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Aspects of Coal Geology, Northwest Colorado Plateau
Some Geologic Aspects of Coal Accumulation, Alteration, and Mining
In Western North America: A Symposium

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Editors

Aureal T. Cross
Michigan State University
East Lansing, Michigan

E. Blair Maxfield
Southern Utah State College
Cedar City, Utah

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Editor

W. Kenneth Hamblin

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Palynology and Petrography of Some Solid Bitumens of the Uinta Basin, Utah

AUREAL T. CROSS AND GORDON D. WOOD
Michigan State University, East Lansing, Michigan 48824

ABSTRACT.—Several solid bitumens and bituminous substances of the Uinta Basin found in veins, brecciated fissures, cracks, joints, and porous rocks have been examined for petrologic character and palynologic content. Some samples of solid ozocerite, a native wax, intercalated in the matrix of brecciated zones and as crack fillings in the fluvial Wasatch Formation on the southwest side of the basin, near Soldier Summit, contain a large number of spores and pollen. These are of sufficient diversity to indicate Paleocene-early Eocene age, comparable to the lower Green River palynomorph assemblages of earlier reports. Associated with the spores and pollen are resins, cuticles, and woody tissue fragments of higher plants; fungal sclerotia and hyphae; and some algal entities including occasional colonies of *Botryococcus*. Present are some vitrinoids comparable to those in the coal beds and shales of associated rocks. The origin of this solid bitumen may be from downdip, time-equivalent lacustrine rocks to the northeast in the lower Green River Formation, but the mechanics of the movement of these palynomorphs out of the source beds into these brecciated fissures and cracks have not been determined. It is probable that coarser, more permeable source beds or reservoir rocks than the typical Green River Shales were intersected by the tension cracks (fissures) which were developing nearly contemporaneously.

Gilsonite samples examined contain very few identifiable palynomorphs, and pollen and spores in these coallike bitumens are generally greatly carbonized. A very sparse representation of larger tissue fragments, lower plant spores, sclerotia, and algae is present. Albertite (nigrite) and wurtzilite samples appear to be barren of plant detritus. Bituminous sandstones seem to contain a few palynomorphs, but they could be indigenous to the reservoir rocks and not from the surrounding source beds of shale.

INTRODUCTION

In the process of examining a variety of solid hydrocarbons and potential source beds for such deposits from rocks of the Devonian of Michigan and Ontario, the Pennsylvanian of West Virginia and Oklahoma, and the Triassic to Tertiary of western U. S., we found particularly interesting terrestrial plant detritus present in some samples of ozocerite and gilsonite from the Uinta Basin in northeastern Utah.

Our present study of the palynology and petrographic characteristics of ozocerite, gilsonite, wurtzilite, and albertite from Utah is being conducted, in part, to identify conditions and events in the origin and diagenesis of these transported, solidified, bituminous deposits in veins, brecciated fissures, joints, and cracks and to compare the interpretations of these conditions of accumulation and events in geologic history with those indicated by similar techniques of study of various lithologic units in the host rock.

Plant material recognized in various samples includes fragments of higher plants (cuticles, tracheids, pieces of wood or other tissue); reproductive entities (spores, pollen, seeds); plant secretions, exudates, or accumulated waste products (amber, resinous canal fillings, internal resin blebs, etc.); and dispersed entities of algae and fungi (colonies, filaments, and hyphae; cysts, spores, frustules, and oogonia). Some of these are in a good state of preservation of the approximate appearance (and rank) of dispersed palynomorphs in associated shales and coals. Others appear to be more extensively altered, some strongly carbonized, particularly those in the asphaltic pyrobitumens (see Table 1). Others appear to be altered by solution or volatilization to the extent that they appear as ghosts or images of their original form. Earlier studies indicate potentially useful information may be obtained from palynologic and petrologic analyses of some samples, which might help in the determination of source beds and migration routes of petroleum, environmental conditions of basins of deposition and surrounding areas, and time relationships of these and later events (Sanders, 1937; Timofeyev and Karimov, 1953; de Jersey, 1965; Horowitz and Langozky, 1965; Banerjee, 1965). Most of these studies were based on the extraction of palynomorphs from liquid petroleum. Horowitz and Langozky (1965), however, also analyzed palynomorphs from solid hydrocarbons (including ozocerite), asphalts, and bituminous rock deposits.

NATURE AND DISTRIBUTION OF SOLID BITUMENS AND BITUMINOUS SUBSTANCES IN THE UINTA BASIN

The solid bituminous substances identified from the northeastern Utah area, particularly the Uinta Basin, include albertite (nigrite), argulite, gilsonite (uintaite), glance pitch, ingramite, ozocerite, tabbyite, and wurzilite (Text-fig. 1). Most are found as solidified, often coallike deposits in fissures, brecciated zones, and smaller cracks and joints associated with both regional (e.g., San Rafael Swell) and local faulting and folding displacements, tension cracks, etc. (Text-figs. 1, 2, and 9). Associated with these deposits are some other concentrated petroliferous rocks, bituminous sandstones and limestones, and asphaltic and tar sands, which are considered potentially commercial when they contain more than 9 percent bitumen, by weight (Covington, 1964). Three of these deposits (Sunnyside bituminous sands, Asphalt Ridge deposits near Vernal, and Whiterocks area on the south flank of the Uinta Mountains in western Uintah County) are estimated to contain more than a billion barrels of commercial oil (Covington, 1964). Estimates on the amount of bitumens in all vein deposits, i.e., the solid hydrocarbons in Uinta Basin, vary from 25 to 50 million tons (Abraham, 1960; Hunt, 1963). Hunt, Stewart, and Dickey (1954), in some interesting calculations, and Hunt (1963) have estimated this is equivalent to only 0.2 percent of the bitumen remaining in the source-bed lake shales, and, since the average organic content of the source rock for the gilsonite deposits is, by weight, 11 percent, the total amount of gilsonite in veins is about 0.1 percent of the weight of the source rocks within one mile of the veins, or about 1 percent of the total organic matter in the nearby source rocks. The significance of these deposits is obvious in the present energy-deficient economy.

Originally, solid hydrocarbons were differentiated largely on the basis of very general physical and chemical characteristics. However, in recent years, much has been done to establish the relationship of these natural bitumens and bituminous substances and parent liquid or gaseous source materials, and in the doing, several inherent distinctive chemical and physical characteristics have been identified.

