cable anchor point for a wooden power pole 80 m west of the second hairpin turn from the bottom of the McAbee Quarry road (Figure 2). The nonconformity has a rugged paleotopography with the conglomerate and intercalated lava flows butting against a subvertical paleo-cliff at their eastern limit uphill from the junction of the Trans Canada Highway and the forestry access road up Battle Creek (Map 3). The slopes above McAbee Quarry expose the more gently dipping paleotopography near the floor of the paleo-valley.

Figure 3: Outcrop of crudely bedded volcanic conglomerate of unit **EТbcg** at the second hairpin from the bottom on the McAbee Quarry road.

Unit **ETbcg** is unfossiliferous except for two shale-sandstone lenses exposed near the eastern limit of the unit. The paleontology of this unit (**ETsl**) dates the enclosing conglomerate host and appears under the description of that unit.

Figure 4: Looking west along the access road on the Zugg 1 claim to subrounded volcanic cobble to boulder conglomerate of unit **ETbcg**, which separates a lens of white-weathering shale of the Zugg beds from the overlying main Zugg beds topped by cliffs of basalt breccia (**EDvbx**).

(b) Basalt Flows (unit* ETvb1*)

This unit may be the most widespread of the volcanic intercalations in the boulder conglomerate. It extends as scattered outcrops for a kilometre from just west of the mouth of Battle Creek to above the boulder conglomerate cliffs north of McAbee Station (Figure 1). An outcrop gap of 3.3 kilometres intervenes before similar rocks appear in the lower slopes above the power pylon road and form a thick unit, which regional mapping (Read, 1988) suggests extends over six kilometres to the west beyond the limit of mapping. At the eastern limit, flows are about 60 m thick where they butt against the steep eastern wall of Eo-Battle creek paleo-valley (Maps 2 and 3). Westward, they thin to 20 m before the outcrop gap, and the same flows may reappear to the west with a 60 m thickness. This is the only flow unit which potentially crosses the paleo-valley from wall to wall.

Figure 5: A few hundred metres east of the Zugg 1 claim, a polymictic conglomerate of unit **ETbcg** containing subrounded cobbles and boulders of volcanic rocks and Guichon Batholith clasts as at the top of the trekking pole.

Two thin sections show that the flows are sparsely porphyritic (augite, olivine pseudomorphs, ±plagioclase (An_{57})) augite basalt with a matrix composed of augite and plagioclase ranging in composition from An_{48} to An_{57}.

At 400 m elevation in a gully 0.5 km north of McAbee Station, the chilled base of the flows lies exposed on a volcanic boulder conglomerate with a few rounded Guichon clasts. A thin section of the chilled flows has a hyalopilitic texture with microlites of plagioclase and augite in a devitrified glass matrix.

(c) Basalt Flows (unit **ETvb2***)*

The presence of this unit depends upon a single exposure in a gully bottom 650 m northwest of the mouth of Battle Creek. Here a medium grey aphyric flow of presumed basaltic composition directly overlies the volcanic boulder conglomerate unit (**ETbcg**). Because this outcrop lies on the lower edge of a broad swath up to a few kilometres long, which is devoid of outcrop, the extent and thickness of the unit are unknown.

(d) Siltstone, Sandstone and Shale (unit **ETsl***)*

Although outcropping in only two locations in the Battle Creek remnant, this is the only fossiliferous unit within the unit **ETbcg**. It lies near the eastern edge of the Eo-Battle Creek paleo-valley fill (Map 2). The second locality is in a slumped road cut on the McAbee Quarry access road. As a 700 m outcrop gap lies between the two localities, the thickness and extent of the unit is unknown.

The buff weathering tuffaceous sediments are medium bedded with 1 to 3 cm thick layers common. At the known fossiliferous site, plant debris, mostly stems, lie scattered along the sandstone bedding planes. Here the unit is immediately overlain by basalt flows of unit **ETvb3**. Because the sediments pass beneath overburden in both localities, the unit may form two lenses each 10 to 15 m thick separated by boulder conglomerate or, less likely, may form a single lens 80 m thick.

A fossil collection from the site northwest of the Trans Canada Highway yields an Eocene age. The Paleontology chapter below gives details of this collection but not a comparison of the fossil abundance, diversity and quality of this site to those of the fossil localities in the Zugg beds (**ETptf**)

(e) Rhyolite Ash (unit **ETra***)*

The rhyolite ash crops out at only two localities. One is at the 530 m elevation on the road to the Kitty Litter Quarry and the second within a 100 m to the east on the powerline road (Map 2). The maximum exposed thickness is 12 m, but given the lack of outcrop, the unit could be up to 50 m thick and the length, several hundred metres.

The sloughed roadcuts expose an unbedded, cream coloured rhyolite ash surrounded by 'pop corn' weathered ash (Figure 6). Two X-ray diffractograms of this material show that it consists of bentonite, clinoptilolite and albite (Read, 2003).

Although contacts with surrounding units are not exposed, the rhyolite ash must directly underlie the basalt flows of unit **ETvb3** to the east and the boulder conglomerate of unit **ETbcg** to the west (Maps 2 and 3).

Figure 6: On the road to the Kitty Litter Quarry, a typical exposure of bentonitic rhyolite ash of unit **ETra** with 'pop corn' weathering of the sloughed material.

(f) Basalt Flows and Tephra (unit **ETvb3***)*

This unit straddles Battle Creek extending up to 0.5 km from the creek on either side (Map 2). The best exposures of the more than 60 m thickness of flows and intercalated tephra, that form the valley walls of the creek, are upstream from the Trans Canada Highway (Figure 7). The most accessible exposure is at the western limit of the unit where the road to the Kitty Litter Quarry crosses a few metre thick flow at 530 m elevation, which is the total thickness of the unit at this point. In overall shape, the unit is a westward tapering wedge with a 70 metre-thickness of flows and tephra that terminates to the east against the sub-vertical eastern paleo-valley wall of Eo-Battle creek (Maps 2 and 3).

A thin section of a sample at the western edge of the unit shows it consists of a few partly altered olivine and resorbed plagioclase phenocrysts lying in a matrix of plagioclase microlaths (An_{43} to An_{48}) floating in devitrified glass.

Although the boundaries to the unit are not exposed, in the west it overlies the rhyolite ash (unit **ETra**) and to the east it overlies sandstone to shale of unit **ETsl** (Maps 2 and 3).

Figure 7: A view to the south of the flows and interflow breccias of unit **ETvb3** forming bluffs on the east side of Battle Creek.

(g) Porphyritic Hornblende-Augite Basalt Flows (unit* ETvbm*)

This unit of flows stretches for three kilometres along the north side of the Trans Canada Highway forming columnar jointed cliffs up to 60 m high (Figure 8). The unit attains a maximum thickness of 120 m but tapers to the east and west (Maps 2 and 3).

The microvesicular upper part of the hornblende porphyry flow unit grades downward to nonvesicular flows. Near the base of the unit, a thin section shows it is sparsely porphyritic with euhedral augite and partly resorbed phenocrysts of plagioclase and basaltic hornblende in a matrix of augite and plagioclase (An_{48} to An_{62}).

Figure 8: A view to the northwest of the Trans Canada Highway of the columnar-jointed cliffs of porphyritic hornblende-augite basalt flows.

At its eastern end, the unit lenses out in volcanic boulder conglomerate (**ETbcg**). In the middle, the flows clearly overlie the well lithified (baked?) boulder conglomerate (Figure 9). At its western end, the unit overlies the volcanic conglomerate, but whether unit **ETvbm** lenses out or ends because of erosion along the overlying intra-Eocene unconformity is unknown.

(h) Volcanic Pebble Conglomerate (unit* ETpcg*)

The volcanic pebble conglomerate unit forms a kilometre long lens with a maximum thickness of 45 m. The best exposures of the unit are along the road to the Kitty Litter Quarry where the bottom of the unit forms a roadcut, and at the southeast end of the lowest bench in the quarry where it underlies the lacustrine beds (Figure 10).

The unit is a polymictic fine pebble conglomerate with subrounded Eocene volcanic clasts ranging from basalt to rhyolite. Although largely waterlain, the unit is not bedded, and in distinction to the rhyolite ash (unit **ETra**), is nonbentonitic. Towards the eastern limit of the lens in the Zugg remnant, the volcanic fragments become angular and a thin lens of bedded tuffaceous sandstone develops at the bottom of the unit (Figure 11). In the Battle Creek remnant, the unbedded unit consists of angular to subrounded volcanic clasts (Map 3).

Figure 9: On the east side of the lower bench of the Kitty Litter Quarry, a bench front shows a nonbentonitic volcanic pebble conglomerate of **Eтpcg** underlying thin-bedded shale of **Eтptf** on a conformable contact just above the coin.

The transition from boulder to pebble conglomerate is abrupt, as also is the transition from pebble conglomerate to lacustrine sediments. These sharp changes make for easy placement of the conformable lower and upper boundaries of unit **Eтpcg**.

Figure 10: Immediately north of the Trans Canada Highway, a cliff exposes grey weathering, platy-jointed hornblende-augite porphyry basalt flows (**ETvbm**) overlying buff weathering volcanic conglomerate of **ETbcg**

(i) Zugg and Battle Creek Beds (unit* ETptf*)

The best exposures of the Zugg beds are the 400 m long bulldozed roadcut on the Zugg 1 claim (Figure 12), adjacent ground to the east and the 150 m long lowest bench of the Kitty Litter Quarry, which lies 750 m to the northeast of the Zugg 1 claim (Figure 13). Between these two exposures, the beds thicken from 20 m at the Zugg 1 claim to approximately 100 m near the Kitty Litter Quarry. East of the Kitty Litter Quarry, the beds thin rapidly towards the west valley wall of Battle Creek, where the beds bifurcate northwards and disappear. To the west of Zugg 1 claim, the beds lens out within a few hundred metres and farther west only reappear as a 150 metre long lens less than a few decimetres thick (Map 2).

Figure 11: A view to the northeast near the eastern limit of unit **ETpcg** where a volcanic breccia overlies a layer of thin white tuffaceous sandstone just above a cliff volcanic boulder conglomerate of **ETbcg** in the gully.

The Kitty Litter Quarry exposes the lower 15 m of the Zugg beds consisting of fossiliferous, white to buff brown, thin-bedded shale and local thin (1-3 cm thick) bentonitic ash beds up to about 13 m above the base of the unit (Figure 13). Above this level, sparsely fossiliferous, buff-brown weathering tuffaceous sandstone appears in crudely bedded layers up to 0.5 m thick (Figure 14). Float and slumpcrop above the quarry indicate thin-bedded, white-weathering shale and localized siliceous argillite and shale layers are important constituents of the remaining, poorly exposed 50 metre thickness. In places where the Zugg beds are up to 30 m thick, only thin-bedded shale, waterlain rhyolite and local bentonitic ash layers form the beds and sandstone is absent. White-weathering, zeolitized tuffaceous shale forms thin layers scattered sparsely throughout, but in the upper 5 m of the beds, the tuffaceous shale combines with crystal (biotite, quartz, feldspar) and rhyolite ash to form a zeolitized sandstone-shale succession. The zeolitized siltstone and sandstone beds are typically fossil-poor. On the Zugg 1 claim, where the beds total 20 to 30 m in thickness, thin-bedded fossiliferous shale dominates (Figure 15). Here the excellent outcrop shows an underlying lens of Zugg beds (Figure 4) enclosed in the boulder conglomerate unit **ETbcg** (Map 3).

Figure 12: A view to the east of light coloured slopes underlain by the Zugg beds (**ETptf**) below the castellated cliffs of unit **EDvbx**.

Figure 13: Lowest bench of the Kitty Litter Quarry exposes thin-bedded, shale of the Zugg beds (**ETptf**) showing westward directed slump folding.

Figure 14: In the Kitty Litter Quarry, a northwest view shows the lowest thick bed of brown-weathering tuffaceous sandstone.

