CANADA

ORIGIN OF THE ALBERT MINES OIL SHALE (NEW BRUNSWICK) AND ITS ASSOCIATED ALBERTITE

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by

Lewis H. King*

ABSTRACT

The Albert Mines oil shale is part of the Albert formation of the Moncton basin of New Brunswick, and is of Mississippian age. The deposit is a varved dolomitic, organic marlstone, and is probably of planktonic algal origin. It bears a striking resemblance to certain facies of the Green River formation.

The oil shale is associated with the type vein of albertite, and the unique occurrence is considered as evidence that the albertite had its origin in the organic matter of the shale. However, the albertite properties are different from those of the organic matter of the shale; the former is more highly aromatic in structure. It is suggested that the albertite developed as a chemical fraction of the shale, possibly from a fraction of degraded aquatic humus. It probably migrated in aqueous solution, assisted by dissociating functional groups that are still in evidence in the infrared spectra. Precipitation of the albertite from the migrating solutions probably resulted from a change in environmental pH.

Various other origins for albertite are discussed.

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ORIGINE DES SCHISTES PÉTROLIFÈRES DES MINES ALBERT (NOUVEAU-BRUNSWICK) ET DE L'ALBERTITE QUI Y EST ASSOCIÉE

par

Lewis H. King*

RÉSUMÉ

Le schiste pétrolifère des mines Albert fait partie de la forma-
tion Albert du bassin de Moncton, au Nouveau-Brunswick; et il est
d'âge mississipien. Le gisement en question se compose de marnes
organiques et dolomitiques, de structure laminée; il eut probablement
son origine dans les algues et le plancton. Sa ressemblance est frap-
pante avec certains facies de la formation Green River.

Ce schiste bitumineux est associé au filon caractéristique de
l'albertite, et cette circonstance unique est considérée comme une
preuve que l'albertite a eu son origine au sein des matières organiques
du schiste. Pourtant, les propriétés de l'albertite sont différentes de
celles des matières organiques du schiste, l'albertite étant de structure
plus aromatique. L'auteur fait la suggestion que l'albertite s'est formée
en tant que fraction chimique du schiste, peut-être à partir d'une frac-
tion d'humus aqueux altéré. Elle a probablement subi une migration
en solution aqueuse, aidée de groupes fonctionnels en dissociation,
lesquels sont encore en évidence au spectre infra-rouge. La précipita-
tion de l'albertite des solutions en migration a probablement résulté
d'un changement dans le pH du milieu.

L'auteur discute aussi de diverses autres origines possibles
de l'albertite.

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INTRODUCTION

Attention was first directed to the Albert Mines oil shale and its associated albertite in 1849 when the albertite was discovered by a local geologist, Abraham Gesner. The albertite, which has since become known as the type deposit, is located on Frederick Brook near Albert Mines, approximately 20 miles south of Moncton, New Brunswick.

The question of the origin of the albertite became of immediate concern since litigation developed in 1852 regarding ownership of the deposit. Gesner claimed the deposit on the grounds that it was not coal, and, therefore, was exempt from the ordinary Crown Land regulations applicable to coal. His contention that the albertite was a mineral pitch or a hardened or inspissated petroleum which occurred in vein form cutting the enclosing strata or oil shale was not upheld by the courts; however, it has long since been realized that Gesner's contention was correct in that the deposit is of epigenetic origin.

The vein of albertite proved to be of commercial importance and was mined from 1850 to 1876, during which time the bulk of the albertite was removed. The Albert Mines oil shale has also attracted commercial and government interests, and in the past various unsuccessful attempts have been made to exploit the deposit. [1]

This paper describes the albertite and organic matter from the oil shale in terms of their physical and chemical properties, and combines these data with geological and petrographic evidence to draw conclusions regarding their possible origin.

STRATIGRAPHY

General

The area under consideration occupies approximately one square mile and represents a very small portion of a structural basin known as the Moncton basin. The Moncton basin occupies an area of approximately 3,000 square miles (1). The stratigraphic succession of the Mississippian section of the Moncton basin is shown in Figure 1, after Greiner (2). Greiner has designated the Albert Mines oil shale as the type section for the Frederick Brook member of the Albert formation and has mapped the member over a large area of the Moncton basin. Recognition of the Frederick Brook

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[1] See Gussow (1) for complete bibliography of the Albert shales.

member is, however, quite tentative, as the formational status of the
Albert formation is not yet confirmed; consequently, for purposes of this re-
port the section in question will be referred to as the Albert Mines oil
shale.

SYSTEM	GROUP	FORMATION	MEMBER	LITHOLOGY
PENNSYLVANIAN				
MISSISSIPPIAN	HOPEWELL			Redbeds: conglomerate, sandstone, shale
	WINDSOR			Limestone, gypsum, anhydrite, rock salt, shale, conglomerate
	MONCTON	Hillsborough		Redbeds: sandstone, conglomerate, shale, basal ash bed
		Weldon		Redbeds: siltstone, shale, conglomerate
	HORTON (Nova Scotia)	Albert	Gautreau	Salt, gypsum, anhydrite, dolomite, limestone, shale
			Hiram Brook	Siltstone, shale, sandstone, mainly calcareous
			Frederick Brook	Oil shale, calcareous shale, siltstone, limestone
			Dawson Settlement	Sandstone, siltstone, shale, conglomerate
		Memramcook		Redbeds: shale, siltstone, sandstone, conglomerate
PRE-CARBONIFEROUS				Devonian granites; Ordovician-Silurian-Devonian slates, volcanics, quartzite; Precambrian schists, volcanics, quartzites, limestone etc.

Figure 1 — Stratigraphic succession of the Mississippian
section of the Moncton basin (after Greiner).

Albert Mines Oil Shale

According to Alcock, Swinnerton and Ells (3), the Albert Mines
oil shale, from the point of view of its oil content, is made up of three main
stratigraphic divisions. The oil contents were determined by distillation
tests on drill cores. The upper zone is 350 feet in thickness and contains
on the average less than 5 gallons of oil per ton. The middle zone repres-
ents approximately 700 feet of strata and averages 10.6 gallons. The third
zone, examined over a stratigraphic interval of approximately 400 feet,
shows an average of less than 5 gallons per ton. Drill logs showing the
stratigraphic distribution of the oil content in the oil shale beds have been
correlated with the stratigraphic section in Figure 3.

In general, the oil shales vary in colour from grey and bluish grey
to buff and dark brown, and in texture from flexible papery shales to blocky
varieties with distinct, closely spaced, organic laminations. The blocky
beds are often minutely contorted and have been called "curly" shales.
The dark papery and curly shales are dolomitic and are usually high-grade

types. Close inspection reveals that both types have regular rhythmic laminations or varves of alternating organic and dolomitic layers, and are actually not shales but varved organic marlstones. These high-grade horizons are more resistant to weathering and crop out along the brook. The outcrops have been mapped by Wright (4), and their location is shown in Figure 2. The low-grade and barren zones vary from gritty shales and siltstones to the odd thin sandstone and have been described by Wright from cores and underground workings.