PHYSICAL AND CHEMICAL CHARACTERISTICS

Table 1 is a summary of various physical and chemical characteristics published by Abraham (1960) and Hunt (1963). As indicated in Table 1 by

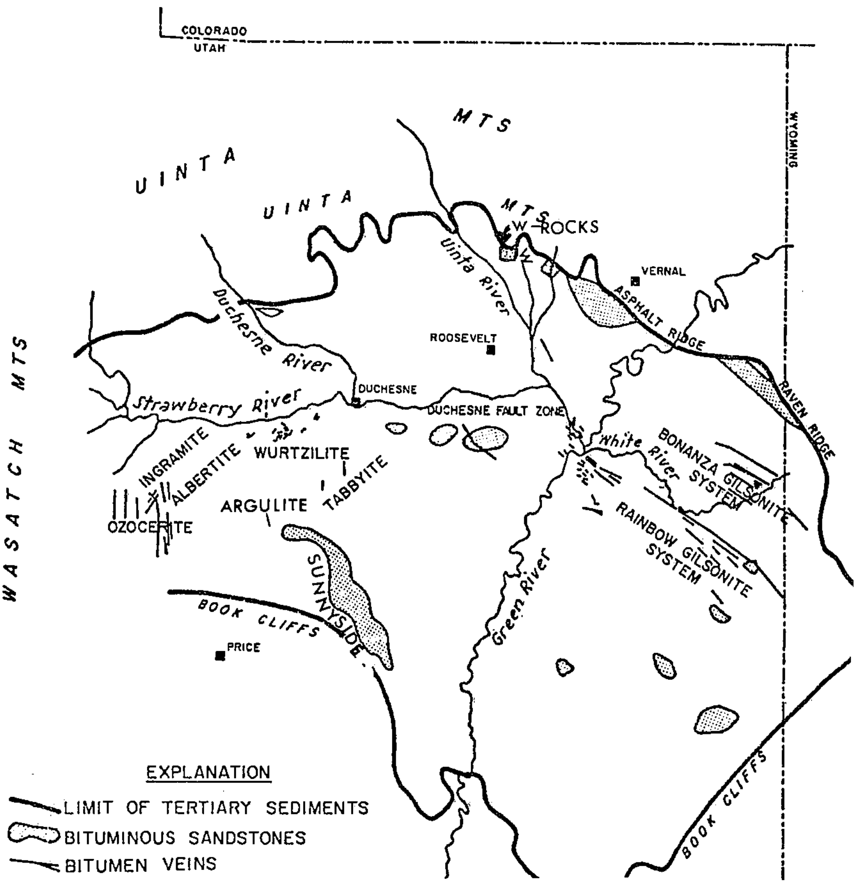
TABLE I
Summary of physical, chemical, and geological characteristics of Uinta Basin bitumens (waxes, asphalts, and asphaltites) and asphaltic pyrobitumens

	Waxes	Asphalts		Asphaltites			Asphaltic Pyrobitumens		
	Ozocerite	Argulite	Tabbyite	Gilsonite	Gilsonite	Glance Pitch	Wurtzilite	Ingramite	Albertite
Source Abraham sample and analysis, 1960 Other sources analyses	Colton, p. 133 Hunt, 1963	Argyle Cr., p. 164-65 Hunt, 1963	Tabby Cr., p. 140 Hunt, 1963	(Select) Center of veins, p. 221 Hunt, 1963	(Jet) Cowboy Vein, p. 222 Hunt, 1963	General, p. 230	Uinta Co., p. 259 Hunt, 1963	Hunt, 1963	Uinta Co., p. 261 Hunt, 1963
Sp. Gr. at 77° F.	0.90-0.92	0.97-1.01	1.006-1.010	1.03-1.05	1.076	1.10-1.15	1.05-1.07	–	1.09-1.1
Refractive Index	1.535	–	1.565-1.585	1.59-1.64	–	–	1.56-1.595	1.57-1.58	1.655-1.665
Hardness	–1	–	–	2	2	2	2-3	–	2
Penetration at 77° F.	30	14	0	0-3	0	0	0	–	–
Fusing point F. (K&S method)	140° (Hunt)	150° (Hunt)	178°	230-240°	320-350°	230-350°	non-fus.	non-fus.	non-fus.
Fixed Carbon (ash free)	9.6% 4.1% (Hunt)	8.55%	8.1-9.2%	10-20% 14-18 (Hunt)	–	20-30%	5-25% 5.9-7.6%	– 8.1-8.4 (Hunt)	37-40% 37.7-38%
Wt.% Sol. Carbon Disulfide	99%	98%	92.1-94.7%	plus 98%	plus 98%	plus 95%	5-10%	–	3-6%
Wt.% Col. 88° Petrol. Naptha	81.7%	88%	61%	50-60%	10-20%	20-50%	0.2%	–	–
Carbenes	2.51%	–	0.0%	0.0-0.5%	–	–1%	0.0-1.5%	–	Trace
Carbon	83.3%	89.9%	82%	85-86%	–	80-85%	79.5-80%	–	–
Hydrogen	13.9%	9.0%	11%	8.5-10%	–	7-12%	10.5-12.5%	–	–
Sulfur	0.29-4.3%	0.0%	2%	0.15-0.6%	–	2-8%	4-6%	1.1%	1%
Nitrogen	Tr.–0.35%	>1.1% (N&O)	2-2.5%	2.0-2.8%	–	>2% (N&O)	1.8-2.2%	1.3%	0.5%
Oxygen	–	–	–	0-2%	–		–	–	–
Atomic H/C Ratio	1.89-1.96	–	1.62	1.42-1.47	–	–	1.59-1.60	1.62	1.32*
Chromatograph, Wt.%:									
Paraffins & naphthalenes	81			18 (liquid)					
Aromatics	10			48					
N,S, and O compounds	9			34					
Infrared spectra (carbon disulfide soluble portion):									
Strong (or characteristic absorption bands)	13.9	–	–	11.58 & 12.3μ		–	8.9, 9.65 & 13.9μ	5.9, 10.8, 13.4 & 13.9μ	
Weak absorption bands (peaks)	–	–	–	8.6, 9.65 & 10.3μ		–	–	–	–
Age	Wasatch	Lower Green River		Upper Green River (L. Uinta?)		–	Uinta	Lower Green River	
Dominant components of sediments:									
Minerals	Calcite	–	–	Calcareous dolomites Pyrite		–	Siliceous dol., pyrite	–	Dolomite
Bitumens	Paraffin	–	–	Aromatics & Nitrogen compounds		–	Naphthalenes, S, & N cpds.	–	Condensed arom. rings