The lower contact of the Zugg beds outcrops on the Zugg 1 claim where the underlying rock is a polymictic pebble to boulder conglomerate (**ETbcg**) containing clasts derived from the Guichon Batholith (Figure 15). To the northeast in the Kitty Litter Quarry, exposures on the lowest bench front show a rhyolite-rich fine pebble volcanic conglomerate (**ETpcg**) directly underlies the Zugg beds (Figure 10).

Directly overlying the Zugg beds are volcanic rocks ranging from basalt volcanic breccia (**EDvbx**) on the Zugg 1 claim (Figure 12) to basalt flows exposed northeast of the Kitty Litter Quarry (**EDvb**). The top of the sedimentary beds is locally squeezed up around the bottom of the overlying volcanic breccia clasts suggesting that the Zugg beds were soft at the time of deposition of the overlying volcanic breccia. Elsewhere, the top of the Zugg beds is channelled and the breccia clasts deposited in the channels (Figure 16).

Figure 15: On Zugg 1 claim, a westward view of white-weathering, thin-bedded fossiliferous Zugg beds (**ETptf**) overlying volcanic conglomerate (**ETbcg**).

Figure 16: On Zugg 1 claim, volcanic breccia of unit (**EDvbx**) fills a channel eroded in the top of the white-weathering shale **ETptf** of the Zugg beds.

In two locations, the Zugg beds bifurcate and a thickness of up to 30 m of volcanic rocks lies within the bifurcation. One of these lies west of the Kitty Litter Quarry, but exposures of the waterlain rhyolite tuffs are so poor that the attitudes of the tuff at the nose of the bifurcation are unknown (Map 3). The other bifurcation lies on the west valley wall of Battle Creek. Here exposures of the thin-bedded tuffaceous shale show steep to vertical dips at the nose of the bifurcation. Soft-sediment slumping of the Zugg beds is obvious in the Kitty Litter Quarry (Figure 13) and in a few outcrops lying to the east. The slump direction is consistently down to the southwest to northwest. The slumping deformation ranges from folded, but coherent beds (Figures 13 and 17) to detached blocks up to metres in length (Figure 18). The common occurrence of slumping may provide an explanation for the bifurcation of the Zugg beds. The bifurcation may be the product of volcanic rocks plowing into already deposited lacustrine sediments.

Figure 17: On the powerline road on the ridge west of Battle Creek, a roadcut exposes a northwesterly directed slump-folded shale in the Zugg beds (**ETptf**).

The Zugg beds die out to the north on the west side of Battle Creek and to the west a few hundred metres west of the Zugg 1 claim either through reaching the edge of the lacustrine environment of deposition or through later erosion of the beds before the deposition of the overlying rocks. Of the two possibilities, the edge of a lacustrine environment is favoured because the Zugg beds are thickest where they overlie waterlain conglomerate and disappear where the underlying rocks pass horizontally into volcanic breccia that is not waterlain. The tuffaceous

Figure 18: An upper bench front of the Kitty Litter Quarry shows blocks of vertically bedded shale on the left edge of the photo and a second one with inclined bedding above the trekking pole lying in a brown tuffaceous sandstone.

upper portion of the Zugg beds probably represents a relatively short period of time representing an eruption of rhyolite tephra from one of the nearby rhyolite vents, such as at Cache Creek, and can be treated as a time line. The thickest portion of the Zugg beds beneath this time line probably represents the infilling of the deepest preserved portion of the lacustrine basin. As a result, the fossils in the lowest portion of the Kitty Litter Quarry might be expected to represent the deepest water fauna while that of the thin part of the beds, such as on the Zugg 1 claim, should contain shallow-water fauna.

The Zugg beds are fossiliferous from their western end eastward to road cuts on a power line road on the ridge west of Battle Creek. Within this length of 1.7 km, the best of the known fossil localities are at the artificial exposures created by the roadwork on Zugg 1 claim (fossil locality **F22**) and the open pit operations at the Kitty Litter Quarry of Industrial Mineral Processors Ltd (**F5** and **F8**). Except for a short road cut to the east of the east boundary of Zugg 1 claim (**F19** and **F21**), all other fossil collecting sites (**F18** and **F20**) are from shale in the weathered zone. The section on Paleontology gives the details concerning the abundance, taxonomic character, diversity and quality of the fossils from each of the fossil localities and a comparison of these parameters among the fossil localities in the Zugg beds. The combination of fossil collections from the road cuts on Zugg 1 claim and the quarry indicate a late early Eocene age for the Zugg beds (Wilson, 2008).

The Battle Creek beds outcrop for a length of 500 m on the east side of Battle Creek. They do not exceed 20 m in thickness, lens out to the northwest and to the east terminate against the east valley wall of Eo-Battle Creek (Maps 2 and 3). The white-weathering lacustrine shale is not as thin-bedded as and appears more tuffaceous than the Zugg beds, and dips about 30°W in two exposures where the bedding is finely rippled. In the Battle Creek beds, the few trenches and pits indicate that the rocks are poorly fossiliferous.

3. Perry Ranch Remnant

The Perry Ranch remnant has an exposed length of 1.8 kilometres and maximum thickness 100 m. The absence of the underlying volcanic boulder conglomerate unit suggests a less energetic depositional environment beneath the lacustrine beds. This environment is consistent with the low gradient of Eo-Semlin valley compared to the high gradients of the Eo-Battle and Eo-Thompson valleys which host the Zugg and Battle Creek remnants. Like the Zugg and Battle Creek remnants, lava flows interfinger with the pre-lacustrine sediments, the fossiliferous lacustrine sediments top the paleo-valley fill and the overlying lavas and breccias have entrained large fragments of lacustrine sediments.

(a)Rhyolite Ash Tuff (unit* ETrtf*)

This thin, white-weathering unit is discontinuously exposed for 350 m along the base of the Perry Ranch remnant (Map 2). North of Perry Ranch on the north side of the Trans Canada Highway, it is a white splash downslope from the base of the cliffs (Figure 19). The unit has crudely developed bedding suggestive of an extrusive rather than an intrusive unit. It is probably about 5 m thick, but its contacts with the host rocks are not exposed. It appears to lie at the base of the Eocene succession (Maps 2 and 3). Elsewhere, to the east and west of the present area, it forms the base of the Eocene succession in the Cache Creek valley and east of Battle Creek (Read, 1988).

(b) Pebbly Bentonitic Ash, Sandstone and Siltstone (unit* ETss*)

North of the Perry Ranch, this unit forms rounded topography with very scattered low outcrops on the ridges but with good exposure in a few of the gullies crossing its 500 m strike length (Figure 20). Together with the intercalated flows, the unit is up to a maximum of 80 m thick. Unlike the fine pebble conglomerate unit **ETpcg,** unit **ETss** is bentonitic. The base of the unit either lies against rhyolite ash tuff (**ETrtf**) or directly on the Ashcroft Formation. The upper contact is against one of overlying volcanic pebble conglomerate (**ETpcg**), white-weathering lacustrine shale (**ETpt**f), or basalt flows (**ETvb**) (Maps 2 and 3).

(c) Basalt Flows (unit* ETvb*)

Two basalt flows interfinger with the bentonitic sediments beneath the lacustrine beds (Figure 21). The two flows, up to 10 m thick, are part of the mass of flows that host the Perry Ranch remnant (Maps 2 and 3) and thicken westward to nearly 300 m. As with the various flows in the Zugg remnant, their presence indicates that volcanism was synchronous with sedimentation.

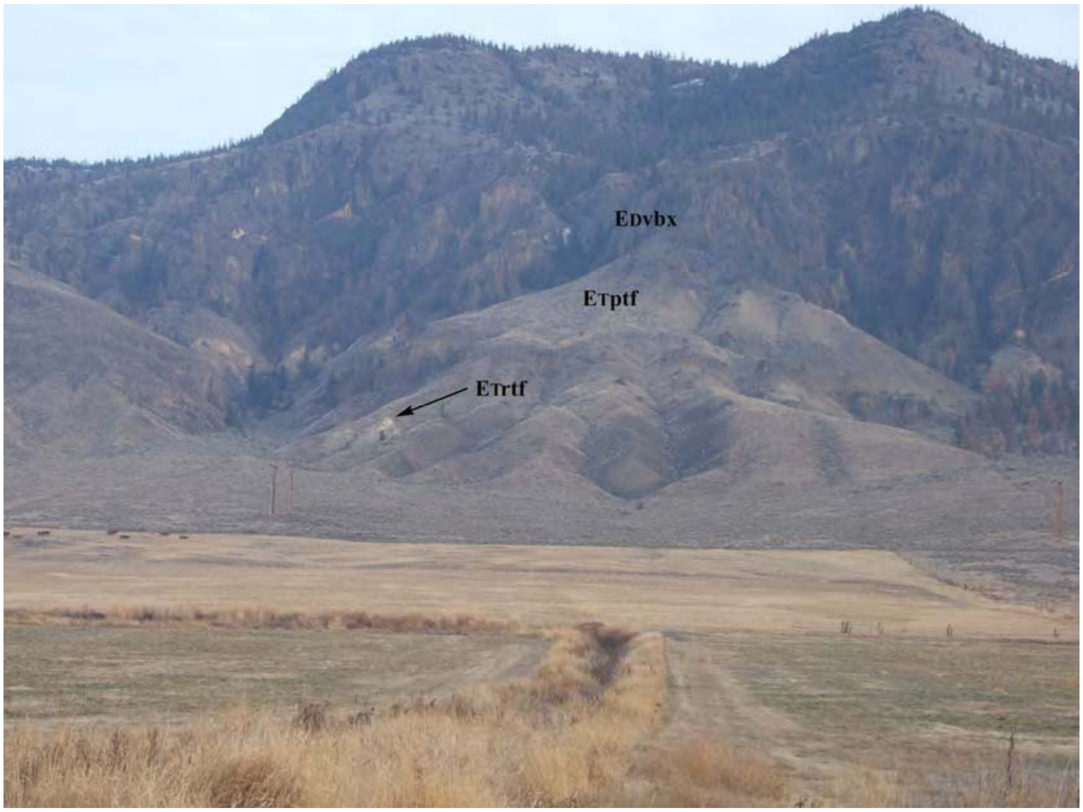

Figure 19: A view to the north from the Trans Canada Highway of the light weathering slopes underlain by the Perry Ranch beds (**ETptf**) immediately below the cliffs of unit **EDvbx**. The white splash to the right above the power pole is unit **ETrtf**.

(d)Volcanic Pebble Conglomerate (unit* ETpcg*)

Near the exposed southeast end of one of the bentonitic sediment lenses and at the northwest end of the lacustrine shale, both units change horizontally into nonbentonitic volcanic sandstone, gritstone and fine pebble conglomerate. The northwestern extension of unit (**ETpcg**) passes under a two kilometre length of overburden, which covers the relationship of this unit to a sequence of rhyolite crystal-lithic tuff and tuffaceous sandstone at the northwest end of the outcrop gap (Read, 1988). Although unfossiliferous, the rocks of unit **ETpcg** are crudely to moderately bedded and are probably waterlain (Figures 22, 23 and 24).

(e) Perry Ranch Beds (unit* ETptf*)

The Perry Ranch beds underlie part of the rounded hillocks at the base of steep cliffs on the north side of the Trans Canada Highway north of the Perry Ranch (Figure 25). Exposures lie north-northwest of the end of the power pylon road where a gully exposes a fairly complete section through the beds. Northwest of the gully, a few ridges and gullies expose parts of the beds before the beds finally form inaccessible cliffs (Figure 26). A second power pylon road accesses the northwest end of the beds where they are present as shale talus slopes. The beds have a strike length of 1700 m, a maximum thickness of 40 m and terminate at the northwest end because of a facies change into volcanic gritstone (Maps 2 and 3).

