ORIGIN OF THE BOGHEAD COALS.

By Reinhardt Thiessen.

The bituminous rocks of sedimentary origin may be classified roughly under two main heads—coals and bituminous shales. In a strict sense no definite line can be drawn between these two groups, because coals may insensibly grade into bituminous shales. Chemically the boghead coals are preeminently bituminous.

COAL.

Coal is composed in the main of the residues of the components of plants. The residues of the ligno-cellulosic components—that is, the woody portions—form the larger part. With these are always associated in varying amounts the residues of the more resistant components and products of plants, of which the resins, resin waxes, fats, and oils or their derivatives are the most abundant. Besides these, many other resistant plant products, too many to enumerate, enter into the formation of coal. The mineral content of coal is relatively low.

BITUMINOUS SHALE.

A shale is generally defined as a rock formed by the consolidation of clay mud or silt, having a finely stratified, laminated, or fissile structure. Some sand is usually mingled with the silt. If such a rock contains organic matter and is dark colored it is termed carbonaceous shale; if the organic matter is of a bituminous nature (highly hydrogenous) the rock is called bituminous shale; and if the rock is rich enough in bituminous substances to yield oil and gas in relatively large amounts on distillation it is called oil shale. The mineral matter in bituminous shales may vary greatly; in oil shales the organic matter is generally less than the mineral matter. Rock in which the mineral and organic matter are approximately in equal proportions may be called cannel slate or cannel shale; and rock in which the organic matter is considerably more abundant than the mineral matter is generally called cannel coal.

Under bituminous shales, therefore, are here considered all bituminous rocks usually designated cannel coals, boghead coals, oil shales, torbanite, tasmanite, and cannel "slates." These rocks have never been classified satisfactorily in accordance with their genetic characters; it is impossible to classify them definitely according to their general appearance and physical properties. However, they may be classified definitely and specifically into several well-defined groups, according to their origin or the origin of their predominant constituent or constituents.

The chief components of organic shale are humic matter—that is, ligno-cellulosic and other matter formed by the degradation of carbohydrates—resinous matter, spore matter, cuticular and other ceric matter, and oil-algal matter. It contains also small amounts of certain other components of unknown origin.

According to their origin, therefore, the bituminous sedimentary deposits may be classed as (1) humic, if the predominant organic constituent is matter derived from the degradation of carbohydrates—that is, such substances as wood, cellulose, lignin, bark, or suberin, gums, mucilage, and starch; (2) spore, if the predominant organic matter is derived from spores; (3) ceric or waxy, if the predominant organic matter is derived from the waxy substances of plants, including oil or fat; (4) resinous, if the predominant organic matter is derived from the natural resins of plants; (5) algal, if the predominant organic matter is derived from oleaceous algae, as in the boghead coals.

Each of these substances is invariably admixed with one or more of the others in different proportions. Usually one predominates, but two or even three components may be present in equal or about equal proportions, with others in less amounts.

THE BOGHEAD COALS.

Boghead coals differ little from any other bituminous shales in outward appearance, and it is often difficult if not impossible to distinguish them. They are close grained, brownish black to black, very tough, elastic, and difficult to break; usually they break with a conchoidal or subconchoidal fracture. In mass they show definite layering, but they will rarely split along definite horizontal planes.

When examined under the microscope in thin sections boghead coals are at once found to differ from all other bituminous shales in that they contain or are composed largely of peculiar irregular oval yellow bodies, through the structure and composition of which they are easily distinguishable from all other bituminous rocks.

Other names have been applied to these deposits, such as kerosene shales, torbanite, torbanehill mineral, brown cannel coal, bathvillite, algal coal, albertite, bituminite, parrot coal, and cannel coal. But as the term "boghead coal" has been most often used, has in general been so consistently applied to deposits of this type and is so thoroughly incorporated into the literature, it can not well be discontinued, although it is not satisfactory. It is used in this paper for want of a better name.

NOMENCLATURE.

The term "boghead" was first applied to coal of this variety found on the Boghead estate, near Bathgate, Linlithgow, Scotland. At Torbane Hill, also near Bathgate, it was called "torbanehill mineral" and "torbanite."

