

**Some Heavy Mineral Investigations of the
Turner Valley Oil and Gas Field, Alberta.**

by

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Table of Contents.

- (1) Introduction.
- (2) Historical.
- (3) Some Principles Concerning the Problem.
- (4) Description of the Area.
 - (a) Geographic Location
 - (b) Geology
- (5) Object of Investigation.
- (6) Methods.
 - (a) Collection of Material
 - (b) Treatment of Material
- (7) Results of Investigation.
 - (a) Description of Minerals Identified.
 - (b) Description of Formations and their Heavy Minerals.
 - (1) "Ferne"
 - (2) Kootenay
 - (3) Blairmore
 - (4) Benton
 - (5) Belly River
 - (6) Edmonton
 - (7) Paskapoo
- (8) Conclusions.
 - (a) Summary
 - (b) General

Numbers in brackets are references to the bibliography
included in this thesis.

1. Introduction.

In view of the fact that the study of sedimentary petrography has proved to be of considerable aid in solving certain correlation problems, it was decided to begin an investigation into the characteristics of a number of well samples from the Turner Valley Oil and Gas Field of Alberta. The method of attacking the problem has been by the examination of the heavy mineral content of the sediments, one which is rapidly being recognized as important and valuable, in Europe, America, and various other parts of the world.

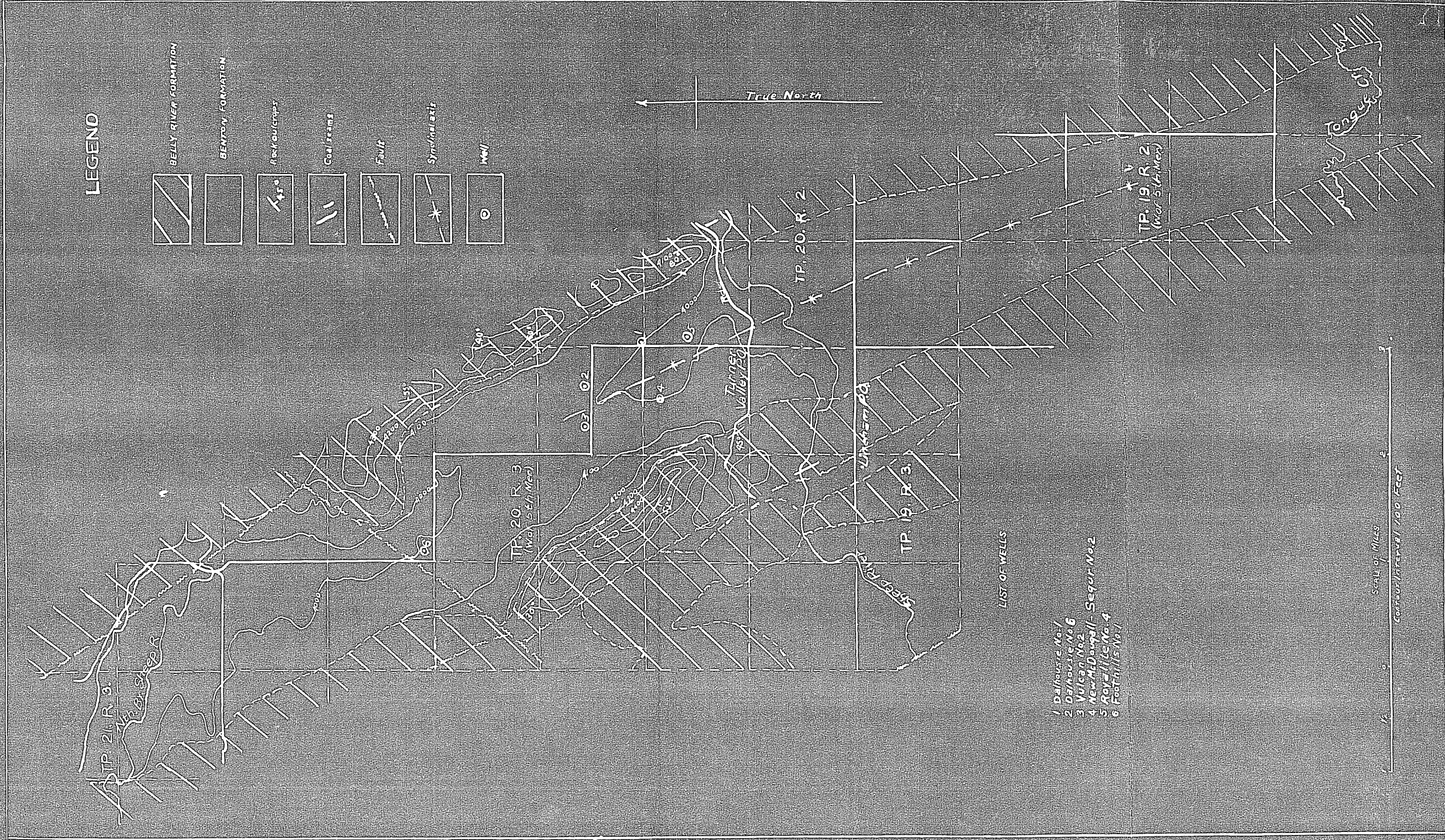
2. Historical.

The application of the microscope to the study of sedimentary rocks was begun in 1851 by H. C. Sorby, a British geologist. In his work he used the thin section and the nicol prism, and in the following years the study was confined chiefly to igneous rocks while sedimentary petrography remained practically unstudied. In recent years however interest in this work has been greatly revived, due largely to the researches of certain British petrographers. Heavy minerals in sediments have and are playing an important part in this study, and such work is being carried out in America, chiefly in connection with the sub-surface correlations of certain oil fields of the United States. An example of the possibilities of such study is the statement by Bailey (15) that twenty nine bore holes of an oil field in California have been successfully correlated by the use of heavy mineral research.

3. Some Principles Concerning the Problem.

In the application of the study of sedimentary petrography to correlation problems it is necessary to bear in mind the following principles:

- (1) Petrographic correlation makes no attempt to replace palaeontological evidence (2) but is rather another weapon of attack when the latter is obscure or lacking.
- (2) The study involves a comprehensive microscopic examination of the component minerals in sedimentary rocks with attention being paid chiefly to the "heavy accessories" (2). Reed defines a heavy mineral as one that will sink in bromoform i.e. whose specific gravity is greater than 2.88
- (3) In correlation there are two applications of the method:
 - (a) The studies of successive horizons in a vertical section followed by (b) an attempt to make a lateral correlation of the various horizons.
- (4) Sediments often change rapidly in both a lateral and vertical direction, more especially in continental than in marine deposits, and for this reason correlations must be confined to relatively small areas. Milner (1) states that for an area of about 400 sq. miles a given mineral assemblage frequently assumes marked consistency in physical, crystallographic, and optical properties, so as to render its differentiation possible from super incumbent or subjacent suites.
- (5) Certain minerals assemblages are suggestive of certain types of rocks, and their recognition is of value in tracing sediments to their source or parent rocks.