Figure 20: A gully through the Perry Ranch remnant showing dark grey weathering flows of unit **ETvb** in the lower left corner underlying bentonitic sandstone and siltstone of unit **ETss.**

Although the lower contact of the Perry Ranch beds against an underlying basalt flow is not exposed, the transition to thin-bedded lacustrine shale is sharp. Part of the shale unit lies below a basalt flow (Maps 2 and 3). The upper contact of unit **ETptf** is well exposed in a gully where basalt breccias of unit **EDvbx** interfinger with shale (Figure 27). In the cliffs above this point, three lenses of disoriented white-weathering shale are scattered in the overlying breccias implying that the volcanic rocks slid into place and in the process incorporated large fragments, up to 60 m long, of the underlying lacustrine shale (Figure 28).

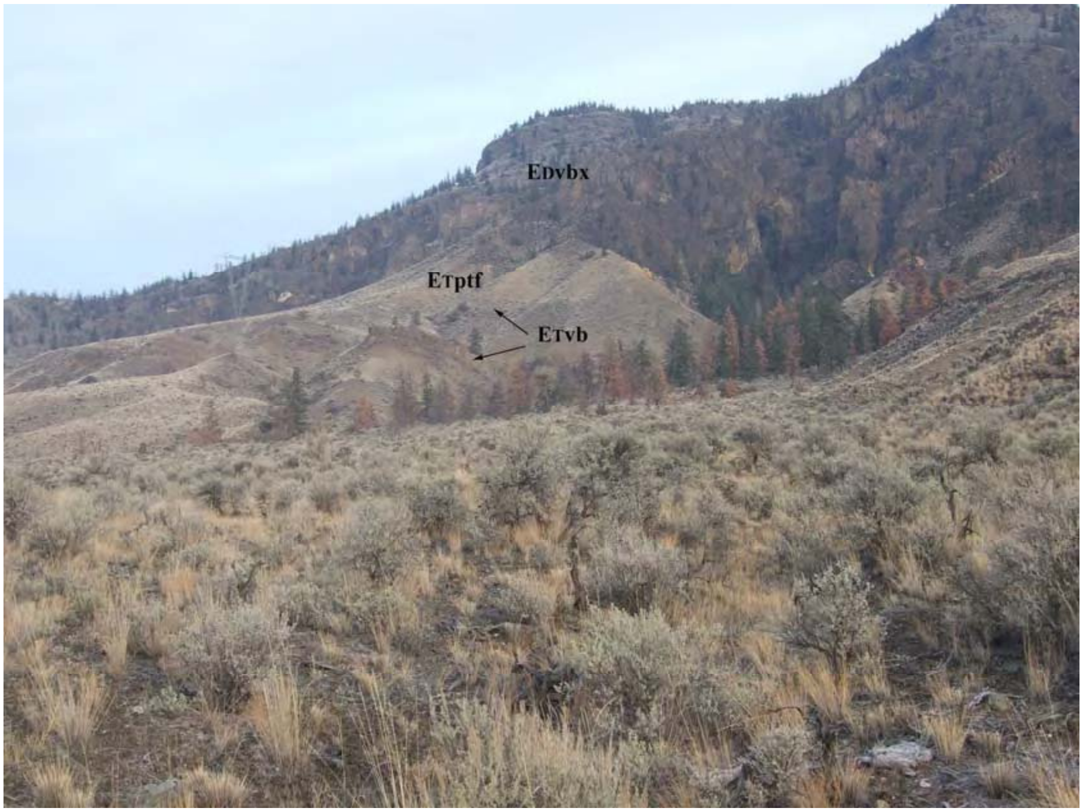

Figure 21: A northwestward view of the Perry Ranch remnant showing two intercalated basalt flows of unit **ETvb** (the lower showing as a low cliff and the upper lying beneath the upper light slope) underlain by the Perry Ranch beds (**ETptf**) all lying beneath the cliffs of basalt breccia (**EDvbx**).

The Perry Ranch beds are fossiliferous over a length of 0.95 km starting in a gully on the southeast to a talus slope to the northwest. Although all of the localities are in the weathered zone, those in the gullies are the least weathered. Only a single fossil collection comes from the Parry Ranch beds (Wilson, 2008), but amateurs have collected from these beds (Hebda, 2008 pers. comm.). Details concerning the abundance, diversity and quality of the fossils from each of the fossil localities and a comparison of these parameters among the fossil localities in the Perry Ranch and Zugg beds are given below.

Figure 22: At the northwest end of the Perry Ranch remnant, a southeastward view shows volcanic pebble conglomerate (**ETpcg**) at top of cliff overlying flows of unit **ETvb** forming lower two-thirds of cliff.

Figure 23: At the northwest end of the Perry Ranch remnant, a roadcut on the power pylon road shows a crudely bedded volcanic conglomerate of unit **ETpcg**.

Figure 24: Crudely bedded volcanic gritstone (**ETpcg**) at the northwest end of the Perry Ranch remnant.

Figure 25: A view to the north of the Trans Canada Highway shows the Perry Ranch remnant exposed in the rounded topography immediately below the cliffs.

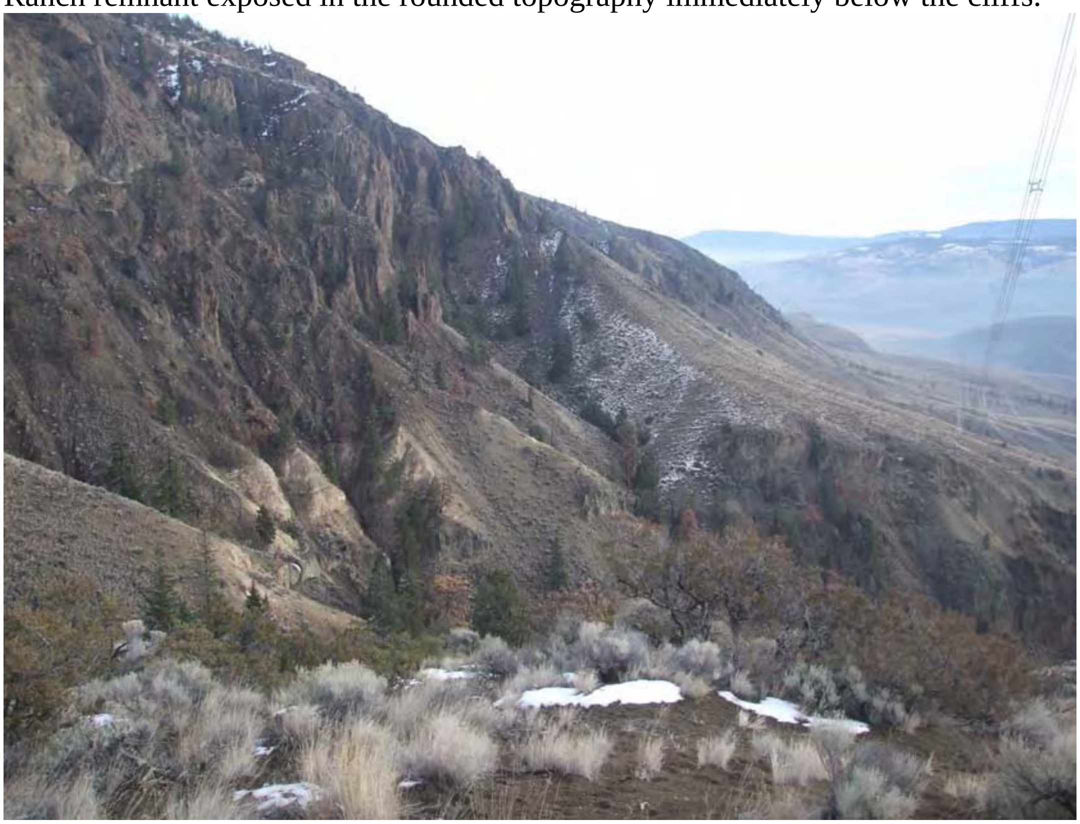

Figure 26: From the southeast end of the power pylon road, a view southeast-wards along the Perry Ranch remnant to cliffs of white-weathering shale (**ETptf**).

Figure 27: Volcanic breccia of unit **EDvbx** intercalated with (lower third of trekking pole) and overlying white-weathering shale of the Perry Ranch beds.

Figure 28: Cliffs of volcanic breccia of unit **EDvbx** host three large fragments (up to 50 m long) of white-weathering shale of the Perry Ranch beds up to 80 m above the top of the Perry Ranch beds.

(b) Dewdrop Flats Formation

This formation encompasses the voluminous volcanic rocks, which overlie a local intra-Eocene unconformity above the volcano-sedimentary rocks of the Tranquille Formation. This investigation includes an examination of only the lowermost hundred metre thickness or less of this formation. The most widespread unit overlying the Tranquille Formation is a basalt volcanic breccia (**EDvbx**) which overlies the Perry Ranch beds, the western half of the Zugg beds and eastern half of the Battle Creek beds. Basalt flows (**EDvb**) cap the eastern half of the Zugg beds, western half of the Battle Creek beds and a few spots elsewhere along the unconformity.

The best exposures of the local unconformity at the base of the Dewdrop Flats Formation are in the Zugg and Perry Ranch remnants where basalt breccia overlies or interfingers with the lacustrine shale of unit **ETptf** (Figure 27). The unconformity not only lacks an underlying weathered zone but on Zugg 1 claim the lacustrine shale wells up around the bottoms of the overlying basalt breccia clasts indicating that the shale was unlithified. In one locality on the west edge of Zugg 1 claim, the lacustrine shale was sufficiently lithified to permit the erosion of channels prior to deposition of the breccia (Figure 16).

1. Basalt Breccia (EDvbx)

On the Zugg 1 claim, the castellated cliffs above the Zugg beds provide excellent exposures of tan weathering basalt volcanic breccia (Figure 12). To the west, it overlies the Perry Ranch beds (Figure 21). Although not mapped, the unit probably exceeds 50 m in thickness above the Zugg beds and more than 200 m above the Perry Ranch beds, but it thins rapidly to the east of the Zugg 1 claim where it underlies a basalt flow unit (**EDvb**).

The angular clasts lie in a lapilli ash matrix of the same composition (Figures 12 and 27). The underlying Zugg beds are not weathered beneath the volcanic breccia unit. In addition, the base of the breccia unit is conformable with the bedding of the shale beds moulding around the bottoms of the overlying volcanic clasts. These features imply that the underlying sediments were soft and unlithified at the time of deposition of the breccia. In one location, channelling of the top of the Zugg beds preceded deposition of the volcanic breccia (Figure 12).

Two thin sections show that the basalt breccia consist of phenocrysts of augite, ±plagioclase (An_{47} to An_{55}) and olivine pseudomorphs in a matrix of subophitic plagioclase microlaths (An_{54} to An_{60}) with augite ±hypersthene.

2. Basalt Flows and Local Breccias (EDvb)

Above the Kitty Litter Quarry, brown cliffs surrounded by brown weathering talus aprons represent basalt flows and local breccias, which overlie the eastern half of the Zugg beds (Figure 29). Although the top of the unit lies outside the mapped area, the basalt must exceed 100 m in thickness. The basalt flows range from aphanitic to slightly porphyritic (plagioclase <15%, 2 mm; augite 5%, 1 mm). The unit disconformably overlies the Zugg beds.

Three thin sections show that the sparsely porphyritic basalt flows consist of phenocrysts of augite, ±plagioclase (An_{52} to An_{59}) ±hypersthene and ±olivine pseudomorphs in a matrix of subophitic plagioclase microlaths (An_{56} to An_{61}) with augite.

Figure 29: Above the Kitty Litter Quarry, brown-weathering cliffs and talus of unit **EDvb** composed of flows ±breccias, which overlie the Zugg beds (**ETptf**).

6. SUMMARY

The geologic history is similar for all the fossiliferous Eocene beds and surrounding rocks near McAbee as summarized in Table 2. Their common history involves the deposition of the Nicola Group in an island arc setting in Middle to Late Triassic time followed by its intrusion by the partly comagmatic Guichon Batholith in Late Triassic to Early Jurassic. Significant folding, uplift and erosion brought the Nicola Group and parts of the Guichon Batholith to the surface. With the subsequent subsidence, marine sedimentation ensued, which initially consisted of a basal conglomerate composed of detritus derived from the Nicola Group and Guichon Batholith. Marine deposition continued with argillite, siltstone and sandstone through the Early to Middle Jurassic. Late Jurassic saw the docking and eastward directed overthrusting of the exotic Cache Creek Complex terrane onto North America and, near the village of Cache Creek, onto the Nicola Group and Ashcroft Formation. Locally an extended period uplift and erosion followed with the first nearby terrestrial sedimentation preserved as an unnamed unit of Cenomanian age (Late Cretaceous) in Deadman River. Further uplift and erosion developed a rugged paleotopography on the basement rocks for the ensuing volcano-sedimentary rocks of the late early to mid-Eocene Kamloops Group.