"Kerosene shale" [1] was first applied to boghead coals by the oil-shale industries of Mount Kembla, near Wollongong, New South Wales, Australia, and became identified with the industries at other localities and in other countries. The term is still used in Australia. "Kerosene coal" is a term used by J. R. M. Robertson,[2] of Scotland.

[1] Carne, J. E., The kerosene-shale deposits of New South Wales: New South Wales Geol. Survey Mem., Geol. No. 3, Dept. Mines and Agr., 1903.

[2] Robertson, J. R. M., Min. Inst. Scotland Trans., vol. 14, pt. 6, pp. 88–112, 1892.

"Wollongite" was proposed by B. Silliman [3] for the substance found at Hartley, New South Wales.

"Petroleum-oil cannel coal" is a term applied by John Mackenzie [4] to the Australian deposits.

"Bituminite" is a name proposed for torbanite by T. S. Traill.[5]

"Parrot coal" is a Scotch term arising from the crackling noise produced when torbanite is placed in the fire.

"Cannel coal," a corruption of "candle coal," was first applied to torbanite because of its property of burning with a clear flame, like a candle, and later became a synonym of torbanite and boghead. The term was soon applied to all coals of similar texture and appearance and so became a generic instead of specific term.

"Brown cannel" was later used by W. B. Clarke [6] to distinguish a boghead from ordinary cannel coal.

"Algal coal" was applied to the boghead coals by Bertrand and Renault.[7]

DISCOVERY AND EARLY HISTORY.

Torbanite was discovered at Torbane Hill, Linlithgowshire, Scotland, in 1850, and later was found at Boghead, Bathville, Inchroos, and Cappers, all near Bathgate, in Linlithgowshire. It was soon found to be a substance exceedingly rich in oily constituents and on this account was brought into special industrial prominence both in Europe and in America. It was about this time that, the patents of Dr. Albert Gesner [8] having been sold to the North American Kerosene Gas Light Co., kerosene was manufactured from coal and introduced generally to the American public. This kerosene or "coal oil" was objectionable on account of its unpleasant odor, and therefore large quantities of torbanite were shipped to America for the manufacture of kerosene that would not have the odor. This led to litigation over patent rights both in America and in England. In England the oil made from tor-

[3] Silliman, B., Am. Jour. Sci., 2d ser., vol. 48, p. 85, 1869.

[4] Mackenzie, John, Mineral production of New South Wales, 1887; New South Wales Dept. Mines and Agr., Annual report for 1887.

[5] Traill, T. S., Roy. Soc. Edinburgh Trans., vol. 21, pp. 7–13, 1857.

[6] Clarke, W. B., Geol. Soc. London Quart. Jour., vol. 22, p. 446, 1866, and elsewhere.

[7] See footnote 18, p. 124.

[8] Gesner, G. W. (son of Albert Gesner), A practical treatise on coal, petroleum, and other distilled oils, 1865.

banite was called "paraffin oil" and was used in "mineral-oil lamps." The litigation over the patent rights led to the institution of a lawsuit that became famous—that of Gillespie *v.* Russel. The dispute concerned the question whether torbanite was coal or not coal and affected the ownership of the deposits. A large number of scientific men in Europe were brought before the court to decide whether the so-called boghead coal is coal or bituminous clay, and the suit incidentally led to the study of the origin of this substance.

Quecket [9] maintained that torbanehill mineral is not a coal; that it is not like any of the combustible substances used in Great Britain as coal; that, although possessing some of the properties of coal, it is nevertheless a mineral having a basis of clay which is strongly impregnated with a peculiar combustible substance; and that any plants found in it are accidental and have no more been concerned in the formation of the mineral than a fossil bone in that of the rocks in which it may be embedded.

Bennett's opinion [10] was that the torbanehill mineral, although it presents essentially no trace of vegetable structure, is rich in bituminoid substances—a circumstance explained by the fact that it is found in the neighborhood of coal, so that the bituminoid or resinoid matter formed in the partly woody structure of the coal has flowed out, mixed itself with, and solidified in the essentially earthy substance of the torbanehill mineral.

