GLACIATION, STRATIGRAPHY, STRUCTURE AND MICROPALEOBOTANY OF THE PRINCETON COALFIELD, BRITISH COLUMBIA

by

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Department of Geology

The University of British Columbia,
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Date March 1, 1962.

ABSTRACT

Glacial, stratigraphic, mineralogical, structural and palynologic studies were carried out in the Princeton coalfield, B. C. Three late Pleistocene lakes on the Tulameen River, Whipsaw Creek and Granite Creek are described for the first time.

Previous workers have described the Princeton Group as being made up of three units, an upper and lower volcanic rock unit separated by a sedimentary unit. Shaw (1952) names these units; the Lower Volcanic Formation (oldest), the Allenby Formation (sediments), and the Upper Volcanic Formation (youngest). The present work indicates that the Upper Volcanic Formation is interbedded with basal Allenby Formation sediments and is transitional downward into the Lower Volcanic Formation. The revised stratigraphic sequence herein proposed is the Lower Volcanic Formation (oldest), the Upper Volcanic Formation, and the Allenby Formation (youngest).

The Allenby Formation is composed of interbedded conglomerates, arkosic and tuffaceous sandstones, shale, coaly shale, coal, and minor amounts of limestone, bentonite, diatomite and ash.

Except for the basal Allenby Formation sediments which apparently formed as talus accumulations, the bulk of the coarse clastic sediments were derived from a granitic terrane. The shales contain silt size grains of microcline, quartz and plagioclase similar to the coarser clastics, suggesting that they are fine grained equivalents of the coarser clastics. Evidence is presented to show that the arkosic sediments were derived from the Osprey Lake Intrusion.

A section of the Allenby Formation at Vermilion Bluffs is unique in that it is composed of a basal silicified diatomite overlain by a silicified dolomitic limestone and shale. Evidence is presented to show that the sequence represents an ancient spring deposit.

The Princeton coalfield consists of two structural lows, separated by a small transverse anticline.

Ninety-three plant microfossil species are described and illustrated. Some of these are identical with previously described material from the Green River Formation and the Fort Union Formation of the United States, and the Burrard Formation of British Columbia. Forty species of spores and pollen are abundant in the Princeton material.

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INTRODUCTION

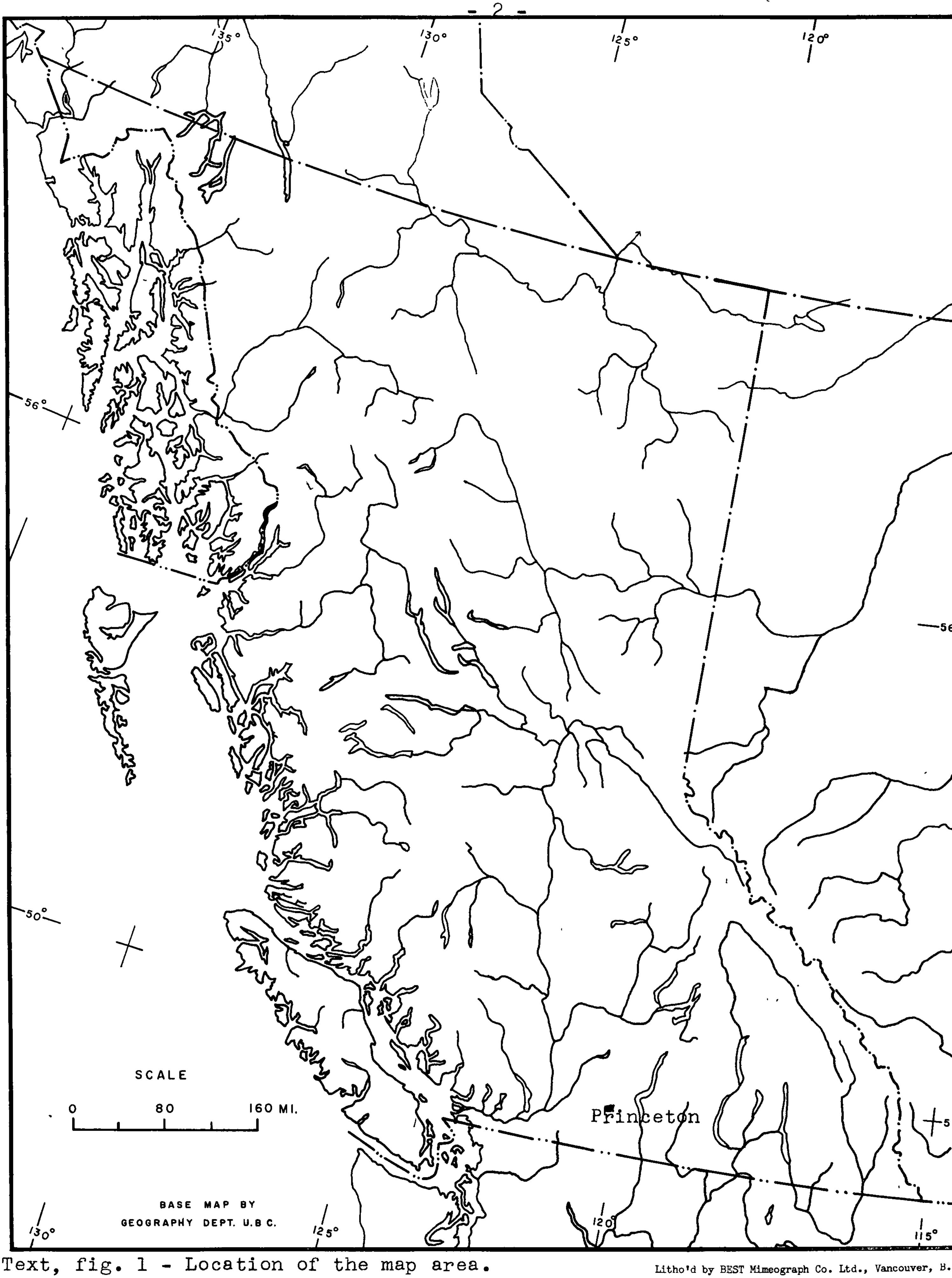
GENERAL STATEMENT

Many isolated occurrences of Tertiary sediments and volcanics have been mapped throughout British Columbia. The absence of diagnostic fossils in many of these occurrences has led to datings ranging from Eocene to Miocene. At Princeton, plant megafossils and insects were thought to be of Oligo-Miocene age (Rice, 1947, pp. 30-31) whereas trogosine tillodont fossils were considered to be of Middle Eocene age (Russell, 1935, pp. 54-55, Gazin, 1953, p. 43). Rouse and Mathews (1961) collected biotite from an ash and obtained a potassium-argon date for the Princeton coalfield of 48 million years.

The purpose of this project is to study the glaciation, stratigraphy, structure, and to collect and describe the microflora of the Princeton coalfield. It is intended that this work will provide a microfloral assemblage which may be used for correlation purposes.

LOCATION AND ACCESS

The map area located at Princeton, B. C. (see location map p.2) is bounded on the south by Whipsaw Creek, and extends some ten miles north of Princeton. The width increases from about four and a half miles at the northern end to about six miles at the southern limit. At Princeton, the east and west boundaries are two miles east and four miles west of Princeton respectively.



Text, fig. 1 - Location of the map area.

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The Hope-Princeton Highway, Whipsaw Creek to Princeton, crosses the southern half of the map area in a north-south direction. The Princeton-Merritt Highway extends northward from Princeton across the northern half of the map area. Secondary roads lead off the main highways and provide access to all parts of the coalfield.

PREVIOUS WORK

Coal in the Princeton coalfield was first recorded by Bauerman (1860) while doing reconnaissance mapping along the 49th parallel. Dawson (1887-8) recorded the presence of lignite and insect fossils on Lamont Creek (Nine Mile). At the same time he noted the color and strong silicification at Vermilion Bluffs. The silicification, he suggested, may be related to a siliceous spring.

Camsell (1907) published the first large scale map of the area (1" = ½ mile). In this report Camsell outlined the area enclosing coal bearing strata and noted locations of lignite outcrops. He indicated that the sediments are underlain and overlain by Tertiary volcanic rocks.

Russell (1935) examined two mammal's teeth found by C. R. Stubb in the W. R. Wilson Coal Mine (Pleasant Valley Coal Mine) situated on the south bank of the Tulameen River, about a mile west of the Canadian Pacific Railway tunnel at Princeton. He provisionally referred the teeth to *Trogosus minor* and suggested that the presence of these teeth indicated a Middle Eocene age for the Princeton coalfield.

Rice (1947) began systematic four mile mapping of the Princeton area in 1939. In his report, Rice compiled all the available information on the Princeton coalfield, and made several plant and insect fossil collections, which were identified by Dr. W. A. Bell and Prof. F. M. Carpenter respectively. Bell concluded that the plants are Upper Oligocene or Lower Miocene age, while Carpenter stated with regard to the insects: "...that they are clearly Tertiary, and almost certainly Oligocene or Miocene." (G.S.C. Memoir 243, p. 30-31.)

Rice (1947, p. 31) in summarizing the age of the Princeton Group states:

> "Some conflict, therefore, exists in attempts to fix the age of the Princeton group as between the evidence of the fossil plants and insects and that of the mammal tooth. There is a bare possibility that the Princeton coal basin contains sediments of both ages, separated by an unconformity that has not yet been recognized, but this explanation is improbable. The final solution of the problem will have to await further study, but in view of the cumulative evidence of the plant and insect material that has been made available, the younger age is provisionally accepted."

In 1951 and 1952 Shaw mapped the coal bearing sedimentary rocks and presented a structural and stratigraphic interpretation of the coalfield (Shaw, 1952).

Gazin (1953) tentatively assigned the two teeth previously described by Russell (1935) and a jaw fragment from the Princeton coalfield to <u>Trogosus</u> (?) <u>latidens</u>.

Russell (1955-56) reported on the molluscan fossils of the coalfield. However, as all of the specimens were new species of gastropods, little was contributed in the way of dating the Allenby Formation sediments.

Rouse and Mathews (1961), in an attempt to settle the age conflict, obtained biotite from an ash (Princeton Ash) interbedded with Allenby Formation sediments, which gave a potassium-argon date of 48 million years. This is considered in the light of current data to correspond to a Middle Eocene Age (Kulp, 1961).

PHYSIOGRAPHY

Regional Setting

The topography of the Interior highlands of B. C., within which the Princeton coalfield is located, is rolling and ranges in altitude from 4000 to 6000 feet. The upland surface is incised by deep valleys. Camsell (1913, pp. 21-22) states of the nearby Tulameen map area:

> "If the whole area were covered with water to the 4500 contour, so that all deep valleys were submerged, we should have exposed an undulating surface with rounded summits and dome-shaped hills rising to heights of 500 to 1500 feet above the water. All the slopes from these summits would appear easy and gentle and no sharp crags nor precipitous bluffs would be seen. The whole exposed topography would be that of mature erosion.
>
> "Below the 4500 foot contour the angle of slope of many of the hills steepens, so that the cliffs flanked by talus slopes are of common occurrence. While this is not true of every hill, it is true of so many that it becomes a noticeable feature."

Isolated peaks or monadnocks rise above the general level. The plateau at the latitude of Princeton is less than one hundred miles wide in an east-west direction. It merges to the east with the Columbia Mountains, and to the south and west with ranges of the Cascade Mountains. Nowhere is the change from plateau to mountain range abrupt, but there is rather a zone of transition where the two types of topography blend.

The highland continues northward from the Princeton area some 500 miles. The width of the highland decreases abruptly southward, and terminates against the Cascade Mountains before reaching the 49th parallel.

The Cascade Mountains trend northward from their southern extremity in Northern California, through Oregon and Washington into British Columbia. This chain of mountains divides into two ranges north of the 49th parallel. One range, the Okanagan Mountains, extends northeastward to Keremeos where it gradually merges into the plateau. The other extends northward and is divided into two ranges, the Skagit and the Hozameen, separated by the deeply incised Skagit River. The Hozameen Range merges with the plateau in the region of the headwaters of Granite Creek, whereas the Skagit extends northward under various names such as the Hope Range as far as the Thompson River. Where the Cascades cross the 49th parallel, peaks are as high as 9000 feet: forty miles to the north, however, they are no more than 7600 feet.

Of the more recent physiographic history of the area, Rice (1947, p. 4) states:

> "The...history of the area includes the following events: (1) the erosion in pre-Glacial time of the land surface to that of a mature, gently undulating plain; (2) the elevation of the area as a whole, and rejuvenation of the drainage; (3) active erosion by the rejuvenated streams, resulting in the deepening of the main valleys but ceasing before all of the plateau area was affected; (4) the advent of the Ice Age with the consequent dislocation of drainage, overdeepening of some valleys and incomplete filling of others; and (5) re-establishment of the drainage with active erosion of the bottoms of certain of the valleys, and the development, in places of post-Glacial canyons."

Local Features

The Princeton coalfield may aptly be described as a basin within a basin. The low central part, underlain by the Allenby Formation sediments, is flanked by older volcanic rocks of the Lower Volcanic Formation, the Upper Volcanic Formation and the Nicola Group, and is separated from them by abrupt walls. Abrupt walls of the older rocks separate the central part of the Princeton coalfield from the outer parts, creating the impression that the topographic low is confined to the area of sediments. However, a topographic cross section shows that surrounding rocks too are somewhat lower than the general highland surface.

Topography in the central part is gentle and almost plainlike, especially in the northern half. This surface is cut by the steep walled valleys of the Similkameen and the Tulameen Rivers, and interrupted in many places by kettles and meltwater channels. North and south of Princeton, kettles are more than a hundred feet deep and several hundred feet across. Kettles are also numerous along the Coalmont road on the western edge of the coalfield. Many dry channels record the diversion of the Tulameen during late glacial stages.

In the northern half of the Princeton coalfield, and on the upper slopes of Mt. Kennedy, bedrock is exposed as elongate north-south ridges, which mark the direction of ice movement during the last glaciation. Whereas these ridges are generally confined to rocks older than the Allenby Formation sediments, some sandstone members form similar ridges within the coalfield.

Drainage

The Similkameen and Tulameen Rivers and many of their tributaries meet in a small area in the vicinity of the Town of Princeton. The Similkameen has its headwaters south of the Princeton coalfield in the Cascades. In the Princeton coalfield, where it is joined by the Tulameen, it changes its course abruptly, leaves the coalfield in an easterly direction, and eventually swings southward again. The Tulameen, with its headwaters in the Hozameen Mountains, controls the drainage in the southwestern part of the Princeton coalfield area. Its main tributaries are Granite

Creek, which flows into it from the south, and Otter Creek from the north. Drainage from the north is controlled by three streams, Allison, Summers and Hayes Creeks. Allison Creek drains a series of lakes and for the most part occupies a valley with steep walls but with a flat floor. Where the valley is broad, the stream meanders. Several lakes (Allison, Borgeson, Dry, Laird) in the upper part of Allison Creek owe their existence to the damming action of tributary alluvial fans. Were one stream itself still active enough to cut and keep clear its valley, such lakes could not form; it is concluded, therefore, that in its upper part at least Allison Creek is a misfit. Several faults (Rice, 1947) are mapped paralleling the stream, and within the valley, suggesting that the stream is in part structurally controlled and hence a subsequent stream. Summers Creek joins Allison Creek six miles north of Princeton. Allison Creek then flows diagonally across the coalfield and empties into the Similkameen one mile below the Town of Princeton. Where the creek has cut down into the sediments, it has left a number of terraces with well preserved meander scars. Summers Creek, which enters the coalfield from the north, follows the contact between the Nicola Group and the younger Princeton sediments and hence, in its lower reaches at least, is structurally controlled.

The valley of Hayes Creek in its upper reaches is broad, with gently sloping walls which reflect glaciation (Plate 1, fig. 1). The general trend is southwestward.

East of Jura the direction of the creek changes abruptly to the south, and continues in this direction until it joins the Similkameen River. Below this change of direction, the valley becomes steep walled and distinctly V-shaped (Plate 1, fig. 2).

A projection of the trend of the upper part of Hayes Creek southwestward coincides with a topographic depression extending from the point of abrupt change of direction of Hayes Creek, through Jura, Separation Lakes, and joins Allison Creek just west of Belfort. It is probable that this represents a former channel of Hayes Creek that has subsequently been diverted to the east, where it has become trapped in the harder bedrock.

PART I

GLACIATION

The following is a summary of the evidence of late glacial activity taken from a literature review of previous work, field observations, aerial photograph and contour map studies. Field observations were restricted to an area within ten miles of Princeton. For areas such as the headwaters of the Tulameen River, Whipsaw Creek and Granite Creek, data were taken from air photos and contour maps. Interpretations are based on abandoned meltwater channels, strand lines, aggradational terraces, dissected valley fills, deltas, pitted outwash, glacial grooves and striae.

The best developed meltwater channels are along the western side of the Princeton coalfield, south of the Tulameen River. Others, such as Roany Creek and the head of Lamont Creek are not as well developed and have not been visited.

Strand lines were observed at three localities: (see Glacial Map, p. 20) (1) northwest slopes of Whipsaw Creek three miles above Corral Creek, altitude about 4700 ft. (verified by Mr. T. Lord, Federal Soils Survey, personal communication); (2) east slope of Granite Creek just northwest of the headwaters of Lamont Creek, altitude about 4700 ft. (presence verified by Dr. W. H. Mathews, personal communication); (3) on the east slopes of the Tulameen valley, opposite Jim Kelly Creek, altitude 4000 to 4300 ft. (verified by Mr. T. Lord, Federal Soils Survey, personal communication), and possibly a second at a lower level at the same place.

Pitted outwash is well developed at several localities in the Princeton area: (1) immediately north and south of Princeton, (2) south of the Tulameen River at Parr, (3) on the Coalmont road about three miles west of Princeton, and (4) on Whipsaw Creek at the mouth of Corral Creek.

Two non-paired degradational benches (Plate 2, fig. 1) and at least one aggradational terrace can be seen west of Belfort Station on the Kettle Valley Railroad. The terraced fill extends at least as far south as Princeton (Plate 2, fig. 1 and 2). Its upper surface apparently slopes gently southward from about 2400 ft. in the north to about 2300 ft. in the south. Just north of Princeton its otherwise continuous surface is broken by several large kettles, several hundred feet across and more than a hundred feet deep. This terraced fill probably represents material derived from both the wasting Pleistocene ice front and the Tulameen River.

The upper benches west of Belfort are apparently degradational stream benches of late glacial age, and presumably antedate the lower outwash terrace. They lack the glacial erratics common at higher altitudes and on non-bench or terrace areas. Several small oxbows which contain water during early spring months, and many meander scars are still well preserved. About two miles south of the Kettle Valley Sawmill (see map) the Princeton-Merritt Highway follows one such meander in order to avoid a rather sudden break in slope.

Terraced fill is found at several localities on the Tulameen River, Granite Creek and Whipsaw Creek. The better developed terraced fills are at the head of Whipsaw Creek above the 4400 ft. contour; the highest is at about 4600 ft. (presence confirmed in the field by Mr. P. Read of Texas Gulf Sulfur, personal communication). Normally these features are not large enough to be recorded on the contour map, but are readily recognizable on the air photos. Many fills are modified by post glacial erosion and occur only as small remnants along one side of the valley.

A study of cross-stratification and pebble orientation of the outwash gravels at Princeton indicates that material was derived both from the north and from the Tulameen River to the west.

Rice (1947, p. 4) states that the entire Princeton map area has been glaciated to an altitude of 8600 ft. Daly (1912, pp. 591-595) records the upper level of glaciation in the Okanagan Range as 7800 ft., the Hozameen Range as 6850 ft., and the Skagit Range as 7000 ft. Dr. W. H. Mathews (personal communication) suspects that the evidence of glaciation at higher elevations (i.e. 8600 ft.) reflects an older glaciation about the equivalent of the Tahoe rather than the Tioga Stage (cf. Blackwelder, 1931). Rice, (Map 889A, 1947) on the basis of glacial striae, states that the ice moved in a southerly direction as far as Princeton. He suggests that as the striae diverge from this point, the ice split; one tongue continued southeast over Mt. Darcy, and the other southwest along the Princeton coalfield, across Whipsaw Creek in the general direction of Three Brothers Mountain. Field observations in the area confirm that this direction of movement is not only evident in the striae, but also in the pattern of bedrock exposures, most of which are elongate in the direction of glacial movement. This pattern is striking on Mt. Kennedy and along the northeast rim of the Princeton coalfield.

Mathews (1944, p. 42) states:

> "During the late glacial time the ice retreated northward or northeastward, evidently persisted for some time in the Princeton basin and deflected the waters of the Similkameen eastward into the valleys of Wolfe and Willis Creek, and thence to the lower part of the Similkameen which had apparently been vacated by the ice."

This diversion took place by successively lower passes; (1) Victor Lake Outlet, (2) Lost Horse Gulch, (3) Verde Creek Outlet, and (4) Smelter Lake Pass. Although Mathews explained the late Pleistocene history of the Similkameen drainage satisfactorily, it is only now in the light of the present study that the history of the Tulameen River is beginning to be understood.

It now appears that lakes existed not only in the Upper Similkameen Valley, as outlined by Mathews (1944), but also in the valleys of Whipsaw Creek, Granite Creek and the headwaters of the Tulameen River. The evidence for these lakes has already been presented.

Although it cannot be exactly determined when these lakes came into being, how many of them were precisely contemporaneous or how long they endured, many of the broader aspects are evident. The following is the writer's interpretation, which it is hoped may be used as a basis for a more detailed field study of the area involved.

For the location of the outlet channels 1, 2, 3..., refer to the Glacial Map on page 20.

Water from the Upper Tulameen River Valley in the initial stages of ice retreat apparently drained southward to (1) Skaist River (pass elevation about 4950 ft.), later escaped westward to (2) Snass Creek (pass elevation about 4850 ft.), and (3) via Podunk Valley (pass elevation about 4750 ft.) to Sowaqua Creek and (4) Vuich Creek (pass elevation about 4550 ft.). With further retreat, the outlet channels shifted northward. Later lake levels are recorded by a well developed strand line (about 4200 ft.) east of Jim Kelly Creek and terraced fill at about the 3950 ft. elevation on the Tulameen River. Further retreat allowed the Tulameen to drain north and eastward along the front of the ice. This outlet connected with Granite Creek and eventually the western edge of the Princeton coalfield and out into the lake which occupied the Upper Similkameen Valley (see Mathews, 1944). Blakeburn Creek (5a)(pass elevation about 4200 ft.), (5) the north fork of Holmes Creek (pass elevation about 3800 ft.), and (6) Roany Creek (pass elevation about 3250 ft.) are examples of this drainage.

Granite Creek, like the Tulameen, drained southward (pass elevation about 5350 ft.), entering the waters of (7) the Tulameen River at the head of Skaist River. With retreat of the ice front, a lower outlet (pass elevation about 5050 ft.) which leads across the divide into (8) Lamont Creek was freed and water drained to the east. The result was a lake with a surface at an elevation somewhere close to 5050 ft. With further retreat, a lower pass was opened to the north, and the lake level fell to about 4700 ft. This level is marked by a well developed strand line and remnants of one or two deltas. The outlet is not apparent on either the air photos or the contour map, and therefore, is presumed to be an ice contact channel which may have flowed wholly or in part on the ice.

Whipsaw Creek in the early stages of development drained southward (pass elevation about 4650 ft.) into (9) Copper Creek, and thence to the lake (elevation about 4250 ft.) in the Similkameen Valley. This outlet channel crosses into Copper Creek about two and a half to three miles west of Friday Mountain. The elevation (about 4250 ft.) of the lake on the Similkameen is recorded by a large delta which has been partially destroyed by subsequent erosion. A strand line (about 4250 ft.) on the north slopes of Copper Creek about three miles east of the Hope-Princeton Highway may also record the same lake level.

The Copper Creek outlet drained the lake on Whipsaw Creek until the ice retreated north of Friday Mountain. Here the break in slope allowed drainage to flow into the lake on the Similkameen via (10) Friday Creek. A small delta remnant on Friday Creek indicates that the Similkameen lake still rose to about the 4250 ft. level.

With further retreat the Friday Creek outlet was replaced by (11) Deep Gulch Creek. The next lower well-marked channel is on (12) Mt. Kennedy at about the 3950 ft. level. By this stage drainage all flowed into the lake on the Upper Similkameen.

Further retreat of the ice tongue which still existed in the Princeton coalfield is now indicated by a series of well developed meltwater channels. The first of these channels starts at (14) Bromley Creek at an altitude of about 3500 ft., continues along the west boundary of the Princeton coalfield, and joins Whipsaw Creek valley at about 3300 ft. The lake on Whipsaw Creek then had its outlet across the nose of (13) Mt. Kennedy at about 3300 ft. The corresponding outlet for the Similkameen lake was via Smelter Lakes. As the ice retreated further, the Tulameen River was diverted down (15) Whipsaw Creek. The Similkameen lake at this time extended into the Princeton coalfield. As the ice melted, channels were shifted successively northward. At about the same time that the Tulameen River occupied (16) Lower Lamont Creek, the waters of Whipsaw Creek attained their present course.

Next, a channel was developed half a mile north of (17) Lamont Creek, then the channel now occupied by (18) Dalby Creek. The waters made contact with the ice sheet near what is now Stevenson Lake, and were diverted south, entering the Similkameen lake a mile north of Lamont Creek. First, Bromley Creek to (19) Stevenson Lake and then Findlay Creek as far as (20) Bromley served as the next channels. The following shift of the Tulameen River brought it back to the south side of its original (pre-glacial) channel. The area extending as far south as Bromley Creek and perhaps a mile and a half west of Princeton was still occupied by ice. The eastern limit of the ice is not known, but it still acted as a dam to the Similkameen River.

The last channel (21) occupied before the Tulameen River returned to its original channel is recorded by a terrace (elevation 2850-2750 ft.) along the south rim of its present valley which extends from above Parr Station east and slightly south to a point just north of where Bromley Creek crosses the Hope-Princeton Highway. Here, it is evident that a delta of sand was being built forward so that the Similkameen lake itself must still have existed, presumably draining via Smelter Lake (elevation 2650 ft.). If further diversion channels were occupied they have been obliterated by subsequent erosion.

The position of the ice front and the point at which the ice dam blocking the Similkameen disappeared is not certain. It appears, however, that it may have persisted for some time after the Tulameen had returned to its original channel. This conclusion is based on the presence of silts and terrace remnants about one hundred feet above the present bed of the Similkameen River (elevation about 2300 ft.), and approximately continuous with the outwash gravels north of Princeton. This conclusion in turn is consistent with that of Mathews (1944, p. 42), who postulated the persistence of an ice dam near the mouth of Hayes Creek.

The only records of the late glacial history in the northern half of the coalfield are the river benches and outwash materials already mentioned. The sequence is interpreted as a period of channel cutting in the initial stages of ice retreat, followed by aggradation during the later stages.

The large kettles immediately north of Princeton are interpreted as the remnants of a stagnating ice block which was imbedded in the outwash.

Substantiation of the foregoing reconstruction requires much more detailed work. Possibilities of other outlets, for example Railroad Creek pass which may have carried the Tulameen River water westward, must be investigated; Newton Creek on the basis of its surprisingly large meanders appears to be a relic of a much larger stream; and finally, the sequence of the development of Hayes Creek deserves further work.

Late Glacial Diversion Channels
of the Similkameen River, Tulameen River,
Granite Creek and Whipsaw Creek

Hills - black lettering
Diversion Channel

(1) Tulameen River to Skaist River (Pass el. ca. 4950 ft.)
(2) Tulameen River to Snass Creek (Pass el. ca. 4850 ft.)
(3) Tulameen River via Podunk Valley (Pass el. ca. 4750 ft.) to Sowaqua Creek
(4) Tulameen River to Vuich Creek (Pass el. ca. 4550 ft.)
(5a) Tulameen River to Blakeburn Creek(5), north fork of Holmes Creek (Pass el. ca. 4200 ft.)
(6) Tulameen River to Roany Creek (Pass el. ca. 3250 ft.)
(7) Granite Creek to the headwaters of the Tulameen River (Pass el. ca. 5350 ft.)
(8) Granite Creek to Lamont Creek (Pass el. ca. 5050 ft.)
(9) Whipsaw Creek to Copper Creek (Pass el. ca. 4650 ft.)
(10) Whipsaw Creek to Friday Creek
(11) Whipsaw Creek to Deep Gulch Creek
(12) Whipsaw Creek across Mt. Kennedy to Similkameen lake (Pass el. ca. 3950 ft.)
(13) Whipsaw Creek across Mt. Kennedy to Similkameen lake (Pass el. ca. 3300 ft.)
(14) Tulameen River to Whipsaw Creek along western edge of coalfield at ca. 3500 ft.
(15) Tulameen River down Whipsaw Creek
(16) Tulameen River down lower Lamont Creek
(17) Tulameen River $\frac{1}{2}$ mile north of Lamont Creek
(18) Tulameen River to Stevenson Lake via Dalby Creek
(19) Tulameen River to Bromley Creek to Stevenson Lake
(20) Tulameen River to Findlay Creek to Bromley Creek
(21) Last recorded diversion channel of the Tulameen

St. L. 1, 2, 3... Strand Lines

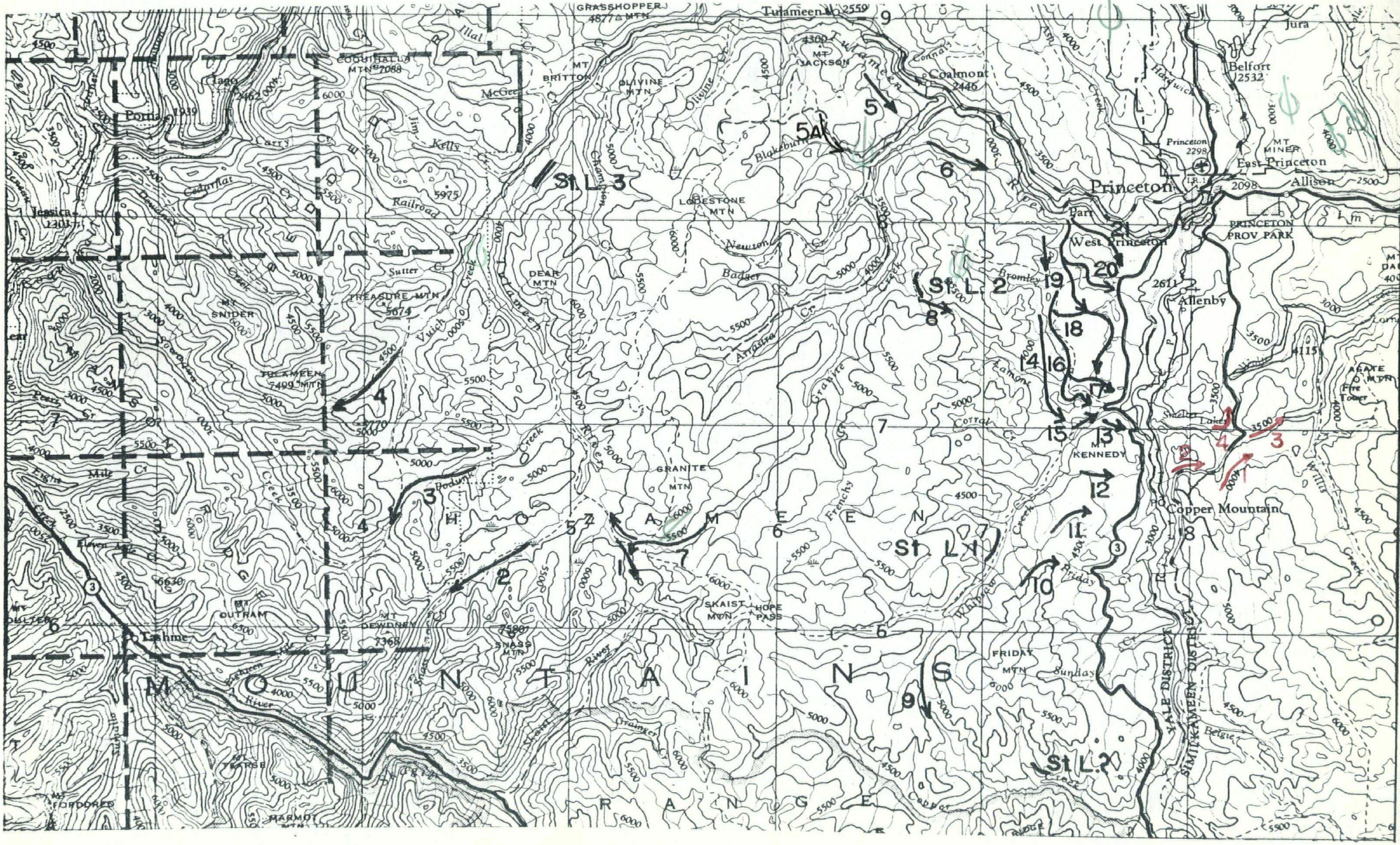
Mathews - red lettering
Diversion Channels

(1) Victor Lake Outlet
(2) Lost Horse Gulch
(3) Verde Creek Outlet
(4) Smelter Lake Pass

Rice (1947) - in green
Glacial Striae

Base Map and Topography
by
Surveys and Mapping Branch
Dept. of Mines and Tech. Surveys, 1957

Scale 1 inch = 4 miles



Princeton
East Princeton
Allison
Belfort 2532
Jura
MT MINER
PRINCETON PROV PARK
Allenby
West Princeton
Coalmont 2446
Tulameen 2559
MT JACKSON
GRASSHOPPER 4877 MTN
MT BRITTON
OLIVINE MTN
LODESTONE MTN
COQUIHALLA MTN 7088
DEAR MTN
TREASURE MTN 5674
TULAMEEN 7499 MTN
MT SNIDER
GRANITE MTN
SKAIST MTN
HOPE PASS
MT DEWDNEY 7368
SNASS MTN
MT OUTRAM
FRIDAY MTN
MT KENNEDY
Copper Mountain
AGATE MTN
YALE DISTRICT
SIMILKAMEEN DISTRICT
Tashme
Jessica 1303
Portia 1919
St L 3
St L 2
St L 1
St L ?
H O Z A M E E N
M O U N T A I N S
R A N G E

PLATE 1

Hayes Creek

Fig. 1: View from southwest showing the gently sloping walls of upper part of valley.

