AMERICAN LIGNITES:
GEOLOGICAL OCCURRENCE, PETROGRAPHIC
COMPOSITION, AND EXTRACTABLE WAXES

By W. A. Selvig, W. H. Ode, B. C. Parks, and H. J. O'Donnell
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Introduction

Requirements of montan wax for industrial use in the United States before World War II were met by imports, nearly all of which came from Germany. An important industry for extraction and refinement of this wax from certain brown coals had developed in Germany. At the beginning of the war, montan-wax imports were shut off, and American industry was forced to rely largely on substitutes. Since the war, relatively small amounts have been imported from Czechoslovakia.

Because of the shortage of montan wax at the close of the war and the fact that industry in the United States had to rely on foreign sources in the past, this investigation was started in 1945 to determine probable yields of wax from domestic lignite. Results of the investigation and the properties of extracted waxes are described in this report. Also included in the report are discussions of the occurrence and geology of lignite deposits of the United States from which samples were obtained for wax extraction and the petrographic composition of lignites, particularly in respect to those components that contribute to wax yields.

Lignite coals were examined chiefly, but some subbituminous coals also were tested. No work was done on peats. Lignites from Arkansas, California, Montana, North Dakota, Texas, and Washington were examined. A detailed field investigation was made of Arkansas lignites because of commercial production of montan wax in Arkansas during the war. The North Dakota lignite field was covered fairly completely by a Bureau of Mines coal sampler. Fewer samples from California, Montana, Texas, and Washington were examined. No samples from lignite deposits in Alabama, Louisiana, Mississippi, and South Dakota were available for test.

In this paper the term “wax” or “montan wax” is used in a broad, generic sense to designate the substance obtained by solvent extraction of the lignites. It is recognized that many of these crude extracts contain large percentages of resinous and asphalitic material.

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SUMMARY AND CONCLUSIONS

1. An examination was made of yields and properties of extractable waxes of typical American lignites. Some subbituminous coals also were included in the survey.

2. The solvents used in extracting the wax were benzene and a mixture of 80 parts by volume of benzene and 20 of ethyl alcohol. The yields of wax when benzene-alcohol was used as solvent were higher than when obtained with benzene alone.

3. The highest yields of wax were obtained from certain Arkansas and California lignites. The yields from some samples, particularly those obtained with benzene-alcohol, were comparable to those obtained from German brown coal used for commercial wax extraction.

4. Lignites from Montana, North Dakota, Texas, and Washington were tested, but their yields of wax were very low as compared with those from Arkansas and California lignites. The yields of wax from the subbituminous coals also were low.

5. The following properties of the waxes were determined: Melting point, acid value, saponification value, ester value, “resin,” “asphaltic” material, ash, and specific gravity. In general, all of the waxes that were extracted from the coals with the same solvent had similar properties. However, there was considerable difference between properties of waxes obtained by solvent extraction with benzene alone and those of waxes obtained with benzene-alcohol solvent. This difference probably is due to the higher content of “asphaltic” material in the benzene-alcohol extracts.

6. Generally, the waxes obtained by extraction with benzene more closely resembled commercial grades of imported montan wax than did the benzene-alcohol extracts. The most significant difference found in this investigation in the waxes obtained from American lignites and the Riebeck brand of montan wax from Germany was the greater resin content of the domestic waxes. In this respect they more closely resembled a commercial grade of montan wax imported from Czechoslovakia.

7. Compatibility tests showed that almost none of the waxes obtained from domestic lignites were completely miscible with paraffin; the Czechoslovak montan-wax sample showed the same degree of compatibility. The Riebeck montan wax, however, was completely miscible with paraffin. The compatibility of the benzene extracts was improved considerably by removal of the resin by selective solvent refinement. No improvement was noted in similar tests of deresinated benzene-alcohol extracts.

8. The range of ultimate analyses of the extracts obtained from one sample each of Arkansas and California lignites, two imported montan waxes, and a commercial grade of semi-refined montan wax from a California lignite was as follows: Carbon, 77.3 to 80.2 percent; hydrogen, 10.6 to 12.6 percent; oxygen, 6.8 to 10.4 percent; sulfur, 0.3 to 0.8 percent; nitorgen, 0.0 to 0.3 percent; and ash, 0.1 to 0.4 percent. The benzene extracts contained slightly more carbon and hydrogen and less oxygen than the benzene-alcohol extracts. The oxygen contents of the benzene extracts more closely resembled those of commercial montan wax examined than did the higher-oxygen benzene-alcohol extracts.

9. Studies of possible improvement of the waxes by various known methods of purification and refinement were not made in this investigation. However, from results obtained in the laboratory determination of resinous and asphaltic material in the wax by selective solvent extraction, removal of these constituents should be feasible if necessary.

10. A study of the petrographic composition of lignites showed that high wax-yielding lignites are atrital, whereas the woody or xylloid lignites contain only small quantities of extractable wax.

11. The main source of the soluble material extracted from lignite with benzene and benzene-alcohol solvents, and which consists of wax, resin, and asphaltic material, was certain ingredients in the atrital ground mass. These ingredients were yellow cuticular material, round resinous bodies, lump-type resinous particles, and probably spores, pollen, and finely divided yellow material not identifiable. Cuticular material was undoubtedly the original source of much of the waxy fraction. The resinous and asphaltic material was derived from particles of lump resin, round yellowish resin bodies, and round reddish resinous and asphaltic bodies.
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OCCURRENCE AND GEOLOGY OF LIGNITE DEPOSITS IN THE UNITED STATES

Lignitic coals of the United States, despite the tremendous quantities that exist, have been exploited commercially on a limited scale and only locally. An even greater abundance of higher-rank coal plus generous supplies of petroleum and gas in the United States have prevented wide use of lignite for fuel. In consequence of the lack of general interest in lignite as a source of fuel, information in regard to deposits and nature of this coal lags far behind knowledge of higher-rank coals.

All the large American lignite deposits have a common characteristic in that they are approximately the same geological age. Whereas in Europe lignitic deposits are known that originated in each of the four great epochs of the Tertiary, only Paleocene and Eocene lignites are known with any degree of certainty in the United States. There are probably small isolated deposits, such as near Auburn, Wash., that may have originated in some Tertiary epoch later than the Eocene, but the interval of extensive Tertiary coal deposition, which in some areas continued from the Upper Cretaceous period, came to an end in Eocene times. Post-Eocene Tertiary time in the United States was marked by general continental elevation and mountain evolution when conditions were not favorable for extensive coal accumulation.

Locations of the most important lignite deposits in the United States are shown in figure 1. Campbell grouped these deposits on the basis of geographical distribution and geological relationship into the Gulf, Northern Great Plains, and Pacific Coast provinces.6

GULF PROVINCE LIGNITE DEPOSITS

GENERAL DESCRIPTION

The Gulf province of Campbell's geographical division of American coal deposits includes parts of Alabama, Mississippi, Arkansas, Louisiana, and Texas. Lignite of early Tertiary age and some local Quaternary peat are the only coal-like solid fuels in this province.


Figure 1.—LIGNITE AND SUBBITUMINOUS-COAL DEPOSITS OF THE UNITED STATES
A narrow marginal belt of outcropping Tertiary beds swings through the States of the lower Mississippi Valley in a great arc, which has the shape of an askew curve, with its apex at the southern tip of Illinois. This great arc outlines a structural basin, the axis of which plunges southward, closely following the general course of the Mississippi River. A broad blanket of Quaternary silt, sand, and gravel is spread over the area, covering many thousands of feet of down-warped Tertiary beds and hiding the structural features.

The slow subsidence of this basin in Cretaceous and Tertiary times permitted the Mexican Gulf to advance northward far beyond the present coast line. This former extension of the Gulf, for the purpose of geological reference, is called the Mississippi embayment. The geological history of the embayment, marked by many reoccurring advances and retreats of the sea, is well-recorded in the thick accumulation of sedimentary beds of marine and continental origin.

The lignite beds of the Gulf province, which are commercially valuable, occur in a zone that extends almost continuously around the margin of the embayment. The lignite is associated with Tertiary formations of Eocene age brought to the surface by the structural dip and exposed by erosion of the Quaternary cover.

LIGNITE DEPOSITS IN THE WILCOX GROUP

NATURE OF THE WILCOX FORMATIONS

The stratigraphic unit that contains the lignite deposits of the Gulf province interbedded with strata of sand and clay bears the geological designation Wilcox group. Virtually all of the sedimentary material representing the Wilcox group is nonmarine in origin and was laid down during the early Eocene epoch of deposition.

Extensive study in the field indicates that the Wilcox group can be divided into as many as five formational units. However, great irregularity in the lithologic character, thickness, and lateral continuity of the sedimentary beds makes it impractical to identify formational subdivisions beyond limited areas. There is, nevertheless, a degree of uniformity of lithologic change from top to bottom of the sedimentary group that permits separation into distinctive divisions that are much alike in widespread areas, if not identical.

The total thickness of Wilcox strata, where reliable measurements of the beds have been obtained, ranges from about 600 to 1,500 feet. This sedimentary material was not deposited in the sea but was spread over a nearly flat coastal plain lying adjacent to the sea. A brief description of the depositional environment will perhaps aid in understanding the present nature of the coal deposits.

ORIGIN OF WILCOX LIGNITE

During the time when basal Tertiary beds, now called the Midway formation, were being laid down in marine waters of the Mississippi embayment, the adjacent land area, over a considerable expanse, was almost completely leveled by erosion, and when the waters of the embayment finally receded toward the open gulf at the close of Midway time, a vast, low-lying coastal area was developed in the wake of the retreating sea. Over this broad coastal plain and along the strand, littoral waters of many kinds were impounded, such as land-locked bays, lagoons, deltaic swamps, estuaries, bayous, swamps, bogs, and marshes. Both brackish and fresh water occurred in the many types of shallow basins in which silt, clay, fine sand, and organic debris accumulated.

The Wilcox coastal plain supported a luxuriant growth of vegetation, as attested by the abundant preservation of plant remains. Beds of lignite, lignitic clays, and carbonaceous sands and clays are characteristic of the Wilcox. Berry collected floral remains from Wilcox beds completely around the embayment from Alabama to Texas; many hundreds of species of arboreal and herbaceous plants were collected and identified. His study of these plant fossils furnishes rather conclusive evidence that Wilcox time was a period of warm, temperate climate and abundant rainfall, which supported a dense, predominately herbaceous flora similar in many respects to that now found on the subtropical shores of the present Gulf of Mexico.

A warm, moist climate, although favoring lush growth of vegetation, does not alone account for coal deposits. It is necessary that there be basins in which conditions are suitable for the accumulation of plant debris and its preservation from complete decay. Many such favorable spots were present along the Wilcox coastal plain, but, as a rule, they were small and very irregular in shape. No vast, continuous, coal-forming swamps were in existence, but, instead, a large number of small, discontinuous areas were present in which peat accumulated, to be converted into lignite later.

NATURE OF WILCOX LIGNITE DEPOSITS

Because the Wilcox deposits are many and relatively small, rather than uniformly thick, widespread, blanketlike beds, general information regarding them must be developed from study of the local deposits. Individual deposits have a unique structure predetermined by the shape and size of the basins in which the coal accumulated. A great many outcroppings of lignite are known around the Mississippi

embayment, and drilling of many test holes and water wells has disclosed coal, but few deposits have been prospected systematically to determine their outline and extent.

Exposures of beds in vertical profile suitable for good field study are not commonly found where unconsolidated sand and clay strata, such as in the Wilcox formations, predominate. The surface exposures of such sedimentary beds are usually indicated by the type of soil, local topography, and sometimes by type of vegetation. Compact, relatively hard beds of lignite do occasionally outcrop in creek beds where vertical erosion is more rapid than horizontal erosion. However, outcrops are too infrequent to provide much information concerning a single deposit from reconnaissance field study. Closely spaced test drilling offers about the only means of outlining and evaluating deposits (fig. 2).

**Figure 2.**—MAP SHOWING TWO SMALL LIGNITE DEPOSITS FOUND AT SHALLOW DEPTHS BELOW SURFACE.

(Interpreted from drill-hole data, Bureau of Mines bauxite test drilling project in Saline County, Ark.)
The typical Wilcox lignite deposits occur, with considerable variation, in elliptical, elongate, and sinuously elongate forms. The deposits are usually thin-edged and downwarped, typical of beds accumulated in small, shallow depressions of various shapes. A field drawing showing a cross-sectional view of perhaps a typical small lignite deposit exposed in a large bauxite strip pit is shown in figure 3.

The quantity of coal in any particular deposit is not likely to be very large. The amount of coal present in probably a majority of Wilcox lignite deposits is less than 1,000,000 tons, or an average of 3 feet of lignite under about 200 acres of land. Thicker beds of lignite do occur in the Wilcox group, and some deposits cover a much greater area than 200 acres; but throughout most of the embayment area, thick beds of large area are exceptional.

In Alabama, a single bed of lignite 4 to 7 feet thick is believed to underlie a considerable area in Morengo and Wilcox Counties. Most of the lignite beds in the State, however, are less than 3 feet thick and of small areal extent.

The Mississippi State Geological Survey reports that a bed thickness of 5 or 6 feet is rare in the State and that it usually is 1 to 3 feet. The deposits observed in outcrops are believed to be small.

The largest known deposit in Arkansas was originally estimated to contain 75,000,000 tons, based upon observed outcrops; the field has never been drilled to substantiate this figure. Most of the many known occurrences in the State are less than 4 feet thick, and the few deposits that have been explored fully have proved to be small.

The largest and thickest known deposits of Wilcox lignite are in Louisiana and Texas.

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Footnotes:
Beds up to 14 feet thick exist in both States. In Texas several deposits containing many million tons have been proved by drilling in conjunction with large-scale mining.

The preceding general discussion of the Wilcox group of sedimentary strata (including the lignite deposits) has been introduced to give a brief description of the only important coal-bearing formation of the Gulf province. Although the individual lignite deposits have been cited to be characteristically local in extent, irregular in outline, and usually less than 3 feet thick, some large deposits of thick beds containing several million tons each are known in Alabama, Arkansas, Louisiana, and Texas.

This description of Gulf province lignite is rather incomplete because of scarcity of extensive field information. In the following section of the report lignite occurrences in Arkansas and Texas are described in greater detail. Some of the deposits in these States were sampled for wax-extraction tests and petrographic study, the results of which are given elsewhere in this report.

**LIGNITE DEPOSITS IN ARKANSAS**

The presence of lignite deposits in two areas of the State, one in the northeast and the other in the southwest (fig. 4), is known from outcroppings, water wells, and test holes.

**CROWLEY'S RIDGE**

The Crowley's Ridge area is perhaps less important than the southwestern area because

![Figure 4](image-url)
local geology and topography do not favor the presence of large quantities of lignite.

Lignite-bearing strata, probably belonging to the Wilcox group, outcrop along the east and west flanks of a relatively narrow, low hill, which extends northward through the Mississippi alluvial plain of northeastern Arkansas. This hill, known locally as Crowley's Ridge, is an erosional remnant carved by the Mississippi River when it formed the present broad flood plain in the lower valley.

In Clay, Greene, Craighead, and Poinsett Counties, the ridge consists of a thick cap of loesslike silt of doubtful origin overlaying an old soil surface developed, in part, at least, on anciently exposed beds of Wilcox age. Erosion has removed the Wilcox beds wholly or partly east and west of the ridge. If any lignite deposits remain outside of the ridge area, the beds are buried beneath river alluvium. Farther south, the regional dip of the strata carries the Wilcox to such depth that the beds do not form an integral part of the ridge.

Exposures of Wilcox beds beneath the loessial silt are infrequent and poor, and only a few lignite outcrops are known. The old, exposed surface of the ridge was highly eroded before the thick cap of loessial silt was deposited, and field evidence suggests that only patches of lignite were preserved beneath the loess.

SOUTHWESTERN COUNTIES

The most extensive deposit of lignite in Arkansas is in an irregular belt 5 to 20 miles wide extending from near Little Rock to the Texas line, as shown in figure 4. In this area the Wilcox strata have been the subject of a more thorough field study, and a few of the lignite deposits have been developed commercially on a small scale.

In the vicinity of the bauxite mines in Saline and Pulaski Counties, the Geological Survey, Bureau of Mines, and private organizations have drilled a large number of bauxite test holes. These holes have been drilled to the base of the Wilcox in seeking contact with the Midway formation, which is the zone of bauxite ore deposition. The test drilling has furnished drill-hole logs that contain good descriptions of the Wilcox beds, and a number of lignite cores have been recovered. Good exposures of Wilcox strata can be seen, also, in the huge strip pits of the bauxite mines. Therefore, in this particular locality the Wilcox is quite well known, but the accumulated information has not yet been published.

United States Government geologists cooperating with Bureau of Mines drilling crews have determined the average thickness of the Wilcox group to be about 900 feet in the bauxite area. They found that approximately the upper one-third consisted of fine-grained sand having a persistent "woody" lignite horizon near the base. Below the sand, a somewhat thicker series of sandy, carbonaceous clay and silt-clay beds were grouped into a formational unit. This formation is characterized by thick beds of dark-brown, lignitic clays, but true lignite beds are not common. The basal Wilcox beds, consisting of about 200 feet of sand, silt, kaolinitic clay, lignite, and bauxitic material, have a group characteristic that seems to warrant designation as a separate unit. The coarse, elastic nature of these beds may be a persistent feature for a considerable distance, but probably the occurrence of bauxite deposits is a local condition in Pulaski and Saline Counties.

Subdivision of the Wilcox group into named and described formational units would more than likely have only local significance. It is quite possible, however, that the variability from the base to the top of the Wilcox group may assume a certain order that may persist for a considerable distance.

RECOVERY OF ARKANSAS LIGNITE

Lignite was mined intermittently in the so-called Camden coal field from before the Civil War until 1943. All of the early mines were simple drift tunnels opened along the outcrop and driven into the bed 50 to 200 feet. Mining was somewhat seasonal, and the cost was relatively low. Wages were not high, and an abundance of timber was readily available to crib the soft clay roof. No stripping was done to uncover the coal.

Originally, the lignite was mined for fuel and used principally by local saw mills, cotton gins, and small steam locomotives on logging roads. Use of the coal for fuel began to decline when the use of natural gas and petroleum products increased shortly after 1900, in which year it was reported that nine mines were producing lignite. When the mining field was visited by White in 1907, he found that lignite was used chiefly to obtain oil by distillation. Two small oil-distilling plants that used lignite were in operation, which gave yields of 10 to 38 gallons per ton.

Distillation of oil from the Camden lignite seems to have been in a more or less experimental stage when visited by White, as there is no record of a large industry being developed and maintained.

Lignite was again mined in the area after 1938. This time it was used to make watersoluble flakes and granules of a type called "Vandyke brown." A small plant was built for processing the lignite at El Dorado and operated about 3 years. Public records show

that 709 tons was mined in 1941. It is not certain whether this lignite was processed at the El Dorado plant or shipped to a similar plant in New Jersey. In 1943 the New Jersey plant was moved to Malvern, Ark. (fig. 5), where lignite processing was carried on throughout the war.

Lignite for processing at Malvern was obtained from small mines in Ouachita, Dallas, and Hot Springs Counties. These were stripping operations and represented the first serious attempts to recover Arkansas lignite in this way. There is no record of the amount of lignite mined during the war years, but annual production probably exceeded 1,000 tons. No lignite mines were in active operation in 1947.

The amount of lignite present in Arkansas cannot be estimated accurately. It has been pointed out that the Wilcox deposits are many, and that they are generally small, irregularly shaped bodies of coal. If all the deposits were known and a fair average of tonnage were determined for each, obviously a safe estimate could be made, but such information does not exist. A few score of outcrops are known, and the presence of lignite in many water wells and drill holes has been reliably reported, but authoritative information regarding the deposits is still scanty.

Taff and White believed that the lignite in the Camden coal field consisted of a single bed, which they thought underlay approximately 50 square miles. Taff computed the area in the central part of the field to contain at least 75,000,000 tons. No other public survey of the field has been made since Taff’s work was done in 1900. As less coal is exposed today because of cessation of mining and subsequent erosion, there is no basis for changing the early estimate. It is possible that if this lignite field were closely drilled, a lignitic zone comprising several discontinuous bodies of lignite existing at the same or about the same level might be found rather than a single bed.