Balfour [11] maintained that torbanite was of the same class as black cannel coal.

OTHER EARLY WORK ON BOGHEAD COALS.

Redfern,[12] lecturer in anatomy, physiology, and histology in the University of Aberdeen, supported the plant origin of the torbanehill mineral and argued that it is like all other cannel coals. Speaking of the yellow bodies of which the mineral is largely composed, he said that he knew of no other interpretation except that they are produced by free vegetable cells, such as spores or pollen grains, yet he could not confidently affirm that they are such; but whatever they may be, they are always to be found in other cannel coals.

The kerosene shale in Australia was discovered long before that in Scotland. Probably the earliest reference to it was published in Paris in 1807, after the return of a French scientific expedition that visited Australia in 1802. It was not utilized, however, until 1865. David,[13] a professor in the University of Sydney, New South Wales, was the first to investigate the kerosene shale of Australia by the most advanced methods of research and the first to propound the hypothesis that this shale is of fresh-water algal origin. The first scientist, however, to suggest the algal origin of the very richly bituminous shales was T. S. Ralph,[14] who claimed that the organic matters forming tasmanite were algae; but in this he was incorrect, as tasmanite is described as a spore cannel coal.[15]

Clarke [16] thought that kerosene shale unquestionably resulted from local deposits of resinous wood and passed gradually into ordinary coal. Dixon [17] argued that the idea of resinous origin must be abandoned, as the resins yield aromatic products and not paraffins. He also thought it more probable that the shales came from oil-producing or wax-producing plants, most likely the latter, in view of the considerable yield of solid paraffins from the shales.

The algal theory of the origin of the boghead coals was most prominently developed by Renault and Bertrand, and the result of their investigations ranging over 25 years was

9 Quecket, John, On the minute structure of a peculiar combustible mineral from the coal measures of Torbane Hill, near Bathgate, Linlithgowshire, Scotland, known in commerce as Boghead cannel coal: Micr. Soc. London Trans., vol. 2, pp. 34-36, 1853.

10 Bennett, J. H., An investigation into the structure of torbanehill mineral and of various kinds of coal: Roy. Soc. Edinburgh Trans., vol. 21, pp. 173-185, pls. 1-2, 1857.

11 Balfour, J. H., On certain vegetable organisms found in and from Fordel: Roy. Soc. Edinburgh Trans., vol. 21, pp. 187-193, 1854.

12 Redfern, P., On the nature of torbanehill and other varieties of coal: Micr. Soc. Quart. Jour., 1855, pp. 106-127.

13 David, T. W. E., Note on the origin of kerosene shale: Linnean Soc. New South Wales Proc., 2d ser., vol. 4, pp. 483-500, 1889.

14 Ralph, T. S., Royal Soc. Victoria Trans., 1865, p. 4; cited by Carne, J. E., The kerosene-shale deposits of New South Wales; New South Wales Geol. Survey Mem., Geol. No. 3, p. 61, 1903.

15 Newton, E. T., On tasmanite and Australian white coal: Geol. Mag., vol. 2, pp. 337-342, 1875; New South Wales Dept. Mines Ann. Rept. 1879, p. 33.

16 Clarke, W. B., Industrial progress of New South Wales, 1871, p. 449; cited by Carne, J. E., op. cit., pp. 59-61.

17 Dixon, W. A., Australasian Assoc. Adv. Sci. Proc., vo. 1, p. 134, 1887; cited by Carne, J. E., op. cit., p. 61.

summed up by Renault.[18] A fundamental jelly, a sort of gelatinous precipitate, supposed to have existed in the ancient lakes, pools, and swamps, is one of the chief assumptions in their theory. In this jelly were suspended spores, pollen grains, plant cells, cuticles, and minute vegetable débris, but paramount were certain gelosic algae surrounded by a gelatinous sheath or matrix, something like the *Nostoc* of to-day. Besides these, certain secretive cells are supposed to have been held in suspension, still presenting in detail their protoplasmic and nuclear contents. The fundamental jelly is supposed to have been produced by the action of microorganisms upon the organic matter, possibly upon the algae themselves. It is the essential part of all coals, and the algae, spores, pollen grains, and other minute bodies are merely accidental; one or another of these nonessential constituents may predominate, thus determining the particular character of the coal.