Increase in Sp. Grav., R.I., Hardness, Fusion Point, Carbenes, Aromaticity →

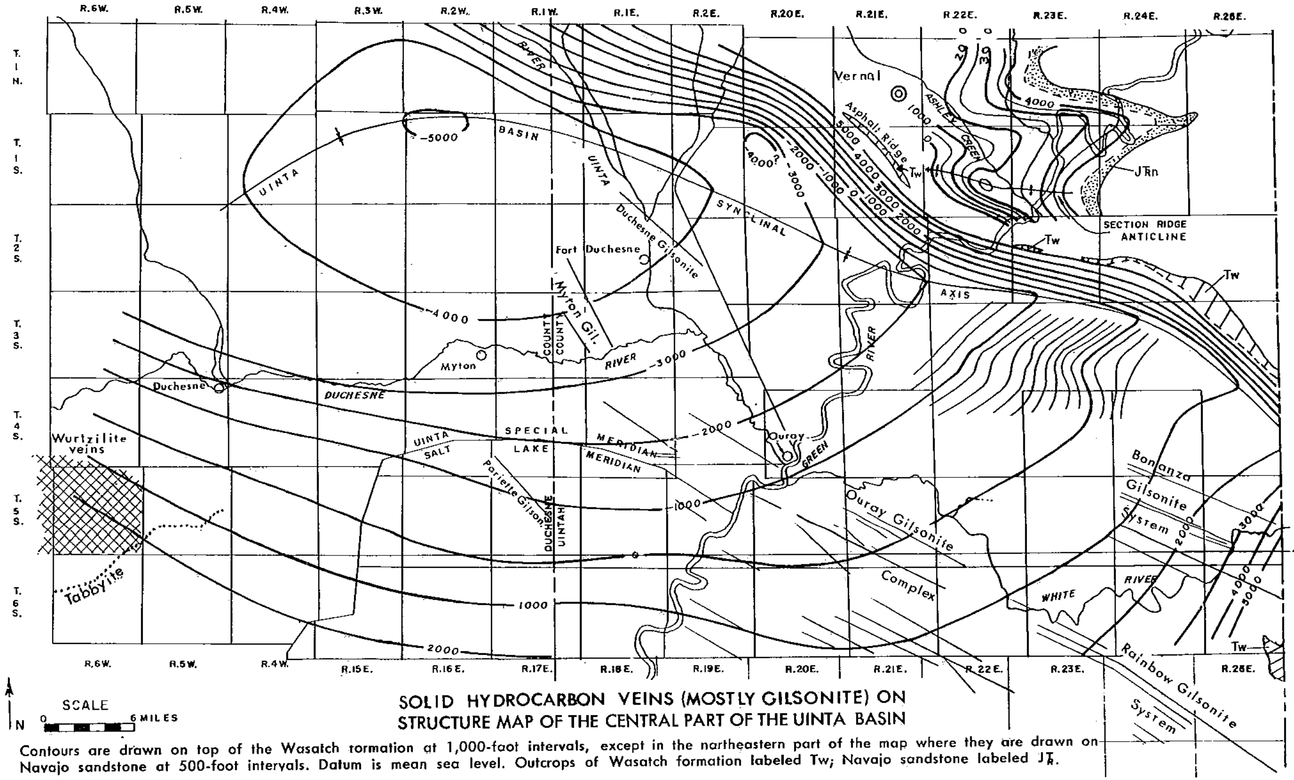
Decrease in Age, Solubility, Volatility, Hydrogen, Paraffin

(*Uinta Basin coal and Standard bituminous coal would have 0.99 and 0.80 H/C ratio, respectively, or 1.28 and 1.05 H/C ratio, resp., on an N, S, and O free basis. See Hunt, 1963, p. 262 and Table XIV.)

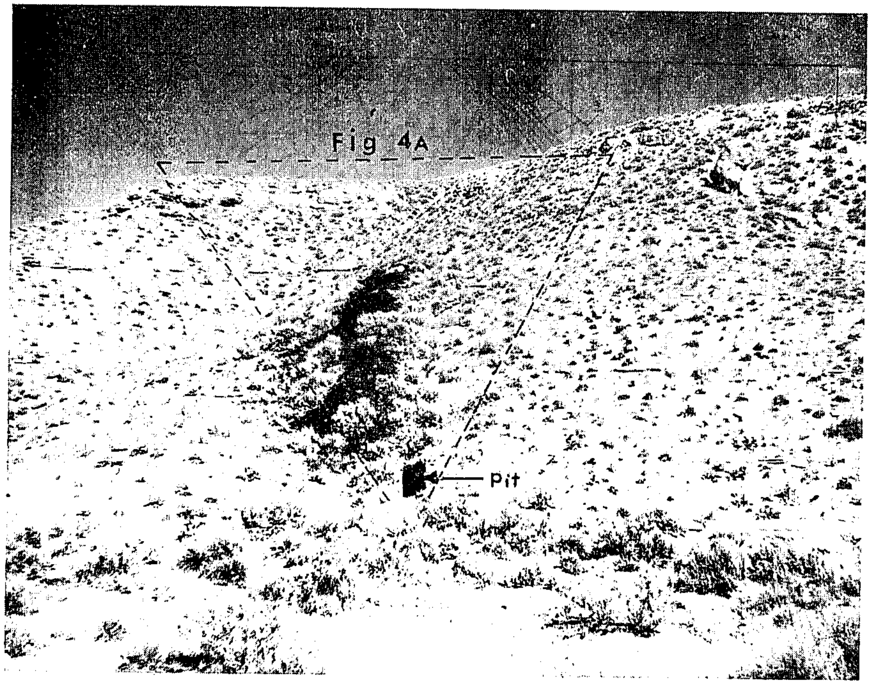


TEXT-FIGURE 1.—Index map, Uinta Basin, Utah. After Hunt, J. M., 1963, Fig. 79: Utah Geol. & Min. Surv. Bull. 54.

the arrow, there are trends of increase or decrease of certain properties from waxes through asphalts and asphaltites to asphaltic pyrobitumens. The physical properties—such as specific gravity (0.90-0.92 for ozocerite to 1.03-1.076 for gilsonite), refractive index (1.535 to 1.64 for ozocerite, argulite, tabbyite, gilsonite, respectively), hardness (<1, on the Mohs scale, for ozocerite to 2 for gilsonite and 3 for wurzilite), and fusing point (which, though quite variable, ranges from 110° in ozocerite to 150° in argulite, to 178° in tabbyite, to 230-350° in gilsonite)—are typical. Most important of the chemical characteristics for identification is degree of solubility, and in carbon disulphide it decreases from 99 percent in ozocerite and 98 percent in argulite and gilsonite to 5-10 percent in wurtzilite and 3-6 percent in albertite. Age and associated minerals or lithology of host rocks may also be factors, but apparent trends in these are probably fortuitous.