Fig. 2: View of junction with the Similkameen. Note that the walls are steeper than in fig. 1.

PLATE 2

Terraces along Allison Creek

Fig. 1: View looking south from a point just west of Belfort. The lower surface is the same terrace as that seen in the picture below. A higher, more restricted terrace is seen on the left. At least three terraces can be seen in the field at this point.

Fig. 2: View looking north across the Similkameen about 3/4 of a mile east of Princeton. Terrace formed by outwash gravels.

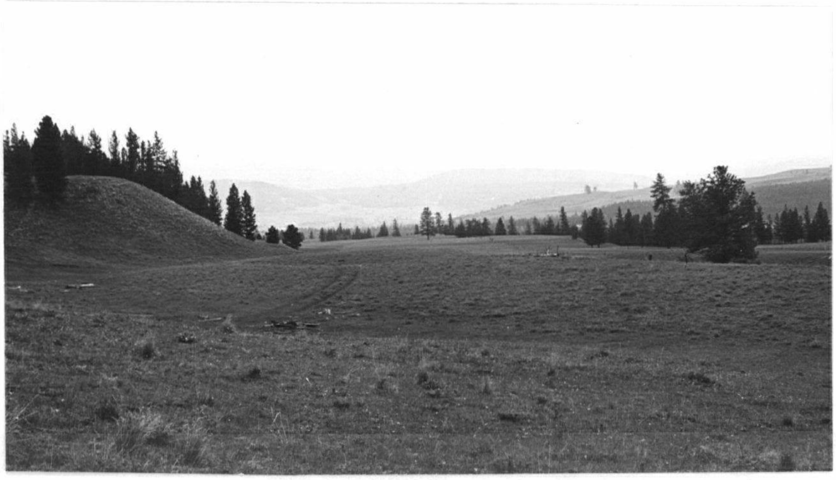
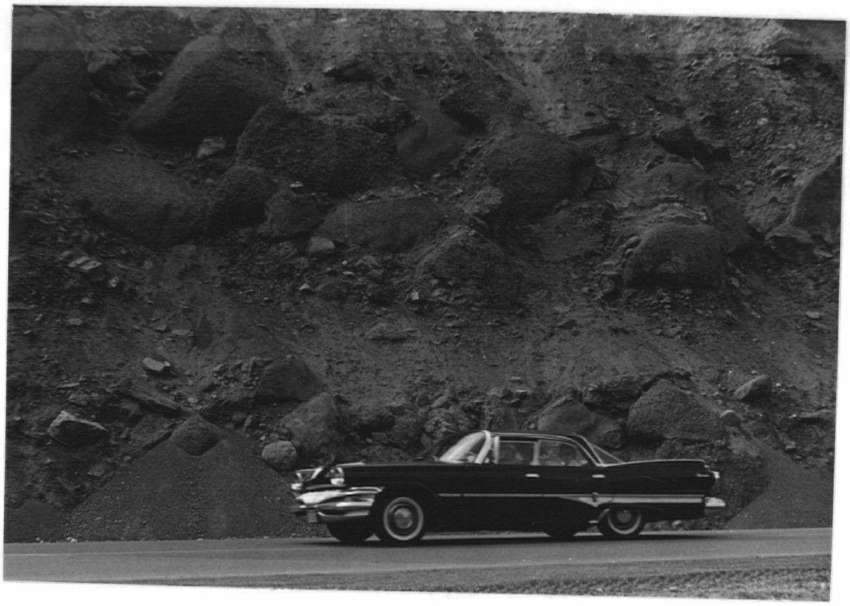


PLATE 3

Pleistocene Exposures Near Princeton

Fig. 1: View to the north. Outwash materials on the Hope-Princeton Highway at Whipsaw Creek. Boulders are predominantly derived from the granule to pebble conglomerates of the Allenby Formation with minor amounts of coaly shale.

Fig. 2: A channel cutting gently dipping Allenby Formation sediment which has been clogged by glacial debris. Outcrop is on the Princeton-Merritt Highway about four miles north of Princeton. View looking west.



PART II

STRATIGRAPHY

GENERAL STRATIGRAPHY

The bedrock within the Princeton coalfield crops out poorly. For this reason only a composite stratigraphic column can be given.

Previous workers (Camsell, 1907; Rice, 1947; Shaw, 1952) interpreted the stratigraphy as consisting of an upper and lower volcanic sequence separated by the Princeton sediments. Shaw (1952) proposed subdividing the Princeton coalfield as follows:

Period	Epoch	Formation	Lithology
Tertiary	Miocene ?	'Upper Volcanic'	Dark brown, grey, vesicular and amygdaloidal basaltic lavas and breccias
		Unconformity	
	Oligocene ?	Allenby	Buff-colored, granule- and pebble-conglomerate; sandstone; massive to fissile shales; massive clay, including bentonite; coal
		'Lower Volcanic'	Brown, red, and grey, partly banded, in places vesicular, basalt and andesite
		Unconformity	
Triassic (mainly)	Upper Triassic (mainly)	Nicola Group (mainly)	Mainly volcanic rocks [1]

[1] See Rice, 1947, p. 6, for details

The revised stratigraphic section is as follows:

FORMATIONS OF THE ALLENBY GROUP

Allenby Formation (Middle Eocene)	1000' - 6000' (only 1000' measured) buff, brown, yellow-orange, white arkosic pebble to granule conglomerates, sandstones, tuffs, tuffaceous sandstones, shales (massive to fissile), coal and bentonite.	Princeton Black Coal Seam 100-120' Princeton Ash
Upper Volcanic Formation (Middle Eocene)	500-1000' grey, dark brown, black, vesicular to amygdaloidal, flaggy or columnar jointed, massive to flow banded basalt, lavas or breccias; phenocrysts of olivine locally abundant; interbedded with Allenby sediments.	
	Arbitrary Contact	
Lower Volcanic Formation (Middle Eocene or earlier)	Brown, red, grey, green, amygdaloidal to vesicular predominantly breccias but locally contains numerous flows. After Shaw, 1952, (pp. 6-7).	Nonconformity
	Unconformable	Osprey Lake Intrusion (Jurassic or later) Rice, 1947
Nicola Group (Upper Triassic)	See Rice, 1947, (p. 7).	Intrusive

The present work indicates that the Upper Volcanic Formation is interbedded with the lower strata of the Allenby Formation (see sections BB_1 and CC_1, page 65). This relationship can be shown at three localities: (1) on either side of the Tulameen River about two and a half miles west of Princeton, (2) on Whipsaw Creek about half a mile west of the Hope-Princeton Highway, and (3) on the east side of the Similkameen River about a mile north of Whipsaw Creek.

The stratigraphic position of the Upper Volcanic Formation on Summers Creek is not definitely known. A careful search of the area covered by these volcanics failed to show any sediments that definitely overlie them. Their stratigraphic position, therefore, can only be inferred by correlation with those of a known stratigraphic position.

The status of the Upper Volcanic Formation is in doubt. At present it seems to represent transition from a volcanic to a sedimentary environment. The reasons for doubt are: (1) it is interbedded with the basal Allenby Formation; (2) where associated with the Allenby Formation, the Upper Volcanic Formation does not form a laterally continuous unit but a series of discontinuous flows and flow breccias which occupy roughly the same stratigraphic position; (3) the contact of the Upper Volcanic Formation with the Lower Volcanic Formation is transitional and is, therefore, arbitrary; (4) both the Upper Volcanics and the Allenby Formation appear to overlie the Lower Volcanic

Formation conformably.

If the Upper Volcanic Formation is to retain its status as a formation, all that is necessary is to include in the definition its intertonguing relationship with Lower Allenby Formation sediments.

The following criteria were used for recognition of the Upper Volcanic Formation: the presence of coalified or petrified wood, grey or grey-black color, highly vesicular to amygdaloidal structure, olivine pheocrysts, a tendency towards spheroidal weathering, flaggy or columnar jointing, and generally fresh appearance. The Lower Volcanic Formation lacks coalified or petrified wood and phenocrysts of olivine, tends towards angular fragments on weathering with red and brown colors predominating, contains more amygdules than vesicles, and lacks columnar or flaggy joints. Breccias appear to be more common in the Lower Volcanic Formation, and in general they are much more altered than those of the Upper Volcanic Formation.

ALLENBY FORMATION

The Allenby Formation as defined by Shaw (1952, p. 8) is best exposed along the Similkameen at Allenby. He states that at least 3500 ft. of sediments are exposed at this locality. Present work indicates that the formation may be as much as 6000 ft. thick, although exposures are too limited to warrant detailed stratigraphic measurements.

The Allenby Formation sediments are described under the various rock types present, viz. conglomerates, breccias, sandstones, limestones and shales. The Princeton Ash, Vermilion Bluffs, and the Summers Creek sections will be described in detail, the ash because of its significance as a source of biotite for age dating, the Vermilion Bluffs because it is notable for the presence of limestone, dolomite and chalcedony. They are, however, only minor components of the Allenby Formation. The Allenby Formation on Summers Creek differs somewhat from the typical Allenby sediments of the southern half of the coalfield. Therefore, it will be described separately.

Conglomerates

Conglomerates are found throughout the entire map area. There is, however, a decided particle size variation from north to south. Known outcrops of cobble-boulder conglomerates are restricted to the extreme northern part of the Princeton coalfield, whereas the granule-pebble conglomerates outcrop throughout the map area, but apparently becoming less abundant in the south. This apparent decrease in the abundance of granule-pebble conglomerates to the south may be the result of poor exposure, however, drill hole logs (Rice, 1947, pp. 117-123) indicate this tendency.

<u>Cobble-Boulder Conglomerate</u>:- About 100 feet of

cobble-boulder conglomerate is well exposed on Summers Creek about three miles upstream from its junction with Allison Creek. The predominant size range of the fragments is from 20 cm. to 50 cm., with an occasional boulder ranging upward to 90 cm. There is a continuous size gradation from the finest to the coarsest particles. Cobbles and boulders comprise 50 percent or more of the total volume of the conglomerate. A cobble and boulder count gave the following composition: 95 percent crystalline igneous rocks, of which granite and quartz monzonite are the most abundant; 3 percent highly altered volcanic rocks (red in color); and 2 percent rock of similar composition to the associated arkosic sandstone. A single cobble of banded chalcedony was found in one count. The cobbles and boulders are predominantly well rounded with a few that are sub-rounded to sub-angular. The matrix is arkosic in composition, with a high microcline-microperthite content very similar to granule-pebble conglomerates which are common in the southern half of the area.

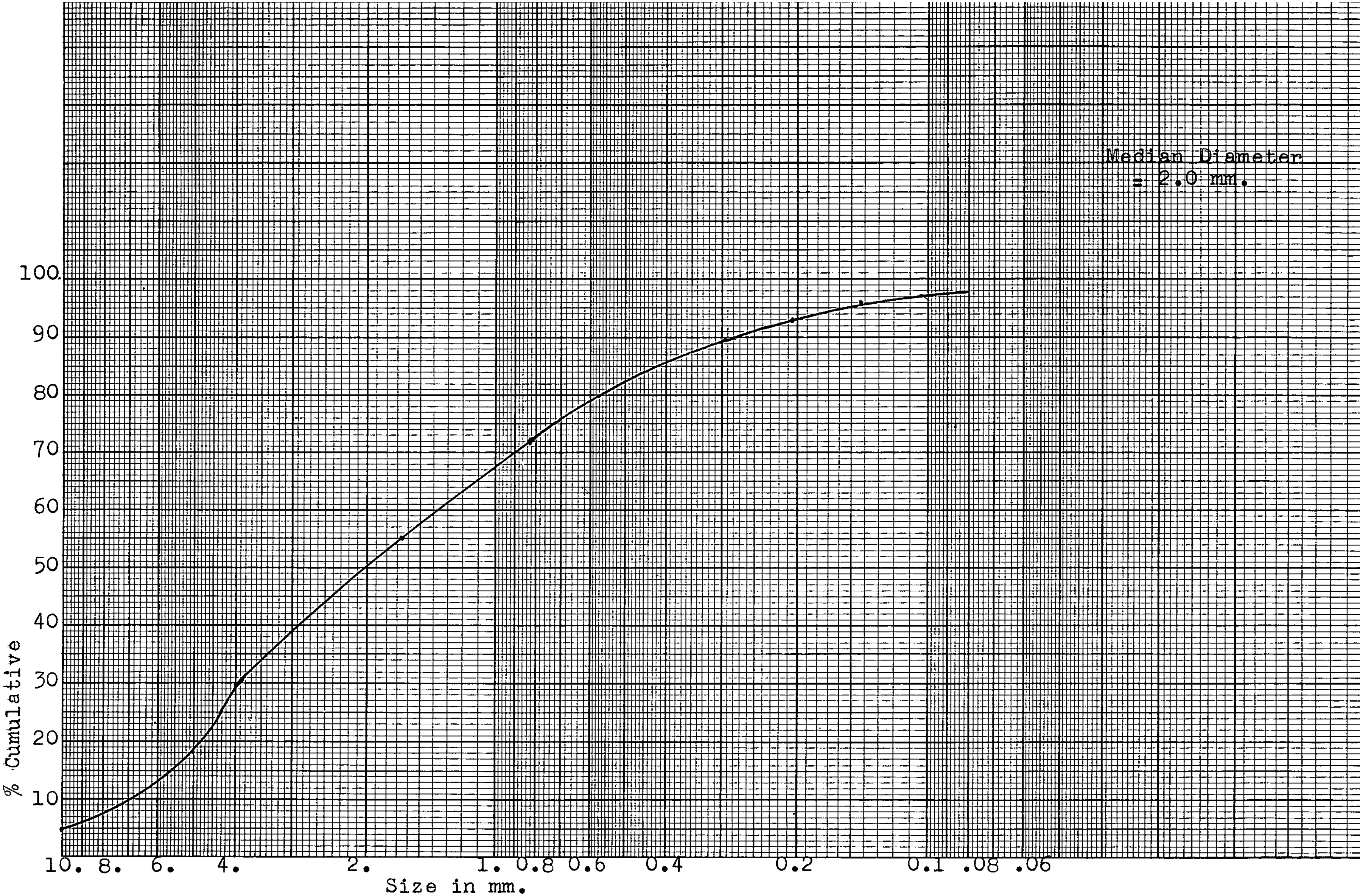
Individual beds are five feet or more in thickness. Bedding is marked by either alternating cobble-boulder and granule-pebble conglomerate beds, or interbedded lenses of sandstone. Imbrication is a common feature of the cobble-boulder conglomerates, whereas cross-stratification is common in the granule-pebble conglomerates.

Five thin sections were made from representative cobbles and boulders. Quartz, microcline-microperthite, plagioclase (An35), biotite, sphene, apatite and magnetite are present in all thin sections. Texturally, the rocks vary from fine grained to coarse grained, and not infrequently contain large microcline-microperthite phenocrysts, ranging upward to 2.5 cm. or more. The microcline-microperthite feldspars tend to be fresh. The plagioclase is, however, predominantly altered to epidote or white mica. Plagioclase grains are generally 1½ mm. or less in size, whereas microcline-microperthite tends to be larger than 1 mm. The quartz is predominantly coarse-grained, ranging from 1 mm. to 3 or 4 mm., and often shows undulatory extinction. Myrmekitic texture is common.

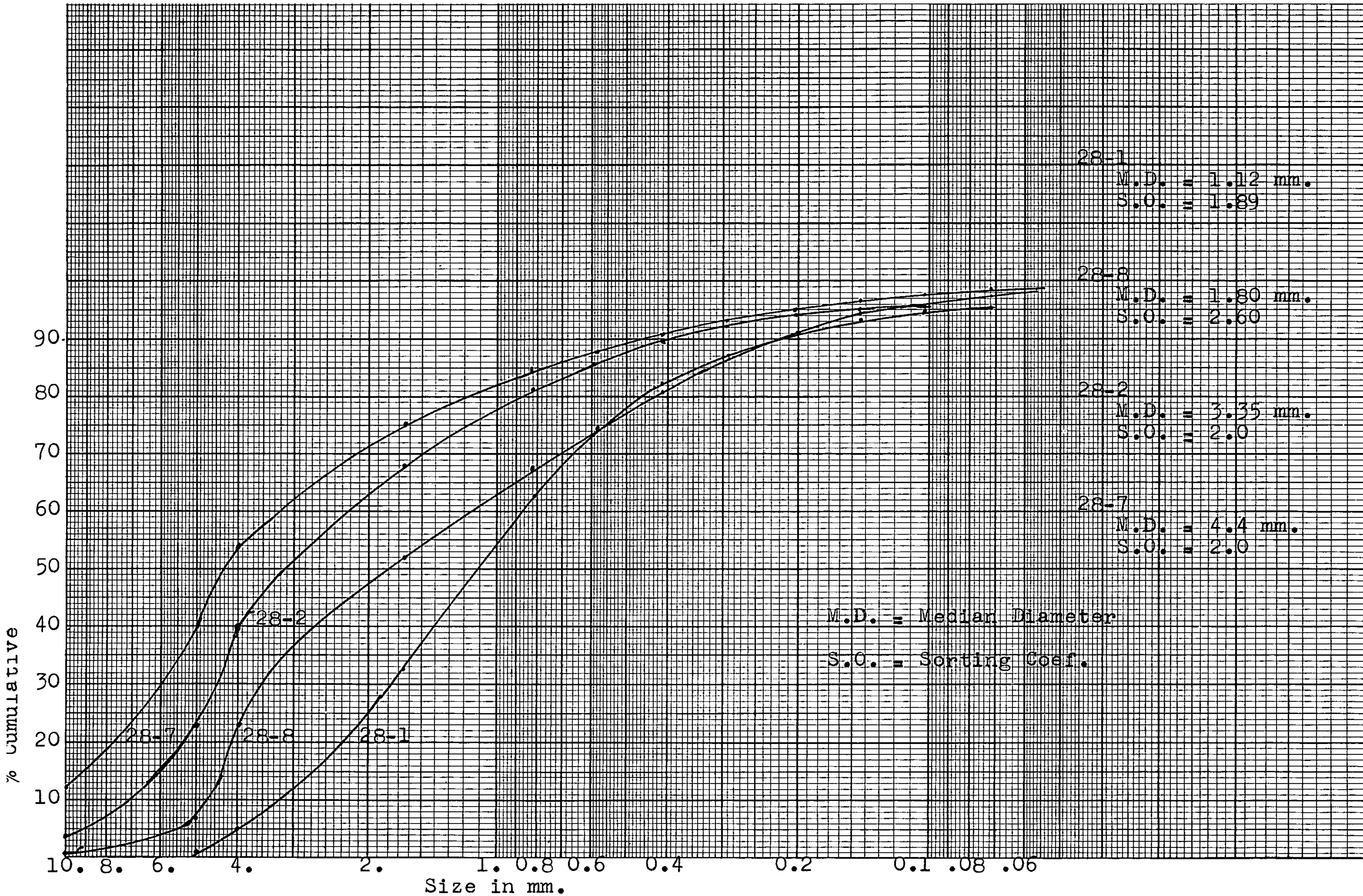
Granule-Pebble Conglomerate:- Samples for laboratory study of the granule-pebble conglomerate were taken from rock outcrops at the rear of the Caribou Brewery (Princeton, B. C.) and west along the Tulameen River.

In weathered outcrops, the granule-pebble conglomerate is tan to buff and not infrequently yellow stained. Outcrops are restricted to river, creek or road cuts.

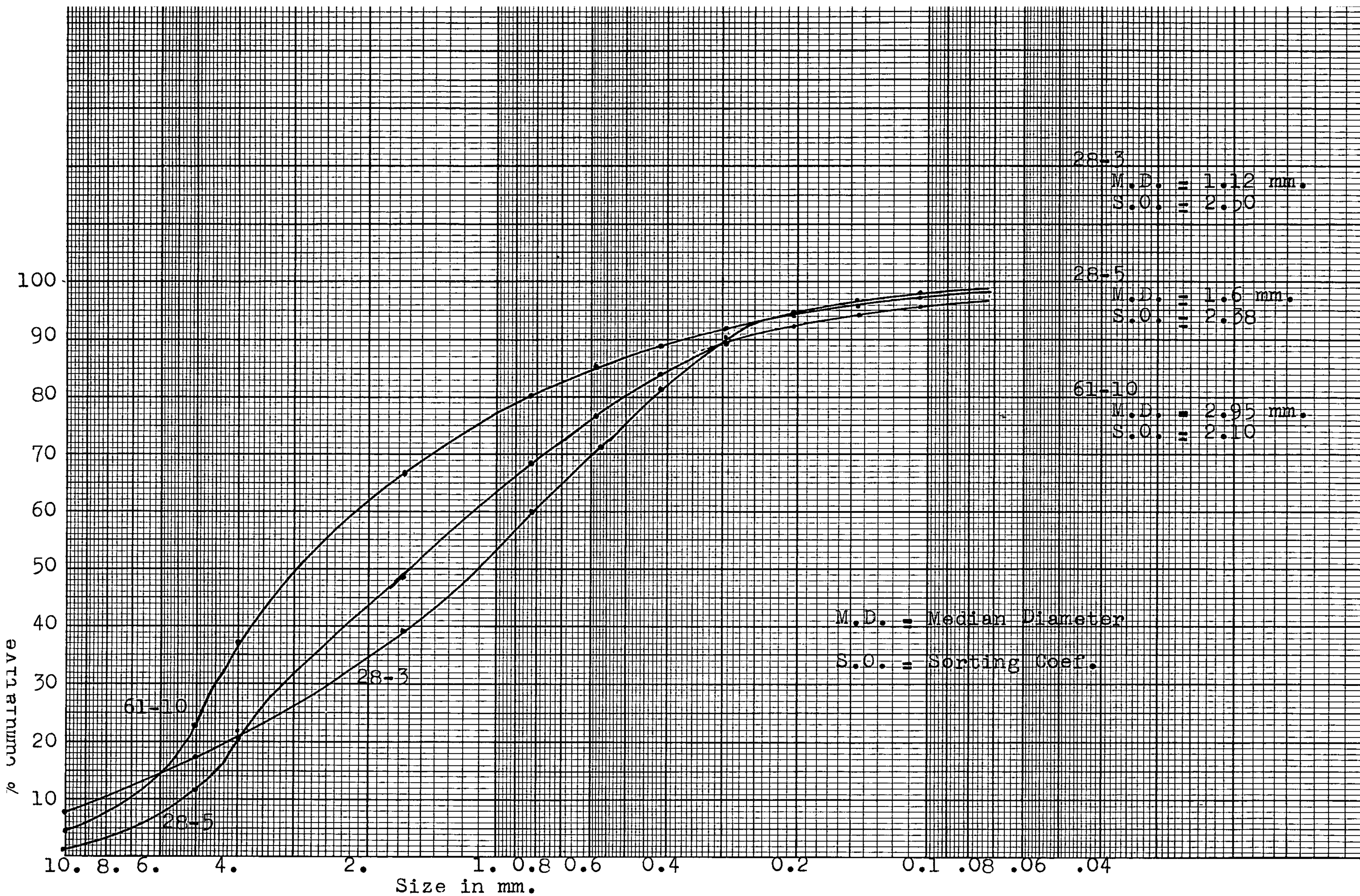
Sieve analysis of 4000 gms. of the granule-pebble conglomerate indicates that on an average 50 percent (range 33-75 percent) by weight of the total (text, fig. 2) sample was coarser than 2 mm. (text, fig.3-4). The average median diameter (matrix included) of the 4000 gms. was 2.1



Text, fig. 2 - Averaged cumulative curve for pebble and granule conglomerates from rear of Caribou Brewery, south side of Tulameen River, and Copper Mtn. R.R. 1 mile north of Allenby.



Text, fig. 3 - Fine conglomerates and sandstones from rear of Caribou Brewery and south side of the Tulameen River.



Text, fig. 4 - Fine conglomerates and sandstones, 28-3 and 28-5, from south side of Tulameen 1½ miles west of Princeton; 61-10 from Copper Mtn. R.R. 1 mile north of Allenby.

mm. (range of 1.12 to 3.35). The granule-pebble conglomerates are moderately well sorted (Krumbein and Sloss, 1956, p. 73). The present studies indicate that the conglomerate is unimodal.

The matrix is predominantly clastic, grading progressively from a coarse sand through fine sand to a silt, with possibly minor amounts of clay. Locally, the granule-pebble conglomerate has a carbonate or silica cement. The carbonate is restricted to concretions, whereas the silica is restricted to those areas adjacent to the volcanic rocks associated with sediments. Most of the granule-pebble conglomerates are extremely friable.

The degree of roundness varies with the size fraction. The coarser material, greater than 1 mm., is generally sub-rounded to rounded. Fragments smaller than 1 mm. are sub-angular and transitional to angular in material less than $\frac{1}{2}$ mm.

Both thin section and stain studies were carried out. The thin section studies were of necessity restricted to carbonate or silica-cemented rocks. Where the matrix was clastic, the rocks tended to be friable, and for these, stain techniques were used. In all instances the granule-pebble conglomerate was arkosic, with the predominant minerals being microcline, quartz, and plagioclase (An_{35}), with minor amounts of biotite, sphene, apatite, hornblende, magnetite, chert, chalcedony (banded), and a few grains of a volcanic rock.

Although the material is arkosic throughout its entire size range, there is considerable variation in the feldspar:quartz ratio with change in size.

Table 1 - Composition of the Granule-Pebble Conglomerates:-

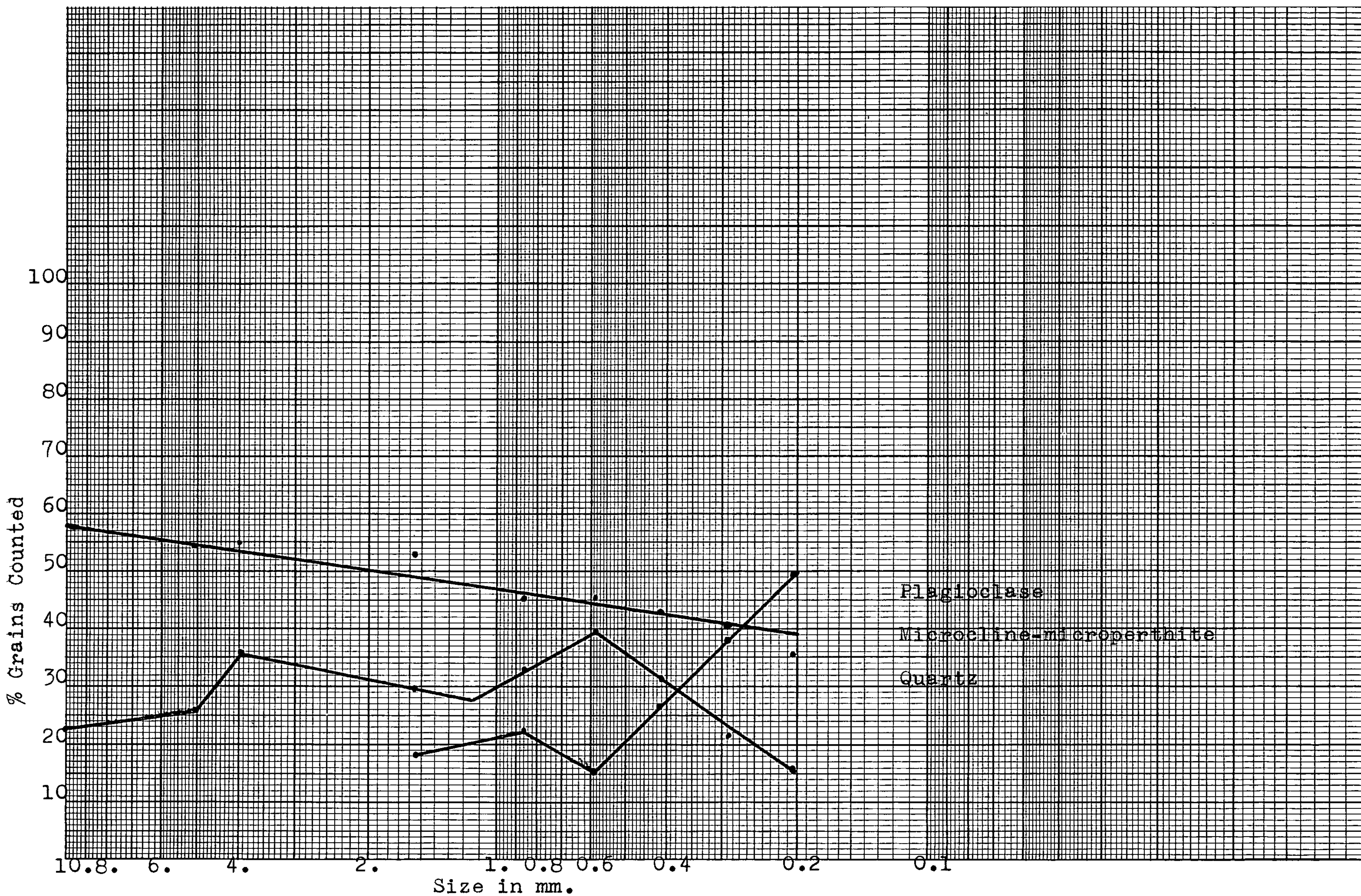
Size		Microcline Microperthite	Plagioclase	Quartz	Composite *
10 mm	20 mm	57.5		22.5	20.0
5 mm	10 mm	54.5		26	19.5
4 mm	5 mm	54.5		35	10.5
1.56 mm	4 mm	52.5	18	29.5	
.833 mm	1.56 mm	45.00	22.5	32.5	
.589 mm	.833 mm	45.50	15.0	39.5	
.417 mm	.589 mm	43.00	26.0	31.0	
.295 mm	.417 mm	40.00	38.0	22.0	
.208 mm	.295 mm	35.00	49.0	16.0	

See also fig. 5

* Composite grains are those which are an aggregate of more than one mineral, i.e. quartz, microcline and plagioclase

Table 1 and text, fig. 5 are based on a count of 200 to 1000 grains per size range in each of eight samples of the granule-pebble conglomerate.

The significance of these data is that they show a variation in composition that is not random but is a reflection of the size range of the component minerals in the source rock. A brief discussion of the mineralogy of the boulders and cobbles from the north end of the map area has already been given (page 26-7). Thus it will be seen that the size range of the minerals of the pebble and granule conglomerate is very similar to that of the cobble-



Text, fig. 5 - Composition change of fine pebble and granule conglomerates with changes in grain size. Note composite grains not shown.

boulder conglomerate on Summers Creek. Further, the mineralogy, feldspar composition and myrmekitic texture are identical, hence it can be concluded that the bulk of these minerals are from the same source.