LIGNITE DEPOSITS IN TEXAS

Lignite deposits most likely to be considered of commercial importance in Texas occur in Wilcox strata. These lignite deposits are exposed with considerable spottingness over a rather broad belt 40 to 175 miles wide extending from the Arkansas and Louisiana State lines to the Rio Grande.

Extensive geological work and test drilling for oil and gas has revealed much concerning the Wilcox deposits. Commercial development of the lignite deposits, which has been of appreciable magnitude, also has added greatly to knowledge of the Wilcox group. Information pertaining to these strata in Texas is much more complete than for any other State in the Mississippi embayment in which the lignite-bearing rocks occur.

Texas geologists have subdivided the Wilcox group into three formational units briefly identified as (1) Seguin formation, approxi-

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**Figure 5.—ABANDONED LIGNITE-PROCESSING PLANT, MALVERN, ARK.**

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mately 100 feet of basal strata of marine origin; (2) Rockdale formation, 500 to 900 feet of continental deposits, including many lignite beds; and (3) Sabinetown formation, less than 100 feet of sediments of marine origin.

ROCKDALE FORMATION

The interbedded sands, clays, and lignites of the Rockdale formation are typical of all the so-called continental deposits that characterize the Wilcox throughout the Mississippi embayment. The depositional environment of the Rockdale sediments interpreted from field data is pictured as a broad, very gently sloping coastal plain, over which was spread, mostly by sluggish, continually shifting rivers, a heterogeneous interfingered mixture of sedimentary deposits. The sedimentary material, which accumulated in lenticular and sinuous deposits, consisted of fine sand, clay, organic silt, and plant debris. The conditions of sedimentary accumulation were not at all favorable for development of extensive, uniformly thick beds of coal. The coastal plain was constantly undergoing slow change marked by shifting rivers and local fluctuations in the shore line. Shallow water basins, sloughs, and swamps suitable for collecting and preserving plant debris were numerous but relatively short-lived and of small extent. Plant material grew luxuriantly, supported by a favorable, warm, moist climate. Coal material accumulated in many local spots, where it was protected from excessively rapid decay and intermingling of sand and clay sediments.

In addition to the deposits of the Rockdale formation, lignite lenses of lesser importance occur associated with the nonmarine sands and clays of the Yegua formation. The Yegua formation, early Eocene in age but younger than the Rockdale, lies about 800 to 1,000 feet above beds of Wilcox age. The continental sediments that represent the Yegua were laid down under environmental conditions essentially similar to those of the Rockdale epoch, but which were not particularly favorable for accumulating and preserving lignite deposits.

RECOVERY OF TEXAS LIGNITE

Mining of Texas lignite was first reported, with production of 20,000 tons, in 1893. Annual increase thereafter was gradual, and in 20 years production reached 1,180,000 tons. During the following 17-year period, the average annual recovery of lignite was approximately 1,000,000 tons. Then a gradual decline set in during the next 11-year period, when the average tonnage mined yearly dropped to 740,000. A more rapid decline began in 1941, and by 1946 production was down to 55,000 tons.

Lignite and bituminous-coal production in Texas began about 10 years apart. It is interesting to compare the production cycles of these two different coals produced in the same region. The period of large-scale production of bituminous coal lasted 45 years, from 1894 to 1929, during which 26,000,000 tons was mined. Peak year was 1917, when 1,260,000 tons was mined.

Large-scale mining of lignite began in 1893 and continued until 1944, a period of 51 years, during which 35,000,000 tons of coal was recovered. Peak production was reached in 1927, when 1,205,000 tons of lignite was mined.

The best explanation for a slower start in mining lignite in Texas probably lies in the fact that generally consumers were unfamiliar with coal of this type and may have been skeptical at first of its burning performance. However, when a demand for lignite was established, it held up for a time after mining of bituminous coal was virtually abandoned. The cost of strip-mining lignite could be reduced considerably below the cost of recovering bituminous coal from thinner and more deeply buried beds. The mining-cost differential more than offset differences in quality of the two coals.

![Figure 6.—View of the South Wall of Darco Strip Mine, Harrison County, Tex., Showing Two Beds of Lignite Separated by a Layer of Clay 3½ Feet Thick.](image-url)
LIGNITE RESERVES IN TEXAS

The Rockdale lignite deposits of Texas are more extensive and thicker and also occur in more stratigraphic positions than in any other Wilcox-zone lignites of the entire Mississippi embayment. The maximum thickness of a single deposit is about 15 feet. Most of the beds that have been worked average more than 7 feet in thickness. Sometimes two workable beds occur in the same locality separated by a few feet of clay, as is shown in figure 6. Many lignite deposits lie sufficiently close to the surface to permit strip mining.

The total amount of lignite in Texas is large, but available information is far from complete enough to permit calculating tonnage with acceptable accuracy. Some published figures seem to be much greater than the probable reserves. Private estimates based upon detailed field information concerning some of the large deposits that have been more or less closely prospected do not support the large figures.

NORTHERN GREAT PLAINS PROVINCE LIGNITE DEPOSITS

GENERAL DESCRIPTION

The lignite deposits in this region are the most extensive in the United States. They occur mainly in western North Dakota, eastern Montana, and northwestern South Dakota and encompass an area of about 40,000 square miles. This area was named the Fort Union region by Campbell from the most important lignite-bearing geological unit.

The Fort Union formation consists of approximately 1,300 feet of soft sandstone, shale, sandy shale, and shaly sandstone interbedded with numerous layers of lignite. The lignite layers are generally the most persistent units in the formation, several having been traced for more than 50 miles. The number of lignite beds contained in the Fort Union formation is great. More than 100 workable deposits are known that range in thickness from 4 to 35 feet. It has never been determined with any degree of certainty how many beds actually exist, including those only a few inches thick.

The beds of the Fort Union are all of continental origin. The sandstones, shales, and gradational sandy-to-shaly beds were deposited in shallow fresh-water basins. Coexisting with the fresh-water basins were swamp and bog areas much more extensive, in which accumulated plant remains later converted to lignite. The persistence of the lignite beds is in strong contrast with the characteristically lenticular nature of the sandstone and shale deposits.

The Fort Union formation is assigned geologically to the Paleocene epoch. It may possibly have been deposited in part contemporaneously with the Wilcox group of the Gulf province. At least, both groups of nonmarine sedimentary deposits are early Tertiary in age, and identifiable plant remains associated with the sedimentary beds in both provinces have some things in common.

Lignite beds of Paleocene age also occur in the upper 100 feet of the Ludlow shale. The deposits, however, are of minor importance, compared with those in the overlying Fort Union formation. The beds are usually less than 20 inches thick. The principal lignite beds mined in South Dakota are in the Ludlow shale.

LIGNITE DEPOSITS IN NORTH DAKOTA

North Dakota has by far the most important lignite deposits in the United States, at least from the standpoint of potential tonnage. Almost the entire western half of the State is underlain with lignite-bearing rocks. The largest area within the Fort Union region lies in North Dakota and includes two-thirds of its total reserves. The most competent estimates that have been made place the amount of lignite in North Dakota at more than 600 billion tons. These estimates represent rational attempts to evaluate the amount of lignite present in the Fort Union formation of North Dakota. The accuracy of the estimates is of no great importance, for if later evaluations on the basis of more complete information and more critical considerations should scale 1 or 2 hundred billion tons from the figure, the remainder would still be tremendously large. It is entirely possible that later revisions might be up rather than down.

The lignite-bearing Ludlow shale at the base of the Fort Union formation is too deeply buried in most of North Dakota, and the coal layers are too thin to warrant commercial consideration at present.

Many of the most important coal deposits in the Fort Union formation occur at depths less than 300 feet below the surface, although the formation contains lignite beds throughout the entire thickness of 1,300 feet. The coal beds are not affected by any pronounced regional or local structure such as crustal folding. They are essentially flat and free of major fault displacements, but local irregularities of some importance result from thickening and thinning of beds. The lateral continuity of the deposits is rather unusual, compared with that of other lignite regions. Several beds can be traced for many miles by surface exposures, and some are known from drill-hole information to underlie hundreds of square miles.
RECOVERY OF NORTH DAKOTA LIGNITE

Mining of lignite in North Dakota can be traced back to 1884, when 35,000 tons of coal was produced. Increase in production was slow until 1900, when mining began to assume considerable importance, with annual production in excess of 130,000 tons. By 1925 the yearly recovery of coal was 1,360,000 tons, and production continued to increase, reaching 2,500,000 tons in 1945. Since about 1925, North Dakota has replaced Texas as the leading producer of lignite. In 1947 North Dakota mining operations accounted for 96.1 percent of total lignite produced in the United States. Texas accounted for 2.1 percent, Montana 1.3 percent, and South Dakota 0.5 percent.

The preminence of the Fort Union region in lignite mining when in other regions production has dropped to an extremely low figure can be attributed to (1) an abundance of the coal in an area of relatively heavy seasonal fuel consumption, (2) suitability of deposits for recovery at relatively low mining costs, (3) absence of local sources of petroleum and natural gas, and (4) absence of local sources of higher-rank coals.

PACIFIC COAST PROVINCE LIGNITE DEPOSITS

CALIFORNIA

The most important lignite deposits in the Pacific Coast province probably occur in Amador County, Calif. This is not known conclusively, for the lignite deposits in this province have been little prospected. However, the deposits in the vicinity of Ione and Buena Vista are the best-known and were developed in a small way from about 1870 to 1912.

The lignite in Amador County occurs in the Ione formation, which consists of white clay and sand interbedded with lignite beds reported to range in thickness from a few inches to as much as 30 feet. The Ione formation is Eocene in age and may belong to the middle portion of this early Tertiary epoch. The Ione lignite is probably a little younger than the Dakota and Gulf States lignites, which are Paleocene and early Eocene, respectively. The Ione formation has been traced for 200 miles and is known to contain lignite beds in other California counties.

From scanty drill-hole information, outcrop observations, some mining, and clay prospecting work, it is believed that at least three workable beds occur in the Ione-Carbondale district. All lie within 120 feet of the surface, although one drilling project near Carbondale reported three beds of lignite 25 to 250 feet in depth. The coal beds, insofar as they have been prospected, seem to be typical lenticular deposits of limited lateral extent.

The few small mines in the Ione district that produced lignite were active from about 1871 to 1912, although recovery of coal was not great after 1902. The total tonnage of lignite mined probably did not exceed 300,000 tons.

As was the case in the Gulf States province, lignite mining virtually ended in California with the advent of an abundant supply of relatively cheap petroleum and natural gas.
GENERAL NATURE AND USE OF MONTAN WAX

Montan wax belongs to the broad class of natural waxes that are useful in many applications and have become important items in industry. The natural waxes may be divided arbitrarily into three groups, depending on their origin and occurrence—animal, mineral, or vegetable. The "mineral waxes" are not mineral by strict definition of the term but are so classified by virtue of their geological occurrence. The animal waxes, including insect waxes, are represented by beeswax, spermaceri, wool wax, Chinese wax, and shellac wax; the mineral waxes by montan wax, ozokerite, and the paraffin hydrocarbons; and the vegetable waxes by carnauba, candelilla, ouricury, Japan, bayberry, and several others. Many of these natural waxes are not produced in the United States, and this country is dependent on foreign sources. The commercial importance of these imported waxes is shown in table 1. In 1939, more than 7,000,000 pounds of montan wax valued at $700,000 came into this country.

The commercial grade of crude or raw montan wax is a high-melting, hard, brittle wax, which, because of its desirable properties, has many uses. It is an important ingredient in certain polishes, electrical insulating compositions, leather dressings, inks, carbon papers, protective coatings, greases, and other products. Before World War II the I. G. Farbenindustrie A. G. in Germany produced chemically modified or so-called synthetic waxes that were processed from crude and desemified grades of montan wax. These were sold as I. G. waxes to replace or supplement many of the commercial grades of natural wax for various uses. The applications of montan wax in the chemical, electrical, fat and oil, food, glue and adhesive, ink, leather, metallurgical, and other industries have been summarized by Gregory. Formulas for many commercial products of which it is an ingredient have been described by Bennett.

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**Table 1.—Imports and import values of natural waxes**

<table>
<thead>
<tr>
<th>Year</th>
<th>Montan wax</th>
<th>Vegetable waxes</th>
<th>Animal waxes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1,000 pounds</td>
<td>1,000 dollars</td>
<td>1,000 dollars</td>
</tr>
<tr>
<td>1925</td>
<td>6,175</td>
<td>362</td>
<td></td>
</tr>
<tr>
<td>1926</td>
<td>8,286</td>
<td>480</td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>7,600</td>
<td>579</td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td>10,901</td>
<td>594</td>
<td>5,471</td>
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<tr>
<td>1929</td>
<td>9,791</td>
<td>617</td>
<td>6,849</td>
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<tr>
<td>1930</td>
<td>12,475</td>
<td>722</td>
<td>7,416</td>
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<tr>
<td>1931</td>
<td>8,010</td>
<td>429</td>
<td>7,447</td>
</tr>
<tr>
<td>1932</td>
<td>5,150</td>
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<tr>
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<td>6,658</td>
<td>454</td>
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<td>7,618</td>
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<tr>
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<td>5,585</td>
<td>545</td>
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<td>783</td>
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<tr>
<td>1943</td>
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<td>18,307</td>
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<tr>
<td>1944</td>
<td>0</td>
<td>0</td>
<td>17,510</td>
</tr>
</tbody>
</table>

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1 Compiled from Foreign Commerce and Navigation of the United States for calendar years 1925 to 1944, U. S. Department of Commerce.
2 Data for years 1925 to 1936 include small quantities of other mineral waxes.
3 Largey beeswax.
Montan wax is essentially a mixture of waxy constituents consisting of monohydric alcohol esters and high-molecular-weight acids with some resinous and asphaltic material. The proportion of these constituents depends on both the source of the brown coal or lignite from which the wax is extracted and the solvents used in the extraction process. Montan wax has been investigated for the purpose of isolating and identifying its various chemical components. Results of the investigations have been summarized in published reports by Kiebler, Fischer, Reilly and Kelly, and Warth. Among the chemical constituents identified are a number of esters, acids, alcohols, ketones, hydrocarbons, and resins.

COMMERCIAL PRODUCTION OF MONTAN WAX IN GERMANY AND CZECHOSLOVAKIA

The technology of montan-wax production in Germany has been reviewed by Bube and Heinez.\(^{17}\) Investigators \(^{18}\) who visited Germany since the close of the war also have reported on the status of the German montan-wax industry and methods used in the commercial extraction and refinement of the wax. The methods reported differ in certain details but are essentially as described below.

The plant capacity in Germany is reported to have been 1,500 to 1,700 tons of wax per month. During and before World War II, all of it was produced at the Riebeck Montan Werke at Amsdorf and Wansleben, near Halle. These plants are in the present Russian zone of Germany. The crude wax produced by this company was extracted from brown coal from central Germany. The coal was mined in open pits at Amsdorf and Oberroblingen, near Halle, and Grube Concordia, near Wachterstedt.

Coal from these areas was richest in wax, the amount ranging from 10 to 15 percent and sometimes as high as 18 percent. The coal was separated in the mine by picking out the high-wax-content coal for montan-wax extraction and selling the remainder as fuel. The brown-coal deposits in western Germany are reported to have a low content of wax.

The coal was crushed, dried to a moisture content of 10 to 15 percent, and sieved to remove dust. The wax was removed from the dedusted coal by solvent extraction in either batch or continuous extractors. The solvents reported to have been used included a mixture of 80 percent benzene and 20 percent ethyl alcohol \(^{19}\) and a mixture of 85 percent benzene and 15 percent unrefined wood alcohol (containing methyl and isopropyl alcohol).\(^{20}\)

Examination of records of the I. G. Farbenindustrie A. G. by Cawley \(^{21}\) showed that extraction process employing benzene alone was the simplest to operate. However, the solvent power of the aromatic hydrocarbons was not considered to be sufficient to remove all of the wax, as the colloidal properties of the coal are lost during drying. The colloidal properties are reported to be regained on adding an oxygen-containing solvent, and both the extraction rate and yield of wax are increased. Cawley states that the exact nature of the alcohol used in the mixture is in doubt, but that isopropyl alcohol is reported to have been the most suitable.

The crude montan wax was sold as such or processed further. In making certain of the I. G. waxes, the crude grade was normally treated to remove the resin. For this purpose the crude wax was powdered and treated with alcohol or the benzene-alcohol mixture used in extracting the wax, but at lower temperatures. The resin was soluble at these temperatures, whereas the wax fraction was relatively insoluble. The separation of wax was not clean-cut. The crude wax is reported to contain approximately 20 percent resin and the desinified wax about 5 percent resin.

The crude montan wax was distilled also for the preparation of so-called refined montan wax. It was distilled in iron kettles under a vacuum of 40 to 50 mm. of mercury at temperatures from 180\(^\circ\) to 500\(^\circ\) C. The distillate was separated into three fractions—oil, wax, and pitch. The wax fraction prepared in this manner was used in the preparation of so-called bleached montan wax and certain other wax products.

Crude and desinified montan wax was shipped to the I. G. Farbenindustrie A. G. in Gersthofen and Oppau for processing into I. G. waxes.\(^{22}\) These were made almost entirely by oxidation of the montan wax to varying degrees, which was sometimes followed by esterification and other procedures to give the desired product.

Montan wax has been produced also in Czechoslovakia from North Bohemian brown coal mined near Karlsbad. Production of this wax was stopped in 1934 following an arrangement with the Riebeck A. G. It was intended to resume production sometime before the war.\(^{23}\)

Crude montan wax has also been reported\(^{24}\) to have been produced in Czechoslovakia, at Karlsbad, by the Bituma Co. This company was not in operation at the end of the war.
COMMERCIAL PRODUCTION OF DOMESTIC MONTAN WAX

During World War II, the American Dye-wood Co. operated a plant at Malvern, Ark., for making dyes or stains and extracting wax from Arkansas lignite. This plant suspended operations shortly after the close of the war. The wax produced was reported to have been acceptable to several of the consuming industries, particularly shoe-polish manufacturers. A low yield of 5 to 6 percent of crude wax obtained from the Arkansas lignite with the equip-


ment and process available was reported to have been one of the chief obstacles to continued commercial operation.

Recently, the American Lignite Products Co. erected a plant at Buena Vista, Calif., for extraction of wax from California lignite mined in Amador County. The raw lignite for the plant is obtained by strip-mining beds near Ione. The properties of a sample of semirefined wax from this plant are described later in this report.
INVESTIGATION OF WAXES EXTRACTABLE FROM BRITISH LIGNITE

During World War II, the Fuel Research Station, Department of Scientific and Industrial Research, London, at the request of the Non-Ferrous Mineral Development Control of the Ministry of Supply investigated native sources of wax to replace imported montan wax for a specific war purpose at a time when supplies of montan wax were not assured. The work was mainly concerned with examination of lignite wax and the possibilities of extracting it on a large scale.

The lignite studied in the survey was that found in the Bovey Tracey Basin in Devonshire. This area contains the only deposits of any magnitude in Great Britain. The lignite is of Upper Oligocene age. The Bovey beds in this basin consist of clays and sands interstratified with lignitic clays and lignite. The clays are used in the manufacture of ceramic ware, but the lignites have had little commercial importance in the past.

Results of a laboratory survey of many samples of lignite from this deposit indicated that the lignite contained up to 5 percent of crude wax extractable with benzene. The properties of the wax were generally similar to those of German montan wax. The resin content of the wax from the Bovey Tracey lignite was higher than that of the German montan wax examined. Higher yields of wax were obtained with other solvents, particularly those containing alcohol, but the nature of the wax was changed because of increased resinous and asphalitic material.

The survey indicated that there would be some difficulty in commercial operation because the lignite beds are discontinuous and intermingled with clay.

Recent reports state that a company has been formed for commercial extraction of wax from the Bovey Tracey deposits. A special type of activated carbon may be produced as a byproduct. It is proposed to dispose of the extracted lignite in the form of briquets made with coal tar as a binder.