TEXT-FIGURE 2.— Base map modified from Goode, H. D., and Feltis, R. D., 1962, Utah Geol. Mineral Surv., Water Resources Bull. 1, pl. III (Prepared by U. S. Geol. Surv.). Solid hydrocarbon veins located from *Geologic Map of Utah*, Northeast Quarter, 1961, compiled by Wm. L. Stokes and J. H. Madsen, Jr., College of Mines & Mineral Indust., Univ. of Utah.

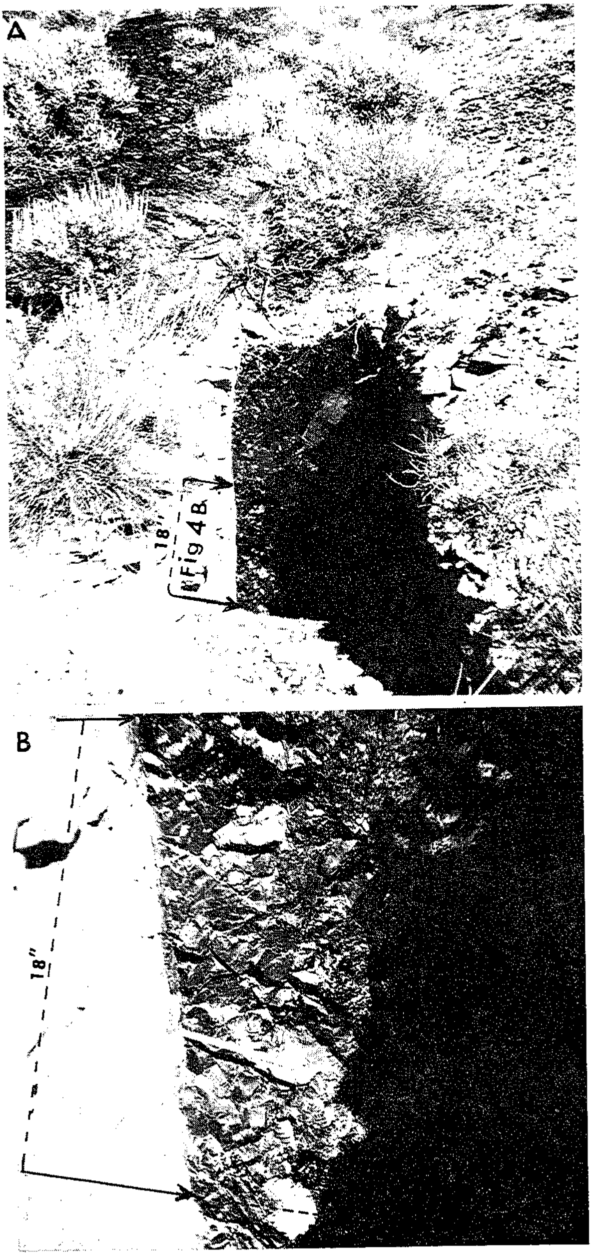


TEXT-FIGURE 3.—Big Bonanza gilsonite vein cutting Uinta Formation above Excavation Creek Member of Green River Fm., 2.7 miles south of Bonanza, Utah.

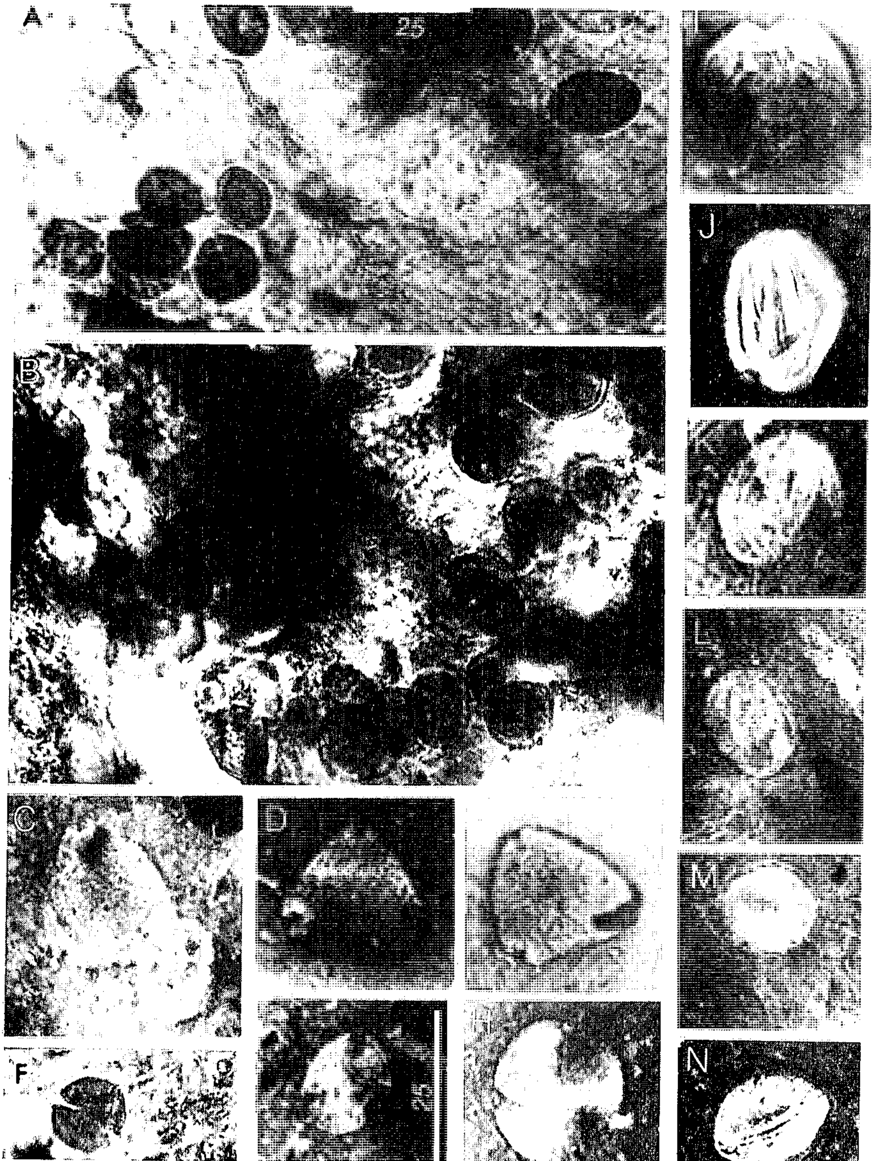
Gilsonite

The wide distribution of the veins of gilsonite, though appearing to be random (Text-figs. 1 and 2), is related to the structure of the Uinta Basin, an area of nearly 9000 square miles, to which gilsonite is delimited. All the veins and crack-filling deposits of gilsonite are south of the synclinal axis of the asymmetrical basin. They range from a few inches to over 20 feet in width, from a few tens of feet to at least as much as 1500 feet high (deep), and from a few hundred feet to over 14 miles in length. They all trend NW-SE with a maximum variation of strike of less than 30°.