Sandstone

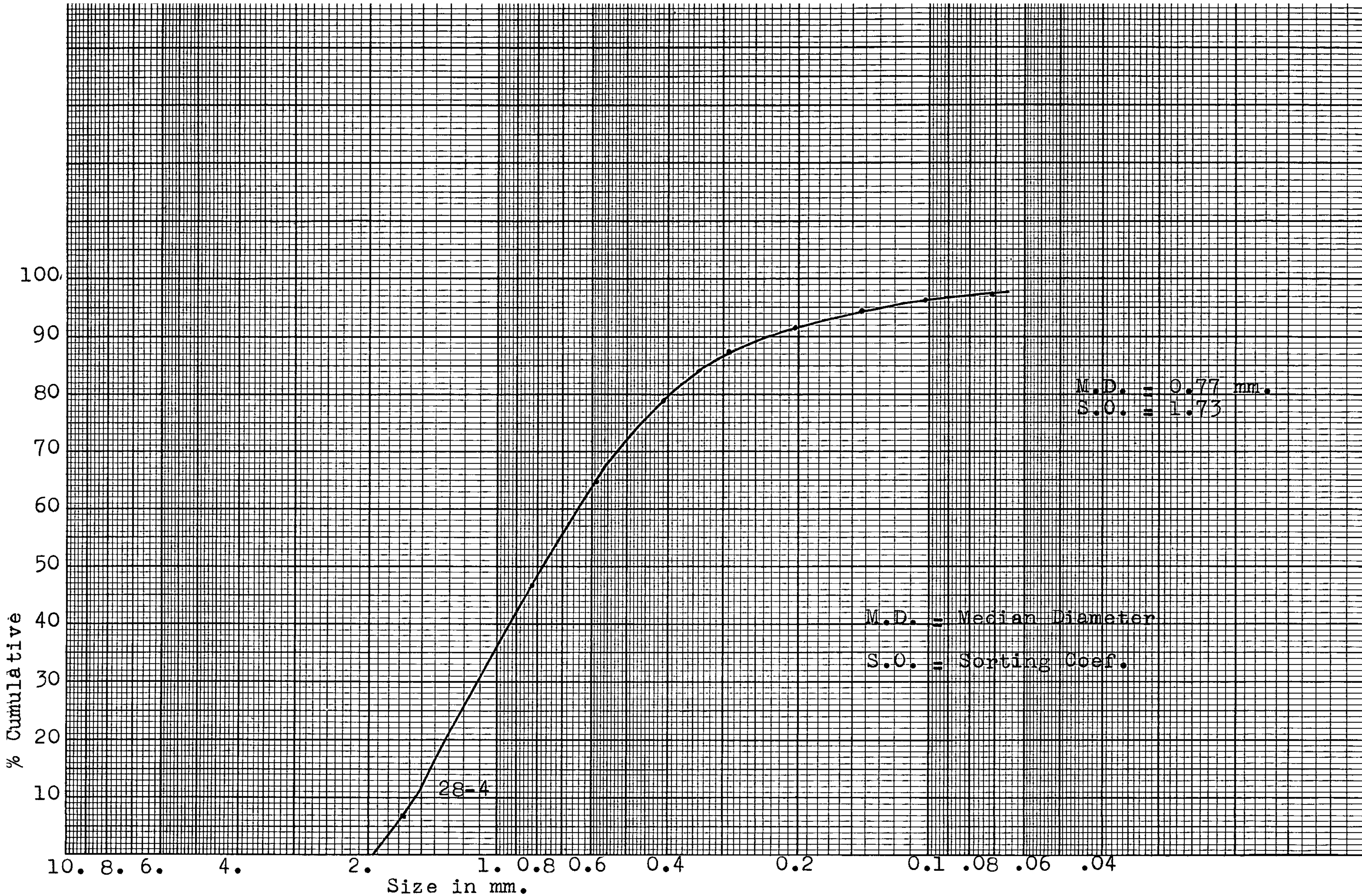
Sandstone is not common in the Princeton coalfield. Mineralogically, it is identical to the granule-pebble conglomerates. In a number of grains, remnants of myrmekitic texture were observed. Only a limited number of grain counts were made; they too show the variation in composition that has been previously described for the granule-pebble conglomerates. The matrix is clastic with locally a carbonate or silica (chalcedony) present.

Breccias

Both volcanic and sedimentary breccias are present within the Princeton Group. Many of the lowermost exposures of the Allenby Formation are breccias. The fragments range from sand size to blocks several feet across. The blocks are unsorted as to size.

Bedding is present only on a large scale, but may be marked in places by lenses of finer material or a lava flow (plate 4, figs. 1 and 2).

The breccias, which are always located along the



Text, fig. 6 - Sandstone from Tulameen River $1\frac{1}{2}$ miles west of Princeton.

edge of the coalfield, are derived entirely from the surrounding volcanic rocks. They appear to be of a composition similar to the rock underlying them, i.e., if they are underlain by Nicola, then the fragments tend to be Nicola.

An excellent example of the local source of the breccias is a roadcut exposure on the Princeton-Merritt Highway about 6½ miles north of Princeton. Here, about 60 ft. of section composed entirely of fragments derived from the Nicola Group is exposed. Rocks of the Nicola are found within 200 to 300 ft. of the exposure. The matrix is predominantly clastic. However, a chalcedonic or carbonate cement is present locally. An excellent example of the latter is found on the south side of the Tulameen River about two miles west of Princeton.

Shales

Pettijohn (1957, p. 341) defines a shale as: "a laminated or fissile claystone or siltstone." On the same page he modifies this statement by saying that: "Siltstones, unlike shales, are commonly bonded by chemical cements, are cross-bedded on a small scale..."

In this study, the term "shales" includes laminated and fissile claystones and siltstones, which may locally contain some carbonate cement.

In weathered outcrop the shales are multicolored, with browns, grey-browns and black predominating. Locally they are red, grey-blue to white. A thin section of the red shales shows oxidized remnants of pyrite crystals which impart the red color. Red shales contain less organic matter than do the darker ones. Plant or fish impressions are the only evidence of organic remains in red shales, whereas the dark (black or grey) shales frequently contain coalified materials.

The shales are laminated or very thin bedded. Several occurrences of extremely fine laminations (about 20-30 per centimeter) were observed in the northern half of the coalfield. The finely laminated shales tend to be well indurated, whereas shale associated with coal seams is more friable.

Mud cracks were seen at several localities, and well preserved rain drop prints were observed at one locality on Whipsaw Creek.

Local burning of coal seams in place has melted some of the shales, producing a porous glassy mass not unlike a scoriaceous volcanic rock.

Two thin sections of shale show the silt fraction to make up as much as 50 percent. Grains of quartz, microcline and plagioclase make up the silt-size fraction. The presence of these minerals suggests that the shales represent fine grained equivalents of the coarser clastics.

Limestone

The occurrence of limestone and dolomite in the Vermilion Bluffs is described on pages 46-50. At two other localities, dark argillaceous limestones were found (1) on the road up Whipsaw Creek, about ½ mile from the Hope-Princeton Highway, and (2) ¼ mile east of the Copper Mountain Railroad, about 3 miles south of Allenby. Their stratigraphic relationship is not known because of the isolated and restricted nature of the outcrops.

Bentonites

Lenticular bentonitic beds (½-2" thick) observed in the field are generally associated with shales or coaly shales. Shaw (1952, p. 8) reported two beds 15 ft. in thickness, but these were not seen during present field work. For a more detailed description of the bentonites, the reader is referred to Rice (1947), Shaw (1952), Spence (1923, 1924) and Spence and Light (1930).

Princeton Ash

The Princeton Ash is exposed at four localities (P.A. 1-4, Map p. 41). Three of these (P.A. 1-3) are road-cut exposures, whereas the fourth (P.A. 4) is in part natural and in part roadcut. The ash is a minimum of 20 ft. thick (P.A. 4), and is 100 to 120 ft. stratigraphically below the Princeton Black Coal seam (see Map). Nowhere is the top or bottom of the ash visible. At P.A. 1 it is overlain and underlain by interbedded shales, coaly shale and minor lenses of coal.

The ash forms conspicuous white to grey outcrops with a blocky or slab-like fracture pattern.

Exposure P.A. 2 can be subdivided into an upper and lower unit separated by a well defined undulatory surface (Plate 7, fig. 2, Plate 8, fig. 1), marked by the development of a ½ inch layer or less of bentonite. Table 2 is a list of features which suggest that the upper unit lies disconformably on the lower unit.

Upper Unit	Lower Unit
(1) Megascopically bedded (Plate 7, fig. 2)	Microscopically bedded (Plate 8, fig. 2)
(2) Shows graded bedding	None observed
(3) Very fine grained	Coarser grained
(4) Plate like fracture parallel to bedding (Plate 7, fig. 2)	Blocky fracture (Plate 7, fig. 1 and 2)
(5) Clastic dykes and sills not observed	Clastic dykes and sills present
(6) Well preserved plant leaves and twigs (*Metasequoia* sp.)	Irregular carbonaceous streaks only

Table 2 - Contrasting Features of the Upper and Lower Units at P.A. 2

The significance of this disconformity is not known. However, for the following reasons it is suggested that the disconformity is local in extent: (1) the similarity of the mineralogy in the upper and lower units, (2) there is no evidence of contamination by Allenby Formation sediments along the contact surface.

Clastic dikes and sills are common in the lower unit of P.A. 2. The sills are seen in thin section to be intrusive parallel to oriented biotite grains, causing little reorientation of the biotite, whereas along the dikes the biotite grains are reoriented and frequently parallel the dike contact. The dominant minerals of the dikes and sills are too fine to be determined in thin section. Xenoliths of biotite and plagioclase feldspar are common in both the dikes and sills.

Exposure P.A. 4 is tentatively correlated with the lower unit of P.A. 2. It is characterized by lack of megascopic bedding, blocky fracture, the unrecognizable carbonaceous materials, and a coarse grain size.

Andesine (An_{40}) and biotite are the most common minerals in the ash. Quartz, hornblende (oxyhornblende), apatite and epidote are present in minor amounts. Several fragments of chert and a fine grained volcanic rock were encountered (Plate 10, fig. 2, Plate 11, fig. 1). Volcanic glass in the form of partially devitrified shards is present in amounts from 40 to 60 percent. Locally a carbonate is present in fractures.

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MINES AND TECHNICAL SURVEYS
GEOLOGICAL SURVEY OF CANADA

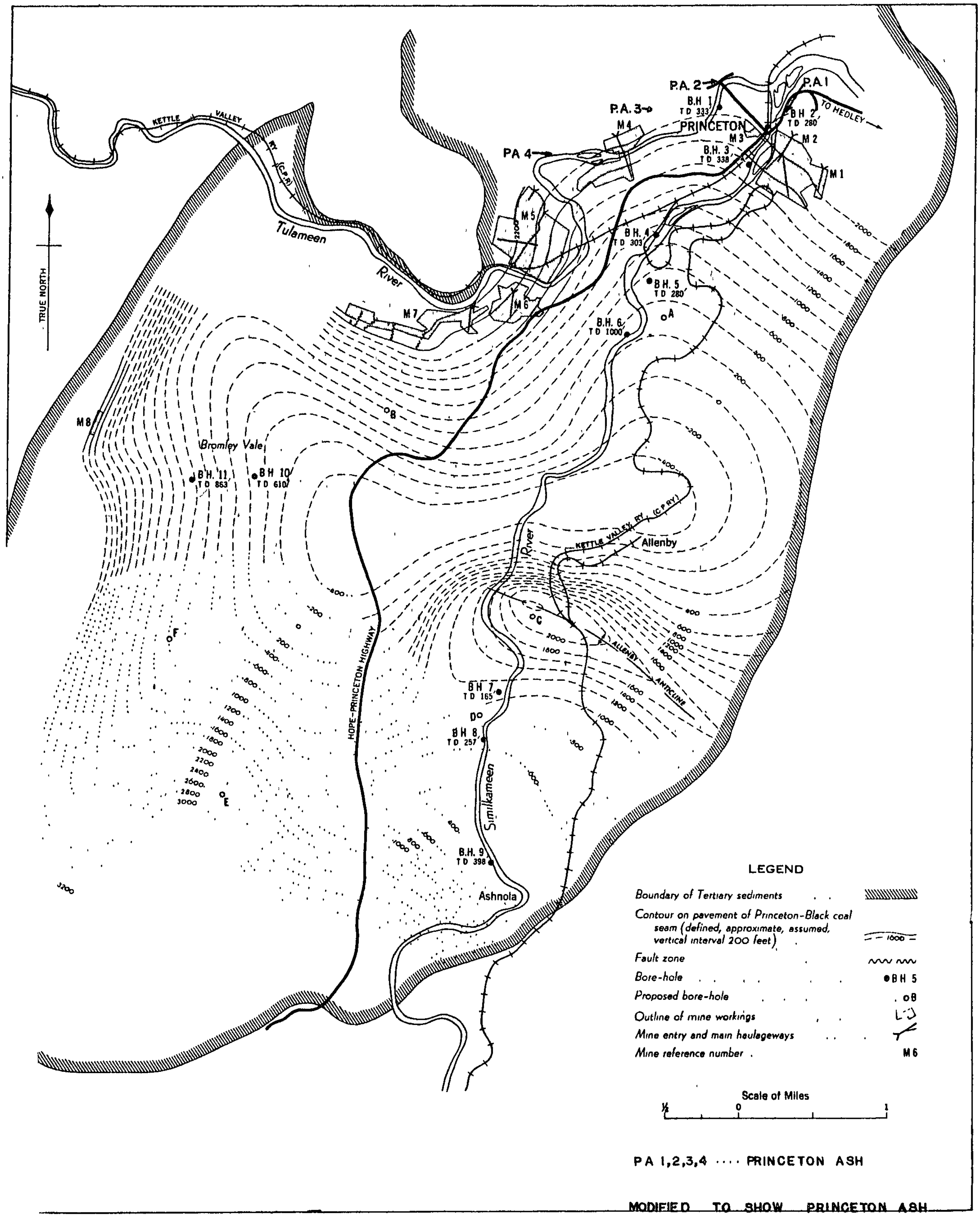


Figure 1B SHAW 1952
Structural contour map of southern half of Princeton coalfield

Biotite is the only mineral recognizable in hand specimen. It is present in all outcrops, but locally it is rare, and nowhere does it exceed 5 percent. In thin section the biotite is pleochroic dark brown to light brown. Locally it is corroded (Plate 10, fig. 1) and the grain borders under crossed nicols remain a dark yellowish to reddish orange on rotation of the microscope stage.

The andesine is generally fresh, but locally shows some alteration to epidote (?). Many feldspars show corrosion rims (Plate 9, fig. 1), others have been partially resorbed along fractures (Plate 13, fig. 1). Almost 100 percent of the crystals are brecciated (Plate 11, fig. 2, Plate 12, fig. 1). The fragments are generally sharp and angular but some may be sub rounded to rounded. Zoned feldspars (Plate 9, fig. 1) and glomeroporphyritic texture (Plate 12, fig. 2) were observed in a single section from the lower 5 ft. of the exposure at P.A. 4. Feldspar microlites are locally abundant.

A sawn slab of the ash was etched with hydrofluoric acid, then was tested for potash feldspar and quartz with sodium cobaltinitrite. The resulting diffuse yellow stain suggests a potash rich glass matrix. Several clear glassy grains of quartz were observed.

In summary, the ash is a minimum of 20 ft. thick and is composed of volcanic glass and crystal fragments of andesine, biotite and minor amounts of quartz. Staining indicates a high potash content and minor amounts of crystalline quartz in the glass.

Summers Creek Section

The following thickness calculations are based on contour map and barometer readings:-

Formation	Lithology
Upper Volcanic	150 ft., grey brown, flaggy, highly vesicular to amygdaloidal basalt and/or andesite. Olivine phenocrysts present locally.
Allenby	700 ft., boulder-cobble-pebble-granule conglomerates, arkosic sandstone, tuffaceous sandstone, tuff, and minor amounts of shale. The finer sediments are strikingly white in color and only locally the buff or brown color typical of the section further south. Bedding is generally very thick, but laminations are present in the finer sediments.
Lower Volcanic	200 ft. or more, dense to vesicular, frequently amygdaloidal (chalcedony) basalt and/or andesite. Grey, red, brown or green in color. Both flows and breccias are present. Overlies Nicola Group on the north and west, Summers Creek intrusive body on the east.
	Unconformity
	Nicola or Summers Creek Intrusion.

<u>Lower Volcanic Formation</u>:- For description of the Lower Volcanic Formation see page 21.

The contact between the Osprey Lake Intrusion and the Lower Volcanic Formation was not seen. However, at one locality only a few feet separated outcrops of each.

Here the lavas show no evidence of contact metamorphism.

This contact could be interpreted as either a fault or a nonconformity. The Allenby Formation which appears to conformably overlie the Lower Volcanic Formation has been derived from the Osprey Lake Intrusion. It is, therefore, suspected that the contact surface between the Lower Volcanic Formation and the Osprey Lake Intrusion is nonconformable.

Allenby Formation:- The Allenby Formation is made up of boulder to granule conglomerates, tuffs, tuffaceous sandstones, arkoses, and minor amounts of shale. (For a description of the conglomerates, see page 25.)

Unlike the arkosic sediments further south which are typically buff colored, the tuffs, tuffaceous sandstones and arkoses are strikingly white on the weathered surface (Plate 13, fig. 2, Plate 14, fig. 1 and 2).

In handspecimen the tuffs cannot be readily told from the arkosic sediments. In thin section there appears to be a gradation between the two end members, tuff and arkose.

The tuffs on Summers Creek are very similar to the Princeton Ash in many respects, notably the following: (1) high proportion of glass matrix, (2) angularity of the crystal fragments, (3) varying amounts of biotite present, and (4) presence of such textures as resorbed biotite and broken, partially resorbed or welded crystals.

There are both vertical and horizontal changes from tuffs to tuffaceous sandstone. To the north and east the tuffs and tuffaceous sandstones give way laterally to arkosic granule-pebble conglomerates and sandstones. The transition zone is poorly exposed and cannot be readily observed in the field. The ash appears to be absent along the northeastern margin of the coalfield.

The Summers Creek tuff, however, differs from the Princeton Ash in that: (1) it is much coarser, with the particle size ranging upward to 4 mm., while that of the Princeton Ash is in all instances less than 2 mm.; (2) it has been reworked by stream action; (3) it contains much more quartz; (4) it lacks the irregular carbonaceous remains found in the Princeton Ash; (5) it lacks zoned plagioclase crystals (in three thin sections studied); and (6) it contains a higher percentage of rounded grains (possibly the result of the reworking and the larger particle size).

<u>Upper Volcanic Formation</u>:- These volcanic rocks, which have been partially removed at the present erosion surface, have a maximum measured thickness of 150 ft., and are of limited horizontal distribution. The upper surface is the present erosion surface. They contain no interbedded sediments, and sedimentary beds are not known to occur above them. They are typically grey to grey-black or brown in color, and are vesicular or amygdaloidal (chalcedonic) textured lavas. Weathering produces a series of plate-like

slabs which may be only one to two inches thick and a foot or more in diameter. No breccias were seen. Columnar jointing is present, but not well developed. Locally, phenocrysts of olivine are present.

These volcanics appear to lie with a slight angular unconformity on the underlying sediments. The unconformity is probably a reflection of the nature of the coalfield and the source of the sediments, and therefore, is not interpreted as a period of non-deposition or erosion.

No Allenby Formation sediments were found overlying the Upper Volcanic Formation at this point. The Upper Volcanic Formation has, in the past, been interpreted as post Allenby Formation sediments. However, the presence of tuffs and tuffaceous sandstone in the sedimentary interval between the Lower Volcanic and Upper Volcanic Formations indicates that there was continued volcanic activity in the interval between the Lower Volcanic Formation and the Upper Volcanic Formation.

Vermilion Bluffs Section

The Vermilion Bluffs section (Plate 16, fig. 2) crosses the Tulameen River about a mile west of Princeton. The section, which is about 95 feet thick, is composed of a basal silicified pyroclastic rock overlain by interbedded silicified diatomite, limy chert, siliceous and dolomitic limestone, shale, coaly shale and minor amounts of bentonite.

The highly silicified members predominate in the lower part of the section and the siliceous and dolomitic limestone in the central part. The shales and coaly shales are present throughout the entire section, increasing upwards until the entire section is composed of this member.

The rocks of the Vermilion Bluffs range in color from brick red in the lower part to red-brown, orange, tan or yellow higher in the section. Rice (1947, p. 28) attributes the color to the presence of ocher.

Individual beds of the silicified dolomitic-limestone are lenticular (Plate 17, fig. 2, Plate 18, fig. 1) and generally have a maximum thickness of less than 3 feet, but beds of 6 feet were seen. Some beds are massive, others are internally laminated. The laminations, marked by carbonaceous matter, are in places parallel to, and at others perpendicular to large scale bedding.

Weathering produces an alternating series of projecting ledges of silicified limestone and receding beds of shale (Plate 16, fig. 2). Several of the limestone members show an irregular weathering pattern similar to recent tufa deposits (Plate 18, fig. 2).

Irregular chert nodules are present throughout the section, but are more common in the basal members. They are present in all rock types except the shales or coaly shales. In thin section the nodules are seen to be composed of fibrous chalcedony and very fine quartz, with numerous impurities such as carbonaceous matter or a carbonate. Relict bedding is frequently indicated in the chert nodules by oriented carbonaceous matter.

Botryoids of calcite are present in the upper part of the section. On the south side of the Tulameen River they occur in a lens which has a maximum thickness of 2 feet and extends horizontally 50 feet or more, whereas on the north side they occur as random individuals. They range in size from $\frac{1}{2}$ mm. to 8 mm., with the majority from 5 mm. to 7 mm. If they occur en masse they exhibit an external form similar to that of polyhedral pisolites (Schrock, 1930), whereas individuals are spherical or sub-spherical. The surface of the botryoids is either smooth or exhibits smaller botryoids. In thin section they are structureless and lack the concentric layers of polyhedral pisolites. None was observed with a nucleus. In thin section it is often difficult to delimit individual botryoids from the matrix which is of similar composition and texture. Occasionally, the botryoids are darker than the surrounding matrix.

The gastropod Physa saxarubensis is present in the limy part of the section, but is most common in the basal members. The gastropod is calcitic in cherty zones, whereas in some of the limy members it has been silicified.

The limestone is impure. Carbonaceous matter, chalcedony, fine grained quartz, diseminated limonite (?) and pyrite can be recognized in thin section. The limestone occurs as anhedral, fine grained masses or as euhedral crystals lining cavities. Intergrown with the fine grained calcite are radiating masses of chalcedony and in places fine grained quartz.

The dolomite occurs as granular to euhedral crystals (Plate 19, fig. 1) with a random distribution. It generally comprises less than 10 percent, but locally may constitute 50 percent or more of the carbonate fraction.

A cavity filling sequence of euhedral dolomite to fibrous chalcedony to quartz and occasionally an inner chalcedony layer is common. Frequently the inner chalcedonic layer and the fine grained quartz are absent (see Plates 19 and 20).

The silicified diatomite occurs as thin beds in the basal part of the section only. It varies from dark grey to brown to almost black. Locally the diatoms are fairly well preserved, but their presence may be indicated only by dark spherical bodies in otherwise massive chert (Plate 21, fig. 2).

Several factors lead the writer to conclude that the Vermilion Bluffs section represents an ancient spring deposit, and that the spring was either intermittent or intermittently inundated by lake waters. The evidence for its origin as a spring deposit lies in the following: (1) the local distribution of the deposit, (2) the irregularity of large scale bedding, (3) the internal fine laminations which do not necessarily parallel large scale bedding, (4) the original high porosity of the limestone,

(5) the irregular weathering pattern suggestive of tufa, (6) the composition, and (7) the basal diatomite.

Petrographic and field studies of the deposit suggest that: (1) the spring was originally siliceous in nature, (2) it became progressively more calcareous, (3) it reverted to the original siliceous character. The evidence for this sequence is: (1) the basal silicified diatomite which contains only minor amounts of calcite, (2) the increase in limestone higher in the section, and (3) the sequence of cavity filling.

Thus the deposits are thought to represent a silicified tufa or siliceous sinter. The spring giving rise to the deposits was originally siliceous, providing an environment in which diatoms thrived. Later the amount of silica decreased, limestone increased, and gastropods became abundant. In the final stages, the spring reverted to its original siliceous nature. At irregular intervals, throughout its history, the normal deposits were interrupted by either drying up of the spring or deposition of mud and organic matter.

The origin of the dolomite, whether it is primary or secondary, is not known. However, it was observed to replace gastropod shells, suggesting that it is a secondary replacement of limestone or aragonite.

Source of the Allenby Formation Arkosic Sediments

Shaw (1952) states:

"Where exposures are large, the coarse-grained sedimentary beds are almost invariably seen to be lenticular. Rough counts made on the granule-conglomerate from several parts of the formation indicate a content of 60 to 80 percent clastic fragments and 20 to 40 percent clay minerals, which form the matrix. Angular to subrounded grains of feldspar comprise 20 to 30 percent of the rock, and angular to subrounded grains of quartz, some of which are strained, from 20 to 30 percent. Fragments of granite and grano-diorite constitute as much as 40 percent, and various volcanic materials from 10 to 25 percent. It is apparent that these materials were derived from a dominantly granitic terrain and suffered little abrasion in passing from the source to the site of deposition. The wide areas in which the Coast intrusions and younger intrusive rocks are exposed are the obvious sources. The volcanic content has undoubtedly been provided by the nearby large areas of the dominantly volcanic Nicola group and Cretaceous volcanic rocks that now occupy lesser areas."

Shaw does not state any paleocurrent direction, nor does he indicate whether the source is from a single intrusion or from more than one of the surrounding intrusions. (See Map 888A, Appendix I, Rice, 1947.) It is the purpose of this discussion to present evidence that the source area lay to the northeast of the coalfield, and that the Osprey Lake Intrusion was the source of these sediments.

Before elaborating on the source of the arkosic sediments, it should be stated that many of the basal Allenby Formation sediments are composed of volcanic rock fragments which have been derived from the Nicola Group, the Lower Volcanic Formation or the Upper Volcanic Formation. The bulk of the sediments have, however, been derived from a granitic terrane.

The mineralogy of coarse conglomerates through progressively finer clastics to shale has already been discussed. The mineralogy, textures, size range of individual minerals, and the percentage of various minerals indicate that the majority of the non-volcanic clastics have as a common source the Osprey Lake Intrusion.

Several lines of evidence including cross-stratification, imbrication, grain size variation, mineralogy, textures of individual minerals and aggregate grains, the size range of specific minerals, and the finding of the arkosic sediments lapping upon the Osprey Lake Intrusion, are used as evidence in determining the source of the Allenby Formation sediments.

Microcline-Microperthite:- Probably the most significant single criterion of the source of the sediments is the abundance and size of microcline-microperthite grains. The large grains ranging up to, and in some cases exceeding 2.5 cm., immediately attracted attention. The Osprey Lake Intrusion is the only source in the area of large microcline-microperthite crystals known to the writer.

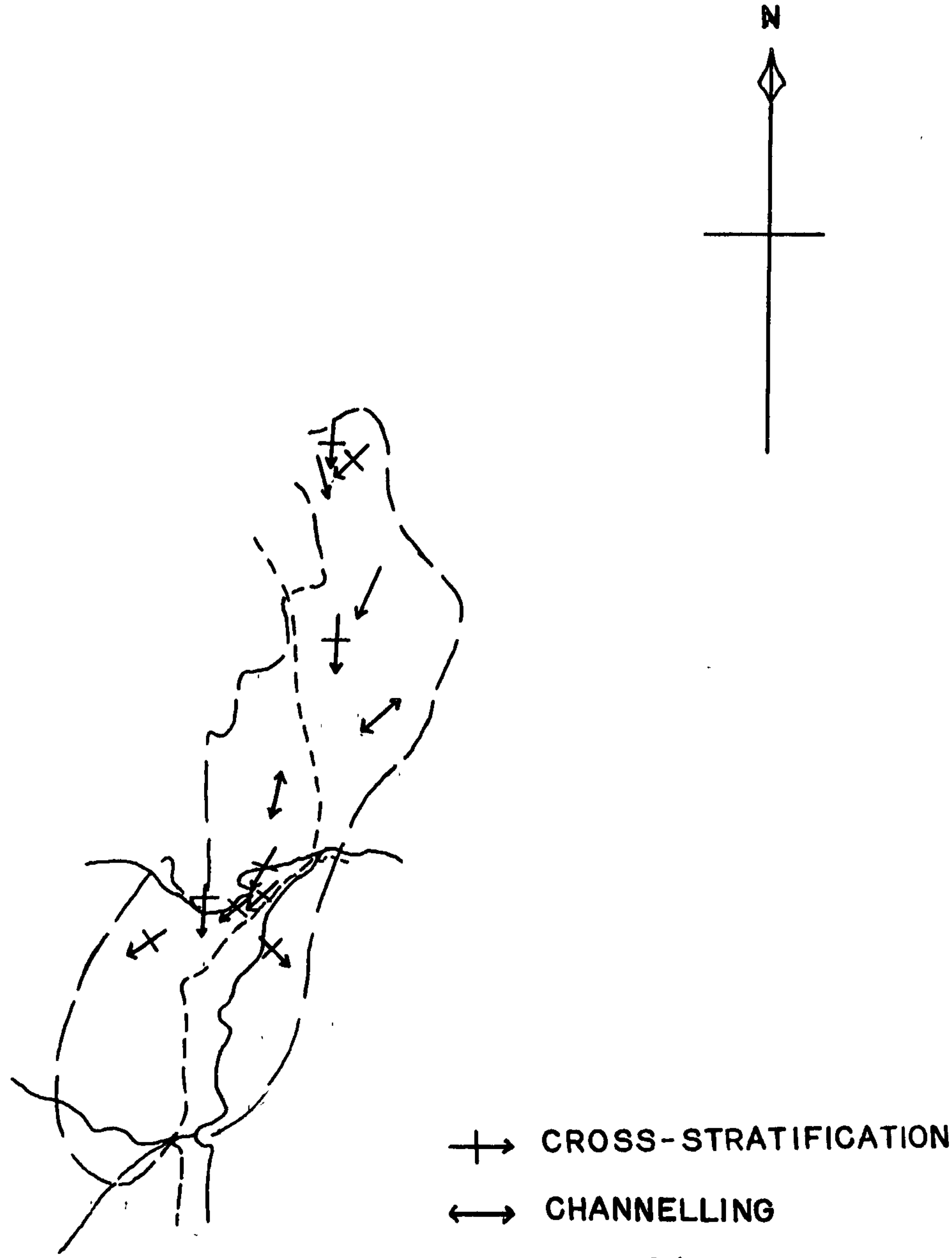
Cross-Stratification:- The term cross-stratification as defined by McKee and Weir (1957, p. 82) "...is the arrangement of layers at one or more angles to the dip of the formation...or...is one with layers deposited at an angle to the original dip of the formation."

Cross-bedding and cross-laminations have been used as synonyms for cross-stratification. However, the terms bed and lamination carry a definite thickness connotation, and therefore, McKee and Weir (1957) suggest that these terms be restricted and used only in this thickness sense.

On the basis of the character of the lower bounding surface (regional stratification) McKee and Weir (1957) subdivide cross-stratification into three basic types: (1) simple, lower bounding surface is non-erosional (common synonym tangential); (2) planar, any cross-strata in which the lower surface is non-depositional (common synonyms are angular, torrential, and regular); and (3) trough, any cross-strata in which the lower surface is erosional (common synonym festoon). The present thesis will follow this classification.

As the Allenby Formation has been folded it is necessary to remove the tilt in order to use cross-stratification data for paleocurrent directional purposes. Stereographic methods involving rotation about the axis of regional stratification bringing it into a horizontal position and correcting the cross-stratification by a similar amount, were used for this purpose. This is the method that has been used by Kapstein (1954), Brett (1955), Pettijohn (1957), Pelletier (1958), and others.

Recently, Ramsay (1961) questioned this method and has pointed out that the above technique can be applied



TEXT-FIG. 7 SOURCE OF THE PRINCETON SEDIMENTS.

only to those sedimentary structures which have been concentrically folded about a horizontal axis. He states that in order to correct for plunge, an additional step which first removes the plunge is necessary. The tilt can then be removed by the standard rotation about the regional stratification plane.

The choice of technique used on the Allenby Formation sediments is further complicated by the lack of detailed structural control. Folding is concentric. However, the attitude of the axis of folding cannot be determined from the present studies. Therefore, in this thesis it is assumed that the axis is horizontal.

Statistical methods of determining significant directional data as outlined by Reiche (1938) and Raup and Miesch (1951) were not applied to the Allenby Formation sediments.

Simple, planar and trough cross-stratifications are common in the coarser sands and granule-conglomerates. The planar type is perhaps the more common. Simple and trough cross-stratification are present in about equal numbers. Trough cross-stratification was not used in this study unless the axial direction of the channel could be determined.