Turner Valley Oil Area
Fig. 1

Table of Formations

Age	Formation	Deposit	Depth
Tertiary	Paskapoo	Freshwater	4000 feet
	Edmonton	Brackish water	1300 feet
Cretaceous	Bearpaw	Marine	
	Belly River	Brackish water	1800 to 1900 feet
	Benton	Marine	2500 to 3000 feet
	Blairmore	Land and freshwater (plants)	
	Kootenay	Continental	
Jurassic	Fernie	Marine	400 to 500 feet
Palaeozoic?	Limestones and dolomites	Marine	?

Note: The thickness of the Blairmore and Kootenay may be less than 1000 feet(19).

Although the above summary is by no means complete it serves to show in a general way to what extent correlation is justified by petrographic study.

Description of the Area.

Geographic Location.

The area is located on the extreme eastern edge of the foothills of Alberta, about 30 miles southwest of Calgary. The nearest railway station is Okotoks, 17 miles distant on the C. P. R. line between Calgary and Lethbridge.

Geology.

The structure of the Turner Valley field is an anticlinal fold (19 & 20) indicated by Turner Valley and its continuation southward. The strike of the fold is northwest by southeast as shown on the accompanying map. The crest has been eroded to form a valley up to two miles in width in which the Benton shale is exposed. The overlying Belly River formation forms two parallel ridges on the flanks. Outcrops on the flanks of the structure vary both in dip and strike, the former varying from 30 to 80 degrees.

That the geology of the area is more complicated than indicated by the surface outcrops is being continually demonstrated by information obtained from the study of well samples.

A table of formations occurring in the area , as given by Hume (19) is given on opposite page.

Object of Investigation.

The object of this investigation is to make a petrographic study of the heavy mineral content of a collection of well samples from each formation, and to note the characteristics of each deposit, with a view to correlation.

Collection of Material.

The material used in this work was collected during the summer of 1927, and the writer is indebted to the office of the Department of the Interior at Calgary and to the geological staff of the Imperial Oil Company at Calgary for assistance rendered in the collection of samples.

In a study of samples from deep borings it is necessary to use considerable caution in the recording of results. The reason for this is that samples from standard cable, and rotary outfits are nearly always contaminated with varying quantities of material that has fallen from higher elevations. In the case of rotary samples this occurs to such an extent as to render them practically valueless for correlation purposes. Fairly representative samples may be obtained from standard cable rigs, if all cavings are promptly cased off, and if the driller ~~is~~ is a careful sampler. However the most useful material consists of cores from diamond drill holes or from rotary core barrels, for such samples are truly representative of definite horizons, besides often showing the inclination at which the underground strata is dipping.

In the collection of the material it was not possible to obtain a complete vertical section of the geological column from any one well. The reason for this is that, to date no drill has yet passed through all the formations occurring in the locality. However partial sections were obtained from several of the older deposits while a few odd samples were collected from the younger formations.

All of the material studied has consisted of sandstone samples from wells drilled by standard cable or by diamond drilling outfits. The reason for confining the study to sandstones is that this type of deposit gives better results and is more easily handled than are shales or limestones.

Treatment of Material.

Treatment of material, prior to the identification of the heavy minerals, varies with the different kinds of samples. For instance, in the diamond drill cores examined, a preliminary crushing to about the size of a pea is necessary, before crushing into separate grains in a deep steel or agate mortar. The crushed material is then screened through standard graded screens. If quantitative data is desirable the percentage by weight of each grade and its heavy mineral content can be determined. After screening the sand it is freed from cement coatings on the grains and from rock dust by treating with hot dilute HCl. In many cases the cement coating is not removed from the grains by the use of acid and in such cases the identification of the heavy minerals is rendered more difficult. Again pyrites may occur to such an extent as to obscure the other minerals present, thus necessitating

its removal with hot dilute HNO_3 . In many of the samples examined pyrites has had to be removed in this way. The chief drawback to such treatment however is that it tends to decompose certain other heavy minerals such as apatite, so that they are unidentified though possibly present. If quantitative results are desired the sand is cleaned by repeated washing with cold water, dried and weighed. If quantitative data is not required the cleaned sand may be panned down to three or four grams by water panning, and the remainder of the heavy material can then be separated from the light residue by means of bromoform. About twenty five grams of a sample is usually required to start with, in order to assure a representative assemblage of minerals.

The type of apparatus used consisted of a conical funnel, equipped with a stop-cock, similar to ~~that~~ that described by Holmes(8) and Milner(1). After separation the heavy residue is washed with alcohol, dried, and is then ready for mounting and microscopical examination. Methods of mounting detrital material are outlined in various texts.