The detailed stratigraphic section is shown in Figure 3 and is based on measurements and lithologic descriptions by Wright. Some of the lithologic description has been supplemented by the writer. Wright's stratigraphic section has been correlated with Alcock's logs which show the stratigraphic oil content distribution. This correlation was made from a consideration of the position of Alcock's drilling sites with respect to the high-grade beds of Wright's measured section. The only discrepancy occurred between boreholes 52 and 54 where, according to the correlation criteria, Alcock's correlation showed a 100-foot duplication in section. Alcock used a thin sandstone bed as a marker.

Boreholes 58, 51, 52 and 54 are 250, 230 and 1050 feet apart respectively, and it can be seen that the high-grade zones vary both in thickness and oil content in a lateral direction.

The total section of significant organic content measures approximately 600-700 feet. The section above bed No. 1, and adjacent to the albertite vein, is highly disturbed over a distance of approximately 350 feet. Wright was unable to measure this sequence, but Alcock's data at the top of hole No. 58 (Figure 3) indicate 125 feet of high-grade shale.

Macroscopic fossil remains occur at various intervals in the section and consist of fish, fish scales, and plant fragments. These fossils have been described by Dawson (5), Lambe (6), Bell (7), and others, and their significance has been reviewed by Gussow (1) and Greiner (2).

STRUCTURE

The major structural trends are northeast and southwest for the local area under consideration. The axis of an anticlinal fold is located along Frederick brook and plunges to the southwest, but according to Wright (4) the fold appears to divide at its western extreme into a number of folds where the beds are intensely crumpled. This indicates a more complex structural picture than just a simple fold. On the southern limb, the beds dip at angles of about 75 degrees near the workings of the albertite vein. The structural picture is further complicated by a highly disturbed zone
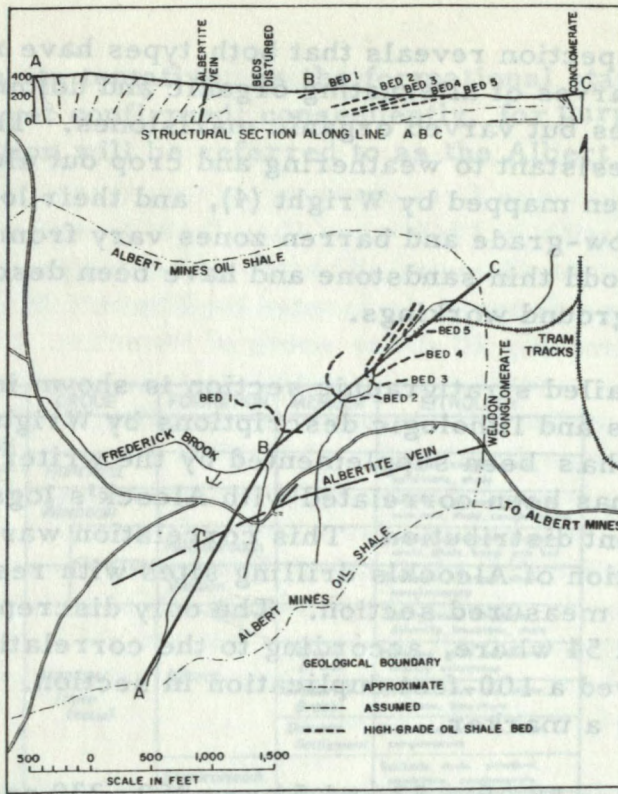
Figure 2 - Geology and structural section of the Albert Mines
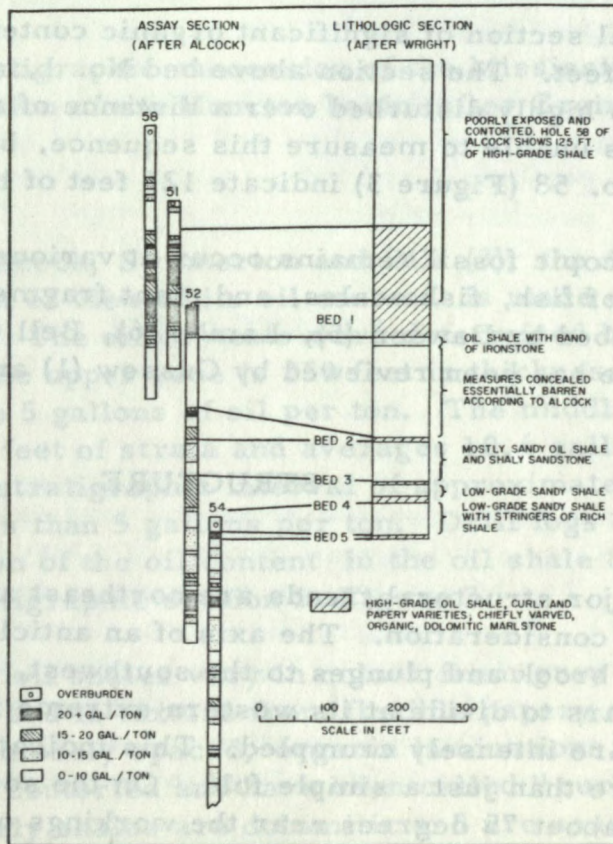oil shale (after Wright).

Figure 3 - Correlation of the assay and lithologic sections.

between the vein and the axis of the fold as mentioned previously, and is indicated in Wright's structural section of Figure 2.

Various early descriptions of the albertite vein have been summarized in a report by Ells (8) which describes the vein as varying in thickness from a few inches to 17 feet and extending laterally for 2,800 feet and to a depth of approximately 1,400 feet. All the workings are said to have been in oil shale. At the lower levels, as well as at the extremities, the vein passed into a brecciated mass of shale fragments closely cemented with albertite. Several smaller separate veins were also encountered in the underground workings.

Gussow (1) has described two main periods of deformation in the Moncton basin during Carboniferous time. The first occurred during Moncton time, following deposition of the Weldon, but preceded the Hillsborough. The second constituted the most intense orogeny and occurred at the close of the Mississippian, before late Hopewell time.

Emplacement of the albertite vein probably occurred during one of these orogenies, but the exact time is not clear from the structural evidence. The vein does not cut an overlying bed of conglomerate that is believed to be of Moncton age, but the exact nature of the oil shale-conglomerate contact is not evident. Wright concluded that the contact is either unconformable or faulted, while Norman (9) assumed it to be faulted. Gussow has mapped it as a nonfaulted contact. From considerations regarding the origin of the albertite that will be discussed later, an early emplacement is suggested.