Cross-stratification is most frequently accompanied by a change of grain size, grading from coarse material at the bottom and becoming progressively finer. Not infrequently, the cross-strata lacked a definite basal termination. What appeared to be simple or planar cross-strata on the upper surface would grade downward into the lower surface and lack a definite basal bounding plane.

The attitude of cross-strata lacking a definite basal plane was checked and found to correspond to simple and planar cross-strata within the same outcrop. Therefore, directional measurements were not restricted to cross-strata having definite basal terminations.

Strike measurements taken on several cross-strata within a set varied as much as 30°. The height of the cross-stratification varied from microscopic in the fine silts to three or four feet in the granule-conglomerates. The thickness of the cross-strata varied from less than one centimeter to greater than two centimeters. Therefore, both cross-laminae and cross-beds are involved. The angle between the regional and cross-strata varied from 12° to 32°, with the majority less than 20°. The 32° angle was associated with a coarse granule-pebble conglomerate with a high regional dip (45°) and may suggest some internal deformation. It is, however, within the angle of repose for such materials.

Despite the sparsity of structural data and statistical studies, consistent results were obtained. The paleocurrent direction shows a marked south to south-westerly trend (see Trend Map, text, fig. 7). The absence of data suggesting different paleocurrent directions is striking.

Imbrication:- Imbrication is the preferred orientation of flattened or elongate pebbles producing the overlapping or so called "shingling" or "imbricate structure."

Becker (1893) recognized the significance of, and explained the manner of formation of imbricate structure.

Imbricate structures were observed and measured only in the extreme northern part of the coalfield (text, fig. 7). The friable to semi-consolidated nature of the rock permitted extraction of the pebble or boulder on which measurements were being made. Only those cobbles or boulders having a long axis:intermediate axis ratio of at least $1\frac{1}{2}$:1 were used. The measurements made were: (1) regional bedding, (2) strike of intermediate axis (perpendicular to direction of paleocurrent), (3) trend of the long axis, and (4) angle (dip) and direction of inclination of the long axis (sense of direction of the paleocurrent). Measurement (3) served as a check on (2). The strike of the intermediate axis and the dip of the long axis were rotated to correct for regional dip in the same manner as for cross-stratification. The variation in paleocurrent direction obtained was a maximum of 30° in a single outcrop. The angle of the inclined pebble with the regional bedding varied from 7 to 15°. Like cross-stratification, the imbricate structure of the conglomerates indicated a source area to the north or northeast.

Several readings were taken which suggested reversals in the current direction. These aberrant readings were usually associated with irregularly shaped pebbles and are probably not true imbricate structure.

Particle Size:- It has already been stated (page 25) that there is a size gradation from cobble-boulder conglomerates in the north to granule conglomerates in the southern half of the area. No outcrops of pebble or coarser conglomerate of arkosic composition are known from the southern half of the map area. Thus, the size range of the coarser clastics support a northern source for the sediments.

Size of Individual Minerals:- The relative sizes of the various minerals and the corresponding size relationship found in the Osprey Lake Intrusion has already been discussed on page 27.

Mineralogical Analysis:- The predominant minerals in the arkose are microcline-microperthite, quartz and plagioclase (An_{35}). The accessory minerals are biotite, sphene, apatite and magnetite. All are present in the Osprey Lake Intrusion. Several slabs were cut from specimens of the Intrusion and stained. The percentages of the microcline-microperthite, quartz and plagioclase agree very closely with the relative abundance of these minerals in the arkosic sediments.

Textures:- As previously stated, such features as myrmekitic texture (Plate 22, figs. 1 & 2), replacement (?) microperthite (Plate 23, fig. 1), undulatory extinction in quartz, and the definition of grain boundaries are common to both the Osprey Lake Intrusion and the arkosic sediments.

Sediments Lapping onto the Osprey Lake Intrusion:- The finding of coarse arkosic sediments lapping onto the Osprey Lake Intrusion east of Summers Creek provides strong evidence in favor of this intrusion being the source of the Allenby Formation sediments.

Thus, cross-stratification, imbrication, mineralogy, grain size, mineral size range, textures and the presence of the arkosic sediments lapping upon the Osprey Lake Intrusion all clearly show that this intrusion was the principal provenance of the Allenby Formation sediments, and that the currents carrying the sediments flowed in a south to southwesterly direction.

PART III

STRUCTURE

The regional structure of the Princeton coalfield was described by Rice (1947, p. 52-54). He indicates that the southern half of the coalfield is flanked by two major fold axes in the Triassic rocks, a syncline to the east, and an anticline to the west. For details of these fold axes see Plate 24.

The northern half is bounded on the east in part by rocks of the Nicola Group, and in part by the Osprey Lake Intrusion. On the west it is bounded by rocks of the Nicola Group.

According to the present interpretation of the stratigraphy and structure, the Princeton coalfield is made up of two related synclinal basins separated by an anticline. The anticline trends across the coalfield in a northwesterly direction from Rainbow Lake (about $1\frac{1}{2}$ miles northeast of Princeton) and disappears in the older Nicola Group rocks to the west of the coalfield. Sediments of the Allenby Formation dip gently ($15 - 30^{\circ}$) away from this fold axis. Exposure is limited and little can be said of the magnitude of the fold except that it completely crosses the coalfield.

Shaw (1952, p. 10-11) described the internal detail of the southern half of the coalfield based on the Princeton-Black Coal-bearing zone as:

> "A large basin-like structure into which project three large anticlinal noses disposed at random about the periphery...
>
> "...The interference of these anticlinal structures

> within the main basin area has resulted in a rather peculiar configuration that is strongly reminiscent of a dumbell in plan. The long axis of the dumbell trends east."

The three anticlinal noses projecting into the coalfield are: (1) about 2 miles west of Princeton trending across the Tulameen at about S 10° E (here referred to as the Tulameen anticline), (2) just south of Allenby (Allenby anticline), (3) in the southwestern corner of the map area in the vicinity of the Blue Flame Mine (see Shaw, 1952, p. 41).

Present work indicates that faulting (see map p. 63) has affected both the Tulameen and the Allenby anticlines. A fault which may have considerable displacement crosses the Tulameen about 3 miles west of Princeton. This fault is a normal fault with the west side down. It is indicated by consistent dips within the Allenby sediments which would, if projected, dip under the nose of Nicola. On the south side of the Tulameen, south and west of Parr Station, Allenby sediments are vertical.

Drift cover prevents the tracing of this fault into the coalfield. However, Shaw (1952) states that a series of normal faults of small displacement were encountered at the western extremity of the Pleasant Valley Company Mine. The strike of the fault is apparently about S 20 - 30° W. The dip is unknown. It is possible that these faults are related to the fault crossing the Tulameen. They may also indicate that a series of small faults, rather than a single fault, is involved.

Possible effects of faulting were observed in the axial area of the Allenby anticline. Faulting was indicated by an abrupt change of attitude from 40° N to vertical over a distance of 100 feet or less. The point at which the change of attitude took place is not exposed, and therefore, the possibility of folding cannot be eliminated.

The structure of the northern half of the coalfield is not as well known as the southern half. This is the result of poorer exposure in general, and to a greater extent on lesser amounts of coal exploration. The eastern limit of the northern half of the coalfield is based on topography and scattered outcrops. The change from previously mapped limits of the coalfield at Jura is the result of a test hole drilled by Kennco Exploration Company in 1960. This drill hole encountered several hundred feet of steeply dipping (55° to 65°) Allenby Formation sediments. The western limit from about 6 miles north of Princeton south is based entirely on topography, outcrops of the Lower Volcanic Formation, and rocks of the Nicola Group.

Dips as high as 55° were recorded along the western margin of the coalfield 6 miles north of Princeton. These dips apparently decrease progressively away from the margin of the coalfield to 15° or less at Belfort Station.

GEOLOGICAL MAP PRINCETON COAL BASIN

LEGEND

MIDDLE EOCENE

6	ALLENBY FORMATION: Mainly shales, arkosic conglomerate, arkose, tuffaceous sandstone, coal.
5	UPPER VOLCANIC FORMATION: Grey to black basalt, varicolored andesite flows; massive, columnar or flaggy. Minor amounts of sediments & breccia.
4	LOWER VOLCANIC FORMATION: Varicolored andesite and basalt. (Rice 1947 No. 17)

JURASSIC OR LATER

3	COPPER MOUNTAIN INTRUSIONS: Syenogabbro, augite, diorite, pegmatite (Rice 1947, No. 8)
2	COAST INTRUSIONS: Mainly reddish coarse-grained siliceous granite and granodiorite (Rice 1947, No. 6) · OSPREY LAKE INTRUSION(S) Quartz-monzonite.

UPPER TRIASSIC

1	NICOLA GROUP: Varicolored lava, argillite, tuff, limestone, chlorite and sericite schist. (Rice 1947, No. 3)

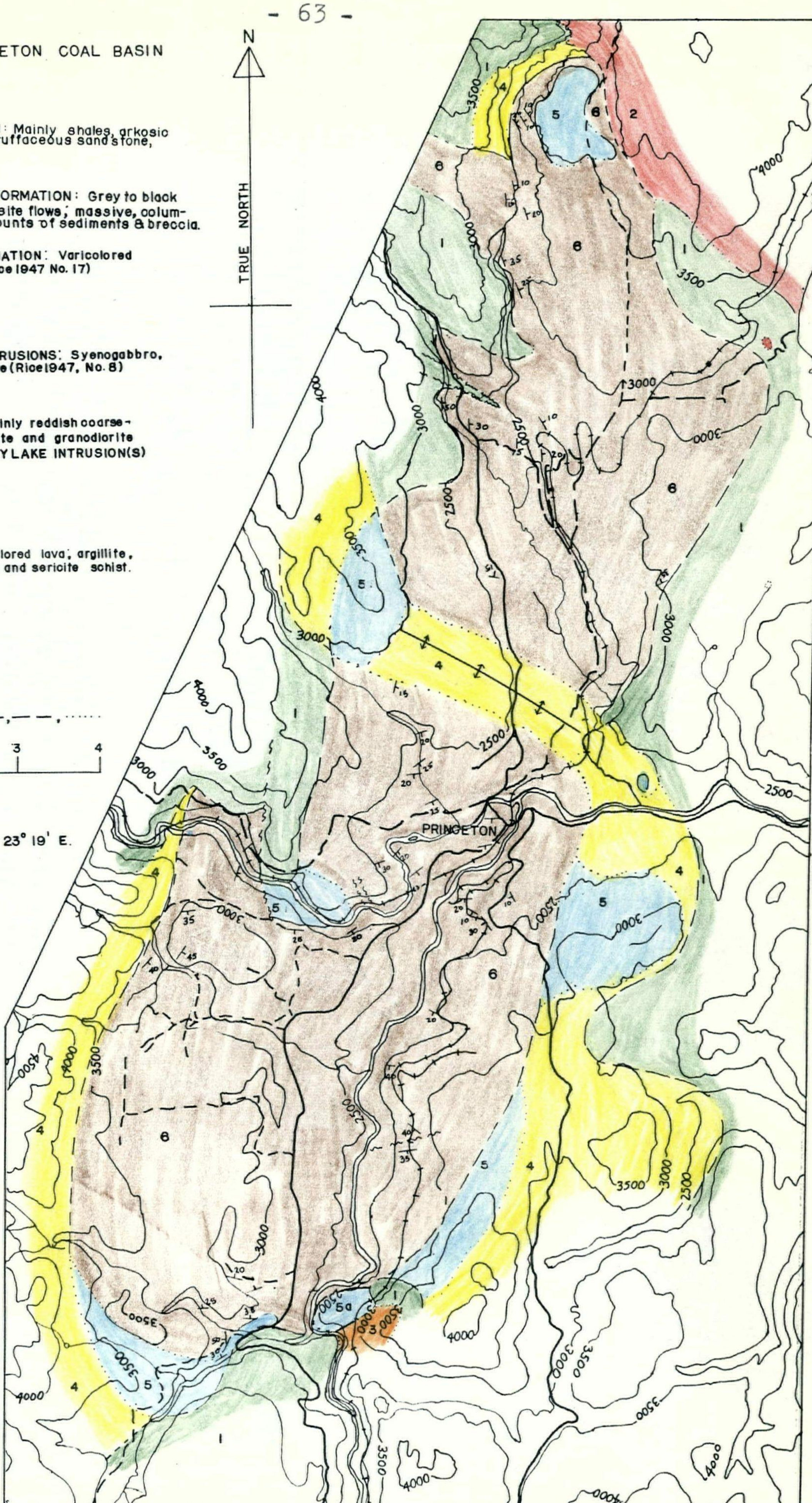
Fault · · · · · · · · · · · · · ~~
Road · · · · · · · · · · · · · ——
Secondary Road · · · · — —
Trail · · · · · · · · · · · · - - - -
Anticline · · · · · · · · · ·
Contour Interval · · · 500 ft.
For Place Names See Outcrop Map
Contact; known, approx., assum. — , — — , · · · · ·

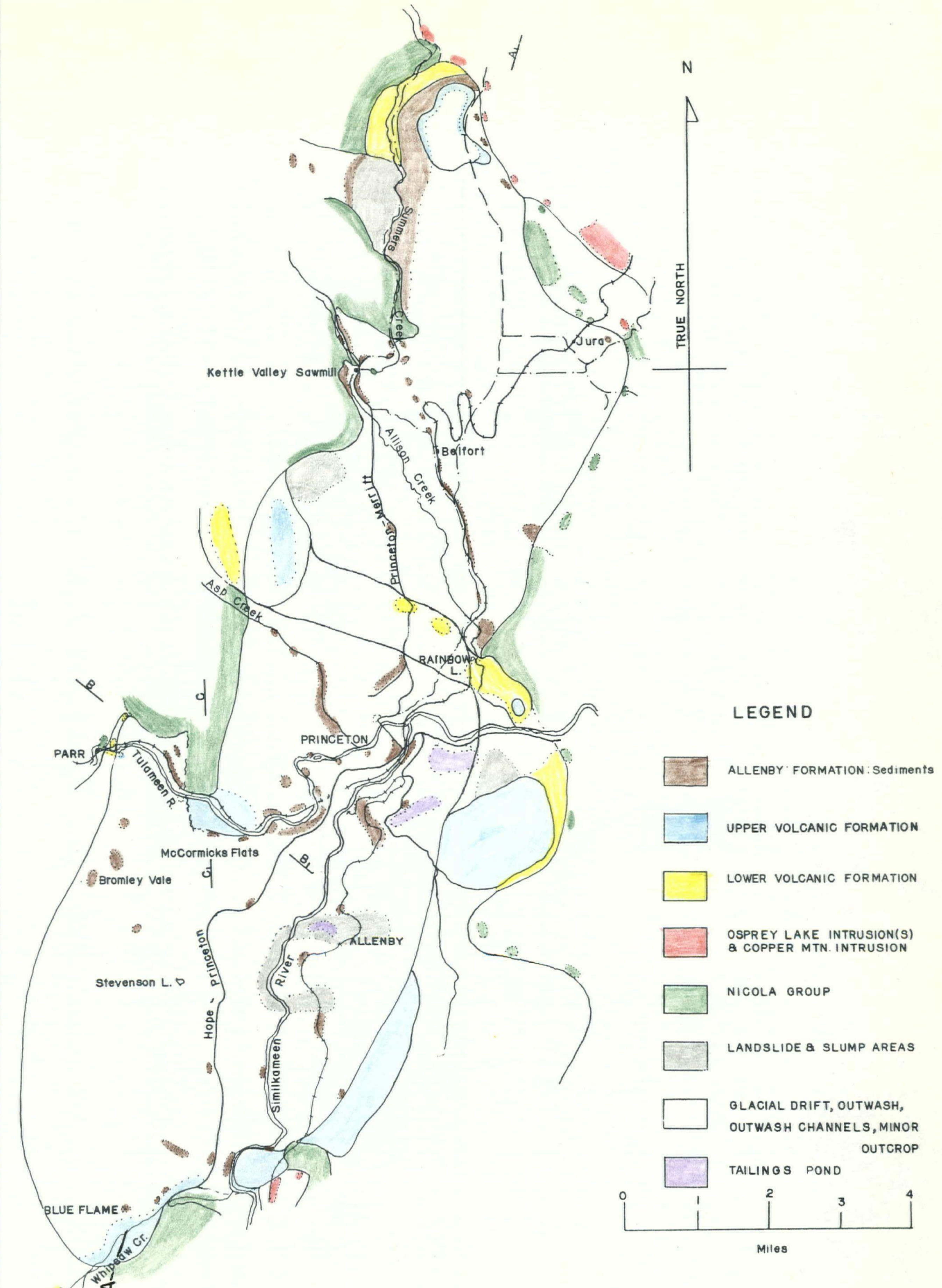
0 1 2 3 4

MILES

Approximate Magnetic Declination 23° 19' E.

BASE MAP & TOPOGRAPHY
BY
Surveys & Mapping Branch
B.C. Dept. of Lands & Forests
1958
Original 1" = 1 mi.





OUTCROP MAP OF ALLENBY FORMATION SEDIMENTS

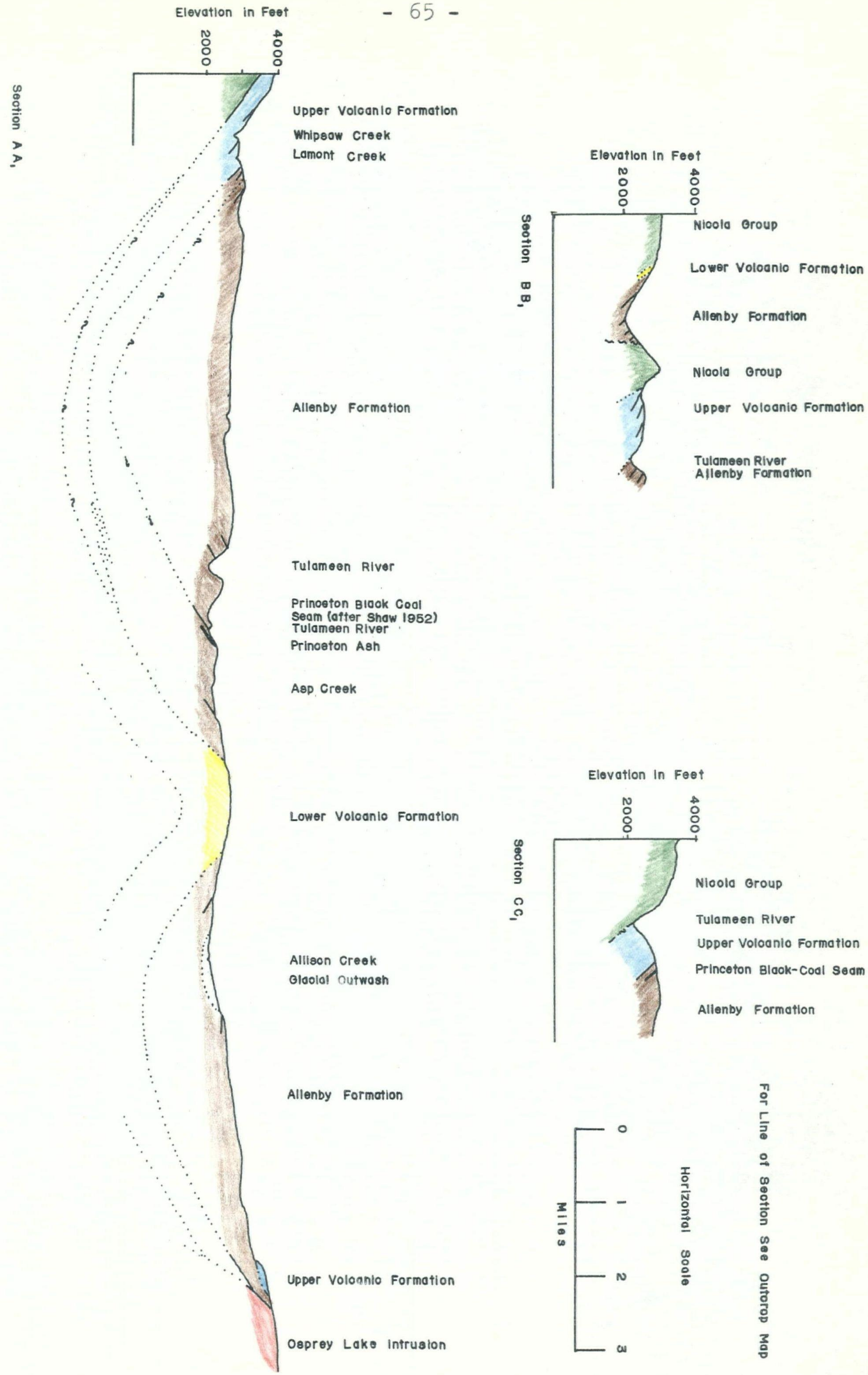

Elevation in Feet
2000
4000
Section A A,
Upper Volcanic Formation
Whipsaw Creek
Lamont Creek
Allenby Formation
Tulameen River
Princeton Black Coal Seam (after Shaw 1952)
Tulameen River
Princeton Ash
Asp Creek
Lower Volcanic Formation
Allison Creek
Glacial Outwash
Allenby Formation
Upper Volcanic Formation
Osprey Lake Intrusion
Elevation in Feet
2000
4000
Section B B,
Nicola Group
Lower Volcanic Formation
Allenby Formation
Nicola Group
Upper Volcanic Formation
Tulameen River
Allenby Formation
Elevation in Feet
2000
4000
Section C C,
Nicola Group
Tulameen River
Upper Volcanic Formation
Princeton Black-Coal Seam
Allenby Formation
0
1
2
3
Miles
Horizontal Scale
For Line of Section See Outcrop Map

PLATE 4

Sedimentary Breccias

Fig. 1: Crude stratification in sedimentary breccias derived from Nicola volcanics. Photo taken about ½ mile north of the Kettle Valley Sawmill on Allison Creek.

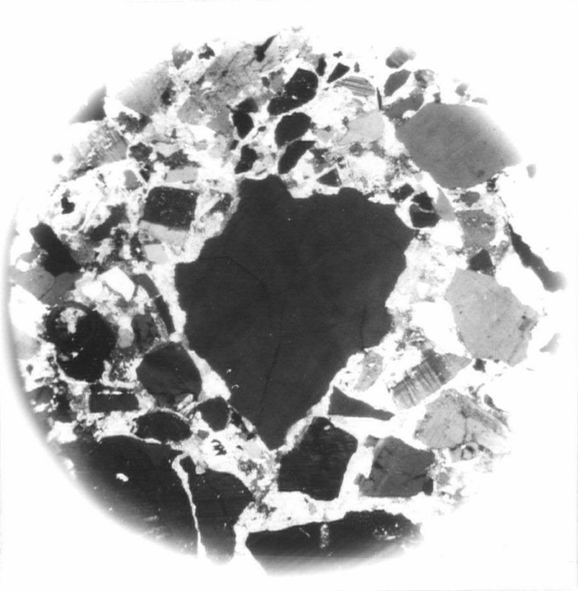
Fig. 2: Close-up of the breccias showing the angularity and the wide range in the size of the fragments.

PLATE 5

Sedimentary Textures

Fig. 1: Large angular much fractured quartz grain. Cement is a carbonate. Crossed nicols, X 55.

Fig. 2: Photo of a thin section taken from a concretion. Note the extreme angularity of the grains. Large grain in the center is quartz. The cement is a carbonate which has apparently replaced much of the original matrix as few of the grains are actually in contact. Crossed nicols, X 55.



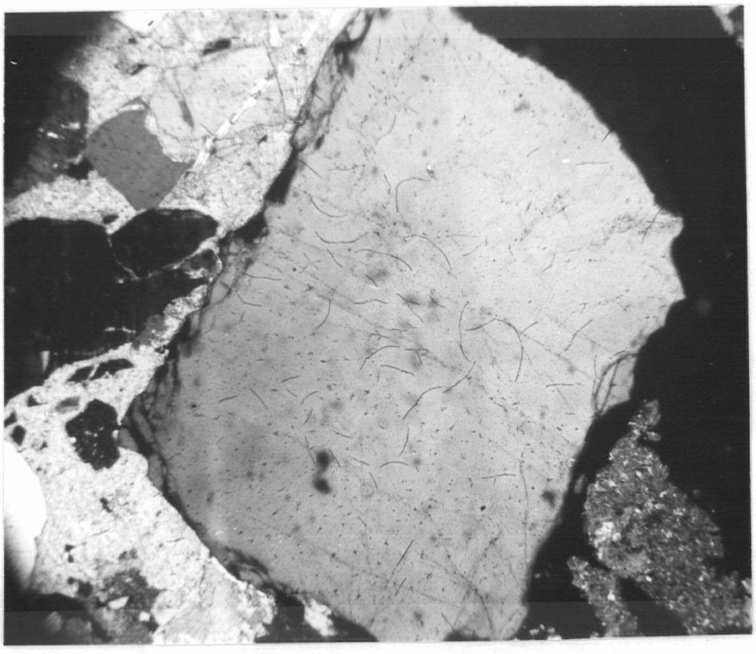


PLATE 6

Sedimentary Textures

Fig. 1: Remnant of a feldspar crystal almost completely replaced by carbonate. Section taken from outcrop at the rear of the Caribou Brewery at Princeton. Crossed nicols, X 55.

Princeton Ash

Fig. 2: Princeton Ash exposed on the Tulameen River. Entire exposure is ash. The change in weathering characteristics in the upper part probably reflects the fact that the lower part has been only recently exposed by road work. This is the locality where a biotite sample was obtained for potassium-argon dating.

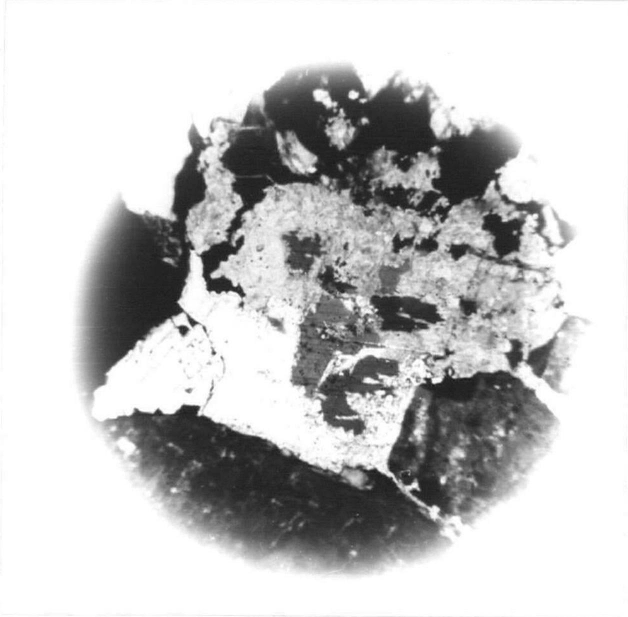


PLATE 7

Princeton Ash

Fig. 1: Blocky fracture of the Princeton Ash below the unconformity. Photo from the outcrop immediately west of the Tulameen bridge.

Fig. 2: Unconformity well marked by change of fracture and bedding. Section of Princeton Ash immediately west of the Tulameen bridge. Both the beds above and below the unconformity are ash.

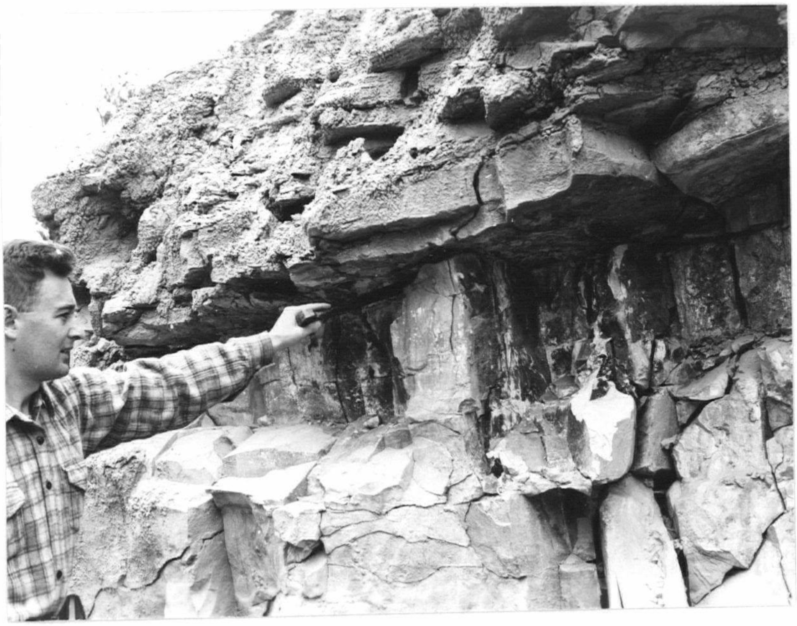


PLATE 8

Princeton Ash

Fig. 1: Close-up of the unconformity in the Princeton Ash. Pick is driven into the bentonitic layer.

Fig. 2: Photomicrograph of the Princeton Ash showing parallelism of biotite and elongate crystal fragments. Section cut from the locality immediately west of the Tulameen bridge and from below the unconformity. X 30.

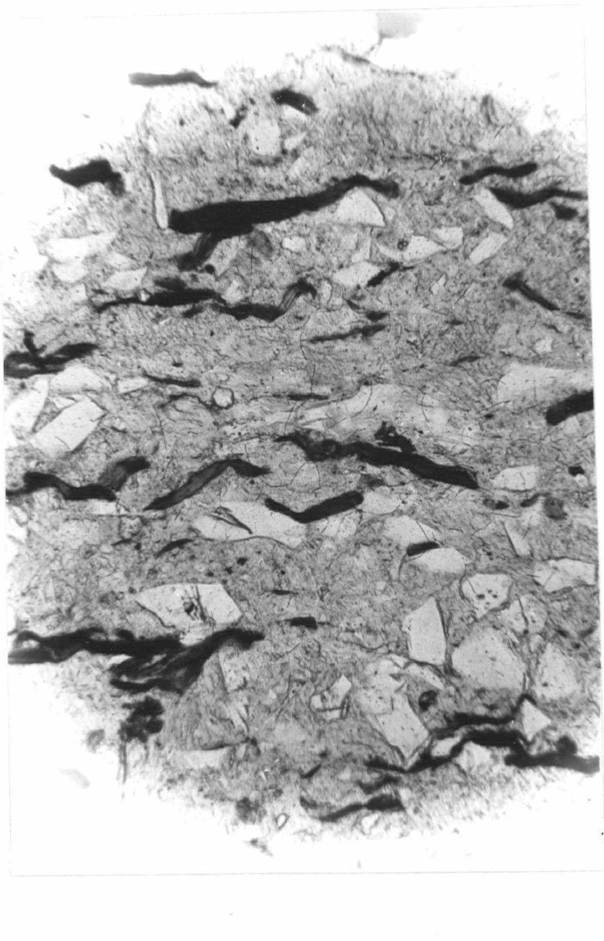
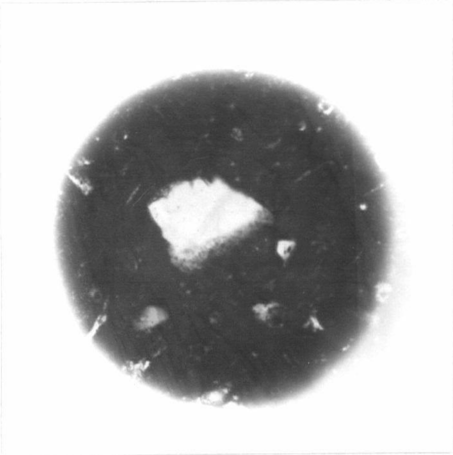


PLATE 9

Princeton Ash

Fig. 1: Corroded feldspar fragment of Princeton Ash surrounded by glass and lesser fragments. Crossed nicols, X 55.

Fig. 2: Zoned feldspar from the base of the exposure of Princeton Ash on the Tulameen River. Crossed nicols, X 55.



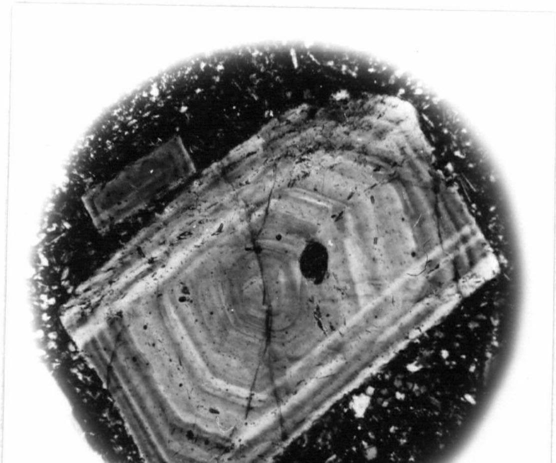
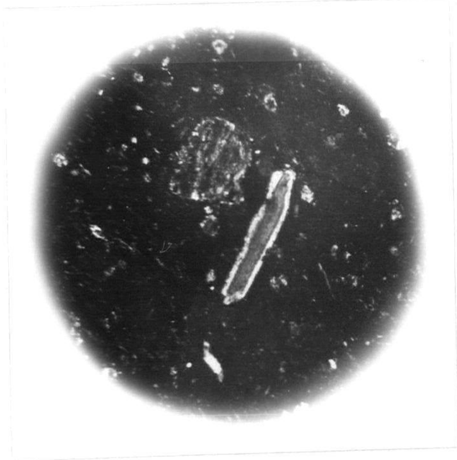


PLATE 10

Princeton Ash

Fig. 1: Corroded biotite grain from the Princeton Ash under crossed nicols. Lighter indistinct patch in the upper left is an inclusion. X 55.