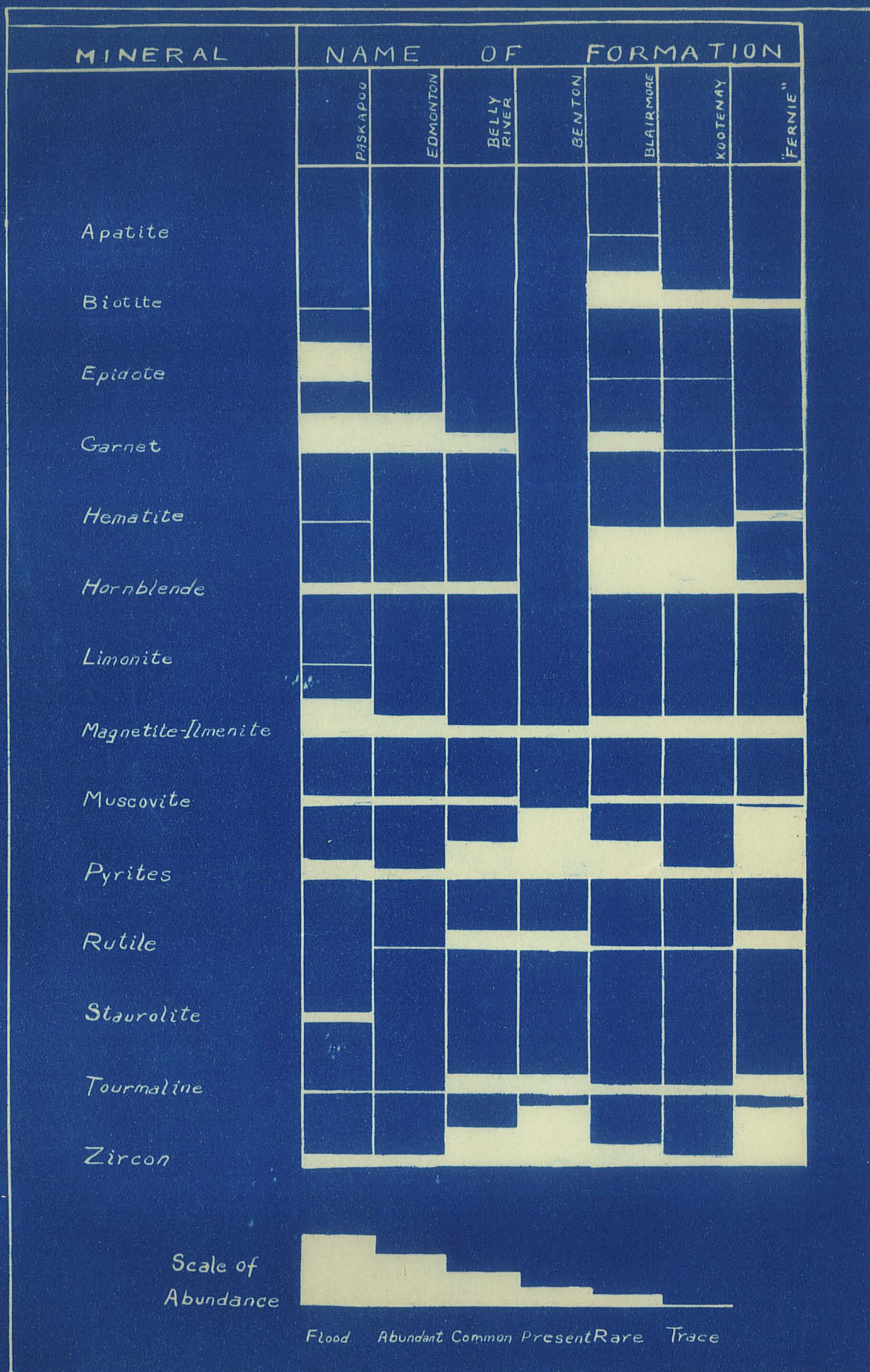
The method of recording the minerals identified and showing their respective abundance is as follows :-

Flood	---	over 50%
Abundant	---	25% to 50%
Common	---	10% to 25%
Present	---	5% to 10%
Rare	---	1% To 5%
Trace	---	less than 1%

Relative Abundance	NAME OF FORMATION						
	"Fernie"	Kootenay	Blairmore	Benton	Belly River	Edmonton	Paskapoo
Flood	Pyrites			Pyrites			
Abundant	Zircon	Amphibole (altered Hornblende)	Amphibole (altered Hornblende)	Zircon			
Common			Pyrites Biotite		Zircon Pyrites	Garnet	Epidote Garnet Magnetite-Ilm.
Present	Tourmaline Rutile Magnetite-Ilm.	Biotite Magnetite-Ilm.	Zircon Garnet Magnetite-Ilm.	Tourmaline Rutile	Garnet Tourmaline Rutile	Magnetite-Ilm.	Pyrites
Rare	Muscovite Hornblende Haematite Biotite	Muscovite Zircon Tourmaline Pyrites	Muscovite Tourmaline	Magnetite-Ilm.	Muscovite Hornblende Magnetite-Ilm.	Zircon Muscovite Hornblende Pyrites	Muscovite Zircon Hornblende Staurolite
Trace	Garnet	Garnet Rutile Epidote	Apatite Epidote Rutile		Monazite	Tourmaline Rutile	Tourmaline Haematite Limonite Biotite

Table Showing Average Relative Abundance of Heavy Minerals
in Each Formation

Fig. 1



Block Diagram Showing Average Relative Abundance of Heavy Minerals in Each Formation

Results of Investigations.

Diagrams illustrating the average relative abundance of the heavy minerals found in each formation are shown in figures 1 and 2.

The following is a list of the minerals identified, with a description of some of the principle characteristics of each mineral.

- Apatite colorless, rounded prismatic grains, low birefringence which along with the refractive index helps to distinguish it from zircon. Traces of basal sections found, confirmed by R. I. test.
- Biotite usually brown cleavage flakes sometimes showing alteration and inclusions.
- Calcite colorless grains with good uniaxial figures, rhombohedral cleavage and high birefringence.
- Epidote pale lemon yellow to colorless grains, usually irregular outline, sometimes showing decomposition. Pleochroism usually good with birefringence high. Some grains give good biaxial figure. Grains often exhibit lemon yellow color in reflected light.
- Felspar grains confined to light residue, not studied in detail.
- Garnet colorless, pale pink and pinkish yellow forms occur. The mineral has a high refractive index, is isotropic, and is nearly always in the form of irregular or angular grains.
- Glauconite believed present in certain sands of the Benton formation but not definitely identified in the heavy residuals.
- Haematite usually rounded opaque grains of earthy appearance with reddish color in reflected light. Sometimes occurs as cementing medium.

- Hornblende found in variety of forms from fresh to highly altered grains. Pleochroism stronger in fresher prismatic forms. Shades of green to brown are common colors while bleached forms due to decomposition are also met with.
- Ilmenite black, opaque grains, usually of irregular form. Difficult to distinguish from magnetite unless by magnetism or by identification of crystal form, and for this reason both are recorded together, as magnetite - ilmenite.
- Limonite irregular opaque grains of earthy appearance showing yellowish brown or cinnamon color in reflected light.
- Magnetite black, opaque grains with metallic lustre, irregular, rounded to well crystallized forms occur, which possess strong magnetic properties. The mineral often exhibits a bluish lustre in reflected light.
- Marcasite fibrous to radiating grains observed which are classed as pyrites.
- Muscovite colorless, rounded to irregular cleavage. Flakes. Usually exhibiting good biaxial interference figure. This mineral is very persistent and of no apparent diagnostic value.
- Pyrites opaque grains with metallic lustre and characteristic brass yellow color in reflected light. The mineral occurs in many forms from irregular massive to euhedral types such as cubes and pyritohedrons.

Pyrites is a very abundant and persistent mineral in most of the Turner Valley samples studied to date, and it is often necessary to remove it with nitric acid. It is often found concentrated in fractures, cavities, shear planes and in the pore spaces between the sand grains. For this reason together with the fact that it is often found in euhedral aggregates while the other associated minerals are well rounded, pyrites is believed to be of secondary occurrence due to precipitation.

Monazite

well rounded, citron yellow colored grains with high refractive index and rough, 'frosted or pitted' surface. Biaxial interference figure. Polarisation colors mainly greyish yellows. The mineral is extremely rare and non-persistent in residues so far studied.

Quartz

occurs in many forms and sizes which are confined to the light residues and therefore not studied in detail.