In the McAbee area, at least three paleo-valleys developed as sites of fluvial and lacustrine deposition. Three remnants remain of the paleo-valley fillings represented by the volcano-sedimentary rocks of the Tranquille Formation. Although the sedimentary and volcanic components differ in detail within each of the Zugg, Battle Creek and Perry Ranch remnants, a description follows for the Zugg; the most complex of them.

After an initial eruptive phase of volcanism, erosion of the paleo-valleys continued cutting down into the basement to the Eocene rocks. In the Zugg remnant, little remains of the *in situ* initial Eocene volcanism except for a small patch of rhyodacite flows (**ETrd**). An unconformity separates this patch from the basalt lahars (**ETbcg**) with some exotic boulders of rocks derived from the Nicola Group and Guichon Batholith. A short distance northwest of Battle Creek, a sequence of basalt flows (**ETvb1**) butts against the east paleo-valley wall and thins to the west. The devitrified glassy lower margin of the unit indicates deposition in an aqueous environment. Deposition of the volcanic boulder conglomerate and lahars continued punctuated by eruption of a thin basalt flow(s) (**ETvb2**) preserved at one location. Near the east paleo-valley wall two local lenses of sandstone to shale (**ETsl**) lie within the boulder conglomerate succession. Volcanism became more widespread initiated by the eruption in the west of porphyritic hornblende-augite basalt (**ETvbm**) flows followed by more volcanic boulder conglomerate. The deposition of rhyolite tephra (**ETra**) followed immediately by a basalt flow and breccia unit (**ETvb3**) butting against the east paleo-valley wall and thinning to the west ended the deposition of volcanic boulder conglomerate. The clast size abruptly diminished accompanied by a change of composition to include rhyolite clasts and matrix in the volcanic pebble conglomerate (**ETpcg**). This unit ended the cycle of coarse clastic deposition and volcanism which totalled a maximum thickness that exceeded 280 m.

Either landslide debris or volcanism dammed the paleo-valley system and established a period of lacustrine deposition composed of thin-bedded shale with diatomaceous laminae and thin ash and crystal-lithic tuff lenses (**ETptf**). These strata deposited in near-shore and shallow to moderate water depths are richly fossiliferous. Typically less than 25 m thick, they locally attain a maximum thickness exceeding 100 m. The coarse clastic sediments, intercalated volcanic rocks and fine lacustrine sediments compose the Tranquille Formation of the Kamloops Group.

A massive episode of initially basaltic eruptions ended the lacustrine sedimentation and buried the paleo-topography under more than a thousand metres of flows and tephra, which continued into the middle Eocene. These volcanic rocks form the Dewdrop Flats Formation of the Kamloops Group.

Following the cessation of volcanism, uplift and erosion developed a Miocene paleo-topography with north to northwesterly draining valleys. Large explosions of rhyolite tephra and ash interrupted fluvial deposition and dammed valleys for differing periods of time creating lacustrine deposition of rhyolite ash and diatomaceous earth. The late Miocene fluvial and lacustrine deposits comprise the Deadman River Formation of the Chilcotin Group. As with the Eocene, volcanism, this time in the form of plateau basalts of the Chasm Formation buried the Miocene paleo-topography.

TABLE 2: Triassic to Recent Time-Event Table for McAbee

Geologic Time	Age in Ma	Rock Unit			Event
Pleistocene to Recent			Qs		Erosion, glaciation and development of present topography
mid-Miocene	~12-13	Chilcotin Group	Chasm Formation		Eruption of Miocene plateau basalt
					Local lacustrine sedimentation (diatomite)
			Deadman River Formation		Damming of paleo-valley system forming paleo-lakes
					Rhyolite volcanism produce tephra blanketing paleo-topography Mio-paleo-valleys
					Development of basal Miocene unconformity with Mio-paleo-valleys
early mid-Eocene	~45-50		Dewdrop Flats Formation		Main Eocene volcanism (units **EDvb**, **EDvbx** etc.)
					Development of intra-Eocene disconformity
late early Eocene	~50-55		Tranquille Formation		Lacustrine sedimentation (unit **ETptl**) **FOSSILS**
					Damming of paleo-valley system
			Zugg Remnant	ETpcg	Deposition of pebble conglomerate **ETpcg**
				ETvb3	Basalt flows **ETvb3**
				ETra	Deposition of rhyolite ash **ETra**
					Deposition of boulder conglomerate **ETbcg**
				ETvbm	Hornblende-augite porphyry basalt flows **ETvbm**
				ETbcg	Deposition: lahar & boulder conglomerate **ETbcg**
				ETvb2	Basalt flows: **ETvb2**
				ETbcg	Deposition: lahar & boulder conglomerate **ETbcg**
				ETvb1	Basalt flows **ETvb1**
				ETbcg	Deposition: lahar & boulder conglomerate **ETbcg**
					Development of intra-Eocene unconformity with Eo-paleo-valleys
					Uplift and erosion
					Initial Eocene volcanism (unit **ETrd**)
					Development of basal Eocene unconformity with paleo-valleys
					Uplift, erosion and gentle folding
Cenomanian	~94-100		Unnamed unit		Terrestrial sedimentation: fluvial and swamp
					Uplift and erosion
Middle Jurassic				CC NA	Docking of Cache Creek Complex (CC) on North America (NA)
Early to Middle Jurassic	~170-190		Ashcroft Formation	lmJA	Deposition of marine shale, siltstone; minor sandstone and conglomerate
					Subsidence
					Deformation, uplift and erosion
Late Triassic to Early Jurassic	194-206		Guichon Batholith	TrJgd	Intrusion of the compositionally complex batholith and associated Cu mineralization
Middle to Late Triassic	~200-230		Nicola Group	uTrNv	Widespread andesite volcanism

PALEONTOLOGY

1. INTRODUCTION

This chapter reports on the paleontological values of selected fossil sites in the McAbee areas observed in the field and in specimens collected as vouchers. It compares sites to each other in order to answer the question of whether or not there is an alternative site to the Zugg 1 claim for the protection of scientific, educational and heritage values. The issue of how much area or where within the Zugg 1 claim has to be protected, if that is the only option, is addressed only in general. Site observations are tabulated (Tables 3 to 8) and compared on a relative scale to each other and to those of the Zugg 1 claim (Table 9). Outside the mapped area, the Split Rock locality at Criss Creek east of Deadman River was visited.

The main areas of investigation include the exposures immediately adjacent to the Zugg 1 claim and to the northeast, the Kitty Litter Quarry, the Perry Ranch beds located in the cliffs north of the Perry Ranch in Semlin Valley, and the Battle Creek beds on the west side of Battle Creek. In these areas, exploration involved a single exposure as well as nearby locations. All are indicated by an F-number in the tables.

At each fossil locality, the records consist of a list of fossil types, a brief description of the site including its extent and its general geological form. Small representative collections from each site are at the Royal British Columbia Museum.

2. ZUGG 1 CLAIM AND ADJACENT SITES

On Zugg 1 claim, road access to the fossiliferous road cut at fossil locality **F22,** is excellent either on foot or with a four-wheel-drive vehicle (Figure 30). Fossils come from unweathered beds in a 380 m long road cut, from piles of debris along it or from talus below it. The slopes around the site are gentle to moderate, but the road cut and overlying cliffs of volcanic rocks are steep. D. Langvin and assistants warn visitors to the site of the potential hazards and keep them away from the most unsafe areas. Continuing excavation of the road cut increases the steepness of the slope and the potential hazards from the volcanic cliffs above.

Although high quality fossils are concentrated in layers and zones, these have not been mapped or located stratigraphically, but are generally known to the claim owners and their staff. A casual collection made from a debris pile at the side of the road cut included a flower and two types of cones. D. Langevin also donated several slabs of superbly preserved Cupressaceae (Cyprus Family) branches. All the common fossils listed in Table 3 are abundant with variable but usually excellent preservation. The character and quality of the fossils are well illustrated by collections at Thompson Rivers University, a well-photographed collection held by J. Leahy of Kamloops and in publications by Archibald (2005, 2007, 2009, in press), Archibald *et al*. (2005), Archibald *et al*. (2006) and Wilson (2008).

TABLE 3: Fossil Locality Data for Zugg 1 Claim

Fossil Locality	Fossils	Abundance and Quality	Site Conditions
ZUGG BEDS **Zugg 1 Claim**			
F19	*Metasequoia* ?Cupressaceae pine long needles	common, highly weathered, fissile	moderate slope with soil and talus
F21	*Metasequoia* ?Cupressaceae pine long needles	common, very highly weathered, fissile	moderate slope with soil and talus
F20	pine long needles	poor, nonfissile, highly silicified	moderate slope with soil and talus
F18	*Metasequoia* deciduous leaves mixed ?seeds pine long needles plant stems	common, fissile	moderate slope with soil and talus
F22	algae: 2 families spiders: 1 family crustaceans: 4 families insects: >87 families fish: 5 families birds: 1 family angiosperms: 27 families ferns: 7 families gymnosperms: 7 families	abundant, fissile, excellent	excellent, unweathered bedrock

Wilson (2008, p. 11-12) summarized the key attributes that make the Zugg 1 claim exposure important to science

- High quality compression fossils with external features preserved in detail and easy to see
- High likelihood of fossils being preserved in entirety and relative ease of exposing them
- Fossils preserved intact and spread out thus exposing key features
- Abundance of specimens
- High taxonomic diversity across the range of groups from insects to plants
- Lateral and vertical exposure enabling high resolution studies of change

The occurrence of fossils new to science can now be added to this list of key attributes as described by Archibald (2005, 2007, 2009, in press), Archibald *et al.* (2005) and Archibald *et al.* (2006). Furthermore, the exceptional quality and abundance of the material contributes to the consideration of major questions of evolution and biogeography (Archibald *et al.* (2006), Archibald (2007). According to Archibald (pers. comm., 2009), McAbee has the greatest diversity and clearest record of the radiation of ants, bees and wasps between the Late Cretaceous ambers and Late Eocene Baltic amber of any place in the world.

Figure 30: D. Langevin and J. Leahy at Zugg 1 claim exposures (**F22**) showing the access road and excellent exposure.

Figure 31: Fossil locality **F20** east of Zugg 1 claim showing thin surface cover.

Immediately east of the Zugg 1 claim boundaries, four localities **F18** to **F21** lie at the same elevation as and in the same stratigraphic position as the main Zugg 1 claim exposures. Access to these sites is good from the east end of the road cut on the Zugg 1 claim. The slopes are moderate and covered in shallow (10-50 cm thick) surface debris below which bedrock can be dug out with hand tools (Figure 31). Preservation in the weathered zone is poor to moderate and the diversity of fossils compared to the main exposures at locality **F22** is low. A bedrock exposure cleared off at the east end of the access road cut lies outside the Zugg 1 claim and, according to J. Leahy, contains high quality fossils.

3. KITTY LITTER QUARRY

A two-wheel-drive road provides access to a quarry consisting of several benches, each up to 5 m high, of which the lower two are in fossiliferous rocks that contain fish fossils of good quality and abundance (Table 4). Plant fossils, especially *Metasequoia* occur in moderate abundance in the quarry debris as do fossilized fish (*Eohiodon*). The occurrence and potential for recovery of large slabs displaying multiple fossils is notable (Figure 32). An assemblage of what appears to be an insect debris field occurred in a slab recovered from roadside debris. Preservation varies from poor to excellent depending upon the layer. The best material comes from slabs and debris in the quarry at or about the level of the lower bench (Figure 33). Visible in the face adjacent to the lower bench are petrified tree trunks (Figure 34).