Fig. 2: Inclusion in Princeton Ash of lava with microlites of feldspar, but the boundaries not distinct, fading gradually into the surrounding glass. X 55.



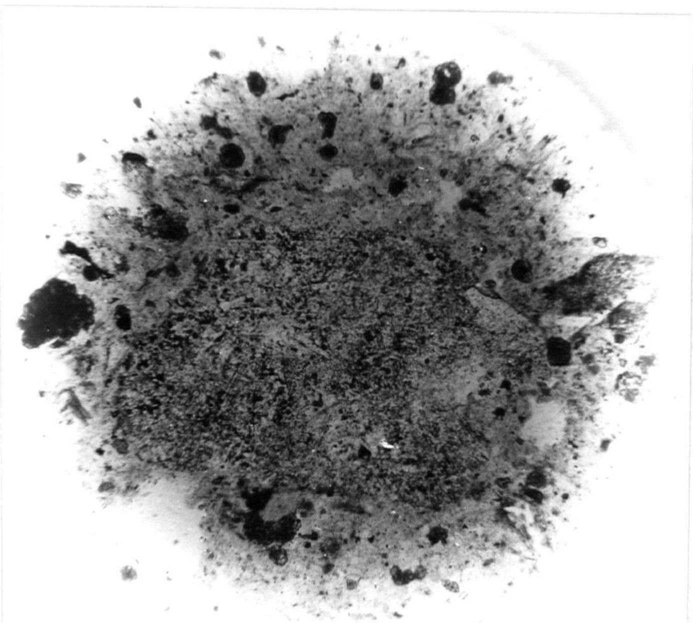
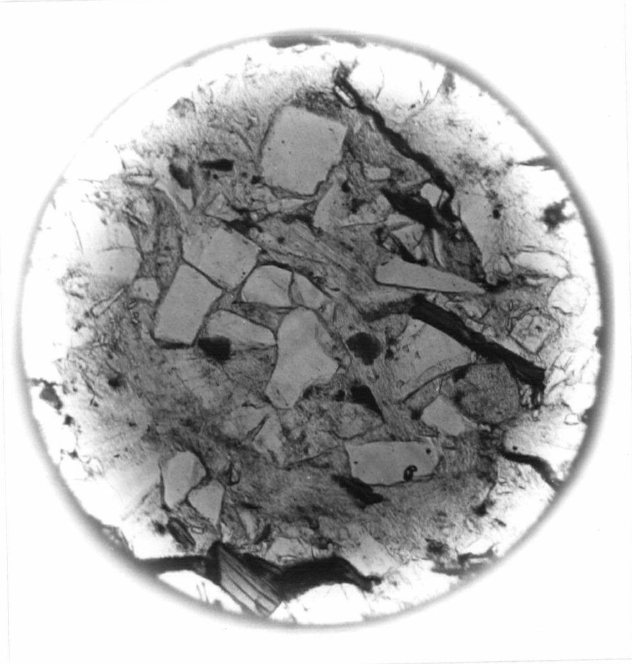


PLATE 11

Princeton Ash

Fig. 1: Small inclusion of a volcanic with feldspar microlites in the Princeton Ash. Boundary of inclusion distinct. Dark spherical bodies represent localized areas of devitrification. X 55.

Fig. 2: Coarse feldspar fragments from the Princeton Ash showing minor amounts of rounding but little or no corrosion. Fragments surrounded by glass, dark minerals, biotite and organic matter. X 55.



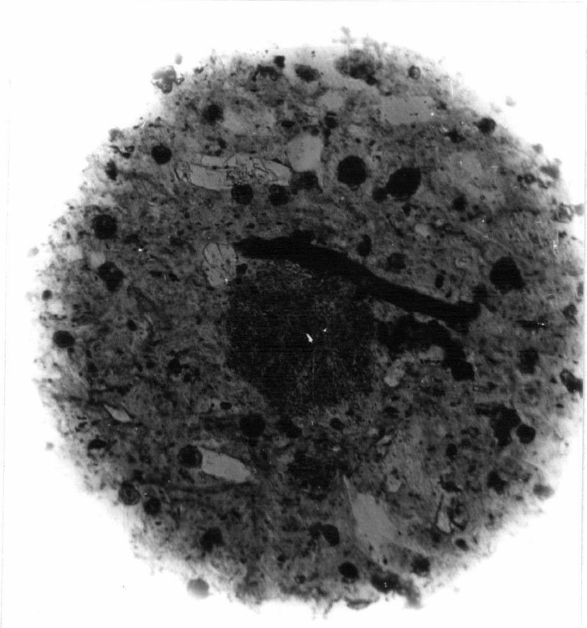


PLATE 12

Princeton Ash

Fig. 1: Sharp angular feldspar fragments from the Princeton Ash showing no rounding or corrosion, completely surrounded by volcanic glass. Dark grains are biotite. Minor parallelism of grains. X 55.

Fig. 2: Glomeroporphyritic texture of the Princeton Ash surrounded by glass containing feldspar microlites. Note the zoning and strong interference, one crystal with another. Taken from the Tulameen River section of the Princeton Ash. Crossed nicols, X 55.

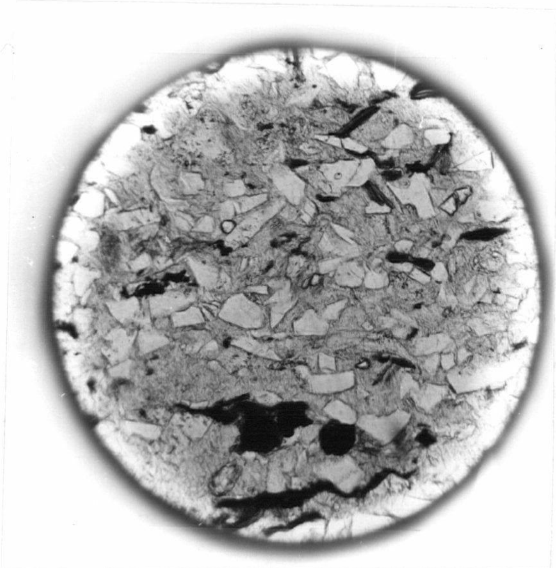


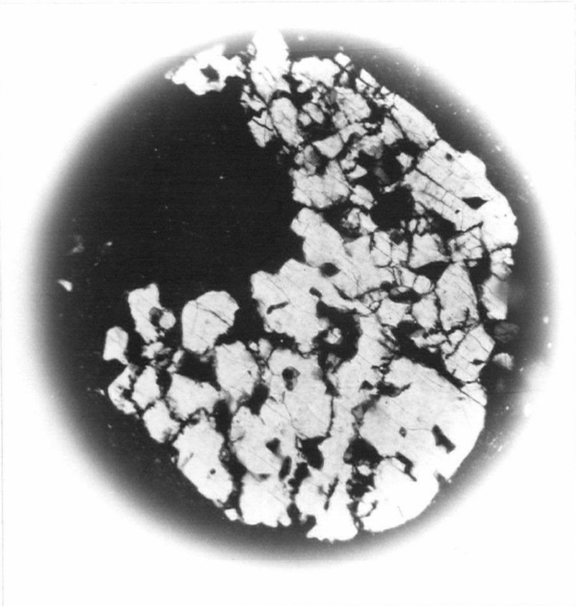
PLATE 13

Princeton Ash

Fig. 1: A rounded feldspar fragment from the Princeton Ash which has been brecciated and then cemented by volcanic glass. Feldspar fragments are in optical continuity. It appears that some of the grain may have been replaced (or partly fused along cracks) by the glass. Crossed nicols, X 55.

Summers Creek Section

Fig. 2: Tuffs and tuffaceous sandstone outcrops on Summers Creek about three miles above junction with Allison Creek.



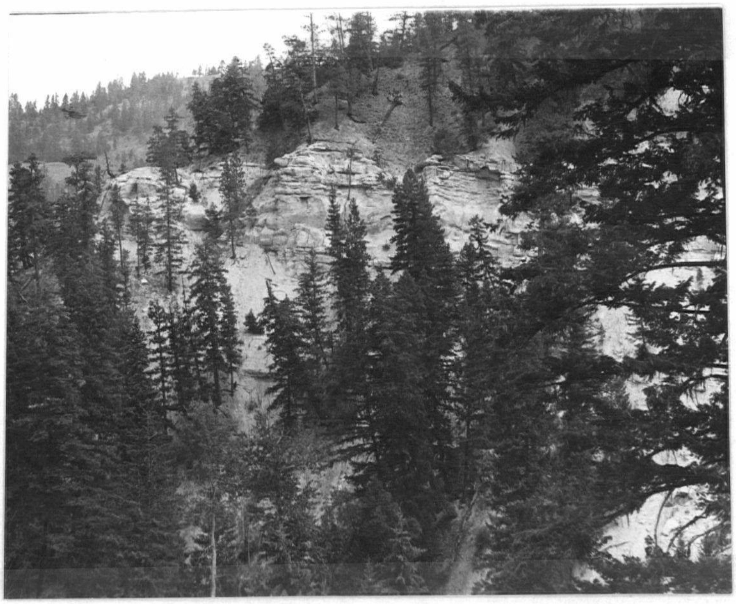
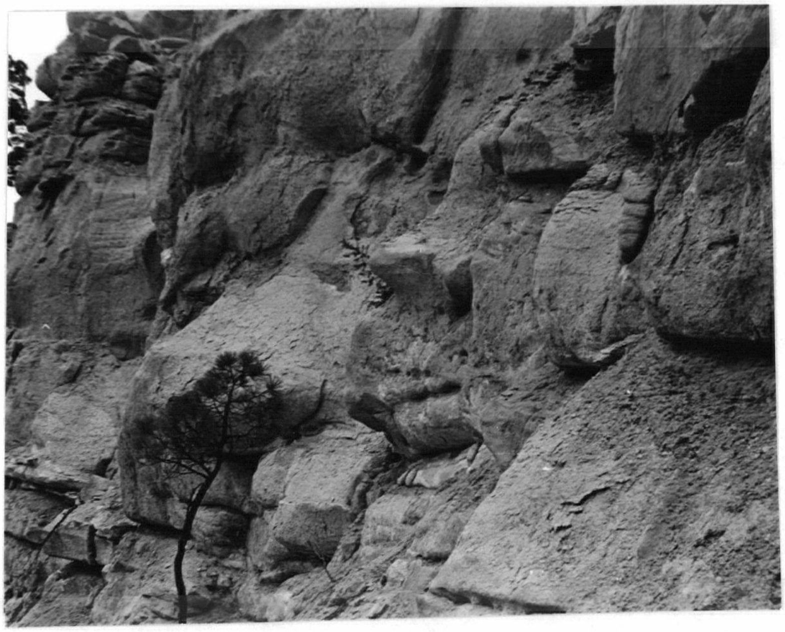


PLATE 14

Summers Creek Section

Fig. 1: Weathering pattern of tuffs, tuffaceous sandstones on Summers Creek.

Fig. 2: Same outcrop as fig. 1, showing the minor amounts of shaly material at the base of the cliffs.



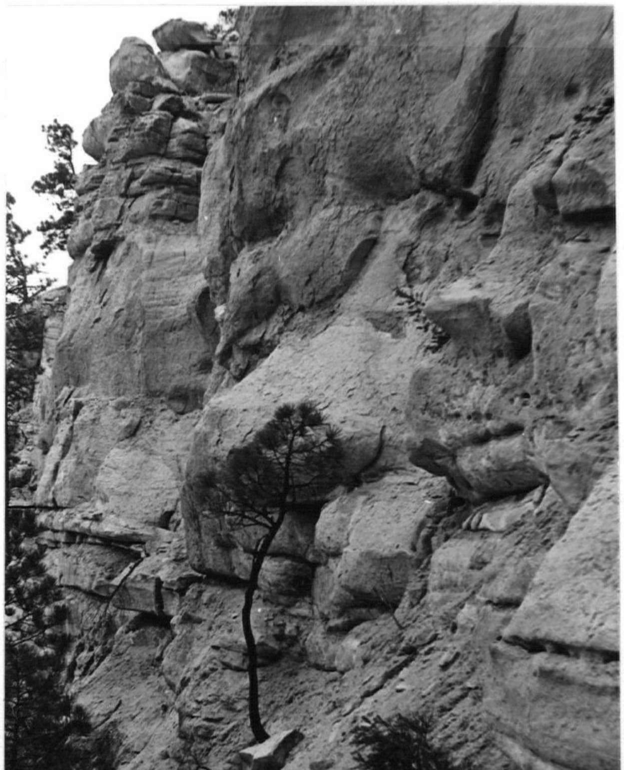


PLATE 15

Summers Creek Section

Fig. 1: Petrified wood found in glacial drift, but associated with tuffaceous sandstones similar to those on Summers Creek west of the exposure photographed in Plate 14.

Fig. 2: Locality as above in glacial drift. The central dark area in the round-sandstone erratic is petrified wood. The radiating rays are zones of silicification (chalcedonic) which apparently represent the root system or branching of the central tree. The main mass is coarse tuffaceous sandstone which has been silica cemented. It appears that the tree trunk acted in some manner as a precipitating agent for the silica.

PLATE 16

Summers Creek Section

Fig. 1: Petrified tree base from tuffaceous sandstone on Summers Creek.

Vermilion Bluffs Section

Fig. 2: Vermilion Bluffs looking northeast shows the irregular nature of the bedding, and the projecting characteristic of the silicified limestone.

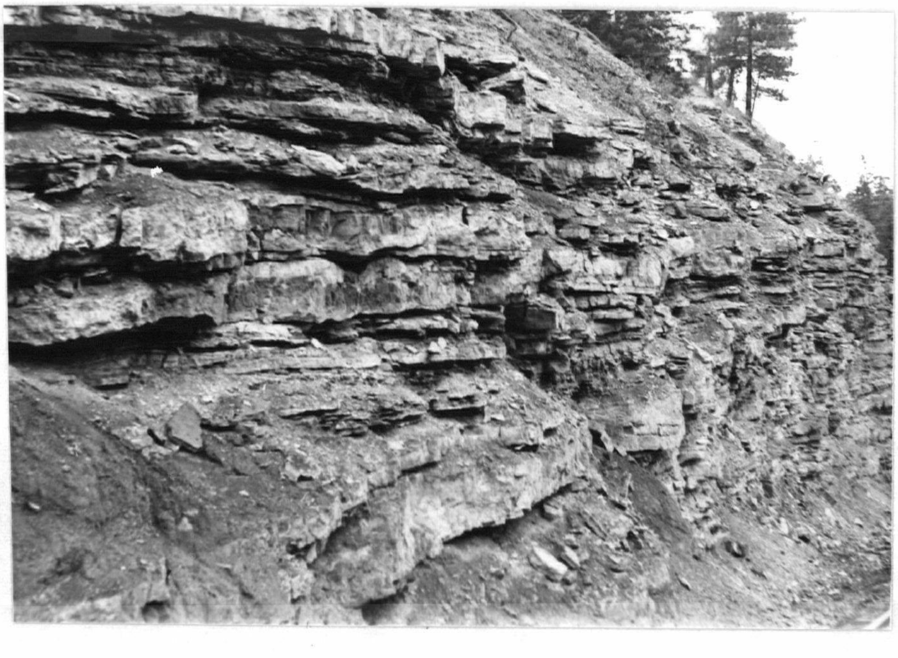


PLATE 17

Vermilion Bluffs Section

Fig. 1: Chert nodule in bentonitic materials immediately below pencil. Band in the upper right hand corner is fibrous calcite. From lowermost five ft. of section.

Fig. 2: Resistant beds are dolomitic limestones, whereas recessive beds are shale.

PLATE 18

Vermilion Bluffs Section

Fig. 1: Bedding of the central part of the bluffs. Note the lenticular nature of the bed of silicified limestone to the left of the pick.

Fig. 2: Weathered surface of a limestone band which appears very similar to recent tufa deposits in general appearance.

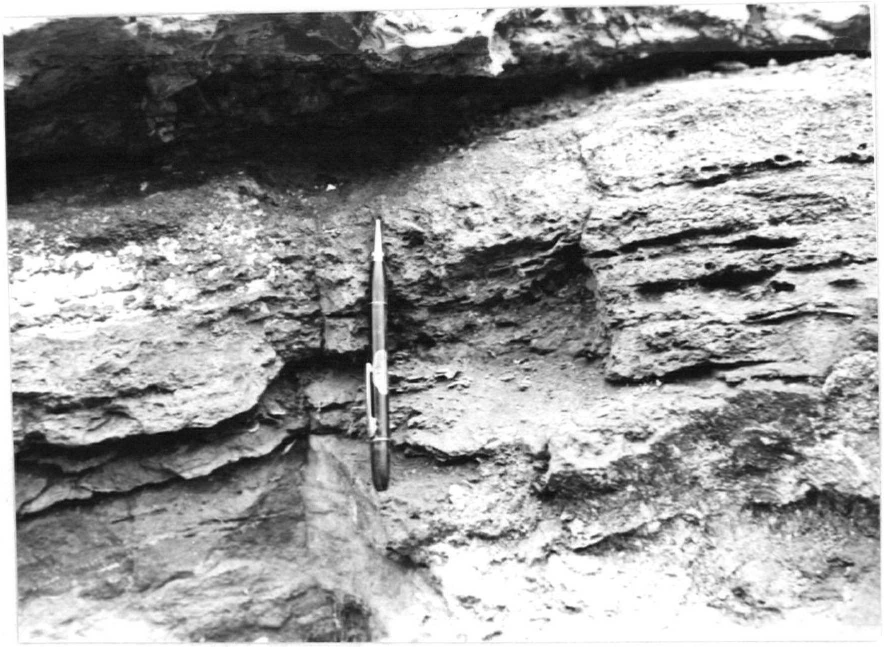
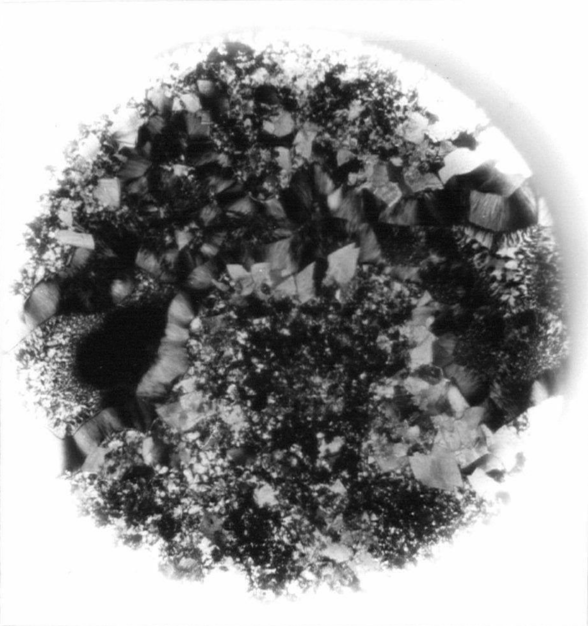


PLATE 19

Vermilion Bluffs Section

Fig. 1: Euhedral dolomite (?) crystals (light grey) in the center. The original porous nature of the rock is again suggested by the localization of the euhedral crystals which apparently lined the cavity and were coated by chalcedony. Crossed nicols, X 55.

Fig. 2: From Vermilion Bluffs, cavity filled principally by quartz surrounded by a discontinuous band of chalcedony, which in turn is surrounded by an intimate intergrowth of anhedral calcite and chalcedony in equal amounts. Crossed nicols, X 30.



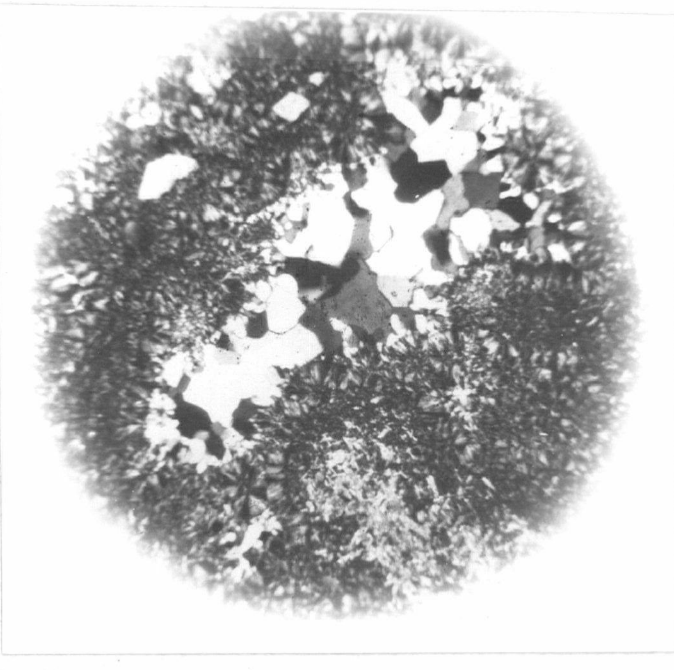


PLATE 20

Vermilion Bluffs Section

Fig. 1: A few euhedral crystals of dolomite followed by fibrous chalcedony and an inner zone of fine quartz. Crossed nicols, X 30.

Fig. 2: From Vermilion Bluffs, triangular carbonate fragment being replaced by fibrous chalcedony. Crossed nicols, X 30.

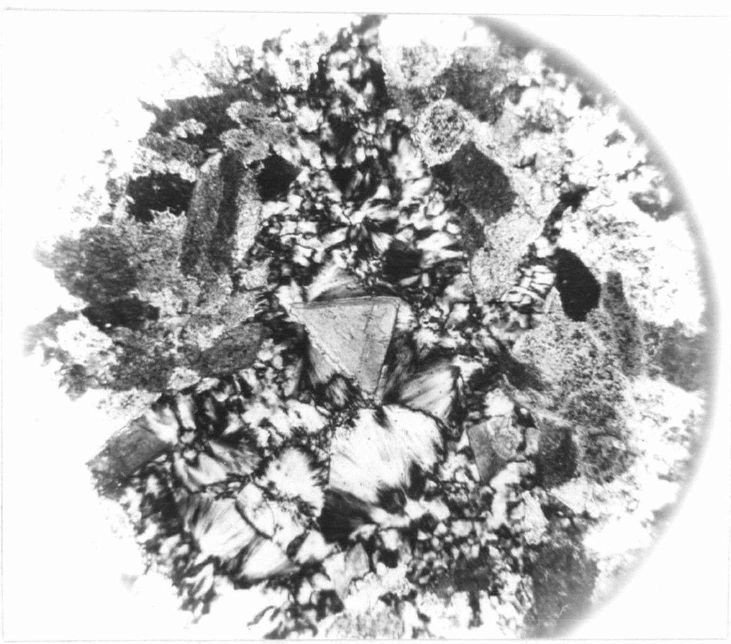
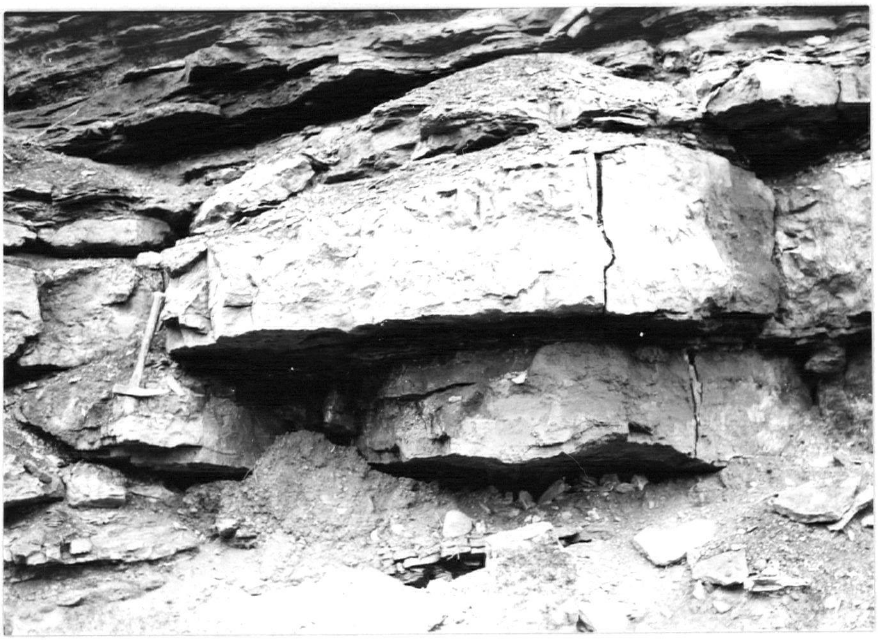


PLATE 21

Vermilion Bluffs Section

Fig. 1: View of the Vermilion Bluffs section showing irregularity of the lamination within the larger units (to right of pick handle).

Fig. 2: Diatoms from the lowermost exposed portion of Vermilion Bluffs. X 55.



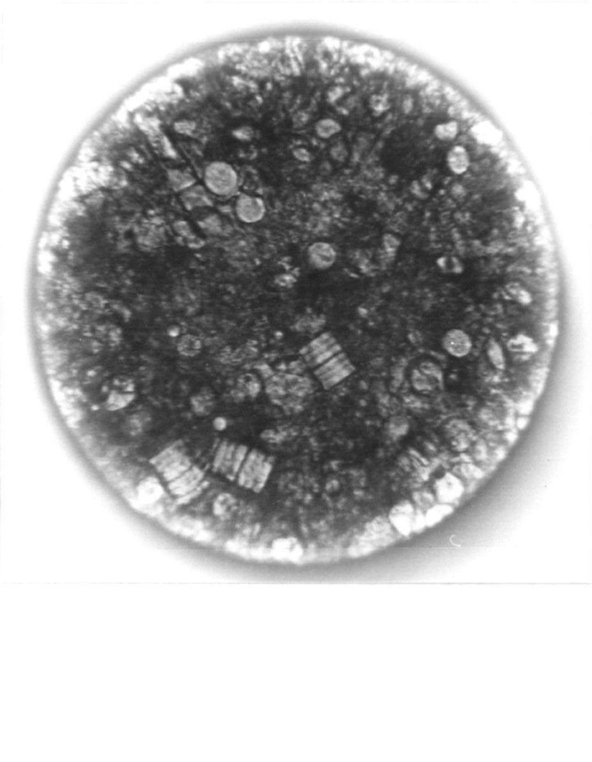


PLATE 22

Myrmekitic Texture

Fig. 1: Myrmekitic texture from a boulder of the conglomerates on Summers Creek. Crossed nicols, X 55.

Fig. 2: Myrmekitic texture taken from a section of the Osprey Lake Intrusion. Crossed nicols, X 55.

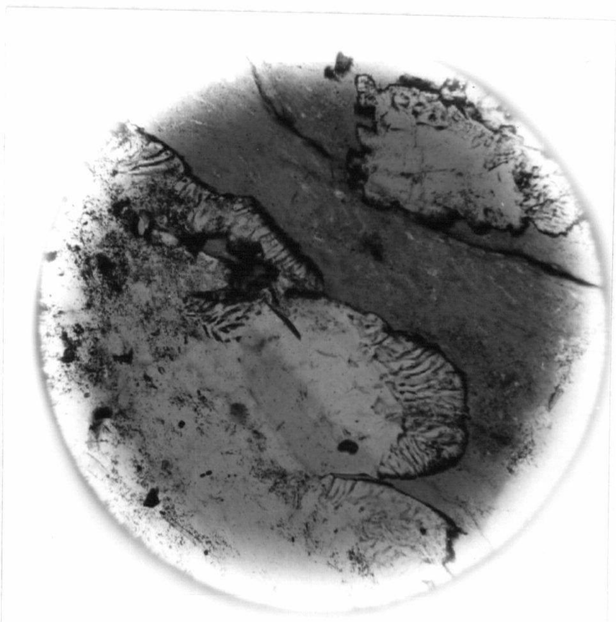


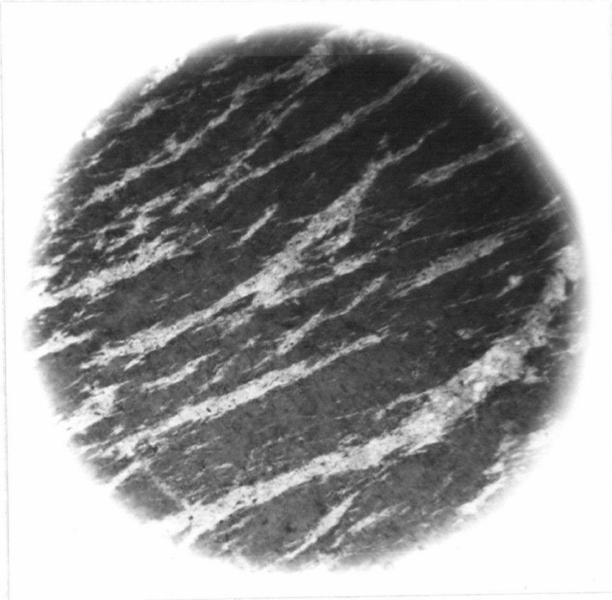
PLATE 23

Microperthite

Fig. 1: Replacement (?) microperthite seen in the Osprey Lake Intrusion. Also found in the boulder and granule conglomerates of the Princeton coalfield. Crossed nicols, X 55.

Faulting

Fig. 2: Small fault in Vermilion Bluffs section with east side down. View looking north.



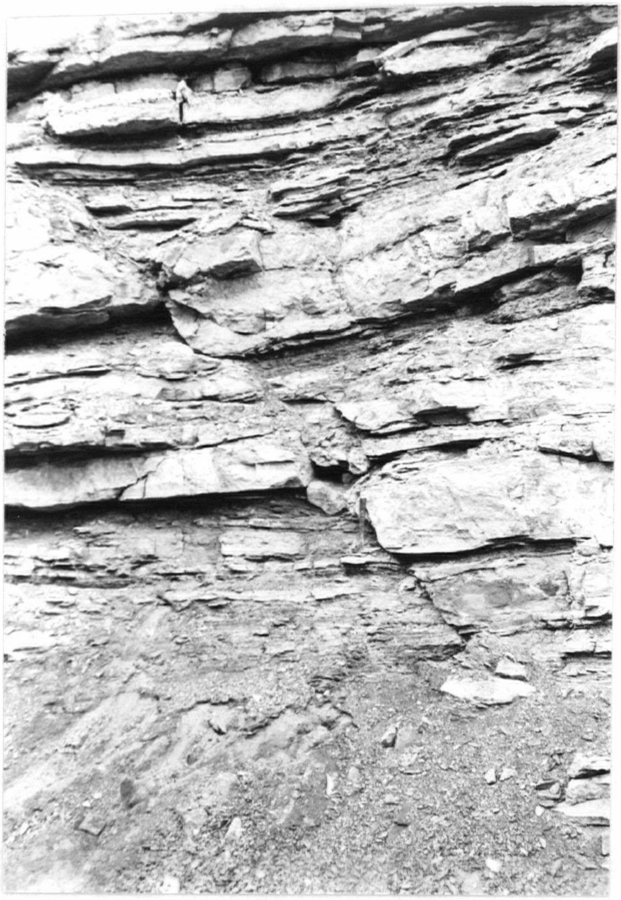
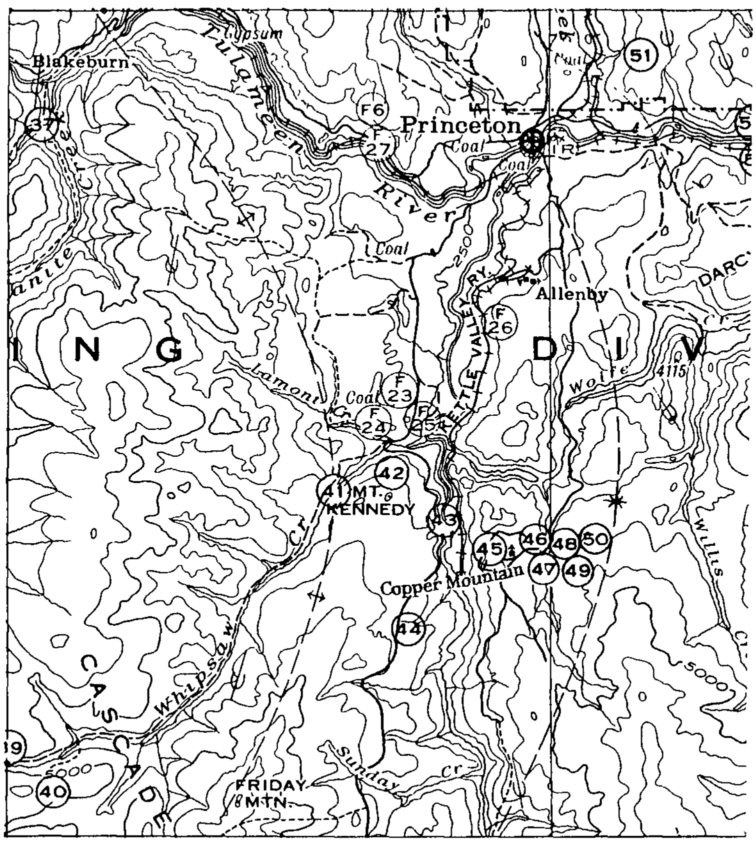


PLATE 24



REGIONAL STRUCTURE

OF THE PRINCETON COALFIELD

After Rice (1947)

Scale - 1" = 4 mi.