Rutile

occurs in irregular, subangular and needle like forms to prismatic grains which are sometimes partly rounded. The color varies from yellow, "foxy red" to reddish brown. In prismatic grains the prism faces commonly show cleavages at an angle of about 60° . Geniculate twins are occasionally met. Rounding of grains is variable, but is

usually slight in comparison to tourmaline provided the latter is associated with rutile in a residue. A characteristic of rutile is its red-dish brown appearance in reflected light.

Sphene

diamond shaped grains occasionally found in association with rutile. On account of the usual smallness of the heavy minerals so far examined and the similarity between sphene and rutile it is not always easy to differentiate between the two minerals.

Staurolite

sharp angular fragments of yellow to brownish color with high refractive index. This mineral appears to be rare and non-persistent. Pleochroism often strong with maximum coloration in the opposite direction to that usually noticed in tourmaline.

Tourmaline

commonly yellow to brownish colored grains. Other colors met with are blue, bluish green, grey, pink to almost colorless. Pleochroism is usually strong in yellow, brown and pink varieties while it is weak in blue colored grains. Birefringence is usually highest in yellow to brownish forms. The characteristic shapes of tourmaline are rounded grains, prismatic (often well rounded) to irregular shaped angular forms. Rounded basal sections are commonly met with. Tourmaline grains are usually comparatively fresh and undecomposed although inclusions may occur.

Zircon

most common forms are colorless, euhedral to well rounded varieties of prismatic forms with a high refractive index and high birefringence. The mineral is straight extinguishing, uniaxial positive. Grains are often well formed prismatic types with pyramidal terminations. Another type of zircon frequently met with is the rose to purple variety while brownish colored types are rare. The shapes of zircon may vary and to some extent are characteristic of certain formations. In connection with the rose-colored zircons it seems noteworthy that they generally occur in more rounded forms than the associated colorless variety. In a paper on purple or rose - pink zircon Boswell(6) states "that this variety of zircon is especially characteristic of those British sediments in which minerals derived from regionally - metamorphosed rocks are abundant and of 'fresh' appearance. They provide additional evidence that the deposits were formed by denudation of land masses composed of crystalline metamorphic rocks." Mackie states that this variety of zircon is usually present as rounded ovoid grains with occasional crystalline forms occurring, and that it is often definitely, though slightly, pleochroic.

Description of Formations.

In a problem of this kind it is necessary to make a petrographic study of the various horizons in order of their geological sequence, and then attempt to correlate these horizons in adjacent sediments. The completion of such a task is one that will take considerable time, and the examination of a great many more representative samples than are available at present. In this paper no attempt has been made to show any lateral correlation, but rather to note the characteristics of the heavy residues from the different formations. The method of attack has been to start with the lowest horizon of the oldest formation available, and from this horizon to work up the geological column.

The "Fernie" Formation.

Before continuing with a description of this formation it might be well to explain why the name "Fernie" is written in parentheses. The "Fernie" was believed to be of Jurassic age and is described as such in Hume's report of 1926 (19). However, since that time, diamond drill cores have been recovered from this formation which are reported to contain fossils suggestive of Carboniferous age. The results of such a discovery have not yet been made public, and for this reason the age of the "Fernie" cannot be definitely stated.

The "Fernie" formation is a marine deposit consisting mainly of black shales with numerous sandstone horizons. Brown impure limestone bands occur in the upper part of the formation. The sandstones are shades of grey to brown and are mostly fine grained. Diamond drill cores have revealed the presence of a

medium grained, light grey, conglomeratic sandstone, with a yellowish colored cementing material. The horizon is not a true conglomerate but contains scattered pebbles up to one half inch or more in diameter. It shows evidence of poorer sorting of material than most of the other sandstone beds within this formation.

The "Fernie" is the oldest formation from which material was collected, so it was decided to make a study of the lowest horizon available from the deposit, and to work upwards through the younger ~~horizons~~ horizons from this depth. The samples examined from the "Fernie" consist of diamond drill cores from the well Dalhousie 1. They were taken between depths of 4178 ft. and 3855ft. This 323 ft. represents roughly about one half the total thickness of the deposit, the bottom of which was reached at a depth of about 4400 ft. while the exact depth of the top of the formation is unknown, due to the fact that the section above the 3855 ft. level was drilled some years ago when samples were not recorded properly.

The "Fernie" sandstones so far examined, although differing considerably in general appearance, bear a marked similarity in their heavy residues. A characteristic of the material is that only a small number of minerals occur, while of these only a few are persistent.

The minerals identified and their average relative abundance are as follows :-

Flood ----- pyrites

Abundant ----- zircon

Common -----

Present ----- tourmaline, rutile, magnetite - ilmenite.

Rare ----- hornblende, biotite, muscovite, haemetite.

Trace ----- garnet.

Of these minerals pyrites is by far the most abundant species, and is of no apparent index value because it is liable to occur almost anywhere. As previously stated it is believed to have formed mainly in place, and therefore to be secondary. The mineral was usually so abundant in this formation, that it was necessary to decompose it with hot dilute HNO_3 in order to identify the other minerals present. When such treatment is necessary the heavy residue must be re-separated by means of bromoform, so as to get rid of quartz or other light material which has previously been cemented to pyrites and thus brought down into the heavy residue.

Apart from pyrites, zircon is the most abundant and persistent mineral. It occurs to a greater extent in the "Fennie" than in any other formation yet studied, with the possible exception of the Benton from which insufficient information is yet known to make a definite comparison. The zircon grains are nearly always very small so that they are mostly concentrated in the finer grades; i.e. under 150 meshes to the inch. The forms most frequently met with are clear colorless ovoid to subrounded euhedral grains. The grains are characterized by their dark borders and high birefringence. Rose colored grains are sometimes met with while brownish and turbid varieties are rare.

The abundance of zircon occurring in this formation and the character of the grains is shown in Plate 1.

Next in order of persistence and prominence are tourmaline and rutile with the former mineral being rather more conspicuous.

Tourmaline occurs in many colors and forms in the formation, the most common varieties being rounded and prismatic grains of a brown or brownish yellow color. Angular shaped grains are also common and may partly be due to crushing in the mortar. Green blue and pink varieties also occur with the bluish types exhibiting very faint pleochroism in comparison to the other colors. Tourmaline is extra abundant between the depths 4137 - 52 ft.

Rutile although not so abundant as tourmaline is nevertheless persistent. It occurs most commonly as subangular grains of reddish brown to yellow color. Needle shaped and prismatic varieties, the latter sometimes showing good cleavages on the prism faces at an angle of about 60° to the principle axis, are commonly encountered, while geniculate twins occasionally occur. Rutile is most conspicuous between the depths 4025 - 31 ft. and 4133 - 52 ft.

