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PAPER 67-42

EARLY TERTIARY STRATIFIED ROCKS, GREENWOOD MAP-AREA, (82 E/2) BRITISH COLUMBIA

(Report, 4 figures and Map 10-1967)

J. W. H. Monger

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ABSTRACT

Early Tertiary continental sedimentary rocks and volcanic rocks and their intrusive equivalents underlie much of Greenwood map-area (82 E/2), British Columbia. Lying with marked unconformity on Cretaceous and older rocks, the Eocene Kettle River Formation consists of feldspathic and lithic volcanic sandstone and shale, with subordinate conglomerate, pyroclastic rocks and dacite, derived largely from acidic and intermediate volcanic rocks and basement rocks. Thickness of this unit ranges from a few hundred to at least 4,000 feet. Volcanic rocks, mainly flows, comprise the overlying Eocene Marron Formation, which is conformable with, and a partial facies equivalent of, the Kettle River Formation. This formation ranges from 300 to 6,000 feet in thickness, and consists of a lower division of sodic trachyte and minor phonolite, an intermediate division of andesite, and an upper division of andesite tending dacite. This stratigraphy is remarkably similar to that in the type-area of the Marron Formation, 30 miles east-northeast of Greenwood map-area. Intrusive equivalents of these flows form numerous small bodies. In one place the Marron Formation is overlain by a possible slide breccia of Oligocene (?) age; everywhere else the upper contact is a Pleistocene or Recent erosion surface.

These rocks are preserved in structurally low fault blocks cut by and bounded by numerous normal faults. Displacement on the faults ranges from a few inches to at least 6,000 feet, and although some faulting probably occurred during deposition of the early Tertiary rocks, most appears to be later, and is possibly Oligocene in age. The only other Tertiary structures are large anticlines formed by arching of Tertiary stratified rocks over intrusions consisting of rocks equivalent to extrusive rocks forming the lower part of the Marron Formation.

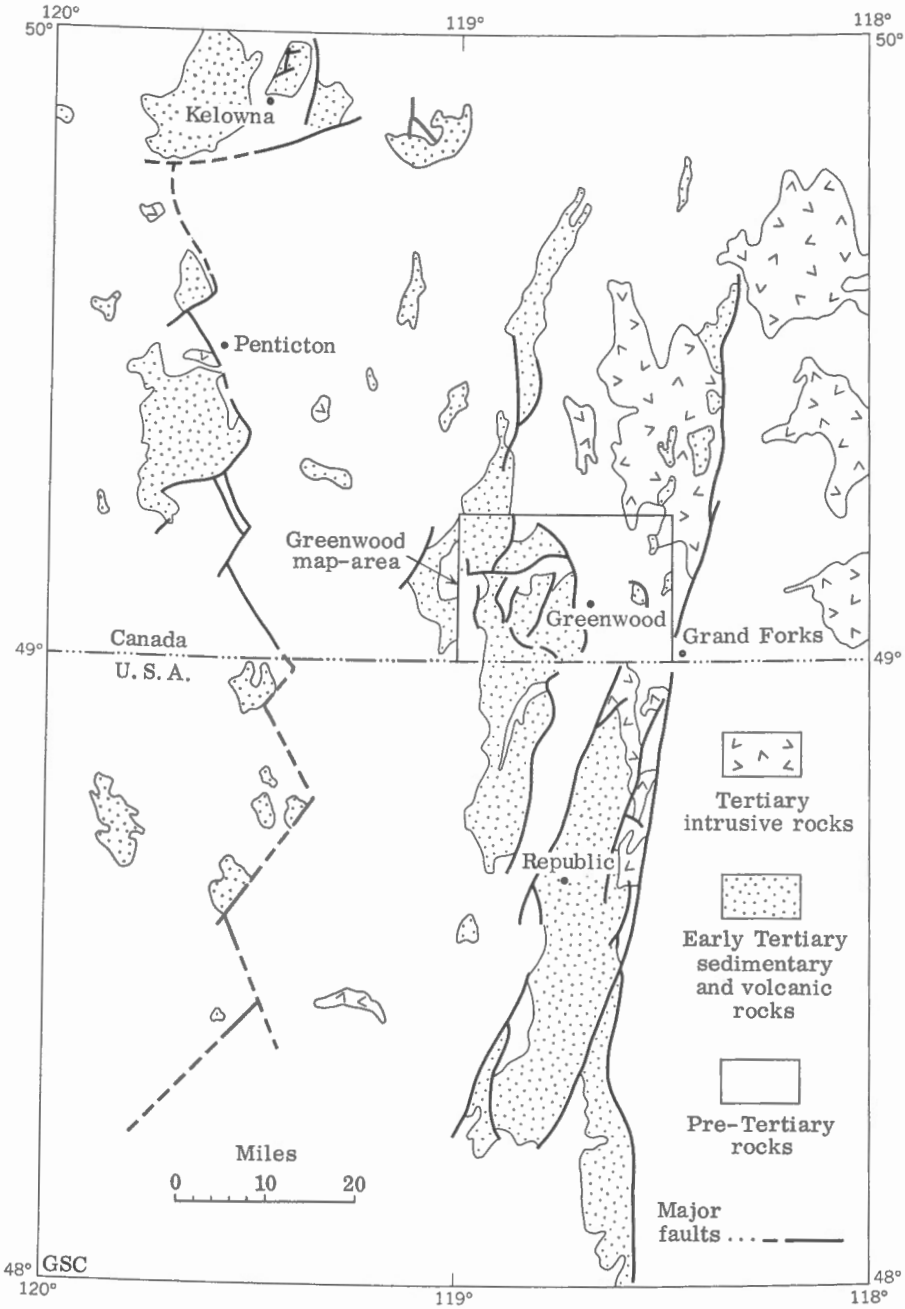


Figure 1. Distribution of early Tertiary rocks in parts of south-central British Columbia and northern Washington

EARLY TERTIARY STRATIFIED ROCKS, GREENWOOD MAP-AREA, BRITISH COLUMBIA

INTRODUCTION

The early Tertiary volcanic and sedimentary rocks in Greenwood map-area (82 E/2, bounded by latitudes 49° to 49°15'N and longitudes 118°30' to 119°W) form one of the larger of the areas of early Tertiary stratified rocks that are scattered across south-central British Columbia and north-central Washington (Fig. 1).

The study on which this report is based was initiated primarily to determine the thickness and structure of Tertiary rocks in the west half of the map-area where they cover older rocks whose stratigraphic equivalents elsewhere in the map-area contain important metalliferous ore deposits. In addition, the results obtained allow the early Tertiary succession in Greenwood map-area to be precisely correlated on the basis of lithology with other early Tertiary rocks in the region, and permit a necessary revision of the stratigraphic terminology.

FIELD WORK AND ACKNOWLEDGMENTS

This investigation is part of a comprehensive, continuing study of the region by H.W. Little, and is based largely on geological mapping on a scale of 1 inch to 1 mile principally in the west half of Greenwood map-area (82 E/2), undertaken by the writer in the summer of 1965. In addition, Tertiary rocks in the east half of Greenwood map-area, mapped on the above scale in 1963 and 1964 by H.W. Little and R.I. Thorpe, were examined briefly by the writer during 1965.

The writer's work was directed by H.W. Little, whose knowledge of the geology of the region was of considerable help. Valuable suggestions were made by B. Neil Church, based on his research experience with early Tertiary rocks in southern British Columbia, and by Robert C. Pearson, of the United States Geological Survey, who mapped the area south of the west half of Greenwood map-area, and who visited the writer in the field. Able assistance in the field was provided by A.N. LeCheminant. Chemical analyses were carried out in the laboratories of the Geological Survey by S. Courville.

PREVIOUS WORK

First recorded geological observations in the map-area were made by Bauerman (1884, p. 20B) who noted, apparently in reference to Tertiary rocks, the abundance of "porphyritic dykes, greenstones, syenites and elvans" penetrating slates and greenstones.

Manuscript received: March 29, 1967.

The earliest work on the Tertiary rocks was done by Brock (1902, 1903) who mapped the topography and geology of the area around Greenwood on a scale of 1 inch to 1 mile. He recognized the two-fold division of the Tertiary rocks into older pyroclastic or sedimentary rocks and very briefly described them.

Daly (1912, pp. 394-423) made the first detailed study and applied the presently widely accepted nomenclature. He called plant-bearing feldspathic sandstone, conglomerate and breccia the Kettle River Formation. Penhallow (in Daly, 1912, p. 828) believed the flora in these rocks to indicate an Eocene, rather than Miocene age, although Daly (1912, p. 397), on Penhallow's evidence, called the rocks Oligocene. Extrusive rocks conformably overlying these rocks Daly called Midway volcanic group. Within this group he distinguished the following nine lava types: olivine basalt, augite andesite, hornblende-augite andesite, biotite-augite andesite, hornblende-augite-biotite andesite, biotite andesite, trachyte, extrusive rhomb-porphyry and an analcitic lava, with intercalated pyroclastic rocks, and described in great detail the petrology of the last two lava-types. In addition, he related some of these extrusive rocks to various Tertiary intrusive rocks in the area, and arrived at a stratigraphic succession (see Table II) seemingly largely on the basis of the crosscutting relationships of these intrusives.

LeRoy (1912, pp. 42-52) described early Tertiary sedimentary and volcanic rocks isolated from the main outcrop area at Phoenix, east of Greenwood, and correlated them with Daly's stratigraphic units, which are named from localities to the southwest of Greenwood.

Little (1957) mapped the Kettle River area, 8E (east), on a scale of 1 inch to 4 miles. He renamed Daly's Midway volcanic group on grounds of priority, calling it the Phoenix volcanic group, and on the basis of plant fossils classified these rocks as Eocene or Paleocene.

Church (1963) described the petrology and chemistry of some volcanic rocks from this area in his study of Tertiary lavas from south-central British Columbia and recognized the following three compositional trends: an andesite to rhyolite trend, an andesite to trachyte trend and an andesite to analcite rhomb-porphyry trend.

STRATIGRAPHY

Early Tertiary rocks of Greenwood area consist of a lower sequence of predominantly clastic rocks and a conformable upper sequence of mainly extrusive rocks, the middle part of which is of middle Eocene age. Extensive normal faulting, with fault displacements ranging from a few inches to more than 5,000 feet, generally accompanied by tilting, has affected all of these rocks and they now occur in fault blocks, and in many places are isolated from equivalent rocks by upfaulted older rocks.

The lower sequence, the continental Kettle River Formation (Daly, 1912, p. 394), lies unconformably on a basement composed of late Palaeozoic and early Mesozoic sedimentary, volcanic and generally low-grade metamorphic rocks, intruded by Cretaceous granodiorite and granite, and consists of a discontinuous basal conglomerate above which are volcanic sandstone and siltstone, acidic pyroclastic rock, acidic lava, shale and relatively minor conglomerate.

TABLE OF FORMATIONS

Era	Period	Formation and thickness (feet)	Lithology
CENOZOIC	Pleistocene to Recent		Glacial silts and sands, alluvium, etc.
	Unconformity		
	Oligocene (?)	Undesignated breccia	Brecciated chert, greenstone, igneous plutonic rocks
	Unconformity (?)		
	Eocene	Marron Formation and related intrusions 5,000 ±	Porphyritic andesite and trachyte, minor pyroclastic rocks
		Kettle River Formation 300 to 4,000	Volcanic sandstones, acidic pyroclastic and flow rocks, shale, conglomerate
Unconformity			
MESOZOIC	Cretaceous	(?) Valhalla and Nelson intrusions	Granite, quartz monzonite, granodiorite, quartz diorite, minor serpentine
	Intrusive contact		
	Triassic		Limestone, chert sharpstone conglomerate, minor skarn, siltstone, green argillite and agglomerate
Unconformity (?)			
PALAEOZOIC	Permian and/or earlier		Chert, greenstone, black phyllite, schist, amphibolite, limestone and argillite

The overlying sequence, the Midway volcanic group of Daly (1912, p. 398), which the writer correlates with Bostock's (1941) Marron Formation and which is referred to as the Marron Formation in this report, consists largely of porphyritic andesitic to trachytic flow rocks with minor interbedded tuffs. These rocks are gradational and partly contemporaneous with the uppermost rocks of the Kettle River Formation, but are mostly younger.

The Marron Formation is apparently overlain by a breccia consisting of fragments of chert, greenstone, and igneous plutonic and hypabyssal rocks of unknown age; this is tentatively correlated with similar rocks of Oligocene age in northern Washington.

The nature of these volcanic rocks and their structure made elucidation of their stratigraphy difficult. In places where such criteria as brecciated flow tops, transitional contacts with tuffs, or conversely, cross-cutting relationships are not seen, it is difficult to distinguish extrusive rocks from stratiform intrusive rocks. In some instances, such stratiform bodies may be inferred to be intrusive either from their anomalous position in a known stratigraphic section, or else by the coarseness of the groundmass of the rock comprising them, relative to that of a known extrusive equivalent. As noted above, the Tertiary rocks are displaced by numerous normal faults, and in many cases precise correlation between stratigraphic sections in different fault blocks is not possible, as individual flows are apparently of limited extent. The faults themselves rarely can be seen directly and are commonly inferred from the anomalous juxtaposition of adjacent strata. In places where lithology is uniform and the unit thick, many faults are probably not detected and apparent thickness, as deduced from the dip and outcrop width of the unit in the dip direction, may be much greater than the true thickness.