PART IV

MICROPALEOBOTANY

COLLECTION OF SAMPLES

It was felt that to be of greatest value, both for a geological correlation tool and for a floral analysis, the stratigraphic relationship of one sample to another should be known. For this reason, remapping of the Princeton coalfield was undertaken.

Samples were taken from 25-foot stratigraphic intervals wherever exposure permitted. In many cases where only scattered outcrops of 5 to 20 feet stratigraphic were exposed, separate samples were collected from each outcrop.

Samples were not collected from coarse sandstones unless they contained lenses of shaly material. Coal seams were collected separately from shale if possible, as coal requires a different treatment from shaly or silty material, and represents different ecological and sedimentary conditions.

Samples of unknown stratigraphic relationship were taken from mine workings on Lamont Creek (Blue Flame) and on the Similkameen at Ashnola.

In order to eliminate the possibility of recent contamination, the outer six to eight inches were removed. The samples were then taken from the inner face of the channel. If there was still a possibility of contamination, the samples were washed thoroughly before maceration.

TREATMENT OF SHALES, SILTS AND FINE SANDSTONES

Several methods have been employed in the past to separate fossil spores and pollen from the enveloping rock. Raistrick(1934) modified the then current method of peat treatment to coals. Subsequent to this work, numerous improvements, changes and new techniques have arisen. The reader is referred to the following for further details: Arms, 1960; Erdtman, 1943; Funkhouser and Evitt, 1959; Holst, 1954; Jeffords and Jones, 1959; Raistrick and Simpson, 1933; Raistrick, 1934, 1937; Staplin et al, 1960; Tschudy, 1958, 1960; Wilson, 1946, 1959; Wodehouse, 1933.

The general method used for the Princeton shales involved macerating the shale or coal to a size range of 1/16 to 1/4 inch, taking care not to powder the sample. The samples were then treated with HCl to remove any carbonate, HF to remove inorganic matter, HNO_3 and a modified Schultze's solution to oxidize the carbonaceous fragments, and K_2CO_3 to dissolve oxidized organic matter.

Several experiments were carried out to test the effectiveness of varying concentrations of acids, their effect on spore and pollen grains, and to see if any one treatment could be adopted for the Princeton shales. The following is an outline of such experiments and their results.

Hydrochloric Acid

As the sediments are differentially cemented with carbonate it is necessary to treat every sample with hydrochloric acid prior to the hydrofluoric acid treatment. While some samples required little or no hydrochloric acid treatment, many were strongly effervescent. It is recommended that a ten to twenty percent solution be used and allowed to stand for several hours, preferably overnight. The reason for not using a higher concentration for a shorter length of time is: (1) if the sediment is heavily carbonated, violent reaction ensues; (2) carbonate from larger fragments may not be digested as the acid may not have time to penetrate; and (3) the sludge formed by thorough removal of carbonate is more reactive and therefore requires less time for the hydrofluoric acid treatment. The amount of dilute hydrochloric acid added should vary depending on the percent of carbonate present. A check should always be made to ensure complete removal of carbonate before hydrofluoric acid is added.

Hydrofluoric Acid

Shales, silts and fine sandstones all require the same treatment. Each sample should be immersed in a volume of hydrofluoric acid:sample of not less than 5:1 and preferably 10:1, and allowed to stand for at least 24 hours. Longer periods of time may serve to remove minor siliceous materials, and as hydrofluoric acid is non-reactive to carbonaceous matter, it is in no way detrimental. If this treatment is incomplete it will be found that a thorough washing and retreatment with hydrofluoric acid will be more effective and will require less time than addition of a fresh acid to an already spent solution.

If only a minor amount of siliceous material remains, it may be effectively removed by proper centrifuging. If the silica fraction is greater than the organic matter, then retreatment is recommended. If strong or even mild effervescenses are noted on first adding hydrofluoric acid, incomplete removal of carbonate is indicated. If the reaction proceeds for any length of time, the material should be discarded, as the calcium fluoride crystals produced are insoluble and may completely mask any spore or pollen grains present. If the reaction becomes violent it may generate enough heat to melt the polyethylene container. Cautions: Hydrofluoric acid should never be poured into other than a polyethylene, copper or lead container; hydrofluoric acid should not be added to any material that has not been checked and rechecked for the presence of a carbonate; always dampen the sample with water and add hydrofluoric acid slowly.

Nitric Acid

A ratio of 2:1 of nitric acid to water for fifteen to sixteen hours is recommended for treatment of carbonaceous materials from Princeton. Concentrated nitric acid requires only four to six hours. The advantage of using 2/3 strength is that it may be left for several days without apparently affecting spore and pollen grains, whereas an hour may be critical when using concentrated nitric acid or Schultze's solution.

Treatment with Schultze's solution (nitric acid plus potassium chlorate plus water) is not recommended, as it is difficult to gauge when the reaction has gone far enough. In addition, increased density and viscosity lead to difficulty in proper centrifuging.

Potassium Carbonate

Potassium carbonate solution was used to dissolve oxidized material in all preparations. The strength of the solution was varied from three to ten percent on the same specimen in order to compare results. In the case of strengths below five percent, incomplete dissolution was noted for short periods, i.e. less than three to four hours. For strengths greater than five percent, the carbonate solution could be added, agitated and washed immediately.

The increased density resulting from the higher concentrations followed by improper centrifuging resulted in a high loss of spore and pollen grains. It is, therefore, recommended that a strength of five to six percent potassium carbonate not be exceeded.

Schultze's Solution

Many of the samples, after having received the above treatment, still required further treatment to clear spore and pollen grains of carbonaceous coats. Several samples were divided, and one-half treated with concentrated nitric acid, the other half with a modified dry Schultze's solution (2 to 3% potassium chlorate crystals plus concentrated nitric acid). In all cases the nitric acid was not considered a strong enough oxidizing agent, while in the case of the dry Schultze's solution, excellent results were obtained in materials treated for one to two hours. It is, therefore, recommended that if initial treatments with nitric acid are insufficient, the addition of a small amount of potassium chlorate will greatly improve the preparation.

If too much potassium chlorate is added, the density of the resultant liquid, combined with films of released gas clinging to the surface of organic particles, will result in a froth forming on the surface of the liquid. In some cases, there is a selective removal of extraneous carbonaceous matter which may simply be discarded. In many cases, however, spores are also floated to the surface. In such cases it is necessary to cause precipitation. This may be done by adding water and agitating, or by spraying the surface with ethyl alcohol.

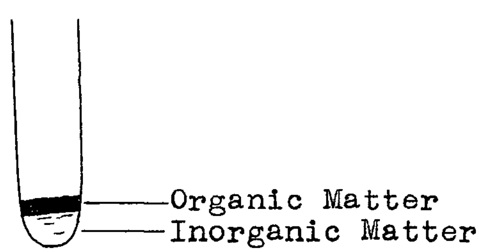
The treatment with Schultze's solution should be followed by a second treatment with potassium carbonate. However, in several cases it was found that simply washing in hot water gave the desired effect, and that the addition of potassium carbonate provided little or no effect. Caution: The froth should not be discarded without first having checked it for spores and pollen grains; the sample should not be left in Schultze's solution for longer than two hours, as in some cases complete digestion of both extraneous matter and spores and pollen occurs in three to five hours.

Washing

Washing of the sample is a very important feature in obtaining good microfossil preparations. For example, much fine organic matter can be removed from the preparation after nitric acid treatment simply by washing in hot water, followed by centrifuging. This allows the potassium carbonate to react with thin films surrounding microfossils and results in cleaner, less obscured spores and pollen. Combined with centrifuging, washing cannot in any way harm the preparation, and is beneficial in most cases.

Centrifuging

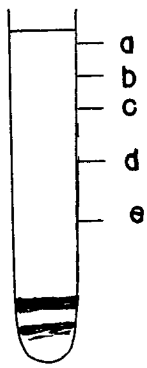
From the series of experiments performed on the Princeton samples in the laboratory, it was concluded that centrifuging is probably one of the most important steps in the treatment. If centrifuging is too slow, too little or employs too large a tube, entire preparations can be lost. However, much of the finer organic matter that is free, and which would tend to mask other materials on the slide, can simply be removed by regulating the time and speed at which centrifuging is carried out. Incompletely digested silica grains can be effectively removed by centrifuging. This is done by first washing all the material into one centrifuge tube. The silica grains are heavier and will settle first, resulting in a layered condition in the centrifuge tube (text, fig. 8).



Text, fig. 8 - Separation of organic and inorganic matter in the centrifuge tube.

Separation is carried out by simply agitating the surface layer and pouring off the resultant mixture, which contains the spore and pollen. If it is suspected that the inorganic fraction contains a high organic content, further separation may be obtained by repeating the process.

Using too large a centrifuge tube or too short a centrifuge time or too slow a revolution can result in extremely high loss of both spore and pollen. It is, therefore, recommended that when treating new materials, checks at several levels in the centrifuge tube should be made before discarding the liquid. This can be done by inserting an eye dropper to various levels and sucking up some of the material.



Text, fig. 9 - The first sample should be drawn from the top. Successive samples should be taken progressively lower. Sample "e" should not be taken too close to the sediment as some of the lighter materials may be drawn up.

By this method one can learn to gauge centrifuging so that there is no excessive loss of spores and pollen. If spores are still in suspension, they may be removed by: (1) increasing the speed of revolution, (2) increasing the length of time of centrifuging, and (3) decreasing the density of the liquid. In some cases all three are required, as in the case of using ten percent solution of potassium carbonate for dissolving oxidized materials. Caution: hydrofluoric acid should be diluted before centrifuging in a glass tube; improper centrifuging can result in the loss of an entire sample. Always check before discarding. When using large centrifuge tubes, it is recommended that 1/4 to 1/2 inch of liquid be retained above the precipitate.

Vibraflute

The vibraflute, developed by Tschudy (1960) may be used to successfully remove calcium fluoride or other insolubles. If the sediment contains silica, it is best to treat again with hydrofluoric acid. The only disadvantage of the vibraflute is that it is very slow; however, in the event that the original material is limited, it may be used very effectively in cleaning up preparations containing an excess of insoluble materials.

TREATMENT OF COAL

The treatment of Princeton coal requires an entirely different treatment than the shales, silts or fine sands. As only a few samples of coal were treated, the following recommendations may not be applicable to all coals from the Princeton coalfield, but should be generally effective.

Hydrochloric Acid

This treatment can be carried out as in the treatment of shales, etc.

Hydrofluoric Acid

In the case of Princeton coals there is always some sand present. Because of this it is recommended that hydrofluoric acid be added in the final stages of treatment after the nitric acid. The reason for this is that carbonaceous matter surrounds sand grains and prevents the digestion of the sand. After the nitric acid treatment, these grains are freed of the coating, and may readily be digested.

Nitric Acid

From samples treated, it has been found that concentrated nitric acid is not strong enough to oxidize coal particles, and it is recommended that Schultze's solution be used in its place. The length of time required for the Schultze's treatment varies from seven to sixteen hours.

Dissolving Oxidized Coals

As for shales, silts and sandstones, potassium carbonate was used and found to be a satisfactory agent. If the sample has been thoroughly oxidized, it may be washed immediately.

Washing and Centrifuging

Washing and centrifuging for coals is the same as for shales except that more washings are usually required. Further, the ratio of spores to extraneous organic matter is lower than in shales and more care must be taken that the microfossils are not lost during washing.

While suitable material for study may be obtained from the Princeton coals, the preservation is not as good as in shales. Many spores and pollen are broken or partially decomposed. It is, therefore, indicated that shaly partings yield better preserved microfossils.

Bentonitic Clay

While no specific tests were made on bentonitic clays, it was observed that this material requires more hydrofluoric acid treatment than ordinary shales. It is, therefore, advisable in sampling that this material be excluded from samples.

Several bentonites were analyzed, and the microfossil yield was found to be very low. It is recommended, therefore, that bentonitic materials be excluded as samples unless they occur in beds of at least several feet thickness. Such beds may represent a considerable gap in time, and may have microfossil-bearing layers, in which case they would provide valuable information concerning the floras and ecology.

PHOTOMICROGRAPHY

Photomicrographs were taken with a Leica 35 mm. camera mounted on a Leitz GmbH Wetzlar microscope (Ser. #533387). The camera mount was a Leitz Wetzlar attachment with a monocular adjusting eye piece. Both Adox KB14 and Duko Pan film were used and found to be satisfactory. However, the Duko Pan film is slower and appears to give better results than Adox KB14 where microfossils have not taken the stain. The majority of the photographs were taken with a green filter inserted in the light source. A test roll using Duko Pan film without the green filter indicated that satisfactory results on very low contrast microfossils (non-stained) could be obtained. This method should be further investigated as many microfossils characteristically do not take the stain.

TAXONOMIC REMARKS

In the following description of the microfossils from the Princeton coalfield, many have been assigned to modern genera, whereas others have been assigned to fossil genera. Those falling into the second category (i.e. form genera) can be subdivided into two groups: (a) those of suspected modern affiliations, and (b) those of unknown modern affiliations. Several have been listed simply as unidentified as they cannot be assigned to either a modern genus or to a previously described fossil genus. Both the fossils of known modern affiliations and those of suspected modern affiliations have been described and mounted on the plates in a phylogenetic sequence as outlined by Rouse (1957, 1959). Those known only by a fossil genus will be dealt with in alphabetical order. Those that have not been identified or assigned to a fossil genus will be included on the plates as unidentified spores or pollen with only a brief description in the text.

A designate system was not used, except where fossils have been assigned a designate by previous workers (i.e. Pistillipollenites mcgregorii, Rouse, 1962, designate Q47). While a designate system has not been used in this thesis, it is not meant to imply that designates are not of value. On the contrary it is felt that where one is dealing with a large number of unknowns, a designate system probably provides the best method of subdividing them. For the limited number of unknowns described here, it is not felt that a designate system is required. Further, a designate system can be more easily applied to graphs and charts than the actual name of the fossil.

It is not the purpose here to identify the various spores and pollen to species, but rather to assign them to the closest modern genus, and if possible, species. An extensive review of previously described Eocene microfossils has been made. Where there is little or no doubt that the Princeton sample is identical with the previously described fossil, it has been assigned to that genus and species (i.e. Alnus quadripollenites, Rouse, 1962, Pinus strobipites, Wodehouse, 1933). Although some of the fossils described and assigned to a genus represent new species, no attempt has been made to assign them species names. The reason for this is that the writer would like to make a more thorough review of the literature before assigning species names to avoid the problem of synonymy.

The following table is the taxonomic classification used by Rouse (1959):

Division	Class
Bryophyta	Hepaticae Anthocerotae Musci
Psilophyta	Psilophytopsida Psilotopsida
Lepidophyta	Lycopsida

Division	Class
Calamophyta	Sphenopsida
Pterophyta	Filicopsida
Spermatophyta	Pteridospermopsida Gymnospermopsida Angiospermopsida

PLANT MICROFOSSIL DESCRIPTIONS

Division FUNGI IMPERFECTI

Order MONILIALES

Family DEMATACEAE

Genus BRACHYSPORIUM Saccardo

BRACHYSPORIUM sp.

Plate 25, fig. 1-2.

The spores assigned to this genus probably belong to two species.

Diagnosis: Spores 20 - 50μ long; length:width = 3:1 - 2:1; multicellular with at least three perforate cross walls. There is a suggestion of a pore at the base (smallest cell). This, however, may only represent the original point of attachment. The cross walls are bilobed and triangular, and are of variable thickness (1 - 3μ) with the wall forming the apical cell being the thickest. The apical cross wall may reach 7 - 8μ in thickness.

The reasons for suggesting two species are: (1) variation in the apical cell size (either largest of all cells or smallest cell, (2) the general shape (either globular or elongate-fusiform).

The only comparative fossil material known to the writer is the specimen referred to as Brachysporium sp., Wilson and Webster (1946). While the shape and size of the larger globular spore (Plate 25, fig. 1) is very similar, the triangular cross walls are directed forward, whereas the specimen described by Wilson and Webster clearly shows the triangular wall pointing towards the base.

Genus DESMIDIOSPORA Thaxter

DESMIDIOSPORA sp. (Microconidia)

Plate 25, fig. 3.

Diagnosis: Spore small 16 - 20μ, edges convolute, with no obvious openings or pores. The conidium wall is thick (1 - 2μ), hyaline and psilate. Of the two conidia observed one still retained the conidiophore.

Cf. Desmidiospora sp.

Barnett, 1955, p. 134, 1st ed.

Barnett, 1960, p. 126, 2nd ed.

Division MYCOTA

Subdivision EUMYCOTA

Class ASCOMYCETES

Remarks: Spores belonging to the Ascomycetes are very common in the Princeton materials, and range in size from less than 5μ to 35μ. While chains of spores indicating the arrangement in the ascus are uncommon in the fossil material, they were observed in enough instances for the writer to state with confidence that the single spores which are globular in shape, thick walled (2 - 3μ thick), and with one or two areas slightly flattened, actually belong to this class. It is also probable that those species described as Inapertisporites laevigatus and I. globossus by Rouse (1962) are actually spores belonging to fungi of this class. Several spores within a single ascus were measured and found to range from 12 - 18μ. Although this probably represents an immature ascus, the wide range of spore size within one ascus points out the problem of relying on size as a criterion for the recognition of species of Ascomycetes spores.

Genus INAPERTISPORITES Van der Hammen 1955
ex Rouse 1959

INAPERTISPORITES sp. (?)

Plate 25, fig. 4 - 5.

Diagnosis: Size 5 - 9μ; spherical, inaperturate, thick walled (1$\frac{1}{2}\mu$); hyaline. These small spores were observed on several slides, but only on those containing little extraneous organic matter.

INAPERTISPORITES GLOBOSSUS Rouse 1962

Plate 25, fig. 6.

There is no doubt that the specimens from the Princeton are identical with those from the Burrard. The size of the Princeton specimens ranges from 25 - 35μ which is some 5μ less than the maximum reported by Rouse.

INAPERTISPORITES LAEVIGATUS Rouse 1959

Plate 25, fig. 7.

Specimens from Princeton, which are identical in all respects to those referred to as I. laevigatus (Rouse, 1959) are common fungal components of the Princeton microflora. It has already been pointed out, however, that in a single chain the size was observed to range from 12 - 18μ.

INAPERTISPORITES sp.

Plate 25, fig. 8.

Diagnosis: Elongate, ca. 1½ times as long as wide (16μ x 12μ); ends distinctly flattened. Spore wall laevigate and ca. 1½ - 2μ thick.

Whether this specimen is distinct from those previously described is not certain. It may represent a flattened specimen of I. laevigatus. The extreme flattening on the poles is not a characteristic of I. laevigatus.

Division BRYOPHYTA

Class MUSCI

Order SPHAGNALES

Family SPHAGNACEAE

Genus SPHAGNUM Ehrhart 1870

SPHAGNUM sp.

Plate 25, fig. 9 - 11.

Diagnosis: Spores trilete with the rays extending at least 2/3 of the distance to the equator. The texture is faintly to broadly punctate to granular (?). All the grains observed were triangular in outline with the corners well rounded. The size range (max. dimension) observed varied from 28 - 32μ. The wall is 1 - 2μ thick.

There is little doubt that this grain is a different species than that described as S. antiquasporites, Wilson and Webster (1946), but is very similar to S. punctaesporites, Rouse (1959). Lack of comparative material prevents comparison with modern species, although the specimens are well preserved and would lend themselves to comparison.

Division PTERIDOPHYTA

Order EQUISETALES

Family EQUISETACEAE

Genus INAPERTUROPOLLENITES Thompson and Pflug 1953

INAPERTUROPOLLENITES sp.

Plate 25, fig. 12.

Diagnosis: Grains 40 - 44μ in diameter; spherical; a fold or pseudomonolete usually present; wall thickness less than 1μ; texture granular to levigate.

Of the comparative material available (Populus, Cupressaceae and Equisetum) the specimens observed most closely resemble Equisetum. The presence of large numbers of macrofossils of Equisetum suggests that the identification is not unwarranted.

Division PTEROPHYTA

Class FILICOPSIDA

Order FILICALES

Family OSMUNDACEAE

Genus OSMUNDACIDITES Couper 1953

OSMUNDACIDITES sp.

Plate 25, fig. 13 - 15.

Diagnosis: Spores large, 68 - 74μ (observed); spherical; trilete with rays extending ca. 1/2 the distance to the margin. The texture is vermiculopapillate with the maximum observed length of papillae about 3μ. The wall is relatively thin (1½μ). Many of the grains are folded and appear prolate in shape.

These grains are not unlike O. javanica described and illustrated by Macko (1959).

OSMUNDACIDITES sp.

Plate 25, fig. 16.

Diagnosis: Spores ca. 44μ long; trilete with laesurae extending almost to the periphery; papillate with papillae ca. 2 - 3μ in length and rounded in transverse section; grains almost invariably folded.

These grains compare favorably with the modern species O. cinamomea and the fossil Osmundacidites primarius, Wolff, 1935.

Division PTERIDOPHYTA

Class FILICALES

Order OPHIOGLOSSALES

Family OPHIOGLOSSACEAE

Genus BOTRYCHIUM Swartz 1906

BOTRYCHIUM sp.

Plate 25, fig. 17 - 18.

Diagnosis: Spores trilete; ca. 32 - 36μ; rounded triangular; walls ca. 1 - $1\frac{1}{2}\mu$ thick; texture of low, rounded, wart-like projections whose outline is such that a reticulate pattern is observed when the inter-projection areas are in focus.

Modern comparative material was limited to B. pinnatum, B. ternatum and B. lanceolatum. Of the three, the fossil most closely resembles B. pinnatum in size, shape and surface texture. However, it is sufficiently different to suggest that further comparisons should be made before concluding that its closest modern counterpart is B. pinnatum. The major differences lie in: (a) the trilete of the fossil spore is longer and in general not as well developed, and (b) the warty surface, while very similar, is less pronounced in the fossil.

Family POLYPODIACEAE

Genus LAEVIGATOSPORITES (Ibrahim) Schopf, Wilson and Bentall 1944

LAEVIGATOSPORITES ALBERTENSIS Rouse 1957

Plate 25, fig. 19 - 20.

Designate: O_1.

Remarks: This specimen is undoubtedly identical with those reported from the Oldman formation of Southern Alberta by Rouse (1957) and again from the Burrard (Rouse, 1962). The closest affiliations are possibly with *Dryopteris* and *Asplenites* (Rouse, 1962).

LAEVIGATOSPORITES DISCORDATUS Thompson and Pflug 1953

Plate 25, fig. 21 - 22.

Designate: O_7.

Remarks: Identical specimens have been reported from the Oldman formation, Rouse (1957), and the Burrard formation, Rouse (1962). Rouse (1962) states: "The closest affiliation appears to be with *Dryopteris*, particularly *D. latifrons*."

LAEVIGATOSPORITES GRACILIS Wilson and Webster 1946

Plate 25, fig. 23.

Remarks: With the exception of the monolete mark which is more pronounced than that reported by Wilson and Webster (1946), the spore is identical. The spores appear similar to *Acrosticum parridum* in shape, size and levigate surface. The monolete mark is much more pronounced in the fossil. Further, the wall thickness of *Acrosticum parridum* is ca. 1μ thicker. Possible affiliations with this genus cannot be overlooked. Wilson and Webster (1946) state of *L. ovatus* and *L. gracilis*:

> "The inclusion of the above two species of spores in the genus *Laevigatosporites* is not entirely satisfactory, for there is little doubt that the spores belong to either *Thelypteris*, *Asplenium*, *Athyrium*, *Aspidium* or *Blechnum*..."

LAEVIGATOSPORITES OVATUS Wilson and Webster 1946

Plate 25, fig. 24 - 25.

Remarks: There is no doubt that the spores are identical with *L. ovatus* as described by Wilson and Webster (1946).

Family POLYPODIACEAE (?)

Plate 25, fig. 26.

Description: Small (28 x 24μ), verrucate, with interareas distinctly reticulate.

Remarks: Only a single specimen was found.

Family SCHIZACEAE

Genus LYGODIUM Swartz 1806

LYGODIUM sp.

Plate 25, fig. 27.

Diagnosis: Spores subtriangular to rounded; ca. 40 - 45μ; trilete with rays indistinct and extending to the equator; walls ca. 1 - 1$\frac{1}{2}\mu$ thick; the surface is covered with low rounded warts.

Remarks: This grain is very similar to the

Botrychium species already described. It differs primarily in the larger size and the absence of a reticulate interarea pattern.

Genus ANEMIA Swartz 1806

ANEMIA POOLENSIS Chandler 1955

Plate 25, fig. 28 - 32.

Remarks: There is no doubt that this is the same spore as described by Chandler. The size range is extremely variable with the majority of grains in the 50 - 54μ range. The observed range was 36 to 60μ which is identical with the size range recorded by Chandler (1955).

ANEMIA (?) sp.

Plate 25, fig. 34.

Diagnosis: Spores large, ca. 50μ; trilete, with narrow rays which extend 2/3 the distance to the equator; the spore wall is about 1 - $1\frac{1}{2}\mu$ thick; texturally it exhibits a faint reticulate pattern; in shape the grain is rounded triangular.

Remarks: Only a single grain of this type was observed. Its affiliation with *Anemia* is questionable.

Order HYDROPTERIDALES

Family SALVINICCEAE

Genus AZOLLA Lamarck 1783

AZOLLA PRIMAEVA (Penhallow) Arnold

Plate 25, fig. 33, Plate 25, fig. 35 - 36, Plate 26, fig. 1 - 9.

Remarks: *Azolla* micro and megaspores from Princeton were described by Arnold (1955). A series of photographs has been taken to show variation in microspores. Also, the arrangement of the microspores in the sporangia is clearly shown in Plate 26, fig. 4. Observed size range for the microspores was 20 - 26μ, while the range for the megaspores was 150 - 350μ. The smaller size is thought to represent immature individuals. The megaspores are distinctly trilete with the rays extending 1/3 - 1/2 the distance to the equator.

The megaspore wall of *Azolla primaeva* is composed of several layers. The inner layer is thin, ca. 1 - $1\frac{1}{2}\mu$, smooth to fine granular, shows no trilete mark, and when observed separated from the outer wall(s) was poorly preserved and much folded (see Plate 26, fig. 6).

The inner wall of *A. primaeva* has been compared to *Magnosporites staplinii*, Rouse (1962) and found identical. This suggests that *M. staplinii* is actually the inner wall of an *A. primaeva* megaspore.

Division SPERMATOPHYTA

Class GYMNOSPERMOPSIDA

Order GINKGOALES

Family GINKGOACEAE

Genus GINKGO Kampfer

GINKGO sp.

Plate 27, fig. 1 - 3.

Diagnosis: Pollen monosulcate; broad; and prolate to subspherical; 39 - 41μ long; the surface texture is smooth to granular.

Remarks: There is no doubt that the pollen grain belongs to Ginkgo. Similar forms have been reported as Cycadopites, Wodehouse (1933), Cycadopites follicularis, Wilson and Webster (1946), and Rouse (1962) identified grains from the Burrard which he states are identical with C. follicularis.

Family PINACEAE

Genus LARIX Miller 1754

LARIX PLICATIPOLLENITES Rouse 1962

Plate 27, fig. 4.

Remarks: These grains are identical with those reported from the Burrard by Rouse (1962) with the exception of a smaller size range. The observed size range for the Princeton specimens was 53 to 63μ.

Genus TSUGA Carriere 1855

TSUGA VIRIDIFLUMINIPITES Wodehouse 1933

Not photographed.

Remarks: With the exception of size (ca. 55 - 60μ) the specimens observed from Princeton are identical with those described by Wodehouse. Rouse (1962) described similar specimens from the Burrard formation and gave the size range as 47 - 70μ. The Princeton specimens are identical with those described by Rouse, except possibly in the size of the convolutions.

TSUGA sp.

Plate 27, fig. 5 - 10.

Diagnosis: Grains large, 68 - 100μ; characteristically dish-shaped; frequently with two well-developed bladders, if there are more than two they are poorly developed. A number of grains were observed with a narrow border only; the surface texture varies from coarse reticulate in the center of the grain, becoming progressively finer towards the border, where it is characteristically coarse-granular. The borders or bladders are offset from the body by a distinct break in the convex nature of the body.

Remarks: There is little doubt that the variations observed in the fossil pollen grain are identical with variations in the modern *T. pattoniana* as described by Erdtman (1943) and Macko (1957 and 1959), and that this pollen is closely related to the modern species.

Genus PINUS Linnaeus 1753

PINUS sp.

Plate 27, fig. 11 - 12.

Diagnosis: Bladdered, with bladders and body about equal in size; body sub-spherical with the cap coarsely granular or reticulate; observed body diameter 55 - 60μ. Germinal furrow 8 - 10μ wide, and smooth to fine granular. The bladder attachment at the proximal root is more or less convolute, while the distal root is straight. The bladders are coarsely reticulate, becoming finer towards the pollen body.

This grain is very similar to those described as Pinus palustris by Macko (1959, Plate 6, fig. 1 - 2) with the exception of body shape. Those described by Macko are elongate in the direction of the bladders, while those from Princeton are almost spherical.

PINUS sp.

Plate 27, fig. 13 - 14.

Diagnosis: Bladdered; body ca. 50 x 34μ; bladders ca. 29μ. The bladders are coarsely reticulate (to 6 or 7μ) becoming progressively finer towards the pollen body. The cap is moderately coarse reticulate (3μ or less). The germinal furrow is ca. 5μ and smooth to fine granular.

Remarks: There is a strong tendency for the cap to curl towards the distal surface, bringing the bladders into direct contact and obscuring the germinal furrow. This grain is very similar in all respects to the modern Pinus contorta.

PINUS TUBERCULIPITES Wodehouse 1933

Plate 27, fig. 15.

Remarks: This specimen very closely resembles those described by Wodehouse, and has been assigned to *Pinus tuberculipites*.

PINUS STROBIPITES Wodehouse 1933

Plate 27, fig. 16 - 21.

Remarks: A number of pollen grains were observed which can be assigned to Wodehouse's *P. strobipites* with a fair degree of confidence.

PINUS TENUEXTIMA Traverse 1955

Plate 28, fig. 1.

Remarks: The correlation of the Princeton specimens with *P. tenuextima* is only tentative. While the grains are very similar in texture, the Princeton specimens appear to be narrower than those described by Traverse. Detailed comparison is hampered by the scarcity of grains of this type.

PINUS sp.

Plate 28, fig. 2.

Diagnosis: Bladders ca. 2/3 the size of the body; body ca. 64 x 52μ. Both the distal and proximal roots form a smooth line. The bladders are attached at opposite ends of the short axis of the body. The germinal furrow is broad (10 - 12μ) and smooth to fine granular. The walls of both the body and the bladders are less than 2μ. The bladders are moderately reticulate (3μ max.) becoming progressively finer towards the body.

Remarks: These grains are similar to those previously described as P. palustris, but differ in the orientation and shape of the body and the convolute distal root.

Genus PICEA Dietrich 1824

PICEA ALIPOLLENITES Rouse 1962

Plate 28, fig. 3 - 7.

Remarks: The correlation of the Princeton specimens with those from the Burrard formation is tentative. They agree in size, shape and texture, and therefore, have been assigned to the species.

PICEA sp.

Plate 28, fig. 8.