TABLE 4: Fossil Locality Data for the Kitty Litter Quarry

Fossil Locality	Fossils	Abundance and Quality	Site Conditions
ZUGG BEDS Kitty Litter Quarry			
F8	*Metasequoia* pine long needled *Gingko* deciduous leaves mixed ?monocot leaf ?elm fruit fish entire and fragments insect carbonized stems petrified wood	uncommon; poor to excellent preservation	exposed bedrock and spoil piles
F5	*Metasequoia* *Sequoia* pine long needled deciduous leaves fish	uncommon; moderate preservation	exposed quarry walls

Figure 32: Shale slab from a debris pile on the lower bench of Kitty Litter quarry showing multiple fossil plant occurrences.

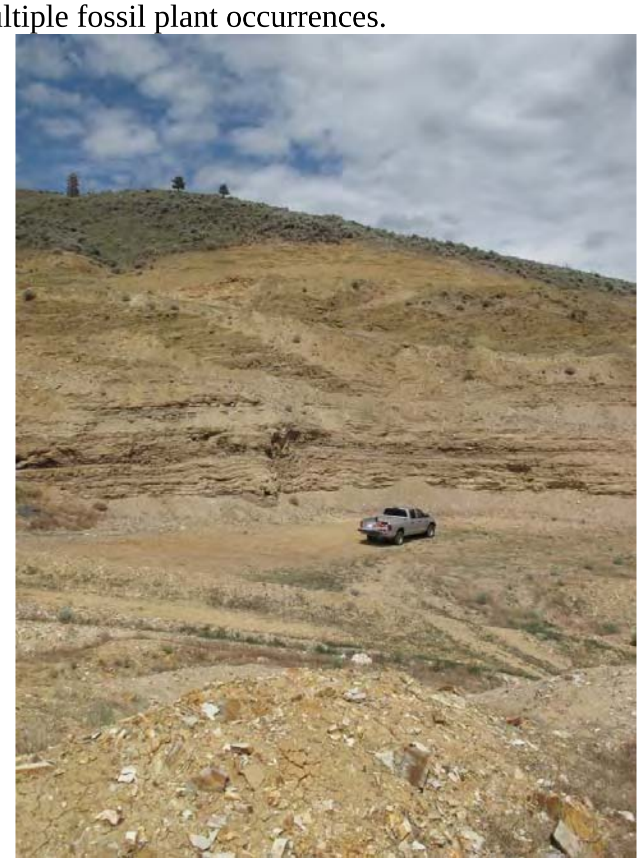

Figure 33: Lower bench at the Kitty Litter quarry showing fossil-bearing slab debris pile in foreground. Petrified wood occurs in the cut face opposite the truck.

Figure 34: Petrified wood exposed in a cut face of the lower bench in the Kitty Litter quarry

The Kitty Litter Quarry has the potential to yield abundant fossils of high quality in an assemblage which differs from that of the Zugg 1 claim. For example, the single occurrence of insect fossils differs from their abundance at the Zugg 1 claim. Considering the easy access to abundant rock pieces in the quarry, the diversity of fossils seems less than that of the Zugg 1 claim. In this context, the quarry beds are not a replacement for the exposures on the Zugg 1 claim. Indeed the quarry beds have the potential to provide different fossil assemblages from a different paleogeographic setting. A detailed lithostratigraphic study is required to precisely relate the beds at Zugg 1 claim to those in the Kitty Litter Quarry and determine where the fossil-rich beds of high scientific value occur.

At the quarry site, the extraction of large volumes of insignificantly zeolitized bentonitic ash of negligible economic value, also removed important fossil-bearing strata.

4. EAST OF KITTY LITTER QUARRY

In the Zugg beds, two fossil localities lie east of the Kitty Litter quarry. Fossil locality **F3** lies 200 m east of and 5 m higher than the quarry on the east bank of an ephemeral stream (Table 5). Unlike the quarry, which is near the base of the Zugg beds, this locality lies near the top of the succession. A farther 150 m to the east and 15 m higher is a small pit (**F7**) at the top of the Zugg beds where branchlets of *Metasequoia* and reputedly fossil fish have been removed. Preservation at both localities ranges from poor to very good.

TABLE 5: Fossil Locality Data for Sites East of Kitty Litter Quarry

Fossil Locality	Fossils	Abundance and Quality	Site Conditions
ZUGG BEDS East of Kitty Litter Quarry			
F7	*Gingko* dissecta type leaf	common; good preservation	8-10 m wide pit; on moderate slope
F3	*Metasequoia* plant debris	rare; poor preservation	on southwest facing slope on northeast side of creek

5. WEST SIDE OF BATTLE CREEK

From the end of the powerline road a short walk brings one to a south-facing gully (Figure 35). Here well preserved fossils lie under a deep talus cover (Table 6). Several other fossil localities, not visited, lie in the Zugg beds on the west side of Battle Creek valley from one to two kilometres farther upstream from the east end of the powerline road.

Figure 35: Typical exposure of fossil-bearing beds at **F2** on the west side of Battle Creek.

TABLE 6: Fossil Locality Data for the Zugg Beds, West Side of Battle Creek

Fossil Locality	Fossils	Abundance and Quality	Site Conditions
BATTLE CREEK BEDS			
F2	*Metasequoia* ?Cupressaceae	uncommon; very good preservation; poor fissility	small exposure in gully covered by talus; gentle slope

6. PERRY RANCH

The Perry Ranch beds outcrop as a 1.8 kilometre-long lens on the north wall of Semlin Valley 8.5 km east of the village of Cache Creek. The beds are on Crown land, but access requires crossing through the Perry Ranch or along a power pylon road with locked gates at 10.6 km east of the village of Cache Creek on the Trans Canada Highway or one kilometre north along Back Valley Road. The latter route gives access to the northwest end of the beds. Either route usually requires a four-wheel-drive vehicle. Except for the road to the northwest end of the beds, a walk of several hundred metres takes one to the steep slopes and gullies exposing the fossiliferous beds. The exposures and talus aprons are easily visible but the slopes range from moderate to unclimbable and are somewhat stable to unstable (Table 7).

Several tens of centimetres to more than a metre of debris mantle most exposures. Steep gully walls expose the sedimentary bedrock, but access is difficult (Figure 36). Some fossils, mostly *Metasequoia*, occur at every exposure, but in general the preservation is poor because the overlying volcanic rocks have heated and deformed the sequence especially near the contact. Some beds have been silicified or infiltrated with yellow sulphate deposits. The relative abundance of *Eohiodon* remains at sites **F10**, **F11**, **F15** and **F16** is notable and here and there an entire fish is preserved.

Fossil locality **F11** has very well preserved fossils in the near surface of the quality of Zugg 1 claim (**F22**) and seems to have a high diversity including insects and deciduous leaves (Figure 37). Considering that the fossils came from the weathered zone, preservation in the subsurface could be excellent. This locality has a small exploratory pit as did fossil locality **F4** in the middle of the Perry Ranch beds.

Extending to the mouth of a prominent gully, a rough four-wheel track provides access to the central portion of the Perry Ranch beds. At localities **F4** and **F6**), the steep-faced fossiliferous beds are well exposed in the back walls of the gully and tributary gullies (Figure 38). In several places at the base of exposures are relatively large pieces of shale. Fossils are scattered throughout, but are not especially abundant, except for an excavated bench perched on a steep slope above a vertical face on the west side of an inter-gully ridge (**F4**). Slabs with well-preserved entire fish fossils occur here along with abundant leaves.

TABLE 7: Fossil Locality Data for the Perry Ranch Beds

Fossil Locality	Fossils	Abundance and Quality	Site Conditions
PERRY RANCH BEDS			
F17	*Metasequoia* *?Sequoia* ?Cupressaceae deciduous leaves mixed fish fragments	common, very fissile, highly weathered, poor	steep to subvertical faces mantled by talus
F16	*Metasequoia* ? *Abies* pine long needles deciduous: elm, beech carbonized stems fish (*Eohiodon*) entire, large fish	uncommon, fish excellent preservation; plants poor	moderate to steep slope on ridge; talus covered
F15	*Metasequoia* ?Cupressaceae deciduous leaves mixed	uncommon, moderate to poor preservation; highly silicified	moderate to steep slope on ridge; talus covered
F13	*Metasequoia* *Sequoia* pine long needles beech ?Rosaceae carbonized stems fish tail	uncommon; moderate to good preservation;	steep slope covered with talus
F12	*Metasequoia* fish insect	uncommon moderate to good preservation	steep slopes covered with talus; only gully has bedrock exposed
F11	*Metasequoia* ?Cupressaceae *Ginkgo* flower, ?fruit deciduous: at least 6 genera including beech carbonized stems fish, fish with scales insect	abundant, excel-lent preservation	moderate to steep slopes on ridge
F14	deciduous leaves, *Eohiodon* type larger fish	abundance uncer-tain; preservation excellent	moderate to steep slopes, subvertical slope above and steep below
F6	*Metasequoia* pine needles deciduous leaves ,?rose family *Gingko biloba* leaf fish	abundant, but preservation moderate to poor	steep unstable slopes and outcrop

TABLE 7 (continued): Fossil Locality Data for the Perry Ranch Beds

Fossil Locality	Fossils	Abundance and Quality	Site Conditions
F4	beech elm pine needles petrified wood fish, entire on slabs	abundant; good preservation on large slabs	bench cut into steep slope above a 20-30 m high cliff
F9	petrified wood, large log with rot	good preservation, agatized and carbonized	undercut basalt cliff, at top of talus and debris
F10	*Metasequoia* deciduous pine needles fish, entire on slabs carbonized twigs	common, moder-ate preservation	moderate slope at end of 4-wheel drive road

Figure 36: Fossil locality **F17** at the east end of the Perry Ranch exposures showing vertically exposed bedrock in gully and difficult access.

Figure 37: Exploratory pits at fossil locality **F11** in the Perry Ranch beds.

Figure 38: Perry Ranch beds at back of gully at **F6** showing very steep slopes. J. Leahy (arrow) at locality **F4** where well-preserved fish fossils occur.

In the west wall of the gully near its opening, fossil locality **F9** marks the occurrence of petrified wood in the underlying volcanic breccia. Pieces of wood several metres long and many tens of centimetres in diameter lie in place. They are flat lying, one with roots still attached and point southwards. Their presence suggests burial in a cataclysmic volcanic event or associated debris flow.

The northwestern end of the Perry Ranch beds is accessed by the B.C. Hydro power pylon road, suitable for four-wheel drive vehicles only, through a locked gate on Back Valley Road one kilometre north of its junction with the Trans Canada Highway. The road ends at a power pylon which overlooks the gully of fossil localities **F4**, **F6** and **F9**, but descent to these localities from here is extremely dangerous. At locality **F10**, beds to the south and west of the pylon contain some relatively well preserved fossils including deciduous leaves and small fish. Most of the fossils are under more than 50 cm of weathered surface material, but locally the bedrock is immediately beneath the surface and easy to expose with hand tools (Figure 39).

In general, the Perry Ranch beds are difficult to very difficult, even unsafe, to access and with the exception of locality **F6** and possibly the very hazardous locality **F4** host fossils of a poorer quality, lower abundance and lower diversity than those found at the Zugg 1 claim.

Figure 39: Fossil locality **F10** at the northwest end of Perry Ranch beds showing shallow surface cover and typical size of fossil-bearing fragments.

7. CRISS CREEK

The Criss Creek Locality lies west of Deadman River, well outside the McAbee area and is two kilometre from the Criss Creek forestry access road (Table 8). At the locality, the well-preserved fossils are in brown shale similar to that at the Zugg 1 claim according to R. Ludvigsen. The fossils occur at the base of castellated cliffs of volcanic rocks where numerous pits dug through the talus expose the underlying fossiliferous shale. *Metasequoia* and deciduous leaves are abundant and a fossil crayfish is reputed to come from here according to D. Langevin.