One vein is shown in Text-figures 3 and 4 from the eastern end of the basin north of White River. In some instances such veins widen with depth (Davis, 1957), but in many there is gradual reduction in size and increase in number of veins in earlier (lower) strata, the changes being recognizable in conjunction with lithologic changes. Eldridge (1901) examined many gilsonite and related veins of solid bituminous substances and identified and illustrated a variety of occurrences, some of which are reproduced here as Text-figure 9. His figure 34 (see Text-fig. 9-34) is probably the most reasonable portrayal of this upward decrease in number of smaller joint and crack fillings and increase in their size until vein status is attained (as in Text-figs. 3 and 4). Hunt, Stewart, and Dickey (1954) (Text-fig. 3) portray the same idea but add some precise measurements to show diminution of size of veins and joint or crack filling and increase in number downward through 800 feet of section. The

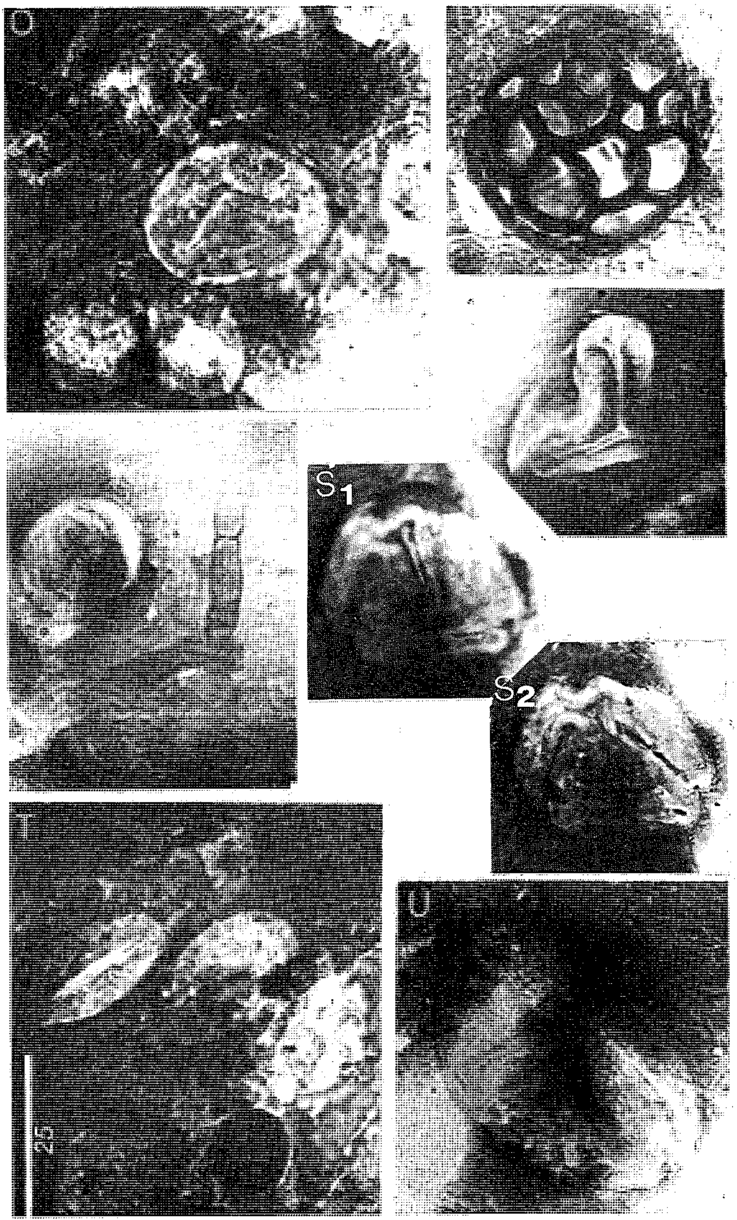


TEXT-FIGURE 4A.—Big Bonanza gilsonite vein (see Text-fig. 3). Closeup of test-pit with conchoidally fractured, weathered gilsonite clinging to wall rock on left. Weathered gilsonite forms black bare outcrop in low gully.
4B..—Bilsonite. Closeup of lower left part of pit in Text-fig. 4A. A few larger conchoidally fractured faces still identifiable.



TEXT-FIGURE 5.—Angiospermous pollen grains embedded in ozocerite from walls of mine, Wasatch Formation, at Soldier Summit (as seen in thin-section).

5A, B.—Several pollen grains dispersed in ozocerite, mostly tricolpate grains.
5C, D.—*Triporopollenites*-type with thickened annulus around pore.
5E.—Triporate, *Momipites*-type.
5F.—*Tricolpites varius* (?), 12-14μm.
5G.—*Tricolpites*, cf *T. psilascabratus* (?), 20 μm.
5H, I, J.—Tricolpate grains.
5K, L, M, N.—*Tricolpopollenites* sp.



TEXT-FIGURE 6.—Several spores, pollen grains, and fungal remains in ozocerite from Soldier Summit mine. (All figures are shown at the same magnification.)

6-O.—*Inundatisporites*-type spore in center with small bisaccate grain.

6P.—Fungal sclerotium, 31 μm.

6Q.—Bisaccate pollen (*Cedripites*-type?) 21 μm longest dimension, with fungal hyphae.

6R.—Spore with triradiate scar (*Gleicheniidites senonicus*-type).

6S_1, S_2.—Two levels of focus on a small trilete spore.

6T.—Small spore with single suture.

6U.—Monolete spore, 35 μm.

significance of these vein, crack, and joint fillings to the translocation of palynomorphs from source or reservoir rocks to the thick vein deposits illustrated will be discussed later.

The continuity and thickness of the veins are major delimiting factors for the mining of gilsonite (Crawford, 1949, 1957, 1963). The mining operation differs considerably from coal mining in northeastern Utah. Because of the conchoidal fracture, general friability and attitude (most veins are nearly vertical) a combination of gravity caving, hydraulic cutting, and large hole drifting are used. Henderson (1957) has described some of the general techniques of mining (1957), transport (pipeline), and refining.

Hunt, Stewart, and Dickey (1954) and Hunt (1963, p. 251-53) have presented some very strong evidence for relating gilsonite and other solid bitumens with the lacustrine facies and each of the separate types of bitumens with definable and separate time intervals. Ozocerite is the oldest stratigraphically, followed by ingramite, albertite, and gilsonite in that order. All the free bitumen veins in the upper Green River appear to be gilsonite.