A careful distinction is therefore drawn by these two investigators between boghead and cannel coals. In the boghead coals the suspended matter consists chiefly of gelosic algae; in the cannel coals it consists of spores. Between the two are found all grades of mixtures, and there may be boghead cannel coals where the algae are more abundant than the spores and cannel bogheads where the spores are more abundant than the algae.

The size of the yellow bodies composing the boghead coals is only a little smaller than it must have been when living. As the mass in the known living gelosic algae contains only a small percentage of solid matter, the remainder being water, it seems clear that such algae could not form the mass of the yellow bodies as found in the bogheads. In order to account for this discrepancy, the algae are supposed to have had a great affinity for bituminous substances and to have been impregnated with and enriched by them to the extent of the present volume. No satisfactory explanation is offered for the origin of the bituminous matter, but probably it was produced by the decomposition of the algae themselves through bacterial activities.

This theory was widely accepted at one time, although some refuted it, foremost among whom was Jeffrey,[19] who concluded from the study of numerous thin sections made from an abundance of material that the bodies interpreted as algae by Bertrand and Renault are not algae but the highly sculptured walls of the spores of cryptogams. When sufficiently thin sections of the bodies in question are cut tangentially through the sculptured spore coats the resemblance to certain algal structures is made very plain. Reconstructions made from serial sections were thought to afford additional evidence of the true spore nature of these bodies by their alveolar structure and triradiate markings and their occurrence in tetrads. With reference to the larger "supposed algae" Jeffrey does not make his case so satisfactory, presumably owing to the distorted condition in which they exist and the difficulty of interpreting thin sections of a larger size. But he presents the apparently reasonable argument that if those which are best preserved and by reason of their size are most easily studied in thin sections of coal prove not to be of algal affinities, a similar conclusion must be applied to the remaining organisms, which either by their large size or their imperfect condition of preservation can not be satisfactorily subjected to microscopic investigation.

At first Zalessky[20] supported Jeffrey's opinion, which he thought was confirmed by examination of a preparation of a siliceous nodule found in the boghead of Autun. The alga, *Pila bibractensis*, seemed to him to be a spore with a reticular sculptured surface, and the walls of the supposed cells seemed to have the form of ribs jutting out on the surface of the

[18] Renault, B., Sur quelques microorganismes des combustibles fossiles. Soc. ind. min. St.-Étienne Bull., 3d ser., vol. 13, pp. 895–1191, 1899; vol. 14, 456 p., 66 figs., 30 pls., 1900.

See also Bertrand, C. E., Le boghead d'Autun: Soc. ind. min. Bull., vol. 6, pp. 453–506, 1892; Bertrand, C. E., and Renault, B., *Pila bibractensis* et le boghead d'Autun: Soc. hist. nat. Autun Bull., vol. 5, pp. 159–253, 1892; Bertrand, C. E., and Renault, B., *Reinschia australis* et premières remarques sur la kerosene shale de la Nouvelle-Galles du Sud: Soc. hist. nat. Autun Bull., vol. 6, pp. 321–425, 1893; Bertrand, C. E., Nouvelles remarques sur le kerosene shale de la Nouvelle-Galles du Sud: Soc. hist. nat. Autun Bull., vol. 9, pp. 193–292, 1896; Bertrand, C. E., Conclusions générales sur les charbons humiques et les charbons de purins: Compt. Rend., vol. 127, pp. 822–825, 1898; Bertrand, C. E., Description d'un échantillon de kerosene shale de Megalong Valley, N. S W.: Linnean Soc. New South Wales Proc., vol. 25, pp. 617–649, 1901.

[19] Jeffrey, E. C., The nature of some supposed algal coals: Am. Acad. Arts and Sci. Proc., vol. 46, pp. 273–290, pl. 1–5, 1910.

