CHAPTER 2 GEOLOGY OF PRINCETON, TULAMEEN BASINS

INTRODUCTION

The Princeton basin (NTS 92H/7 to 10) is a northerly trending trough filled with Eocene volcanic rocks of intermediate composition composing the Cedar Formation, and an overlying mid-Eocene sedimentary sequence comprising the Allenby Formation (Figure 2.1). Basaltic andesite flows clearly overlie the Allenby Formation only at the north end of the basin. The basin contains up to 1370 metres of volcanic rocks overlain by 1600 to 2100 metres of sandstone, tuffaceous sandstone, shale, waterlain rhyolite tephra and coal (McMechan, 1983). In contrast, to the south, Sunday contains at least 1500 metres of volcanic rocks overlain by 320 metres of volcanic conglomerate, sandstone and zeolitized rhyolite tephra of the Allenby Formation.

To the west of the Princeton basin lies the Tulameen basin. It contains 1300 metres of Eocene volcanic and sedimentary rocks that overlie the Upper Triassic Nicola Group and underlie two remnants of the Miocene Chilcotin Group (Church and Brasnet, 1983). Up to 500 metres of grey, sparsely porphyritic hornblende dacite flows, and locally rhyodacite to rhyolite flows and waterlain tuffs of the Cedar Formation underlie a 790-metre thickness of sedimentary rocks of the Allenby Formation.

Geological data from Shaw (1952a, 1952b), Preto (1972, 1979), McMechan (1983) and numerous coal assessment reports have been used extensively in the preparation of the geological map (OF 1987-19).

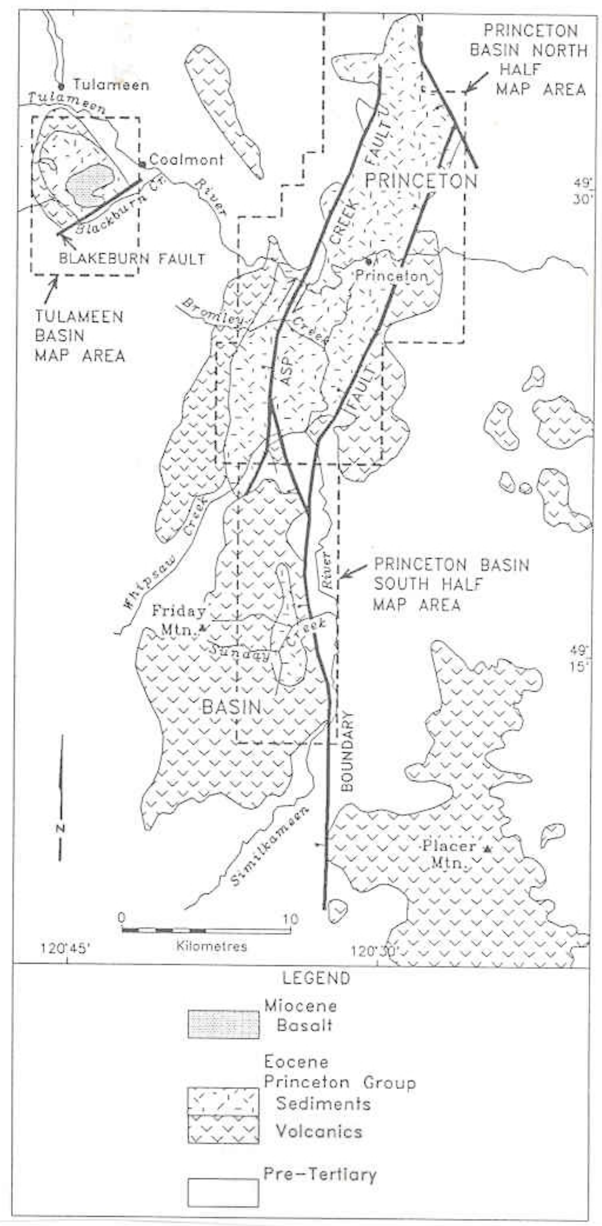

Figure 2.1. Simplified geological map of the Princeton and Tulameen basins showing the distribution of Eocene rocks, faults and the outlines of mapped areas.

STRATIFIED ROCKS

Volcanic and minor sedimentary rocks of the Upper Triassic Nicola Group form most of the basement for the Eocene basins. Along the east side of the Princeton basin, Eocene rocks either overlie Nicola or are faulted against Early Jurassic intrusions along the Boundary fault. Along the southeast side of the Tulameen basin, the Blakeburn fault juxtaposes the Eocene rocks against the Nicola Group. Elsewhere in the basins, the contact is an unconformity buried beneath hundreds of metres of Eocene volcanics. However, in the northern part of the Princeton basin and the eastern edge of the Tulameen basin, where the Eocene sediments are the thickest, Eocene volcanic rocks are thin to absent and Eocene sediments usually lie directly on the Nicola Group (OF 1988-29).

PRINCETON GROUP

Camsell (1907), Shaw (1952a), Hills (1962) and McMechan (1983) subdivided the Tertiary stratigraphy of the Princeton area into upper and lower volcanic packages and an intervening sedimentary unit. Rice (1947) called the Tertiary sedimentary and volcanic rocks the Princeton Group, and Shaw (1952a) proposed the threefold subdivision of `Lower Volcanic', Allenby and `Upper Volcanic' formations. In the Tulameen basin, Camsell (1913) named the Eocene volcanic rocks underlying the Tertiary sediments the `Cedar volcanic series' after a now unnamed creek immediately west of Mount Jackson. Although Camsell included in the Cedar Formation some volcanic rocks now known to belong to the Spences Bridge Group (Monger, 1989a), most of Camsell's description involved the volcanic rocks of the Princeton Group. Church and Brasnet (1983) recognized the priority of Camsell's (1913) `Cedar volcanic series' for the Tertiary volcanic rocks underlying the Tertiary sediments of the Tulameen basin. This name has been retained as Cedar Formation, in place of the informally named `Lower Volcanic' formation and applied to the Eocene volcanic rocks of the Princeton Group underlying the sedimentary rocks of the Allenby Formation. McMechan (1983) followed Hills' (1965) suggestion that the `Upper Volcanic' formation should be included within the Allenby Formation.

CEDAR FORMATION (UNITS Epvd and Epvr)

In the Tulameen basin, Camsell (1913) described the volcanic rocks as ranging from basalt to dacite with andesite dominant. Basalt flows and breccia are common in the lower part of unit Epvd, and sparsely porphyritic hornblende dacite flows prevalent in the upper part. Along Blakeburn Creek, the upper contact of unit Epvd lies at the top of aphanitic rhyodacite to dacite flows that underlie an unbedded sedimentary breccia composed exclusively of fine (1 to 2 cm) volcanic detritus. On the east side of the basin, Cedar Formation is completely eroded.

In the Princeton basin, Cedar Formation mainly consists of grey, sparse hornblende and plagioclase-bearing dacite flows and tephra (Epvd), and near the Tulameen River, red-brown andesite and basaltic andesite lahars and tephra with subordinate flows and volcaniclastic sediments (Epvd). South of Whipsaw Creek, in the Sunday basin, dacite flows form a unit which overlies a unit rich in dacite breccia (Section E-F, OF 1987-19), but northward this distinction disappears. All areas that Shaw (1952a) mapped as `Upper Volcanic' formation and McMechan (1983) mapped as `volcanic member', except one on the northern edge of the basin, are now part of the Cedar Formation. Because unit Epvd lacks industrial mineral potential, it formed the limit of mapping and was not studied in detail.