PETROGRAPHIC DESCRIPTION

The rock descriptions in this section are representative of the five high-grade beds mapped by Wright (see Figure 2) and do not include in detail the lean and barren zones that constitute the remainder of the section. These high-grade beds are dominantly varved organic marlstones that vary from friable papery varieties to tough, blocky, distinctly laminated varieties. Also included in the high-grade zones are a few thin beds of massive dolomitic marlstone and some low-grade sandy marlstone with microbands of a clay-organic complex.

1. Blocky Laminated Marlstone

The blocky laminated variety represents the beds of richest oil shale which contains up to 30-40 percent organic matter and 30-40 percent of very fine inorganic grains identified as dolomite by X-ray techniques. The beds are generally highly contorted, and contain numerous microfolds and microfaults.

The laminae generally occur as couplets in which one is distinctly richer in organic matter than the other. Each couplet constitutes a non-glacial varve and the varves repeat in rhythmic fashion to give these rocks their conspicuous lamination.

The laminae range in composition from pure organic layers to almost organic-free crystalline dolomite; however, a typical couplet consists of a relatively pure organic lamina and one in which the dolomite grains are suspended, or barely touching, in a groundmass of structureless organic matter. Various types are shown at different magnifications in Photos 1 to 5.* Under plain light the boundaries are fairly distinct, but under crossed nicols they appear more gradational (Photos 3 and 4).

The thickness of the varves illustrated in Photos 1 and 2 is approximately 0.2-0.3 millimetre and is fairly representative; however, the extreme range in thickness for the specimens examined is from 0.05 to 2.0 millimetres. In the highly contorted beds, varve measurements in a given section can be quite apparent, due to variable orientations; therefore, the 2-millimetre extreme might be high.

The bulk of the organic matter has a low index of absorption and is generally translucent and structureless. Its colour is dependent on the thickness of the thin section. Since microspores are generally present, they have been used as an index in preparing the thin sections to a standard thickness. At a thickness where the spores are barely beginning to show as cherry red, most of the organic matter throughout the slide is lemon-yellow in colour. Boundaries between the pure organic laminae and the organic matter that occurs as a groundmass between mineral grains blend without any colour change, indicating that the properties of the two occurrences are very similar; however, the pure organic bands are anisotropic, indicating a higher degree of optical organization. The dominant structureless and uniform aspect of the organic matter, as well as the dispersed nature of the mineral grains through the organic groundmass, suggests that during deposition the organic matter was a gel-like mass. Subsequent metamorphism has polymerized the gel to a tough, resilient mass with properties similar to wurtzilite.

Although morphological structure in the organic matter is not prominent, it is nevertheless present. The most common structures occur as fusiform bodies of pure lemon-yellow organic matter, and range in length from approximately ten to several hundred microns. These bodies are exclusively defined by the surrounding mineral grains, as they show no

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* Photos 1-12 appear on pages 18-21.

ornamentation or colour differences at their boundaries. Structure is also completely absent within the bodies. Well-preserved examples are illustrated in Photos 6 to 9.

The best preservations of fusiform bodies are often associated with either a partially or a fully developed inorganic cap or film on one side of the specimen (Photo 7). The optical properties of the cap compare most closely with anhydrite, so it is unlikely that the cap represents the remnant of a varve. More than likely the anhydrite was precipitated at the depositional interface and this possibly accounts for the excellent state of preservation of some of the fusiform bodies. As the state of preservation deteriorates, the bodies become more stringy and fibrous in outline and are not readily recognized. Vague outlines suggest that a fairly large proportion of the pure organic laminae originate from the fusiform bodies.

Other morphological entities, composed of brown organic matter, can be observed at high magnification in the organic groundmass between the mineral grains. Some of these forms appear to resemble the assemblage of bacteria, fungi and algae described by Bradley (10) from the Green River formation. Small yellow fusiform bodies can also be observed in the organic groundmass, but the bulk of the yellow groundmass is structureless and appears to completely wet the mineral grains.

The chief inorganic component is dolomite which is present in quantities up to 30-40 percent; thus, approximately 70-80 percent of these rocks is composed of organic matter and dolomite. The remaining 20-30 percent occurs as quartz and orthoclase feldspar, usually less than 20 microns in diameter. A portion of the quartz is secondary. These rocks also contain approximately 2 percent pyrite.

The dolomitic grains occur as extremely fine, more or less spherical crystals, some with a suggestion of reniform surfaces. These grains are mixed with even finer angular fragments. The grain size varies from 1 to 10 microns, and each grain constitutes a single crystal of dolomite. They are best illustrated in Photo 5. Occurrences of a similar aspect have been found in many Recent deposits and in the geological column (11), and are generally thought to have been precipitated through the activity of algae. Wood (12) has described such material as "algal dust". According to Bradley (13), euhedral carbonate crystals are more or less distinctive of the organic laminae in the richer oil-shale beds of the Green River formation.

If the grains are truly of organic origin, the highly reducing environment and the sedimentary pattern suggest that they were associated with planktonic organisms. Thus, the bulk of both the organic and inorganic constituents apparently rained down on the sedimentational interface. On the other hand, in some of the closely packed, dense laminae of dolomite the surfaces of adjacent grains sometimes conform suggesting a cellular pattern, but it is difficult to determine whether this is a primary feature.

The possibility of an inorganic origin for the dolomite crystals cannot be completely discounted, but it appears unlikely that they are oolitic, since neither concentric growth patterns nor nuclei are in evidence.

2. Papery Marlstone

These rocks have a lower organic content than the blocky varieties. The organic matter is lemon-yellow, but individual laminae of pure organic matter are less common. The carbonate content is also less, in the order of 20 to 30 percent, but is similar in size, structure, and composition. The feldspar and quartz content is higher and some mica is present. The grain size of the feldspar and quartz is larger, varying up to 60 microns in diam-.eter. The increased detrital aspect imparts a certain vagueness to the varve development in this rock; however, the varves are still quite evident in thin section and average about 0.1 millimetre in diameter.

3. Low-grade Sandy Marlstone

The sandy marlstone consists of thin beds of detrital quartz and feldspar in a disorganized matrix of dolomitic ooze and organic matter, interbedded with thin layers of a clay-organic complex. The organic content of these rocks is less than 10 percent. The organic matter has a reddish tinge, indicating a change in composition from that of the organic-rich shales.

4. Massive Dolomitic Marlstone

The massive marlstone is also a mixture of detrital grains, ooze, and organic matter, but the beds are more thickly developed. A portion of the ooze consists of dolomitic spherical bodies, similar in some respects to the unicellular algae, Chlorellopsis coloniata Reis, described by Bradley (14) from the Green River formation. They are, however, much smaller (10 to 20 microns as compared with 103 to 122 microns) and are filled with reddish-brown organic matter instead of microcrystalline carbonate. They are illustrated in Photo 10.