KETTLE RIVER FORMATION (UNIT 3)

The term Kettle River Formation was applied by Daly to the Tertiary sedimentary rocks that are exposed intermittently along Kettle River valley for 15 miles west of the settlement of Midway. Daly remarked that the formation is now extremely discontinuous, being cut by numerous faults and intrusions and buried by overlying volcanic rocks, and largely because of this discontinuity he was unable to describe a complete section from any one locality, and instead gave a composite section with a minimum thickness of 2,100 feet (Daly 1912, pp. 394-395).

Thickness and distribution

The Kettle River Formation (unit 3) is widely distributed in the western half of Greenwood map-area, particularly in the northern part; it occurs locally in the eastern half. The formation apparently underlies the Marron volcanic rocks everywhere, and in places where the volcanic rocks are in juxtaposition with rocks older than the Kettle River Formation, then the existence of a fault between the two is certain or at least probable.

The topographical expression of the formation is rarely strong, and never as great as that of the overlying Marron Formation. In places such as in the Kettle River valley between Midway and Rock Creek, it is very weak. There the formation, largely fine-grained clastic rock, is locally cut by numerous minor bodies of intrusive rock which tend to form outcrops, in contrast to the recessive Kettle River rocks. Thus the intrusive rocks may appear to be far more abundant than the host rocks, even though the former probably comprise only a relatively small part of the underlying bedrock. Elsewhere, particularly in the northern part of the west half of Greenwood map-area, the Kettle River Formation is coarse-grained and has a relatively strong topographic effect, as shown by the prominent, white-weathering cliffs of Kettle River sandstone on the east side of Kettle River, just south of its confluence with West Kettle River.

The original thickness of the Kettle River Formation, in the southern part of the west half of the map-area is about 2,000 feet, and in the northern part is at least 4,000 feet, and may be considerably greater. In the east half of the map-area, the thickness is several hundred feet. Only approximate thicknesses can be given and even these can be obtained from relatively few places, because of the common paucity of outcrop, the general lithological uniformity of the unit in any one area and the concomitant difficulty of recognizing repetition or omission of strata by faulting, the possible dilation effects due to stratiform intrusions, and the fact that the stratigraphic base of the unit is exposed in only a few localities. On the divide between Nicholson Creek and Kettle River, about 5 miles west-northwest of the settlement of Rock Creek, both the stratigraphic base and top are exposed in what appears to be the same fault block. The thickness here is probably just over 2,000 feet. About 2 miles to the north, the Kettle River Formation is deformed into a large north-northwest trending anticline and the thickness of the formation, from the base of the Marron Formation exposed on the eastern limb to the lowest rocks exposed in the core of the anticline, is about 4,000 feet, but the base is not seen. Thickness of the sandstone-shale sequence on the north side of the west end of Myers Creek canyon is about 2,000 feet, but there the base is an intrusive contact. The formation appears to have a thickness of many thousands of feet to the south of Windfall Creek, in the north-central part of Greenwood map-area. However, the presence of several known faults and doubtless many undetected faults, makes the apparent thickness probably much greater than the true thickness. The isolated patch of Kettle River sandstone exposed at Phoenix, 4 miles east of Greenwood, has a maximum thickness of 260 feet (LeRoy, 1912, p. 42). At Fisherman Creek, about 4 miles east of Phoenix, the formation is about 1,200 feet thick.

No sections were measured and described in detail because of the uncertainty of structure and lack of continuous outcrop in most places. However, several lithological types are distinguished within the formation; these are feldspathic volcanic sandstone, lithic volcanic sandstone and finer equivalents of these, together with shale, tuff, agglomerate, dacite and conglomerate.

Feldspathic volcanic sandstone

Feldspathic volcanic sandstone is the most characteristic and apparently the most abundant rock type in the formation, and is a white,

cream, pale grey or buff clastic rock largely composed of very coarse sand-sized grains of feldspar and subordinate quartz. This rock type forms the lower part of the formation in Kettle River valley, just south of its junction with West Kettle River valley, most outcrops in the extreme northwest part of the map-area, to the north and west of Wallace Creek, in Nicholson Creek valley, and in the area to the east between Nicholson and Ingram Creeks. It is present at several localities on the north side of Kettle River valley west of Midway, although there it is generally subordinate to finer grained rock. Rock of similar lithology is present at Phoenix and comprises most of the formation at Fisherman Creek, 4 miles east of Phoenix.

This rock is typically structureless and generally massively-bedded. It forms characteristic white weathering outcrops, in many of which no bedding can be distinguished; in others bedding is defined by layers of slightly coarser, angular to rounded clasts, consisting of white quartz-feldspar porphyry, leucogranite or granodiorite. Typical examples of this rock may be friable or indurated, are moderately to well-sorted and consist of clasts most of which range from 0.5 mm to slightly greater than 2mm in diameter. They are composed of up to 60 per cent feldspar, with plagioclase generally two or three times as abundant as orthoclase, and up to 20 per cent quartz, with subordinate, bent and broken wisps of muscovite, lithic volcanic fragments, rare granitic fragments, chert and shale chips, and in places, carbonaceous fragments or pyrite (Fig. 2). The feldspars are angular, and the plagioclases are mainly albite but may be as calcic as An_{50}. They are commonly altered to very fine-grained brownish material, sericite, or rarely, carbonate. The quartz is generally unstrained, and many grains are sub-equant and are rounded or embayed; others are both partly rounded and partly angular and still others are wholly angular. These factors indicate that much of the quartz in these rocks is of volcanic origin (Folk, 1961, p. 69).

These rocks, composed largely of feldspar and quartz, are called feldspathic volcanic sandstone because although the presence of granitic clasts in some slightly coarser, conglomeratic layers suggests that some of the material in the finer grained rocks may be of plutonic origin, and that this rock could possibly be called an arkose (a term classically applied to consolidated granitic detritus, Oriel, 1949), most of the material appears to be of volcanic origin. This is suggested by the presence of quartz-feldspar porphyry clasts in the coarser layers, together with interbedded (?) dacite, the characteristics of the ubiquitous quartz grains, and the subordinate amounts of any identifiable non-volcanic clasts. The rock is commonly too well-sorted to be a primary tuff, even though the common angularity of the grains suggests a short transport history, and no direct evidence of a tuffaceous origin, such as the presence of shards, has been seen. Thus these rocks are called feldspathic volcanic sandstones, to emphasize their origin, although possibly they grade locally into either acidic tuff or arkose.

Lithic volcanic sandstone

On both sides of Kettle River valley, south of its junction with West Kettle River valley, the feldspathic volcanic sandstones are replaced upwards in the section by grey to grey-green, brown-weathering. lithic volcanic sandstones. In this part of the map-area the total exposed thickness of

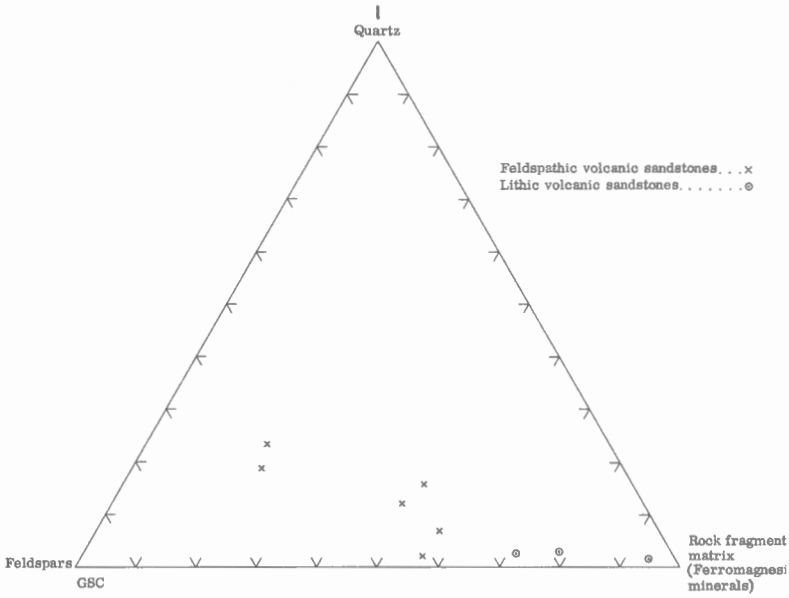


Figure 2. Compositions of some Kettle River Formation sandstones from Greenwood map-area

the formation is 4,000 feet. Of this, the lower 2,300 feet is white to buff feldspathic volcanic sandstone and the upper 1,700 feet grey-green lithic volcanic sandstone. The lithic volcanic sandstone tends to be of finer grain size than the feldspathic volcanic sandstone, although similar in other physical characteristics, but it differs markedly in composition. Lithic volcanic fragments predominate, and comprise 30 to 40 per cent of the rock (Fig. 2). These fragments are typically very fine grained, semi-opaque, contain abundant microlites, and are of andesitic composition. In addition, uniformly altered detrital grains of chloritic material (altered glass ?) are common. Feldspars may comprise up to 20 per cent of the rock, and are mainly sodic plagioclase, although orthoclase is present in minor amounts. The amount of quartz is commonly less than 5 per cent, and some grains are sutured, have undulose extinction, and are probably of plutonic origin. Minor amounts of biotite are present in some of these rocks. This rock type grades upwards into andesitic tuff and local agglomerate just below the base of the Marron Formation.

In and to the south of Kettle River valley between the settlements of Midway and Rock Creek, and in the southernmost part of Nicholson Creek valley, the formation as a whole is much finer grained than in the northern half of the map-area, although massive beds of coarse-grained feldspathic volcanic sandstone occur locally. In addition, the division between the 'white', lower, feldspathic volcanic sandstones and 'green', upper, lithic volcanic sandstones becomes much less marked, and apparently disappears completely south of Kettle River valley, about 3 miles east of Rock Creek. At this point on the north side of Kettle River valley, the lower part of the section consists of pale to dark grey shale, siltstone (some of which is pale grey and extremely hard), and fine- to medium-grained buff weathering feldspathic volcanic sandstone. These rocks form regularly alternating thin beds, and locally contain massive beds, 20 feet or more in thickness, of buff to white feldspathic volcanic sandstone. Local crossbedding laminae occur in some fine-grained beds but they are very rare, and grading appears to be absent. Shale fragments are present in many beds and carbonaceous plant material is common, particularly on bedding planes. These sedimentary rocks grade upwards into tan weathering, grey-green to brown, fine grained lithic volcanic sandstones, siltstones and shales, which correspond to the coarse lithic volcanic sandstones farther north in the map-area. To the south of Kettle River valley at the west end of Myers Creek canyon, thin to massively bedded lithic volcanic sandstones with interbedded shales comprise much of the section. One medium-grained, moderately sorted sandstone from this part of the map-area is composed of approximately 35 per cent volcanic fragments, 15 per cent feldspar and 10 per cent quartz clasts, the remainder being chloritic matrix. All of the clasts are angular. The volcanic clasts are predominantly lithic fragments of intermediate composition, consisting of microlites in a semi-opaque groundmass, but some appear to be altered volcanic glass. The feldspars are mainly sodic plagioclase but orthoclase is present as well. The characteristics of the quartz grains indicate that most are of volcanic origin, but a few sutured grains with undulose extinction, appear to be derived from plutonic rocks.

Primary volcanic rock

Two varieties of primary volcanic rock are in the formation; both are of minor abundance compared to the sandstones described above.

Porphyritic dacite in the lower part of the formation is associated with and probably gradational to the feldspathic volcanic sandstone, and tuff of intermediate composition forms the transition between the uppermost lithic volcanic sandstone and overlying intermediate volcanic rock of the Marron Formation.

The dacite outcrops locally in the northwestern part of the map-area, in and south of the lower part of Fiva Creek, and in Kettle River valley, about 2 miles south of its junction with West Kettle River valley and appears to be intercalated with the coarse, white feldspathic volcanic sandstone. It is invariably porphyritic, generally consisting of round quartz "eyes" up to 5 mm in diameter, although as a rule considerably less, and white or pink feldspar up to about 8 mm long in a fine-grained, pale green, white or pale purplish-grey matrix, the latter making up about 60 per cent or more of the rock in some cases. The matrix to grain ratio is commonly high, and serves to distinguish it from the feldspathic volcanic sandstones, which otherwise it would closely resemble. The quartz is invariably clear and commonly corroded. Most feldspars are plagioclase, usually andesine to oligoclase, and potassium feldspar, though present, is relatively minor. The matrix consists largely of devitrified glass, but in places contains minute orthoclase crystals and greenish mica shreds. Because the relationship between the dacite and contiguous sandstone was not observed by the writer, he is uncertain whether these rocks are near-surface intrusions or flows.

A few feet of tuff of intermediate composition is present at almost all localities where the contact between the Kettle River Formation and the Marron Formation has been observed. The tuff is composed largely of lithic clasts, but in addition locally contains crystals of clinopyroxene, feldspar euhedra, some of which are rhomb-shaped, and, very rarely, quartz crystals. These rocks grade downwards into the lithic volcanic arenites, from which they differ in their total lack of sorting and absence of any material of non-volcanic origin. They are overlain by agglomerates consisting of lava fragments in a matrix of similar composition and porphyritic flow rocks containing feldspar rhombs forming the basal part of the Marron Formation.

Conglomerate, breccia

Conglomerates and breccias occur at all stratigraphic levels in the formation. In addition to a local basal conglomerate derived from basement rocks, there are conglomerates and breccias generally consisting of clasts derived either from basement and acidic volcanic rocks or from basement and intermediate volcanic rocks. The former are associated with the feldspathic volcanic sandstones, and the latter with the lithic volcanic sandstones.