On the east side of the Princeton basin south of the Similkameen River and east of the Boundary fault, cream and light pink and grey aphanitic to slightly porphyritic rhyolite flows and breccia of unit Epvr are up to a few hundred metres thick. The unit lies on volcanics of the Nicola Group for nearly 10 kilometres from August to Smelter lakes. The same unit lies immediately west of the Boundary fault opposite the mouth of Whipsaw Creek. Here the rocks are rusty weathering, slightly pyritized and hydrothermally altered. Near the fault, the rhyolite is locally massive, but it grades outwards through unbedded breccia, to bedded lapilli and ash tuff intercalated with sediments of the Allenby Formation. Two interpretations seem possible for the genesis of unit Epvr west of the fault: it may represent a faulted remnant of an underwater rhyolite centre which was active during deposition of the Allenby Formation immediately to the north, or it may represent a basement that was onlapped by overlying sediments of the Allenby Formation. Because the rhyolite apparently truncates the Summers Creek sandstone (OF 1987-19), it may have been erupted near the boundary between the deposition of the Summers Creek sandstone and the overlying Ashnola shale. Although the deposition of Tailings ash and Bromley Vale tephra occurred near this boundary, neither unit thickens toward the possible vent, but instead both thin and disappear several kilometres to the north. An explanation favouring formation during the deposition of the Allenby Formation would result in the rhyolite being part of the volcanic member of the Allenby Formation, as mapped by McMechan (Figure 2, 1983). If the rhyolite is part of an onlapped basement, then the bedded lapilli and ash tuffs and intercalated sediments have developed as a result of the products of local erosion of the rhyolite being mixed and deposited with nontuffaceous sediments derived from the north. This latter explanation is consistent with both the thinning and disappearance of Bromley Vale tephra and Tailings ash several kilometres to the north, and correlation of the rhyolite across the Boundary fault. It results in the rhyolite west of the Boundary fault being part of the underlying Cedar Formation and is the favoured interpretation.

Whole-rock K/Ar dating yields a Middle Eocene age for the Cedar Formation (Appendix B)

ALLENBY FORMATION

The Allenby Formation contains the Eocene sedimentary rocks of the Princeton, Sunday and Tulameen basins. In the Princeton basin, the recognition of widespread, waterlain rhyolite tephra units in the Allenby Formation and a distinctive conglomerate allow a detailed stratigraphic subdivison of more than 2000 metres of sediments. In ascending stratigraphic order the tephra are: Sunday Creek tephra in the Sunday basin and in the Princeton basin; Snowpatch ash and Asp Creek ash northwest of Princeton; Princeton ash through Princeton and Tailings ash and Bromley Vale tephra south of Princeton. A distinctive polymictic pebble conglomerate extends for 11 kilometres from near the mouth of Summers Creek north of Princeton to the Princeton-Coalmont road west of the town. These lenticular units form the basis for the subdivision of the Allenby Formation in the Princeton basin. Although a gap in outcrop of only 8.5 kilometres separates rocks of the Allenby Formation north and south of Whipsaw Creek, there is no detailed stratigraphic continuity across this gap.

In the Tulameen basin, the Allenby Formation contains a lower sedimentary breccia to sandstone transition, a medial section of shale and coal, and an upper sequence of mainly sandstone and granule conglomerate with minor zeolitized rhyolite tephra, that total a 790-metre thickness of sedimentary rocks. The lower transition outcrops in Blakeburn Creek, the 90-metre shale and coal section is sparsely exposed in roadcuts and the 590-metre upper sandstone-conglomerate section is poorly exposed. In spite of a

12-kilometre gap in outcrop from Princeton to Tulameen basin, the detailed stratigraphy of the Princeton basin appears to bridge the gap.

The middle Eocene age of the Allenby Formation rests on more than 50 palynologic macroflora and vertebrate fossil determinations (Appendix A, Table A.1)

SUNDAY CREEK CONGLOMERATE (UNIT Epscg) And Tephra (UNIT EPsct)

A conglomerate and medial rhyolite tephra form the sedimentary fill of the Sunday basin for 7 kilometres from south of Friday Creek to south of Sunday Creek on both sides of Highway 3. The combined thickness of the two units is 350 metres (Section E-F, OF 1987-19). About 320 metres of this thickness is volcanic pebble to cobble conglomerate, minor volcanic wacke and siltstone, and rare micaceous sandstone of the Sunday Creek conglomerate. The underlying grey andesite and dacite flows (EPvd) contribute the dominantly angular to subangular clasts composing the overlying coarsely bedded sediments. The micaceous sandstone occurs only in the stratigraphically highest sediments above the tephra. The best outcrops of the unit are in both forks of Sunday Creek, that provides the name for the units, and in roadcuts along Highway 3.

Sunday Creek tephra is the only zeolitized horizon in the southern portion of the Princeton basin, where it lies within 200 metres of the base of the Allenby Formation. The tephra is mainly a fine (1 to 4 cm) rhyolite lapilli tuff with a vitric-crystal (biotite, feldspar, quartz) matrix and a few percent subangular dacite and andesite clasts up to 5 centimetres in diameter. It is unbedded to crudely bedded, and contains fragments of carbonized wood up to 50 centimetres long. The tephra outcrops over a distance of as much as 500 metres south of the south fork of Sunday Creek in a roadcut that is 5 metres high and on the west side of Highway 3 (Figure 7.2a and Photo 7.3). The only other exposures are in the south fork of Sunday Creek, downstream from Highway 3, where the creek twice intersects the tephra. It has a thickness of 30 metres and an exposed strike length of 1300 metres with both ends passing beneath drift.

HARDWICK SANDSTONE (UNIT EPHhss)

Hardwick sandstone partly fills old river channels on the northwestern edge of the Princeton basin from north of the confluence of Allison and Summers creeks to the Tulameen River. It averages a few hundred metres in thickness, but reaches a maximum thickness of 400 metres in a channel near Allison and Summers creeks (Section M-N, OF 1987-19). Unit Ephss contains some siltstone and shale, but the characteristic rock is a white to cream quartzofeldspathic sandstone that is free of rhyolite ash. Toward the base, the unit loses its quartzofeldspathic composition and whiteness, and becomes a greenish brown lithic sandstone. At the base, unit EPHSS locally includes a rusty brown weathering basal conglomerate, such as that exposed on Highway 5 north of Summers Creek, where angular to subrounded clasts of basement rocks exceed a metre on edge (McMechan, 1983). Of the sparsely scattered outcrops of Hardwick sandstone, slumped roadcuts along the farm road on the north side of Hardwick Creek are typical of the unit. The sandstone is the only unit of the Allenby Formation west of the Asp Creek fault and north of the mouth of Summers Creek, and it probably forms most of the basal basin-fill east of the fault between the mouth of Summers Creek and the Tulameen River where drill hole UP-5 (Carpenter, 1980) intersected 87 metres of Hardwick sandstone overlying Eocene flows (Figure 2.3; Section O-P, OF 1987-19).