5. Oil Shale Containing Albertite Veinlets

Specimens of oil shale containing albertite veinlets were obtained from the mine dump. Thin section studies of these specimens gave the first indication that the organic matter of the shale and the albertite differed considerably in composition. The differences are illustrated in Photos 11 and 12, where at a given thickness the organic matter of the shale is yellow while the veinlet of albertite is dark reddish-brown. Spores in the section are a deep red.

Similar results were also obtained by inserting a thin slice of albertite, a few millimetres in diameter, between two thicker slices of oil shale and mounting them in a lucite pellet before sectioning. Such a comparison of the relative light absorption of two organic components appears to be more critical than the method used by Hunt, Stewart and Dickey (15) whereby comparisons were drawn between infrared spectra of carbon disulphide extracts of the Green River beds and their associated "vein hydrocarbons". The latter technique compares only a fraction of the matter, and the spectra are not highly definitive unless they are examined on a quantitative basis.

PHYSICAL, CHEMICAL AND OPTICAL PROPERTIES

A sample of oil shale for detailed analysis of its organic matter was selected from Bed 1, Figure 2. The specimen was a conspicuously varved marlstone of the following composition: 37.5 percent organic matter, 32.3 percent dolomite, 0.3 percent sulphur, the remainder being quartz, feldspar, and minor constituents.

The organic matter was separated from the shale by a combination of methods, I and III, which are fully discussed in another report (16). In essence, the separation technique was a flotation in zinc bromide, followed by a hydrofluoric acid treatment. The albertite was obtained from a collection of the Fuels and Mining Practice Division and was purified by handpicking.

The properties of the albertite and its organic separate were measured according to methods previously described (16), and the results are shown in Table 1.

The infrared spectra from which the quantitative data were obtained are shown in Figure 4. The similarities of the curves make it very evident that the infrared data are greatly enhanced by the quantitative treatment. In addition to the absorption regions considered in Table 1, both spectra show absorption in the 2.90-2.95 micron region, and the organic separate from the shale absorbs in the 10.35 micron region. It is not possible to treat the former region quantitatively, because of interference from moisture associated with the potassium bromide pellets. The 10.35 micron band is possibly olefinic and also shows in the albertite when run in Nujol.

The short wavelength region was checked by running the samples as a Nujol suspension and the spectra showed a broad OH absorption between 2.9 and 4.0 microns, indicating the presence of carboxyl groups. These polar functional groups are probably highly significant with regard to the origin of the albertite, and were probably stronger at the time of deposition.

TABLE 1

Physical, Chemical and Optical Properties of Albertite and the
Organic Separate from the Albert Mines Oil Shale, plus Additional
Data on the Green River and New Glasgow Oil Shales for Compari-
son with the Albert Mines Oil Shale

	No. 89 Albert Mines Oil Shale	No. 34, Albertite	Mahogany Shale, Green River [1]	No. 121 New Glasgow Oil Shale
Physical Properties:				
Colour in mass:	Brown	Black		Dark brown
Streak:	Light brown	Brown to black		Light brown
Tenacity:	Sectile and tough to grind	Brittle		Tough to grind
Fracture:	Conchoidal	Conchoidal		Conchoidal
Density, d_4^{25}:	1.006	1.078		0.984
Chemical Properties:				
Carbon, wt. %, ash-free	82.1	84.1	77.9	85.7
Hydrogen	10.7	9.4	9.7	11.4
Nitrogen	1.2	2.0	2.7	0.7
Sulphur	1.4	0.3	2.3	0.4
Oxygen	4.6	4.2	7.4	1.8
Ash	1.0	-	8.1	0.6
Volatile Matter:	93.0	69.3	93.0	92.8
Atomic H/C:	1.56	1.34	1.49	1.60
Atom % Carbon:	38.4	42.1	39.0	38.4
Aromaticity:	0.29	0.41	-	0.22
Solubility in CS_2:	3.1	1.8	-	-
Optical Properties:				
Refractive Index, n_D^{25}:	1.55	1.65	1.60	1.55
Infrared Data (in terms of relative absorptivity):				
Aliphatic groups:				
3.42 μ, CH_2	1.23	0.72		
7.27 μ, CH_3	0.05	0.09		
13.9 μ, CH_2 chain ...	0.067	0.031		
Aromatic CH,				
11 – 14 μ total:	0.27	0.52		
Carbonyl, 5.87 μ:	0.13	0.23 [2]		
Aromatic C=C, 6.27 μ	0.10	0.26		
Background at 5 μ	0.03	0.14		
Background at 8 - 10 μ	Considerably stronger in the albertite.			

[1] Properties after Forsman and Hunt (17).
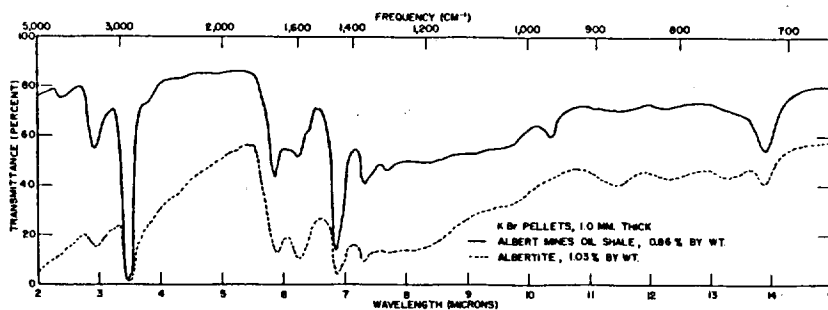[2] Albertite peak is broad, indicating additional groups.

Figure 4 - Infrared spectra of albertite and the organic separate
from the Albert Mines oil shale.

The data of Table 1 clearly show significant differences between
the albertite and the organic separate from the shale. The fundamental
reason for these differences between the majority of properties measured
is the higher aromaticity of the albertite. This is indicated specifically by
the values obtained for aromaticity using van Krevelen's densimetric analysis
(18), as well as by the infrared data. Other properties sensitive to aromat-
icity confirm this evidence -- for example, the higher refractive index and
atom percent carbon, as well as the lower volatile matter and atomic hydro-
gen-carbon ratio, shown by the albertite.

The degree of polymerization is high in both samples, as ind-
icated by their low solubilities.

For a graphical presentation of the differences between the
albertite and organic matter from the shale, as well as their relation to a
much larger spectrum of natural organic matter from geological formations,
the reader is referred to a previous report (16).

ORIGIN

Albert Mines Oil Shale

The presence of rhythmic bedding and the abundance of organic
matter impart a unique aspect to the oil shale, and both characteristics im-
ply a rather specific type of deposition. Formation and preservation of the
fine laminae suggest deposition below wave and strong current action at an
interface relatively undisturbed by benthonic organisms. Extreme condi-
tions of quiescence, and lack of by-passing of the sediments, are also sug-
gested by the extreme fineness of the grains. The deposit apparently rep-

resents a maximum of accumulation of both the inorganic and organic sediments, limited only by the rate of supply of the sediments.