TABLE 8: Fossil Locality Data for Criss Creek

Fossil Locality	Fossils	Abundance and Quality	Site Conditions
CRISS CREEK (Split Rock)			
F1	*Metasequoia* deciduous leaves	common; moderate preservation	numerous fossil pits dug through talus veneer to bedrock

8. OVERALL RANKING OF SITES

A relative ranking scale was developed to compare the fossil localities investigated in this study. A scale of 1-5 was used, with 5 being the best and 1 being the poorest. The following site attributes were evaluated: access, content (diversity, exceptional specimens), abundance and quality. The ranking is based on evaluation of the locality data (Table 9) and the professional expertise of the author and R. Ludvigsen.

In consideration of Wilson's (2008) report and recent papers by Archibald and others (Archibald, 2005, 2007, 2009, in press; Archibald *et al*., 2006), the Zugg 1 claim locality is ranked at 5 for all attributes. The occurrence of well-preserved insect remain was considered a key attribute for assigning a high ranking for fossil content (=diversity).

The site ranking table (Table 9) demonstrates that no other locality visited in the mapped area has a ranking as high as the main exposure on the Zugg 1 claim. On all counts, the exposures on the Zugg 1 claim are as good as or mostly better than any of the other sites. First of all, no other locality has the demonstrated diversity of fossils that the Zugg 1 claim locality has, particularly for insects. Secondly, the access to most other sites, especially those to the north of the Perry Ranch is poor and in some sites unsafe. The Kitty Litter quarry (**F5** and **F8**) and sites to the east have reasonable access, but with the exception of the quarry, the quality, abundance and diversity of fossils is not nearly that of the Zugg 1 claim (**F22**).

Two sites, the Kitty Litter quarry (**F5** and **F8**) in the Zugg beds and **F11** in the Perry Ranch beds are noteworthy because the quality of preservation and potential fossil diversity, but they should not be viewed as replacement sites for the Zugg 1 claim exposures. Instead, they merit consideration as complementary sites for fossil management in and of their own right.

TABLE 9: Ranking of Fossil Localities in the McAbee Area

Fossil Locality	Access	Fossil Content	Abundance	Quality	Overall
Zugg 1 F22	**5**	**5**	**5**	**5**	**20**
Kitty Litter F5, F8	4	4	4	4.5	16.5
F11	2.5	4	4	5	15.5
F7	4	3.5	3.5	3.5	14.5
F18, F20	5	3	2	3	13
F14	1.5	3	3	5	12.5
F4, F6	1	3.5	4	3.5	12
F10	2	3.5	3	3	11.5
F2	4	2	2	3.5	11.5
F19, F21	5	2	2	2.5	11.5
F15, F16	1	3.5	3	3.5	11
F12	1	3	3	4	11
F13	1	3	2	4	10
F9	3	2	2	2.5	9.5
F17	1	2	2	2	7
F3	4	1	1	1	7

On the basis of visits to nearly all known fossil localities in the McAbee area and evaluation of their access, fossil diversity, quality and abundance, there is no alternate equivalent site for the Zugg 1 claim locality (**F22**) for the purposes of scientific values and study. In particular, none of the other sites preserves insect fossils in the quality and quantity of the Zugg 1 claim. Immediately to the east of the Zugg 1 claim boundary, beds at the same stratigraphic level may have potential as a scientific study site.

KNOWN AND POTENTIAL EOCENE FOSSIL LOCALITIES

1. INTRODUCTION

The combination of a number of the following parameters may pinpoint fossil localities with significant scientific and heritage attributes. These attributes are:

- Abundance of fossils
- Excellence of preservation
- Taxonomic character and diversity of fossils
- Fissility of fossiliferous rock

Attributes which are specific to the McAbee area include:

- Paleo-topographic setting of fossil locality
- Lack of weathering of fossiliferous rock
- Accessibility

In the McAbee area, use of these parameters, on known or potentially fossiliferous localities emphasizes those aspects of known fossil localities that require attention and indicates other potentially fossiliferous sites suitable for study.

2. ZUGG REMNANT

All of the known and potential fossil localities within the Zugg remnant lie within easy reach of the Trans Canada Highway on a network of side roads. However, until the paleontological investigation of this report, none had been compared to the Zugg 1 claim.

(a) Zugg 1 Claim (F22)

The fossiliferous beds on the Zugg 1 claim extend for 380 m along the subhorizontal portion of a bulldozed access road (Cover). The roadcuts extend down into unweathered rocks and intersect beds containing abundant fossils of high diversity, high taxonomic/paleontological significance and excellent state of preservation, which lie along the bedding of the fissile rock. All of the fossil insects described by Archibald (2005, 2007) and Archibald *et al.* (2005a, 2005b, 2006a and 2006b) come from this locality (Archibald, pers. comm., 2009), which is the best Eocene fossil insect site in North America. Because most of the fossil collections come from strata 10 to 20 m below the top of the Zugg beds and lie less than 400 m from the lakeshore (Map 1), the fossils should represent a shallow-water near-shore assemblage.

(b) Kitty Litter Quarry (F5, F8)

At the Kitty Litter Quarry, the fossiliferous beds are best exposed on the bench front of the lowest bench (Figure 13). These strata lie up to 4 m above the exposed base of the Zugg beds, which are approximately 80 m thick in this area. The fossil localities lie less than 300 m from the lakeshore yielding a moderate water depth, near-shore depositional setting for fossils collected from the lowest bench in the Kitty Litter Quarry. As a result of studies by Wilson (1980, 1988) of Eocene lacustrine fossil assemblages in Washington and British Columbia, the fossil assemblage collected from the Kitty Litter Quarry should reflect the different paleo-environment and differ from that of the Zugg 1 claim. Wilson's observation (2008, p. 16) that the quarry is the site of many fish fossils, including most of the larger specimens of *Eosalmo*, the fossil trout, indicates the different paleogeographic setting of the Kitty Litter Quarry in comparison to all the other fossil localities.

(c) East of Zugg 1 Claim (F18, F19, F20 and F21)

The subhorizontal portion of the access road on the Zugg 1 claim was accidentally extended to a point about 50 m east of the eastern claim boundary. This portion exposes the Zugg beds beneath the weathered zone, though farther to the east the beds underlie a shallow cover of weathered talus. The fossil assemblages from here should represent a shallow-water near-shore environment similar to that of the Zugg 1 claim.

(d) West of Zugg 1 Claim (Fe)

West of the Zugg 1 claim, the Zugg beds continue westward for 120 m where they crop out on a steep, gullied slope at the base of a cliff of basalt breccia. Beyond this, the Zugg beds are lenticular, up to a few tens of metres long and less than a metre thick. The fossil assemblage from here should represent a paleo-environment that is shallower and closer to shore than that of the Zugg 1 claim.

(e) Creek Northeast of Kitty Litter Quarry (F3)

The east bank of the first creek northeast of the Kitty Litter Quarry exposes a slumped outcrop of white-weathering shale, which is only a few hundred metres east of the Kitty Litter Quarry. This thin-bedded shale lies within approximately 10 m stratigraphically of the unexposed top of the Zugg beds against the overlying basalt flows. The weathered talus contains plant fossils on the fissile bedding planes. The lack of evidence of previous fossil collecting at this site suggests that it has been overlooked. As map 3 shows, this locality is within 10 m of the top of the lacustrine deposits and should represent a near shore shallow-water environment in contrast to the near-shore but moderate water depth of the Kitty Litter Quarry.

(f) East of Kitty Litter Quarry (F7)

A machine-trenched outcrop lying 350 m east of the Kitty Litter Quarry exposes white-weathering shale within five metres stratigraphically of the top of the Zugg beds (Figure 30). From the number of rebar pegs driven into the ground and presence of sheets of plywood used to construct a shelter, this was a site of serious fossil collecting. Like the creek locality (**F3**), this locality exposes the shallow-water strata at the top of the Zugg beds in a similar near-shore environment.


Figure 40: A view to the northwest from the flagged middle rebar pin of a set of three to the fossil excavation at locality **F7**.

3. PERRY RANCH REMNANT

The Perry Ranch remnant lies 1.8 km north of the Trans Canada Highway. Its southeast half lies 250 to 700 m walking distance from the end of a power pylon road. The northwest half lies within walking distance from the end of a 6.5 km long power pylon road suitable for 4-wheel drive vehicles. The area lacks large pits and trenches and is not a site of extensive fossil collecting. As a result, the most complete exposures of the Perry Ranch beds are in the gullies of this steep area. The following three potentially fossiliferous sites represent shallow-water near shore environments. Both Wilson (2008, p. 6) and Archibald (pers. comm., 2009) have made small collections from geographically unspecified locations in the Perry Ranch remnant.

(a) East and Middle Gullies and Ridges (F4, F6, F9 and F11 to F17)

The East Gully locality (**F17**) is a 300 m walk and the Middle Gully locality (**F12**), a 400 m walk north-northwest of the end of the power pylon road. Here the gullies expose a nearly complete section of fossiliferous Perry Ranch beds. Because of erosion by the ephemeral creeks, the rocks are not deeply weathered, but the slopes are steep.. These localities represent a near-shore, shallow water paleo-environment.

(b) Power Pylon Road End (F10 and Fb)

Locality **Fb** is 150 m southeast of the end of the upper power pylon road on a steep slope within a few metres of the base of the Perry Ranch beds. Upon a quick examination, the beds contain sparse plant fossils in a somewhat fissile siltstone. This area has not been examined for its fossil content.

4. BATTLE CREEK REMNANT

On the east side of Battle Creek, this remnant contains fossiliferous strata at two or more different stratigraphic levels. The lower fossiliferous stratigraphic level is in the shale, siltstone and sandstone of unit **ETsl**, which lies in the middle of the volcanic boulder conglomerate unit (**ETbcg**). It is about 80 m below the upper fossiliferous stratigraphic level, which consists of the lacustrine shale of the Battle Creek beds (**ETptf**).

(a) Forestry Access Road (Fd)

This locality is at the base of low cliffs of basalt flows and breccia of unit **ETvb3** some 220 m northwest of the junction of the Trans Canada Highway and the Forestry Access road up Battle Creek. The sandstone, siltstone and shale split easily along bedding planes to reveal plant debris in the sandstone and fossil leaves in the siltstone and shale. Unlike the lacustrine setting of all the previously described localities, this locality represents a fluvial to overbank setting that is a maximum distance of 250 m from the paleo-valley wall.

(b) Quarry Access Road (Ff)

On the McAbee Quarry Access road 350 m from its junction with the Trans Canada Highway, is a sloughed roadcut of siltstone and sandstone. This locality is another 80 m stratigraphically lower than locality **Fd** and formed in a fluvial overbank setting that is less than 50 m from the paleo-valley wall. Although upon quick examination it is apparently unfossiliferous, local people report collecting fossils from this roadcut.

(c) Powerline Road (Fa)

This locality is on a powerline road about 500 m west of its junction with the Forestry Access Road up Battle Creek (Figure 41). A roadcut exposes white-weathering tuffaceous shale of the Battle Creek beds, which is sparsely fossiliferous. Although the rocks are moderately fissile, the bedding is locally rippled and the easy splitting direction does not always follow bedding. The rippled bedding probably represents a very shallow-water and very near-shore environment that is less than 150 m from the paleo-valley wall.

Figure 41: A view northwestward from the powerline road to the fossil excavation at locality **Fa** on the north side of the powerline road.

(d) Below Powerline Road (Fc)

This locality is in the same white-weathering shale horizon of the Battle Creek beds about 80 m from locality **Fa** down the dip of beds (Figure 32). The fossil digging is 20 m in elevation below locality **Fa** and the rocks have the same fissility and rippling of the bedding as at **Fa**. The rippled bedding probably represents a very shallow-water and very near-shore environment that is less than 150 m from the paleo-valley wall.