In the Tulameen basin, the basal 100 to 150 metres of sediments are part of the Hardwick sandstone. On the west side of the basin, in Blakeburn Creek, the unit grades upwards from an unbedded sedimentary breccia composed of Eocene volcanic clasts, through crudely bedded breccia, to a bedded, feldspar-rich, volcanic-lithic wacke. In addition to the vertical facies change, the volcanic-dominated sediments of the west thin eastward and grade to basal conglomerate and overlying arkosic sandstone.

VERMILION BLUFFS SHALE (UNIT EPVBp)

Vermilion Bluffs shale is the thickest and most extensive shale-rich unit in the Princeton basin. It is the host for the most productive coal seams in the basin (Table 2.1), and for some of the zeolite and bentonite showings (Table 7.1). The unit extends for more than 22 kilometres from north of the mouth of Summers Creek to south of Whipsaw Creek. It fills the basin from east to west and extends westward to the Tulameen basin, but its thickness is highly variable. The unit thins drastically or disappears over basement highs such as the one near the Tulameen River (Section C-E, OF 1987-19,) where it thins from 1000 metres north of the high to 100 metres over the high, and thickens again southwards to about 900 metres near Whipsaw Creek. Widely scattered outcrops show that Vermilion Bluffs shale contains mostly shale, carbonaceous and bentonitic variants and minor thin sandstone layers. The best, but in part an atypical exposure, is at Vermilion Bluffs where uncharacteristic siliceous sinter, siliceous and dolomitic limestone, and silicified diatomaceous sediments form some of the section. The more characteristic unsilicified shale usually does not outcrop but instead underlies slumped topography. Granby strip mine in the Princeton basin and Blakeburn mine in the Tulameen basin expose coal-rich sections of the unit. Bromley Vale tephra and Tailings ash aside, the remaining stratigraphic marker horizons, which allow subdivision of the Allenby Formation, lie within the unit.

A shale tongue or lens within Summers Creek sandstone lies 2 to 3 kilometres south of Princeton where it outcrops along the Similkameen River. Originally named Power Plant shale (Read, 1987b), it consists of shale, carbonaceous and bentonitic variants and layers of quartzofeldspathic grit and coarse sandstone. Because of sparse outcrop, the distribution of the unit west of Highway 3 is unknown and the proportions of shale and sandstone are uncertain but are estimated as probably more shale than sandstone. At showing B6 (OF 1987-19), bentonite layers within the shale have contributed to the only recorded production of bentonite in British Columbia. The tongue attains a maximum thickness of 250 metres along the Similkameen River (Section C-D north of its intersection with Section S-T, OF 1987-19). Based on southerly di-

TABLE 2.1
STRATIGRAPHIC CORRELATION OF COAL SEAMS IN THE PRINCETON BASIN ARRANGED IN DESCENDING STRATIGRAPHIC ORDER

Mine or Prospect	Rock Unit	Coal Zone or Seam	Metres*	Stratigraphic Level
Bethlehem	EAAp	Golden Glow?	-510	400 above top of EAVBp
Bromley Vale #2	EAAp	Golden Glow	-470	360 above top of EAVBp
Golden Glow	EAAp	Golden Glow	-470	360 above top of EAVBp
Bethlehem lower	EAAp	Bromley Vale #1?	-370	260 above top of EAVBp
Bromley Vale #1	EAAp	Bromley Vale #1	-350	240 above top of EAVBp
Burr's	EASCss	unknown	-?	? m above top of EAVBp
Gem	EASCss	Gem	-340	200 above top of EAVBp
Summers Creek	EASCss	Summers Creek	-?	70 above base of EASCss
Pleasant Valley #1	EAVBp	Pleasant Valley	-90	20 below top of EAVBp
Jackson #1	EAVBp	Pleasant Valley	-90	20 below top of EAVBp
Black & Granby strip	EAVBp	Princeton #1	0	110 below top of EAVBp
Taylor #1	EAVBp	Princeton #1	0	110 below top of EAVBp
Pleasant Valley #2	EAVBp	Princeton #1	0	140 below top of EAVBp
Pleasant Valley #4	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton #1	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton #2	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton #3	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton-Tulameen #1	EAVBp	Princeton #1	0	140 below top of EAVBp
Tulameen #1	EAVBp	Princeton #1	0	140 below top of EAVBp
Tulameen #2	EAVBp	Princeton #1	0	140 below top of EAVBp
Tulameen #3	EAVBp	Princeton #1	0	140 below top of EAVBp
Fairley	EAVBp	unknown	+70#	210# below top of EAVBp
Ashington	EASCss	Ashington	+140	280 below top of EAVBp
China Creek prospect	EASCss	Ashington	+140	280 below top of EAVBp
Blue Flame #1	EAVBp	Blue Flame	+180#	320 below top of EAVBp
Blue Flame #2	EAVBp	Blue Flame	+180#	320 below top of EAVBp
Red Triangle	EACCg	Red Triangle	+310?	450 below top of EAVBp
Deer Valley	EAVBp	unknown	+350?	490 below top of EAVBp
United Empire	EAHss	United Empire	+460?	600 below top of EAVBp

** Distance to the nearest 25 metres above (-) or below (+) Princeton #1 seam.*
-? stratigraphic level above Princeton #1 seam.
+? stratigraphic level below Princeton #1 seam.
 # Because of intercalation of the top of Summers Creek sandstone and the top of Vermillion Bluffs shale, stratigraphic intervals followed by # cannot be compared with any of the other distances.

rected paleocurrents during deposition of the Allenby Formation (Map 2) and a northern source area for the coarse sediments of the formation, I favour an interpretation which makes this shale a tongue of the Vermilion Bluffs shale as shown on Section C-D south of its intersection with Section S-T (Map 1). Vermilion Bluffs shale disappears south of Whipsaw Creek and diminishes to 90 metres in the Tulameen basin.

SNOWPATCH ASH (UNIT EPsa)

Snowpatch ash is the stratigraphically lowest rhyolite ash exposed in the Princeton basin. It lies on the northwest side of the basin astride Asp Creek, and outcrops at 860 metres (2825 feet) elevation 2300 metres up the road to Snowpatch ski area from the Princeton-Tulameen Highway. A roadcut on the south side of the road exposes about 5 metres of yellow ochre weathering, coarse tuffaceous sandstone composed mainly of quartz, feldspar and biotite grains. Although neither the top nor bottom contact is exposed, the zeolitized horizon is probably not much thicker. About 800 metres to the south-southwest, at 945 metres (3100 feet) elevation and east of a powerline, a dip slope exposes a 30-metre width of white-weathering vitric-crystal tuff that is locally zeolitized. The exposed strike length of the tephra horizon is 2400 metres with both ends passing under drift. The ash is crystal rich, only partly zeolitized and not considered to be of economic interest.