Magnetite and ilmenite although somewhat persistent are generally rare and are recorded together. The heavy residues show angular, crystalline and rounded grains. Their occurrence is most conspicuous between the depths 4086 - 4101 ft. which is the conglomeratic sandstone previously mentioned.

Other minerals present are rare and of sporadic occurrence. Muscovite is rather persistent especially in coarse grades, but it is of no apparent correlative value unless by its marked

abundance in certain brown colored sands of the lower "Fernie", which are not available at present. Other minerals of rare occurrence are hornblende, garnet, biotite and possibly staurolite. Only one grain identified as staurolite has been seen and its occurrence is doubtful. It is significant that none of these last four minerals have been noted in the "Fernie" above the conglomeratic sandstone between 4086 - 4101 ft.

The characteristic feature of the "Fernie" samples is the relative abundance and persistence of three minerals, namely zircon, tourmaline and rutile. These minerals together with magnetite and ilmenite make up by far the greater part of the heavy residues studied, and in the majority of cases are about the only minerals identified.

The Kootenay Formation.

The Kootenay formation which overlies the "Ferne" is a continental deposit of lower Cretaceous age. The top of the Kootenay is marked by a coal seam while a geyish white sandstone or quartzite occurs at the base. The beds which go to make up the formation are mainly grey to black, green grey and maroon colored shales with light grey and green grey 'pepper and salt' sandstones.

Samples studied from the Kootenay are of the standard cable type collected from the Dalhousie 6. and the Vulcan 2. wells.

The minerals noted and their average relative abundance are as follows :-

<u>Flood</u>	}	---- amphibole (altered hornblende)
<u>Abundant</u>		
<u>Common</u>	-----	
<u>Present</u>	-----	biotite, magnetite - ilmenite.
<u>Rare</u>	-----	muscovite, zircon, tourmaline, pyrites.
<u>Trace</u>	-----	garnet, rutile, epidote.

The heavy residues of the Kootenay are distinctly different from those of the "Ferne".

Pyrites although still present has not been noted in such large quantities as in the "Ferne". The most abundant mineral in the Kootenay is an amphibole type which shows considerable alteration. The mineral occurs in irregular flakes in shades of green to brown. Occasional prismatic structures are discernable. The appearance of the mineral varies greatly and this is believed

to be due to different stages of decomposition. The material is suggestive of a hornblende type of mineral that has undergone alteration to such an extent that a chloritic type of material is now commonly met with. The specific gravity evidently varies, for sometimes part of the material remains in the light residue. It is evidently the presence of this mineral that gives the greenish coloration to many of the Kootenay sands. The material is noticeably affected by treatment with HCl and if treated with the hot acid for a period of perhaps four or five hours the greenish coloration will practically disappear from the mineral thus masking its identity. According to Iddings(17) the monoclinic amphiboles of simple chemical composition such as tremolite and actinolite are less subject to decomposition by HCl than those of a more complex composition such as certain of the hornblendes. He also states that certain minerals belonging to the chlorite group are totally decomposed by treatment with hydrochloric acid.

Commonly occurring with the above type of amphibole is a brown variety of mica which is also somewhat altered. It occurs in brown colored flakes of irregular outline while traces of grains showing pseudo-hexagonal outlines have been noted.

Muscovite occurs in colorless irregular flakes which yield good biaxial interference figures.

Zircon is now greatly decreased and occurs mainly in fresh euhedral grains to subrounded forms. The mineral is generally noticeably less rounded than in the "Fernie".

Magnetite and ilmenite are more conspicuous than ⁱⁿmost of the "Fernie", especially in the part of the latter section studied above the conglomeratic sandstone between 4086 - 4081 ft.

Tourmaline is noticeably less conspicuous than in the "Fernie", although it is fairly persistent. It usually occurs in prismatic or angular forms while rounded forms are rare.

Other minerals identified were only found as traces and were non persistent. Such types were rutile, garnet and epidote.

In samples containing the altered amphibole described in this formation care must be taken in treating with acid to dissolve cementing material without altering the mineral itself. A method which has been found successful is to use a very dilute solution of HCl, say 10%, and boil the heavy residue in this solution for a period of not more than fifteen minutes.

The Blairmore Formation.

Overlying the Kootenay is the Blairmore formation. It is a land and fresh water deposit and is described by Hume (19) as being partly upper Cretaceous and partly lower Cretaceous in age. The combined thickness of the Kootenay and Blairmore formations has been estimated to be about 1000 ft. The beds of the Blairmore consist of variegated shales and sandstones which are very similar in lithology to those of the Kootenay. If the coal seam which marks the top of the Kootenay is not recognized in well samples it is very difficult to tell when the Blairmore is passed through by the drill. At the top of the Blairmore there occurs a hard coarse sandstone or grit which serves as a contact marker between the Blairmore and the overlying Benton formation. This horizon was discovered by Hume in the field and has since been recognized in the majority of the Turner Valley well samples. It occurs at the ~~same stratigraphic horizon~~ same stratigraphic horizon as the Crowsnest Volcanics in the vicinity of Blairmore, Alberta, and from its appearance has been considered to represent a rewashed volcanic ash. It is a hard, coarse, angular grit of ununiform texture, and of dark color, containing a few small well-rounded pebbles. The thickness of the horizon is about one foot.

The heavy residues of the Blairmore* are very similar to those of the Kootenay and from the material studied it is difficult to differentiate between them. However an attempt will be made to point out any differences noted in the following description of the minerals identified from the Blairmore formation.

* Blairmore samples are from Tuleen No. 2.

The minerals identified and their average relative abundance are as follows :-

Flood

---- amphibole(altered hornblende)

Abundant

Common ----- biotite, pyrites.

Present ----- garnet, zircon, magnetite - ilmenite.

Rare ----- tourmaline, muscovite.

Trace ----- apatite, rutile, epidote.

The amphibole and biotite occur much the same in the Blairmore as in the Kootenay, and are distinctive for identifying these two formations from others so far studied. Sandstones of similar greenish grey appearance to those of the Kootenay and Blairmore occur in the Belly River, Edmonton and possibly the Paskapoo formations and their heavy residues may yet reveal similar types of amphiboles. However the amphiboles of the Kootenay and Blairmore are not found in the "Ferne" nor in the Benton, and since the latter is the youngest formation exposed within the Turner Valley (with the possible exception of the north end of the field about which little is known), there is little danger of their causing confusion in samples from wells drilled within the valley.

Magnetite and ilmenite occur as in the Kootenay while pyrites is more conspicuous in the samples examined from the Blairmore.

Garnet has been found to be commoner and more persistent in the Blairmore, occurring in the usual angular, isotropic, pink to colorless forms with high refractive index.

Tourmaline is inconspicuous but persistent, occurring much the same as in the Kootenay.