Conglomerate is present locally at the base of the formation, and varies from a few feet to several hundred feet in thickness. On the divide between Kettle River and Nicholson Creek the basal conglomerate is a few feet in thickness, lies unconformably on grey to greenish chert, and consists of boulders up to 4 feet in diameter, but commonly less than 1 foot, of chert, greenstone and granodiorite in a feldspathic matrix. The larger clasts are angular, the smaller rounded. About 4 miles farther north, on the divide between Nicholson and Fiva Creeks, the basal conglomerate is local and composed of rounded boulders of leucocratic pink granite, granodiorite and minor

chert and overlies both cherty argillites and granodiorite. In the southwestern part of the map-area several hundred feet of conglomerate rests on chert or crystalline limestone; this contains chert and granodiorite clasts up to 2.5 feet in diameter.

The conglomerates and breccias intercalated with the feldspathic volcanic sandstones contain either clasts derived from basement rocks, or from acid volcanic rocks, or from both. Such conglomerates are particularly abundant in the formation just south of Fiva Creek, in the northwestern part of the map-area. A typical specimen contains 70 per cent granodiorite cobbles, 10 per cent chert fragments with the remainder acid volcanic clasts, mainly quartz-feldspar porphyries, set in a feldspathic matrix. Although most of these conglomerates are cobble or pebble conglomerates, some contain very coarse clasts. A granodiorite block nearly 12 feet long was seen in a boulder-cobble conglomerate to the south of Fiva Creek.

Breccias composed almost entirely of angular quartz-feldspar porphyry and dacite tuff (?) clasts in a feldspathic matrix occur at many localities in the formation, and with a decrease in grain size these grade into the typical feldspathic volcanic sandstones.

In the upper part of the formation about 1 1/2 miles south of Fiva Creek, conglomerates interbedded with lithic volcanic sandstone contain cobbles of andesite and trachyte in addition to material derived from basement rocks, in a rusty weathering lithic volcanic matrix. In one such conglomerate, 75 per cent of the cobbles are granitic rocks and the remainder, porphyritic andesite and trachyte. As feldspar-rhomb phenocrysts in the latter characterize rocks forming the lower part of the Marron Formation, both the conglomerates and lithic volcanic sandstones may be partly derived from rocks of the Marron Formation.

Summary, age and correlation

Clastic rocks in the Kettle River Formation in Greenwood map-area were derived from four sources, listed below in the probable order of amounts derived from each source. Acid volcanic rocks, probably mainly crystal tuff, but including some flow and hypabyssal rocks, were the major source, and supplied the volcanic quartz and presumably much of the feldspar to the feldspathic volcanic sandstone. Intermediate volcanic rocks, probably of the Marron Formation, are the source of the lithic clasts that are prominent in the lithic volcanic sandstones which form the upper part of the formation in some places. Basement rocks supply granitic detritus, chert and greenstone clasts, some quartz and possibly some feldspars. Finally, intraformational shale beds provide some shale chips.

Local relief at the time the formation was being deposited may have been considerable. Evidence for this is provided by the conglomerates, which locally are very coarse and which consist of both basement and volcanic rocks. Possibly this relief was due in part to contemporaneous faulting, for the formation is at least 4,000 feet thick just north of the prominent east-west fault in the west-central part of the map-area but only 2,000 feet thick 1 1/2 miles south of this fault. In addition, the formation as a whole is coarser on the north side of this fault than on the south.

Both plant fossils and radiometric ages indicate that the Kettle River Formation is of Eocene age. Penhallow (in Daly, 1912, p. 828) considered that plant fossils collected by Daly from the formation indicate an Eocene, rather than Miocene age, although Daly (1912, p. 397) on Penhallow's evidence, called these rocks Oligocene. On the basis of palaeobotanical evidence, Little (1957) believed the formation to be Paleocene or Eocene. Plant fossils collected by Little from the southern end of Nicholson Creek were determined by G.E. Rouse to be of Eocene, probably middle Eocene age (Little, pers. comm., 1967). Rouse and Mathews (1961), and Mathews (1963, p. 4) obtained a potassium-argon age of 49 ± 2 million years for biotite from a tuff in the middle part of the Marron Formation, and considered this to be a middle Eocene age. As the Marron conformably overlies the Kettle River, and in part appears to be stratigraphically equivalent, the Kettle River Formation is probably also of Eocene age. Furthermore, Mathews (1963, p. 9) determined an age of 46 ± 2 million years for biotite from dacite exposed about 40 miles north of the map-area considered by Little (1961) to be equivalent to the Kettle River Formation in Greenwood map-area.

Clastic rocks of early Tertiary age outcrop in relatively small, isolated areas across much of south-central British Columbia and northern Washington (Fig. 1). These rocks are generally of similar lithology to the Kettle River Formation in Greenwood map-area and invariably lie unconformably on pre-Tertiary rocks and are overlain by volcanic rocks of intermediate composition. Little (1957, 1961) correlated isolated outcrops of Paleocene or Eocene acidic tuff and clastic sedimentary rocks in Kettle River map-area. In the east half of Kettle River area, which contains the Greenwood area, he included in the Kettle River Formation all early Tertiary "rhyolite and dacite tuff; local conglomerate, sandstone and shale; minor rhyolite flows and intrusive porphyritic rhyolite". Previously, Drysdale (1915) had described conglomerates, arkosic grits and waterlain tuffs associated with rhyolite flows in Franklin Camp, about 22 miles north of the northeasternmost part of Greenwood map-area and assigned them to the Kettle River Formation. In the western half of Kettle River map-area, the nomenclature applied to these rocks is diverse, and Little (1961) referred to them as Paleocene or Eocene sedimentary and pyroclastic rocks. Reinecke (1915) gave the name Curry Creek Series to conglomerate and tuff outcropping a few miles north of the northwesternmost part of Greenwood map-area, and believed them to be equivalent to the Kettle River Formation. On the west side of Okanagan Valley, sedimentary and pyroclastic rocks called Springbrook Formation by H.S. Bostock (1941) are analogous in stratigraphic position and lithology to the Kettle River Formation. A tuffaceous phase of this formation, described by H.H. Bostock (1966, pp. 7-12) is generally similar in composition to the feldspathic volcanic sandstone in Greenwood map-area. In northern Washington, Muessig (1962) Staatz (1964) and Parker and Calkins (1964) have demonstrated the presence of Eocene (?) pyroclastic and sedimentary rocks, unconformably above pre-Tertiary rocks and below Eocene volcanic rocks, for about 50 miles south of Greenwood map-area. Muessig (1962, pp. D56-D57) called these rocks the O'Brien Creek Formation and considered them to be roughly equivalent to the Kettle River Formation.

MARRON FORMATION (UNIT 4)

The writer proposes that early Tertiary volcanic rocks of intermediate composition which overlie the Kettle River Formation in Greenwood map-area be designated Marron Formation. These rocks were originally called "Midway volcanic group" by Daly (1912, p. 398) who applied the latter terminology to a sequence of early Tertiary volcanic rocks, predominantly flows, exposed for a distance of 14 miles to the west and 3 miles to the east of the settlement of Midway. Subsequently, Little (1957) renamed Daly's Midway volcanic group, on the grounds that the well-established, marine, sedimentary Eocene Midway Group of the Gulf Coast region of the United States has priority, and called it the Phoenix volcanic group. Later, Little (1961) retracted this new term. In 1941, H.S. Bostock applied the term Marron Formation to early Tertiary volcanic rocks outcropping in the vicinity of Marron River on the west side of Okanagan Valley, about 40 miles west-northwest of Greenwood map-area. The Marron Formation at this locality is complete and well-exposed and thus very suitable for a type-section according to B.N. Church, who has recently restudied the formation in great detail, and defined members within it. Because Daly's Midway volcanic group has to be renamed, and the stratigraphy of this unit in Greenwood map-area is remarkably similar to that of the Marron Formation in the type-area (see below, in discussion of correlation), the term Marron Formation is applied to it. This usage both emphasizes the similarity of the volcanic sequences in the two relatively widely separated areas, and also reduces the number of stratigraphic names applied to the various early Tertiary volcanic successions in south-central British Columbia.

Thickness and distribution

Rocks of the Marron Formation (units 4A, 4B, 4C) are widespread in the west-half of Greenwood map-area and in the east-half they outcrop at Phoenix and along to the north of Fisherman Creek. In the west-half of the map-area these rocks conformably overlie rocks of the Kettle River Formation, are locally gradational with it, and in places appear to be a partial stratigraphic equivalent. At Phoenix, LeRoy (1912, p. 28) stated that the Tertiary volcanic rocks unconformably overlie both the Kettle River Formation and older rocks. However, as this relationship is partly the result of later faulting, there appears to be no good evidence of unconformity at this locality. Elsewhere in the east-half of the map-area, the rocks are conformable. The Marron Formation is overlain by a breccia of Oligocene (?) age (unit 6) at one locality in the south-central part of the map-area.

The topographic expression of the Marron Formation in Greenwood map-area is generally strong. Different flows in the succession vary in resistance to weathering, flow breccias marking the tops of individual flows may weather more readily than the main body of the flows and there may be recessive tuff beds between flows. As most of the flows are now tilted, the net result is a series of cuestas in most areas underlain by Marron volcanic rocks. This feature is particularly well displayed on air photographs of the northwesternmost part of the map-area, about 6 miles north-northeast of the junction of Kettle and West Kettle River valleys, where the flows are tilted toward Kettle River valley and form closely spaced ridges. Even more spectacular is the stepped appearance of the hill on the

north side of Kettle River valley, about 6 miles east of the settlement of Rock Creek, where differentially weathered flows form a series of east-dipping terraces.

The original total thickness of the Marron Formation in the map-area is not known, as its upper limit is either an erosional surface or a fault plane. The present total thicknesses, given in Table I, are only approximate and some are possibly greater than true, because of repetition by undetected faulting. The maximum total thickness of the formation in Greenwood map-area, about 6,000 feet, is from a section about 3 miles west of Greenwood, on the north side of Copper Creek.

TABLE I

Maximum thicknesses (in feet) of the Marron Formation and its divisions, Greenwood map-area

Location of section	Division 4A	Division 4B	Division 4C	Total thickness	Nature of upper contact
Northwesternmost part of map-area	4,300	1,000	–	5,300	fault
West side, south end Nicholson Creek	1,000	2,000	–	3,000	fault
Myers Creek (composite section)	1,000	2,000	1,200	4,200	fault
1 1/2 miles north-northwest of Midway	600	2,000	600	3,200	fault (?)
1 mile southwest of Midway	700	1,400	1,400	3,500	limit of mapping
3 miles west of Greenwood	2,000	4,000	–	6,000	fault
Phoenix	> 300	–	–	>300	erosional surface
Fisherman Creek	300	–	–	300	erosional surface

The Marron Formation is composed largely of porphyritic trachytic to andesitic flow rocks with minor interbedded tuffs. On the basis of field work guided by earlier work (Daly, 1912, Church, 1963) the succession is divided into: a lower division 4a, composed predominantly of sodic trachyte, in part undersaturated and tending towards phonolite; an intermediate

division 4B of andesite to trachyandesite; and an upper division 4C consisting of andesite tending towards dacite. The distribution of these divisions is shown on the map. Although locally it is possible to subdivide these units on the basis of texture into different lava types which in some cases correspond to individual flows, these can rarely be traced very far, and are not distinguished on the map. A comparison of the terminology applied by Daly (1912, p. 420) with that used in this report is given in Table II.

TABLE II

Comparison of the terminology and stratigraphic succession of the early Tertiary lavas according to Daly (1912) with that in this report. Numbers in parentheses denote Daly's lava types and their revised nomenclature.

Daly (1912, p. 420)		This report	
Youngest group	analcitic lava (9) extrusive rhomb-porphyry (8) alkaline trachyte (7)	Division 4C	biotite-pyroxene or pyroxene andesite hornblende andesite (3, 4)
Middle group	biotite andesite (6) biotite-augite andesite (5) hornblende-augite-biotite andesite (4) hornblende-augite andesite (3)	Division 4B	Trachyandesite to andesite (7) amygdaloidal pyroxene andesite (2, 5, 6) pyroxene andesite (2 and ? 1)
Oldest group	augite andesite (2) olivine basalt (1)	Division 4A	predominantly sodic trachytes (8, 9)

Division 4A

Rocks included in division 4A (units 4Aa, 4Ab, 4Ac) are found in all localities in the map-area where the lowest part of the Marron Formation is exposed. This division ranges in thickness from over 4,000 feet in northwesternmost part of the map-area to about 600 feet in the vicinity of Midway (Table I).

Division 4A is composed mainly of sodic trachytes, some of which approach phonolite in composition, and minor amounts of true phonolite. All are porphyritic, and the phenocrystic feldspar is invariably anorthoclase and/or orthoclase. There are five main lithological varieties. In order of decreasing age these are local basal lavas characterized by flow breccias and agglomerates, pyroxene-feldspar and pyroxene-feldspar-rhomb-porphyry, dark analcite-bearing rhomb porphyry, and fine-grained feldspar porphyry. Most of these varieties are included in unit 4Aa, the local basal lava is distinguished as map-unit 4Ab, for reasons given below, and rocks mapped as 4Ac appear on field evidence to be related to the other rocks in the division, but have not been studied in sufficient detail to prove this.

The basal part of the formation at the northern end of the ridge between Nicholson Creek and Kettle River and for about 4 1/2 miles due east as far as the head of Ingram Creek valley, consists of grey-green to greenish brown flow and pyroclastic rocks, largely composed of angular to rounded, vesicular, fine-grained porphyry fragments up to about 6 inches in diameter, which contain pyroxene or feldspar phenocrysts, in a matrix similar in composition to the porphyry clasts. Pyroxene, generally with very high birefringence, is common in these rocks, feldspar is less common and generally is orthoclase (or anorthoclase (?)) and quartz is very rare. These rocks typically are partly altered to carbonate. They grade downwards through a few feet of lithic tuff into lithic volcanic sandstone forming the upper part of the Kettle River Formation in this part of the map-area.