CHINA CONGLOMERATE (UNIT EPccg)

China conglomerate is the most extensive marker horizon in the Vermilion Bluffs shale. It extends 11 kilometres from south of the mouth of Summers Creek to south of the Princeton-Tulameen Highway, and is up to 130 metres thick. McMechan (1983, p.15) noted its presence near Asp Creek but did not map its distribution. It is well exposed on the road to Snowpatch ski area, in Asp Creek (formerly China Creek), northwest of Princeton airfield, on Allison Creek west of the trailer park, and on Highway 5 to Merritt. In addition, diamond drilling intersected it in holes PC1 to PC3 (Nicholson, 1981). In Asp Creek, unit EPccg is a fine (5 mm) sedimentary breccia composed of white to red-brown or grey-brown aphanitic volcanic clasts derived from the Nicola and Spences Bridge groups, but free of Eocene rhyolite clasts. Nearby, on the road to Snowpatch ski area, shale accompanies the same sedimentary breccia. To the northeast of Asp Creek, exposures near the airfield show a mixture of breccia and volcanic and quartz-pebble conglomerate which continues to west of the trailer park on Allison Creek. The grain size diminishes northwards and the northernmost exposures on Highway 5 are brownish weathering lithic grit and coarse wacke.

ASP CREEK ASH (UNIT EPca)

In the Princeton basin, Asp Creek ash is the stratigraphically lowest ash that is significantly zeolitized. It is exposed on the highway to Tulameen at the northwest end of the single-lane bridge across the Tulameen River within the Princeton town limits (Photo 7.1). Although Hills (1962, see map p.41) included this outcrop as part of the Princeton ash, backyard exposures show that Asp Creek ash continues westward to Asp Creek where it outcrops in cliffs on the right bank of Asp Creek about 500 metres upstream from its confluence with the Tulameen River and 150 metres north of the Princeton ash (Figure 7.2b and OF 1987-19). The tephra contains scattered plant fragments in a bedded, white ash with intercalated layers of vitric-crystal (biotite, plagioclase, sanidine, quartz) tuff. In Asp Creek, the tephra is 7.3 metres thick, overlies a fine-grained biotite-bearing sandstone tongue of the Summers Creek sandstone and underlies the carbonaceous Vermilion Bluffs shale. The strike length of the tephra is about 1000 metres with both ends covered by drift, but with an eastern extension likely.

PRINCETON ASH (UNIT EPPA)

Princeton ash (Hills, 1962) outcrops on the north bank of a bend in the Tulameen River, 2.1 kilometres upstream from the Princeton-Tulameen road bridge across the river. Additional outcrops are scattered along the north bank for another 400 metres upstream. These outcrops, together with a roadcut on the Princeton- Tulameen road immediately west of Asp Creek and a low outcrop on the east bank of the Similkameen River, yield an exposed strike length of 3 kilometres. Although no outcrop shows both upper and lower contacts, the ash is at least 9 metres thick along the Tulameen River. The medium grey crystal (biotite, hornblende, quartz, andesine) vitric ash is vaguely bedded and contains plant fragments which indicate that it is waterlain. Unlike all the other rhyolite tephra of the basin, Princeton ash is unaltered and zeolite free. It is the highest of three stacked ash lenses which lie in the Vermilion Bluffs shale between two easterly trending paleohighs (Section C-D, OF 1987-19). The northern paleohigh, lying approximately along the Rainbow anticline, and the southern one lying along the Tulameen River, probably controlled the distribution of the waterlain rhyolite ash lenses.

SUMMERS CREEK SANDSTONE (UNIT EPscss)

Summers Creek sandstone is the most extensive sedimentary unit in the Princeton and Tulameen basins. It extends 25 kilometres from the northern edge of the Princeton basin to Lamont Creek in the south, and 15 kilometres westward across the basins. It yields the best outcrops of all units of the Allenby Formation with large exposures scattered along the east bank of Summers Creek, on the south bank of the Tulameen River 3 kilometres upstream from Princeton, and on the east bank of the Similkameen River 5 kilometres upstream from Princeton. Near and south of Princeton, the unit is mainly a quartzofeldspathic grit, granule conglomerate and coarse sandstone with local calcite and quartz cement, but to the north, the rhyolite ash and biotite content increase. Northward along Summers Creek the bedded, tuffaceous and quartzofeldspathic sandstone loses its bedding with an increase in rhyolite ash content, until near the north edge of the basin the rock is a crystal (quartz, feldspar, biotite)-vitric tuff that is locally waterlain. The increase in vitric rhyolite ash whitens the rock and creates the mealy-weathering outcrops encountered along the railroad grade to Jura.

South of Princeton and west of the Similkameen River, outcrops of the Summers Creek sandstone are very sparse as the unit diminishes to less than 300 metres in thickness (Sections C-D and U-V, OF 1987-19). The decrease in thickness results from the southward termination of two basal tongues of Summers Creek sandstone, the lower and upper tongues, in the upper part of the Vermilion Bluffs shale. Extensive diamond drilling by Bethlehem Copper Corporation in the Dalby Creek and Meadows areas (Anderson, 1972; 1976) and a few bedded outcrops are the basis for the extension and distribution of the Summers Creek sandstone, the bounding shale units, and the Asp Creek fault (OF 1987-19). Northeast of the mouth of Whipsaw Creek, the truncation of the Summers Creek sandstone probably results from the unit onlapping the underlying rhyolite (*see* Cedar Formation). This truncation and the lack of detailed stratigraphic continuity southward are evidence that a basement high lies south of Whipsaw and formed a barrier to the southward deposition of Summers Creek sandstone and Vermilion Bluffs shale.

In the Tulameen basin, a few scattered outcrops of quartzofeldspathic sandstone and coarse sandstone to grit with a rhyolite ash component are part of the Summers Creek sandstone. In a few places the ash is dominant and a waterlain, crystal (quartz, biotite, feldspar)-vitric tuff results in which the rhyolite glass has been zeolitized (see Tulameen Bridge occurrency description). The unit reaches a thickness of 590 metres beneath a cap of Miocene basalt flows.

TAILINGS ASH (UNIT EPTA)

Tailings ash is the most extensive zeolitized horizon in the Princeton basin. A series of outcrops, stretching for more than 3.5 kilometres, exposes the gently southward-dipping ash from west of Highway 3 to east of the Similkameen River. A second series of outcrops, spanning only 1.1 kilometres, shows the gently northward dipping unit extending eastward from the Similkameen River. These exposures outline the north and south limbs of the west-trending and gently plunging Tailings syncline. On Highway 3 on the north limb of the syncline, the ash is more than 13 metres thick (Photo 7.2), and on the old Copper Mountain Railway grade on the south limb it is more than 4.2 metres thick (Figure 7.2c). Neither top nor bottom contact is exposed at either location. Roadcuts on Highway 3 expose crystal (biotite, quartz, feldspar)-vitric tuff and lapilli tuff with the rhyolite glass shards completely altered to clinoptilolite cores with montmorillonite rims. On the railway grade, only the crystal-vitric tuff is present.