Zircon occurs mainly as colorless euhedral grains with rose colored varieties also present. The rose zircons usually show more rounding^{than} do the associated colorless types. Zircon is more prominent in the Blairmore studied so far than in the Kootenay.

Apatite has been noted in rounded prismatic grains of low birefringence. Traces of isotropic grains of hexagonal outline have been found whose refractive index was determined as approximately 1.635. Such grains are believed to be basal sections of apatite. Apatite has been found in several horizons of the Blairmore, but not in conspicuous quantities.

Two separations, one from a field specimen and one from a well sample, were made of the grit bed occurring at the top of the Blairmore. Both gave a large percentage of heavy residue, that of the well sample of Okalta l. giving 11.23 %. The heavy residues were almost identical in that they contained a flood of massive pyrites of a dull brassy color. Hume (19) describes this horizon as being extremely porous and this may account for the large quantity of pyrites which is evidently of secondary origin.

The Benton Formation.

Of the formations overlying the Blairmore, no complete sections of suitable well samples were available for study, due to the fact that very little drilling has been done in any of these deposits with the exception of the Benton. However a few separations were made from each formation with a view to noting whether or not their heavy residues held any appreciable differences from those which have already been described.

The oldest of these formations is the Benton, which overlies the Blairmore. The Benton is a marine formation belonging mostly to the Colorado series, while certain fauna found near the top are believed to be of Montana age(19). Lithologically the deposit consists of grey black shales with many thin sandstone horizons. These sandstones are very uniform in appearance, consisting of fine to very fine grained types, grey to dark grey in color. The thickness of the formation has not yet been accurately determined in Turner Valley. Estimates have been made which vary from 2000 ft. to 3000 ft., with 2500ft. being a conservative estimate.

Samples were examined, for heavy mineral content, from two horizons in the Benton. Of these one was from the Vulcan 2. at 2280 ft., representing a Lower Benton sand, while the other was from New McDougall-Segur at 820-30 ft. representing an Upper Benton sand.

The most characteristic feature of the residues is that they are very similar to those of the "Fernie".

The minerals noted and their average relative abundance is as follows :-

Flood ----- pyrites

Abundant ----- zircon

Common -----

Present ----- tourmaline, rutile.

Rare ----- magnetite - ilmenite.

Trace -----

Pyrites masked the presence of the other minerals and was removed by dilute hot HNO_3 .

Zircon occurs in clear colorless subrounded to euhedral grains, while traces of rose to brownish types are present also.

Tourmaline occurs mainly as yellowish brown, rounded and prismatic grains which are strongly pleochroic.

Rutile occurs as yellowish to reddish brown, irregular to prismatic grains, some of which show good cleavages on the prism faces.

Magnetite - ilmenite are present as black opaque grains of irregular outline.

The Belly River Formation.

The Belly River is a brackish water deposit of Montana age, which is part of the Upper Crataceous system. It is described (19 & 20) as consisting of light green clays and shales, and light grey and greenish massive and thin bedded sandstones with a coal seam occurring at the base of the formation. It is the Belly River that forms the parallel ridges which flank Turner Valley. The crest of the structure has been eroded into the Benton formation which forms the valley floor.

Until very recently the Belly River was not believed to occur within the valley, but well samples taken from the Foothills 1. have revealed over 300 ft. of sandstone before penetrating the Benton shales. No sandstone of so great a thickness is known to occur in the Benton and the horizon is believed by some, to be Belly River in age. The Foothills 1. well which struck this horizon is located in about the centre of the valley, just north of the cross fault shown on the accompanying field map.

The thickness of the Belly River is estimated to be between 1850 and 1900 ft.

The minerals noted in the Belly River, and their average relative abundance is as follows ;-

Flood -----

Abundant -----

Common ----- zircon, pyrites.

Present ----- garnet, rutile, tourmaline

Rare ----- hornblende, muscovite, magnetite - ilmenite.

Trace ----- monazite.

The above represents a study of two horizons, the one being a "Lower Belly River" sand from the Foothills l. at depths of 240 and 360 ft. while the other is a field specimen taken from an outcrop occurring on the north branch of Sheep River, 390 ft. from the top of the formation. This latter specimen was partially saturated with bitumen which gave it a brownish appearance. The bituminous material was removed by dissolving in benzol and washing the sample. The sand was then treated with hot dilute HCl for one hour and washed. It then appeared clean and of a light grey color.

The heavy residues from the above horizons differed inasmuch that the lower one contained a "flood" of zircon while this mineral is much less conspicuous in the upper one. Tourmaline and rutile are rather conspicuous in both sands while hornblende is rare. Garnet is more noticeable in the upper horizon. Traces of monazite occur in the lower sample which is significant in that it is the only occurrence of this mineral noted to date.

The Edmonton Formation.

The Edmonton is a brackish water deposit of Upper Cretaceous age overlying the Belly River. It is described in field reports(19 & 20) as being composed of dark green clays and hard greenish sandstones with a carbonaceous horizon occurring at the base. Recent drilling has indicated the presence of several coal horizons within the formation. The Edmonton although not occurring in the Turner Valley is present just beyond the eastern flank (Belly River) of the structure. The thickness of the Edmonton is estimated at 1300 ft.

Examination was made of one horizon in this formation. The heavy residue is from a medium grained whitish 'pepper and salt' sandstone, containing traces of carbonaceous material, which overlies a coal seam. The sample was taken from New Valley 1. at a depth of 780 - 790 ft.

The minerals noted and their average relative abundance is as follows :-

Flood -----

Abundant -----

Common ----- garnet

Present ----- magnetite - ilmenite.

Rare ----- hornblende(bleached variety), zircon, muscovite, pyrites.

Trace ----- tourmaline, rutile.

This residue is similar to the Upper Belly River sand described, but garnet is more prominent while zircon, rutile and tourmaline are less conspicuous. Garnet occurs as pink to yellowish isotropic grains of irregular outline.

The Paskapoo Formation.

The Paskapoo is a fresh water deposit of Tertiary age, overlying the Edmonton formation. It consists(19) mainly of light ash colored sandstones with greenish clays and shales. Its thickness is estimated at 4000 ft.

The Paskapoo does not outcrop in Turner Valley but overlies the Edmonton to the east of the anticline. Material for study consists of standard Cable samples from Ranchman l. Lsd. 16, S 13, T 20, R 29, W 4. This well is located about twenty five miles south east of Turner Valley.

Heavy residues were studied from depths of 290 and 315 ft. respectively.

The minerals noted and their average relative abundance are as follows;-

Flood -----

Abundant -----

Common ----- epidote, garnet, magnetite - ilmenite.

Present ----- pyrites

Rare ----- hornblende, zircon, muscovite, staurolite.

Trace ----- tourmaline, limonite, haemetite, biotite.