Diagnosis: Bladders broader than body; observed range for bladders 64 x 81μ to 72 x 81μ. The bladders are attached at the ends of the long axis of the body (84 x 65μ). The germinal furrow is very narrow (3μ or less) and may be represented only by the line of suture of the bladders. The cap is finely reticulate to granular, while the bladders are moderate to finely reticulate (2½μ or less).

Remarks: No similar grains have been described to the writer's knowledge, nor has he been able to relate the grain to a modern species. At least six grains all answering the above description were observed, and therefore, there is little doubt that it is a distinct pollen species.

PICEA (?) sp.

Plate 28, fig. 9.

Diagnosis: Bladdered, with one bladder much larger and partially enclosing the second bladder. Body 95 - 100μ in length. Bladders 66 - 73μ in length. The texture of the bladders is fine to coarsely reticulate, while the body is granular to finely reticulate. The germinal furrow was not observed, but must be curved and very narrow. Cap only slightly thickened.

Remarks: This pollen type was assigned to Picea because of its size, texture and the nature of the cap.

PICEA (?) sp.

Plate 28, fig. 10.

Remarks: Only two grains of this type were observed. They were first assigned to Podocarpus, but unlike Podocarpus the attachment of the bladders is not a distinct suture. Unlike Cedrus and Abies, the cap is not appreciably thickened, and its size is larger than any Pinus sp. observed by the writer.

The specimens are characterized by a large (67 x 80μ) sub-spherical body; the bladder dimensions are ca. 50 x 80μ. The bladders are coarsely reticulate, becoming progressively finer and gradually blending into the body. The germinal furrow is ca. 8μ and finely granular.

While this grain resembles Picea alipollenites, it is distinctly broader and the reticulation is heavier and coarser.

Order CONIFERALES

Plate 28, fig. 11.

Remarks: Only a single grain of this type was observed. It is characterized by a large body (110 x 78μ) and two very small bladders. The texture of the bladders is moderately reticulate (3μ or less). The germinal furrow is smooth.

Macko (1957, Plate 11, fig. 4 - 12) describes a similar grain as Tsuga pattoniana.

Family PODOCARPACEAE

Genus PODOCARPUS L'Heritier ex Persoon 1807

PODOCARPUS sp.

Plate 28, fig. 12.

Remarks: A specimen of Podocarpus has been identified from the Burrard by Rouse (1962). Like the Burrard specimen, the Princeton specimens (five) compare favorably with a Miocene pollen grain referred to as *Podocarpus nageia* R. Browning, by Macko (1959, Plate 39, fig. 9).

Family TAXODIACEAE

Genus METASEQUOIA Miki ex Hu et Cheng 1948

METASEQUOIA PAPILLAPOLLENITES Rouse 1962

Plate 29, fig. 1.

Remarks: The only difference between the species described by Rouse (1962) is the size of the pollen body. The maximum size observed in the Princeton material was 22 , while Rouse indicates a size range of 24 - 26 for the Burrard specimens.

Only three grains were encountered in the Princeton material, and the size observed (20 - 22μ) may not be representative. If the above size is typical, it is suggested that the size range be extended to include all grains from 20 - 26μ.

Genus TAXODIUM Richard 1910

TAXODIUM HIATIPITES Wodehouse

Plate 29, fig. 2.

Remarks: There is considerable variation in the shape, texture and characteristic splitting of the grains assigned to this species. While there is little doubt that some are identical with those referred to as *T. hiatipites*, Wodehouse (1933), also Rouse (1962) and Wilson and Webster

(1946), there is a suggestion that many of the grains are more closely allied with Libocedrus. The reasons for this are the shape and character of the rupture, and many small scale-like flecks on the exine when viewed under oil immersion. It may be that both Taxodium and Libocedrus are present.

Genus SCIADOPITYS

SCIADOPITYS sp.

Plate 29, fig. 3.

Diagnosis: Grains large (44 - 48μ), spherical, with the surface covered with short ($1\frac{1}{2}\mu$) broad papillae. The papillae appear to be aligned into rows.

Remarks: The grains resemble Sciadopitys verticillata. It differs from illustrations of Sciadopitys pollen figured by Erdtman (1943) in the development of the papillae. According to Erdtman the papillae are low and rounded and more wart-like, whereas those of the fossil specimens are longer than broad and stand erect as well defined projections.

While the specimens of this type have been assigned to Sciadopitys, there is enough difference between the modern and fossil to suggest that further comparisons should be made. It is, however, beyond the scope here to attempt further comparisons, and the problem will be assigned to future work.

Family CUPRESSACEAE

Genus INAPERTUROPOLLENITES Thompson and Pflug 1953

INAPERTUROPOLLENITES sp.

Plate 29, fig. 4 - 5.

Diagnosis: Grains spherical, 20 - 30μ in diameter, thin-walled (1μ or less), exine smooth to granular.

Remarks: These grains are very similar to pollen of *Chamaecyparis*, although there are other members of the *Cupressaceae* to which it could also be assigned.

Division SPERMATOPHYTA

Class ANGIOSPERMOPSIDA

Sub-class DICOTYLEDONIDAE

Order FAGALES

Family BETULACEAE

Genus ALNUS Miller 1754

ALNUS QUADRIPOLLENITES Rouse 1962

Plate 29, fig. 6.

Remarks: Pollen of this species is rare in the Princeton microflora. There is, however, no doubt that the specimens observed are identical with the Burrard specimens. While no comparative material is available, it also may be tentatively correlated with the four-pored specimens from the Green River which Wodehouse (1933) lumped with the five-pored and referred to as *Alnus speciipites*. Macko (1959, Plate 19, fig. 6 - 11) referred similar pollen grains from the Miocene to the modern species *A. maritima*.

ALNUS QUINQUEPOLLENITES Rouse 1962

Plate 29, fig. 7 - 10.

Remarks: Rouse (1962) gives a size range for the species of 20 - 22μ, whereas the Princeton specimens have a size range of 20 - 33μ. Other features (arci, pores) are identical, and it is on the basis of these features that the specimens have been assigned to the previously described species.

Genus BETULA Linnaeus 1753

BETULA CLARIPITES Wodehouse 1933

Plate 29, fig. 11 - 12.

Remarks: Pollen that can be definitely assigned to Betula are not common in the Princeton microflora. While the angular nature of the one specimen photographed (Plate 29, fig. 12) is not mentioned by Wodehouse, his description fits exactly other specimens observed at Princeton.

Genus CARPINUS Linnaeus 1753

CARPINUS ANCIPITES Wodehouse 1933

Plate 29, fig. 13 - 17.

Remarks: The observed size range for the Princeton specimens was 30 - 40μ. While three-pored grains are the most common, four and five-pored specimens were observed (see Plate 29, fig. 16 and 17). The writer has no doubt that the specimens observed are identical with those described by Wodehouse (1933).

Family FAGACEAE

Genus CASTANEA Tournefort

CASTANEA sp.

Plate 29, fig. 18.

Diagnosis: Grains small (16 - 18μ), tricolporate with colpae extending almost to the poles. Each colpae encloses a well marked germinal pore and transverse furrow. The exine is smooth even under oil immersion.

Remarks: These grains are not common, but easily recognized because of the combination of pores and transverse furrows. The writer suspects that this is a new species, but would reserve this decision until a more thorough search of the literature can be made.

The affiliation with the modern genus *Castanea* is undoubted, and except for its slightly larger size, is identical with grains of *C. dentata*.

Order JUGLANDALES

Family JUGLANDACEAE

Genus CARYA Nuttall 1818

CARYA JUXTAPORIPITES Wodehouse 1933

Plate 29, fig. 19.

Diagnosis: 24 - 32μ(?); subrounded to subtriangular, triporate, pores distinct round to oval with only a slight thickening of the exine. The walls are 1 - $1\frac{1}{2}\mu$ thick and smooth.

Remarks: These grains are very similar to *C. juxtaporipites* Wodehouse (1933) and to the Burrard specimens as described by Rouse (1962). These grains are very similar to some species of *Corylus* and were at first associated with that genus. However, the absence of distinct arci invalidates this correlation.

Genus PTEROCARYA

PTEROCARYA sp.

Plate 29, fig. 20 - 23.

Diagnosis: Observed size 28 - 38μ; variable number of pores (6 - 9), with pores confined to a single plane. The shape is distinctly angular with the number of sides depending on the number of pores. The pores are distinct, spherical to oval in outline, with little or no thickening of the exine.

Remarks: There is a distinct size break between the larger and smaller size grains, with a tendency for the grains to be close to either end of the range. This strongly suggests that two species are present.

Order MALVALES

Family TILIACEAE

Genus TILIA Linnaeus 1753

TILIA CRASSIPITES Wodehouse 1933

Plate 29, fig. 24.

Remarks: Pollen grains of this type are rare in the Princeton material. There is no doubt of the correlation with _T. crassipites_.

The specimen very closely resembles the modern species _T. americana_ to which species Macko (1959, Plate 17, fig. 17 - 19) assigned similar Miocene fossils.

Order RHAMNALES

Family RHAMNACEAE

Genus RHAMNUS Linnaeus 1753

RHAMNUS sp.

Plate 29, fig. 25.

Diagnosis: Pollen small (ca. 18μ), triangular with sides usually concave; triporate with deep, narrow openings. The wall is ca. 1μ thick and smooth.

Remarks: Only a single specimen was seen, but there is little doubt that it belongs to _Rhamnus_. It closely resembles _R. pershiana_, the only modern material available for comparison.

Order SALICALES

Family SALICACEAE

Genus SALIX Linnaeus 1753

SALIX DISCOLORIPITES Wodehouse 1933

Plate 29, fig. 26 - 27.

Remarks: Affiliations with Salix are undoubted, and as the size and texture are identical with that given for S. discoloripites, Wodehouse (1933), it has been assigned to that species.

SALIX sp.

Plate 29, fig. 28 - 29.

Diagnosis: This grain is very similar to Salix discoloripites at first appearance, but closer inspection indicates that it probably belongs to a different species. The grains are tricolpate with colpae extending almost to the poles; sub-prolate to prolate (length:width = $1\frac{1}{2}$:1); the exine is coarsely reticulate; observed size range 28 - 32μ. It differs from S. discoloripites in its size and in the much coarser reticulate ornamentation. The coarse reticulate pattern is very similar to the extant S. hookeriana. It is, however, much larger than pollen grains of this species. It is only slightly larger than S. nigricans.

SALIX sp. (?)

Plate 29, fig. 30 - 31.

Diagnosis: Dimensions ca. 24 x 18μ; sub-prolate to prolate; tricolpate with the colpae extending almost to the poles; the exine is only faintly reticulate; wall thickness ca. 1μ.

Remarks: The main feature which sets this grain off from the two previous species is the faint reticulate pattern, otherwise it is very similar to S. discoloripites.

Genus INAPERTUROPOLLENITES Thompson and Pflug 1953

INAPERTUROPOLLENITES sp.

Plate 29, fig. 32.

Diagnosis: Grains spherical, 30 - 36μ in diameter; inaperturate. The exine is extremely thin (0.5μ), and psilate to almost levigate.

Remarks: This grain resembles some species of Populus and it is tentatively affiliated with this genus.

Order SAPINDALES

Family ACERACEAE

Genus ACER (Tourn.) Linnaeus 1753

ACER sp.

Plate 29, fig. 33 - 34.

Diagnosis: Size 33 - 36μ(?); spherical in polar view and prolate to sub-prolate in equatorial view; tricolpate with colpae well developed but extending only ca. 3/4 the distance to the pole; exine ca. 1μ thick, thinning somewhat towards the colpae; smooth to very fine granular.

Remarks: Less than a dozen pollen grains of this type were seen. They are normally poorly preserved, folded and/or broken.

ACER sp.

Plate 29, fig. 35 - 39.

Diagnosis: Grains sub-prolate to sub-spherical in equatorial view; tricolpate with colpae extending 3/4 of the distance from the equator to the poles; size 26 - 30μ in diameter; wall ca. 1μ thick, smooth to granular. There is a pronounced thinning of the exine towards the colpae.

Remarks: This species is distinguishable from the preceding by size alone. Prior to the present studies, there had been no mention of Acer in the Princeton specimens. During the course of field work four Acer samaras were collected.

Family HIPPOCASTANACEAE

Genus AESCULUS Linnaeus 1753

AESCULUS sp.

Plate 29, fig. 40 - 41.

Diagnosis: Grains small (22 - 28μ) prolate; tricolpate with the colpae well defined, narrow and extending almost to the poles. In well preserved specimens and where the colpa area can be observed, it is covered by small spines. The wall exclusive of the colpae areas is smooth to fine granular in texture and less than 1μ thick.

Remarks: Less than six pollen grains of this type were seen. There is no doubt, however, of their identity.

Order ERICALES

Family ERICACEAE

Genus ERICIPITES Wodehouse 1933

ERICIPITES sp. (?).

Plate 29, fig. 42.

Remarks: Wodehouse (1933) described two pollen grains from the Green River formation which appear to be very closely allied to the two grains found in the Princeton material. The writer cannot say anything which has not been previously stated by Wodehouse.

Family CARYOPHYLLACEAE (?)

Genus (?)

Plate 29, fig. 43.

Diagnosis: Spherical, ca. 36 - 38μ in diameter; cribellate with the pores roughly spherical and not marked by a marginal rim. The pore area is flecked with numerous granules. The exine is reticulate to granular.

Remarks: Unlike the Caryophyllaceae they lack the distinct border around the pores. In this respect they are very similar to Liquidambar. The reticulate pattern of the exine is not characteristic of Liquidambar.

These specimens are rare as only three were observed.

Genus PISTILLIPOLLENITES Rouse 1962

PISTILLIPOLLENITES MCGREGORII Rouse 1962

Plate 29, fig. 44 - 46.

Remarks: The Princeton samples are identical with those described by Rouse (1962) from the Burrard formation. Observations on several grains suggested that the apertures were simple, short (2 - 3μ max.) areas of thinning next to one of the club-shaped papillà. Further, there is a suggestion that the papillae may be arranged in a definite pattern, forming a series of parallel lines rather than a cluster. A single tetrad with three of the grains still in contact was observed. A cluster of grains measured 160μ in length, (Plate 29, fig. 46) and contained at least 30 pollen grains.

Sub Division MONOCOTYLEDONIDAE

Order NAJADALES

Family POTAMOGETONACEAE

Plate 29, fig. 47 - 49.

Diagnosis: Grains ca. 27μ; spheroidal with a single depression (monocolpate) which gives the grain the appearance of having been flattened on one side. The exine is reticulate with a more or less beaded appearance.

Remarks: Pollen grains of this type resemble some Potamogeton species, but still retain a sufficient degree of difference to cause hesitation in assigning them to that genus. The resemblances suggest that they may belong to a species not present in the modern preparations, or at least to a very closely related plant. It is for this reason that the grains have been referred only to the family. This grain appears to be very similar to P. perfoliatus as described by Erdtman (1943, p. 63).

Order PENDALES

Family SPARGANIACEAE

Genus SPARGANIUM (Tourn.) L.

SPARGANIUM sp.

Plate 30, fig. 1 - 2.

Diagnosis: Grains spherical to sub-spherical; 24 - 30μ in diameter; exine reticulate with a mesh diameter of ca. 1 - 2μ. The fossil grains frequently have an irregularly shaped area where the exine is partially or wholly disintegrated. This appears to be an area of thinning for the germ pore.

Remarks: The grains are fairly common. The smaller grains occasionally show a small trilete mark, the rays of which extend about 1/2 the distance to the equator. A comparison of the surface texture of the trilete and alete grains leaves little doubt that the grains are borne by at least very closely related species. It is suspected that those showing the trilete are immature specimens. This conclusion is supported by the fact that the trilete mark is restricted to the smaller grains. The possibility of having two species cannot be eliminated.

The pollen of Sparganium resembles pollen grains described here as belonging to the family Potamogetonaceae. The open reticulate pattern of Sparganium compared with the distinctly pebbly appearance of the Potamogetonaceae microfossils, makes the differentiation easy.

Order PRINCIPES

Family PALMACEAE

Genus SABAL Adamson 1763

SABAL GRANOPOLLENITES Rouse 1962 (?)

Plate 30, fig. 3.

Remarks: While the specimen found at Princeton is very similar to the grain described by Rouse (1962), it is assigned to that genus with some reservations. A single specimen only was found at Princeton.

ALGAE

That the following belong to the algae is uncertain. They have been assigned to this group with many misgivings. However, the closest comparative material appears to be with the algae. The use of modern generic names for several of these forms is not meant to imply complete identification, but only to suggest botanical affiliation.

Division CHLOROPHYTA

Family MESOTAENIACEAE

Genus GONATOZYGON DeBary 1856

Plate 30, fig. 4.

Diagnosis: Filament at least ten times as long as broad; circular in cross-section. The wall is densely papillate and thick (ca. 2μ). The transverse wall is perpendicular to the main body wall. The papillae are 1½ - 2μ in length. Only a single specimen was observed, which measured 150 x 15μ.

The above description compares favorably with the median layer of the cell wall of Gonatozygon as described by Smith (1950).

Genus BOTRYOCOCCUS Kutzing 1849

BOTRYOCOCCUS sp. (?)

Plate 30, fig. 6 - 14.

Diagnosis: 20 - 50μ in length and of variable width (length:width = ½:1 to 1:1). The body shape is that of a dumbbell. The constriction angle varies from acute (30°) to obtuse (160°). The body wall is smooth to roughened and seldom punctate. Those cells with the roughened walls appear to be made up of a series of overlapping elongate hexagonal (?) plates. The apex of these cells is normally ragged, whereas those with smooth outer walls are terminated with a symmetrical curve. A partial or complete wall separates the two ends of the dumbbell. This phenomena is very similar to the cross walls of some desmids. A dark cross bar projects perpendicularly to this cross wall. In some instances the constriction appears to be much like one would get by inflating a balloon and then pinching it at the equator. In other instances it appears to be related to a pore (?) which connects the two semi-cells (partial wall development between two related cells), and may represent an opening which originally connected the two semi-cells. A variation was observed in which two cross bars were present. In this case the bars were oriented at 90° to each other, and 45° to the cross wall.

Remarks: These fragments are very common in the roof shales of the Princeton Black Coal zone on the south side of the Tulameen River. It is noteworthy that where they are present, spores and pollen are extremely rare.

The variation in form and texture with little or no transition between them suggests to the writer that at least two genera are involved: (a) those with the smooth outer wall, and (b) those with the wall made up of overlapping plates. This suggestion is further supported by the way in which the cells divide. In the case of the smooth walled specimens (a), a mother cell undergoes division to produce four daughter cells. These cells initially are in a single plane, but with further development the cells on the diagonals fuse, with a corresponding shift into two planes (see Plate 30, fig. 10).

At this stage or shortly thereafter, the mother cell wall breaks down and the two dumbbell shaped individuals become separated (Plate 30, fig. 10). In the case of those with the roughened platy walls (b), the sequence of development cannot be as easily demonstrated. However, it appears that following the four cell divisions producing the daughter cells, the fusion is not across the diagonals, but rather side by side. The end result is that the four daughter cells remain in the same plane until the disintegration of the mother cell wall. This latter type of division is similar to the division described for Botryococcus and is the main reason for suggesting that this is possibly a fossil representative of this genus. Botryococcus has been identified in the fossil form by a number of writers: Blackburn and Temperly (1936), Cookson (1953), Jeffrey (1910), Rao and Misra (1949), Traverse (1955), Vimal (1953).

A more complete reconstruction seems to be possible with the material available. It is the writer's intention to attempt this at a future date.

Division CHLOROPHYTA

Class CHLOROPHYCEAE

Order CHLOROCOCCALES

Family HYDRODICTYACEAE

Genus PEDIASTRUM West and Fritsch 1932

Cf. PEDIASTRUM KAIJAITES Wilson and Hoffmeister 1953

Plate 30, fig. 15.

Remarks: The Princeton material is much smaller than *P. kaijaites*, although it resembles this species closely in other features. This form is known only from a single specimen. It is 23 - 24μ long; contains 12 or more coenocytes which are distinctly bean-shaped and about 8 - 9μ in length.

Cf. PEDIASTRUM PALEOGENEITES Wilson and Hoffmeister 1953

Plate 30, fig. 16.

Remarks: The walls of this alga (?) are too highly corroded to reconstruct anatomical details. They superficially resemble P. paleogeneites. The observed size range for the Princeton material was from 50 - 70μ although fragments of what must have been much larger coenobia were found.

This alga (?) is rare, and is in an extremely poor state of preservation.

Genus ALTERNOSEPTITES Rouse 1962

ALTERNOSEPTITES sp.

Plate 30, fig. 17.

Diagnosis: Elongate series of unbranched (?) rectangular cells which are almost square, ca. 12 - 14μ along the side; filament parallel sided with only a slight constriction at each cross wall; cross wall perpendicular to outer wall, two-layered with every second wall perforate. The perforate walls tend to be triangular, but this may be a compression phenomena.

Remarks: These filaments are rare in the Princeton sediments. They resemble the previously described species of Brachysporium in the triangular nature of the perforate walls. They differ in that their cross walls are only alternately perforate, while in Brachysporium every wall is perforate. They differ also in the varying thickness of the cross walls of Brachysporium. Further, the shape is so different that there is little doubt but that they belong to a different genus.

Rouse (personal communication) has found similar filaments from the Burrard formation and has proposed the name Alternoseptites.

FUNGI

Genus BRACHYSPORIUM Barnett 1955

Cf. BRACHYSPORIUM sp.

Plate 30, fig. 18.

Diagnosis: Conidia dark, 3-celled (?), with a somewhat flattened apex; tapers to the point of original attachment to the conidiophore; ca. 26 x 12μ; walls heavy, ca. 2μ; cross walls (2) ca. $2\frac{1}{2}$ - 3μ. The texture is striate-granular.

Remarks: Only a single conidia of this type was observed in the Princeton material.

Genus Cf. TRICHOTHECIUM Barnett 1955

Plate 30, fig. 19.

Diagnosis: Two-celled with the apical cell large and bulbous;hyaline; outer wall 1μ or less thick. The cross wall is ca. 2μ and normally is marked by a slight constriction in the outer wall.

Cf. W_{29} Rouse 1962

Plate 30, fig. 20 - 25.

Remarks: There is a wide range of form in this fossil. There is no doubt, however, that they all belong to the same genus. They are characterized by their multicellular nature, single germinal pore; an expanding nature so that the apical cell is the largest; cross walls becoming progressively thicker towards the apex; all walls hyaline to dark. They are frequently hook-shaped. The germinal pore is of variable width, suggesting that detailed work may show that more than a single species is involved. Several were observed with a hyaline sheath which characteristically did not take the safranin stain.

It is not known whether this actually represents a fungal or algal spore. The high degree of preservation and the abundance of these spores warrant a more detailed study than has been undertaken.

MUSCI (?)

Plate 30, fig. 26 - 27.

Diagnosis: Grains spherical, 22 - 28μ in diameter; inaperturate; entire surface covered by a dense mat of fine hairs which project 2 - 3μ beyond the margins of the grains; wall ca. 1μ.

Remarks: These grains resemble some moss spores described by McClymont (1954) and have tentatively been assigned to that order. Further studies are hampered by lack of modern moss spores for comparison.

INCERTAE SEDIS

Genus DELTOIDOSPORA Miner 1935

DELTOIDOSPORA sp.

Plate 30, fig. 28.

Diagnosis: Grains 30 - 34μ; trilete, laesurae extending to the corners, open or marked by a well defined fold. The corners are only slightly rounded and are characterized by a thickening of the exine. The sides of the triangle tend to be concave. The texture is psilate. Grains are sometimes split along the trilete.

Remarks: While these grains are distinct and are readily recognizable in the fossil form, they cannot be assigned definitely to a modern genus. They appear to be closely allied to either *Gleichenia* or *Pteridium*.

DELTOIDOSPORA sp.

Plate 30, fig. 29 - 30.

Diagnosis: Grains 20 - 26μ, trilete with the laesurae smooth or ragged, extending almost to the periphery; the corners of the triangles are rounded; the wall is ca. 1μ thick; psilate.

Remarks: This is similar to the preceding species. It differs in a number of respects (i.e. rounding of corners, size, and the detail of the laesurae). It is of unknown modern affiliation and the writer has not been able to correlate it with any previously described fossil.

DELTOIDOSPORA sp.

Plate 30, fig. 31.

Remarks: This fossil is known from only a single specimen. It is characterized by the sides forming almost a perfect equilateral triangle; trilete with the laesurae strap-like and extending to the equator where they form a notch in the corners. The wall is ca. $1\frac{1}{2}\mu$ thick, psilate to finely granular.

This specimen is similar to D. microforma, Rouse (1962).

DELTOIDOSPORA sp. (?)

Plate 30, fig. 32 - 34.

Diagnosis: Size ca. 45μ, rounded triangular; trilete with laesurae well defined and extending more than 3/4 the distance to the equator. Two wedge-shaped parallel folds extend along the distal surface of the grain. The wall is thin (less than 1μ), psilate to levigate.

Remarks: Pollen of this type is sufficiently common to recognize that it is a distinct type. Occasionally one of the folds is much shorter and narrower than the other. (Plate 30, fig. 34.) While the folds may not be a feature of the original grain, they most certainly reflect some consistent weakness in the wall. Modern affiliations are not known to the writer.

Genus DIPORITES van der Hammen 1956

DIPORITES sp.

Plate 30, fig. 35.

Diagnosis: Pollen grains elongate, fusiform; with two diametrically opposed costate pores; pores elongate and projecting well into the wall; wall ca. $1\frac{1}{2}\mu$, smooth; size ca. 36μ.

Remarks: This differs from the following species in size and the shape of the pore.

DIPORITES sp.

Plate 30, fig. 36 - 37.

Diagnosis: Grain size 60 - 65μ(?); elongate, fusiform, two pores diametrically opposed, costate, and shallow. The wall is ca. 1 - $1\frac{1}{2}\mu$ thick and smooth.

Remarks: Both species of Diporites observed at Princeton are rare. Two-pored pollen grains are known in the modern families Liliaceae, Onagraceae and Proteaceae.

Genus TRICOLPOPOLLENITES Thompson and Pflug 1953

TRICOLPOPOLLENITES sp.

Plate 30, fig. 38 - 39.

Diagnosis: Tricolpate with colpae extending almost to the poles; prolate; size ca. 27 x 16μ. Exine distinctly granular under oil immersion but appearing smooth under hi-dri; wall thickened towards the colpae.

Remarks: This pollen grain is rare and may represent a compressional form of Acer.

TRICOLPOPOLLENITES sp.

Plate 30, fig. 40.

Diagnosis: Grains 25 - 35μ; subspherical; tricolpate, with colpae short and poorly developed. Exine 1μ or less thick, smooth to fine granular.

Remarks: The pollen grain bears some resemblances to Cercidiphyllum, but cannot definitely be assigned to that genus at this time. Pollen grains of this type are rare unless some of the grains that appear to be alete actually belong to this species.

TRICOLPOPOLLENITES sp.

Plate 30, fig. 41.

Diagnosis: Grains small (ca. 20μ), tricolpate with colpae extending about 3/4 of the distance to the poles. The exine is thick (ca. 1½μ) and exhibits a faint reticulate pattern.

Remarks: This grain resembles that of Salix sitchensis. As only a single grain of this type was seen, it has been referred to Tricolpopollenites until further comparisons can be made.

TRICOLPOROPOLLENITES Thompson and Pflug 1953

TRICOLPOROPOLLENITES sp.

Plate 30, fig. 42.

Diagnosis: Grains ca. 22 x 16μ; tricolporate; prolate; wall ca. 0.5μ granular to faintly reticulate under oil immersion; colpae broad and extending almost to the poles; pores well defined.

Remarks: Except for small differences in the pore, this grain is identical with the pollen of *Cornus mas*. There seems little doubt that the specimens belong to *Cornus*, although further work will have to be done before this can be decided.

TRICOLPOROPOLLENITES sp.

Plate 30, fig. 43.

Diagnosis: Tricolporate, with the colpae broad, open, and extending almost to the poles. The pores are equatorially located and indistinct. The grains are large (50 - 55μ) and prolate. The exine is thick (1$\frac{1}{2}\mu$). The areas between the colpae are coarsely reticulate, becoming progressively finer towards the colpae. The colpae are smooth to fine granular.

Remarks: Only two specimens of this type were observed, and they both occurred in shales underlying the Princeton Black Coal seam on the south side of the Tulameen

River.

TRIPLANOSPORITES Thompson and Pflug 1953

TRIPLANOSPORITES sp.

Plate 30, fig. 44 - 45.

Remarks: These specimens can undoubtedly be referred to the genus <u>Triplanosporites</u>, but neither the species nor its modern affiliations can be suggested at the present time.

Genus INAPERTISPORITES van der Hammen ex Rouse 1959

INAPERTISPORITES ELONGATUS Rouse 1962

Plate 30, fig. 46.

Remarks: Spores of this type are fairly common among the fungal elements of the Princeton material.

INAPERTISPORITES sp.

Plate 30, fig. 47.

Diagnosis: Sub-spherical, ca. 4μ in diameter, inaperturate (?) and dark in color. Its surface is smooth.

Remarks: The texture, color and heavy wall suggest that it is a fungal spore.

INAPERTISPORITES sp.

Plate 30, fig. 48 - 49.

Diagnosis: Inaperturate; spherical ca. 8 - 16μ; exine covered by dense granulations; dark in color.

Remarks: The specimen is similar to some of the fungal spores illustrated by Barnett (1955; 1960).

INAPERTISPORITES sp.

Plate 30, fig. 50.

Diagnosis: Grain elongate ca. 54 x 22μ; hyaline; wall psilate to levigate and irregularly thickened. Wall thickness varies from 2 - 4μ.

Remarks: This specimen is readily recognized by the irregular thickening and thinning in the wall. Only a single specimen was observed. It is of unknown affiliations.

INAPERTISPORITES sp.

Plate 30, fig. 51 - 52.

Diagnosis: Spherical (?) ca. 14 - 18μ in diameter, with the entire surface covered by a coarse reticulation.

Remarks: Except for size, this grain is similar to Lycopodium reticulumsporites, Rouse (1959).

Genus INAPERTUROPOLLENITES Thompson and Pflug 1953

INAPERTUROPOLLENITES sp.

Plate 30, fig. 53 - 54.

Diagnosis: Grains spherical to subspherical; 20 - 30μ in diameter; inaperturate; wall levigate ca. 0.5 - 1μ thick. The entire surface is covered by a series of small, irregular folds.

Remarks: These specimens resemble another species of *Inaperturopollenites* suggested as possibly *Chamaecyparis*. It is possible that this grain is simply a much folded *Chamaecyparis* pollen.

The use of spores and pollen as a geological correlation tool is rapidly finding its place. Of the approximately one hundred types identified in this study, the following are easily recognized and occur in sufficient numbers to indicate that they may eventually be used for correlation:

Sphagnum sp.
Osmundacidites primarius
Osmundacidites sp.
Laevigatosporites ovatus
Laevigatosporites discordatus
Laevigatosporites gracilis
Laevigatosporites albertensis
Anemia poolensis
Azolla primaeva (micro and megaspore)
Ginkgo sp. - *Cycadopites follicularis*
Larix plicatipollenites
Tsuga veridifluminipites
Tsuga sp.
Pinus spp.
Picea spp.
Metasequoia papillopollenites (rare)

Taxodium hiatipites (?) (*Libocedrus*)

Alnus quadrapollenites

Alnus quinquepollenites

Betula claripites

Carpinus sp.

Carya sp.

Pterocarya sp.

Tilia crassipites

Salix spp.

Acer spp.

Pistillipollenites mcgregorii

Sparganium spp.

Alternoseptites sp. (rare)

Brachysporium sp. (?)

Diporites spp.

Triplanosporites sp.

Inapertisporites globossus and similar species have not been included as readily recognizable fossils because of the wide range of size and the inability of the present writer to subdivide them on any feature other than size. It is recommended that the total size range be recorded. Once large populations are available from several localities, it may be possible to subdivide them on more than simply an arbitrary size range, or possibly sort out size frequencies which may indicate distinct species.

The stain reaction of the various types of pollen grains to safranin is varied. It was noted that while some take the dye readily, others are unaffected. For example, grains of *Pinus* sp. are usually deeply stained, while *Anemia poolensis* characteristically does not stain. The explanation of this phenomena is not known. Two possible explanations are: (1) the thicker wall of the pine pollen takes up more stain than the thinner wall of *Anemia*; and (2) there is a slightly different chemical composition of the walls of the various spore and pollen types.

The possibility of varying composition of the wall presents itself as a possible tool for the practicing palynologist. While it is beyond the scope of this study, it is suggested that the chemistry of the spore and pollen wall be more fully investigated, together with the possibility of the application of stains to detect differences in chemical composition if indeed they exist.