BROMLEY VALE TEPHRA (UNIT EPBV)

Bromley Vale tephra only outcrops at and upstream from Bromley Vale No. 1 mine adit on Bromley Creek (Figure 7.2d). The easterly flowing creek exposes 9 metres of fine, white to cream-coloured rhyolite breccia overlain by 13 metres of white to light grey vitric-crystal (biotite, feldspar, quartz) bedded tuff with fragments of carbonized wood and leaves, and a thin, dark grey albitized tuff. The 22-metre thickness of tephra has neither top nor bottom contacts exposed, and to the south very thick overburden mantles any possible extension. The tephra does not reappear to the north, perhaps because of truncation by the Asp Creek fault. If the Asp Creek fault has a right-lateral strike-slip displacement of about 1200 metres, then Bromley Vale tephra should correlate with Tailings ash. Sharp's borehole (Rice, 1947) may have intersected the tephra at a depth of 140 metres (460 feet) beneath which a "white clay with dark spots" was logged for 23.2 metres (76 feet).

ASHNOLA SHALE (UNIT EPAP)

Ashnola shale is the highest sedimentary unit in the Princeton basin. Scattered exposures along the Similkameen River extend for 6.2 kilometres downstream from the mouth of Whipsaw Creek, and are best at a distinctive bend 1.8 kilometres downstream, at a place labelled on old maps as `Ashnola'. West of the river, only three outcrops and a number of diamond-drill holes indicate its presence in the core of the Tailings syncline. The unit consists of shale, silty shale and siltstone with minor sandstone layers, and a fine waterlain lapilli tuff on the east bank of the Similkameen River at Ashnola. The abundant shale and silty shale are locally carbonaceous or bentonitic. Ashnola shale reaches a maximum thickness of 550 metres in the core of the Tailings syncline (Section U-V, OF 1987-19).

JURA ANDESITE (UNIT EPJva)

Jura andesite forms a remnant of basaltic andesite flows which lies at the northern edge of the basin east of Summers Creek. The slightly porphyritic hypersthene-augite basaltic andesite flows are vesicular, up to 50 metres thick and cover a few square kilometres. They overlie waterlain tuff of the Summers Creek sandstone (Section A-B, OF 1987-19), but whether they overlie the whole of the Allenby Formation, or just the Summers Creek sandstone is unknown. A K-Ar whole-rock age from this remnant is 49.4 $\pm$ 2.0 Ma (Table 3 on OF 1987-19 and Appendix B).

In this study, the `Upper Volcanic' formation of Shaw (1952a) and the `volcanic member' of the Allenby Formation of Hills (1962) and McMechan (1983) have been named the Jura andesite and restricted to only those volcanic rocks which overlie sediments of the Allenby Formation. Of the five areas listed by Shaw as underlain by the `Upper Volcanic' formation only the area at the northern margin of the basin immediately east of Summers Creek meets this criterion. Of the remaining four areas, one on the western margin of the Princeton basin, 1.6 kilometres north of Asp Creek, and a second astride the Tulameen River 3.2 kilometres upstream from the town of Princeton, underlie the Allenby Formation, unconformably overlie the Nicola Group and are part of the Cedar Formation. In part of the first area north of Asp Creek, where the volcanics appear to overlie the Allenby Formation, movement on the Asp Creek fault has set the volcanic rocks east of the fault against, but not over, sediments west of the fault. A third area straddling Highway 5, 2.4 kilometres north of Princeton, contains no evidence of Jura andesite. The fourth and largest area is a more or less continuous belt that extends along the east side of the basin from about 3 kilometres northeast of Princeton southward to Smelter Lakes. Here Shaw (1952a, p. 9) described the `Upper Volcanic' formation as "a group of volcanic rocks that appear to lie with structural discordance on the Allenby Formation, and, farther east, on pre-Tertiary rocks." Because Shaw did not recognize the faulted contact between Eocene sediments and volcanic rocks in this area, and did not realize that movement on the Boundary fault placed the volcanics against the sediments; he mistakenly thought that the volcanics overlay the sediments.

CHILCOTIN GROUP (Mcvb)

In the Tulameen basin, two erosional remnants of flat-lying basalt flows cap the folded sediments of the Allenby Formation. The largest, immediately north of Granite Creek, covers nearly 4 square kilometres and attains a thickness of 150 metres; a second thin one to the northwest is only 0.25 square kilometre. The augite-bearing olivine basalt flows are sparsely vesicular and locally columnar jointed. Church and Brasnet (1983) reported a K-Ar whole-rock radiometric age of 9.0±0.9 Ma (Table 3 on OF 1987-19).

CORRELATION OF COAL SEAMS IN THE PRINCETON BASIN

In the Princeton basin, Fahrni (1945), Shaw (1952a) and McMechan (1983) developed slightly differing correlation schemes for the coal zones. These geologists realized that the thick workable coal seams, though highly variable in thickness, do occur in definable coal-bearing zones, and that broad-scale correlation of these zones is possible (McMechan, 1983). Columnar sections, derived from surface and drilling information at Princeton and at Bromley Vale, were correlated on the basis of number, thickness and spacing of coal seams (Shaw, 1952a; McMechan, 1983), but McMechan noted that the absence of a detailed stratigraphy for the Allenby Formation forced this approach to correlation. In 1952, Shaw did not know that the Asp Creek fault lay between the coal seams of the Princeton and Bromley Vale areas, and in 1983 McMechan did not possess a detailed stratigraphy for the Allenby Formation.

The correlation scheme for the coal seams and zones of the Princeton basin is based on the detailed stratigraphy developed in this study and the stratigraphic thicknesses between the seams and the top of the middle tongue of Vermilion Bluffs shale as measured in plan or cross-sections (OF 1987-19). Shaw's and McMechan's correlation of the Princeton #1 seam in the Princeton area with the Black seam in the Bromley Vale area is corroborated by the positions of the two seams in the detailed stratigraphy of the Allenby Formation. Both seams lie in the Vermilion Bluffs shale about 110 to 140 metres beneath the top of the middle shale tongue (Sections C-D and S-T, OF 1987-19).

The Pleasant Valley seam, exposed in Pleasant Valley No. 1 mine, is in the Vermilion Bluffs shale about 20 metres beneath the top of the middle tongue (Section C-D, OF 1987-19). The stratigraphic interval between the Pleasant Valley seam, at 20 metres and the Princeton #1 seam, at 140 metres beneath the top of the shale, is 120 metres. Hughes (1949, p. A223) estimated the same interval between the Pleasant Valley and Princeton #1 seams as approximately 140 metres (460 feet).

The Ashington mine and seam are in the lower tongue of the Summer Creek sandstone, very close to the Asp Creek ash, at about 320 metres below the top of the middle tongue of the Vermilion Bluffs shale (Section C-D, OF 1987-19), and about 180 metres below the Princeton #1 seam. This position is probably equivalent to the seam exposed at the China (Asp) Creek coal prospect which also lies very close to Asp Creek ash. Although the stratigraphic position of the mine and prospect appears equivalent to that of the Blue Flame seam, the intercalation of the Summers Creek sandstone and the Vermilion Bluffs shale near Princeton spoils the equivalence. As Section B-E (OF 1987-19) shows, the Summer Creek sandstone thins southwards from a thickness of 1000 metres north of Princeton to less than 300 metres north of Whipsaw Creek. The thinning results from the southward termination of the lower and upper tongues of the Summers Creek sandstone in the upper part of the Vermilion Bluffs shale.