The palynologic evidence is too inconclusive to corroborate this conclusion. Several types of palynomorphs found in gilsonite, mostly strongly carbonized, are illustrated in Text-figure 8. The three triporate pollen grains figured (8D, E, and F) are too carbonized to be identified accurately. All the other palynomorphs shown are nondiagnostic stratigraphically. These specimens are in thin-sections. The maceration of gilsonite to free such entities has been unsuccessful.

Ozocerite

Ozocerite, a native wax, has accumulated as the embedding matrix of brecciated zones along fractures, particularly on the southwest side of the Uinta Basin. This bitumen is in cracks and fissures which cut the upper part of the Wasatch beds in a north-south trending series of fractures, generally paralleling one of the sets of faults in a regional system represented by the north end of the Pleasant Valley graben system a few miles to the west.

Most of the fractures and fissures vary less than 20° from the regional joint or fault system, which is about 10° W of north and has been considered subparallel to, and a lateral element of, the San Rafael Swell. The structure which crosses the highway near Soldier Summit and which may be directly

TEXT-FIGURE 7.—Palynomorphs in ozocerite: Flattened or distorted pollen, spores, and cuticles in edge view.

7A.—Cuticle (2.79 mm long); waxy covering of leaf or small seed; folded.

7B.—Pollen grain, 18.5 μm diam (length); walls thicker in equatorial zone.

7C.—Flattened pollen grain? (gymnospermic?). Arrow points to a smaller grain.

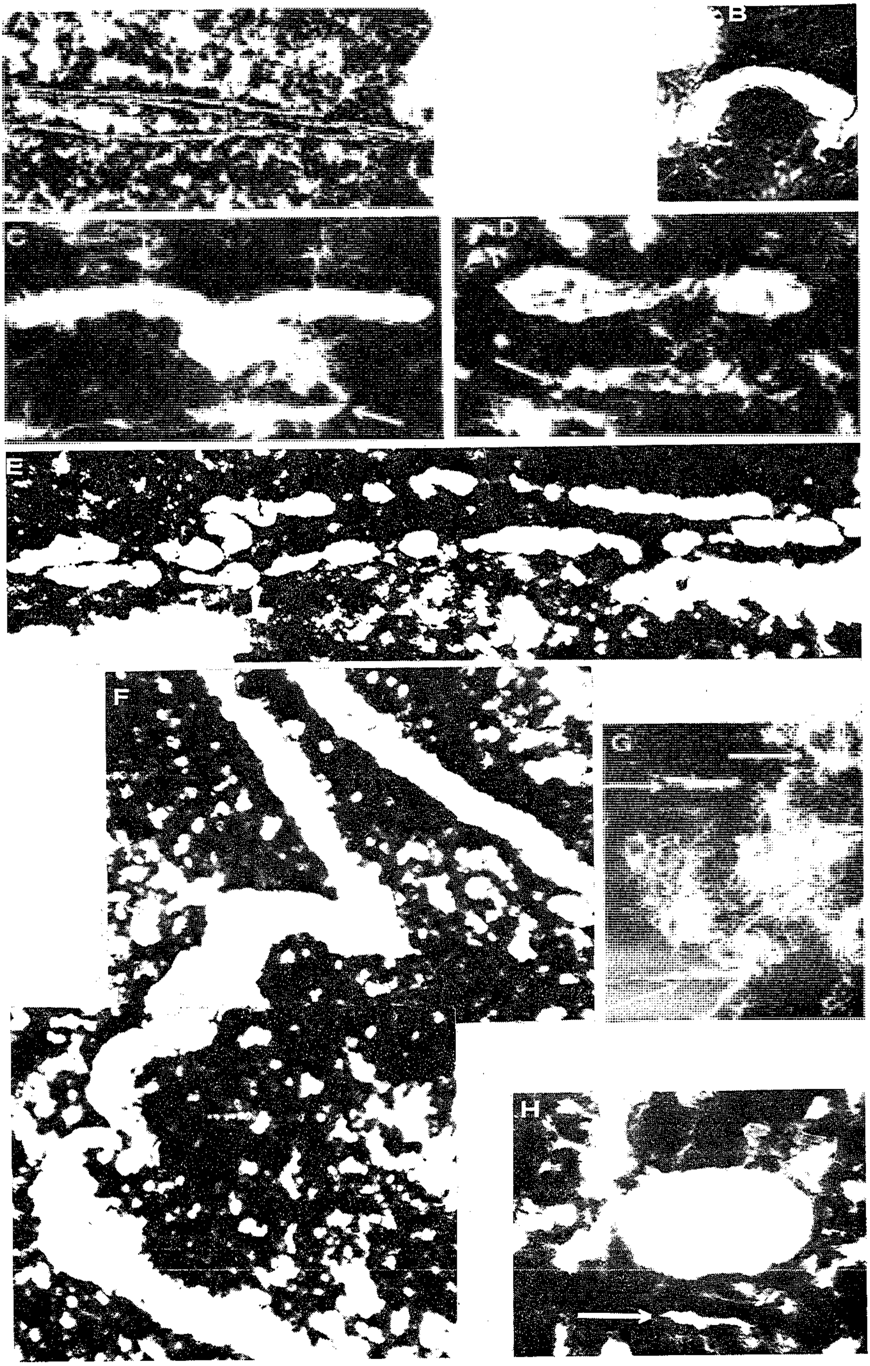
7D.—Flattened pollen grains. Larger specimen could be monosulcate or monocolpate grain with thicker end walls or a spore with thicker wall in equatorial region (max. diam., 100 μm).

7E.—Flattened waxy body; about 40 μm thick; 1.117 μm max. dimension.

7F.—Portion of large megaspore wall from 40 to 100 μm thick, considerably distorted, folded.

7G.—3 flattened pollen grains. The grain in upper right appears to have several appendages.

7H.—Resin bleb, probably derived from gymnospermic tissue and released during decay. Flattened pollen grain at arrow.


B
C
D
E
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G
H

related to the fault system containing the ozocerite is identified by some as the Clear Creek-Monument Butte Uplift, which can be traced for about 70 miles in a north-south direction and which is separated from the San Rafael Swell structure by the Straight Canyon syncline (Cross et al., 1975). It is in this setting that the ozocerite veins of the Soldier Summit area are postulated.