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INVESTIGATIONS OF WAXES EXTRACTABLE FROM PEAT

A wax similar in many ways to montan wax is obtained from certain peats. It differs from montan wax, however, in several important properties and cannot be used generally as a direct substitute. The literature on the chemistry of peat wax has been reviewed by Kiebler.\textsuperscript{28}

Thiessen and Johnson,\textsuperscript{29} in a study of a Wisconsin peat deposit, found that the ether-soluble material from the peat fluctuated irregularly between approximately 2 and 6.6 percent from top to bottom of the deposit. The ether extract consisted chiefly of fats, resins, waxes, and some chlorophyll. The wax fraction constituted 50 percent of the total extract. The wax, purified by recrystallization from petroleum ether, had a melting point, acid number, saponification number, and iodine value similar to montan wax.\textsuperscript{30}

Investigation by Ivanovszky\textsuperscript{31} of wax extracted from a sample of peat from the Chatham Islands, New Zealand, showed that it generally had a lower melting point than montan wax and was not as compatible with paraffin wax. Some of the difference was attributed to the relatively high content of asphalthic material in the peat wax. The wax probably could be improved to resemble montan wax more closely if the proportions of resinous and asphalthic material in the peat wax were reduced by suitable methods.

Reilly and coworkers have made an extensive study of Irish peat waxes, results of which have been summarized in a recent report.\textsuperscript{32} Yields of wax ranging from 3.1 to 14.5 percent on a dry-peat basis were obtained in extraction tests of 23 samples of Irish peat made with trichloroethylene as solvent. The yields and properties of the wax were found to be dependent on the type of solvent used. The properties of the peat waxes were generally somewhat similar to those of montan wax, but the peat wax was not as hard as montan wax. The peat waxes generally had a lower melting point and were darker in color than crude montan wax; dielectric properties and “solvent retentivity” values were similar.

In a survey of Canadian peat, Davis\textsuperscript{33} analyzed 28 samples for their wax content. Yields of wax ranged from 2.1 to 15.8 percent. The properties of the waxes were not reported.

The Fuel Research Station, Department of Scientific and Industrial Research, London, investigated 47 samples of English and Scottish peat.\textsuperscript{34} The yields of wax obtained by benzene extraction ranged from 2.7 to 17.4 percent on a dry-peat basis. The properties of the peat waxes were similar in many ways to montan wax but had several important differences. The peat wax in general contained more resinous and asphalthic material, was not as completely miscible with paraffin wax, and had a lower melting point than montan wax. The compatibility of the wax with paraffin wax was improved by solvent treatment to remove the asphalthic material. Oxidation of the crude wax with chromic acid and sulfuric acid yielded pale yellow waxes. The oxidized waxes may have commercial importance in preparation of waxes similar in type to the I. G. waxes.

It has been reported that an experimental plant is to be erected at North Connel, near Oban, Scotland, for wax extraction of peat from deposits at Achnachree Moss, North Argyle.\textsuperscript{35}

\textsuperscript{28} Kiebler, M. W., Work cited in footnote 16, pp. 679-690.
\textsuperscript{31} Ivanovszky, L., Work cited in footnote 21.
\textsuperscript{32} Reilly, Joseph, and Kelly, Denis F., Work cited in footnote 16.

\textsuperscript{34} Cawley, C. M., Carville, J. H. G., and Nokes, C. C., Ester Waxes from British Peat: Petroleum, vol. 11, 1948, pp. 77-82.
WAXES EXTRACTABLE FROM AMERICAN LIGNITES

PUBLISHED REPORTS ON LABORATORY INVESTIGATIONS OF AMERICAN AND CANADIAN LIGNITES

Little information has been published concerning solvent extraction of domestic low-rank coals. It was concluded from an examination of several American lignites that the wax yields were low and probably would be unprofitable under conditions at that time, even if the wax content approached that of European brown coals. In connection with briquetting tests of certain domestic lignites to determine the percentage of bitumen or natural binding material in the raw or briquetted fuel, solvent extraction tests with carbon disulfide were made with the following results (dry basis): briquets from Ione lignite, Amador County, Calif.—7.0 to 8.4 percent; North Dakota lignite—1.1 to 1.8 percent; and Texas lignite—1.3 to 1.9 percent. Abraham has reported that Graefe obtained 2.07 percent of montan wax from dried Texas lignite. Glenk found that extraction of Mansfield, La., lignite with petroleum ether, ethyl ether, and ethyl alcohol yielded so little material that these solvents were discarded at once. Chloroform extracted 0.5 percent of a waxy substance melting at 104° F., and carbon disulfide removed 0.48 percent of hard, shiny wax that melted at 155° F. Extraction of Velva lignite from North Dakota with benzene under pressure yielded up to 4.3 percent extract on a dry, ash-free coal basis, and Harris, Belcher, and Gauger concluded from this study that the portion of the extract obtained up to a pressure of 17 atmospheres had a composition closely analogous to montan wax from German brown coal. Rietz, in an investigation at the University of North Dakota, found that the benzene extracts from North Dakota lignite contained small quantities of phenols.

Certain Canadian coals from Alberta, British Columbia, and Saskatchewan, have been surveyed. Some of the fields in which these coals occur are extensions of those of northwestern United States. It was concluded from one of these studies that the montan-wax content of the Alberta samples examined was low. In another report, montan wax (benzene extract) was found in only one coal, and that was so small as to be considered commercially unimportant.

LABORATORY EXTRACTION METHOD

Numerous solvents have been used in investigative work on European brown coals and peats. From these studies it has been found that the yields as well as the properties of the waxes are affected considerably by the type of solvent used in the extraction. The choice of a solvent, therefore, will depend somewhat on the desired properties of the wax. The solvent used in the German montan wax industry is reported to be a mixture of benzene and an alcohol. In the survey of wax extraction of lignite from a deposit in Devonshire, England, it was found that extraction with benzene gave a product similar to German montan wax in appearance, melting point, acid value, and ester value; higher yields were obtained with solvents containing ethyl alcohol, but the waxes were different in quality. The solvents used in the determination of the extraction yields of domestic lignites reported in this paper have been largely confined to benzene and a mixture of 80 parts by volume of benzene and 20 of ethyl alcohol.

The laboratory extraction tests were made in duplicate in the usual type of Soxhlet apparatus on air-dried samples crushed to pass a No. 20 sieve. Tests also were made of a few coals that had been dried at 105° C. Preliminary tests to determine the effect of fineness of the samples upon the extraction yields were made on samples crushed to pass No. 60 and No. 200 sieves. The results of these tests were generally not satisfactory, as the extraction rate was slow because it was difficult for the solvent to percolate through such finely divided lignite. The yields of wax from the coals examined

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27 Graefe, Edmund, Beurunkohlen-Industrie; Verlag von Wilhelm Knapp, Halle, Germany, 1908.
were determined for extraction periods lasting up to 12\(\frac{1}{2}\) hours. These showed that nearly all of the wax was extracted in the first few hours. Figure 7 shows the cumulative removal of wax from a sample of typical lignite from the American Dyewood Co. mine in Dallas County, Ark. Figure 8 gives similar data, in which is shown the time required to remove various percentages of the extractable wax. For example, 90 percent of the wax was removed from this coal in 1 hour by solvent treatment with benzene and in 3 hours with a benzene-alcohol mixture. It may be that the differences in cumulative removal of the wax with benzene and benzene-alcohol can be accounted for by differences in the composition of the extractable material, as is shown later in the report in table 4.

At the end of the extraction period, the wax solution was transferred to a short-neck, round-bottom flask, and the solvent was removed by distillation. The last traces of solvent were removed from the wax under reduced pressure, first with a water-aspirator pump and finally to constant weight at 100°C with a mechanical vacuum pump. Care must be taken in removing the last traces of solvent, as the extracts froth considerably until all of the solvent has been removed. Finally, the extract in the flask was weighed, and the percentage yield was calculated based on the weight of the sample taken for extraction. Completeness of extraction was verified by treating the residue with fresh solvent.

In using the benzene-alcohol solvents, certain of the lignites swelled to such an extent as to rupture the extraction thimbles. This trouble was overcome by placing the sample in a thimble, which was then inserted in one of the next larger size and extraction proceeded as usual. Any particles passing through the rupture were caught in the outer thimble.

**EXTRACTION YIELDS**

Table 2 gives the source and analysis of the coals studied in this survey. A more complete description of the samples is given in the appendix. The analyses listed in the table are shown on the as-received, air-dry, dry, and moisture-and ash-free bases. Comparison of the analyses shows that on the moisture- and ash-free basis the volatile-matter contents of the Arkansas and California lignites are in general about 10 to 15 percent higher than those of the samples examined from the other States. A notable exception is the brown-coal sample from King County, Wash., which had been in storage for several years. This coal has a volatile-matter content of 65.3 percent on the moisture- and ash-free basis. Its calorific value of 10,320 B. t. u. per pound on the same basis is lower, however, than that of any other sample. A fresh sample of this coal had a volatile-matter content of 61.9 percent and calorific value of 10,810 B. t. u. per pound on the moisture- and ash-free basis. The calorific values of the other lignite samples examined in the wax-extraction survey range from 11,560 to 13,320 B. t. u. per pound on the moisture- and ash-free basis.

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**Table 2. Analyses of coals examined—Continued**

**LIGNITIC COALS—Continued**

**AMERICAN LIGNITES**
### Subbituminous C Coals

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1. Sample as received; 2. air-dried; 3. dried at 105°C; 4. moisture- and ash-free.
2. Sample air-dried during several years' storage.
Table 3 shows the extraction yields that were obtained in the examination of 45 samples of lignite from mines, outcrops, and drill holes in Arkansas, California, Montana, North Dakota, Texas, and Washington. The yields shown in this table are reported on the as-tested basis and are also calculated to the dry and the moisture- and ash-free bases. Although the survey was confined largely to lignitic coal, 11 subbituminous coals from Colorado, Montana, Oregon, and Wyoming were examined for comparison with extraction yields of lignitic coals. Results of these tests also are recorded in table 3. Figure 1 shows the geographical location of all of the samples examined.

As mentioned in the introduction, for convenience in discussion the term “wax” is used in a broad generic sense to designate the extractable material. Analysis of this material (table 4) shows that it contains relatively large amounts of resinous and asphaltic substances.

Solvent extraction tests made of certain petrographic components separated from various samples of lignite are described in another section of this report.

Most of the extraction tests were made on air-dried samples, moisture contents of which are shown in table 2. For a few coals, benzene extraction tests were made of samples dried at 105° C., but the yields were lower than those obtained from air-dried samples when compared on the dry basis. This characteristic has also been noted by other investigators. Yields from the dry coals were 68 to 88 percent of those obtained from air-dried samples. Although no attempt was made in this investigation to determine the cause of the difference in yields, a possible explanation may be that the colloidal nature of the coal was changed during the severe drying, so that permeation of the solvent into the dried particles was reduced.

For all of the samples examined, yields of extract obtained when a solvent mixture of benzene and alcohol was used were 1½ to more than 2 times greater than when benzene alone was used as solvent.

LIGNITIC COALS
AR KANSAS

Extraction tests were made of 16 samples of lignite from 12 abandoned strip and drift mines and outcrop exposures in Clay, Dallas, Hot Spring, Ouachita, Poinsett, and Saline Counties. A map giving the location from which these samples were obtained is shown in figure 4. With the exception of the samples of Clay County lignite and high-ash bench samples from an outcrop in Dallas County, the yields of benzene extract ranged from 5.7 to 11.1 percent and those of benzene-alcohol extract from 9.6 to 16.4 percent on an air-dry coal basis. Some of the yields are within the range of 10 to 15 percent that has been reported for German brown coals used for commercial wax extraction.

The yields of extract from the coal sampled on Crowley’s Ridge in Clay County, in the northeast corner of Arkansas, were 2.5 and 5.1 percent, respectively, when benzene and a benzene-alcohol mixture were used as solvents. These yields were lower than generally were obtained in the survey of lignites from this State.

Extraction tests were made with lignite from an abandoned strip mine and an outcrop exposure in Dallas County. The strip-mine sample was from the American Dyewood Co. mine formerly operated near Manning. The yields of extract from this coal were 7.8 and 12.0 percent, respectively, when benzene and benzene-alcohol were used as solvent. Bench samples from the same mine also were examined to determine whether there might be a significant concentration of wax in parts of the bed. These samples were standard channel samples obtained by arbitrarily dividing the bed into three benches, each 2 feet thick. The results showed that although slightly lower yields of extract were obtained from the middle bench, there was no significant concentration in any of the benches, which would indicate that selective mining of this lignite would be advantageous. The samples examined from the outcrop exposure south of Carthage were bench samples from a bed exposed in the bank and bed of Tulip Creek. Although lignite from this outcrop contained very large amounts of ash-forming mineral matter, the samples were examined because it was reported that this lignite was representative of those known locally as “young” lignites, and which were believed to have a high wax content. Extraction tests showed, however, that the yields were low and, if calculated to a dry, ash-free basis, were lower than those from most of the other Arkansas samples examined when compared on the same basis.

Yields of wax from two outcrop exposures in Hot Spring County obtained with benzene and benzene-alcohol solvents ranged from 9.5 to 11.1 percent and 14.9 to 16.4 percent, respectively. These yields are slightly higher than those obtained from coals from other counties in Arkansas.

Solvent extraction of four samples of lignite from abandoned strip and drift mines and a prospect pit in Ouachita County showed that the yields of extract from these coals are quite similar. The yields of benzene extract ranged from 6.3 to 7.3 percent, and those of the benzene-alcohol extracts from 10.2 to 11.7 percent.
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### Subbituminous C Coals

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One sample of Poinsett County lignite taken from an outcrop exposure in the Crowley's Ridge area of northeastern Arkansas had an extractable wax content similar to the average of most of the other Arkansas samples examined. The yields of extract were 7.6 and 11.6 percent with benzene and the benzene-alcohol solvents, respectively.

The Saline County lignites examined were from an outcrop and a prospect pit. On an air-dried basis, the yields were quite different. The outcrop sample gave 5.7 percent of benzene extract and 9.6 percent of benzene-alcohol extract; the prospect sample yielded 9.4 and 14.4 percent of extract when the same solvents were used. This difference is due largely to a higher ash content of the outcrop sample. If results of tests of the samples are calculated to a dry, ash-free basis, the difference is less significant.

CALIFORNIA

Extraction tests were made of six samples of lignite from the Lone formation in Amador County. Two were channel samples collected in the Buena Vista and Edwin No. 2 clay mine. The clay mine had a 3-foot exposure of lignite. The third was a grab sample of crushed lignite; the only information available termed this sample Lone lignite. The yields of extract from these samples were quite similar; yields of benzene extract ranged from 6.6 to 7.1 percent, and the yields of benzene-alcohol extract from 9.5 to 11.2 percent. The fourth sample was representative of an 81-inch column sample cut from the upper part of a lignite bed that was stripped to supply lignite for the extraction plant of the American Lignite Products Co. On an air-dried basis, the yield of benzene extract and benzene-alcohol extract was 14.2 and 21.2 percent, respectively. The other two samples examined were grab samples of wax-rich lignite that had been mined from the face of a strip pit of the American Lignite Products Co.; the yields of benzene extract were 19.6 and 27.0 percent, and those of the benzene-alcohol extract were 31.5 and 38.3 percent.

MONTANA

Two samples of lignite from Powder River and Sheridan Counties were examined. These coals occur in the Fort Union formation, which extends through western North Dakota into eastern Montana and northwestern South Dakota. The Sheridan County sample yielded 2.1 percent and the Powder River lignite yielded 2.9 percent of benzene-alcohol extractable wax on an air-dry coal basis. Because of these low yields, benzene-extraction tests were not made, as tests of similar coals from North Dakota gave lower yields with benzene than with a benzene-alcohol solvent.

NORTH DAKOTA

Extraction tests were made of samples of lignite from 10 mines in Burke, Burleigh, Divide, Mercer, Mountrail, Ward, and Williams Counties. These coals occur in the Fort Union formation, which contains the most extensive known lignite reserves in the United States. Yields of wax from all of the samples examined were low. Yields of benzene-extractable wax from air-dried samples ranged from 1.2 to 1.6 percent, and those obtained in benzene-alcohol extraction tests ranged from 2.1 to 3.4 percent. These low yields indicate that probably none of the coals examined would be attractive as commercial sources of wax.

TEXAS

Nine samples of lignite from two operating strip mines in Harrison and Milam Counties were examined. On an air-dry coal basis, the yield of benzene extract ranged from 1.5 to 2.4 percent, and the yields of benzene-alcohol extract from 3.6 to 4.8 percent. Although these lignites occur in sedimentary deposits of the same age (Wilcox) as the Arkansas samples examined, their yields of wax were generally much lower than those obtained from most of the Arkansas lignites. The differences in yields are accounted for by differences in petrographic composition. The Texas lignites, like those of North Dakota, are the xyloid or woody type, whereas the Arkansas lignites are the attritional type. The petrographic composition of Texas lignites is described more completely in another section of this report.

Extraction tests of seven of the Texas coals were made on bench samples arbitrarily cut out of the coal beds in each of the mines to determine whether there was any significant concentration of waxy constituents in any of the benches. Although there was some variation in wax yields from different benches, there is not sufficient concentration of wax in any of the benches to make selective mining advantageous.

WASHINGTON

A sample of brown coal from a prospect in King County yielded 2.0 and 4.3 percent wax when benzene and benzene-alcohol, respectively, were used as solvents. Although the sample examined had been in storage for several years, it is not likely that the yields were affected thereby to any great extent. A fresh sample could not be obtained, as the entry to the prospect has been blocked by caving.

Solvent extraction tests were made of three bench samples of lignite obtained from a drill hole near Toledo in Lewis County in connection
with a drilling project 47 to determine minable reserves of lignite in this area that could be obtained by strip mining. Low yields of wax were obtained from each of the bench samples. Yields of benzene-alcohol extract ranged from 2.6 to 3.3 percent on the air-dry coal basis.

SUBBITUMINOUS COALS

Yields of wax were determined on samples of subbituminous B and C coals from Colorado, Montana, Oregon, and Wyoming. These tests were made to compare wax yields with those of lignitic coals. Although there was considerable variation in the amounts of extract, the yields were quite low. The yields of benzene-alcohol extract of the subbituminous C coals ranged from 2.3 to 4.4 percent, and those of the subbituminous B coals from 1.6 to 3.6 percent. With the exception of the higher wax-bearing Arkansas and California lignites, the yields of extract from the subbituminous coals were generally similar to those of most of the lignites from Montana, North Dakota, Texas, and Washington.

PROPERTIES OF WAXES EXAMINED

The extracts obtained in this study were examined by methods used in wax-technology investigations. The following determinations were made: Melting point, acid value, saponification value, ester value, “resin,” “asphaltic” material, ash, and specific gravity. The acid value is the number of milligrams of KOH required to neutralize 1 gram of wax. The saponification value is the number of milligrams of KOH required to hydrolyze 1 gram of wax. The ester value is the difference between the saponification value and the acid value and shows the amount of alkali consumed in the saponification of the esters. The term “resin” is usually applied to the fraction of the wax that is more soluble in certain cold solvents such as ethyl ether, ethyl acetate, ethyl alcohol, and a mixture of benzene and alcohol. The last two solvents are reported to be used in commercial deserification of montan wax in Germany. The “asphaltic” material in montan wax is defined by Ivanovsky 48 as that portion of the wax that is insoluble in hot aromatic-free petroleum ether. This material was removed in the commercial preparation of improved I. G. waxes from the crude or deserified montan wax during subsequent oxidation with chromic acid.

As many of the determinations are empirical in nature, with results depending on the particular methods used, a description of the methods used in this investigation is given in the following section in some detail.

The tests were made in duplicate on wax samples crushed to pass a No. 60 sieve.

METHODS OF EXAMINING WAX

MELTING POINT

The melting points of montan wax reported in the literature seldom give the methods used in the determination. Because of variations among different procedures used, the results may not always be strictly comparable. Melting points may be determined by the open capillary tube and closed capillary tube methods and modifications thereof, drop-point methods, data prepared from cooling curves, and other methods. Melting and softening points are sometimes reported by the ring-and-ball method (A. S. T. M. Designation: E 28–42 T) or somewhat similar type of apparatus and procedures in which the softened or melted sample rises through a bath of heated mercury.

The melting-point method used in this study was confined to the closed capillary-tube procedure. In this method, a sample of crushed wax is placed in a capillary tube about 1 mm. in diameter and closed at one end. The depth of the wax in the tube is 1 to 2 cm. The tube containing the wax can be heated in various types of equipment. In this investigation the apparatus used was designed by Hershberg 49 in which accurate temperature control can be maintained. The samples were heated at a rate of 1°C. per minute.