The Gem mine and seam are hosted by the upper part of the upper tongue of the Summers Creek sandstone (OF 1987-19) about 200 metres above the top the middle tongue of the Vermilion Bluffs shale. Although the Gem mine is 1 kilometre east of section C- D (OF 1987-19), the stratigraphic position above the Princeton #1 seam and the measured stratigraphic interval (Table 2.1) should be reliable.

Two mines, the United Empire and the Red Triangle, and two prospects, the Summers Creek and the Deer Valley, are located in the northern part of the Princeton basin. The presence of faults and absence of outcrop result in uncertain stratigraphic positions for the seams worked in the two mines and the Deer Valley prospect. The Red Triangle mine is near the bottom of the China conglomerate which is about 450 metres below the top of the middle tongue of the Vermilion Bluffs shale (Section B-D, OF 1987-19). Because the mine is sited 1.7 kilometres east of Section B-D, within a sliver of Boundary fault and close to the edge of the sedimentary basin, measurement of the interval below the Princeton #1 seam is uncertain. However, the mine's position near the base of the China conglomerate indicates that it is stratigraphically lower than the Ashington seam. The Deer Valley prospect is within a thin tongue of the Vermilion Bluffs shale, east of the Boundary fault, but close to the same stratigraphic position as the seam in the Red Triangle mine. The United Empire mine is located near the top of the Hardwick sandstone, and is about 600 metres below the top of the middle tongue of the Vermilion Bluffs shale on Section B-D (OF 1987-19). Although this position is stratigraphically lower than that of the Red Triangle mine, a similar degree of uncertainty in the estimation of the stratigraphic interval exists for the same reasons. The Summers Creek prospect is 70 metres above the base of the Summers Creek sandstone and the underlying rocks of the Nicola Group. Because the middle shale tongue does not extend this far north, the stratigraphic position of the seam relative to the top of the middle shale tongue is indeterminable.

Southwest of Princeton, the Jackson mine and seam are in the Vermilion Bluffs shale very close to the base of the Summers Creek sandstone (OF 1987-19) in a position that is stratigraphically equivalent to the Pleasant Valley seam. This stratigraphic position agrees with Shaw's and McMechan's correlation of the Jackson and Pleasant Valley seams. In addition, Shaw followed Hughes (1948, p.A257) in believing that the seams exposed in the Jackson and Taylor mines are equivalent. However, the Taylor No. 1 seam appears to be about 120 metres below the base of the Summers Creek sandstone (OF 1987-19). This position, stratigraphically equivalent to the Black and Princeton #1 seams, has a large degree of uncertainty because of the assumed position of the base of the Summers Creek sandstone.

In Bromley Creek, the Bromley Vale No.1 and No.2 mines and the Golden Glow prospect exploit seams that are above the Summers Creek sandstone. The Bromley Vale No.1 and the Golden Glow seams are located 350 and 470 metres respectively above the Black seam (Section S-T, OF 1987-19). Because of the equivalence of the Black and Princeton #1 seams, the distances above the top of the Vermilion Bluffs shale are 210 and 350 metres respectively. The stratigraphic position of the Bromley Vale No.1 seam is uncertain, but it probably lies immediately beneath the Bromley Vale tephra.

The Blue Flame seam, at about 320 metres below the top of the Vermilion Bluffs shale (Section D-E, OF 1987-19), indicates a 180-metre southward increase in the distance that the coal seam lies below the top of the shale, agrees with Shaw's observation (1952a, p.16), "that the Blue Flame coal occupies a position several hundred feet stratigraphically below the Princeton-Black coal zone", and negates McMechan's (1983, p.30) equivalence of the Blue Flame to the Princeton-Black seams. The 430-metre stratigraphic interval (Table 2.1) is valid only if no further intercalation develops along the top of Vermilion Bluffs shale between Bromley and Whipsaw creeks.

North of the Blue Flame mine and west of the Asp Creek fault, data from Anderson's (1972) sketch maps of structural contours on the Bethlehem seam yield the position of the seam shown in Section U-V (OF 1987-19). Because the nearest intersections of the top of the Vermilion Bluffs shale are 2 to 2.5 kilometres distant in diamond-drillholes 75-13 and 75-14, a large degree of uncertainty attends the 400-metre distance that the seam lies above the top of the shale. The large discrepancy between the 510-metre distance that the Bethlehem seam lies above Black seam (Table 2.1), and McMechan's (1983, p.30) estimation of 1010 metres results from McMechan's correlations of the Blue Flame and the Black seams, and the Bethlehem lower seam with the Allenby seam. An alternate interpretation is that the lower seam is equivalent to the Bromley Vale #1 seam.

Coal exposed at the Fairley prospect occupies a position in the Vermilion Bluffs shale that is about 210 metres beneath the top of the unit (Section W-X, OF 1987-19) and does not correlate with any other seams. However, because of close proximity to the edge of the sedimentary basin, the position of the base of the Summers Creek sandstone near Fairley prospect is very uncertain.

The coal at Burr's prospect is in the middle to lower part of the Summers Creek sandstone in the core of Allenby anticline (OF 1987-19). Although it is impossible to estimate stratigraphic separations, the seam should lie between the Gem and Bromley Vale seams as shown in Table 2.1.

STRUCTURE

The Princeton basin is the site of a major northerly trending half-graben, bounded on the east by the northerly to north-northeasterly trending Boundary fault, and near the western edge, by the Asp Creek fault. Both faults dip steeply and probably have both strike-slip and dip-slip components of displacement. Folds are upright and open to closed but are irregular in both trend and plunge. The westerly trending portions of the Allenby anticline and Tailings syncline are well defined, but their swing into and extension along the south-southwesterly trend is unexposed and complicated by the Asp Creek fault. Near Whipsaw Creek, north-northwesterly striking faults, and the northerly plunge of the Tailings syncline and Allenby anticline bring rocks of the Nicola Group to surface. A few kilometres to the south, between Kennedy Lake and Deep Gulch Creek, the southerly plunge of the Kennedy Lake syncline, the probable extension of the Tailings syncline, preserves the volcanic-dominated Sunday basin.

The Tulameen basin preserves a portion of a southeasterly plunging syncline which has been truncated on the southeast by the Blakeburn fault.

FOLDS

In the Princeton basin, folds are open and upright but lack continuity as a result of either significant changes in trend or dying out along plunge. Of the four large folds affecting Eocene rocks, the Rainbow Lake anticline (Hills, 1962) and Asp syncline lie north and west of Princeton, and the Allenby anticline (Shaw, 1952a) and Tailings syncline extend for many kilometres south of Princeton (OF 1987-19). North of the Rainbow Lake anticline, gently east-dipping Eocene sediments form a homocline that terminates against the Boundary fault. East of the fault, a sliver of westerly dipping sediments represents the faulted remnant of the other limb of a syncline (Sections M-N and O-P, OF 1987-19). This syncline diverges from the Boundary fault near Jura, extends northward and may be partly responsible for the shape of the northeastern corner of the basin.