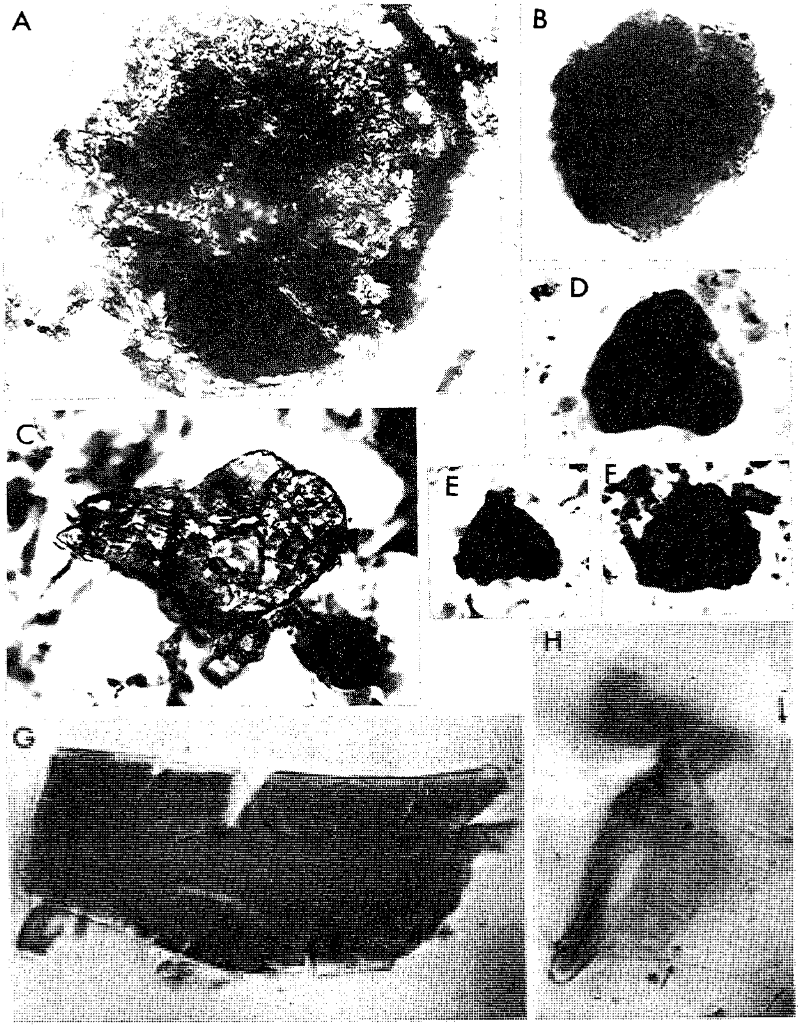
The geology and the distribution of the veins have been given by Eldridge (1901), Taff and Smith (1906), Robinson (1916), Crawford (1954), and Morrow (1957). According to Robinson's detailed report and map (1916), there are 17 sites for potential development of the ozocerite. The host rock of the ozocerite in the Soldier Summit area is the upper part of the fluvial Wasatch Formation, but the source of the bitumens is from the overlying lower beds of the Green River Shale or the nearly synchronous, lacustrine facies of Wasatch which is a gradational facies downdip to the north toward the axis of the basin. This stratigraphic relationship is adequately discussed by Picard (1955) and by Hunt, Stewart, and Dickey (1954). The Wasatch Formation here is characterized by channel sandstones in variegated shales and some interbedded lacustrine shales and limestone beds further downdip to the north in the Uinta Basin. Most of these beds contain good suites of indigenous pollen and spores, and some contain good ostracode faunas but few other fossils. The fluvial Wasatch beds do not seem to be the source of the ozocerite.

Ozocerite is, therefore, the oldest of the vein and crack-filling solid bitumens or bituminous substances in the Uinta Basin. It occurs at levels more than 500 feet below the position of the algertite or ingramite deposits of the lower middle part of the Green River Shales. On the south side of the basin, all the strata of the Green River age are much thinner than in the center of the basin where they are about 7000 feet thick. Ozocerite has been mined to a depth of over 600 feet. In the lower strata of one of the deeper mined veins, liquid ozocerite has been reported to drip from the walls. Crude oils taken from wells penetrating correlative strata have chemical characteristics similar to ozocerite (Hunt, 1963).

Some of the palynomorphs in the ozocerite are illustrated in Text-figures 5 and 6. The pollen are principally triporate angiosperms, but a few tricolpate angiosperms are also present. A number of grains of *Pinuspollenites*-type of gymnospermic bivesiculate pollen are present. Several fern spores of both monolete and trilete types represent at least four kinds of ferns. We have not been successful in freeing the spores and pollen from the ozocerite, even by using several basic techniques. The grains appear to be constituted of original exinous wall material when viewed in thin-section, but if it is not possible to remove them from the embedding matrix, it may be that they are pseudomorphs. From what can be determined by examining several thin-sections, the grains appear to be of early Tertiary age, probably Eocene. The actual goal for a more precise interpretation of the age by palynology is to show whether the palynomorphs represent the source beds of the mother petroleum of the ozocerite, the host rocks containing the solidified bitumen, or another source.

Albertite and Ingramite

In the western and southern part of the Uinta Basin, two solid asphaltic pyrobitumens, albertite and ingramite, occur in limited areas (Text-fig. 1 and Table 1), about 500-600 feet stratigraphically above the ozocerite, in the



TEXT-FIGURE 8.—Palynomorphs and detritus in gilsonite.

8A.—Partially decayed boghead colony (sl. 00300, 27.8 x 119.5, Leitz).

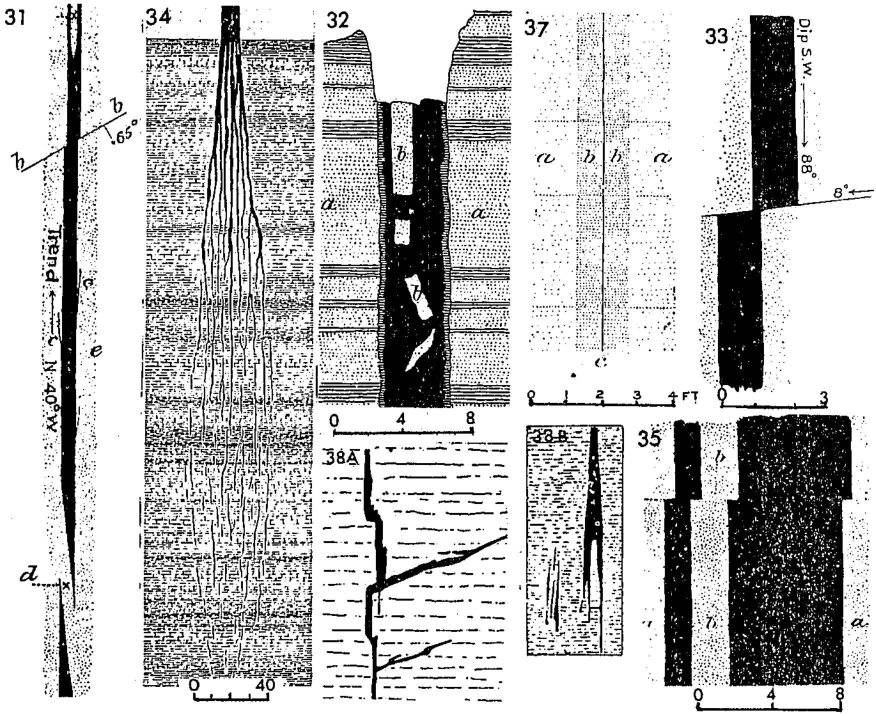
8B.—Smaller (32 μm) more extensively decayed, 4-lobed boghead colony (slide 00300, 35.5 x 118.1, Leitz).