[20] Zalessky, M. D., On the nature of the yellow bodies of boghead, and on sapropel of the Ala-Kool Gulf of the Lake Balkash: Com. géol. Bull., vol. 33, pp. 495–507, Petrograd, 1914; Flore gondvanienne du bassin, de la Petchora, I, Rivière Adzva: Soc. ouralienne amis sci. nat. Bull, vol. 33, 1913.

spores. Studies of material sent to him later by Bertrand and Combray changed his opinion to one in support of Renault and Bertrand's algal theory. In preparations of these siliceous boghead samples he clearly observed the cellular *Pila* structure, as if occurring in a more or less natural state in the bog, giving good evidence to accept that these cellular bodies are algae.

As illustrating the nature and origin of boghead coal Zalessky offers an example from the plant world of to-day in an alga, which he calls *Botryococcus braunii*,[21] growing in the brackish, shallow Ala-Kool Gulf, overgrown with marsh and aquatic plants, at the southern extremity of Lake Balkash, in Turkestan. This alga, bearing a considerable amount of oil, comes to the surface of the water. Zalessky states that when these algae accumulate on the shore, a hydrogen sulphide fermentation takes place; and finally, when in contact with the air, they dry and change from a dark-green into a yellow-brown elastic, rubber-like mass, which can be easily cut with a knife. Thin sections of this mass sometimes clearly show the structure of the algae, which much resemble the bodies in the siliceous boghead sample examined. From this observation deductions are made as to the origin of the bogheads. A further study of the habits of the algae and their transformation into the elastic mass had not been made.

Similar conclusions[22] are drawn from a study of sapropelic substances found at the bottom of Lake Bioloe at Tver, Russia, in a deposit 9 meters thick, said to be composed of blue-green algae, principally of the genera *Microcystis, Aplanocapsa, Alphanatheca, Chroococcus, Gleotheca, Synechococcus;* and of the green algae *Scenedismus obliquus, Scenedismus bijugatus*, and *Pleurococcus vulgaris*.

Later Zalessky[23] found that the bituminous rock of the "Lower Silurian" in Petrograd and Esthonia along the Baltic coast, called kukersite, were similar in nature to the boghead shales of Autun. The fossil organisms in these rocks have a structure very similar to that of the blue-green algae of the genus *Gloeocapsa*, and Zalessky therefore proposed the name *Gloeocapsamorpha prisca* for them.

Conacher[24] examined the oil shale and torbanite of England and Scotland and concluded that they are derived from the same substances as coal but that in the shale there has been a much larger elimination of the woody matter, leaving a large proportion of resinous matter mixed with sand.

In 1914 the present writer[25] maintained that no algae were found in any of the boghead coals he investigated, although many of the bodies called algae by various investigators were found. Many of these, however, were shown to be spores; others were of unknown origin. Some of Renault's illustrations of *Reinschia*, showing both cross and horizontal sections, were certainly those of spore exines. The weakest points in Renault and Bertrand's algal theory, however, were those clauses relating to the "fundamental jelly" and the "bituminous affinity" of the algae. No algae having the structure revealed by the yellow bodies in the boghead coals were known to the writer, nor any that had as massive a cell wall as those in the bogheads indicated. Ordinary living algae, as well as those in the ancient swamps referred to as being analogous, contain at the most only a small quantity of solid matter, by far the largest part of their mass being composed of water. Also, the cell walls of ordinary algae are of pectic-cellulosic nature—that is, they are carbohydrates, which are readily attacked by putrefying organisms and are quickly decomposed under ordinary conditions. Any algal bodies that might have been preserved in the coals would be represented by only an exceedingly thin residue. Renault and Bertrand probably also realized this difficulty, and to overcome it they propounded the hypothesis of bituminous affinity, through which the gelatinous cell walls of the algae were supposed to have absorbed a certain amount of bituminous substances, to account for their solidity and relative massiveness as represented by the yellow bodies in the coals. The fundamental jelly in which these bodies were supposed to have been suspended has never been observed

[21] Zalessky, M. D., On the nature of *Pila* of the yellow bodies of boghead and on sapropel of the Ala-Kool Gulf of the Lake Balkash: Com. géol. Bull., vol. 33, pp. 495–507, Petrograd, 1914. Litinsky, L. L., Balchash-Sapropelite: Petroleum, vol. 17, pp. 437–440, 1921.