In the northern part of the basin, the southeasterly plunging structures are probably a combination of folding and the paleotopography of the basin. The northwest and east margins of the basin show that the Rainbow Lake anticline extends along a belt where the Cedar Formation is preserved beneath the Allenby Formation (OF 1987-19). In the middle of the basin, immediately west of Highway 5, the bottom 16 metres of diamond-drillhole UP-5 intersected amygdaloidal and vesicular, olivine-bearing flows and minor breccias of the Cedar Formation along the hinge of the Rainbow Lake anticline (Figure 2.3) not volcanic rocks of the Nicola Group as mapped in this location by McMechan (1983). North and south of the anticline, the Nicola directly underlies the Allenby Formation.

Statistical analysis of the few bedding attitudes indicates the fold axis for Rainbow Lake anticline trends and plunges 135/12SE (with a standard deviation of ±02). Southwest of the anticline, bedding attitudes on either side of Asp Creek outline the southeasterly plunging Asp syncline which broadens and disappears south of Princeton. Analysis of bedding attitudes (Figure 2.2) yields a fold axis trend and plunge of 139/22SE (±06) which differs from the 160º strike for the subvertical trace of the axial plane shown on OF 1987-19. Near the northwest margin of the basin, Asp Creek fault dextrally displaces the syncline. On the margin, the Allenby Formation directly overlies volcanics of the Nicola Group. Farther southwest, bedding attitudes and the old workings of Pleasant Valley Company's mines outline the southeasterly plunging Pleasant Valley anticline which also broadens and disappears southeastwards. Statistical analysis of bedding attitudes gives a fold axis orientation of 135/15SE (±05) after elimination of the three steepest southeasterly dipping beds (Figure 2.2). Outcrops on the northwest margin of the basin

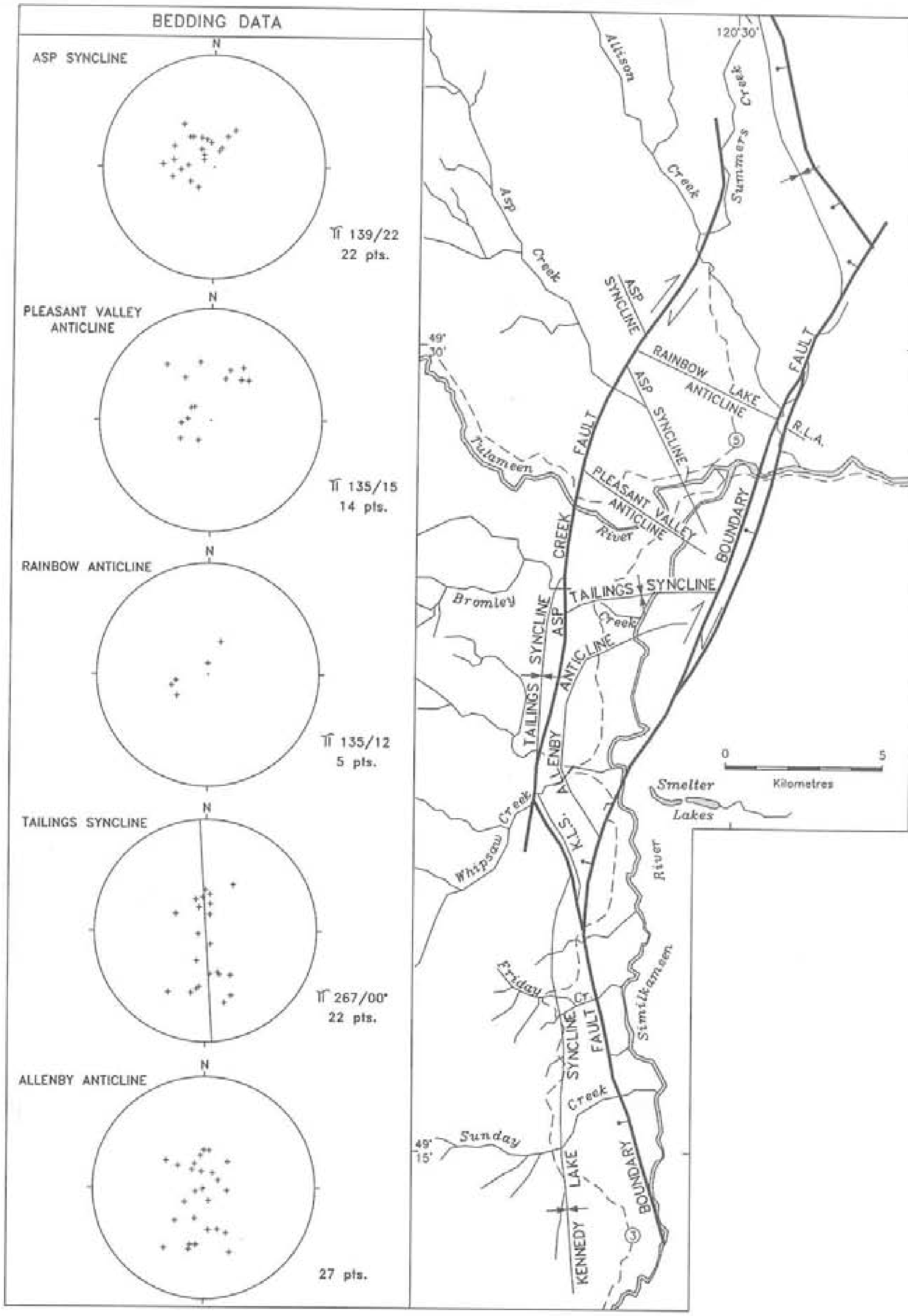

Figure 2.2. Bedding and fold data from the Allenby Formation of the Princeton basin.