In the northwestern part of the map-area, east of Kettle River, and north of a line due east of the confluence of Kettle and West Kettle Rivers, the lithic volcanic sandstone of the Kettle River Formation is conformably overlain by a succession of amygdaloidal, pyroxene-bearing, maroon weathering, medium grey-green lavas, flow breccias and probable agglomerates. In many places these rocks are highly altered to carbonate and semi-opaque clay minerals, and the apparent pyroxene phenocrysts are chlorite pseudomorphs. Feldspar phenocrysts are not common, although feldspar rhombs were seen at one locality.

The stratigraphic classification of these rocks is problematical. South of Fiva Creek, about 3 miles east of Kettle River, they are overlain by the pyroxene-feldspar porphyry below, which is the most characteristic lithological type in division 4A. North of Fiva Creek they grade upward into pyroxene andesite that is similar to rocks forming the lower part of division 4B elsewhere in the map-area. The pyroxene andesite is overlain in turn by pink trachyandesite, typical of the upper part of division 4B. The pyroxene-feldspar porphyry thus appears to be missing from this section, although it is rather thick and typically developed just to the west across Kettle River. With the exception of the trachyandesite, all of these rocks are included in division 4A, largely because of their stratigraphic position, but they possibly are closer lithologically to rocks forming the lower part of the division 4B. They are therefore distinguished on the map as unit 4Ab.

The most common lithological type in this division is probably pyroxene-feldspar porphyry (unit 4Aa) which forms much of the lower part. In places it overlies the basal lavas and agglomerates (unit 4Ab) described above, and elsewhere lies directly on the Kettle River Formation. This porphyry is characterized by conspicuous, commonly euhedral, clinopyroxene phenocrysts, by subhedral or euhedral feldspar phenocrysts, some of which are rhomb-shaped, and by the matrix, which is pale grey to medium grey in colour when fresh, or buff to pale grey when weathered. The ratio of phenocrysts to groundmass is generally about 1:4. Locally the rock is amygdaloidal, with large irregular phenocrysts filled with calcite, zeolites or, rarely, quartz. The pyroxene phenocrysts may be as much as 10 mm long but are commonly less than 5 mm. They are colourless to very pale green in thin section, 2V's range from about 60° to 80°, and many of the crystals have an abnormally high birefringence for common augite. Some phenocrysts enclose small apatite euhedra, or opaque mineral grains, and more rarely others are mantled by feldspar. The feldspar phenocrysts are generally smaller than pyroxene phenocrysts in the same rock. In some cases they consist of a core and mantle of different composition. The core is invariably

partly altered to carbonate and/or sericitic white mica and not uncommonly contains numerous opaque inclusions, whereas the mantling feldspar is generally fairly fresh. Where the core feldspar is in contact with the groundmass it is invariably corroded, but where it is surrounded by a mantle, the contact between the two feldspars is usually sharp, not uncommonly outlines a perfect rhomb, and the outer boundary of the mantle feldspar is corroded. Twinning of any kind is not common, but where present is of the grid type and restricted to the core feldspar. In phenocrysts that have been stained for potassium using sodium cobaltinitrite, the core shows patchy staining or is unstained, but the rim, where present, is stained yellow. Similar feldspars from the intrusive equivalents of this lava type were investigated both optically and chemically by Daly (1912, pp. 402-404) who concluded that the core feldspar was "best described as an abnormal anorthoclase, rich in the barium-strontium feldspar molecules", with an outer rim of orthoclase or sodic-orthoclase. Biotite, as euhedral and subhedral phenocrysts, invariably with an irregular frayed rim altered to iron oxide (?), is present in many places, but is never abundant. The finely granular groundmass commonly consists in large part of glass, but generally also contains small feldspar phenocrysts, opaque minerals, apatite and patchy carbonate. Nepheline is present in the groundmass of lava capping the knoll about 3/4 mile east of the mouth of Nicholson Creek. Leucite, characterized by its twinning, occurs both in the groundmass and in amygdules of lava just west of the confluence of Kettle and West Kettle Rivers.

About 3 miles southeast of this confluence, the basal flow in the Marron Formation is a pale grey, feldspar-rhomb porphyry, that grades upwards into pryroxene feldspar porphyry. This rhomb-porphyry is unusual in that the mafic mineral content is extremely low, being represented by very minor amounts of biotite, and the core has been completely altered in many of the feldspar phenocrysts, leaving a rhomb-shaped rim of feldspar.

Dark pyroxene or biotite-feldspar rhomb porphyry called 'shackanite' by Daly (1912, pp. 411-416), after a locality 4 miles west of the settlement of Rock Creek, is intercalated with the more common pyroxene-feldspar porphyry on the prominent north-trending ridge about 1 1/2 miles east of Nicholson Creek, on the south side of Kettle River valley one mile south of the southern end of this ridge, and also near the head of Ingram Creek valley. This rock is characterized by a groundmass which is very dark grey or brownish grey in colour and consists of small feldspar laths, small polygonal, euhedral analcite crystals and minor opaque minerals, in brownish, semi-opaque material. The feldspar phenocrysts in this rock, in contrast to those of the pyroxene-feldspar porphyry, tend to be fresh, glassy and small, and the pyroxenes are much less conspicuous.

Feldspar porphyry consisting of small white to pale green feldspar phenocrysts in a grey-green groundmass outcrops at the western end of Myers Creek canyon, on the western side of Nicholson Creek, in the northwestern part of the map-area and about 1 3/4 miles northwest of Midway. It overlies and is partly gradational with pyroxene-feldspar porphyry and is overlain by rocks included in division 4B. Feldspar phenocrysts comprise up to 20 per cent of the rock and are rarely greater than 4 mm in diameter. They are commonly subhedral with irregular grain boundaries, but poorly developed rhombs are seen locally. In composition these feldspars appear similar to those in the pyroxene-feldspar porphyry. They are zoned; staining with cobaltinitrite produces a yellow rim, whereas the core is unstained or only

patchily stained. These phenocrysts are always partly altered to carbonate. The groundmass consists of small, stubby feldspars, glass, chlorite, opaque minerals, apatite and very minor biotite. With an increase in pyroxene content, these rocks grade into pyroxene-feldspar porphyry.

Extrusive rocks exposed at Phoenix, referred by LeRoy (1912, p. 40) to the Midway volcanic group, belong to division 4A. According to LeRoy (1912, p. 45), the principal type is an augite trachyte, which he described as a "light brownish grey porphyritic rock with white weathering phenocrysts of feldspar, dark pyroxenes, and plates of brown biotite in a fine microcrystalline base, which contains noticeable grains of pyrite". The chemical composition of this rock is similar to that of the intrusive rhomb-porphyry from just west of the map-area (LeRoy, 1912, p. 46) which is the intrusive equivalent of the feldspar-rhomb porphyry in the west half of the map-area. The east-dipping succession of flow rocks on Deadman Ridge, just north of Phoenix, consists largely of the pyroxene-feldspar porphyry, but also contains fine-grained feldspar porphyry composed of small feldspar phenocrysts in a grey-green matrix, which is very similar to the fine feldspar porphyry in the west half of the map-area.

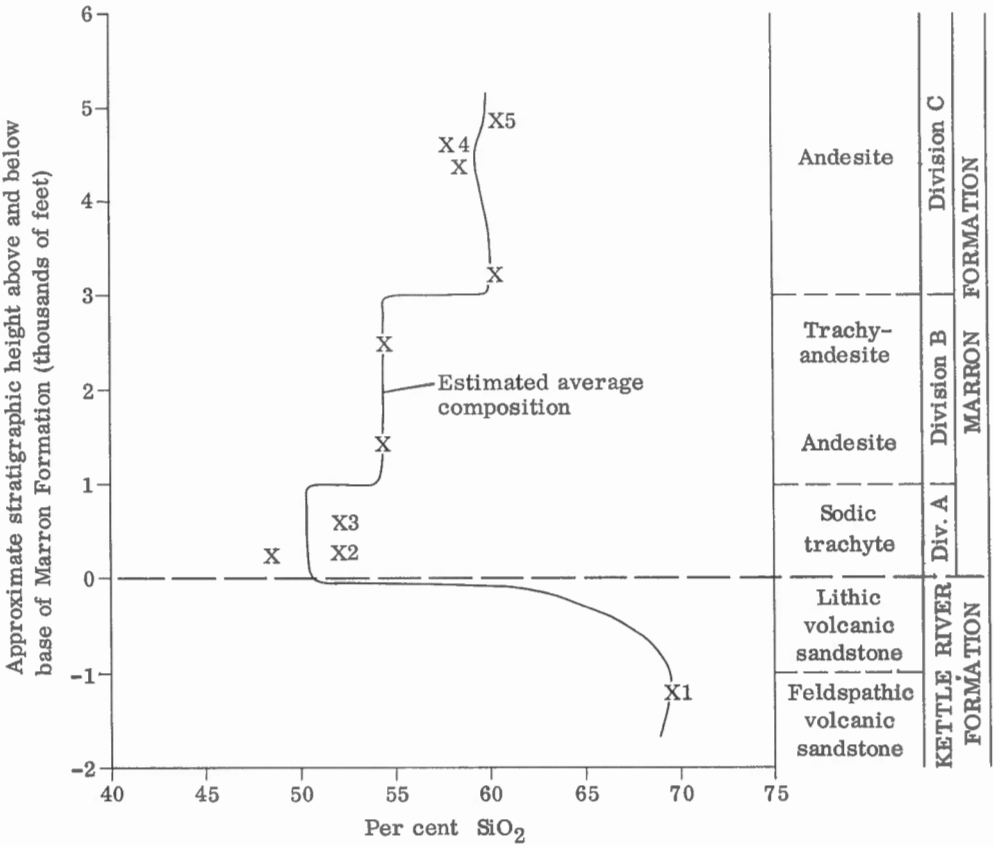
The medium grey feldspar porphyries (unit 4Ac) near Fisherman Creek in the westernmost part of the map-area have not been investigated in detail but are tentatively included in division 4A because their composition appears to be closer to rocks of this division than to any other.

These rocks of division 4a are mainly sodic trachytes. The silica content of analyzed rocks from this division is about 5 per cent lower than that of any other rocks in the Marron Formation in the map-area (Table III and Fig. 3), and the presence in some rocks of this division of such minerals as nepheline, analcite and leucite indicates their undersaturated nature. Some of these rocks thus approach phonolite in composition, and some, such as Daly's shackanite, are true phonolites. However, such undersaturated minerals have not been recognized in most rocks of this division; they are therefore grouped under the general term of 'sodic trachytes'.

Division 4B

Rocks included in division 4B (units 4Ba, 4Bb) outcrop in the western and southern parts of the map-area, and range in thickness from about 1,000 feet in the northwesternmost part of the map-area to 4,000 feet, 3 miles west of Greenwood.

Division 4B is composed of saturated andesite and trachyandesite with minor intercalated tuff. The several distinctive lithological varieties within it are given below, roughly in order of decreasing age. Locally, the oldest rock is a coarse- to medium-grained feldspar porphyry, possibly transitional in part to rocks of division 4A, but elsewhere division 4A is overlain by dark, heavy pyroxene andesite. Above these rocks there are highly amygdaloidal, altered pyroxene andesites and aphanitic andesite. Overlying these is a tuff (unit 4Bb) above which is the uppermost lithological variety, andesite to trachyandesite, generally with glomeroporphyritic texture.



X Specimens collected by writer
X1 Rhyolite within Kettle River Formation at Franklin camp collected by Drysdale, 1915, and included for comparison
X2 Augite trachyte, phoenix, collected by LeRoy, 1912
X3 'Shackanite' from just west of map-area, collected by Daley, 1912, and included for comparison
X4,5 Andesite, collected by Church, 1963

GSC

Figure 3. Variation of silica content with stratigraphic height

The coarse- to medium-grained feldspar porphyry outcrops on the ridge west of Nicholson Creek and in the northwesternmost part of the map-area, and overlies and is possibly intercalated with the fine-grained porphyry of division 4A. It consists of stubby phenocrysts of plagioclase, up to 1 cm long, associated with minor clinopyroxene and biotite phenocrysts in a brownish grey to pinkish grey groundmass. The plagioclase phenocrysts are generally solitary but may be in clusters. They are zoned and the composition, determined from Carlsbad-Albite twinning, ranges from An_{45} to An_{64}, most being in the sodic end of the range. Very rarely these plagioclases are mantled by potassium feldspar. The plagioclase feldspars are commonly altered, largely to carbonate. The pyroxenes are relatively fresh in some specimens, but generally are partly altered to carbonate, opaque minerals and chlorite; the shape of carbonate pseudomorphs suggests they were originally pyroxene. Biotite is generally rimmed by opaque alteration minerals. The groundmass consists chiefly of very small feldspars, scattered through a semi-opaque, greyish brown, probably glassy matrix.