[22] Zalessky, M. D., Soc. paléont. Russie Annuaire, vol. 1, pp. 25–42, 1916.

[23] Zalessky, M. D., Sur le sapropélite de l'âge silurien formé par une algue cyanophycée: Soc. paléont. Russie Annuaire, vol. 1, pp. 25–42, 1916.

[24] Conacher, H. R., A study of oil shales and torbanites: Geol. Soc. Glasgow Trans., vol. 16, pt. 2, pp. 164–192, 1917.

[25] White, David, and Thiessen, Reinhardt, The origin of coal: U. S. Bur. Mines Bull. 38, p. 277, 1914.

by the writer. These points—namely, the structure and chemical nature of algae as then known and the unacceptability of the hypotheses of bituminous affinity and the fundamental jelly as proposed by Renault and Bertrand—were sufficient in the writer's mind to overthrow the algal theory.

On the other hand, the writer could not agree that the yellow bodies in the bogheads were invariably spores. The kerosene shales of New South Wales, the typical *Reinschia* coals, stood out most clearly as contravening the theory of spore origin, and the bodies of unknown origin in the cannel coal from the Pottsville of Kentucky could not be classed as spores. For this reason the boghead and cannel coals have been objects of thought and investigation from time to time. Their nature and structure have now been fairly well worked out.

The boghead coals that have been studied were the kerosene shales from Newnes, New South Wales; bogheads from Torbane Hill and from Bathgate, both in Scotland; and American bogheads from Alaska and from Kiskiminetas Junction, Pa.

STRUCTURE OF THE YELLOW BODIES COMPOSING CERTAIN BOGHEAD COALS.

The organism that gave rise to these boghead coals was colonial—that is, a number of individuals were united into a larger body. (See Pls. XXXII–XXXVII.) In many places a number of such colonies were united into a larger mass. Some of the colonies were apparently in the form of a hollow sphere.

The protoplasmic or living part of the organism was of an oval form, as shown in thin sections and illustrated in Plates XXXIII, *B;* XXXIV, *A;* XXXV, *B;* XXXVI–XXXVIII, *A*, and was surrounded by a relatively thick cell wall. This constituted a unit cell or organism. A considerable number of these were joined together into spherical bodies or colonies by a matrix of slightly different character. Whatever the nature of the cell wall and its cementing matrix, they were resistant enough to withstand weathering, putrefying, and oxidizing agencies and the coal-forming processes so well as to retain more than half of their original volume. Their structure points clearly to an organism other than spore matter of any plant.

THE BOGHEAD-FORMING ORGANISM.

The kind of organisms that gave rise to the bogheads is clearly represented by an oil-bearing organism now living in salt lakes and salt lagoons of South Australia and surrounding islands. A recent study of this organism has shed much light on the nature of the yellow bodies composing the boghead coals and on the formation of the bogheads themselves.

The exact position of the organism in the plant kingdom, together with its life history and habits, are yet unknown and are still under investigation. It resembles in some respects certain of the blue-green algae, but in the nature and chemistry of the cell wall it differs greatly from the ordinary blue-green algae.

As no family or genus group to which this organism could be assigned is described in monographs such as Engler and Prantl's "Die natürlichen Pflanzenfamilien" or Toni's "Sylloge algorium," a new name had to be found for the organism. The name *Elaeophyton*,[26] meaning oil plant, is therefore suggested. As the plant examined was found near The Coorong, the specific name *coorongiana* is also proposed.