As montan wax is composed of a mixture of chemical constituents, it does not have a sharply melting point like pure organic compounds. There is usually a range of several degrees between incipient and complete melting, as determined by the capillary tube method. With one exception, all of the waxes examined in this investigation melted within a range of 2°C. to 5°C.

ACID VALUE 50

One gram of powdered wax is refluxed for 10 minutes in a 250-ml. boiling flask with 20 ml. of reagent-grade benzene; 100 ml. of absolute ethyl alcohol is then added down the condenser, and refluxing is continued for 20 minutes. The flask is removed and cooled, 3 ml. of 1-percent phenolphthalein is added as indicator, and the solution is titrated cold with 0.1 N alcoholic potash. A blank determination is made of the reagents used in the test.

For some of the tests, especially those made on the benzene-alcohol extracts, there is difficua

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cully in detecting the end point because of the dark color of the solutions. In those cases the solution is divided into two portions, and the solution in one is titrated with the standard alkali until a change in the color is noted when compared with the other portion. The two solutions are then mixed together, redivided, and titration of one portion is repeated. This procedure is continued until the end point is reached.

**Saponification Value**

One gram of powdered wax is refluxed in a 250-ml boiling flask with 25 ml. of 0.5 N alcoholic potash \(^{21}\) for 1½ hours; 100 ml. of absolute ethyl alcohol is added down the condenser, and the solution is brought to boiling and titrated hot with 0.5 N hydrochloric acid, using 3 ml. of 1-percent phenolphthalein as indicator. After the end point is reached, the solution is refluxed for an additional 15-minute period; several drops of standard acid usually are required to remove the pink color that returns during the additional refluxing. A blank determination is made of the reagents used in the determination.

For those solutions in which it is difficult to detect the end point, the same titrating procedure was used as for the acid value.

**Ester Value**

The ester value is the difference between the saponification value and the acid value.

**Ash**

One gram of powdered wax is weighed into a porcelain capsule dish and placed in a cold muffle furnace, which is gradually heated to 750° C. Heating must be slow enough to prevent frothing of the wax over the sides of the crucible during the ashing. The ash is ignited to constant weight at 750° C.

**Specific Gravity**

One gram of powdered wax crushed to pass a No. 60 sieve is placed in a 25-ml. specific gravity bottle, and the bottle is partly filled with boiled and cooled distilled water. To facilitate wetting of the wax particles, a small amount of 0.1-percent solution of Aerosol OT is added, and the bottle is gently shaken. After foaming has ceased, the bottle is filled with water, the stopper inserted, and the temperature adjusted to 20° C. Any excess water is removed from the capillary, and the bottle is gently shaken and weighed. Specific gravity at 20° C. is calculated as follows:

\[
\text{Specific gravity} = \frac{W}{W - (W' - P)}
\]

where

- \(W\) = weight in grams of sample,
- \(W'\) = weight in grams of bottle + sample + water required to fill the bottle, and
- \(P\) = weight in grams of bottle + water required to fill the bottle.

Slightly lower specific gravities are obtained if larger pieces of wax are used, probably because of internal voids in the larger pieces.

**Resin**

**Solubility in Cold Ethyl Ether**

One gram of powdered wax is placed in a Buchner-type funnel with a fritted glass disk of medium porosity. Ten ml. of ethyl ether is poured over the wax in the funnel, and the solvent with dissolved wax is allowed to drain into a weighed flask. Extraction is continued with nine additional 10-ml. portions of ether. After completion of the extraction, the solvent is removed from the extract by distillation, the last traces being removed under reduced pressure with a water aspirator pump, and finally to constant weight at 100° C. with a mechanical vacuum pump. Completeness of extraction is determined by treatment of the residue in the funnel with five 10-ml. portions of ether; about 1 to 2 percent of additional ether-soluble extract is obtained.

**Solubility in Ethyl Acetate at -10° C.**

One gram of powdered wax is placed in a 15-ml. centrifuge tube; 10 ml. of ethyl acetate is added, the tube is shaken and is then placed in an ice-salt bath maintained at -10° C. After being allowed to stand for 30 minutes, the tube and contents are quickly centrifuged, and the solution is decanted into a Buchner-type funnel with a medium-porosity fritted-glass disk. Extraction of the residue in the centrifuge tube is repeated with nine additional 10-ml. portions of ethyl acetate at -10° C. The combined extracts are freed of solvent by distillation, followed by removal of the last traces of solvent under reduced pressure at 100° C. Completeness of extraction is determined by additional solvent treatment of the residue with five 10-ml. portions of solvent.

**Solubility in Cold Ethyl Alcohol \(^{22}\)**

One gram of powdered wax mixed with 10 grams of clean sand is extracted with 70 ml. of anhydrous ethyl alcohol in a Soxhlet apparatus. At the end of the extraction, the flask containing both resin and wax in solution is removed from the apparatus and cooled in a water bath for 1 hour at 20° C. The precipitated wax is then removed by filtering through a Buchner-type funnel with medium-porosity fritted-glass disk. The solvent is removed from the resin


\(^{22}\) Ivanovsky, L., Work cited in footnote 28.

by distillation, the last traces being removed under reduced pressure in the usual manner.

**Solubility in Benzene-Alcohol Mixture**

One gram of powdered wax is placed in a 15-ml. centrifuge tube; 10 ml. of solvent consisting of 80 percent benzene and 20 percent ethyl alcohol is added; the tube shaken and then placed in an ice-water bath maintained at 0° C. After standing for 30 minutes, the tube and contents are quickly centrifuged, and the solution is decanted into a Buchner funnel with medium-porosity fritted disk. The extraction of the residue in the centrifuge tube is repeated with six additional 10-ml. portions of solvent mixture. The combined extracts are freed of solvent by distillation followed by removal of last traces of solvent under reduced pressure at 100° C. Completeness of extraction is determined by additional solvent treatment of the residue with seven 10-ml. portions of solvent.

**Asphalitic Material**

One gram of powdered wax is mixed with 10 grams of clean sand and extracted in a Soxhlet extraction apparatus with petroleum ether (b. p. 180°–212° F.) that has been freed of aromatics. The extracted material is freed of solvent by distillation, the last traces being removed under reduced pressure at 100° C. The weight of the extract is subtracted from the weight of the sample, the difference representing the weight of the “asphaltic” material.

The aromatics are removed from the petroleum ether by sulfonation followed by absorption on silica gel. Five hundred ml. of the petroleum ether is placed in a 2,000-ml. separatory funnel, 500 ml. of 98 percent sulfuric acid is added, and the solutions are mixed for 10 minutes by a motor-driven stirrer. The sulfuric-acid layer is drained off, and sulfonation is repeated with two fresh portions of acid. The petroleum ether is then washed once with water, once with a solution of sodium bicarbonate, and finally three additional times with water. The petroleum ether is then distilled. Any aromatics that may still be present are then removed by passage of the petroleum ether through a column of silica gel 1 inch in diameter and 3 feet long. The petroleum ether is proved to be free of aromatics by test with an ultraviolet spectrophotometer.

**Results of Examining Wax**

Table 4 shows the chemical and physical properties of representative samples of extractable material that were obtained in the investigation. The extracts obtained by both benzene and benzene-alcohol extraction of Arkansas and California lignites were examined. Only benzene-alcohol extracts were tested for samples from the other sources, as the yields of benzene extract from the same coals were so low that commercial extraction made with this solvent probably could not be considered economically feasible.

The properties of three samples of commercial grades of imported montan wax were determined for comparison with those of waxes extracted from domestic low-rank coals. These properties are listed in Table 4. Two of the samples were obtained by the Office of the Chief Quartermaster, Headquarters European Command, from stocks of montan wax held by the I. G. Farbenindustrie A. G., Werk Gersthofen. One of these samples consisted of crude wax and the other of dersinified wax. Both were from Riebeck production. According to a representative of the I. G. Farbenindustrie, the resin was extracted with cold benzene. The crude-wax sample consisted of small blocks shaped like truncated rectangular pyramids with a base 1½ inches square and a top 1⅜ inches square, the name “Riebeck” being imprinted on the top surface. The blocks appeared nearly black in mass color and broke with conchoidal fracture surfaces. When powdered, the color of the wax was light brown. The dersinified wax consisted of small flakes about ½ inch thick. The flakes could be crushed readily between the fingers.

The third sample of commercial wax examined was purchased from an American importer. It was described by this supplier as a refined “genuine montan wax” imported from Czechoslovakia and having a melting point of 178° F. (81° C.). The sample consisted of irregular lumps of various sizes, the color was black with a slight brownish cast, and the fracture was typically conchoidal.

All of the waxes examined and listed in Table 4 were hard and brittle and could be scratched with the fingernail. In mass they were black with a brownish hue. Fracture surfaces were conchoidal. When powdered, the benzene extracts were light brown and the benzene-alcohol extracts were dark brown.

Examination of Table 4 shows that in general all of the waxes had similar properties when extracted from the coal with the same solvent. The melting points of benzene extracts from Arkansas and California lignites ranged from 77° to 85° C. These were quite similar to the melting point of Riebeck brand montan wax; they were, however, slightly higher than that determined for the Czechoslovak wax. The melting points of benzene-alcohol extracts from Arkansas lignites were generally 5° to 15° C.
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<th>Source of coal</th>
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<th>Mine</th>
<th>Yield of extract, air-dried coal, basis, percent</th>
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<th>Acid value</th>
<th>Saponification value</th>
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<th>Ash, percent</th>
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<td></td>
</tr>
<tr>
<td>46057</td>
<td>Texas</td>
<td>Harrison</td>
<td>do</td>
<td>1.05</td>
<td>1.09</td>
<td>74 97</td>
<td>68 65</td>
<td>56 54</td>
<td>51 55</td>
<td>7 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46067</td>
<td>Washington</td>
<td>Lewis</td>
<td>do</td>
<td>1.05</td>
<td>1.09</td>
<td>74 97</td>
<td>68 65</td>
<td>56 54</td>
<td>51 55</td>
<td>7 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46080</td>
<td>Wyoming</td>
<td>Converse</td>
<td>do</td>
<td>1.05</td>
<td>1.09</td>
<td>74 97</td>
<td>68 65</td>
<td>56 54</td>
<td>51 55</td>
<td>7 31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
higher than those determined by benzene extraction. Their melting characteristics, also, were different, in that the benzene-alcohol extracts from the Arkansas lignites appeared to form a more viscous melt than the benzene extracts. The melting points of the benzene-alcohol extracts from the California lignites were only slightly higher than those of the benzene extracts from the same coals. The benzene-alcohol extracts obtained from coals from the other States had melting points that ranged from 72° to 82° C., temperatures that are about the range of those of the commercial montan wax samples. The only exception was the wax from the Darco No. 3 lignite in Texas, which melted at 83° to 87° C. This wax appeared to form a very viscous melt.

The ranges of acid values of the benzene extracts from Arkansas and California lignites were 36 to 40 and 44 to 51, respectively. All of the benzene-alcohol extracts had acid values significantly higher than those of the benzene extracts. The acid value for the waxes obtained by benzene extraction agreed more closely with those of the commercial wax samples than did the benzene-alcohol extracts.

The saponification values of the benzene extracts from the Arkansas and California lignites were lower than those of the benzene-alcohol extracts from the same coals.

The ash contents of all of the extracts examined were 0.6 percent or less. These low contents were similar to those of the commercial wax samples.

The specific gravity of only a few samples of wax was determined. Although the benzene-alcohol extracts had slightly higher specific gravities than the benzene extracts, gravities of the waxes obtained with both solvents were higher than those of the Riebeck waxes. In this respect, the benzene extracts more closely resembled the Czechoslovak wax than the Riebeck wax.

The most significant difference between the extracts obtained in this survey and the Riebeck brand of crude montan wax was their greater resin content, as measured by solubility tests made with several of the solvents that have been proposed for this determination. Many of the extracts more closely resembled the Czechoslovak wax in this respect. Inspection of table 4 shows that significant differences in resin content were obtained with the various solvents. These should be considered as relative rather than actual, as the separation of the resin from the wax fraction is not clean-cut. For example, in the commercial dersinification of Riebeck montan wax by solvent treatment, the dersinified wax is reported to contain about 5 to 7 percent of resin and the extracted resin about 60 percent wax and 40 percent resin. Source of the resinous material probably is the round resinous bodies and lump-type resin particles petrographically identified in the atrial ground mass of the lignitic coals examined and described later.

The amount of asphaltic material in the benzene extracts examined was quite similar to that of the imported commercial montan waxes. Considerably more of this material was found in the benzene-alcohol extracts. It may be that many of the differences between the benzene extracts and benzene-alcohol extracts can be accounted for by the large differences in the amount of asphaltic material in the extracts obtained with these different types of solvents.

Tests were made of the compatibility with paraffin wax of the extracts shown in table 3. The tests were made by adding 0.5 gram of wax to 1.0 gram of melted paraffin in a porcelain crucible. The crucible was gently heated, and the waxes were mixed by a swirling motion. Compatibility was estimated visually. With the exception of the benzene extracts from the column sample and one grab sample of lignite from the American Lignite Products Co. stripping operation near Tone, Amador County, Calif., none of the extracts examined from the domestic low-rank coals was completely miscible with paraffin. For the incompatible waxes considerable black sediment settled on the sides and bottom of the crucible.

The Czechoslovak montan wax showed the same degree of compatibility. The Riebeck brand of montan wax, however, was completely miscible with paraffin, and no black sediment was observed. Tests also were made of the benzene extracts from which the resin had been removed by solution in ethyl ether. The results showed that compatibility was increased considerably by removal of the resin. No improvement was noted in similar tests of dersinified benzene-alcohol extracts.

Compatibility tests with carnauba wax also were made of the extracts obtained from the Arkansas and California coals. All of the benzene extracts were nearly completely miscible with the carnauba wax; the benzene-alcohol extracts were not as completely compatible.

Ultimate analyses of two imported montan waxes, extracts from an Arkansas and California lignite, and a commercial semirefined montan wax from California lignite are shown in table 5. The range of analyses was as follows: Carbon, 77.3 to 80.2 percent; hydrogen, 10.6 to 12.6 percent; oxygen, 0.8 to 10.4 percent; sulfur, 0.3 to 0.8 percent; nitrogen, 0 to 0.3 percent; and ash, 0.1 to 0.4 percent. The benzene extracts contained slightly more carbon and hydrogen and less oxygen than the benzene-alcohol extracts. The oxygen contents of the

20 Steinle, J. Vernon, Work cited in footnote 18 (p. 20).
Table 5.—Ultimate analyses of wax samples, dry basis, percent

<table>
<thead>
<tr>
<th>Laboratory No.</th>
<th>Source of wax</th>
<th>Ash</th>
<th>Hydrogen</th>
<th>Carbon</th>
<th>Nitrogen</th>
<th>Sulfur</th>
<th>Oxygen (by difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>46036</td>
<td>Riebeck brand montan wax, not deresinified</td>
<td>0.3</td>
<td>12.6</td>
<td>79.7</td>
<td>0.0</td>
<td>0.6</td>
<td>6.8</td>
</tr>
<tr>
<td>45846</td>
<td>Czechoslovak montan wax</td>
<td>.4</td>
<td>11.7</td>
<td>79.2</td>
<td>.2</td>
<td>.3</td>
<td>8.2</td>
</tr>
<tr>
<td>46085</td>
<td>Lignite from Hot Spring County, Ark.:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Benzene extract</td>
<td>.1</td>
<td>11.4</td>
<td>80.2</td>
<td>.2</td>
<td>.4</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>Benzene-alcohol extract</td>
<td>.2</td>
<td>10.6</td>
<td>78.4</td>
<td>.3</td>
<td>.4</td>
<td>10.1</td>
</tr>
<tr>
<td>45736</td>
<td>Lignite from Ione, Amador County, Calif.:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Benzene extract</td>
<td>.1</td>
<td>11.8</td>
<td>78.9</td>
<td>.1</td>
<td>.6</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>Benzene-alcohol extract</td>
<td>.4</td>
<td>10.9</td>
<td>77.3</td>
<td>.2</td>
<td>.8</td>
<td>10.4</td>
</tr>
<tr>
<td>46373</td>
<td>American montan wax C</td>
<td>.3</td>
<td>12.2</td>
<td>79.3</td>
<td>.0</td>
<td>.3</td>
<td>7.9</td>
</tr>
</tbody>
</table>

Benzene extracts resembled those of the commercial wax samples more closely than did the higher-oxygen benzene-alcohol extracts.

A sample of commercial wax extracted from Ione lignite by the American Lignite Products Co., Amador County, Calif., was obtained in 1948 and subjected to chemical and physical tests. The wax, designated as American Montan Wax C, is a semirefined product prepared by selective extraction of a crude primary extract. Its physical and chemical properties are listed in table 4 and its ultimate analysis in table 5. Results of the tests show that the domestic wax has properties similar to those of the Riebeck brand of imported crude montan wax; its resin content is considerably lower than that of the imported Czechoslovak montan wax examined. Compatibility tests showed that the American wax examined is miscible with paraffin.

Studies of possible improvement of the waxes by various known methods of purification and refinement were not made in this investigation. However, from results obtained in the laboratory determination of the resinous and asphaltic material in the wax by selective solvent extraction, if required, removal of these constituents probably would be feasible.

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Footnote: Communication from Raymond L. Drew, American Lignite Products Co., Ione, Calif.
PETROGRAPHY OF LIGNITIC COAL

In the A. S. T. M. system of coal classification, the term "lignite" is applied to coals of low rank having heating values less than 8,300 B. t. u. per pound on a moist, mineral-matter-free basis. Lignite coals, according to this classification, are divided into two groups—lignite and brown coal. Lignite is the consolidated variety and brown coal the unconsolidated variety. Although lignite is indicated to be further advanced in coalification than brown coal, their rank differentiation is based more on physical appearance than analysis. Lignite is dark-brown and firmly consolidated. Although some lignite is non-banded, it occurs most commonly distinctly laminated with bright and dull layers. Brown coal is lighter-colored and less consolidated than lignite and not conspicuously banded.

The term "lignite" is of French origin and first came into use in that country in referring to the deposits of dark-brown, firmly consolidated, banded coals of a type common in France. The French lignite deposits therefore can be considered prototypes of similar coals occurring in other countries that are classified as lignite.

The term "brown coal" (Braunkohle) probably first came into general use in middle Europe, where extensive deposits of this coal have considerable economic importance. The brown-coal industry of central Germany is particularly well known for the improved fuel in the form of briquettes and extractable products obtained from the raw coal. German brown coal is loosely consolidated and is reported to contain prominent "woody" layers.

Although the general terms "lignite" and "brown coal" are used most widely, a number of descriptive names have been used in designating lignitic coals that are noticeably different in physical appearance. Among the descriptive names that have been used generally and to some extent rather indiscriminately in coal literature are the following: woody lignite, xyloid lignite, brown coal or brown-coal, mature lignite, immature lignite, young lignite, earthy lignite, amorphous lignite, fibrous lignite, brown lignite, black lignite, and bituminous lignite.

If the terms "lignite" and "brown coal" are to be used in a restricted sense for binomial grouping of lignitic coals with reference to degree of rank, confusion would be avoided if rank differentiation could be established on the basis of a measurable characteristic such as heating value.

A secondary grouping based on petrographic composition also may be advisable to classify lignitic coals properly. The terms "attrital" and "xyloid" are used to some extent to describe coals of distinctly different petrographic composition. A term indicating the predominant petrographic characteristic of a coal could be combined with the term indicating its degree of rank as "attrital brown coal," "xyloid brown coal," "attrital lignite," and "xyloid lignite."

The feasibility of systematically classifying lignitic coals of different rank, petrographic composition, and geological age is suggested in table 6, which gives proximate analyses and heating values of certain peats, brown coals, and lignites occurring in the United States, Australia, France, Germany, and Greece.

The order in which the 15 coals are tabulated was determined by the geological age. The calorific values on the moist, ash-free basis are fortuitously in orderly agreement with geological age, with the exception of the Paleocene coal of South Dakota. The anomalously low calorific value of the oldest coal in the table may be the result of shallow sedimentary burial. The rank designations of the coals in the table were derived from common usage. The classification of most of the foreign coals as to petrographic variety was obtained from available descriptions and that of American and Greek coals from petrographic analyses.