This portion of the Paskapoo is characterized by the relative abundance of epidote, part of which is decomposed. The prominence of this mineral serves to distinguish the horizon from any other yet studied. The mineral occurs mainly as pale yellow to almost colorless grains (many showing decomposition)

with a characteristic lemon yellow color in reflected light. Pleochroism is quite marked in many of the grains and birefringence and refractive index are high. The grains are mostly irregular but a few prismatic forms show parallel extinction.

Garnet and magnetite - ilmenite are next in prominence while zircon and hornblende are inconspicuous. This variety of hornblende is much less altered than the amphiboles described in the Kootenay - Blairmore formations. It occurs in green pleochroic, prismatic grains with low extinction angles. Tourmaline is very inconspicuous while no rutile has been observed in the horizons studied. Staurolite occurs but is very rare. The grains are a decided brownish yellow to brown and differ from epidote in birefringence and in that they do not show the lemon yellow color of the latter in reflected light.

Conclusions.

The results of the work done on the Turner Valley sands indicate that the study of heavy minerals is a useful method to assist in the sub-surface correlation of the area.

Summary.

A summary showing the heavy mineral characteristics of the various formations will serve to justify the above statement. The important characteristics may be briefly stated as follows ;-

(1) "Fernie"

- (a) Prominence and persistence of zircon followed by tourmaline, rutile and to some extent magnetite - ilmenite.
- (b) Zircons are generally more rounded than those of the overlying Kootenay - Blairmore.
- (c) Heavy residues generally contain only the most stable and resistant minerals.

(2) Kootenay

- (a) Abundance of amphiboles showing alteration.
- (b) Zircons mostly fresh euhedral types.

(3) Blairmore

- (a) Similarity of amphiboles and zircons to those of the Kootenay.
- (b) Occurrences of apatite in several horizons.
- (c) Rather persistent occurrence of garnet.

(4) Benton

- (a) Prominence of zircon, tourmaline and rutile.
- (b) Resemblance of heavy residues to those of "Ferne".

(5) Belly River

- (a) Prominence of garnet, zircon, tourmaline and rutile.
- (b) Occurrence of monazite.

(6) Edmonton

- (a) Prominence of garnet and magnetite - ilmenite while tourmaline and rutile are very scarce.

(7) Paskapoo

- (a) Relative abundance of epidote with magnetite - ilmenite, and garnet being conspicuous.
- (b) Occurrence of staurolite significant in that it has not yet been definitely identified in the other formations.

General Conclusions.

Although the problem of tracing the above deposits to their sources, and of determining their main parent rock types is one requiring a great deal more work, both in the field and in the laboratory, it is felt that the results shown are suggestive of certain types of source rocks for several of the formations occurring in Turner Valley.

For instance, the significant feature of the "Ferne" is the abundance of zircon followed by tourmaline, rutile and magnetite - ilmenite in persistent quantities. The uniformity of grade of most of the "Ferne" sands together

with the rounding of the heavy residues in comparison to the overlying deposits suggests a long period of transport or erosion, while the predominance of the more stable minerals such as zircon, tourmaline and rutile to the almost complete exclusion of others suggests the possibility of a derivation from pre-existing sediments(1). Boswell(3) states that sediments derived from igneous or metamorphic rocks show a greater variety of minerals and more variable characteristics than do those derived from older sedimentary deposits. Minerals characteristic of metamorphic rocks are practically absent in the "Fernie" while the small number of mineral species is not suggestive of immediate derivation from an igneous rock type, unless the parent rock has been subjected to a long continued disintegration by transport or other erosional influences.

The similarity of the sands of the Kootenay - Blairmore suggests similar transport and derivation in the main. The heavy minerals show less rounding and poorer grading than do those of the "Fernie", thus indicating shorter transport. The abundance of amphibole in the Kootenay - Blairmore is suggestive of derivation from an altered amphibole rock source. Further evidence in support of this suggestion is the occurrence of such minerals as garnet and epidote. Although one would naturally expect to find kyanite, staurolite and possibly andalusite in such a sediment these minerals have not yet been identified.

Too little is known of the heavy residuals occurring in the formations overlying the Blairmore to advance more than the following concluding suggestions ;-

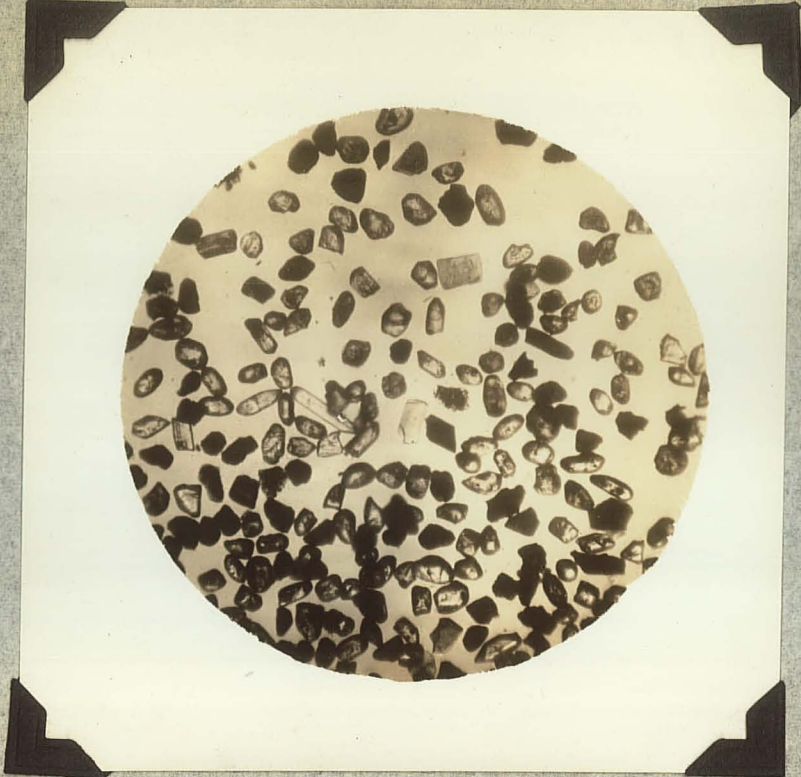
- (1) That the fineness of grain and uniformity of grade of the Benton sands, together with the minerals identified, suggest similar conditions of erosion to those of the "Fernie"
- (2) The Belly River and Edmonton sands show a greater variety of minerals than do those of the Benton, indicating a poorer sorting of material.
- (3) The variety of minerals in the Paskapoo and their relative roundness is not suggestive of good sorting or of great distance of travel, while the relative abundance of epidote, together with the prominence of garnet and the occurrence of staurolite are indicative of source from a metamorphic rock type for the portion of the Paskapoo formation studied.