At the end of each winter a green scum called "seepage material" is formed on the lakes and lagoons and is blown by the prevailing winds to the southeastern shores. As the hot weather progresses and the lakes dry up this material is deposited on the sand of the bank and quickly dries and solidifies into large sheets of a rubber-like dark-brown material, called coorongite. This material has been the object of much discussion, and all endeavor to discover its origin has heretofore been unsatisfactory.[27]

Samples of both the green seepage material and the coorongite were obtained through the courtesy of Mr. John Claffey, of Adelaide. The organisms are colonial: a considerable number of unit individuals or cells are associated into colonies and form globules just visible to the naked eye. (See Pl. XXVII, *A*.)

[26] On account of the resemblance of this organism to forms that are often termed cocci and the large amount of oil it yields, the name *Elaeococcus* was first proposed for it by the writer and has appeared in print. But it was found that the term *Elaeococca* had been applied by Moritz Hill to one of the Euphorbiaceae found in Japan and China, *Elaeococca vernicia*. The name *Elaeococca* therefore has priority over *Elaeococcus*, which had to be abandoned.

[27] Data from personal communication from John Claffey, of Adelaide, South Australia.

These colonies may be either single or compound; in the latter type a number of single or primary colonies are united. A number of colonies may be coalesced into larger globules (Pl. XXVII, *A*), or a larger number of colonies may in turn be united into a large mass (Pl. XXVII, *B*). Plate XXVIII, *A*, represents a stained colony at a high magnification, somewhat flattened under the cover glass.

The structure may be best seen through stained thin sections. The section of a single colony, as on Plate XXVIII, *B*, shows it to be composed of an outer zone of living cells, usually several cells deep, irregularly forming a thick spherical shell. This shell incloses a number of irregular cells of variable size and without protoplasmic contents, thus forming a central blank core. Plate XXVIII, *B*, shows several colonies. Usually several primary colonies are coalesced into secondary or compound colonies, in which the central blank cores of the primary colonies are in communication with one another. (See Pl. XXIX.)

The protoplasmic or living part of the cells is of an oval shape and relatively small, not over 5 microns (0.0002 inch) in length and 3 microns in diameter. No definite nucleus is distinguishable, but the whole cell content takes up a nuclear stain and is shown as a granular mass. In the living condition it contains chloroplasts of a blue-green color (Pls. XXX, XXXI). The protoplasmic part is surrounded by a relatively thick colorless cell wall of a clear and not particularly firm consistency, which stains with difficulty. The cell walls of the several individuals are cemented together by slightly denser matter of similar appearance, which, however, stains more readily (Pl. XXXI). As shown in Plates XXVIII, *B*, and XXIX, the active living cells are formed irregularly into a thick zone, several to many cells deep, inclosing a group of blank cells in the center. These central blank cells are on the whole larger but are more variable in size, are irregular in shape, and together form a looser structure than the outer living cells (Pls. XXIX, *B*; XXX; and XXXI, *B*).

Where several colonies are united into larger secondary colonies, the cells at the junction have either lost their protoplasmic contents or have been squeezed out and replaced by the central blank cells. (See Pl. XXIX, *A*.) A colony or a larger number of colonies form a soft, flexible, but not mobile nor waxy mass. When they are placed under a cover glass considerable pressure is required to flatten or spread them out.

The cell walls lend the organisms their peculiar properties. They do not decay or putrefy when exposed to the air in mass but congeal into a rubbery, elastic mass, which does not undergo further marked changes and, as already noted, forms the substance called coorongite. They are not composed of pectin, mucin, pectocellulose, or mucocellulose, as in ordinary algae, but consist largely of oils or oily substances, the nature of which is under investigation.

COORONGITE.

ORIGIN.

There can be no doubt that coorongite is formed from the green seepage material or mass of living *Elaeophyton*. When a mass of the green living organisms is exposed to the air it quickly changes its color to a dark brown or grayish black and congeals to an elastic, rubber-like mass, exactly like the coorongite, in which the colonies and individual organisms and their structure are more or less clearly discernible, together with a small amount of extraneous matter, like sand grains, bits of plant tissues, cuticles, diatoms, and other algae.

Coorongite as received from the field is plainly seen to be composed of the same organisms and contains the same kind of extraneous matter. Some of the colonies and individual cells of the organism are very well preserved, others not so well; but even in the most poorly preserved material the characteristic structure is still recognizable.