Rusty to brown weathering, very dark grey to grey-brown pyroxene andesite overlies fine-grained feldspar porphyry of division 4A in Myers Creek canyon, about 2 miles from its western end, and outcrops on higher ground both north and south of the canyon. Similar dark brown pyroxene andesite overlies coarse-grained feldspar porphyry on the ridge west of Nicholson Creek, and about 1 mile west of Kettle River valley on the northern boundary of the map-area and also is in contact with pyroxene-feldspar porphyry of division 4A 3 1/2 miles west of Greenwood. This rock is porphyritic, with clinopyroxene and feldspar phenocrysts in an aphanitic groundmass, the latter comprising about 80 per cent of the rock. The feldspar phenocrysts are commonly fresh, show normal or oscillatory zoning, and are labradorite, ranging in composition from about An_{63} to An_{54}. In some examples the pyroxene phenocrysts have a faint greenish colour and a higher birefringence than common augite. Biotite, which is rare, is partly altered to opaque minerals. The groundmass consists of minute feldspar laths or microlites, glass, and minor opaque minerals.

Although these rocks are pyroxene andesites, they closely resemble typical basalts in Myers Creek canyon, where they have a crude columnar jointing, a dark grey to black colour and rusty appearance on weathering. Chemical analyses (Table III), however, show the similarity in composition between these rocks and the trachyandesites which are also included in division B, and the silica content of 54.8 per cent is greater than the 52 per cent maximum for basalts given by Williams, Turner and Gilbert (1954, p. 43).

As well as pyroxene (augite) andesite there may be olivine basalt described by Daly (1912, pp. 398-399) from "the slopes northwest of Midway, various other points on the north side of Kettle River (and) ... on the rolling plateau between the river and Myer's Creek canyon". No olivine basalt was collected by the writer, but Daly described it as lithologically similar to the augite andesite, and in the writer's opinion it is closely related and should be included in division 4B (see Table II).

This commonly non-vesicular pyroxene andesite is overlain by rocks of similar composition, and which are probably gradational with it, but that differ somewhat in appearance. In places the overlying rock is an

aphanitic andesite but elsewhere it is an amygdaloidal or vesicular pyroxene andesite; where the two occur together, the latter is younger.

The aphanitic andesite outcrops in Myers Creek canyon and between Myers Creek and Kettle River and forms the basal part of division 4B in the succession just northwest of Midway. Somewhat similar rock outcrops in the northwesternmost part of the map-area and about 5 miles west of Greenwood. It is a dark brown-grey to dark maroon-grey weathering rock, dark grey-green on fresh surfaces, hard, extremely fine grained, and with no or very few phenocrysts or vesicles. The groundmass is made up of felted or locally oriented feldspar microlites, and in places contains opaque grains. The shapes of the sparse patches of carbonate and chlorite, suggest that they are pseudomorphs after pyroxene phenocrysts.

The amygdaloidal pyroxene andesite is exposed both in and to the north and south of Myers Creek canyon. In much of the canyon and south of Kettle River it overlies the aphanitic andesite. The same lava, probably repeated by faulting, is exposed 1/4 mile east of the abandoned railway tunnel at the east end of Myers Creek canyon, and outcrops due north of this, both on the south side of Kettle River valley and also on the hillside about 1 mile northwest of the bridge over Kettle River. A similar rock forms the lowest part of the fault block composed of rocks of division 4B at the southwestern extremity of the ridge west of Nicholson Creek. This lithological type weathers dark brown and is very friable in most outcrops, and is characterized by abundant small vesicles or amygdules, the latter consisting of carbonate, opal, chlorite or zeolites. Pyroxene phenocrysts are prominent and generally similar to those in the pyroxene andesite described previously, but in many cases are altered in part or wholly to carbonate and chlorite. Biotite occurs in some specimens but is never very prominent and is altered. Feldspar (labradorite) phenocrysts are rare or absent. The groundmass is very fine grained and contains lath-like feldspar crystals.

Similar rocks occur on the east side of Kettle River north of Fiva Creek, where they grade down into maroon pyroxene-bearing rocks containing flow breccias. South of Fiva Creek these maroon lavas underlie pyroxene feldspar porphyry of division 4A. As noted earlier, all of the above rocks are included in division 4A, largely by virtue of their stratigraphic position, but as they may have closer lithological affinities with rocks of division 4B, they are distinguished on the map as unit 4Ab.

The biotite-augite andesite and biotite andesite described by Daly (1912, pp. 399-400) are equivalent to this vesicular pyroxene andesite (see Table II), although orthoclase, reported by Daly as occurring in the groundmass, has not been recognized by the writer.

In the southwestern part of the map-area a green, red to buff weathering, coarse- to fine-grained tuff (unit 4Bb), commonly containing euhedral or subhedral biotite flakes, separates the amygdaloidal pyroxene andesite from the overlying andesite to trachyandesite. This tuff is exposed near the western portal of the abandoned railway tunnel at the east end of Myers Creek canyon, is repeated by faulting about 3/4 mile to the southwest, and also to the southeast on the abandoned railway grade south of the confluence of Myers Creek and Kettle River. At the last locality it is at least 100 feet thick. To the north it outcrops on the south side of Kettle River valley 1 mile due south of the highway bridge over Kettle River, and occurs

in several fault blocks on the north side of the valley, 1 1/2 miles northwest of the bridge, where it appears to be more than 100 feet thick. To the west, a bed of red-weathering tuff about 6 feet thick, exposed on the face of the bluff at the southwestern end of the ridge west of Nicholson Creek, separates friable pyroxene andesite below from massive trachyandesite above. This is the bed from which Mathews (1963, p. 4) extracted biotite to determine a potassium-argon date of 49 $\pm$ 2 million years. On the east side of Kettle River, in the northwesternmost part of the map-area, maroon to buff tuffs separate pyroxene andesite (assigned to unit 4Ab) from overlying trachyandesites, and are possibly a lateral equivalent to this tuff horizon. In this area, on the forest access road about 1/4 mile south of the northern limit of the map-area and 1/2 mile east of Kettle River, coarse, brown tuff containing flattened pumice inclusions, which are indicative of its welded nature, may be a further lateral equivalent.

The stratigraphically highest and most distinctive unit of division 4B is an andesite to trachyandesite which is commonly glomeroporphyritic. Although this rock is very different in appearance from the pyroxene andesite in division 4B, in chemical composition it is remarkably similar (Table III), and the two are included in the same subgroup. This rock, which corresponds to Daly's (1912, p. 400) biotite trachyte, is found everywhere in the map-area above the pyroxene andesite. Flows of it form the upper part of the terraced hill 2 miles north of the highway bridge over Kettle River, and outcrop to the south of this on both sides of Myers Creek. The abandoned railway tunnel at the eastern end of the canyon is completely in rock of this type. To the east, similar rocks occur north of Midway and underlie part of Ingram Ridge. Westward they cap the southernmost knoll on the ridge west of Nicholson Creek, and are exposed in the northwesternmost part of the map-area, both east and west of Kettle River. This rock is generally a light-coloured porphyry. The groundmass, comprising 80 to 95 per cent of the whole rock, is very fine grained, rarely vesicular, and ranges in colour from pink-buff, pale greenish grey or greenish yellow, when fresh, to brown, buff or rarely maroon, when weathered. It commonly contains small clots ('rosettes' of Church, 1963, p. 134) up to about 5 mm in diameter of radiating plagioclase laths, together with far less abundant, solitary, alkali feldspar phenocrysts, and small biotite or pyroxene phenocrysts. No alkali feldspar is present in many specimens of this lithological type. In places the rock is porphyritic rather than glomeroporphyritic, and contains small, oriented plagioclase laths. The plagioclase phenocrysts are generally fresh, although many have a thin alteration rim. Some are zoned and range in composition from bytownite to andesine (An_{70} to An_{45}). In some cases a biotite crystal forms the nucleus of the clots into which the plagioclases are aggregated. Alkali feldspar mantles some of these plagioclase clots, and also occurs as solitary, subhedral phenocrysts up to about 7 mm long which Church (1963, p. 135) identified as anorthoclase and determined their composition as $Ab_{43}Or_{57}$. Ferromagnesian minerals are minor in all of these rocks. Euhedral and subhedral biotite, of deep red-brown colour, and with a bronze-like sheen in hand specimen, is the most common, and is generally rimmed by opaque alteration products. Euhedral to subhedral, small, pale green clinopyroxene phenocrysts occur in many of these rocks but are far less common. The groundmass of this rock is generally trachytic and consists of small, oriented feldspar laths, with interstitial glass, apatite, opaque minerals, and minor biotite. Upon treatment with sodium cobaltinitrite the glass stained yellow but few of the small feldspars were stained.

The association of alkali feldspar with plagioclase feldspar permits these rocks to be classified as trachyandesites (Hatch, Wells, and Wells, 1956, p. 274; Williams, Turner, and Gilbert, 1954, p. 97). However, some of the rocks in which there are no alkali feldspar phenocrysts, and in which plagioclase laths alone occur, and no alkali feldspar has been recognized in the groundmass, are probably andesites, and appear to be transitional between the pyroxene andesites of the lower part of division 4B and the trachyandesites above.

Division 4C

Rocks comprising division 4C (unit 4Ca, 4Cb) are the youngest in the Marron Formation in the map-area and, except in one place, are overlain only by Pleistocene or Recent drift. They outcrop in the southern part of the map-area and range in thickness from a minimum of 1,200 feet just west of the confluence of Myers Creek and Kettle River to possibly several thousand feet on the east side of Boundary Creek, about 3 miles northeast of Midway.

Division 4C is composed mainly of porphyritic andesites which have a higher silica content than any other rocks in the formation (Table III, Fig. 4). The lower part of the division consists of hornblende andesites and the upper part pyroxene and biotite-pyroxene andesite. Minor amounts of pyroclastic and clastic rocks (unit 4Cb) are intercalated with these flow rocks.

Hornblende andesite is separated by a few feet of green or maroon tuff from underlying trachyandesite 1 1/4 miles north of Midway and also on the abandoned railway grade just southwest of Midway. The prominent hill slightly east of the confluence of Myers Creek and Kettle River is formed largely from hornblende andesite, which overlies trachyandesite. At the last locality, also to the south on the abandoned railway grade, and at the locality southwest of Midway, the basal hornblende andesite is atypical in that no feldspar phenocrysts are present. In places it is a very dark grey, brown weathering rock, containing oriented, scattered oxyhornblende phenocrysts up to about 1 cm long, together with smaller clinopyroxene phenocrysts, in a groundmass of small, locally oriented feldspar laths and glass. Elsewhere the rock is pinkish-grey, buff weathering, locally vesicular, forms flow breccias, and is associated with tuffs containing oxyhornblende crystals. The oxyhornblende in thin section is seen to be almost entirely altered to opaque material, with only small patches of brownish oxyhornblende remaining. The crystals are mostly corroded, but appear to have been perfectly euhedral originally.

The typical hornblende andesite, in places overlying the rock described immediately above, but elsewhere lying on trachyandesite, is a hornblende feldspar porphyry, in which the phenocrysts comprise about 35 per cent of the rock. Of the phenocrysts 30 per cent are plagioclase feldspars and the remainder largely hornblende. The rock is commonly yellowish grey to grey-green in colour and weathers buff but varies from blue-green to pinkish grey on some fresh surfaces. The euhedral or subhedral, sub-equant to lath-like plagioclase phenocrysts are generally about 1 to 2 mm in length, although a few are as long as 5 mm. They are commonly fresh, the grain boundaries of smaller phenocrysts are generally sharp, and those of larger phenocrysts are corroded. Both normal and oscillatory zoning are the rule rather than

the exception, and feldspar compositions range from An_{37} to An_{67}, with most being about An_{55}. The hornblende occurs as euhedral or subhedral phenocrysts, which are generally fairly fresh, although some are corroded, with opaque materials developed at grain boundaries. Shapes of chlorite and carbonate aggregates in some rocks suggest that these are pseudomorphs after amphibole. Most phenocrysts have the pale green to greenish brown pleochroism typical of common hornblende, but specimens from the prominent hill west of the confluence of Myers Creek and Kettle River, like the underlying andesite described above, contain dark brown oxyhornblende rather than common hornblende. Phenocrystic pyroxene is present in some of these hornblende andesites but is usually very minor in amount. The matrix consists of feldspar microlites or minute feldspar laths and opaque minerals in altered glass. Rarely, small hornblende crystals are present in the groundmass. Small quartz anhedra and feldspar microlites in glass, which was patchily stained yellow with sodium cobaltinitrite, form the groundmass in one specimen from north of Midway. Chlorite- and zeolite-filled vesicles are locally present but never abundant.

These rocks were referred to by Daly (1912, p. 399) as hornblende-bearing andesite (see Table II). He observed biotite phenocrysts in some of these rocks, and noted considerable primary quartz in the groundmass.

Pyroxene and biotite-pyroxene andesites overlie the hornblende andesites north of Midway, and form most of the exposed Tertiary succession northeast of Midway and east of Boundary Creek. These rocks are similar texturally to the hornblende andesite in that they contain about 30 to 35 per cent of small feldspar phenocrysts, and up to 5 per cent of phenocrysts of ferromagnesian minerals. These pyroxene and biotite-pyroxene andesites are generally pale yellowish green and weather buff, but they are dark grey to pinkish grey on some fresh surfaces. Flow breccias are common, particularly in rocks of the division exposed east of Boundary Creek, and flow banding and tuff horizons occur locally. Feldspar phenocrysts in these andesites are small (2 mm or less in length), euhedral to subhedral, and lath-like to sub-equant in shape. They are zoned, and compositions range from An_{69} to An_{45}, most being about An_{55}. Clinopyroxene is the most common mafic mineral and is the very pale green variety seen in most other rocks of the formation. Chlorite patches in a few rocks were probably originally pyroxene. In some rocks, biotite is nearly as abundant as clinopyroxene, and generally has a reaction rim composed of opaque material. The matrix is commonly very fine grained, semi-opaque, and brownish; it is probably altered glass and contains small opaque mineral grains and apatite euhedra.