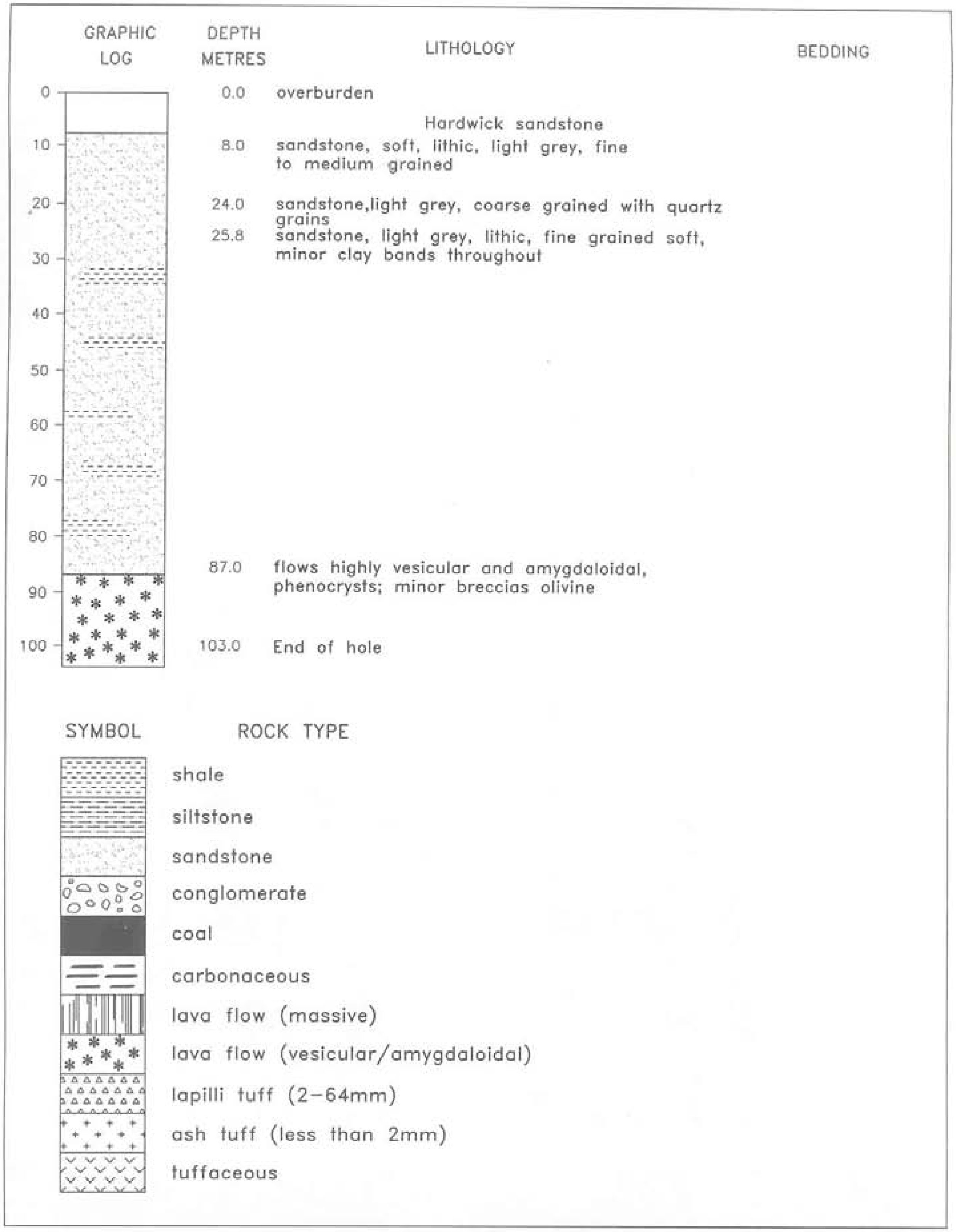

Figure 2.3. Log of vertical rotary-drillhole UP-5, Princeton basin.

show that Cedar Formation underlies the two anticlines, but it is absent in the intervening syncline.

In the Allenby Formation, the distribution of Eocene sedimentary units clearly shows that the Pleasant Valley anticline lies along a paleotopographic high, capped by Eocene volcanic rocks, that apparently prevented the southward distribution of the Hardwick sandstone, Snowpatch ash, China conglomerate, Asp Creek ash and Princeton ash (Section C-D, OF 1987-19). The northern limit of the ash units lies south of a paleotopographic high, capped by Eocene volcanic rocks, along the Rainbow Lake anticline. The intervening Asp syncline, with no underlying Eocene volcanic rocks, lies along a paleotopographic low which contains the ash units and the greatest thicknesses of the Hardwick sandstone, Vermilion Bluffs shale and probably the Summers Creek sandstone.

South of Princeton, the Tailings syncline and Allenby anticline dominate the structure of the Eocene basin for more than 30 kilometres. The shorter of these, the Allenby anticline, extends for 10 kilometres between its terminations on the Boundary fault (OF 1987-19). Although it is clearly defined by bedding attitudes and the distribution of the Ashnola shale on the Similkameen River 6 kilometres south of Princeton, the irregularity of bedding attitudes thwarts determination of the orientation of the fold axis (Figure 2.2). West of the Similkameen River a few northerly striking bedding attitudes show that the fold has changed its trend to south-southwesterly (Section U-V, OF 1987-19), and in the Blue Flame No.2 mine workings, Shaw (1952a, p.22) and Hughes (1955, p. A234) noted that the workings are wrapped around the northwesterly plunging hinge of a gentle anticline. With the change to a northwesterly plunge, the Allenby anticline broadens, disappears southwards and perhaps does not reach the Boundary fault.

Near the Similkameen River, about 5 kilometres south of Princeton, bedding attitudes and the distribution of the Summers Creek sandstone, Tailings ash, and Ashnola shale, define the west-trending Tailings syncline (Figure 2.2 and Section C-D, OF 1987-19). East of the Similkameen River, a statistical analysis of the bedding indicates that the orientation of the fold axis is 267/flat. West of the Similkameen River, projection of the syncline mimics that of the adjacent Allenby anticline and fulfills the restriction that the axial plane must lie east of the Summers Creek sandstone intersected in diamond-drill holes 75-13 and 75-14 (Anderson, 1976). Furthermore, in the vertical diamond-drill holes 71-12 and 76-15 (Anderson ,1972, 1976), the depth of intersection of a distinctive sandstone layer in the Ashnola shale, and bedding that is perpendicular to the core axis, indicate horizontal bedding atitudes which are consistent with proximity to the fold hinge as shown in Section U-V (OF 1987-19). South of Whipsaw Creek, a splay from the Boundary fault subparallels the syncline and complicates its southward projection. In this area, bedding attitudes in the Nicola Group define the Kennedy Lake syncline (Preto, 1972, p. 51). Not until Sunday Creek, do bedding attitudes in the Eocene Sunday Creek conglomerate and tephra outline the open, gentle northerly plunging Kennedy Lake syncline.

FAULTS

Two major northerly striking faults affect the Princeton basin. The Boundary fault (Preto, 1972) defines most of the eastern margin of the basin, and the Asp Creek fault, part of the western margin of the basin. Near Smelter Lakes, the Boundary fault veers to the north-northeast and lies close to the boundary between Eocene and older rocks. The dip of the fault has been defined in two places: one a short distance south of Deep Gulch Creek and immediately east of Highway 3, where drilling defined a 45° to 60° westerly dip (Preto, 1972, p.57); the second in an exposure on the east bank of Allison Creek, south of the United Empire mine, where the attitude of the fault is 350/68SW with dip-slip slickensides and a fault drag that is consistent with normal displacement. McMechan (1983, p.34) inferred a displacement in the order of 1400 metres. Along the east side of the basin, the Boundary fault is probably a zone of faults as described by Preto for the area south of Smelter Lakes. West of Allison Creek, a splay seems necessary to resolve structural and stratigraphic inconsistencies.

The Asp Creek fault is a north-northeasterly striking structure which lies mainly within the Eocene basin and only locally forms the faulted edge on its western side. The Asp Creek fault of this study coincides with McMechan's Asp Creek fault (1983, p.34) only where he defined it in the Tulameen River about 4 kilometres west of Princeton. From Tulameen River it strikes north-northeasterly to a roadcut between Hardwick and Asp creeks where an exposed subparallel fault has an attitude of 051/72SE with horizontal slickensides. The fault continues north-northeasterly along Summers Creek west of diamond-drill holes PC-4 and PC-5 (Nicholson, 1981; Section A-B, OF 1987-19). Six kilometres south of Tulameen River, near Tracey Lake, drill intersections of fault zones and sandstones are reconciled by a southward extension of the Asp Creek fault along the trace of an unnamed fault shown by Anderson (1972). Because the continuity in the old workings of the Blue Flame No.1 mine precludes a projection of the fault east of the mine portal, the fault probably passes to the west where the lack of development workings could be the result of the fault termination of the seam against the Asp Creek fault.