5. SOUTH SIDE OF THE THOMPSON RIVER

On the south side of the Thompson River, McMillan (1978) outlined areas underlain by his map unit 12b, which comprises sandstone, mudstone, conglomerate, minor diatomite and lava flows. This unit and a volcanic conglomerate, his unit 12c, are lithologically similar to the sedimentary portion of the Tranquille Formation mapped in the present area north of the Thompson River. Significantly, the presence of diatomite indicates a lacustrine setting for some of the sedimentation and, hence, the potential for fossil occurrences similar to the known fossil localities in the Tranquille Formation near McAbee on the north side of the Thompson River.

Figure 42: A view to the northwest from the top of a spoil heap to the fossil excavation at locality **Fc**.

(a) Southwest of Pennie Lake (Fh)

On an old logging road 1.75 km southwest of the centre of Pennie Lake and within unit 12b, sloughed roadcuts expose diatomite with at least one intercalated basalt flow. The diatomite is not known to be fossiliferous. The area is accessible from Ashcroft by a combination of a paved highway, a publically maintained gravel road and a final 1.5 km length of old logging road suitable for two-wheel drive vehicles in dry weather.

(b) West of Pennie Lake (Fg)

This area lies 1.3 km west-southwest of the centre of Pennie Lake where McMillan (1978) mapped a kilometre long, westerly oriented lens of sediments of unit 12b at about 950 m elevation. Given the regional gentle northeasterly dip of the Eocene rocks, this sedimentary lens could be a correlative of the lacustrine sediments on the north side of the Thompson River. Although a road lies within 100 m of the area, it is probably accessed only after a long drive on old roads from Savona. The rocks have not been geologically mapped or assessed for their fossil content.

(c) Jimmies Creek (Fi)

This very poorly exposed area lies at the head of Jimmies Creek at about 1200 m elevation where McMillan (1978) mapped a 2.5 km long westerly oriented lens of unit 12b. The rocks have not been geologically mapped or assessed for their fossil content.

INDUSTRIAL MINERALS

1. INTRODUCTION

Within the mapped area and surroundings, the main industrial minerals of concern are railbed ballast, bentonite, zeolites and diatomaceous earth. Near McAbee on the main line of the Canadian National Railway, the company presently operates a quarry in the plutonic rocks of the Guichon Batholith. The bentonite, zeolites and diatomaceous earth reported by Mustoe (2005) occur in the sedimentary rocks of the Zugg and Perry Ranch remnants and deserve a separate discussion.

TABLE 11: Exchangeable Cation Analyses and
Cation Exchange Capacity (CEC) of Zeolite Occurrences

Locality	Exchangeable Cation Analyses (mequiv/100g)					CEC
	Mg	Ca	K	Na	Total	mequiv/100g
Z1	2.25	23.25	14.50	22.00	62.00	67.0
Z1	0.65	15.50	7.00	24.50	47.65	50.0
Z2	9.40	47.20	19.70	38.60	114.90	111.8
Z2	3.75	17.75	8.75	32.00	62.25	41.5
Z3	2.75	20.50	12.75	38.25	74.25	87.6
Z4	4.40	9.60	5.60	8.10	27.70	22.3
Z4	4.80	12.50	7.50	12.30	37.10	28.1
Z4	2.29	10.00	4.58	3.75	20.62	22.3
Z4	6.75	21.75	18.75	18.50	65.75	58.9
Z4	1.28	3.25	1.70	2.00	8.23	13.9
Z4	7.00	14.25	7.25	18.00	46.50	46.1
Z4	5.25	29.75	13.75	36.25	85.00	63.8
Z4	1.75	31.25	12.50	19.58	65.08	56.7

In an area up to 15 kilometres east of the village of Cache Creek, Read (1988) reported the occurrence of waterlain tuff containing the mineral heulandite-clinoptilolite, a member of the zeolite group of minerals with a wide variety of industrial uses. Even though exchangeable cation analyses and cation exchange capacities of the tuffs yielded mostly sub-economic values, with the exception of a sample from locality Z2 with a value of >100 mequiv/100 g (Table 11), the occurrences were soon staked due to their proximity to the Trans Canada Highway. Subsequently, Industrial Mineral Processors made an unsuccessful attempt to produce kitty litter and other products from weakly zeolitized shale with thin bentonitic horizons in the lower part of the Zugg beds.

2. BENTONITE

Bentonite forms as an alteration product of thin, usually centimetre-scale ash-tuff layers and lenses sparsely scattered in such sub-economic quantities through the fossiliferous lacustrine shale of the Zugg and Perry Ranch beds, that it has no economic potential. In the Perry Ranch remnant, the apparently unfossiliferous sediments of unit **ETss**, underlying the Perry Ranch beds have not only a sub-economic bentonite content, but the gently northeasterly dipping beds are exposed on southerly dipping slopes with a gradient approaching that permitted in an open pit wall of such material. The implication is that the only economic method of mining bentonite, quarrying, would not be feasible.

By contrast, the bentonitic but unfossiliferous rhyolite ash-tuff of unit **ETra** may have an economic potential depending upon the physical properties required for its end use and the amount of material available for quarrying. As the probably flat-lying unit outcrops in only two artificial exposures, exploration work would be required to determine the volume and grade of material present. Because this unit is more than 400 m away from the fossiliferous Zugg beds and 70 m stratigraphically below them, its exploration and any subsequent exploitation will not pose a risk to any fossiliferous rocks (Maps 2 and 3).

3. ZEOLITES

The Zugg, Battle Creek and Perry Ranch beds contain thin layers up to 10 cm thick of white-weathering, waterlain rhyolite crystal-ash tuffs. As a generalization, the number of zeolite-bearing beds increases stratigraphically upwards. X-ray diffraction and exchangeable cation analyses (Table 11) show that the zeolite belongs to the heulandite(CaAl)-clinoptilolite(NaSi) solid solution series with compositions falling in the intermediate to NaSi-rich end of the spectrum.

In the Zugg beds, the most richly fossiliferous beds are relatively zeolite-poor with the most zeolite-rich rocks restricted to the stratigraphically highest ash-tuffs such as at locality **Z2** (Maps 2 and 3). Northwest and northeast of the Kitty Litter Quarry, the stratigraphically highest members of the Zugg beds are fossil-poor and carry the highest zeolite content as determined by a Cation Exchange Capacity of 111.8. These beds probably attain a thickness of less than 10 m, lie in steep terrain and are enclosed by unzeolitized volcanic flows and breccia rendering the zeolitized beds economically unattractive.

In the Perry Ranch beds at locality **Z4**, sampling of the beds at a stratigraphic interval of one metre indicated the widespread presence of heulandite-clinoptilolite, but the Cation Exchange Capacity measurements indicate that the material is of low zeolite content (Table 11). The low Cation Exchange Capacity values combined with the steep southerly exposures of the gently dipping zeolitized beds mean that negligible quantities of this sub-economic material are available for quarrying.

4. DIATOMACEOUS EARTH

Mustoe (2005) reported the presence of diatoms in the Zugg beds. However, these thin interbeds have suffered sufficient recrystallization since deposition that the fluid absorption has been adversely affected. The interbeds are so thin and sparse that the average large sample has a near normal density and very low fluid absorption values. In addition, the steep southerly facing slopes (Figure 12) of the area prohibit the development of a quarry in these gently dipping beds. All of these factors combine to indicate a markedly sub-economic potential for these rocks. In unit 12b of the Kamloops Group, McMillan (1978) reported diatomite at locality **Fh** on the south side of the Thompson River. Both the presence of fossils and proximity to diatomite on this relatively inaccessible side of the Thompson River are unknown.

CONCLUSIONS

This investigation of the geology and paleontology of the basal portion of the Kamloops Group of Eocene age near McAbee leads to the following conclusions:

1. Near McAbee, the basal portion of the Kamloops Group consists of a volcano-sedimentary succession correlated with the Tranquille Formation disconformably overlain by basalt flows and breccias correlated with the Dewdrop Flats Formation.
2. The basal Eocene unconformity has a rugged paleo-topography dominated by three paleo-valleys, Eo-Semlin, Eo-Battle and Eo-Thompson, which join near the southern edge of the map area.
3. The fluvial portion of the volcano-sedimentary paleo-valley fillings consists mainly of lahar and conglomerate with intercalated basalt flows, and minor lenses of rhyolite ash and shale to sandstone. These rocks exceed a maximum thickness of 280 m
4. A temporary damming of the paleo-drainage resulted in the deposition of lacustrine shale **ETptf** with thin intercalations of crystal-lithic and ash tuffs. These strata are the richly fossiliferous Zugg and Perry Ranch beds and the less fossiliferous Battle Creek beds. The Zugg beds attain a maximum thickness exceeding 100 m, the Parry Ranch beds do not exceed 30 m and the Battle Creek beds are less than 20 m thick.
5. The eruption of voluminous basalt breccia and flows of the Dewdrop Flats Formation abruptly buried the late early Eocene drainage and lake system under hundreds to over a thousand metres of volcanic rocks.
6. On the north side of the Thompson in the McAbee area, at least 27 fossil localities are known. Twenty-four of these localities are in the lacustrine shale unit **ETptf** near the top of the paleo-valley fill. Of these 24, at present only two have been extensively excavated below the weathered zone and are well known. The three remaining localities, not in the lacustrine shale, two, **Fd** and **Ff,** are in shale to sandstone of unit **ETsl** between 70 to 150 m stratigraphically beneath the lacustrine shale unit. Fossil locality **F9** is in a volcanic breccia of unit **ETvb**.
7. The paleogeographic settings of the 27 fossil localities on the north side of the Thompson River near McAbee are known. They range from very near-shore (<150 m) and very shallow-water (<15 m) (**Fa**, **Fc** and **Fe**) through near-shore (<400m) and shallow-water (<20 m) (**Fb**, **F9** to **F17**, **F4**, **F6**, **F18** to **F21, F3** and **F7**) to near-shore (<400 m) and moderate water depth (<75 m) (**F5** and **F8**). To date, the best insect fossil locality in the McAbee area is the Zugg 1 claim (**F22**). It is the site of excellently preserved specimens of nearly 300 newly documented species and at least one new family in phylum Arthropoda (Archibald, 2007).
8. On the south side of the Thompson River, McMillan's (1978) geological mapping outlined three areas of Eocene sedimentary rocks which are described as containing minor diatomite, a typical lacustrine sediment. The fossil content here is unknown.
9. The fossiliferous lacustrine beds of unit **ETptf** contain thin lenses of bentonitic sediments and zeolitized waterlain tuffs and thin laminae of diatomite. These

industrial minerals are both separately, and in combination, of markedly sub-economic grade as proved by the abandonment of the Kitty Litter quarry by its past owners. In addition, the flat-lying lacustrine shale of unit **ETptf** usually underlies steep slopes, which allow removal of only limited volumes of materials from open pit quarrying. The sub-economic grade and limited amount of material available for quarrying negate any present or future economic potential for the lacustrine shale of unit **ETptf**.