The abundance of organic matter provides additional environmental information indicating a highly reducing environment in which it is doubtful that living organisms other than bacteria could exist. A reducing environment also accounts for the well-preserved fish remains. A high rate of planktonic production in clear waters above the stagnant bottom apparently constituted the source of organic sediment.

The source of the fine dolomitic grains that were simultaneously deposited with the organic sediment is not so clear. The carbonate phase might be attributed to precipitation through photosynthetic activities of planktonic algae, or it might have resulted from the association of carbonate-bearing waters with the stagnant bottom water. At any rate, both the organic and inorganic sediments appear to have originated above the sedimentational interface, and the relative and periodically changing rates at which each rained upon the bottom and passed through the interface gave rise to a laminated sedimentary accumulation.

The laminae of the oil shale are thought to represent nonglacial varves, not by virtue of direct evidence, but by analogy with the varved facies of the Green River formation. Observations on the organic-rich phase of the Albert Mines oil shale appear to conform in most respects to the vivid and detailed descriptions of the Green River by Bradley (13). Bradley interpreted the laminae couplets, through several lines of evidence, as deposits resulting from a seasonal sequence of events and thus established them as true nonglacial varves.

Murray (19) and Greiner (2) have also compared the Albert formation with the Green River formation. Greiner, on the basis of a regional study of the Moncton basin, recognized the remarkable resemblance between the two formations, on the basis of gross stratigraphic character and fine detail, and has postulated a lacustrine environment for the Albert formation.

The properties of the organic matter separated from the Albert Mines and Green River deposits provide additional evidence of their similar nature (Table 1), especially in terms of atom percent carbon and volatile matter. Since an algal origin has been suggested for both deposits, their comparison with the organic separate from the New Glasgow oil shale (Sample 121) is pertinent. The New Glasgow material is quite definitely of algal origin, since well-preserved remains of algae resembling Botryococcus brauni are the chief constituents. Strong similarities between all three are evident. The exceptionally low oxygen content of the New Glasgow material is probably a reflection of its limited degree of degradation; conversely, the higher oxygen content of the Green River sample probably results from slight oxidation during some stage of its deposition.

Throughout the course of accumulation of the Albert Mines deposit, depositional conditions sometimes gave rise to sediments not so enriched in organic matter; for example, the low-grade sandy marlstones. In the petrographic description of these rocks a reddish tinge was noted in the colour of the organic matter, as opposed to the lemon-yellow in the high-grade material. The colour change is indicative of a compositional change in the direction of higher aromaticity, possibly resulting from an increase in the degree of chemical and biochemical degradation of the organic matter. An increase in the degree of mechanical degradation of the organic matter is certainly in evidence, as indicated by the lack of the delicate yellow fusiform bodies and by the increased abundance of more resistant botanical entities such as spores. Such developments are compatible with the increased detrital aspect of the sediment, and it is thought that the degree of chemical and biochemical degradation would increase as well.

Albertite

The parallel between the Albert Mines and Uinta basin deposits can be extended even further, since both are associated with veins of organic matter: the former with albertite, and the latter with albertite, gilsonite, wurtzilite, and ozokerite. Such associations are unique and can be considered as evidence that the secondary deposits are related genetically to the organic matter of their respective shales. This investigation shows, however, that the albertite is different from the primary organic matter in the Albert Mines shale (Table 1), so it follows that the albertite probably arose as a mobile chemical fraction of the parent organic matter.

The problems related to the origin of secondary solid organic materials are in many respects similar to those for the origin of petroleum; in fact, some investigators believe that the vein materials are merely inspissated deposits of petroleum. For example, Murray (20) suggests such an origin for the Uinta basin gilsonite. Abraham (21) concludes that the deposits of asphalt are produced by the metamorphosis of asphaltic petroleum, and similarly ozokerite results from paraffinic petroleum. Abraham further regards elaterite, wurtzilite, albertite and impsonite as representing the final metamorphic stage of petroleum. Crawford (22) also proposed a metamorphic origin for the gilsonite, suggesting that it originated by fractionation of a kerogen under the influence of heat and pressure, perhaps catalyzed by associated minerals. These investigators have all implied a rather high degree of metamorphism as a factor in the formation of the indurated deposits.

Hunt, Stewart and Dickey (15) believe, on the other hand, that the major differences in the vein deposits of the Uinta basin are not due to metamorphic evolution but result from variations in the depositional environment. In this respect these authors were the first to postulate an origin for the organic vein deposits in keeping with modern theories on the origin

of oil. They identified the source rocks with their respective "vein hydro-carbons" on the basis of comparisons of refractive indices and comparisons of infrared analyses of carbon disulphide extracts. They recognized a definite and clear transition in their comparisons, going up the entire Eocene section, that paralleled closely the changes in the lithology. It is not per-fectly clear that the extracts adequately represent the composition of the whole of the materials from which they were obtained, and hence it is dif-ficult to say whether chemical fractionation occurred at the time of migra-tion of the vein deposits.

The writer is also of the opinion that a high degree of meta-morphism need not be invoked to account for the composition of the second-ary organic deposits in the albertite range. If metamorphic conditions were of sufficiently high intensity to distill destructively a portion of the mother shale, or even inspissate a petroleum deposit in the fissure, it seems like-ly that the organic matter of the shale would likewise have suffered altera-tion and acquired a higher aromatic aspect than is indicated in Table 1. On the other hand, a more intense metamorphic environment is probably important to the origin of deposits in the impsonite-anthraxolite range, but this is discussed in another report (23).

Reference has already been made to the apparent compositional changes in the direction of higher aromaticity, noted in the petrographic studies, that accompany changes in the degree of degradation of the organic matter. These changes are probably related to depositional environment. It is suggested that a soluble fraction of the more highly degradated aquatic humus migrated and gave rise to the albertite. Material of such a nature was probably dispersed throughout the entire shale deposit, just as the soluble and suspended humic acids are dispersed in the bog waters through-out any peat deposit.

Little is known of the chemical nature of the migrating fraction, and it can only be suggested that the migrating fraction was of such a nature that it gave rise to a material of higher aromaticity than the whole of the mother substance. Both the mother shale and the migrating fraction were in part oxygenated with polar groups, as these groups are still in evidence according to the infrared analysis. A point of possible significance is that in its present state the albertite resembles the asphaltene fraction of pet-roleum -- in fact, the albertite is very similar to the asphaltene fraction of the McMurray oil sands on the basis of elemental analysis, refractive index, volatile matter, aromaticity, and density, although the asphaltene has a much higher solubility in carbon disulphide (84 as opposed to 1.8 per-cent) and a higher sulphur content.