Photographs of several characteristic horizons are shown in Plates 1. to 4.

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P Plate 1. "Ferne" formation, Dalhousie No. 1, Depth 4137
 Showing abundance of zircon with subordinate tourmaline
 and rutile.

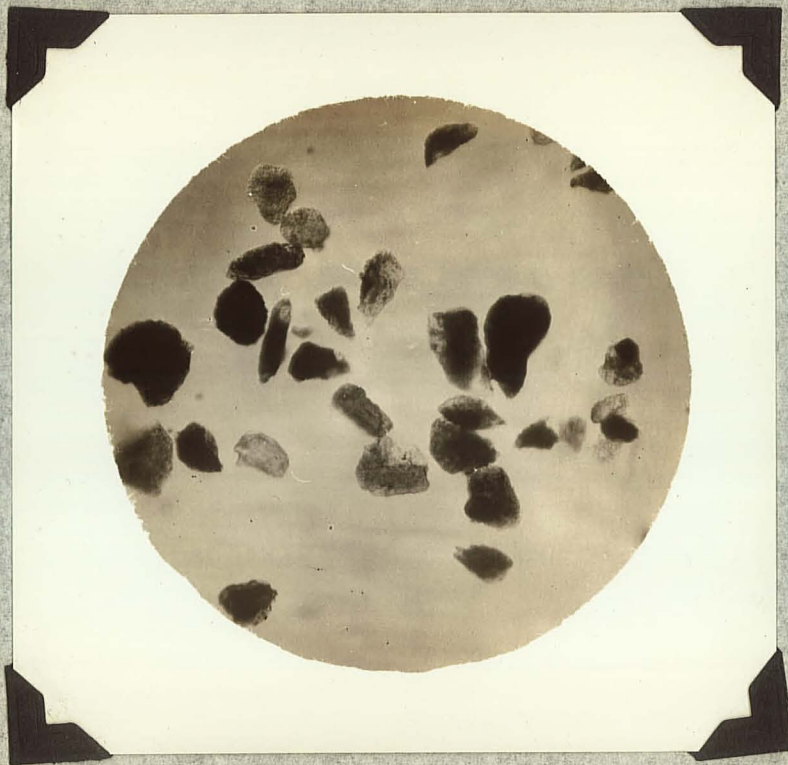


Plate 2. Kootenay formation, Dalhousie 6, Depth 4060
 Showing flood of altered amphibole.

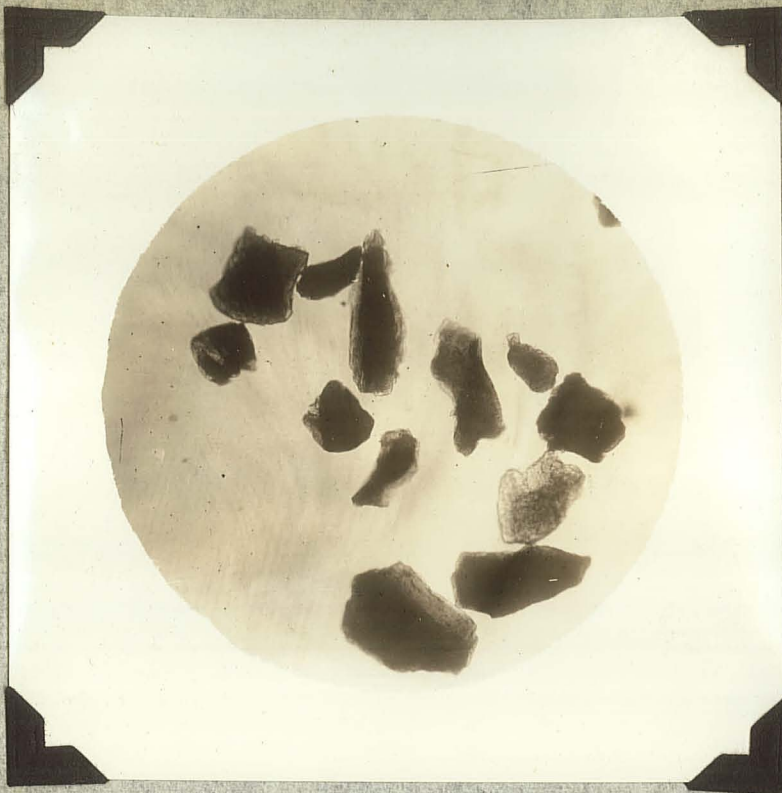


Plate 3. Blairmore formation, Vulcan No. 2, Depth 2940
Showing abundance of altered amphibole similar to Kootenay.

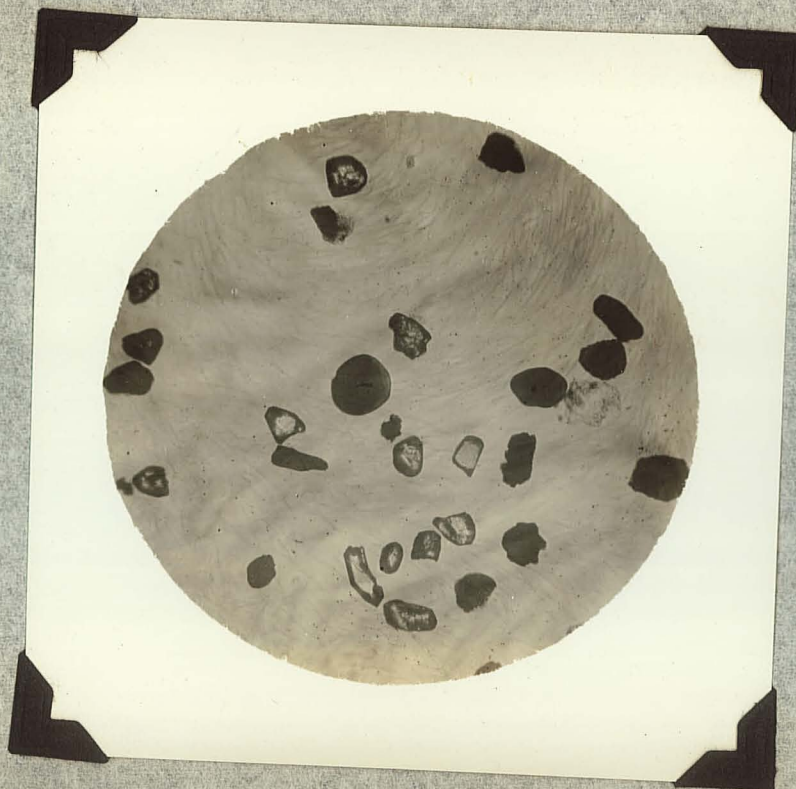


Plate 4. Benton formation, New McDougall-Segur No. 2
Depth 820,
Showing zircon, tourmaline, and rutile.

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