8C.—Resin bleb (amber), 22-24 μm (slide 00300, 42.8 x 118.4, Leitz).

8E, F.—Three possible triporate pollen grains, carbonized: D, 22.8 μm (slide 00300, 38.7 x 119.2, Leitz); E, 18.0 μm (slide 00299, 25.5 x 123.9, Leitz); F, 21.5 μm (slide 00299, 25.5 x 123.7, Leitz).

8G.—Vitrinite fragment (transparent glassy wood, fragment, 60 x 25 μm), showing shrinkage cracks (slide 00300, 30.7 x 114.6, Leitz).

8H.—Cyst or inner membrane of spore exine folded at left. Margin of elongate, horizontal, transparent portion of wall indicated by arrows (slide 00300, 28.6 x 121.1, Leitz).



TEXT-FIGURE 9.—Some occurrences of gilsonite and related veins of solid bituminous substances. From Eldridge, G. H., 1901, USGS Ann. Rpt. 22, Part 1, p. 209-452.

lower Green River Formation lake shales. These substances are found as crack fillings and veins of only a few inches thickness (width) surrounded by bitumen-bearing shales. Only one sample from this area has been processed for palynologic and petrographic analysis, but another specimen from the type locality, Albert County, New Brunswick, was also processed. No palynomorphs were recognizable in these carbonized bitumens.

Wurtzilite and Tabbyite

Two other solid bitumens, wurtzilite, an asphaltic pyrobitumen similar to albertite, and tabbyite, an asphaltic bitumen, are found in thin veins and joint fillings in the Uinta Formation overlying the Green River Shale on the south edge of the basin (Text-figs. 1 and 2). Wurtzilite is in a number of veins with a maximum width of nearly two feet, though generally much narrower. Samples were obtained in Avintaquin Canyon and Sams Canyon. The veins are quite similar in many ways to gilsonite veins in their occurrence, and they extend from a few hundred feet to two or three miles. The wurtzilite is quite hard, hornlike, or like very hard rubber. Some translucent plant detritus can be identified in thin-sections, but no palynomorphs were freed by maceration techniques.

Tabbyite is found only in Tabby Canyon about 30 miles west of Duchesne. It is in thinner, discontinuous veins extending for nearly two miles along this canyon. Hunt (1963, p. 254) has reviewed the occurrence and character of this bituminous substance more fully. No samples of these solid asphaltic bitumens have been processed for palynomorphs, and only one sample was available for thin-section examination. No recognizable organic detritus was found in the thin-section prepared.

Bituminous Sandstones

Bituminous sandstones from the thick deposits near Sunnyside and from Asphalt Ridge near Vernal were examined, both in thin-sections and macerated preparations, but at this time no palynomorphs have been identified. Thin-sections are extremely difficult to make without losing the viscous hydrocarbons, so that our preparations might have had some dispersed organic detritus, and we would not have been able to see it. Movement of bituminous substances through these sands is quite obvious, for there is a continuous oozing of the tarlike bitumen wherever such strata have been quarried. These deposits should provide some basic information for determining whether or not migrating hydrocarbons flush the dispersed organic detritus out of the reservoir rock as it moves through the pores. Through the assistance of Robert E. Covington and Lee C. Marchant, we have recently obtained a number of samples representing various bituminous sandstones from Triassic to Eocene in age. Further work on these samples may improve our present low level of results for bituminous sandstones.

The Significance of the Palynomorphs Recovered

Palynomorphs have been found in several samples of ozocerite studied by thin-section. Plant detritus is much less common in the gilsonite samples examined and is of little importance in any of the other solid bitumens of bituminous substances studied. The techniques of preparation and examination of these rocks are quite imperfect, however, so we may have failed to recover or to recognize such plant detritus in thin-sections. Preparation of these samples by various maceration techniques has, to this date, proven to be unproductive. It does not compare favorably with the more successful results obtained by Horowitz and Langozky (1965), Banerjee (1965), de Jersey (1965) and several Russian scientists by the maceration of the entrapping rocks or by the dissolution of oil to free any residue and to release the dispersed organic detritus.

However, our studies of thin-sections of both gilsonite and ozocerite have been reasonably successful, and it is necessary to consider the evidence we have for identifying the source of the palynomorphs. Are they derived from the original source beds of the petroliferous substances or from the strata through which the hydrocarbons have migrated? Are they from the strata which were fractured and which now form the wall rock for the veins and crack fillings of the solid hydrocarbons?

Many palynomorphs in the ozocerite are less than 25 μm in diameter, which is in the size range of medium to fine silt. It is therefore possible that they could have moved through porous reservoir beds to the present location of the bituminous substances in veins or other openings. But some of the organic detritus found includes large cuticles, pieces of vitrain or fusain, and other large plant debris which are much larger physically than the pore size of the present reservoir beds and could not have moved through these sediments. The abundance of the spores and pollen in the ozocerite and the approximate age of these fossils indicate to us that they are not derived from fine-grained rocks or rocks with low permeability and porosity. These organic bits and pieces may have been flushed from coarser and more porous strata which have been intersected by vertical joints or cracks and thus are in solidified bituminous fillings very close to the rocks in which they were indigenous. Thus such palynomorphs probably have not moved very far except upward in the system of cracks, clearly depicted in Text-figure 9, as diagrammed by Eldridge (1901) and later by Hunt, Stewart, and Dickey (1954). They have apparently migrated some distance through the more permeable beds in juxtaposition to the vertical cracks or joint systems and then more freely upward with the flow of the oil. It is interesting to note that in one of the samples of ozocerite, the flattened pollen grains are actually oriented parallel to each other by some sorting mechanism as though they were bedded in the ozocerite. But the orientation of the original sample had not been identified; so whether the pollen were oriented parallel to the wall rock or perpendicular to it is not known.

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