The problem of setting up definite standards for systematically classifying lignitic coals seems to be one of obtaining a sufficient number of petrographic and chemical analyses made on a comparable basis.

The extensive deposits of lignitic coal in the United States are Paleocene and Eocene in age. Small deposits of younger age, described as brown coal, occur at two localities in the State of Washington. Although most American lignitic coals are classed as "lignite," they do have considerable range in degree of rank as determined by the heating value. The most significant differences in American lignites are probably to be found in petrographic composition.
Table 6.—Composition of peat, brown coal, and lignite of various geological ages occurring in the United States, Australia, France, Greece, and Germany

<table>
<thead>
<tr>
<th>Rank</th>
<th>Petrographic variety</th>
<th>Geological age</th>
<th>Geocurrence</th>
<th>Number of analyses averaged</th>
<th>Proximate analysis, moist basis</th>
<th>Calorific value, B.t.u. per pound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moisture</td>
<td>Volatile matter</td>
</tr>
<tr>
<td>Peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Recent (post glacial)</td>
<td>Kiel, Wns.</td>
<td>76.5</td>
<td>18.7</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Pleistoecene (glacial)</td>
<td>Bridgewater, Pa.</td>
<td>63.4</td>
<td>15.2</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Victoria, Australia</td>
<td>66.3</td>
<td>17.0</td>
<td>15.4</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Victoria, Australia</td>
<td>58.7</td>
<td>19.5</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Rhineeland, Germany</td>
<td>58.8</td>
<td>21.5</td>
<td>17.4</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Auburn, Wash.</td>
<td>52.0</td>
<td>26.4</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Peloponnese, Greece</td>
<td>51.7</td>
<td>24.6</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Grola and Lehnhardt, Germany</td>
<td>51.0</td>
<td>25.3</td>
<td>18.4</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Victoria, Australia</td>
<td>50.0</td>
<td>26.0</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Attica, Greece</td>
<td>43.1</td>
<td>24.9</td>
<td>17.2</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Mioene</td>
<td>Heimstedt and Biddenden, Germany</td>
<td>44.2</td>
<td>27.5</td>
<td>22.8</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Middle Eocene</td>
<td>40.8</td>
<td>31.1</td>
<td>18.1</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Lower Eocene</td>
<td>Arkansas</td>
<td>38.4</td>
<td>30.4</td>
<td>21.8</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Xyloid</td>
<td>Texas</td>
<td>37.4</td>
<td>26.4</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Xyloid</td>
<td>North Dakota</td>
<td>35.5</td>
<td>28.9</td>
<td>20.9</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Xyloid</td>
<td>Pyrenees Region, France</td>
<td>32.8</td>
<td>21.5</td>
<td>26.5</td>
</tr>
<tr>
<td></td>
<td>Do</td>
<td>Xyloid</td>
<td>South Dakota</td>
<td>37.3</td>
<td>20.5</td>
<td>29.2</td>
</tr>
</tbody>
</table>

1 Analyzed by Bureau of Mines, unless otherwise stated.
2 Moist refers to the coal or peat containing its natural bed moisture.
3 Analysis.
5 Average of unstated number of analyses.

Petrographic Characteristics of Attrital and Xyloid Lignite Coal

Attrital lignites are composed predominantly of a variety of microscopic ingredients of plant origin that are classed generally as attritus. Attritus is the residual remains of plant debris that was macerated and rotted by bacterial and chemical action, principally during the peat stage. Much of the attritus consists of remains of fibrous tissues of plants reduced by attrition to a finely divided state and leaving little evidence of original organic structure. An important element of the attritus is composed of decay-resistant protective coats of organs associated with reproduction of plants, such as spores, pollen, fruit, berries, and seeds. The cuticular coverings of leaves, petals, and fruit contribute to attrital debris, which also contains resinous products excreted by the growing plant.

When attritus is examined in thin sections under the microscope with transmitted light, some of it is opaque, and part of the opaque matter is identifiable as fusain. Spores, pollen, seed coats, and cuticular material are yellowish in color and have a definite structural form. The finely divided translucent humic matter varies in color from brown to reddish hues. Resinous substances are yellow to reddish translucent. Most attritus in lignitic coals is translucent in thin section, but in some coals the quantity of opaque attritus may be as much as 15 percent. The proportion of the different plant ingredients comprising the attritus varies with lignite deposits. When coal is analyzed microscopically, much can be learned about the environmental conditions under which it accumulated.

Lignitic coals that are predominantly attrital in composition are nonbandable and distinguishable by the appearance of uniform, grainy texture and tendency in surface coloration toward a light-brownish hue, although some are very dark-brown. Yellow translucent matter in the attritus seems to be responsible for the light-brown color of some attrital lignites and for the slick oily trace made when the surface of such coal is cut with a sharp tool.

Attrital brown coals are relatively soft and loose-textured, but they become firm and tough in the advanced lignite stage.

At present there is no accepted definition for xyloid lignite in terms of petrographic composition. However, a xyloid lignite may be described as one containing enough anthraxylon to give a prominent banded appearance to the coal. Available petrographic analyses of American lignites indicate that typical xyloid lignite, such as that which occurs in North Dakota, contains more than 50 percent anthraxylon. Typical attrital lignite occurring in Arkansas and California contains less than 25 percent anthraxylon and more than 75 percent attritus.

Anthraxylon is principally derived from the woody and bark tissues that form the sup-
porting organs of the treelike plants, such as roots, trunks, stems, and branches. In the early stages of coalification, anthraxylon develops a homogeneous appearance, which persists at least through the bituminous coal stages.

On the surface of a lump of coal, anthraxylon is recognized by its uniform appearance, smooth texture, brittleness, conchoidal fracture, and bright luster. These characteristics are not as pronounced in lignitic coal as in bituminous, but in all stages of lignitic and bituminous coal anthraxylon is distinctly different from the attrital ground mass. Anthraxylon seen in thin section is readily identified by its characteristic structure and coloration. The structure of woody or bark tissue, seen in transverse or longitudinal cross section, is nearly always clearly discernible. The reddish translucence of anthraxylon becomes more pronounced with advance in rank.

Anthraxylon represents a more rapid advance in conversion to coal than attritus, particularly the ingredients of attritus identified as spores, pollen, cuticles, wax, and resin. These plant substances with inherently low oxygen content successfully resist decay in the peat stage and apparently react very slowly to geochemical processes during the lignitic stage. A xylloid lignite composed predominantly of anthraxylon is more advanced in coalification than attrital lignite of contiguous occurrence, but it is not necessarily of higher rank.

The terms "rank" and "coalification" cannot be used synonymously in referring to lignitic coal. The rank of a lignitic coal is determined by measuring calorific value on a moist, mineral-matter-free basis. Xylloid lignite does not possess greater heating value by virtue of being more coalified. On the contrary, resin- and spore-rich attritus contains more volatile matter than anthraxylon and consequently has higher calorific values.

As most lignite deposits do not consist wholly of attritus or of anthraxylon, rank, as determined by heating value, is influenced by petrographic composition. The B. t. u. value determined for a representative sample from a lignite deposit obviously is an average of the B. t. u. values of all components present in the coal.

The descriptions given of attrital and xylloid lignitic coals are adequate to show considerable differences in physical composition of the two varieties. The descriptions state or imply that the chemical nature of the physical constituents differs, and the rate of coalification also is variable. The most important factors responsible for the development of rank in lignitic coals are petrographic composition, depth of burial under sedimentary cover, duration of burial (geological age), and, in some areas, crustal movement and igneous rock intrusions. The visual physical characteristics of lignitic coals are determined mainly by the predominant component in their petrographic composition. It is suggested that an orderly relationship exists between petrographic composition, depth of burial, geological age, rank, and physical appearance. Systematic classification of lignitic coals on the basis of petrographic composition and rank seems possible from microscopic determinations and chemical analyses.

The petrographic composition of certain lignite samples from Arkansas, Texas, North Dakota, and California are discussed in detail in the following section of this report.

PETROGRAPHIC COMPOSITION OF LIGNITE FROM ARKANSAS, TEXAS, NORTH DAKOTA, AND CALIFORNIA

Results of preliminary work to determine the extractable wax content of American lignites showed that certain samples collected in Arkansas and California were promising and warranted further study of their wax-bearing properties. Also, it was considered advisable to conduct petrographic studies of the lignites to determine whether any measurable relationship existed between the petrographic composition and the yields of wax. The Arkansas, Texas, North Dakota, and California deposits were selected for the combined investigation. A brief field study was made of the geology of the Arkansas and Texas deposits sampled, but the field work consisted chiefly of systematically sampling the lignite beds for petrographic and chemical study.

SAMPLING AND THE PREPARATION OF THIN SECTIONS

Samples were obtained wherever most convenient from mines and outcrops. After a standard channel sample was cut, the face of the bed was smoothed with picks, and a column approximately 15 inches on the sides and the full height of the exposed bed was cut out. The toughness of the lignite made cutting columns relatively simple when other conditions were favorable. A photograph of a lignite column obtained in Ouachita County, Ark., is shown in figure 9, and the preliminary preparation of a coal bed for sampling is shown in figure 10.

The laboratory procedure of preparing column samples for thin-section study was begun by sawing out a small subcolumn down the center of the large column. The subcolumn, in turn, for its entire length was cut up into small blocks about 0.8 inch wide, 1 inch long,
Column was 39 inches high, about 15 inches on the sides, and weighed approximately 230 pounds. Note uniform texture and absence of banding.

and ½ inch thick. These small blocks were polished on one face and cemented to microscope slides. The opposite face then was ground and polished on abrasive wheels and a Belgian hone. The finished thin sections were less than 0.010 mm. thick and translucent, revealing, when examined under the microscope with transmitted light, the various structural forms and coloration of the coal ingredients. About 14 thin sections were prepared from each foot of lignite. With some of the column samples, less than 5 percent of the coal was lost in sawing and polishing.

The thin sections prepared from the lignite columns were examined with a binocular-type microscope at magnifications of 60 and 150 diameters. The various ingredients in the coal were clearly distinguishable within this range of magnification when a strong light was passed through the thin section into the microscope. Quantitative determinations of the petrographic components in the lignite were made by measuring with a calibrated eyepiece micrometer and scanning the thin sections systematically. The method of petrographic analysis of coal by thin-section study has been described in a recent
Table 7.—Petrographic analyses of column and layer samples of lignite from Arkansas, California, North Dakota, Texas, and Washington

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Source of sample</th>
<th>Kind of sample</th>
<th>Percent of petrographic components</th>
<th>Yields of extractable material, air-dry basis 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anthracite</td>
<td>Translucent</td>
</tr>
<tr>
<td>1</td>
<td>Arkansas</td>
<td>Layer sample 12 inches of lignite from 18-inch bed</td>
<td>21.8</td>
<td>30.3</td>
</tr>
<tr>
<td>2</td>
<td>Dallas</td>
<td>58-inch column sample</td>
<td>95.1</td>
<td>14.8</td>
</tr>
<tr>
<td>3</td>
<td>Abandoned strip mine (American Dyewood Co.), near Manning, ... do ...</td>
<td>Top 24 inches of above column</td>
<td>15.4</td>
<td>85.2</td>
</tr>
<tr>
<td>4</td>
<td>do</td>
<td>Middle 24 inches of above column, Bottom 10 inches of above column</td>
<td>17.1</td>
<td>91.7</td>
</tr>
<tr>
<td>5</td>
<td>do</td>
<td>18-inch column sample</td>
<td>7.8</td>
<td>90.7</td>
</tr>
<tr>
<td>6</td>
<td>Abandoned drift mine (Old Big House), near Lester, ... do ...</td>
<td>36-inch column sample</td>
<td>74.6</td>
<td>24.1</td>
</tr>
<tr>
<td>7</td>
<td>Ouachita</td>
<td>Block 1, 6 inches thick from middle of above column</td>
<td>21.1</td>
<td>78.0</td>
</tr>
<tr>
<td>8</td>
<td>do</td>
<td>Block 2, 35 inches thick from base of above column</td>
<td>34.9</td>
<td>64.7</td>
</tr>
<tr>
<td>9</td>
<td>Poinsett</td>
<td>Layer sample of lignite from 60-inch bed</td>
<td>13.6</td>
<td>16.2</td>
</tr>
<tr>
<td>10</td>
<td>Amador</td>
<td>Top 1 inch of 157-inch bed</td>
<td>86.9</td>
<td>10.3</td>
</tr>
<tr>
<td>11</td>
<td>Strip mine (American Lignite Products Co.)</td>
<td>Block 9, 5 inches thick, 12 inches below top of column, light-brown at- tential layer</td>
<td>9.6</td>
<td>89.1</td>
</tr>
<tr>
<td>12</td>
<td>do</td>
<td>Block 2, 10 inches thick, 13 inches above base of column, dark-brown at- tential layer</td>
<td>19.6</td>
<td>80.0</td>
</tr>
<tr>
<td>13</td>
<td>do</td>
<td>Burleigh strip mine</td>
<td>94.1</td>
<td>63.0</td>
</tr>
<tr>
<td>14</td>
<td>Burleigh</td>
<td>115-inch column sample</td>
<td>15.4</td>
<td>55.5</td>
</tr>
<tr>
<td>15</td>
<td>Do</td>
<td>72½-inch column sample</td>
<td>87.4</td>
<td>50.2</td>
</tr>
<tr>
<td>16</td>
<td>Divide</td>
<td>Layer sample from 12½-inch column,</td>
<td>32.0</td>
<td>55.4</td>
</tr>
<tr>
<td>17</td>
<td>Bunkol-Noaman mine, ... do ...</td>
<td>Layer sample from 30 inches of lignite from top bed 90 inches thick</td>
<td>82.2</td>
<td>61.0</td>
</tr>
<tr>
<td>18</td>
<td>Morer</td>
<td>Layer sample, 30 inches of lignite from bottom bed 86 inches thick</td>
<td>10.0</td>
<td>29.7</td>
</tr>
<tr>
<td>19</td>
<td>El Dorado No. 3 strip mine, ... do ...</td>
<td>Layer sample, 36 inches of lignite from bottom bed 86 inches thick</td>
<td>8.0</td>
<td>34.8</td>
</tr>
<tr>
<td>20</td>
<td>King</td>
<td>Selected lump</td>
<td>20.0</td>
<td>71.0</td>
</tr>
</tbody>
</table>

1 The extraction tests were made on samples described in table 3 and appendix.
2 These values represent the yellow translucent matter clearly discernible with the microscope at magnifications used in making the petrographic analysis (600X). They represent only a moderate portion of total translucent attritus but appear to be an important indicator of wax-bearing lignite.
Data from the petrographic determinations of the Manning column thin sections are shown opposite items 2, 3, 4, and 5 in table 7. The Manning coal is distinctly attrital; it contains nearly 84 percent of translucent attritus, of which 2.4 percent consists of prominent yellow bodies 30 microns or more in diameter. The distribution of the translucent and yellow bodies in the column sample is shown graphically in figure 11.

In the upper bench of the sample, an anthraxylon band more than 1 inch wide and extending entirely across the column was measured. A photomicrograph of a thin section made through a portion of the anthraxylon layer is shown in figure 12. The anthraxylon shows excellent preservation of wood tissue, which is characterized by inclusions of dark-red elliptical and spherical bodies.

Solvent-extraction tests of the three bench samples indicated no preferential distribution of extractable material. However, the middle bench gave about 25 percent less yield than the top and bottom benches.

The petrographic composition of the three benches was fairly uniform. The bottom

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**Figure 11.—DISTRIBUTION OF TRANSLUCENT ATTRITUS AND YELLOW BODIES IN COLUMN SAMPLE OF LIGNITE FROM ABANDONED MINE OF AMERICAN DYEWOOD CO., DALLAS COUNTY, ARK., AS DETERMINED BY PETROGRAPHIC ANALYSIS. (DIRECT PLOT OF THIN-SECTION DATA.)**
Petrography of lignitic coal

The petrographic analysis (opposite item 6, table 7) shows the lignite to be composed almost entirely of translucent attritus. Only eight percent of anthraxylon was present and this occurred in very fine shreds. There was no visible banding in the raw coal. The extraction yields were the highest for any of the Arkansas samples tested.

Other Arkansas Samples

Layer samples were obtained from the lignite deposits sampled in Clay and Poinsett Counties. Layer samples consisting of small blocks 4 to 6 inches square were cut from the bed at measured intervals from top to bottom.

The Clay County sample (opposite item 1, table 7) contained more anthraxylon and less translucent attritus and gave lower extraction yield than any other Arkansas sample.

The Poinsett County sample was similar in petrographic composition and wax-extraction yield to the samples obtained farther south along the embayment area.

Texas Lignite

Layer samples were cut from the upper and lower bed at the Darco No. 3 mine south of Marshall, Harrison County. The petrographic composition of the Darco samples (opposite items 18 and 19, table 7) is quite different from that of Arkansas lignite. The anthraxylon content is considerably higher, and the translucent attritus is correspondingly lower. Considerably more opaque attritus is present, and there are measurable quantities of fusain, which was almost completely absent from the Arkansas lignites examined. Only small quantities of yellow bodies were visible. The petrographic composition indicates that the lignite is xyloid.

North Dakota Lignite

Petrographic analyses were made of column samples of lignite occurring in the Fort Union formation in Burleigh, Divide, Mercer, and Ward Counties. The results of the analyses are shown opposite items 14, 15, 16, and 17 in table 7.

The North Dakota xyloid lignite is strikingly different in petrographic composition from the attrital lignite of Arkansas. All four columns contained more than 50 percent anthraxylon and less than 35 percent translucent attritus. Opaque attritus and fusain combined ranged from a low of 6 percent in one sample to a high of 21.5 percent. Yields of extractable product were low from all of the samples.

A photomicrograph of anthraxylon seen in thin section, made from the Ward County sample, is shown in figure 14. The anthraxylon
contains the dark-red bodies similar to the anthraxylon from Manning, Ark., lignite shown in figure 12. A photomicrograph of attrital lignite from the same North Dakota column sample is shown in figure 15. No yellow bodies were visible in the attritus.

CALIFORNIA LIGNITE

Petrographic analysis was made of a column sample from the American Lignite Products Co.'s mine in Amador County. The sample represented only the upper 81 inches of a bed reported to be about 13 feet thick. Results of the thin-section analysis are shown opposite item 11 in table 7.

On the basis of this analysis, the California column can be classified as attrital lignite similar in composition to Arkansas attrital lignite. The proportions of anthraxylon and translucent attritus for the two coals agreed closely. There was close agreement between Arkansas and California lignite, also, in the low content of opaque attritus and absence of fusain. However, a significant point of difference was the smaller particle sizes of the translucent attritus, particularly the yellow translucent matter in the Amador County column. The Amador County column contained 1.2 percent of yellow translucent matter clearly discernible in form and size at the magnification used (60×). Maceration of a sample cut from the column resulted in a recovery of yellow translucent residue, of which 97 percent passed a 325-mesh sieve.

The Amador County column contained very little of the lump-type resinous particles and round resinous bodies that were so characteristic of Arkansas attrital lignite—the lump resin often of size visible to the unaided eye.

The Amador County column for the most part was very dark brown in color, but layers of light-brown lignite were present. The thin section assay showed that the dark variety consisted predominantly of finely divided, translucent, humic degradation matter, orange-colored, with distinctly subordinate amounts of yellow translucent attritus such as spores, pollen, cuticles, resin, etc. The orange, translucent, humic matter evidently was derived from extreme degradation of woody and bark tissues. The light-brown lignite, on the other hand, contained a considerable amount of yellow matter in the attritus. Over 24 percent of a macerated sample of light-brown lignite was recovered as yellow translucent residue.

In order to test for possible difference in benzene extractable yields from the light-brown and dark varieties, two samples were cut from zones in the column typically variable in color. The first sample was from a layer 12 inches below the top of the column. The other sample was cut from a layer 13 inches above the base of the column. The sampled layers were identified in thin-section preparation as blocks 9 and 2 and were light brown and dark brown, respectively. Petrographic compositions and benzene-extraction yields are shown opposite items 12 and 13 in table 7. Extraction yields seemed to substantiate field reports of greater yields from light-brown lignite when extracted in a plant-scale operation. The microscopic observation of considerably less attritus definitely identifiable as resinous in the Amador County lignite, compared to lignite from Arkansas, was confirmed by tests of the physical and chemical properties of the extractable products.