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APPENDIX A: Bibliography of Paleontology, McAbee Area

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Museum Collections: CDM Courtenay and District Museum, Courtenay, British Columbia, Canada; RTM Royal Tyrrell Museum, Drumheller, Alberta, Canada; BMNH Burke Museum of Natural History and Culture, Seattle, Washington; ROM Royal Ontario Museum, Toronto, Ontario, Canada; UA University of Alberta, Edmonton, Alberta, Canada; UCC University College of the Cariboo, Kamloops, British Columbia, Canada; UW University of Washington, Seattle, Washington, USA

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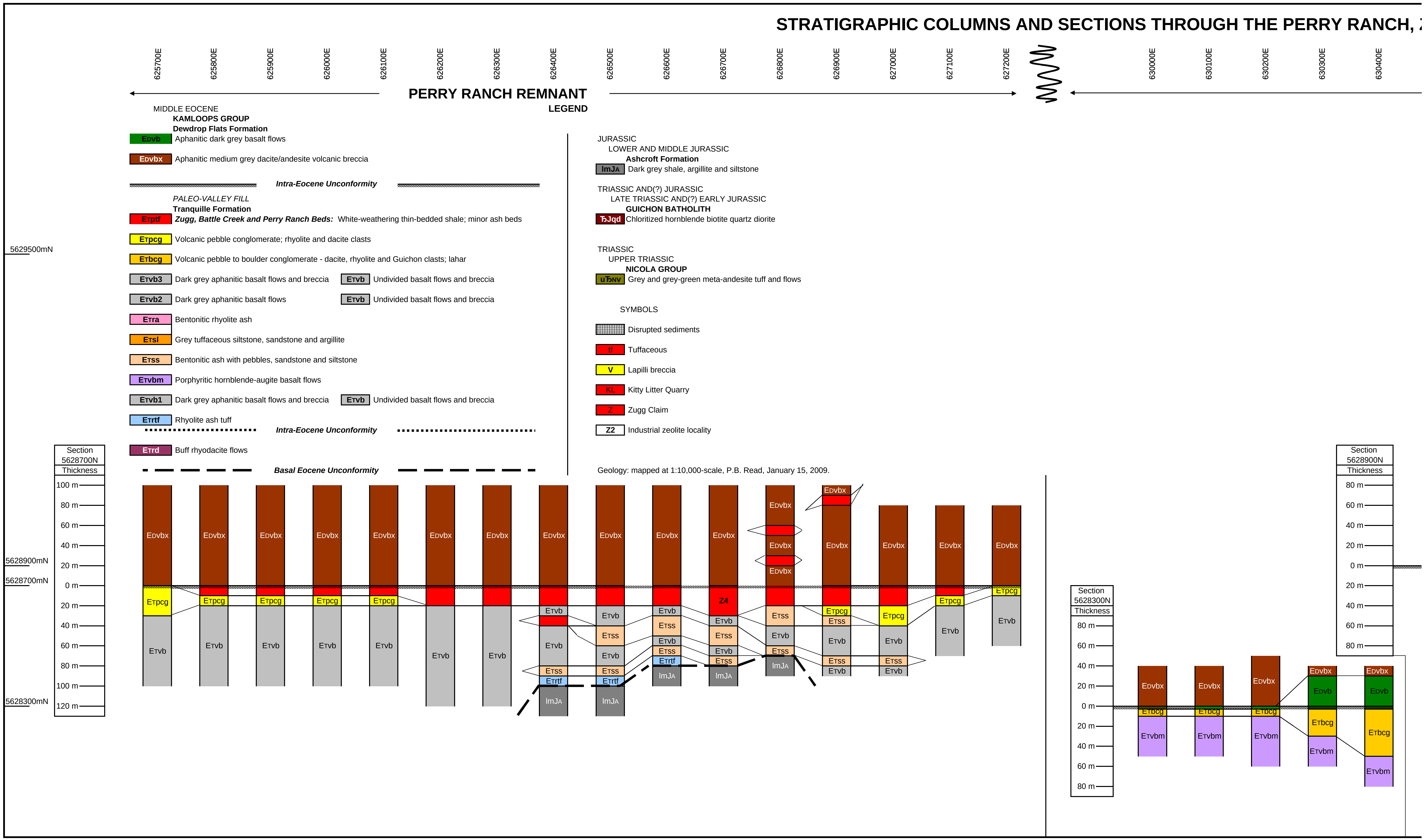
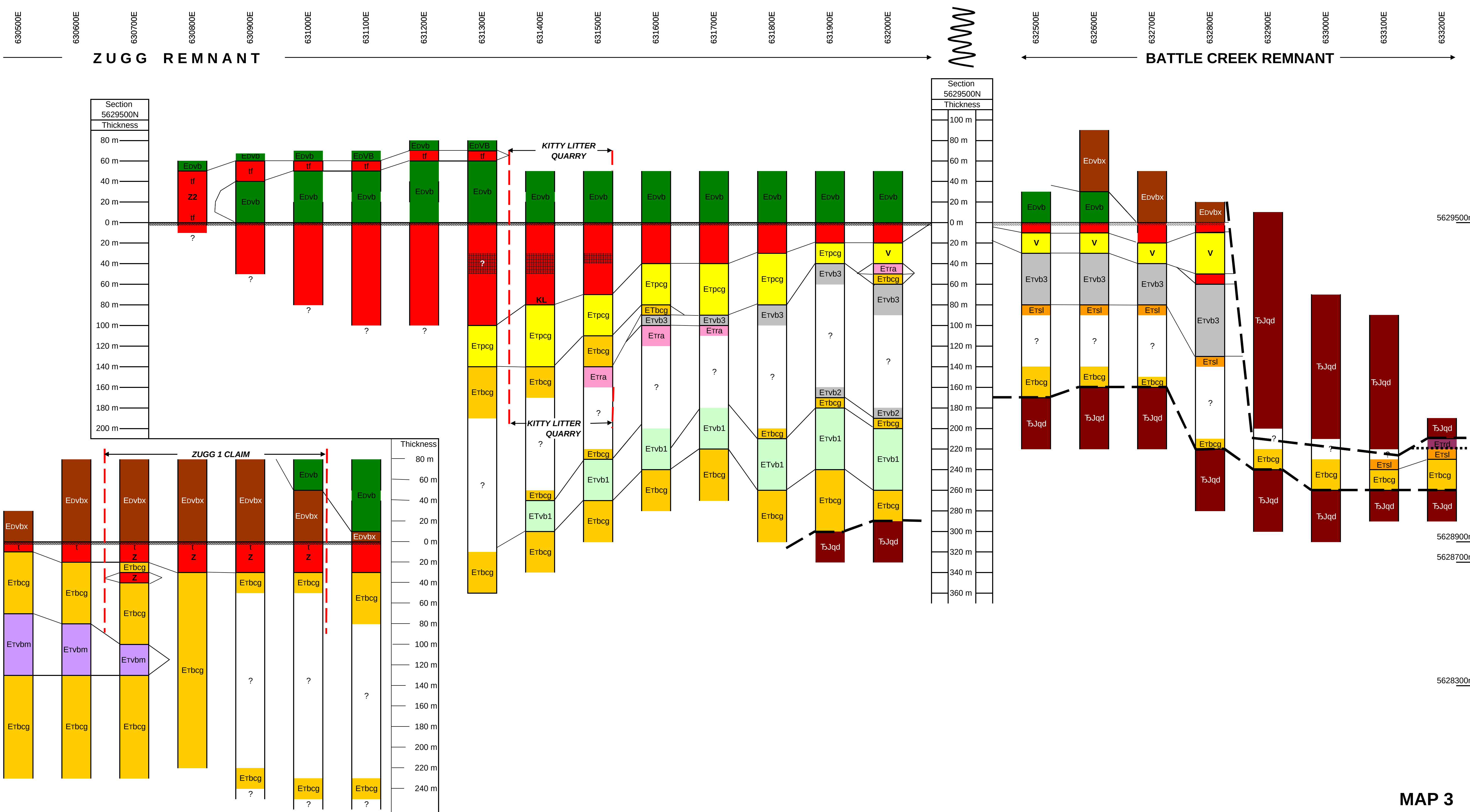
QUATERNARY
PLEISTOCENE AND RECENT
Qs(ETpcg) Unconsolidated sediments: glacial deposits, colluvium and alluvium; few if and outcrops; probable subcrop unit within parentheses
MIDDLE EOCENE
KAMLOOPS GROUP
Dewdrop Flats Formation
EDvb Aphanitic dark grey basalt flows
EDvbx Aphanitic medium grey basalt volcanic breccia
Intra-Eocene Disconformity
PALEO-VALLEY FILL
Tranquille Formation
Zugg, Battle Creek and Perry Ranch Beds:
ETptf White-weathering thin-bedded shale; minor ash beds
ETpcg Volcanic pebble conglomerate; rhyolite and dacite clasts
ETbcg Volcanic pebble to boulder conglomerate - dacite, rhyolite and Guichon clasts; lahar
ETvb3 Dark grey aphanitic basalt flows and breccia
ETvb Undivided
ETra Bentonitic rhyolite ash
ETsl Grey tuffaceous siltstone, sandstone and argillite
ETvb2 Dark grey aphanitic basalt flows
ETvb Undivided
ETss Bentonitic ash with pebbles, sandstone and siltstone
ETvbm Porphyritic hornblende-augite basalt flows
ETvb1 Dark grey aphanitic basalt flows and breccia
ETvb Undivided
ETrtf Rhyolite ash tuff
Intra-Eocene Unconformity
ETrd Buff rhyodacite flows
Basal Eocene Unconformity
JURASSIC
LOWER AND MIDDLE JURASSIC
Ashcroft Formation
lmJA Dark grey shale, argillite and siltstone
TRIASSIC AND(?) JURASSIC
LATE TRIASSIC AND(?) EARLY JURASSIC
GUICHON BATHOLITH
ŦRJqd Chloritized hornblende biotite quartz diorite
TRIASSIC
UPPER TRIASSIC
NICOLA GROUP
uŦRNV Grey and grey-green meta-andesite tuff and flows
SYMBOLS
Geological boundary (defined (approximate (assumed
Fault (defined
Bedding (horizontal (inclined
Platy jointing (inclined
Foliation (inclined
Fold
Outcrop outline
Limit of mapping
Geology: P.B. Read, 2008 at 1:10,000-scale
SCALE 1:10,000
0 100 200 300 400 500 1000
Metres
MAP 2
KITTY LITTER QUARRY
ZUGG 1
McABEE QUARRY
McAbee
THOMPSON
RIVER
CACHE
CREEK
HILLS


STRATIGRAPHIC COLUMNS AND SECTIONS THROUGH THE PERRY RANCH,
625700E
625800E
625900E
626000E
626100E
626200E
626300E
626400E
626500E
626600E
626700E
626800E
626900E
627000E
627100E
627200E
630000E
630100E
630200E
630300E
630400E
PERRY RANCH REMNANT
LEGEND
MIDDLE EOCENE
KAMLOOPS GROUP
Dewdrop Flats Formation
Edvb Aphanitic dark grey basalt flows
Edvbx Aphanitic medium grey dacite/andesite volcanic breccia
Intra-Eocene Unconformity
PALEO-VALLEY FILL
Tranquille Formation
Etptf Zugg, Battle Creek and Perry Ranch Beds: White-weathering thin-bedded shale; minor ash beds
Etpcg Volcanic pebble conglomerate; rhyolite and dacite clasts
Etbcg Volcanic pebble to boulder conglomerate - dacite, rhyolite and Guichon clasts; lahar
Etvb3 Dark grey aphanitic basalt flows and breccia
Etvb Undivided basalt flows and breccia
Etvb2 Dark grey aphanitic basalt flows
Etvb Undivided basalt flows and breccia
Etra Bentonitic rhyolite ash
Etsl Grey tuffaceous siltstone, sandstone and argillite
Etss Bentonitic ash with pebbles, sandstone and siltstone
Etvbm Porphyritic hornblende-augite basalt flows
Etvb1 Dark grey aphanitic basalt flows and breccia
Etvb Undivided basalt flows and breccia
Etrtf Rhyolite ash tuff
Intra-Eocene Unconformity
Etrd Buff rhyodacite flows
Basal Eocene Unconformity
JURASSIC
LOWER AND MIDDLE JURASSIC
Ashcroft Formation
lmJA Dark grey shale, argillite and siltstone
TRIASSIC AND(?) JURASSIC
LATE TRIASSIC AND(?) EARLY JURASSIC
GUICHON BATHOLITH
TJqd Chloritized hornblende biotite quartz diorite
TRIASSIC
UPPER TRIASSIC
NICOLA GROUP
uTNv Grey and grey-green meta-andesite tuff and flows
SYMBOLS
Disrupted sediments
tf Tuffaceous
V Lapilli breccia
KL Kitty Litter Quarry
Z Zugg Claim
Z2 Industrial zeolite locality
Geology: mapped at 1:10,000-scale, P.B. Read, January 15, 2009.
5629500mN
5628900mN
5628700mN
5628300mN
Section 5628700N
Thickness
100 m
80 m
60 m
40 m
20 m
0 m
20 m
40 m
60 m
80 m
100 m
120 m
Section 5628300N
Thickness
Section 5628900N
Thickness
Z4

ZUGG AND BATTLE CREEK REMNANTS



MAP 3