These rocks are called pyroxene, biotite-pyroxene, or hornblende andesites. However, they differ from andesites of division 4B in that they are more acidic, and their chemical composition (Table III) approaches that of the average dacite of Nockolds (1954, p. 1015). No quartz phenocrysts have been observed in these rocks, and although the groundmass of some specimens contains free quartz, it commonly consists only of glass and plagioclase. In contrast to rocks of division 4B which, at least in silica content, are typical andesites, rocks of division 4C are andesites transitional to dacites.

Because of the abundance and small size of phenocrysts in porphyries of division 4 C, it is difficult in the field to distinguish these porphyritic extrusive rocks from fine- to medium-grained holocrystalline intrusive equivalents. Fortunately, flow breccias are common in these rocks, and where present, allow the distinction to be made readily.

A cobble conglomerate (part of unit 4Cb) is interbedded with the top of division 4C about 1 1/4 miles due east of the confluence of Boundary Creek with Norwegian Creek. This conglomerate consists of clasts of volcanic rocks of intermediate composition, some of which resemble rocks of division 4A.

Division 4C is overlain by Pleistocene to Recent drift everywhere except in a small area north of the International Boundary, about 3 miles east of Midway. There, a breccia (unit 6) composed of a variety of basement rocks appears to lie on rocks of division 4C (Little and Thorpe, in Jenness, 1965, p. 57).

Summary, age and correlation

The Marron Formation in Greenwood map-area consists of a basal division 4A, composed of sodic trachyte, in part transitional to phonolite, an intermediate division 4B, consisting of andesite to trachyandesite, and an upper division 4C of andesite tending in composition towards dacite. The formation thus shows a progressive increase in silica content from the base to the top (see Table III, and Fig. 3).

In some places the base of the formation is defined as the base of the lowest flow of division 4A. Elsewhere, it is the base of flow breccia and minor intercalated tuff, continguous with, and of similar composition to, flow rocks of division 4A. In this case the essential difference between basal rocks of the Marron Formation and the uppermost rocks of the Kettle River Formation is that the former are demonstrably of extrusive and pyroclastic origin whereas the latter are seemingly sedimentary rocks. The base of the formation is diachronous, for clasts of rhomb porphyry that are typical of division 4A occur in conglomerates in lithic volcanic sandstone near the top of the Kettle River Formation, indicating that the lithic volcanic sandstone is in part derived from volcanic rocks of the Marron Formation.

The middle part of the Marron Formation is of middle Eocene age. Daly (1912, p. 420) believed flow rocks in his Midway volcanic group were the products of Oligocene and possibly Miocene extrusion. Little (1957) collected Paleocene or Eocene plants from rocks which at that time were considered to be part of Daly's Midway Group, but which are now known to be part of the Kettle River Formation. Mathews (1963, p. 4 and p. 8) obtained radiometric ages of 49 ± 2 million years on a tuff bed underlying trachyandesite of division B at the southern end of the ridge west of Nicholson Creek, and 48 ± 2 million years on a syenite porphyry (pulaskite?) sill intrusive into Kettle River sandstone in the southern part of the map-area. This syenite porphyry is believed to be the intrusive equivalent of the trachyandesite of division 4 B. These radiometric data therefore give a consistent age of middle Eocene for the middle part of the Marron Formation.

TABLE III

Available complete and partial chemical analyses of Marron extrusive rocks from Greenwood map-area

	1	2	3	4	5	6	7	8
Division	4A	4A	4B	4B	4C	4C	4C	4C
SiO_2	48.5	52.64	54.8	54.6	60.1	58.7	60.30	58.61
Al_2O_3	25.3	20.69	20.2	20.3	16.5	17.5	14.06	14.90
Fe_2O_3	1.9	2.54	2.7	3.1	2.9	2.5	-	-
FeO	2.5	1.82	2.8	1.6	1.7	2.0	4.9	6.0
CaO	3.5	3.93	5.5	4.4	5.0	4.9	7.7	8.6
MgO	1.7	1.61	1.9	1.0	2.7	2.5	3.65	4.90
Na_2O	5.8	4.84	4.3	4.2	3.5	4.3	-	-
K_2O	4.83	5.99	4.19	4.45	2.26	2.27	-	-
H_2O	4.1	-	1.3	1.8	4.4	2.0	1.19	1.19
H_2O+	-	2.23	-	-	-	-	-	-
H_2O-	-	0.28	-	-	-	-	-	-
TiO_2	0.81	0.64	0.91	0.92	0.72	0.74	0.95	1.01
P_2O_5	0.49	0.41	0.49	0.44	0.24	0.25	0.43	0.44
MnO	0.08	0.07	0.10	0.11	0.08	0.08	0.04	0.02
CO_2	0.8	0.75	0.6	1.5	<0.01	0.3	-	-
BaO	-	0.61	-	-	-	-	0.16	0.23
SrO	-	0.21	-	-	-	-	0.11	0.14
S								
Total	100.31	99.26	99.79	98.42	100.11	97.77	93.49	96.04

1 Nepheline-bearing pyroxene-feldspar porphyry from top of knoll, 1 mile northwest of confluence of Nicholson Creek and Kettle River.

2 Augite trachyte from Phoenix, collected by LeRoy, 1912, p. 46.

3 Pyroxene andesite from south side of Myers Creek Canyon, 1/2 mile west of abandoned railway tunnel at east end of canyon

4 Trachyandesite from east end of abandoned railway tunnel, east end of Myers Creek Canyon.

5 Hornblende andesite from south side of prominent hill, immediately west of confluence of Myers Creek and Kettle River.

6 Hornblende andesite from top of ridge, 1 1/2 miles due north of Midway.

7 (Biotite) pyroxene andesite from south of Norwegian Creek, collected by Church, 1963, pp. 105, 111.

8 Pyroxene andesite from south of Norwegian Creek, collected by Church, 1963, pp. 105, 111.

Analyses 1, 3, 4, 5, 6 done by the rapid method by S. Courville in the laboratories of the Geological Survey of Canada.

Several workers have correlated the volcanic rocks described above with other volcanic sequences in south-central British Columbia. The Franklin Camp area, about 25 miles north-northeast of Greenwood map-area, was studied by Drysdale (1915, p. 85), who applied the term "Midway volcanic group" to trachyte, phonolitic trachyte and alkalic basalt lying unconformably on feldspathic clastic rocks and rhyolite flows equivalent to the Kettle River Formation. These rocks thus occupy a similar stratigraphic position to rocks of division A, and the phonolitic trachytes, at least, are of similar lithology. Reinecke (1915, p. 60) correlated his extrusive Nipple Mountain series, which outcrops about 25 miles north-northwest of Greenwood map-area, with the Midway volcanic group of Daly, and noted that the lavas correspond most closely with Daly's "Middle group" of lavas (see Table II), although, according to Little (1961 and pers. comm.) Reinecke included some Miocene basalt in his Nipple Mountain series. Little (1957, 1961) and Church (1963, pp. 92-102) correlated early Tertiary extrusive rocks of intermediate composition overlying sandstone and acidic tuff across the Kettle River map-area, which is bounded by latitudes 49° and 50°N, and longitudes 118° to 120°W. Using radiometric dating, Rouse and Mathews (1961) and Mathews (1963) demonstrated the middle Eocene age of volcanic rocks widely dispersed across south-central British Columbia.

The stratigraphical order of lithological types in the early Tertiary volcanic sequence is remarkably similar to that of Tertiary volcanic rocks of the Marron River area, west of Okanagan Falls in Okanagan Valley, about 35 miles west-northwest of the map-area. These rocks, first mapped by Bostock (1941) who called them the Marron Formation, subsequently have been studied in some detail by Church (pers. comm. 1967) who has determined the following generalized stratigraphic succession. At the base are rhomb-porphyry flows that closely resemble many rocks of division 4A in Greenwood map-area. These are overlain by feldspar porphyry flows that are possibly comparable to the coarse feldspar porphyry flows on the ridge west of Nicholson Creek in Greenwood map-area. Above this is a thin, vesicular pyroxene andesite overlain by trachyandesite with glomeroporphyritic texture, both directly comparable to rocks forming division 4B in Greenwood map-area. Finally the upper part of the formation consists of pyroxene andesites, similar to rocks forming the upper part of division 4C. The hornblende andesite, forming the lower part of division 4C in Greenwood map-area, alone appears to be missing in the Marron area. As Daly's term 'Midway volcanic group', applied to the rocks in Greenwood map-area, cannot be used for reasons of priority, it is felt that the remarkable lithological similarity between the volcanic successions in Greenwood and Marron map-areas justifies the name Marron Formation for the rocks in Greenwood map-area.

Early Tertiary (Eocene ?) volcanic rocks exposed over a wide area in northeastern Washington due south of Greenwood map-area (Fig. 1) are called Sanpoil Volcanics (Muessig, 1962, p. D57). Rocks of division 4C, exposed just east of Midway, extend south into Washington where they have been mapped by Parker and Calkins (1964, pp. 49-50), who used Johannsen's classification (1932, pp. 309-310), as porphyritic quartz latites and rhyodacites. These rocks are identical to those in the upper part of division 4C, but contain slightly more silica (62 to 63 per cent SiO_2, as opposed to 58 to 60 per cent), and Parker and Calkins note that their chemical analyses correspond closely to the analysis of average dacite of Nockolds (1954). Still

farther south, quartz latite and rhyodacite flows make up the greater part of the unit (Muessig, 1962, p. D57, 1964, pp. F35-F41), the silica content of which is as high as 67 per cent. There thus appears to be a gradual southward increase in the silica content. As described by the above workers, the Sanpoil Volcanics are similar to rocks of division 4C in the Greenwood map-area, and divisions 4A and 4B do not appear to be represented, except in the western part of Bodie Mountain Quadrangle, south of the west half of Greenwood area, where R.C. Pearson (pers. comm.) found rocks similar to divisions 4A and 4B.

BRECCIA (UNIT 6)

About 3 miles due east of Midway, in the south-central part of the map-area, a breccia (unit 6) rests upon rocks of the Marron Formation (Little and Thorpe, in Jenness, 1965, pp. 57-58). This breccia consists largely of chert and greenstone fragments but contains syenite, diorite, gabbroic rocks, and serpentine as well and resembles lithologically an early Mesozoic or late Palaeozoic rock-unit. In places well bedded chert becomes increasingly fragmented and passes gradually into a breccia, and elsewhere outcrops within the general area of brecciated rock do not appear to be fragmented. A dyke of possible Tertiary age that cuts these rocks, has rough columnar jointing along most of its exposed length, but is brecciated at one end. The contact between brecciated chert, and sheared volcanic rocks of the Marron Formation is seen to within 1 foot, at a point about 1/2 mile north of the International Boundary and approximately 2 miles east of Boundary Creek.

The age of this breccia is not known. It is part of a zone of breccia extending southwestward, through the northeast corner of Curlew Quadrangle in Washington where it was mapped as a fault breccia between thrust slices. R.C. Pearson of the United States Geological Survey (pers. comm. to Little, 1963) suggested that this zone, which he traced into Bodie Mountain Quadrangle, due east of Curlew Quadrangle, is a slide breccia that forms the basal part of the Oligocene Klondike Mountain Formation (Muessig, 1962, p. D58). Little concurs that this is the most probable explanation of its origin.

INTRUSIVE EQUIVALENTS OF THE MARRON FORMATION

Probable intrusive equivalents of rocks comprising the Marron Formation are described briefly in order of decreasing age. The relative ages of these intrusive rocks are determined both by their lithological similarity to extrusive rocks of known stratigraphic position and from crosscutting relationships. This is the reverse, in part, of the procedure followed by Daly (1912, p. 420) who seemingly relied mainly on the latter criterion to determine the stratigraphic succession of lava types given in Table II. These descriptions are followed by brief accounts of rocks, apparently of Tertiary age, but with no known extrusive equivalents.

Feldspar-rhomb syenite (unit 5a), the intrusive equivalent of rocks in division 4A, forms dykes which occur throughout the map-area, and also large, irregularly-shaped, sill-like bodies that intrude, or are in

contact with, rocks of the Kettle River Formation. Two such bodies are in the westernmost part of the map-area. One is at the western end of Myers Creek canyon and is probably continuous with several large outcrops that extend to the north as far as Kettle River. The other and apparently larger body outcrops over about 2 square miles between the headwaters of Nicholson Creek and Kettle River. Possibly these two bodies were originally united, but they are now separated by downfaulted rocks in the southern part of Nicholson Creek. In addition the northern body is cut off on its north side by an east-west fault, north of which the intrusion may be concealed under the Kettle River Formation.

The feldspar-rhomb syenite comprising these bodies ranges in colour from medium grey, grey-green, or pinkish grey to dark grey. It is porphyritic and composed of various amounts of phenocrysts of euhedral to subhedral feldspars up to 10 mm long, many of which are rhomb-shaped, clinopyroxene of similar maximum size, and biotite, all set in a finely crystalline matrix. In many examples the phenocrysts are so abundant that the rock appears to be granular, and it is extremely difficult to estimate relative percentages of phenocrysts and groundmass. The rhomb-porphyry in the intrusion at Myers Creek has up to 15 per cent mafic minerals and is very similar to that described in great detail by Daly (1912, pp. 401-410) from another body, a mile west of the southwesternmost part of the map-area. On the other hand, rocks of the intrusion between Nicholson Creek and Kettle River contain a higher percentage of mafic minerals, generally about 25 per cent, but in one case, nearly 40 per cent. Petrology of both of these bodies has been described by LeCheminant (1966).