Many modern treatments of the origin of petroleum (24)(25)(26) (27)(28)(29)(30)(31) associate its migration with the expulsion of water from the compacting sediments, and it would likewise be difficult to exclude a similar association in discussing the origin of the albertite. In other words,

the albertite fraction probably moved in an aqueous medium; either in solution or as discrete droplets. Of these possibilities the writer favours the solution method, as it represents the simplest means for explaining the passage of the fraction through the fine pores of the gel-like mass representing the oil shale at the time of compaction. The solution mechanism is rendered even more attractive by the presence of the polar groups that would promote solution and subsequent migration of the albertite fraction in water. Conversely, the polar groups could obstruct migration because of their well known affinity for clay minerals. However, such obstruction is unlikely to have occurred, because of the paucity of clay minerals in much of the Albert Mines section.

During deformation of the Albert Mines shale, a fluid pressure gradient of considerable magnitude must have existed between the axis of the fold and the fissured area that now contains the albertite. The stress pattern was apparently one of compression in the fold and tension at the fissure. Since the oil shales were compacting sediments, fluid pressures in excess of the hydrostatic head were probably generated during compaction and deformation, and the large pressure drop would funnel most of the albertite-bearing fluids through the fissure.

In the consideration of possible release mechanisms for the albertite, the pressure drop does not seem to have been important; otherwise, the low-grade sandy beds, which probably acted as aquifers with lower fluid pressures than the high-grade beds, would be impregnated with albertite. Precipitation by temperature change would also be unlikely, as there is no apparent reason for a temperature differential over such a small area.

The most likely reasons for precipitation are a change in pH between the shale and fissure environments, and salting out. Probably the stability of the migrating albertite molecule would be governed to the greatest extent by the pH of the medium; the salinity would exert a secondary influence. Since nitrogen is present in the albertite, it is possible that the molecule would exhibit an amphoteric character in solution, in which case its stability would also be influenced by dissociating basic groups. Precipitation would also depend, to some extent, on the pH gradient between the environments of different pH, and on the rate at which the migrating molecules passed through the gradient. Considerable fractionation could occur across such a gradient, depending on the distribution and relative strengths of the dissociating functional groups. In effect, the isoelectric point would act as a barrier to some if not all of the migrating molecules.

Such a simple solution hypothesis as that suggested for the genesis of the albertite is most unlikely to account for the origin of petroleum, because of the high hydrocarbon content of petroleum. On the other hand, it seems possible that some indurated deposits in the albertite range

could arise from the petroleum as a consequence of selective processes
related to basin development and to differential solution and migration of
petroleum. Baker (26)(27) believes that a suitable solution mechanism for
petroleum must provide for adequate solubilities of hydrocarbons in the
proportions in which these normally occur in crude oils. On the basis of
experimental evidence he has suggested natural solubilizers or dilute col-
loidal electrolyte solutions to accomplish this. He further suggests a pos-
sible unloading mechanism whereby the hydrocarbon is released as oil
droplets as a result of dilution of the soap solutions where the migrating
solutions pass from a compacting shale to an aquifer. Once the oil drop-
lets have formed in the more permeable and porous rocks, they will con-
tinue to grow in size and, due to forces of buoyancy, collect finally in the
highest points of the reservoir. During this second stage of migration,
Baker (26)(27) and Meinschein (31) suggest, leaching of the oil droplets by
moving waters gives rise to differential migration. The more soluble
hydrocarbon and the non-hydrocarbon are selectively removed from the
oil droplets, and consequently a given oil can become progressively en-
riched in the more paraffinic hydrocarbons.

It has further been suggested by Weeks (25), in his discussion
of differential migration, that the soluble fractions, especially the oxygen-
ated materials, migrate farthest towards the basin flanks and upon encount-
ering a suitable trap give rise to the well-known tar or asphalt belts.

Indurated insoluble accumulations of organic matter of the
albertite range are also encountered in pores and cavities along the same
migration routes followed by the asphalts. These accumulations probably
represent a portion of the high molecular weight materials that occur as
part of the asphaltene fraction in the asphalt deposits. Some apparently
differentiate and precipitate short of the major asphalt accumulations.

Albertite is sometimes associated with mineralized veins; for
example, sample 90 of an earlier report (16). This deposit is close to
impsonite in composition and probably had an origin more closely related
to that suggested for impsonite and anthraxolite (23).

SUMMARY AND CONCLUSIONS

Following is a summary of the observations and conclusions re-
garding the origin of the albertite and the organic matter of the Albert Mines
oil shale. Some of the conclusions regarding the albertite are of necessity
speculative in nature, and are mainly of interest in that they suggest pos-
sible factors pertinent to a comprehensive theory of origin.

1. The Albert Mines oil shale is characterized by nonglacial
varves of alternating organic and dolomite-rich laminae, and in most

respects bears a striking resemblance to certain facies of the Green River formation.

2. The organic matter of the shale is lemon-yellow in thin section and generally occurs as thin, pure bands or as a structureless groundmass between fine dolomitic grains. Unidentified fusiform bodies of the same colour are sometimes in evidence. Various lines of evidence suggest that planktonic algae constituted the source of organic sediment.

3. The albertite was deposited in a vertical fissure adjacent and parallel to the axis of a plunging anticline, and the occurrence is confined to the shale. An early emplacement of the albertite is suggested.

4. The unique association of the albertite vein with the oil shale is evidence for a genetic relationship. Similar occurrences in the Uinta basin substantiate this conclusion.

5. Although the albertite and shale are related, the bulk of the organic matter in the shale is physically, optically and chemically different in many respects from the albertite. This suggests that a chemical fraction of the shale gave rise to the albertite.

6. A fraction of highly-degraded aquatic humus is suggested as the source of the albertite. The albertite contains a few dissociating functional groups, so it probably migrated as a dilute aqueous solution and was possibly precipitated by a pH change in the environment of deposition. Clay minerals would normally obstruct such migration, so it is considered significant that clay occurs only in minor quantities through much of the section.

7. The possibility is suggested that some albertites and related materials originate in a more indirect manner from petroleum, possibly as a product of differential migration. Other mechanisms might also be responsible for some albertites, especially for those associated with mineralization where a higher degree of metamorphism is implied.

ACKNOWLEDGEMENTS

DESCRIPTION OF PHOTOMICROGRAPHS

Photo 1 - Thin section of Albert Mines oil shale (blocky laminated variety), illustrating typical nonglacial varves approximately 0.2 to 0.3 millimetre in thickness. Magnification 30X. Each varve consists of a lemon-yellow organic-rich lamina (light grey in photo) containing a few dolomitic grains, and an adjacent dolomite-rich lamina (dark grey in photo) where the dolomite crystals are suspended in a groundmass of organic matter. Colour differences between the laminae are due to the variation in dolomite content, as the organic matter is a uniform lemon-yellow throughout. Some of the tiny, elongate, black particles are microspores; other black particles are pyrite grains.