INVESTIGATION OF PETROGRAPHIC COMPONENTS CONTRIBUTING TO EXTRACTION YIELDS

As the attrital type of lignitic coal was found generally to give higher yields of extractable product than the xyloid type, an investigation was made to determine whether any of the identifiable petrographic components in the
attrital ground mass contributes to the yields of extractable material obtained by solvent treatment.

Thiessen, studying the microscopic composition of lignite during the pioneering period of his work in coal petrography, distinguished between the yellow and reddish bodies in attritus by terming them, respectively, "light resinous bodies" and "dark resinous bodies." He surmised that the dark bodies were composed of true resin, and that the light bodies probably were of a waxy nature. Other coal petrographers and paleobotanists have concurred in this belief.

To determine whether the yellow bodies, which are prominent in many of the attrital lignites (figs. 16 and 17), were soluble in the solvents used in the extraction tests, the sample of lignite from Hot Spring County, Ark., was examined (item 6, table 7). A small block of this coal was ground down until a smooth surface was obtained, and a photograph was taken of the surface as shown in figure 18 A. Then the smooth surface was immersed in boiling benzene for 2 minutes. The treated surface is shown in figure 18 B. In figure 18 A, the yellow bodies are seen as minute light-colored areas. The solvent action of the hot benzene can be detected in figure 18 B through disappearance of many of the light areas and specks, circular pitting of the surface, and emergence of yellow spherical particles to the surface from partial solution and flotation.

Although the results of the test show that the yellow bodies dissolve in the solvent and add to the extraction yields, they do not account for the entire yield. Table 7 shows that, with only one exception, the yield of extractable product from the lignites examined was several times that of the total amount of yellow bodies determined petrographically. However, in general the lignites that contained the most yellow bodies yielded the largest amount of extractable product.

Solvent-extraction tests were made also of an anthraxylon band cut out of the column sample of lignite from the American Dyewood Co. mine, Dallas County, Ark. Microscopic
determination showed that the anthraxylon contained 21 percent by volume of dark-red bodies included in the woody tissue. The yields of extractable products obtained with benzene and a benzene-alcohol mixture as solvents were 0.3 percent and 3.1 percent, respectively. The results show that the dark bodies prominent in some lignite are relatively insoluble and do not contribute significantly to extraction yields.

To study the physical and chemical nature of the yellow bodies and allied ingredients in the attritus ground mass in greater detail, attempts were made to separate these materials from the attritus by mechanical separation. Various methods of crushing were used to obtain fine particle size to free the attritional ingredients from the coal matrix. Float-and-sink tests of the crushed lignite were made in salt solutions of various specific gravities. No appreciable concentration of desired ingredients was obtained despite careful manipulation of the solutions.

As mechanical separation of the petrographic ingredients was not satisfactory, a chemical maceration procedure employing Schultze's reagent was used. This method is used in coal-paleobotany studies for separating spores from the more reactive coal matrix. Although it was realized that this oxidation procedure is open to criticism because of possible chemical reaction of coal constituents with the oxidizing reagents, care was taken throughout the work to prevent, as much as possible, too vigorous reaction of the coal with the oxidizing solution.

**MACERATION PROCEDURE AND RECOVERY OF RESIDUES**

A 5-pound sample of lignite containing 10.2 percent of yellow bodies was cut from a 6-inch layer near the middle of the coal sample from the Old Big House mine, Ouachita County, Ark. The sample was broken into lumps less than ½ inch in size and was air-dried at 30° to 35° C. After drying, the coal was crushed to pass a No. 3 sieve and was divided into four equal portions, each of which was placed in a 4-liter beaker. To each beaker was added 60 grams of potassium chlorate and 1,000 ml.
Figure 16.—Photomicrographs (× 100) of portions of thin sections prepared from old Big House Mine column sample, Ouachita County, Ark., showing occurrence of yellow bodies in attritus.
A—About normal distribution; B—a particularly rich concentration of the yellow bodies.

Figure 17.—Photomicrograph (× 100) of portion of thin section prepared from column sample, American Dyewood Co. strip mine (abandoned), Dallas County, Ark., showing yellow bodies in matrix of translucent attritus.

The round, yellow bodies in illustration range in size from 0.030 to 0.080 millimeter.

water. Concentrated nitric acid was added slowly to the beakers and in small measured quantities to prevent extreme effervescence and rise in temperature. When the reaction became too vigorous, the oxidizing solution was diluted with water, and the beaker was immersed in a cold-water bath. The final concentration of nitric acid was 25 percent.

The oxidizing mixture in each beaker was allowed to stand for 36 hours, after which the acid solution was decanted from the settled residues. The residues were filtered and washed free of acid. The washed residues were transferred to beakers, and 2,000 ml. of ammonium hydroxide was added to each residue to convert the insoluble humic acids formed in the oxidation to soluble humates. Ammonium hydroxide, because of its lower specific gravity than either sodium or potassium hydroxide solutions usually used to dissolve the humic acids, permitted the low-gravity ingredients in the residues to settle, which facilitated removal of the humate solutions.

After standing for 3 days, the humate solutions were siphoned out of each beaker without disturbing the residue until about 90 percent had been removed. The remaining solution was diluted with 1,000 ml. of water, and the
contents of each beaker was poured through 180- and 325-mesh sieves nested together. The sized residues were washed with water, and the washings were added to the filtrate. After standing for several days, the filtrate and washings were filtered under vacuum through linen cloth. The extremely fine particles that passed the filter cloth were removed from the filtrate by centrifuging.

PETROGRAPHIC COMPOSITION OF RESIDUES FROM MACERATION TREATMENT AND THEIR YIELDS OF EXTRACTABLE MATERIAL

The residues were examined under a stereoscopic microscope with reflected light. Photographs of typical material from each of the sized fractions are shown in figure 19.

The plus 180-mesh fraction consisted of the following substances: (1) yellow cuticular material, more than 60 percent; (2) hard, dull, dark-brown, irregular-shaped rodlets with annulated surfaces, about 30 percent; (3) hard, dark-red, vitreous rodlets, less than 5 percent; (4) yellowish and amber-colored fragments of lump-type resin, less than 3 percent; and (5) yellow and reddish round bodies, less than 1 percent.

The principal ingredients in the 180- by 325-mesh fraction were round, resinous bodies of yellow, amber, and dark-red color. These spherical bodies, about 0.045 to 0.080 mm. in diameter, comprised more than 75 percent of the material present. Some irregularly shaped particles of resinous matter made up less than 25 percent of the fraction.

In the minus 325-mesh fraction, a small number of round, resinous bodies were identified, but for the most part the ingredients consisted of finely divided yellowish to reddish material of indefinite shape. Some fine, granular particles were present. Many spores and much pollen were present, recognizable by structural form. Considerable mineral matter, principally clay and silt particles, was associated with the yellow substances.

Soxhlet extraction tests were made of the sized residues with benzene and an 80 percent benzene-20 percent ethyl alcohol mixture as solvents. Table 8 gives the yields of extractable product from each of the residues. On a dry, ash-free basis, the yields of benzene-soluble products from the maceration residues were: plus 180 mesh, 17.5 percent; 180 by 325 mesh, 63.0 percent; and minus 325 mesh, 41.7 percent. The yields of benzene-alcohol extract were 10 to 15 percent higher. These results show that the components in the maceration residues from attrital coal are contributors to the extraction yields of the raw coal.
Figure 19.—Photomicrographs showing residues obtained from maceration layer of old Big House Mine column.

Examination of Maceration Residues and Extraction Products with Microscope Hot Stage

The effect of heat upon the ingredients in the attrital material was determined to further identify those components that contribute to extraction yields. Tests were made with a microscope hot stage for comparison of melting characteristics of various ingredients in the maceration residues, benzene and benzene-alcohol extracts from the residues and untreated lignites, commercial wax samples, and lump-type resins from coal. Objectives of the tests were not to establish accurate melting points but, rather, to determine the temperature at which melting begins, length of melting period, and fluidity and color of melt.
TABLE 8.—Yields from standard benzene and benzene-alcohol extractions of residues from maceration of selected 6-inch layer Old Big House mine column

<table>
<thead>
<tr>
<th>Moisture, percent</th>
<th>Ash, percent</th>
<th>Extraction yields, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Benzene</td>
<td>Benzene-alcohol</td>
</tr>
<tr>
<td></td>
<td>As tested</td>
<td>Dry ash-free</td>
</tr>
<tr>
<td>Plus 180 mesh</td>
<td>4.6</td>
<td>7.3</td>
</tr>
<tr>
<td>180 by 325 mesh</td>
<td>6.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Minus 325 mesh</td>
<td>12.4</td>
<td>17.1</td>
</tr>
</tbody>
</table>

The hot stage consisted of a suspended nichrome ribbon with a shallow depression on the upper surface for holding the sample. The hot junction of a thermocouple was welded to the bottom surface of the ribbon immediately below the depression for measurement of the temperature. The ribbon hot stage was enclosed in a removable metal chamber fitted with glass windows in top and side for transmitting a strong beam of light and viewing the stage with a stereoscopic microscope. The ribbon was heated with electric current controlled by a rheostat. The temperature of the hot stage was calibrated with chemical compounds of known melting point.

For comparison with the melting characteristics of the extracts and petrographic components of the lignites examined in this investigation, tests were made on the hot stage with samples of commercial montan, ozokerite, carnauba, paraffin wax, and lump-type resin. The results of these tests are shown in table 9. The melting temperature of the waxes was 83° C. or lower. Melting was sharp, and the range between incipient and complete melting, with exception of ozokerite waxes, was generally about 2° C. All of the waxes produced free-flowing melts. None of the resins tested showed a critical melting point as sharply defined as the waxes. The melting periods were considerably longer, and the melts varied from viscous fluids to nonflowing spherical globules. None of the resins melted below 170° C.

TABLE 9.—Melting characteristics of commercial waxes, commercial resins prepared from coal, and lump-type resin hand-picked from coal

<table>
<thead>
<tr>
<th>Source</th>
<th>Sample</th>
<th>Color</th>
<th>Melting temperatures (°C)</th>
<th>Characteristics of melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah, Soldiers Summit</td>
<td>Ozokerite, refined</td>
<td>White</td>
<td>45-80</td>
<td>Clear, slow-flowing melt.</td>
</tr>
<tr>
<td>Petroleum</td>
<td>Paraffin, white, solid</td>
<td>... do</td>
<td>60-72</td>
<td>Brown, slow-flowing melt.</td>
</tr>
<tr>
<td>Galicia, Borysław</td>
<td>Ozokerite, crude wax</td>
<td>Brown</td>
<td>64-70</td>
<td>Yellow, slow-flowing melt.</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>Montan wax from brown coal</td>
<td>... do</td>
<td>73-74</td>
<td>Light-brown melt, free-flowing.</td>
</tr>
<tr>
<td>California, Lone</td>
<td>Montan wax from lignite</td>
<td>... do</td>
<td>75-75</td>
<td>Do</td>
</tr>
<tr>
<td>Brazil, Parahyba</td>
<td>Carnauba wax from palm leaves</td>
<td>Yellow</td>
<td>77-78</td>
<td>Light-yellow melt, free-flowing.</td>
</tr>
<tr>
<td>Arkansas, Malvern</td>
<td>Montan wax from lignite</td>
<td>Brown</td>
<td>80-83</td>
<td>Brown melt, free-flowing.</td>
</tr>
<tr>
<td>Germany</td>
<td>Montan wax from brown coal</td>
<td>... do</td>
<td>82-83</td>
<td>Do</td>
</tr>
</tbody>
</table>

RESINS PREPARED FROM UTAH COAL

<table>
<thead>
<tr>
<th>Source</th>
<th>Sample</th>
<th>Color</th>
<th>Melting temperatures (°C)</th>
<th>Characteristics of melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah, Castlegate</td>
<td>Clarified resin °</td>
<td>Clear amber</td>
<td>170-175</td>
<td>Light-brown melt, slow-flowing.</td>
</tr>
<tr>
<td>Do</td>
<td>Fossil resin °</td>
<td>... do</td>
<td>205-220</td>
<td>Brown melt, very viscous.</td>
</tr>
<tr>
<td>Do</td>
<td>Montan wax from lignite</td>
<td>Dark brown</td>
<td>212-243</td>
<td>Dark-brown melt, very viscous.</td>
</tr>
<tr>
<td>Do</td>
<td>Montan wax from brown coal</td>
<td>Yellow</td>
<td>223-245</td>
<td>Brown melt, slow-flowing.</td>
</tr>
<tr>
<td>Do</td>
<td>Commercial resin °</td>
<td>Clear amber</td>
<td>355</td>
<td>Do</td>
</tr>
</tbody>
</table>

LUMP-TYPE RESIN HAND-PICKED FROM COAL

<table>
<thead>
<tr>
<th>Source</th>
<th>Sample</th>
<th>Melting temperatures (°C)</th>
<th>Characteristics of melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkansas, Dallas Co</td>
<td>Lump-type resin picked from lignite</td>
<td>Yellow granular</td>
<td>170-175</td>
</tr>
<tr>
<td>Do</td>
<td>Lump-type resin picked from bituminous coal</td>
<td>do</td>
<td>280-222</td>
</tr>
<tr>
<td>Utah, Huntington</td>
<td>do</td>
<td>do</td>
<td>206-224</td>
</tr>
<tr>
<td>British Columbia, Merritt</td>
<td>do</td>
<td>do</td>
<td>242-349</td>
</tr>
<tr>
<td>Do</td>
<td>do</td>
<td>do</td>
<td>269-379</td>
</tr>
<tr>
<td>New Zealand, North Island</td>
<td>do</td>
<td>Clear pale yellow</td>
<td>276-371</td>
</tr>
</tbody>
</table>

1 The lowest value representing each test is the temperature at which melting was first observed and the higher-value temperature at which the melting was complete. The temperature rise was kept at a constant low rate, and the size of each sample tested was about the same.


3 Sample furnished by the Combined Metals Reduction Co.

4 Sample furnished by the U. S. Refining & Melting Co.
Table 10 shows the melting characteristics of waxes obtained in solvent extraction tests of Arkansas and California lignite and residues from maceration treatment of the 6-inch layer from the Old Big House column sample. The benzene extracts from the Arkansas lignites had lower melting temperatures than the benzene-alcohol extracts and formed a melt that was more free-flowing. The differences between the melting characteristics of the benzene and benzene-alcohol extracts from the Ione, Calif., lignite, were less significant, although the benzene-alcohol extract formed a slightly more viscous melt.

The melting characteristics of the benzene and benzene-alcohol soluble products extracted from the maceration residues showed significant differences. The benzene extract from the plus 180-mesh residue began to melt at 84° C., and a complete melt, which was brown and viscous, was obtained at 102° C. The benzene-alcohol extract from the same residue melted between 112° and 135° C. and formed a more viscous melt. The benzene extract from the 180- by 325-mesh fraction began to melt at 86° C., became strongly melting at 150° C., and was completely melted at 206° C. The melt was dark-colored and viscous. Melting temperature of the benzene-alcohol extract was slightly higher than that of the benzene extract from the 180- by 325-mesh fractions, and the melt was dark-colored and more viscous. The initial melting temperatures of the benzene and benzene-alcohol extracts from the minus 325-mesh residue were higher than those obtained on the extracts from the 180- by 325-mesh fraction, but the final melting temperatures were lower, and the melt was slightly less viscous.

### Table 10. Melting characteristics of benzene and benzene-alcohol extraction products from lignite, ingredients from lignite-maceration residues, and benzene-soluble products from certain ingredients selected from maceration residues

<table>
<thead>
<tr>
<th>Source</th>
<th>Sample</th>
<th>Melting temperatures, °C.</th>
<th>Characteristics of melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia, Maljwdena...</td>
<td>Paper coal (Papierkohle) from Moscow lignite coal basin...</td>
<td>67-71</td>
<td>Light-brown melt, free flowing.</td>
</tr>
<tr>
<td>California, Ione...</td>
<td>Lignite from Amador County...</td>
<td>74-79</td>
<td>Do.</td>
</tr>
<tr>
<td>Greece, Ptolemia...</td>
<td>Atrital-type brown coal...</td>
<td>74-81</td>
<td>Do.</td>
</tr>
<tr>
<td>Arkansas...</td>
<td>Column sample from American Dyewood Co. mine...</td>
<td>76-84</td>
<td>Do.</td>
</tr>
<tr>
<td>Do...</td>
<td>Column sample from outcrop, Hot Springs County...</td>
<td>80-84</td>
<td>Do.</td>
</tr>
<tr>
<td>Ouachita...</td>
<td>Sample—6 inch layer from Old Big House mine column...</td>
<td>88-94</td>
<td>Light-brown melt, slow flowing.</td>
</tr>
<tr>
<td>Do...</td>
<td>Plus 180-mesh maceration residue from above sample...</td>
<td>84-102</td>
<td>Brown, viscous melt, slow flowing.</td>
</tr>
<tr>
<td>Do...</td>
<td>180 X 325-mesh maceration residue, same sample...</td>
<td>89-206</td>
<td>Do.</td>
</tr>
<tr>
<td>Do...</td>
<td>Minus 325-mesh maceration residue, same sample...</td>
<td>150-175</td>
<td>Do.</td>
</tr>
</tbody>
</table>

### Products from Benzene-Alcohol Extraction of Lignite and Residues from Macerated Lignite

| California, Ione... | Lignite from Amador County... | 81-84 | Brown melt, slow flowing. |
| Arkansas... | Column sample from American Dyewood Co. mine... | 95-114 | Do. |
| Do... | Column sample from outcrop, Hot Springs County... | 111-131 | Do. |
| Ouachita... | Sample—6 inch layer from Old Big House mine column... | 113-125 | Do. |
| Do... | Plus 180-mesh maceration residue above sample... | 86-135 | Dark-brown melt, slow flowing. |
| Do... | 180 X 325-mesh maceration residue, same sample... | 94-230 | Do. |
| Do... | Minus 325 mesh maceration residue, same sample... | 164-196 | Do. |

### Ingredients from Maceration Residue of a Selected 6-Inch Layer Sample, Old Big House Column ¹

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Characteristics of melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow, cuticular material from the plus-180 mesh maceration residue...</td>
<td>No melting</td>
</tr>
<tr>
<td>Round, yellow bodies from the 180 X 325-mesh maceration residue...</td>
<td>200-255</td>
</tr>
<tr>
<td>Round, amber bodies from the 180 X 325-mesh maceration residue...</td>
<td>200-257</td>
</tr>
<tr>
<td>Round, dark-red bodies from the 180 X 325-mesh maceration residue...</td>
<td>330</td>
</tr>
<tr>
<td>Particles of lump-type resin, plus 180-mesh residue...</td>
<td>170-200</td>
</tr>
<tr>
<td>Dark-red, vitreous rodlets plus 180-mesh residue...</td>
<td>No melting</td>
</tr>
<tr>
<td>Dull, dark-brown rodlets plus 180-mesh residue...</td>
<td>No melting</td>
</tr>
</tbody>
</table>

### Benzene-Soluble Product from Ingredients Separated from Maceration Residue, Old Big House Column ¹

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Characteristics of melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow, cuticular material, hot benzene-soluble product...</td>
<td>72-78</td>
</tr>
<tr>
<td>Lump-type resin, hot benzene-soluble product...</td>
<td>178-218</td>
</tr>
<tr>
<td>Round bodies—yellow-amber and dark-red mixed—hot benzene-soluble product...</td>
<td>190-280</td>
</tr>
</tbody>
</table>

¹ Variation in shades of color was more or less characteristic of all types of ingredients found in the maceration residue. For the tests made, specimen typical of the color designated were selected.
Data obtained for some of the ingredients isolated from the plus 180-mesh and 180- by 
325-mesh fractions are included in table 10. No melting was observed for the particles of 
yellow cuticular material or the dark-brown 
rodlets. The dark-red rodlets did not melt, 
but softened and expanded slightly at high 
temperatures. The only ingredient in the plus 
180-mesh residue that showed definite melting 
characteristics were particles of lump resin that 
melted at 170° to 200° C. Examination of the 
round bodies that ranged in color from yellow 
through amber to dark red showed that the 
yellow bodies melted at 200° to 255° C., the 
amber bodies at about 10° C. higher, and the 
dark-red bodies formed a black, globular, non-
flowing melt at 350° C. Ingredients in the 
minus 325-mesh fraction were too small to be 
isolated and tested.