Although the proportion of phenocrysts to matrix varies considerably in all of these rocks, the composition of the phenocrysts remains similar. The feldspar phenocrysts have a triclinic core which, according to Daly, is probably anorthoclase, and which is mantled by a rim of orthoclase. The clinopyroxenes are generally pale green, have fairly high birefringence, enclose apatite as opaque mineral grains, and are partly altered to chlorite or carbonate. Aggregates of serpentine and carbonate were reported both by Daly (1912, p. 404) and LeCheminant (1966, pp. 15, 16) who believed them to be altered olivine, and LeCheminant identified olivine in rocks from the intrusion between Nicholson Creek and Kettle River. Little altered pale yellow to brown pleochroic biotite is also present. The matrix contains small lath-shaped feldspars, together with clinopyroxene, biotite, opaque minerals, apatite and some brownish glass (?).

One very distinctive rock that forms a large outcrop about 3 1/2 miles south-southeast of the confluence of the Kettle and West Kettle Rivers, on the southwest side of the intrusion between Nicholson Creek and Kettle River, is dark grey and contains from 35 to 40 per cent of randomly oriented, euhedral, black clinopyroxene phenocrysts up to 10 mm long. As this rock forms the base of the intrusive body at this place, possibly this concentration of clinopyroxene phenocrysts is due to gravitational settling of early-formed crystals.

In addition to crosscutting relationships, several other lithological criteria distinguish the intrusive rocks forming these larger bodies from their extrusive equivalents. The ratio of phenocrysts to matrix is generally much higher, and the groundmass is finely crystalline and contains

patches of non-porphyritic, fresh biotite, which is readily visible in hand specimens, and produces a distinctive sheen on fresh surfaces.

Contact metamorphic effects associated with these intrusive bodies are slight. The host rock, usually feldspathic volcanic sandstone of the Kettle River Formation, merely shows increased induration for a few feet from the contact.

Smaller intrusive bodies, mainly dykes, of this rock occur throughout the map-area. They are commonly intermediate in texture between the rocks described above and extrusive rocks of division 4A, and vary in colour from light to dark grey. Their most characteristic feature is the euhedral clinopyroxene phenocrysts, which generally are accompanied by less prominent feldspar phenocrysts.

Numerous intrusive bodies (unit 5b) believed to be equivalent to flow rocks of division 4B range in size from dykes to bodies comparable to the larger intrusions described above. They are emplaced principally in the Kettle River Formation, but cut rocks of divisions 4A and 4B, and in one locality, north of Midway, possibly intrude rocks of division 4C.

These rocks are of two principal lithologies: diorite and syenite. The former is believed to be the intrusive equivalent of pyroxene andesite forming the lower part of division 4B in the southwestern part of the map-area, and the latter, which is far more common, to correspond in part to trachyandesites forming the upper part of division 4B.

The diorite forms a thick concordant sill, with local well-developed columnar jointing, and is intruded into the top of the Kettle River Formation just below the contact with overlying clinopyroxene-feldspar porphyry of the Marron Formation. This sill is exposed on both sides of the southernmost part of Nicholson Creek valley and to the east of the valley mouth for a distance of about 1 1/2 miles, where it is repeated in a series of fault blocks. When fresh the diorite is dark brownish grey to black in colour, and weathers rusty brown, forming a characteristic rusty soil. It is a porphyry, with euhedral, fresh phenocrysts of plagioclase feldspar and minor pyroxene, the latter comprising less than 10 per cent of the whole rock. The plagioclase feldspar ranges in composition from about An_{45} to An_{50} and shows both normal and oscillatory zoning. The matrix consists largely of small randomly oriented plagioclase crystals, which to some extent are gradational in size with the phenocrysts, together with opaque minerals. Daly (1912, p. 417) called this rock a gabbro. However, in spite of its dark colour, both the low content of mafic minerals and the plagioclase composition indicate that it is a diorite. On the basis of composition and general location in the map-area, this sill is regarded as the intrusive equivalent of extrusive pyroxene andesite exposed on the west side of the southern part of Nicholson Creek valley, and also to the south, on the south side of Kettle River.

Just east of Nicholson Creek, the sill appears to range in composition upwards from the diorite, through grey-green, 'speckled' diorite to pale greenish white, finely granular syenite, composed mainly of small, stubby orthoclase euhedra and interstitial quartz. Still farther east, similar rock is present locally at the top of the largely dioritic sill. Because no sharp contacts have been recognized between these rock types, which appear

to grade into one another, the sill appears to have differentiated. Further, more detailed work is necessary to substantiate this.

Syenite porphyry is probably the most common intrusive rock of early Tertiary age in the map-area, and in places forms bodies of similar size to the largest of the rhomb-porphyry intrusions. This porphyry is characteristically brownish pink in colour, with the finely crystalline groundmass comprising at least 90 per cent of the rock, and the remainder being largely two types of phenocrystic feldspar. The commonest phenocrysts are pale pink, solitary, tabular to lath-like orthoclase crystals, usually with a turbid centre and fresh rim, which typically are about 7 mm long but which range up to 15 mm. The other feldspar phenocrysts are smaller and generally consist of a 'clot' of small white plagioclase laths, which in some cases are arranged radially to a biotite nucleus. These plagioclase aggregates are identical in form to feldspar phenocrysts in the glomeroporphyritic trachyandesites forming the upper part of division 4B. They differ in that they are less calcic, being oligoclase or andesine below An_{32}, and as a rule are mantled with pink orthoclase. Clinopyroxene and biotite crystals occur principally in the groundmass, which is finely crystalline and composed of a randomly oriented mesh of feldspar laths, with interstitial opaque minerals, quartz and 'chlorite'. The 'pulaskite' or alkaline syenite as described by Daly (1912, pp. 417-418) and LeRoy (1912, pp. 49-52) is merely a variety of the above syenite, characterized by its aphanitic fawn to buff matrix, and appears to occur only in the smallest intrusive bodies.

As first suggested by Daly (1912, p. 400), this syenite is believed to be equivalent to trachyandesites forming the upper part of division 4B. Best evidence for this is the textural similarity of many trachyandesites to the syenites, and the negative evidence that these syenites resemble no other extrusive rocks in Greenwood map-area. This correlation is further supported by radiometric ages of 48 ± 2 million years for a 'pulaskite' dyke, and 49 ± 2 million years on a tuff bed underlying the probable extrusive equivalent of the 'pulaskite' (Mathews, 1963, p. 4, pp. 8-9). The chemical analysis of trachyandesite from the map-area differs from Daly's analysis of 'pulaskite' although the analysis of 'pulaskite' given by LeRoy (1912, p. 51) is closer to that of the trachyandesite than to the analysis of 'pulaskite' given by Daly (1912, p. 149). Crosscutting relationships generally support the equivalence of this syenite to rocks of the upper part of division 4B. LeRoy (1912, p. 49) notes that 'pulaskite' is the youngest intrusive rock in the Phoenix area, and although Daly (1912, p. 396, Fig. 25) shows 'pulaskite' sills cut by rhomb-porphyry, the writer was unable to find this relationship. Furthermore Daly (1912, p. 420) notes that this relationship is reversed at two other points, and consequently believed that the flows of trachyte (now trachyandesite) and rhomb-porphyry apparently alternated, which is not the case in Greenwood map-area. However, to the north of Midway, a sill of greenish syenite porphyry (unit 5d), containing glassy feldspar phenocrysts intrudes rocks of division 4C. If this syenite is the same age as the other syenites, then possibly some rocks of division 4C are partial stratigraphic equivalents to rocks of division 4B. Alternatively, this particular syenite may be later, and unrelated to any rocks of the Marron Formation in Greenwood map-area.

Intrusive rocks (unit 5c) related to extrusive rocks of division 4C are common in the south-central part of the map-area, particularly just north and northwest of Midway. As noted earlier, the porphyritic extrusive rocks

of division 4C have a high phenocryst to groundmass ratio and thus generally appear in hand specimens as medium-grained equigranular rocks. Because of this it is difficult to use texture to indicate the intrusive or extrusive nature of the rock. In places where these rocks cut older rocks there is no problem; however, where they intrude rocks of division 4C the distinction is difficult, but can be effected in places by the presence of flow breccias in the extrusive rocks.

There are two varieties of these rocks. One, characterized by hornblende phenocrysts, is the intrusive equivalent of hornblende andesites forming the lower part of division 4C. The other and more common variety contains biotite and altered pyroxene phenocrysts and is the intrusive equivalent of rocks forming the upper part of division 4C.

The hornblende-bearing rocks are medium grey to grey-green in colour and consist of about 30 per cent of small, stubby plagioclase phenocrysts up to about 3 mm long, and small hornblende phenocrysts up to 5 mm in length, in a finely crystalline, rather felsic matrix. The feldspars are zoned, and compositions range from about An_{30} to An_{60}. The hornblende has pale green to greenish brown pleochroism and is generally fresh, but in places is corroded and associated with opaque minerals. The groundmass is similar but finer grained.

The biotite-bearing rocks have a speckled appearance, and the phenocryst to groundmass ratio is so high that the rocks appear to be medium-grained crystalline rather than porphyritic. The phenocrystic plagioclase is of similar composition to that in the hornblende-bearing rocks. The pyroxene phenocrysts are partly or wholly corroded and altered to uralite, but the biotite is fresh. Anhedral grains of quartz are scattered through the groundmass. This rock closely resembles rocks of the Scatter Creek Formation of northern Washington, as described by Parker and Calkins (1964, pp. 52-54). Muessig (1962, pp. D57-D59), who applied the name "Scatter Creek Rhyodacite" to these rocks, believed them to grade into the Sanpoil Volcanics, the equivalent of division 4C of the Marron Formation.

There are other intrusive rocks in the map-area whose Tertiary age is demonstrated by crosscutting relationships but which cannot be related to any particular lava type. Relative to the rocks described above they are rare and form small intrusions, mainly dykes. The commonest of these are the feldspar porphyry dykes that occur in the western part of the map-area. These are dark grey-green and contain up to 15 per cent clear or white tabular plagioclase phenocrysts which are generally about An_{50} in composition, and minor pyroxene. The matrix is composed of stubby feldspars, biotite, and opaque minerals. Possibly these rocks are feeders to some rocks of division 4B, but this is not certain. Other intrusive bodies in the map-area which may be of Tertiary age (e.g. unit 8a of Little and Monger, 1966, p. 68), are not considered here, as their age is not determinable by crosscutting relationships.

It is pertinent at this point to consider the relationship between the rocks mapped as Coryell intrusions (Daly, 1912, p. 358, Little, 1960, p. 90) whose type locality is about 25 miles east of the northeastern part of the map-area, and rocks of or related to the Marron Formation. Daly (1912, p. 419) first suggested that 'pulaskite' from Greenwood map-area, believed

to be the intrusive equivalent of rocks forming the upper part of division 4B of the Marron Formation, was contemporaneous with the Coryell intrusions. He based this suggestion on their analogous positions as the youngest or nearly youngest intrusive rocks in their respective areas, and on the remarkable similarity of chemical compositions of these two rocks. Although this particular similarity may be fortuitous (c.f. the analysis of 'pulaskite' given by LeRoy, 1912, p. 51), rocks of the Marron Formation and related intrusives and rocks mapped as Coryell intrusions have the same variation in silica content, which ranges from 50 to 65 per cent (see Daly, 1912, LeRoy, 1912, Little, 1960, Church, 1963, Parker and Calkins, 1964, etc.).

Evidence for any relationship between the two as deduced from crosscutting relationships is inconclusive. Buff and pink weathering syenites mapped by Little and Thorpe (1965, p. 59) as Coryell intrusions (in part, unit 5d) outcrop in the northeastern part of Greenwood map-area and are the southern tip of a large pluton of similar composition. These rocks intrude Marron volcanic rocks in this part of the map-area, and the same relationship is seen elsewhere, beyond the map-area (Little, pers. comm.). However, this is true of 'pulaskite' as well, which cuts rocks of division 4A and the lower part of division 4B, and also of somewhat dissimilar, but possibly related, syenite which cuts division 4C north of Midway. Thus Coryell intrusive rocks appear to be younger than rocks of the Marron Formation as deduced from crosscutting relationships, but this may be because the upper part of the Marron Formation is missing as the result of erosion in areas where this relationship has been observed.

Similarly, no conclusions can be reached from available radiometric dates. Ages of early Tertiary lavas in south-central British Columbia range from 45 to 53 million years (Rouse and Mathews, 1961; Mathews, 1963) and, with rapid cooling of the lavas these ages appear to represent accurately their time of extrusion. Ages of Coryell plutonic rocks are 27, 32, 53, 54, 56, 58, and 60 million years (Baadsgaard, et al., 1961, p. 697, Lowdon, 1961, pp. 12-13, 1962, pp. 10-11) and are probably minimum ages, representing the time at which these rocks had cooled sufficiently to prevent free diffusion of argon, and not necessarily the time at which these rocks were emplaced. The ages of 56 and 60 million years are from the type Coryell batholith, and thus at least part of this particular intrusion appears to have been emplaced earlier than rocks related to the Marron Formation.

In conclusion, there is no proven relationship between the Coryell intrusions and Marron Formation at present and they appear merely to have been formed at roughtly the same time in the same general area and show the same general range of compositions. Answers to the following questions might resolve the problem:

(1) What are the crosscutting relationships between typical Coryell rocks and early Tertiary volcanic rocks of known stratigraphy?

(2) Is there any recognizable analogy between the petrogenesis of a Coryell-type pluton and that of a contiguous succession of early Tertiary lava types?