Photo 2 - Same view as Photo 1, under crossed nicols. Magnification 30X. The organic matter is black and the dolomite grains light-grey. The distribution of organic and inorganic components is much clearer under crossed nicols, and the boundaries between varves are more distinct. Organic matter in solid bands is slightly anisotropic.

Photo 3 - Typical organic-rich lamina (light grey) between two dolomite-rich laminae (dark grey), at a magnification of 150X. Note the dark colour of the microspores, illustrating the low degree of absorption of the surrounding organic matter.

Photo 4 - Same view as Photo 3, under crossed nicols. Note the gradational boundary at the bottom of the black organic lamina. At 150X magnification the dolomitic crystals are beginning to resolve. Note their fine size, uniform diameter (1 to 10 microns), and more or less spherical shape. Higher magnifications show that even in the dense dolomitic bands such as those shown at the top and bottom of the photo, the dolomitic grains are surrounded by organic matter.

Photo 5 - Dolomitic grains (white) in a groundmass of structureless organic matter (black). Photo taken under crossed nicols at a magnification of 900X. The shape and nature of the dolomitic crystals are best illustrated in this photo. The concentric structure in a number of the grains is due to optical interference.

Photo 6 - Unidentified organic fusiform body (black) in a dolomite-rich layer. Taken under crossed nicols at a magnification of 90X. In plain light these morphological bodies are lemon-yellow in colour and range in length from ten to several hundred microns. They are slightly anisotropic.
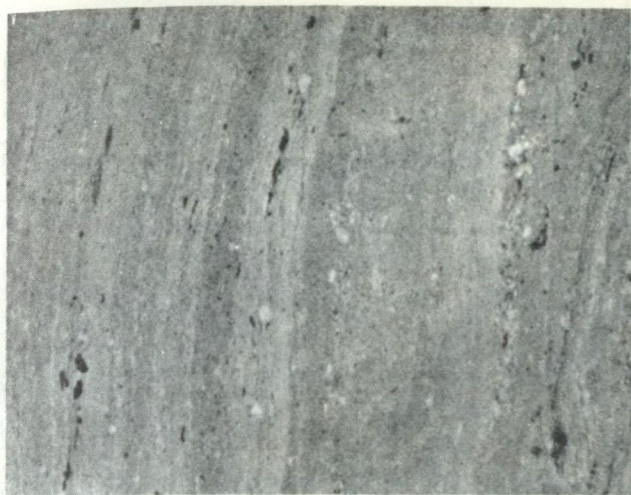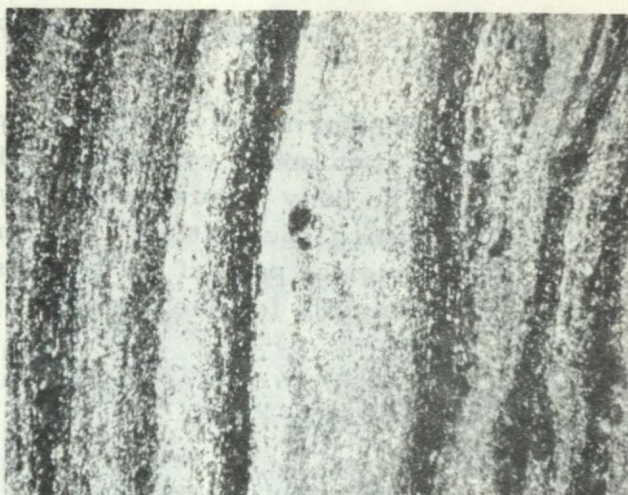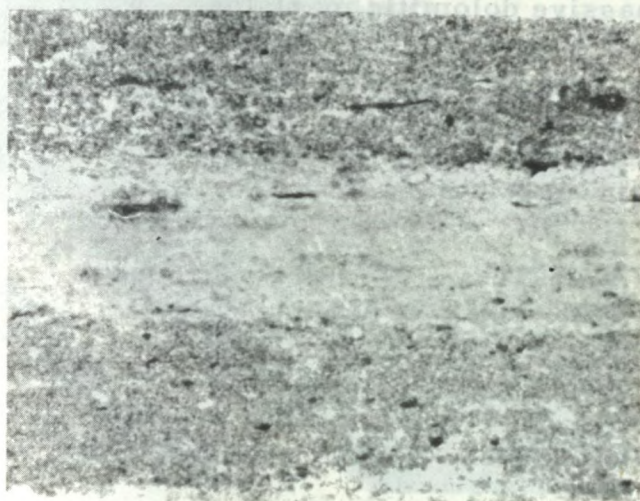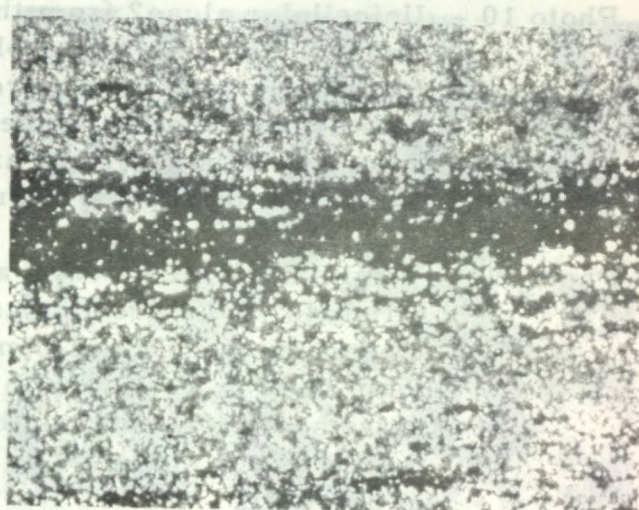
Photo 1

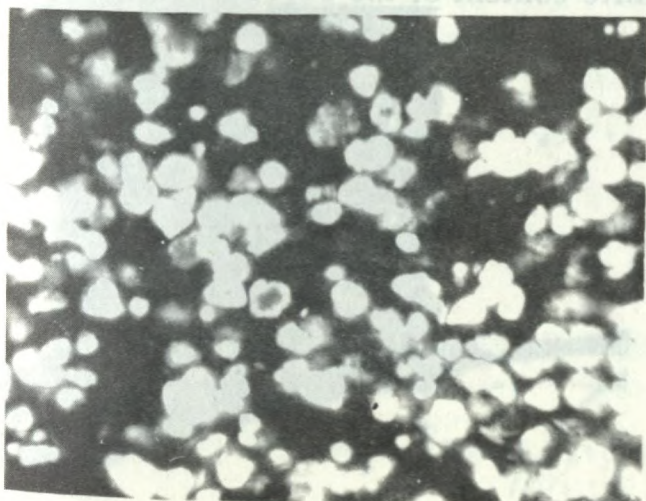Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

DESCRIPTION OF PHOTOMICROGRAPHS

Photo 7 - Fusiform body with thin anhydrite cap along the top surface. Taken under crossed nicols at a magnification of 150X. The body is surrounded by dolomite grains in a groundmass of organic matter. The inorganic cap is apparently not an original part of the organism, but possibly it is in part res- ·ponsible for the excellent preservation of the delicate body.