In the preceding study, the size range of microfossils has been obtained by measuring a number of isolated individuals. In the cases of *Acer*, *Sparganium* and *Osmundacidites*, two species of each have been postulated on the basis of size differences. This does not take into account immature individuals. There is no known method of determining an immature individual, and there is always a question of the validity of a species if only small differences in size exist. A worthwhile contribution to palynology would be to treat individuals of a modern species at several stages in their development in order to outline changes as they occur.

Pollen grains such as *Anemia poolensis*, *Cycadopites follicularis*, *Sphagnum* sp., *Alnus quadrapollenites*, *Alnus quinquepollenites* (cf. Wodehouse *Alnus speciipites*), *Laevigatosporites albertensis*, *L. discordatus*, *L. gracilis*, *L. ovatus*, and *Pinus* spp. are known from a number of localities. Comparison and assignment to the genera and species are based (for practical reasons) on photographs and written descriptions. A series of misidentifications on the part of a single investigator may lead to erroneous conclusions. It is felt that there is a strong need for detailed and monographic comparisons of such grains, and that future investigators should undertake such a project.

With the rapidly increasing amount of data available to the research worker, a study of the paleoclimate is a desirable feature of any microfossil study. It is the impression of the writer that the Princeton paleoclimate was warm to cool temperate. This statement is based not on a detailed study of the flora involved, but on a limited distribution study of only a few genera. In order to come up with more than a suggestion or an impression of the climate, it would be necessary that the various fossils be related to their closest known modern counterpart, and then using the distribution of these, postulate the paleoclimate. The basic assumption is that the fossils are definitely ancestors of the modern species and that they required a similar habitat. Such a study is beyond the scope of this report.

While one of the basic purposes of this study was to provide a microfossil assemblage for geological correlation, it is also beyond the scope here to perform such a correlation. It will, however, be the subject of a future paper by the writer.

Microfossil zonation can be clearly demonstrated with the Princeton material. The reasons for this zonation are not known at the present time, but it may be due to one or a combination of the following: (1) changes of environment, (2) evolution of a flora in a given area. It is here suspected that zonation is primarily influenced by ecology. The zonation is of interest for correlation purposes because a single sample is not representative of the whole flora. Unfortunately the subject of zonation cannot be dealt with adequately at the present time, and will be referred to future work planned by the writer.

PART V

SUMMARY AND CONCLUSIONS

GLACIATION

In addition to the lakes on the Similkameen River (Mathews, 1944) ice dammed lakes were formed on the Tulameen River, Whipsaw Creek and Granite Creek. It is postulated that in the initial stages, these lakes drained southward, but with the retreat of the ice, that outlet channels were replaced by more northerly outlets until the present drainage pattern was established.

STRATIGRAPHY

The Princeton Group is made up of three formations, the Lower Volcanic Formation (oldest), the Upper Volcanic Formation and the Allenby Formation (youngest).

STRUCTURE

The Princeton coalfield is a composite basin made up of two related synclinal basins separated by an anticline which crosses the basin about one mile north of Princeton.

ENVIRONMENT AND SOURCE OF SEDIMENTS

It is almost certain that the Allenby Formation is of fluvio-lacustrine origin. The direction of the paleocurrent was from north to south, parallel to the long axes of the present Princeton coalfield. The writer envisages an environment not unlike that suggested by Shaw (1952), of a meandering river with numerous bordering oxbow lakes and swampy areas which supported a lush vegetation.

The northern source of the sediments may explain the distribution of coal in the coalfield. The currents coming from the Osprey Lake Intrusion, on entering the Princeton coalfield, probably suffered a sudden decrease in velocity, resulting in the deposition of the coarser material. This rapid accumulation of coarse debris would tend to make and prevent large accumulations of organic debris, while to the south the river was slower and carried finer debris.

Thus, in the early stages, accumulations of organic debris took place in the southern half of the area. As time progressed, the coarse debris advanced further and further southward, eventually encroaching on the swamps and oxbow lakes and covering the accumulations of organic debris with coarse sandstones and granule conglomerates. According to Shaw (1952) coal accumulation occurred late in the history of the coalfield, and the coal seams are underlain by much coarse debris. From the present studies, it appears that while the coal seams are underlain by some detrital material, the greatest accumulations of sandstones and granule conglomerates occur above the coals. Those coarse clastics underlying the coal are derived principally from the adjacent areas in the form of talus, with some arkosic sediments brought into the area from the north.

MICROPALEOBOTANY

In the Princeton sediments, spores and pollen are very well preserved. The shales, however, are generally too friable for the satisfactory collection of plant macrofossils. While several localities provide excellent specimens, at many only fragments are found, and these normally crumble if handled, or if they are exposed to the atmosphere. The friable nature of the sediments lends itself well, however, to the recovery of spores and pollen. In the case of the Princeton coalfield, spores and pollen far outnumber the macrofossils and provide a more complete picture of the flora at that time. In addition, spores and pollen of most species are usually found in large numbers.

Ninety-three plant microfossils were studied. Of these, fifty-three can be assigned to modern genera, thirty to form genera (some of suspected modern affiliations), four to family, one to an order, and five are unidentified. About forty of these spores and pollen are easily identifiable and occur in sufficient numbers to indicate possible use in geological correlation. Several specimens are considered identical with specimens from the Burrard Formation, Green River Formation, and the Fort

Union Formation.

The potassium-argon age (Rouse and Mathews, 1961) of Middle Eocene, and the presence of trogosine tillodont remains (Russell, 1935; Gazin, 1953) are considered by the writer to clearly indicate a Middle Eocene age for the Princeton coalfield. The plant microfossils described in the text are from about 1000 feet of strata which encompass the two horizons from which age data were obtained. It is, therefore, suggested that the microfloral assemblage herein described may serve for geological correlation to other Tertiary basins in British Columbia from which potassium-argon dates have not been obtained.

With the present knowledge of the plant microflora of Middle Eocene age, it would be possible to make a climatic analysis.

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PLATE 25

Fig. 1 - 2	*Brachysporium* sp.
3	*Desmidiospora* sp.
4 - 5	*Inapertisporites* sp.
6	*I. globossus*
7 - 8	*I. laevigatus*
9 - 11	*Sphagnum* sp.
12	*Inaperturopollenites* sp.
13 - 15	*Osmundaeidites* sp.
16	*Osmundacidites* sp.
17 - 18	*Botrychium*
19 - 20	*Laevigatosporites albertensis*
21 - 22	*L. discordatus*
23	*L. gracilis*
24 - 25	*L. ovatus*
26	Polypodiaceae
27	*Lygodium* sp.
28 - 32	*Anemia poolensis*
33	*Azolla primaeva* (glochidia of)
34	*Anemia* sp. (?)
35 - 36	*Azolla primaeva* microspores

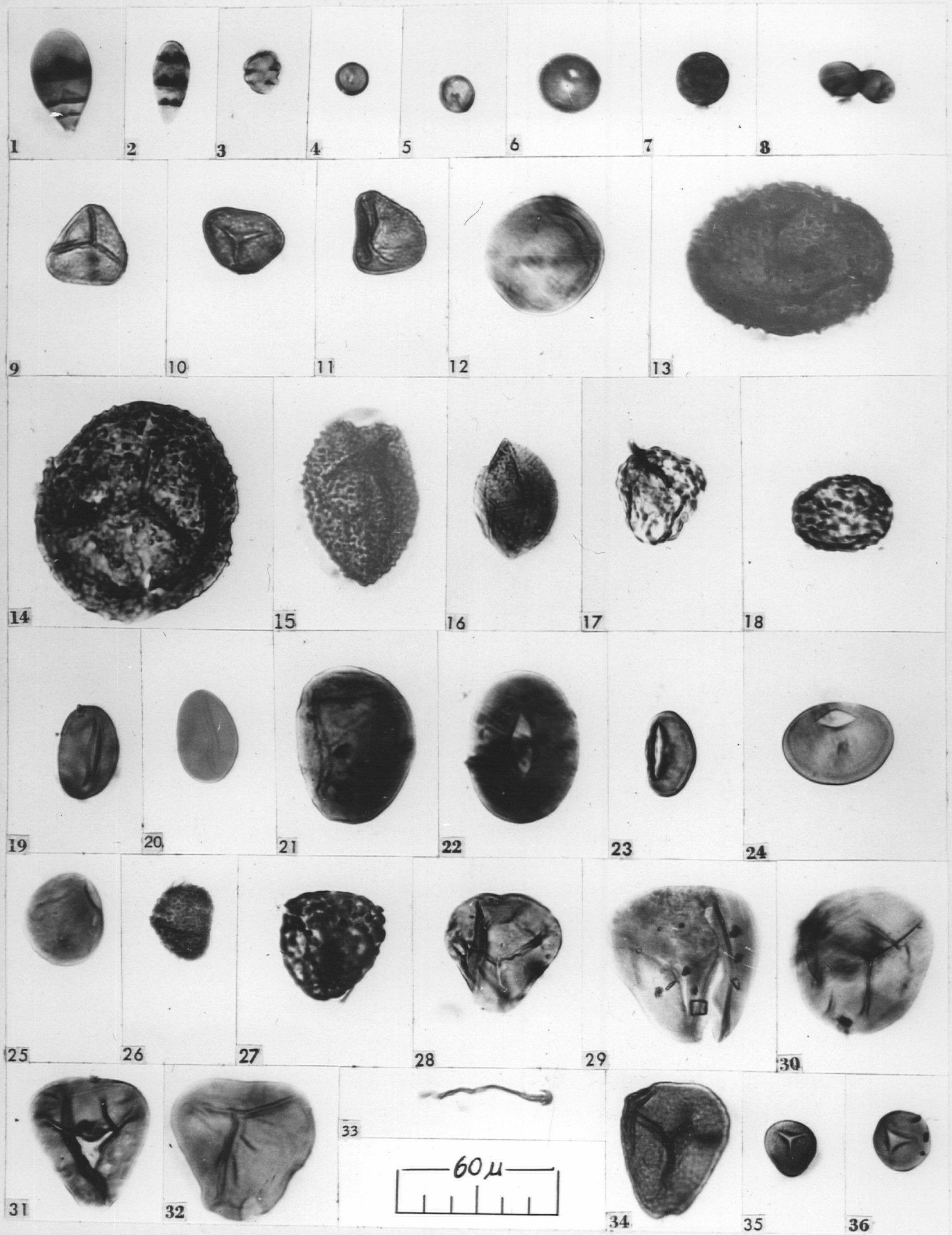
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PLATE 26

Fig. 1 - 2	*Azolla primaeva* microspores
3	Massulae
4	Arrangement of microspores in microsporangia
5	*Azolla primaeva* megaspore - note the two-layered wall. X 300
6 & 9	Inner wall of *Azolla primaeva* megaspore, X 300, cf. *Magnosporites staplinii*
7 & 8	Immature (?) megaspores. X 300

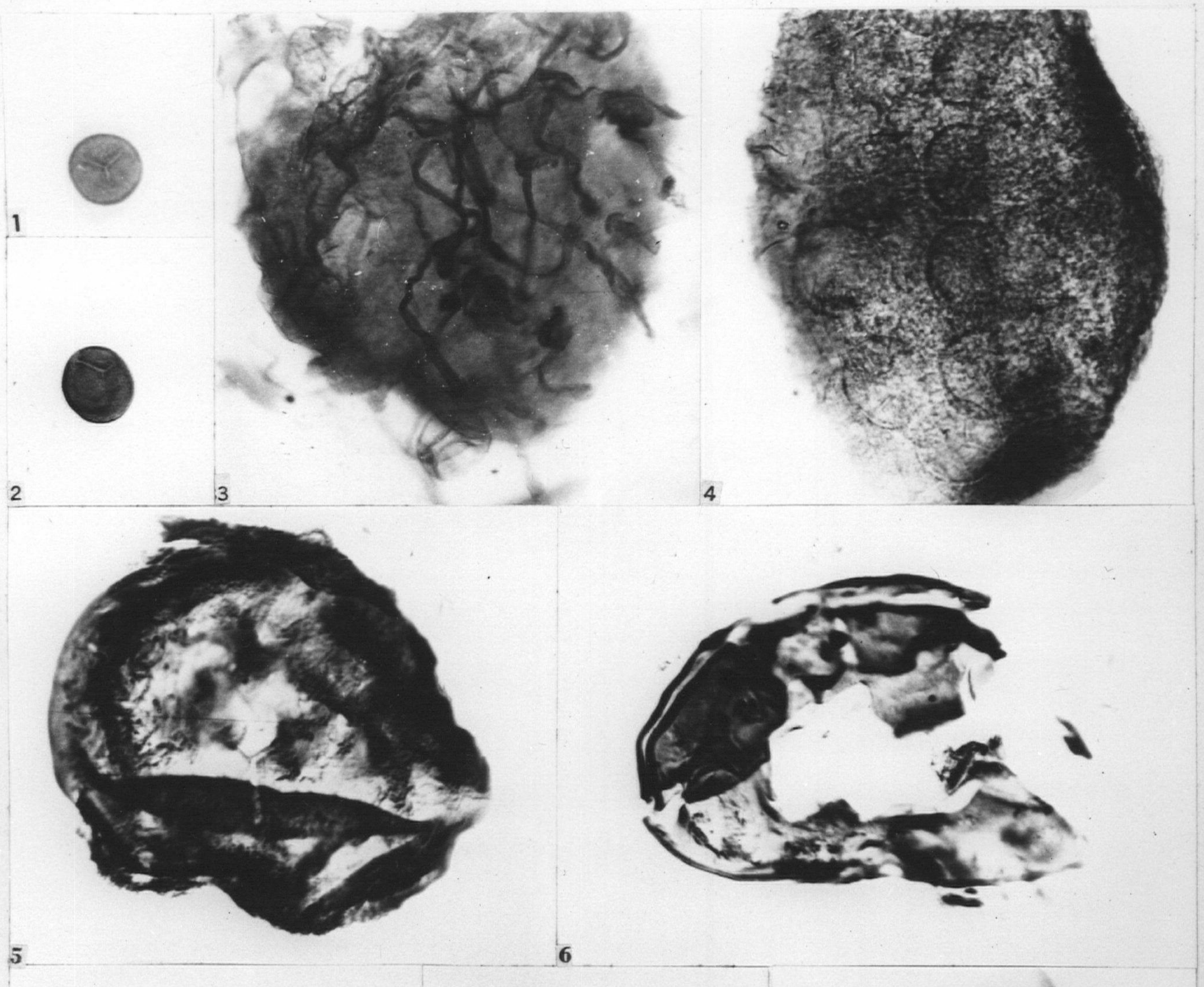
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PLATE 27

Fig. 1 - 3	*Ginkgo* sp.
4	*Larix plicatipollenites*
5 - 10	*Tsuga* sp. cf. *T. pattoniana*
11 - 12	*Pinus* sp. cf. *P. palustris*
13 - 14	*Pinus* sp. cf. *P. contorta*
15	*Pinus tuberculipites*
16 - 21	*P. strobipites*

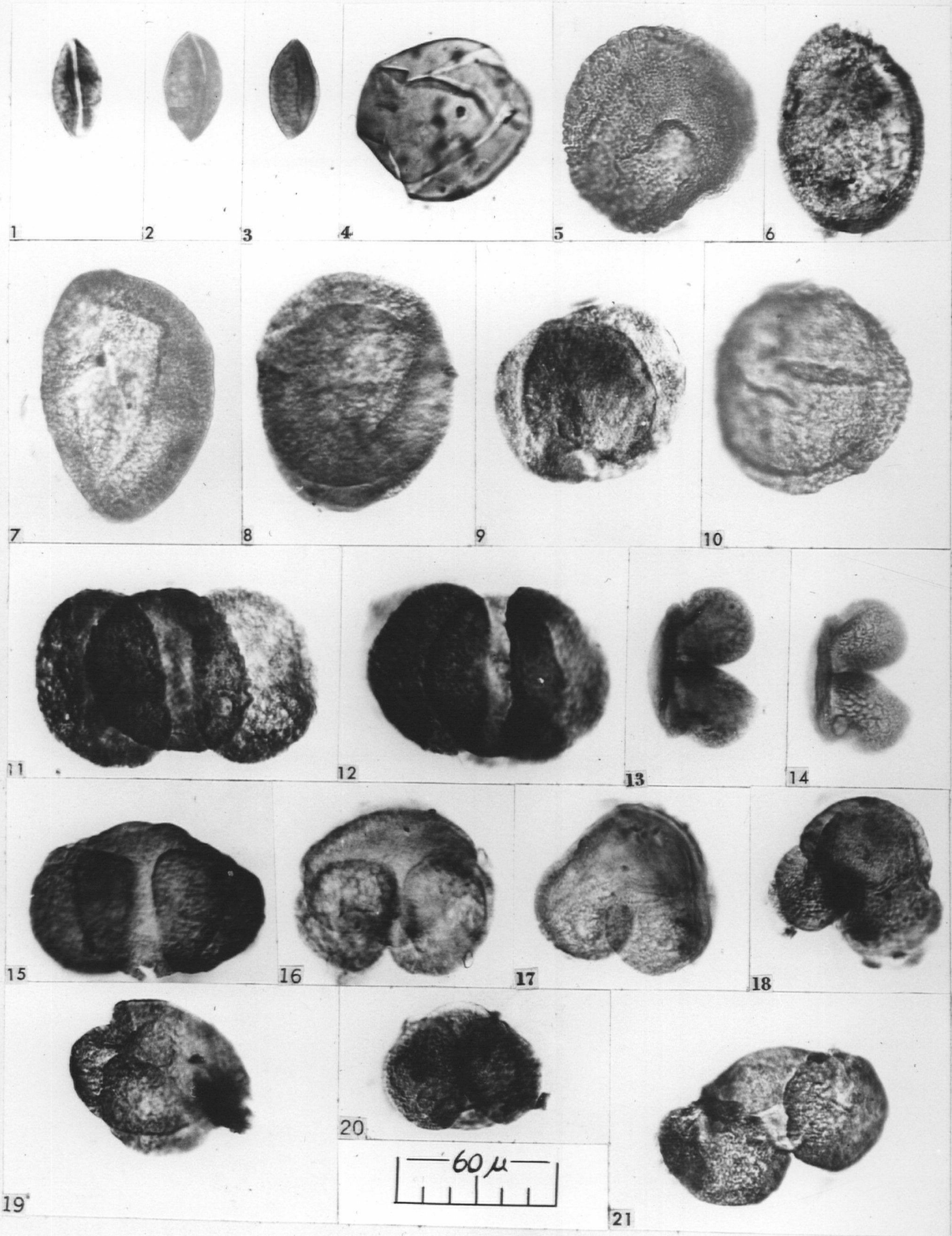
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PLATE 28

Fig. 1	*Pinus tenuextima*
2	*Pinus* sp.
3 - 7	*Picea alipollenites*
8	*Picea* sp.
9	*Picea* sp. (?)
10	*Picea* sp. (?)
11	Coniferales
12	*Podocarpus* sp. cf. *P. nageia*

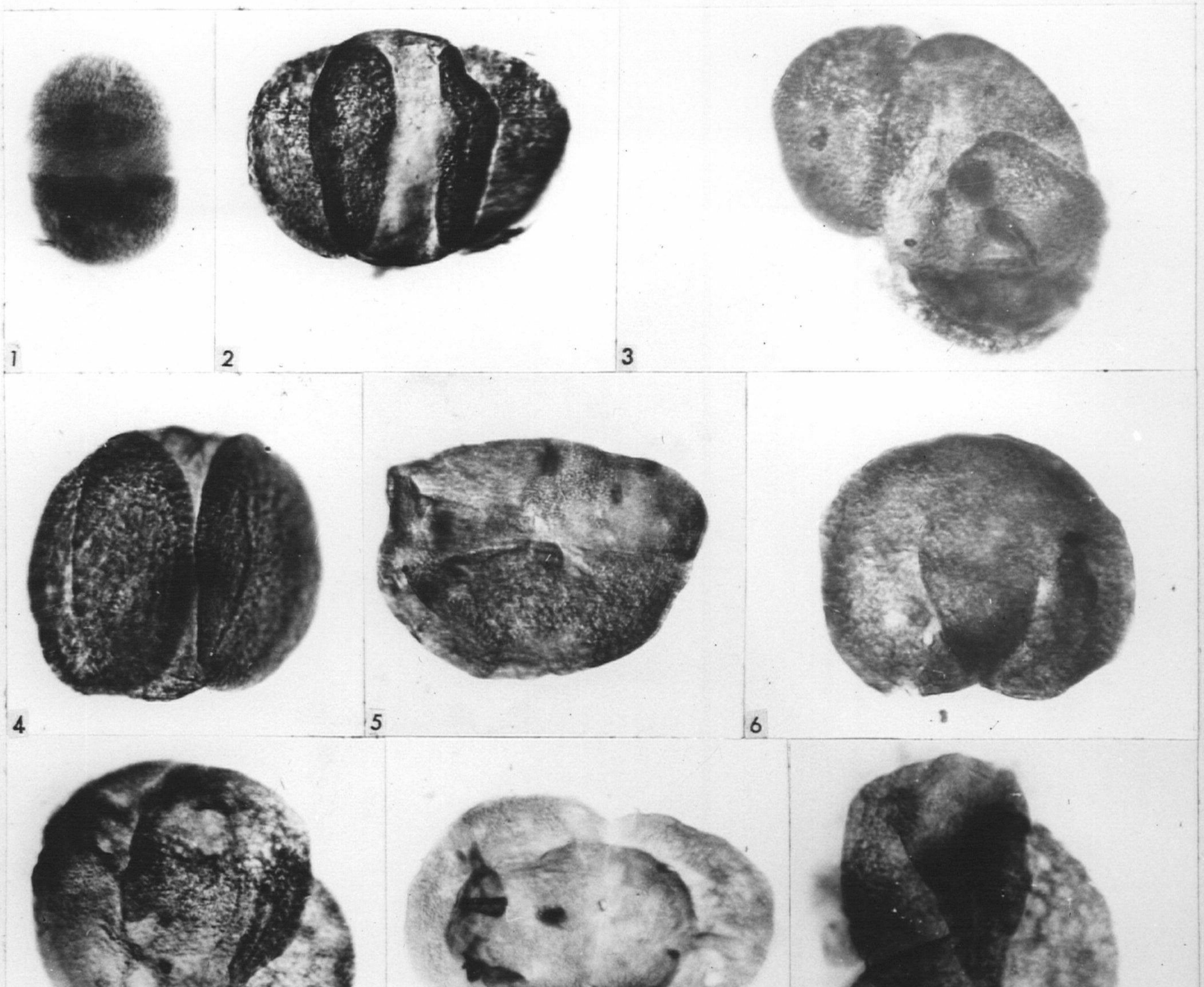
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PLATE 29

Fig. 1	Metasequoia papillapollenites
2	Taxodium hiatipites - see also Libocedrus
3	Sciadopitys sp.
4 - 5	Inaperturopollenites sp.
6	Alnus quadripollenites
7 - 10	Alnus quinquepollenites
11 - 12	Betula claripites
13 - 17	Carpinus ancipites
18	Castanea sp.
19	Carya juxtaporipites
20 - 23	Pterocarya sp.
24	Tilia crassipites
25	Rhamnus sp.
26 - 27	Salix discoloripites
28 - 29	Salix sp. cf. S. hookeriana and S. nigricans
30 - 31	Salix sp.
32	Inaperturopollenites sp.
33 - 34	Acer sp.
35 - 39	Acer sp.
40 - 41	Aesculus sp.
42	Ericipites sp. cf. Ericipites sp., Wodehouse (1933)
43	Caryophyllaceae
44 - 46	Pistillipollenites mcgregorii
47 - 49	Potamogetonaceae

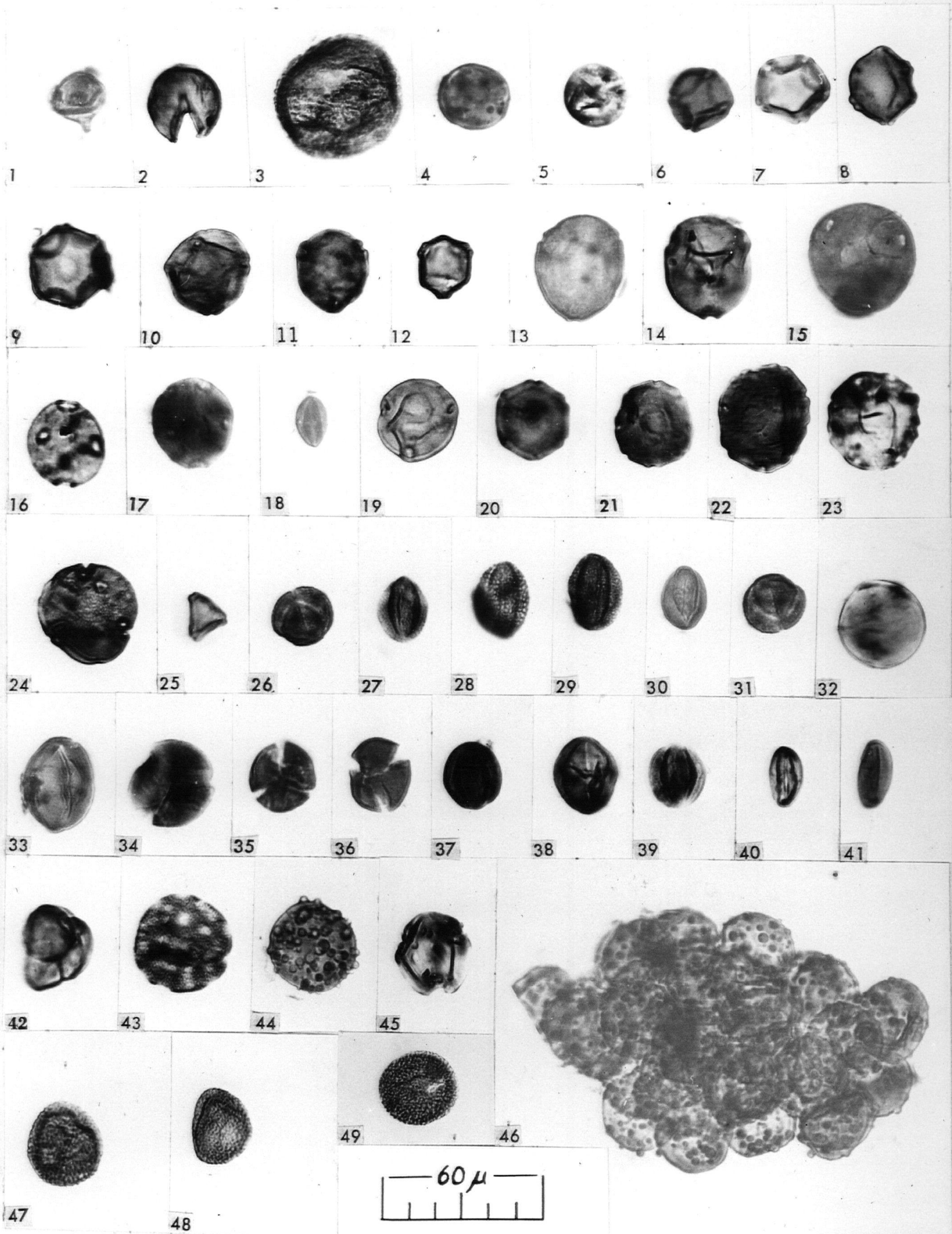
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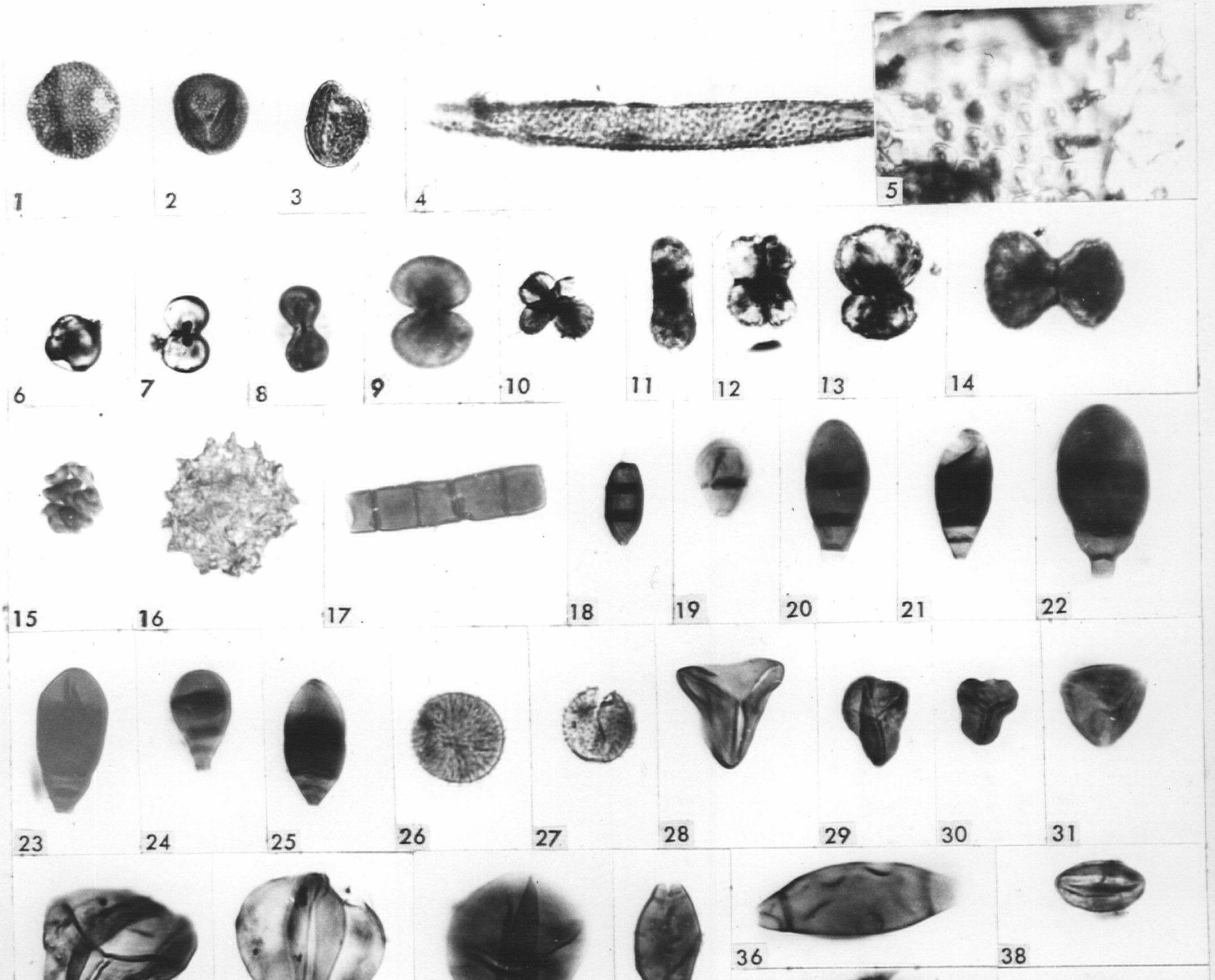
PLATE 30

Fig. 1 - 2	*Sparganium* sp.
3	*Sabal granopollenites*
4	cf. *Gonatozygon* sp.
5	Multiseriate bordered pits
6 - 14	cf. *Botryococcus* sp.
15	cf. *Pediastrum kaijaites*
16	cf. *Pediastrum paleogeneites*
17	*Alternoseptites* sp.
18	cf. *Brachysporium* sp.
19	cf. *Trichothecium* sp.
20 - 25	cf. W_{29}, Rouse 1962
26 - 27	Musci (?)
28	*Deltoidospora* sp.
29 - 30	*Deltoidospora* sp.
31	*Deltoidospora* sp. cf. *D. microforma*
32 - 34	*Deltoidospora* sp.
35	*Diporites* sp.
36 - 37	*Diporites* sp.
38 - 39	*Tricolpopollenites* sp.
40	*Tricolpopollenites* sp.
41	*Tricolpopollenites* sp.
42	*Tricolporopollenites* sp.
43	*Tricolporopollenites* sp.
44 - 45	*Triplanosporites* sp.
46	*Inapertisporites elongatus*
47	*Inapertisporites* sp.

PLATE 30 - cont'd

Fig. 48 - 49	*Inapertisporites* sp.
50	*Inapertisporites* sp.
51 - 52	*Inapertisporites* sp.
53 - 54	*Inaperturopollenites* sp. cf. *Chamaecyparis*
55	unidentified
56	unidentified
57	unidentified
58	Fern annulus
59	unidentified
60	unidentified
61	Stone cell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