Melting characteristics were determined also 
of the material extracted by benzene from cer-
tain of the ingredients separated from the 
amaceration residues. The results are given at 
the bottom of table 10. The initial melting 
temperature of the benzene-soluble material 
from the lump-type resin was 178° C., which 
agrees closely with that of the untreated resin 
from the same source. The melting tempera-
ture of the extract from a mixture of yellow, 
amber, and red round bodies ranged from 195°

to 280° C., which corresponds generally to 
that of similar particles before extraction. A 
yield of 17 percent of yellowish product that 
was softer than montan wax was obtained in 
benzene extraction of the yellow cuticular 
material. Its melting temperature ranged from 
72° to 78° C., which is closer to that of montan 
wax than of any of the other identifiable ingre-
dients in the maceration residues or their ben-
zene-soluble products.

An extraction test was made of a small sam-
ple of paper coal (papierkohle) from the Mos-
cow coal basin near Maljowka, Russia. This 
coil is unusual in petrographic composition, 
as it consists almost entirely of cuticular ma-
terial. It is a Paleozoic lignitic coal of lower 
Carboniferous (Mississippian) age. Using ben-
zene as solvent, 1.6 percent of the sample was 
extracted. The waxlike product was soft and 
light brown. It closely resembled, in appear-
ance and melting characteristics, the waxy 
extract from cuticular material isolated from 
the Arkansas lignite. The extracted wax 
tested on the hot stage began to melt at 67° C. 
and was completely melted at 71° C.

The comparative study of melting behavior 
of the commercial waxes, extracts from Ameri-
can lignites, and petrographic components in 
attritional lignite resulted in information that 
suggests conclusions as follows:

1. Commercial montan wax extracted from 
certain European brown coal and American 
lignite melts sharply into free-flowing, slightly 
viscous amber melts at similar temperatures.

2. The product obtained by benzene extrac-
tion of American lignite is similar in melting 
characteristics to commercial montan wax. 
Benzene-alcohol extraction products from the 
same lignite have higher melting temperatures 
with a darker, more viscous melt.

3. Lump-type resins from lignitic and bitu-
ninous coals characteristically have melting 
temperatures considerably higher than montan 
 wax. This is true, irrespective of color of the 
resin or rank of coal from which obtained. The 
melts are either very viscous or nonflowing.

4. The round bodies of yellow to reddish 
color common in the attrital lignites examined 
have melting characteristics similar to those of 
lump-type resin from the same coal.

5. The dark-red rodlets, also common in the 
lignites examined, have a low degree of solu-
bility in benzene and benzene-alcohol solvents. 
They react to heat in such a way as to suggest 
they may be coalified material rather than true 
resins.

6. The benzene extract from the yellow 
cuticular material isolated from the lignite is 
the only substance obtained from a particular 
attritional ingredient that possesses melting char-
acteristics comparable to those of montan wax.

SOURCE OF WAX AND RESIN AND ORIGIN OF WAX-
BEARING LIGNITE

The main source of the substance extracted 
from lignite with benzene and benzene-alcohol 
solvents and which consists of wax, resin, and 
asphaltic material was certain ingredients in 
the attritional ground mass of the lignite. These 
materials were yellow cuticular material, 
round resinous bodies, lump-type resinous 
particles, and probably spores, pollen, and 
finely divided yellow material not identifiable. 
Most of these ingredients can be identified 
readily in a thin section of attritional lignite 
examined under the microscope with trans-
mitted light and can be isolated from the attritus 
by maceration. Nearly all appear yellowish 
translucent with transmitted light and yellow 
to amber under reflected light.

The original source of much of the waxy 
element in products extracted from lignite, as 
determined from study of maceration residues, 
was undoubtedly the thin, yellowish, trans-
lucent substances in attritus identified as 
particles of cuticular material. The isolated 
particles examined were necessarily relatively 
large, a few measuring several millimeters in 
greatest dimension, but most of the material 
from the attritus was finely divided, ranging 
down to granular size. Wax derived from 
complete disintegration of cuticles also probably
occurs in granular form disseminated through the attritus.

The resinous and asphaltic portion of the soluble extracts from lignite was derived certainly from particles of lump-type resin, round, yellowish resin bodies, and round, reddish, resinous, and asphaltic bodies. Spore and pollen remains and dark-red, vitreous rodlets may have contributed something to the resinous and asphaltic composition.

Vegetable wax is formed in growing plants in the integumentary parts—that is, the epidermal layers of leaves, fruit, seeds, berries, petioles, and stems. The outer protective covering of the epidermis, called the cuticle, is composed of cutin, a complex substance that has associated with it wax in the form of grains, rodlets, and crusty masses. Wax also is associated with suberin, a fatty protective substance formed in cork tissues of plants.

Wax is excreted by the plant into the protective layers of various epidermal tissues, where it serves as a waterproofing agent, preventing excessive moisture loss in warm, dry atmospheres and excessive water absorption in moist environments.

The waxy nature of cuticles is familiarly known in the peels of certain fruit such as apples, plums, persimmons, and bananas. The high surface polish that can be given to some apples is due to the wax content of the cuticle or peel. Wax does not seem to be secreted and stored to any extent internally in the xylem tissues of the plant as is resin.

Wax is produced most prolifically by vegetation such as trees, shrubs, herbs, canes, and grasses growing in warm and in dry climates. The leaves of a wax-bearing palm tree found in Brazil are the source of commercial carnauba wax. The wax coatings of certain palm leaves measure 1 to 5 millimeters in thickness. Vegetation native to temperate climates is not conspicuously wax-bearing, although the berry-like fruit of the bayberry bush is a source of commercial wax.

Resin is a well-known excretory product of growing plants, and its function is not thoroughly understood. It occurs in greatest abundance stored in resin ducts and canals and in cell walls and cavities of the woody tissues. Some resin also is found in the cork, epidermal, and leaf tissues. The southern yellow pine is a striking example of a richly resinous plant. This tree exudes a large amount of resin, which appears as a sticky yellowish substance on the bark, injured surfaces, and in the needlelike leaves.

The prevailing occurrence of waxy matter in the cuticular coverings of reproductive and leafy organs of plants suggests a clue to the occurrence of wax in lignite. Leaves, seeds, fruit, berries, spores, pollen, and petioles are the parts of plants whose remains are known to contribute heavily to the attrital matter in coal. The protective coverings of these plant parts are usually very thin and constitute a very small part of the organ, but the amount of leaves seeds, berries, fruit, spores, pollen, etc., grown and shed annually by plants is large. The fleshy tissues in these organs decay rapidly, leaving the decay-resistant cuticular material to accumulate as attrital debris. Therefore, lignite and peat that is predominantly attrital in composition should logically be the best source material for extractable wax. It would seem, too, that peat and lignitic deposits originating in a subtropical or tropical environment might give higher wax yields than temperate-zone deposits. Berry’s study of Wilcox flora established the fact that the wax-bearing Arkansas attrital lignite accumulated in a subtropical environment.

Xyloidal lignite, in which the amount of anthraxylon is high and that of translucent attritus is relatively low, also has a low content of extractable wax. This is shown in table 11, which gives the content of translucent attritus and extraction yield of some attrital and xyloid lignites arranged in descending order.

### Table 11.—Translucent attritus and extraction yield of attrital and xyloid lignites

<table>
<thead>
<tr>
<th>State</th>
<th>County</th>
<th>Variety</th>
<th>Translucent attritus, per cent</th>
<th>Extraction yield, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkansas</td>
<td>Hot Spring</td>
<td>Attrital</td>
<td>91.6</td>
<td>11.1</td>
</tr>
<tr>
<td>California</td>
<td>Amador</td>
<td>do</td>
<td>86.1</td>
<td>14.2</td>
</tr>
<tr>
<td>Arkansas</td>
<td>Dallas</td>
<td>do</td>
<td>83.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Do</td>
<td>Polkett</td>
<td>do</td>
<td>83.4</td>
<td>7.6</td>
</tr>
<tr>
<td>Do</td>
<td>Ouachita</td>
<td>do</td>
<td>75.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Texas</td>
<td>Harrison</td>
<td>Xyloid</td>
<td>64.4</td>
<td>1.8</td>
</tr>
<tr>
<td>North Dakota</td>
<td>Divide</td>
<td>do</td>
<td>33.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Do</td>
<td>Burleigh</td>
<td>do</td>
<td>31.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Do</td>
<td>Ward</td>
<td>do</td>
<td>27.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Do</td>
<td>Merrer</td>
<td>do</td>
<td>26.1</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Attrital lignite may likely have originated in a swamp environment where plant material decayed at such rapid rate that only decay-resistant attritus and very finely macerated woody tissues were preserved. Periodic renewal of fresh water by flooding from streams or heavy rains would promote rapid decay. Attrital lignite, too, may have accumulated in shallow fresh or brackish water pools in which not much vegetation actually grew, but into which drifted, blew, or fell large quantities of debris shed from vegetation that fringed the

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pool. It is likely that many of the Arkansas deposits originated in this manner. The absence of fusain, the small amount of opaque attritus, thinness of the beds, and shape of the deposits suggests such origin.

On the other hand, xyloloid lignite would seem to have accumulated best under conditions peculiar to stagnant-water peat swamps where decay was somewhat retarded and much woody material was included in the peat debris. The slower the rate of vegetable decay, the more anthraxylon and proportionately less attritus accumulated, therefore lessening the possibility of wax and resin concentration. Texas lignite originated under conditions of slow decay, as indicated by thicker beds, more anthraxylon, and less translucent attritus than Arkansas attrital lignite. Appreciable amounts of opaque attritus and fusain suggest occasional dry conditions in the swamp. The extensive deposits of the Fort Union formation probably accumulated in great arboreal or tree-growing swamps much like our vast temperate-zone peat swamps of today. A preponderate amount of woody material and slow decay resulted in lignite composed predominantly of anthraxylon and relatively poor in attritus.
APPENDIX—DESCRIPTION OF COAL SAMPLES

The descriptions that follow have been compiled from notes made by collectors of the samples and from other data. They supplement the information given in table 2 of coal analyses and table 3 of wax-extraction yields. The initials after the sampler’s name show the organizations with which they were associated when the samples were collected, as follows: USBM, Bureau of Mines; USGS, Geological Survey; ARDC, Geology Division, Arkansas Resources and Development Commission; UA, Bureau of Research, University of Arkansas.

GULF PROVINCE

ARKANSAS

CLAY COUNTY

POLLARD—OUTCROP EXPOSURE

Location.—Outcrop exposure along the west slope of Crowley’s Ridge, 6 miles west and 2 miles south of Pollard, in the SE4/4NE1/4NW1/4 sec. 6, T. 20 N., R. 7 E., on property of E. Jennings.

Description.—Compact, dark-brown, dense-textured lignite. Bed 18 inches thick at point of sampling but thickens to 24 inches and more laterally. Thin clay partings near top in thicker portions of the bed.

Sample obtained.—A standard channel sample taken by N. F. Williams (ARDC), November 4, 1947.

Analyses.—Coal analysis, C-84896; wax extraction tests, 46145; and petrographic analysis, table 7 (item 1).

Remarks.—A descriptive profile section of the lignite bed and overburden is shown in figure 20, profile 1. The brown and black lignitic clay above and below the coal beds shown in this profile helps explain why lignite beds are often reported after casual examination to be much thicker than they actually are.

DALLAS COUNTY

CARThAGE—OUTCROP EXPOSURE

Location.—Lignite outcrop exposed in west bank and bed of Tulip Creek, about 5 miles southwest of Carthage, in the SW1/4NW1/4 sec. 9, T. 8 S., R. 15 W., on property of Malvern Lumber Co.

Description.—Firm, light-brown, earthy lignite containing small gray blebs and lenses of sand and clay. A sand and clay parting 2 to 6 inches thick separates the bed into two benches. At the point of sampling, the thickness of the upper bench is 20 inches and the bottom bench 23 inches.

Samples obtained.—A standard channel sample was taken from each bench. Sampled by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARDC), September 13, 1947.

Analyses.—Upper bench—coal analysis C-83517 and wax-extraction tests 46096. Lower bench—coal analysis C-83518, and wax-extraction tests 46097.

Remarks.—The lignitic material exposed in Tulip Creek appears to represent the marginal edge of a lignite deposit. The bed dips upstream at an angle of 7 degrees to the horizontal. Lignite 5 to 8 feet thick is commonly reported to have been penetrated in water wells dug in the vicinity of Carthage, but no other exposure than the Tulip Creek deposit was seen. Impure lignite of this type is known locally as “young” lignite. A profile section of the deposit is shown in figure 20, profile 3.

MANning—AMERICAN DYEWOOD CO., MINN.

Location.—Abandoned strip mine 2 miles south of Manning, in the SW1/4SE1/4 sec. 25, T. 8 S., R. 17 W., on property of Sturgis Brothers Lumber Co.

Description.—Compact, dark-brown lignite, dense-grained, and with occasional vitreous lenticles. Six feet of lignite exposed in the east rib above the water level in floor of pit.

Samples obtained.—Sample 1 was obtained by J. N. Payne (UA) and B. C. Parks (UA), July 17, 1946. Six feet two inches of the lignite exposed in the east rib was sampled by cutting a 3-inch channel across the bed.

Sample 2 was obtained by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARDC), September 10, 1947. The 6 feet of exposed lignite was divided arbitrarily into three benches, each 2 feet thick. A standard channel sample was taken from each bench. A column sample approximately 18 inches on sides was cut from the upper 58 inches of the exposed bed at a position adjacent to the sample channel.

Analyses.—Sample 1, coal analysis C-61585 and wax-extraction tests 45738. Sample 2, coal analysis, top bench, C-84033; middle bench, C-84034; and bottom bench, C-84035; wax-extraction tests 46097.
Figure 20.—DESCRIPTIVE PROFILE SECTIONS SHOWING OVERBURDEN, UNDERCLAY, AND LIGNITE BEDS SAMPLED FOR WAX EXTRACTION TESTS AND PTEROGRAPIC ANALYSIS.

extraction test, top bench, 46107; middle bench, 46108; and bottom bench, 46109; and petrographic analysis, table 7 (items 2, 3, 4, and 5) and figure 11.

Remarks.—This mine was originally opened on an outcrop of lignite exposed in a cut along the Malvern-Camden branch of C. R. I. & P. R. R. The mine was operated from 1943 to 1945 by the American Dyewood Co. and was one of the sources of raw lignite for the company’s processing plant at Malvern.

Because lack of drainage facilities in the abandoned mine caused an excessive amount of water to collect, the base of the lignite bed could not be exposed and its full thickness determined. The coal was reported by former workers at the mine to be 6 to 8 feet thick. The overburden in ground that rises steeply above the strip pit extends 100 feet in thickness. Forty-one feet of the overburden immediately overlying the coal was measured in detail; a columnar diagram and description are shown in figure 20, profile 2.

HOT SPRING COUNTY

Malvern—Outcrop exposure

Location.—Lignite outcrop exposed in east bank of Two-Mile Creek, about 2 miles southeast of Malvern, in the SE¼ sec. 36, T. 4 S., R. 17 W., on property of the Malvern Lumber Co.

Description.—Compact, dense-textured, dark-brown lignite. Exhibited slick, smooth surfaces when cut into with a knife or pick. Freshly broken surfaces contained numerous bodies easily visible to the unaided eye. The lignite exposed was 18 inches thick.

Samples obtained.—A standard channel sample was taken, and a small column sample was cut from the bed. Sampled by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARDC), September 8, 1947.

Extraction.—Coal analysis C–82380 and wax-extraction tests 46084.

Remarks.—As there was some doubt that a complete thickness of the lignite bed was present in the outcrop exposure, another outcropping of apparently the same deposit was sampled about one-eighth mile upstream.

Malvern—Outcrop exposure

Location.—Lignite outcrop exposed in bed of south fork of Two-Mile Creek, about 2 miles southeast of Malvern, in the SE¼ sec. 36, T. 4 S., R. 17 W., on property of Malvern Lumber Co.

Description.—Compact, dense-textured, dark-brown lignite. Exhibited slick, smooth surfaces when cut into with a knife or pick. Freshly broken surfaces contained numerous bodies easily visible to the unaided eye. The lignite exposed was 18 inches thick.

Samples obtained.—A standard channel sample was taken, and a small column sample was cut from the bed. Sampled by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARDC), September 8, 1947.

Analysis.—Coal analysis C–82381, wax-extraction tests 46085, and petrographic analysis, table 7 (item 6).

Remarks.—The deposit sampled at this point was probably the same lignite sampled one-eighth mile down the creek, as described for the preceding sample. This outcrop was about 50 yards from a small abandoned strip mine. The mine was developed during the war and was a source of raw lignite for the Malvern processing plant. Approximately 3 acres of the creek bottom underlain with lignite was stripped. A profile section of the overburden measured in the old strip pit and profiles of
lignite beds sampled are shown in figure 20, profiles 4, 5, and 6.

OUACHITA COUNTY

CHIDESTER—GARNER MINE

Location.—Lignite exposed in abandoned strip pit, ½ mile east of Chidester, in the NE\(_4\)SE\(_4\) sec. 12, T. 12 S., R. 19 W., on property of E. S. Garner.

Description.—Dark-brown, compact, dense-textured lignite. Basal 4 inches of the bed consisted of shaly lignitic clay. Thirty-four inches of lignite was measured and sampled.

Sample obtained.—A standard channel sample was cut from a lignite bed exposed in the south rib of the strip pit. Sampled by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARD), September 12, 1947.

Analyses.—Coal analysis C-82692, and wax-extraction tests 46088.

Remarks.—Lignite was mined during the war in this strip pit and shipped to the Malvern plant of the American Dyewood Co. When sampled, the mine had been abandoned for several years. The lignite bed in the Garner pit was overlain with a medium course, yellowish sand. Farther south, at other examined exposures of supposedly the same lignite bed, the roof rock consisted of a relatively thick bed of compact gray clay. Profile section of lignite and overburden is shown in figure 21, profile 8.

CHIDESTER—PROSPECT PIT

Location.—Lignite exposed in small prospect pit dug on farm of P. M. Jackson, about 4 miles southeast of Chidester, in the SE\(_4\)SW\(_4\) sec. 8, T. 12 S., R. 18 W.

Description.—Brown, compact, dense-grained lignite with occasional thin, vitreous bands. Lower 4 inches of the bed soft and shaly. Bed 40 inches thick.

Sample obtained.—A standard channel sample was taken from the fully exposed bed by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARD), September 1, 1947.

Analyses.—Coal analysis C-89486, and wax-extraction tests 46089.

Remarks.—Two outcroppings of lignite approximately 400 feet apart are exposed at this locality in separate ravines. The Jackson prospect pit has been dug near the head of the east ravine. The lignite apparently has the same sand overburden observed at the Garner strip pit east of Chidester. A profile section of the lignite and overburden is shown in figure 21, profile 9.

LESTER—DUNN MINE

Location.—Dunn mine, 4 miles north and 1 mile east of Lester.

Description.—Dark-brown, compact lignite 49 inches thick. Roof, compact gray clay; floor, soft, light-gray, plastic clay.

Sample obtained.—A standard channel sample was cut from the south rib of the drift entry 25 feet from opening of adit. Sampled by J. D. Turner (USGS), October 5, 1944.

Analyses.—Coal analysis C-28938, and wax-extraction tests 45301.

Remarks.—The mine was operated in 1943 according to local information. At the time of sampling the drift was blocked by a roof fall 30 feet from adit opening.

LESTER—OLD BIG HOUSE MINE

Location.—Abandoned drift mine 5 miles north of Lester, near the center of NE\(_4\) sec.
12, T. 12 S., R. 18 W., on property of the International Paper & Pulp Co.

Description.—Compact, dense-textured, dark-brown lignite 40 inches thick. Thin lenticles of vitreous lignite occur but are not conspicuous. Middle of the bed lighter-brown in color than upper and lower portions. Top 3 inches of bed laminated and loosely compacted. Lignite underlain with light-gray fire clay containing many vitrinite rootlets.