Photo 8 - Fusiform bodies in various states of preservation. Magnifica- tion 90X.

Photo 9 - Same view as in Photo 8, under crossed nicols. Magnification 90X. The black band of organic matter contains remnants of anhydrite caps and films.

Photo 10 - Unicellular algae? from the massive dolomitic marlstone. Taken under crossed nicols at a magnification of 400X. The main white body is calcareous, while the black centre repres- ents organic matter. The bodies are similar to Chlorellopsis coloniata Reis (14), but are much smaller (10-20 microns as compared to 103-122 microns).

Photo 11 - Veinlet of reddish brown albertite (dark grey in photo) cutting oil shale with a groundmass of lemon-yellow organic matter. Magnification 50X. A comparison of the well-preserved fusi- form body in Photo 8 with the albertite further illustrates the extreme optical contrast between the albertite and the organic matter of the shale. The veinlet contains a few scattered grains of dolomite.

Photo 12 - Same view as Photo 11, under crossed nicols. Magnification 50X. This illustrates the high dolomite content of the surrounding shale.
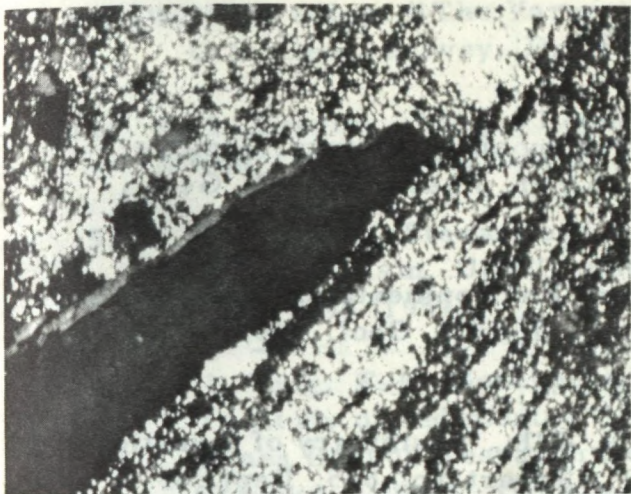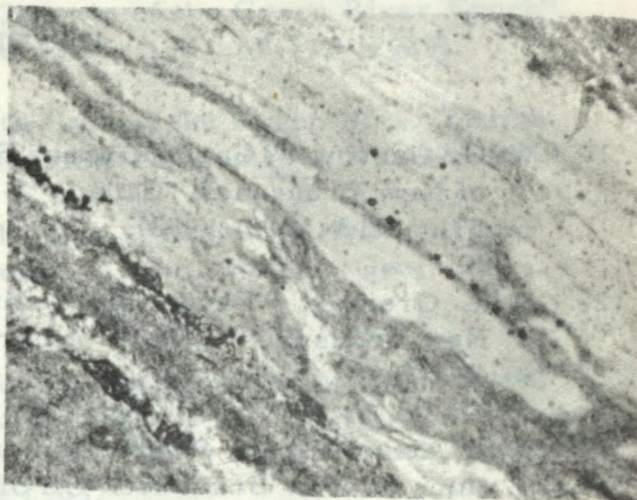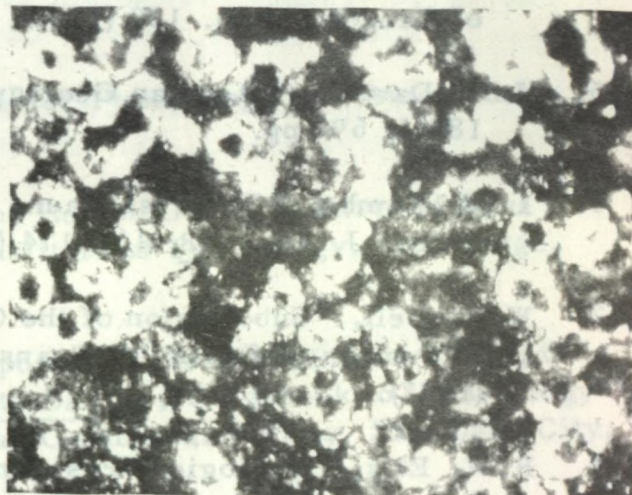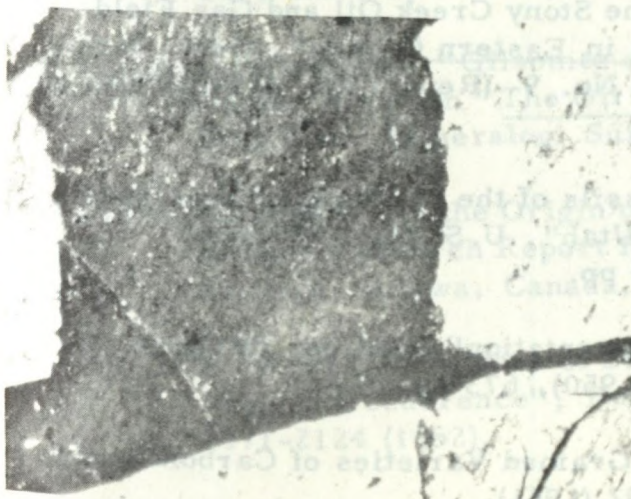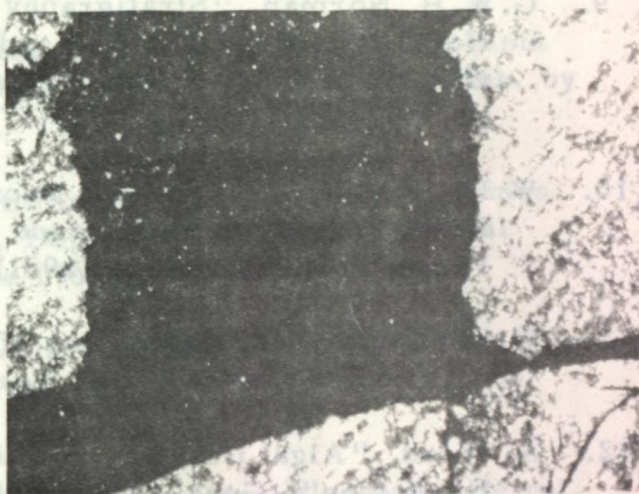
Photo 7

Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

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