(3) What are the ages of the various early Tertiary lava types, and how do these compare with ages of various phases of contiguous Coryell plutonic rocks?

STRUCTURE

The early Tertiary volcanic and sedimentary rocks described in this report are preserved in structurally low, typically eastward-tilted fault blocks that are separated by normal faults. The most common trend of these faults is north-northeasterly, and displacements on them range from a few feet to more than a thousand feet. The faults appear to be confined largely to the western half of the map-area where Tertiary rocks are abundant. However, as the structure of the small areas of Tertiary stratified rocks in the east half is completely analogous to that in the west half, the same style of faulting may prevail throughout the map-area. Possibly such faulting has not been detected because of the absence of any readily recognizable datum horizon and the structural complexity of the pre-Tertiary rocks which underlie most of the east half of the map-area.

So far as is known, all larger faults involving Tertiary rocks are normal, although lateral movement has taken place as well on at least one. Most faults dip westerly at steep to moderate angles; such faults are visible on the north side of Kettle River valley, about 1/2 mile east of the confluence of Kettle River with Nicholson Creek, and on the north side of the west end of Myers Creek canyon. The straight traces of other faults indicate that they are vertical near the ground surface. If this vertical dip is assumed to continue to depth, then the dip of bedding in contiguous fault blocks relative to the vertical dip of the fault plane invariably suggests that the faults are high-angle reverse faults, and that crustal shortening has taken place. This interpretation is incompatible with the fact that all faults actually seen in cross-section are normal, and result from crustal extension.

Therefore, fault planes that appear vertical at the surface are shown to curve and dip less steeply at depth in the cross-sections, and it is suggested that rotational movement has taken place on them, with the production of normal faults. Conversely, some fault planes dip at relatively low angles; the fault bounding the east side of the Marron Formation at Phoenix dips west at about 30° (H.W. Little, pers. comm.). Even less steep is the dip of the fault with a "V"-shaped trace that is located about 2 miles southeast of the confluence of Kettle and West Kettle Rivers. This fault separates the uppermost Kettle River Formation and basal Marron Formation from the underlying basal Kettle River Formation, and dips north at about 7°.

Vertical displacement on these faults is of all magnitudes up to about 6,000 feet. Minor faults whose displacement can be observed directly are common in the Kettle River Formation, and are well exposed in the Marron Formation on the hillside about 1 1/4 miles northwest of the highway bridge over Kettle River, 5 miles west of Midway. There the tuff (unit 4Bb) in the middle of division 4B of the Marron Formation is downdropped to the west on several west-dipping normal faults. Repeated normal faulting of relatively little displacement in the Tertiary rocks at Phoenix is shown by Seraphim (1956, Fig. 3, p. 385). This repetitive normal faulting with little displacement on individual faults is possibly very common, and may be the cause of the anomaly between dips measured on bedding planes in the field, and the general dip of a rock unit as determined from the map, which is commonly much less than the local dip. In addition, such undetected normal faulting also leads to overestimation of thicknesses which are calculated from measured dips. These points are illustrated in Figure 4.

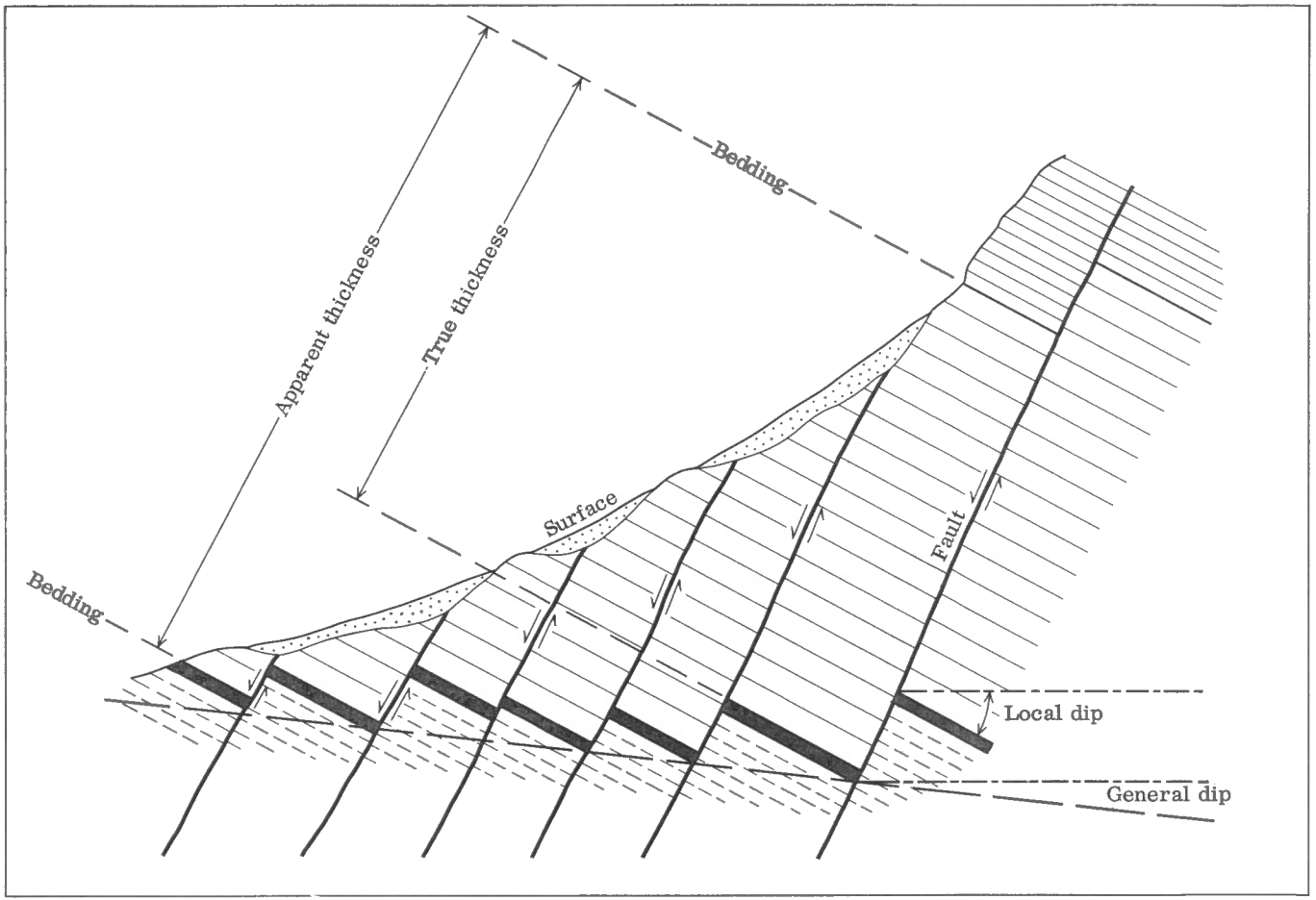


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Figure 4. Effect of repetitive normal faulting on thickness and dip

Whereas the amount of movement can be observed directly on minor faults, on major faults it must be calculated from the thicknesses of the nearest stratigraphic sections. Two main sources of error exist in determining displacement on major faults. Stratigraphic thicknesses may be overestimated as noted above, and also the assumption must be made that either the base of the Tertiary was initially at the same elevation on both sides of the fault, or that marked changes in thickness and stratigraphy do not occur across the fault. With this in mind, the minimum amount of movement on the roughtly north-trending fault west of the confluence of the Kettle and West Kettle Rivers can be determined with reasonable accuracy. There, the uppermost Kettle River and basal Marron Formations are in fault contact with gneissic basement rocks. Immediately east of the fault the Kettle River Formation has a minimum thickness of 4,000 feet and therefore the vertical movement is at least 4,000 feet. Vertical movement on the prominent east-west fault immediately south of the above fault is possibly of a similar order, although here the Kettle River Formation appears thicker on the north side of the fault than on the south. This east-west fault has also undergone lateral movement. Horizontal slickensides exposed in the side of the Forest Service access road where it crosses this fault on the west side of Kettle Valley, indicate that movement of the northern block is to the east and appear to contradict evidence from the map-pattern, which suggests that the southern block has moved eastward. The major, north-south fault about 3 miles west of Greenwood, which bounds the main outcrop area of Tertiary rocks on the east, brings rocks of the upper part of division 4B of the Marron Formation against basement rocks, which are locally overlain by Kettle River Formation. The indicated displacement here is at least 6,000 feet. Movement of a similar order also appears to have taken place on the fault 3 miles to the west of this fault.

With the exception of small irregular crumples in thin-bedded rocks of the Kettle River Formation, which are restricted to the immediate vicinity of some faults, the only folds in the Tertiary rocks are large-scale anticlinal structures, made apparent by mapping. The axial trace of the best defined of these is about 1 1/2 miles due east of the confluence of Kettle and West Kettle Rivers, and trends roughly north-northeast. Kettle River sandstone forming the core of this anticline, dips away on both sides of the crest at angles up to 40°, and is overlain on both limbs by the Marron Formation. A similar, but much faulted, anticline occurs about 5 miles due south, in the southernmost part of Nicholson Creek valley, and a third, poorly defined anticline is located about 3 miles north of the highway bridge over Kettle River, 5 miles west of Midway.

H.W. Little suggested to the writer that these anticlinal structures were formed by the arching of Kettle River sandstone over intrusive bodies. Such an origin is compatible with the tensional nature of all other structures affecting Tertiary rocks in this area. The anticline due east of the confluence of the Kettle and West Kettle Rivers is truncated on the south by a large east-west trending fault. On the southern, upthrown side of this fault, a large irregular, sill-like body of rhomb-porphyry intrudes the basal Kettle River sandstone, and is abruptly cut off on its north side by the fault. Allowing for lateral displacement on this fault, the northern extension of this intrusion presumably underlies the Kettle River Formation and thus could well be responsible for the anticline. This interpretation is shown on cross-section G-H-I on Map 1967 (in pocket). In addition, numerous nearly vertical dykes

cutting the Kettle River Formation trend roughly parallel to the axial trace of the anticline, and thus appear to have been intruded along extension, 'a-b' joints. Other large bodies of rhomb-porphyry intrusive into the Kettle River Formation south of Kettle River, are due south of the axial trace of the faulted anticline at the south end of Nicholson Creek valley. Possibly all of these rhomb-porphyry bodies originally formed a single elongate intrusion that was emplaced in the Kettle River Formation, and up-arched it into a single north trending anticline. Subsequently, this anticline was segmented and laterally displaced by faulting.

It has not proven possible to demonstrate the exact time at which faulting took place in the map-area. As it involves the youngest lavas of the Marron Formation and the overlying breccia, it is at least in part later than these rocks. A minimum age is given by the presence of flat-lying Miocene (?) basalts which unconformably overlie faulted Tertiary rocks about 18 miles north of the map-area (Little, 1957 and pers. comm.). Similarly, in northern Washington, Yates et al. (1966, p. 55) note that either faults involving early Tertiary rocks (stratigraphically equivalent to those in the map-area), did not extend as far south as the upper Miocene or lower Pliocene Columbia Plateau basalts, or else movement on them was over before this time. Faulting may have been initiated in the map-area during deposition of the Kettle River Formation, for poorly rounded blocks of basement material and cobbles of rhomb-porphyry lava in the formation possibly result from rapid erosion accompanying local uplift caused by block faulting. In addition, the Kettle River Formation appears to be about 4,000 feet thick just north of the prominent east-west fault in the northwestern part of the map-area, and about 2,000 feet thick to the south of it, suggesting the faulting occurred during deposition of these rocks. Proof that faulting was contemporaneous with early Tertiary vulcanism in northern Washington has been obtained by Staatz (1964, pp. F58-F59), who discovered a fault breccia containing fragments of rhyodacite from the Sanpoil Volcanics, the lateral equivalent of the upper part of the Marron Formation in Greenwood map-area which locally had been cemented by later rhyodacite. Staatz also gives evidence that faulting probably continued until Miocene time. By analogy, it seems likely that fault movements in Greenwood map-area took place during deposition of the Tertiary rocks, but as some faults, such as that about 3 miles south-southwest of Greenwood, are of very great displacement and involve the youngest rocks of the Marron Formation, it seems probable that the greatest amount of movement took place subsequent to deposition of the Marron lavas. The breccia (unit 6) apparently overlying the Marron Formation and tentatively correlated with the Oligocene or (?) later Klondike Mountain Formation, may be the result of the extreme development of a fault scarp, with the concomitant production of a landslide of major proportions, and perhaps indicates that the climax of faulting in the map-area was in Oligocene time.

Even though faulting was possibly contemporaneous with deposition of early Tertiary rocks in Greenwood map-area, there is no evidence to show that these rocks accumulated in restricted fault-bounded basins whose outlines roughly corresponded to the present distribution of Tertiary rocks in the map-area, as occurred locally in northern Washington according to Parker and Calkins (1964, pp. 83-84) and Staatz (1964, pp. F58-F59). Instead, the stratified Tertiary rocks of Greenwood map-area appear to be the erosional remnants of a cover at least as widespread as the map-area.

The main basis for this inference is the relative stratigraphic uniformity of all Tertiary rocks over the whole area. In particular, the Kettle River Formation, which is largely water-lain and thus presumably deposited at or near local base level, is nowhere missing and overlapped by the Marron volcanic rocks in the map-area. Possibly the Marron volcanics were laid down on a flood plain at least as wide as the map-area. Subsequent normal faults, some of which have vertical displacements of several thousands of feet, have split the area into many fault blocks, in some of which the Tertiary rocks are preserved.

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