Samples obtained.—Sample 1 was taken by J. N. Payne (UA) and B. C. Parks (UA), July 17, 1946, from the exposed bed of coal at mouth of the mine. A 3-inch channel was cut from the full 42 inches of exposed bed.

Sample 2 was taken by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARDC), September 11, 1947. This was a standard channel sample cut on the opposite side of the adit opening from where sample 1 was obtained.

A column sample was cut from the exposed face of the lignite bed in a position adjacent to the channel cut for sample 2, figure 9.

Analyses.—Sample 1—coal analysis C–61584, and wax-extraction tests 45737. Sample 2—coal analysis C–83949, and petrographic analysis, table 7 (items 7, 8, and 9) and figure 13.

Remarks.—The lignite sample collected at this locality was commonly called the Lester lignite in the early days of mining in the Camden coal field. The coal was recovered in some quantity from several small mines in the vicinity of Lester approximately 50 years ago, and as late as 1943 mining was resumed at the Old Big House mine, and the lignite was processed at a small plant in El Dorado, Ark. The mine had been inactive for several years at the time of sampling. A descriptive profile section of the lignite and overburden is shown in figure 21, profile 7.

POINSETT COUNTY

HARRISBURG—OUTCROP EXPOSURE

Location.—Lignite exposed in outcropping strata in creek bed at the foot of Crowley’s Ridge, 2 miles north and 1 mile east of Harrisburg, in the N½SE¼ sec. 7, T. 11 N., R. 4 E., on property of J. G. Vanhooser.

Description.—Compact, dull brown, hard lignite containing thin layers, near top and bottom of bed, of soft, earthy lignite. Thickness of bed, 5 feet at the outcrop sampled.

Samples obtained.—A standard channel sample was taken by N. F. Williams (ARDC) January 8, 1948. Lump samples 4 inches square also were cut out of the bed at intervals of 6 inches from bottom to top for thin-section examination.

Analyses.—Coal analysis C–88707, wax-extraction tests 46234, and petrographic analysis, table 7 (item 10).

Remarks.—Apparently the deposit of lignite sampled is exposed at several other points along Bolivar Creek in this locality. The same bed thickness of 5 feet was measured at a point 300 feet from where the sample was taken, but ½ mile downstream from the sample point only 2½ feet of lignite is present. It seems to be characteristic of this particular deposit that the compact lignite ranges in thickness from 2 to 5 feet, the top and bottom of the bed becoming soft and earthy as the hard lignite thins. A profile section of the lignite bed sampled and overburden is shown in figure 21, profile 10.

SALINE COUNTY

DETONI—OUTCROP EXPOSURE

Location.—Lignite exposed in a roadside ditch 3½ miles southwest of Detoni, in the SE¼ sec. 7, T. 3 S., R. 14 W., on property of the International Paper & Pulp Co.

Description.—Firm, compact, dark-brown lignite with dull luster. Shows smooth, slick surfaces when cut. Bed 42 inches thick when completely exposed.

Sample obtained.—A standard channel was taken by B. C. Parks (USBM), H. J. O’Donnell (USBM), and H. B. Foxhall (ARDC), September 9, 1947.

Analyses.—Coal analysis C–82469, and wax-extraction tests 46087.

Remarks.—No other outcrop of this deposit was seen in the immediate vicinity. A profile section of the lignite and overburden is shown in figure 22, profile 11.

DETONI—PROSPECT PIT

Location.—Lignite exposed in a small hand-dug prospect pit on the farm of O. B. Hicks, 3¼ miles southeast of Detoni, in the S½S½SE¼ sec. 8, T. 3 S., R. 14 W.

Description.—Fifty-one inches of the lignitic bed was exposed. The lower 27 inches consisted of hard, compact, dark-brown lignite, dull in luster, and showed a slick, oily trace when cut with knife or pick. The sample was cut from this. The upper 24 inches, which was not sampled, consisted of soft, earthy, light-brown lignite.

Sample obtained.—A standard channel sample was taken by B. C. Parks (USBM) H. J. O’Donnell (USBM), and H. B. Foxhall (ARDC), September 9, 1947.

Analyses.—Coal analysis C–82468 and wax-extraction tests 46086.

Remarks.—The small prospect pit had been dug by the owner, who used some of the lignite for fuel. Immediately south of the pit, on the gentle sloping rise, 7 prospect holes had been drilled. It was reported to the sampling party that all of these holes penetrated lignite about 5 feet thick at relatively shallow depths.
Most of the holes were within a radius of 300 feet of the prospect pit. A profile section of the lignite and overburden in the prospect pit is shown in figure 22, profile 12.

TEXAS

HARRISON COUNTY

MARSHALL—DARCO NO. 3 MINE

Location.—Darco No. 3 strip mine, operated by McAlester Fuel Co. for the Darco Corp., Marshall, Tex., owners. The mine is 12 miles southwest of Marshall on State highway 43.

Description.—Two beds of lignite in close proximity were exposed in the strip pit. The upper bed was 7 feet 6 inches thick at the point sampled by the Bureau of Mines and was separated from the 7-foot 2-inch bed by a clay band 3 feet 6 inches thick (fig. 6). Both coal beds consisted of dark-brown to almost black, hard, compact lignite. Sand and clay blebs seemed to be more common in the lower bed.

Samples obtained.—Face sample submitted by V. C. Robbins, chief engineer, McAlester Fuel Co., McAlester, Okla. Bench samples also were collected by B. C. Parks (USBM) and H. J. O’Donnell (USBM) September 16, 1947. The upper bed was arbitrarily divided into two benches each 3 feet 9 inches thick, and the lower bed was divided into benches each 3 feet 7 inches thick. Standard channel samples were cut from all four benches. Selected blocks of coal 6 inches square were cut out of each bed from top to bottom at intervals of 12 inches for thin-section examination.

Analyses.—Face sample—coal analysis C-67352 and wax-extraction tests 45876. Top bench of upper bed—coal analysis C-84699 and wax-extraction tests 46114. Bottom bench of upper bed—coal analysis C-84700 and wax-extraction tests 46115. Top bench of lower bed—coal analysis C-84701 and wax-extraction tests 46116. Bottom bench of lower bed—coal analysis C-84702 and wax-extraction tests 46117. Petrographic analysis of upper and lower beds, table 7 (items 18 and 19).

Remarks.—Both coal beds are mined in successive strip operations with a drag line and small power shovel. The coal is loaded directly into 15-ton trucks and transported to the Darco plant at Marshall. About 120 tons of coal a day are mined, all of which is taken by the Darco plant, which produces activated carbon from the raw lignite. Several million tons of reserve coal has been proved on the property by test drilling. A profile section of the lignite beds and overburden is shown in figure 22, profile 14. A photograph of the south wall of the strip mine is shown in figure 6.

MILAM COUNTY

SANDOW—SANDOW STRIP MINE

Location.—Lignite exposed in an operating
strip mine of the McAlester Fuel Co. known as the Sandow operation, located at Sandow on a
branch-line railroad, about 10 miles southwest of Rockdale.

Description.—The lignite bed at the point sampled by the Bureau of Mines consisted of
11 feet 8 inches of coal. The coal was hard and compact, and much of it was distinctly banded
with thin, vitreous layers. Color ranged from brown to dark brown, and some of it was
nearly black. Softer less compact layers were noted, but these were of minor importance.
Many blebs of sand and clay occurred in some layers.

Samples obtained.—One sample was taken from a lot submitted by the McAlester Fuel Co.
for carbonization tests. For the other samples the coal bed was separated arbitrarily into
three benches, each approximately 4 feet thick. The bench samples were collected by B. C.
Parks (USBM) and H. J. O'Donnell (USBM), September 15, 1947.

Analyses.—Sample for carbonization—coal analysis C-38297 and wax-extraction tests
46257. Top bench—coal analysis C-84231 and wax-extraction tests 46111. Middle bench—
coal analysis C-84232 and wax-extraction tests 46112. Bottom bench—coal analysis C-
84233 and wax-extraction tests, 46113.

Remarks.—The Sandow mine was in operation when visited. In the part of the mine
designated area 3, a 3½-yard drag line was moving about 20 feet of overburden consisting
of clay and soil. Coal was loaded with a small power shovel into trucks and hauled to the
tipple. Four sizes of coal, defined as modified mine run (fines screened out), commercial lump,
domestic lump, and stoker fuel, are prepared. The largest consumer of the mine's coal output
at present is the University of Texas, where it is used in the power plant. In August, 5,000 tons
of coal was mined in 18 working days. This is
by no means the potential daily capacity of the mine, which obviously is limited by the volume
of coal sales.

NORTHERN GREAT PLAINS PROVINCE
COLORADO
EL PASO COUNTY

COLORADO SPRINGS—FRANCEVILLE MINE

Location.—Franceville mine, 13 miles east of Colorado Springs, in the NE¹/₄ sec. 30, T. 14 S.,
R. 64 W.

Sample obtained.—Composite tipple sample of Fox Hill bed coal of subbituminous B rank. Sampled by H. Fowler (USBM), August 26, 1947.

Analyses.—Coal analysis C-82045 and wax-extraction tests 46083.

WELD COUNTY

DAcono—BOULDER VALLEY No. 3 MINE

Location.—Boulder Valley No. 3 mine, ½ mile west of Dacono, in the NE¹/₄SW¹/₄ sec. 1, T. 1 N.,
R. 68 W.

Sample obtained.—Composite of three face samples. Coal, subbituminous B rank. Average
thickness of bed, 7 feet 7 inches. Sampled by H. Fowler (USBM), November 29, 1946.

Analyses.—Coal analysis C-65913 and wax-extraction tests 45858.

MONTANA
MUSSEL SHELL COUNTY

RouDUP—KERNE No. 2 MINE

Location.—Keene No. 2 mine, 7 miles east of Roundup, in NW¹/₄NW¹/₄ sec. 26, T. 9 N.,
R. 30 E.

Sample obtained.—Composite sample of mine-run coal, subbituminous B rank, Carpenter
Creek bed. Sampled by H. Fowler (USBM), July 29, 1946.

Analyses.—Coal analysis C-66313 and wax-extraction tests 45739.

POWDER RIVER COUNTY

BROADUS—BLACK DIAMOND MINE

Location.—Black Diamond mine, 6½ miles southwest of Broadus, in NE¹/₄NE¹/₄ sec. 11,
T. 5 S., R. 50 E.

Sample obtained.—Composite sample of lignite obtained from three points channeled
across the coal face. Coal bed 17 feet thick, but only lower 8 feet are worked. Sampled
by H. Fowler (USBM), May 5, 1947.

Analyses.—Coal analysis C-77342 and wax-extraction tests 46000.

SHERIDAN COUNTY

COALRIDGE—ACME MINE

Location.—Acme mine, ½ mile northwest of Coalridge.

Sample obtained.—Sample of 1½-inch lump coal of lignitic rank. Coal bed 12 feet thick,
but only lower 9 feet are worked. Sampled by H. Fowler (USBM), November 12, 1946.

Analyses.—Coal analysis C-65415 and wax-extraction tests 45842.

NORTH DAKOTA
BURKE COUNTY

COLUMBUS—KINCAID MINE

Location.—Kincaid strip mine, 4 miles south and 1 mile west of Columbus, in SE¹/₄ sec. 19,
T. 162 N., R. 93 W.

Sample obtained: Coal bed, not named; formation, Fort Union; average thickness of bed,
7 feet; average cover, 50 feet. Sample consisted of composite increments of run-of-mine
APPENDIX—DESCRIPTION OF COAL SAMPLES

WARD COUNTY

Sawyer—Miller mine

Location.—Miller strip mine, 9 miles southwest of Sawyer.

Sample obtained.—Composite tipple sample from the Coteau lignite bed in the Fort Union formation. Sampled by H. Fowler (USBM), October 21, 1946.

Analyses.—Coal analysis C-64366 and wax-extraction tests 45797.

Velva—Velva mine

Location.—Velva mine, 10 miles southwest of Velva, in sec. 34, T. 152 N., R. 81 W.

Sample obtained.—Composite mine-run coal sample from upper 10 feet of coal being mined. Lignite bed known as the Coteau seam in the Fort Union formation. Sampled by H. Fowler (USBM), September 25, 1946.

Analyses.—Coal analysis C-64606, wax-extraction tests 45800, and petrographic analysis, table 7 (item 17).

DIVIDE COUNTY

Noonan—Baukol-Noonan mine

Location.—Baukol-Noonan strip mine, 1 mile east of Noonan, in sec. 10, T. 162 N., R. 95 W.

Sample obtained.—Sample of composite mine-run lignite from Noonan bed in the Fort Union formation. Thickness of bed, 7 feet. Sampled by H. Fowler (USBM), October 31, 1946.

Analyses.—Coal analysis C-65444, wax-extraction tests 45809, and petrographic analysis, table 7 (item 15).

MERCER COUNTY

Beulah—Beulah mine

Location.—Beulah mine, 2 miles northeast of Beulah.

Sample obtained.—Delivered 4-inch by 8-inch lump lignite.

Analyses.—Coal analysis C-40701, wax-extraction tests 45548, and petrographic analysis, table 7 (item 16).

Zap—Indian Head mine

Location.—Indian Head mine, near Zap.

Sample obtained.—Delivered 1½-inch lignite screenings. Coal bed, Zap-Beulah; formation, Fort Union.

Analyses.—Coal analysis C-43508 and wax-extraction tests 45549.

MOUNTAIL COUNTY

White Earth—Timmel mine

Location.—Timmel mine, 20 miles south of White Earth, in SW¼NE¼ sec. 19, T. 154 N., R. 94 W.

Sample obtained.—Run-of-mine lignite from lower 8 feet of coal bed. Total bed thickness, 12 feet. Sampled by H. Fowler (USBM), November 7, 1946.

Analyses.—Coal analysis C-65494 and wax-extraction tests 45817.

WYOMING

Converse County

Glenrock—Badger mine

Location.—Badger mine, 17 miles north of Glenrock.

Samples obtained.—Tipple samples of sub-bituminous C coal from Badger bed. Sampled by H. Fowler (USBM), December 7, 1946.

Analyses.—2½-inch lump coal—coal analysis C-66104 and wax-extraction tests 45872. ½-inch slack coal—coal analysis C-66107 and wax extraction tests 45880.
WESTON COUNTY

Upton—CUMMINGS MINE

Location.—Cummings strip mine, 51 miles southwest of Upton, in the SW¼ SE¼ sec. 18, T. 42 N., R. 68 W.

Sample obtained.—Sample taken at face of north side of pit. Bed 5 feet 10 inches thick; upper 2 inches rejected in sampling. Subbituminous C rank. Sampled by H. Fowler (USBM), November 25, 1946.

Analyses.—Coal analysis C-65874 and wax-extraction tests 45856.

ROCKY MOUNTAIN PROVINCE

COLORADO

JACKSON COUNTY

Coalmont—MOORE NO. 2 MINE

Location.—Moore No. 2 strip mine, at Coalmont, in SE¼NE¼ sec. 26, T. 7 N., R. 81 W.

Sample obtained.—Tipple sample of mine-run subbituminous B coal from Riaach bed. Thickness of bed 32 feet. Sampled by H. Fowler (USBM), September 2, 1947.

Analyses.—Coal analysis C-77708 and wax-extraction tests 46042.

WYOMING

CARBON COUNTY

Rawlins—PETTIGREW NO. 2 MINE

Location.—Pettigrew No. 2 mine, 28 miles northwest of Rawlins.

Sample obtained.—Sample of mine-run coal of subbituminous C rank.

Sampled by H. Fowler (USBM), December 4, 1946.

Analyses.—Coal analysis C-66088 and wax-extraction tests 45857.

FREMONT COUNTY

Hudson—GEORGE MINE

Location.—George slope mine, 2½ miles south of Hudson.

Sample obtained.—Sample of mine-run coal of subbituminous B rank. Thickness of bed worked, 4 feet. Sampled by H. Fowler (USBM), June 13, 1947.

Analyses.—Coal analysis C-78941 and wax-extraction tests 46041.

PACIFIC COAST PROVINCE

CALIFORNIA

AMADOR COUNTY

Ione—BUENA VISTA MINE

Location.—Buena Vista mine, 5½ miles southeast of Ione.

Sample obtained.—Face sample from lignite bed in Ione formation taken 100 feet east of Buena Vista mine shaft. Thickness of bed, 8 feet. Sampled by A. B. Wallen (California Clay Corp., Ione, Calif.), January 30, 1946.

Analyses.—Coal analysis C-57102 and wax-extraction tests 45571.

Ione—EDWIN NO. 2 CLAY MINE

Location.—Edwin No. 2 clay mine near Ione.

Sample obtained.—Face sample from 3-foot bed of lignite in Ione formation. Sampled at end of 500-foot inclined shaft by A. B. Wallen (California Clay Corp., Ione, Calif.), January 30, 1946.

Analyses.—Coal analysis C-53823 and wax-extraction tests 45474.

Ione—UNKNOWN

Location.—Near Ione.

Sample obtained.—Twenty-pound sample of 1-inch x 0-inch Ione lignite. Submitted by John F. Culp, Jr. (Vulcan Iron Works, Wilkes-Barre, Pa.), June 1946.

Analyses.—Coal analysis C-61583 and wax-extraction tests 45736.

Ione—STRIP MINE

Location.—No. 1 pit of the American Lignite Products Co.'s mine, 1 mile southwest of Ione.

Description.—The upper part of an unmined coal bed in the Ione formation exposed in rib at west end of strip pit. Bed reported to be approximately 13 feet thick at point sampled, but the lower 6 feet was undermined and was not sampled.

Sample obtained.—A column sample representing 6 feet, 9 inches of upper portion of the lignite bed was collected by A. L. Toenges and T. R. Jolley (USBM), February 10, 1949. A representative channel sample was cut from the column in the coal-petrography laboratory.

Analyses.—Coal analysis D-13068, wax-extraction tests 46602, petrographic analyses, table 7, items 11, 12, 13.

Remarks.—The mine sampled consisted of three small strip pits opened along the outcrop of a lenticular bed of lignite that reportedly ranged in thickness from 1 to 13 feet. The locality is the site of former underground mining by means of drift adits that are now abandoned. The immediate roof of the coal consisted of 4 feet of limonitic clay. Overlying this, the overburden consisted of 3 feet 4 inches of gray clay, 13 inches of limonitic clay, and 20 to 40 feet of undifferentiated sand and clay. The mine is operated by the DeAngelis Coal Co., and the coal is used exclusively for processing in the American Lignite Products Co.'s nearby plant. This is the only wax-extraction plant using limonitic coal in operation at present in the United States. The coal, as it appeared in the pit exposures, is compact, grainy, and nonbanded; some of it is very dark brown, but relatively thick portions of the bed
are light brown. It was reported that the
light-brown lignite contained appreciably more
wax than the dark-brown variety, but the two
coals are blended in processing to facilitate
crushing and pulverizing. Present output of
the mine is about 15 tons per day.

OREGON

COOS BAY—DRILL HOLE 13–16

Location.—Drill hole 13–16, 3,010 feet west
and 773 feet south of NE corner sec. 16, T. 27
S., R. 13 W., Willamette meridian.

Sample obtained.—Coal core from Beaver
Hill bed. Bed thickness, 7 feet 5 inches. Coal,
subbituminous B rank. A detailed description
of the core has been published.41

Analyses.—Coal analysis C–41050 and wax-
extraction tests 45664.

COOS BAY—DRILL HOLE 5–9

Location.—Drill hole 5–9, 774 feet north and
1,187 feet west of SE corner sec. 9, T. 27 S., R.
13 W., Willamette meridian.

Sample obtained.—Coal core from Beaver
Hill bed. Bed thickness, 6 feet, 11½ inches.
Coal, subbituminous B rank. A detailed
description of the core has been published.42

Analyses.—Coal analysis C–19045 and wax-
extraction tests 45771.

41 Toenges, Albert L., Dowd, James J., Turnbull, Louis A., Schoof,
J. M., Cooper, H. M., Abernethy, R. F., Yancey, H. F., and Geer, M.
R., Minsale Reserves, Petrography, Chemical Characteristics, and
Washability Tests of Coal Occurring in the Coos Bay Coal Field, Coos
42 Work cited in footnote 61.