HISTORY.

Coorongite was discovered in 1865 on the shores of The Coorong, in South Australia. It has been variously known and described as Australian caoutchouc, mineral gumboge, elaterite, elastic bitumen, and coorongite, and it has been the object of curiosity and discussion ever since its discovery. The discussions have mostly concerned its origin, whether mineral or organic, and they are so numerous and generally so unauthoritative that it is impossible to give even a summary of the ideas presented. A number of eminent scientists, however, have investigated coorongite and have made reports on it. Among these are Thiselton-Dyer,[28] Boodle,[29] Cumming,[30] Höfer,[31] and Wiesner.[32] An accurate description of coorongite in the field is given by De Hautpick,[33] who says:

Coorongite is found in the depressed portions of occasionally submerged sandy plains of considerable extent and is spread upon the ground chiefly near the edges of the depressions at the high-tide mark. Coorongite occurs in this district spread over a great area in the form of cake lying on the sand without any connection with the ground on which it is deposited. It represents undoubtedly the solidification of some substance which previously floated on the surface of the water and then was deposited on the sand and gradually dried up, absorbing and uniting with, during the drying process, all matter that happened to come in contact with it. Coorongite is of various thickness from an inch to 1 foot, and in color and appearance it is closely akin to the so-called "paraffin dirt" of the Gulf coast oil fields of Texas and Louisiana.

Coorongite shows a peculiar rubber-like texture. When moist the material breaks much after the fashion of "green cheese." Although rubbery under compression, it does not resemble rubber in tenacity or cohesion, and in this respect it is identical with its twin, the "paraffin dirt" of America. It is clear, then, that coorongite is not a caoutchouc, although in appearance and color it resembles caoutchouc. It is soft, flexible, and easily cut, clammy to the touch, yet does not soil the skin. It has a characteristic "swampy" or "mucky" odor when wet and a characteristic odor of humic soils when moist. If the material is brought into suspension in water, very fine sand settles out and may be recovered by successive washing and decantation. When moist, it is gelatinous but neither markedly adhesive nor plastic. It is easily affected by water but is insoluble therein. In thin slips it burns like a taper, melting before the flame, which is smoky.

A substance very similar to coorongite, called n'hangellite, is found in Portuguese East Africa. Boodle[34] quotes a report made by J. Gething Hancock as follows:

N'hangellite is an elastic description of bitumen and may be termed a mineral india rubber. It is dark green in color and is lighter than water and has probably been formed in the oxidation of petroleum. It is most prevalent in the plain to the north and northwest of Lake N'hangella and to a large extent may be described, as far as this neighborhood is concerned, as peculiar to that locality.

The n'hangellite in occurrence is generally about half an inch in thickness and lies in patches varying from a few square yards to probably half an acre in extent. It is chiefly found in long, narrow strips on the surface anticlines of slightly undulating ground and gives the impression that it has been washed there by water, having largely the appearance of a high-tide mark. On the other hand, it is occasionally found in small pans, again indicating that it has been taken there by water and remained after the water had subsided. * * * I made the most searching inquiries * * * and was informed by many that after the rains it is possible to see this deposit gradually collecting and that it is then of a light-brown color and gelatinous in appearance.

Boodle's description of n'hangellite is as follows:

Specimens of this substance, when examined microscopically, prove to consist of a yellowish matrix, in which are embedded diatoms, sand grains, and sometimes sponge spicules, pollen grains, spores, etc.; but these inclusions are unimportant, forming only a small proportion of the mass. Fungal hyphae are also present and are often crowded and very distinct near the surface of the specimens, more sparse and forming an irregular reticulum in the interior.

The yellowish matrix, when examined in thin sections under a high power, is usually seen to contain numerous very small cells, which are more refractive and for the most part more colored than the substance in which they are embedded. The latter may appear colorless in very thin sections, while the cells in question are yellow or brownish or pale green. They are usually elongated, and their sectional shape is elliptical or pyriform, or circular when seen in end view. In length they vary from 2 to 6 microns, or occasionally 8 microns, and their breadth may be about half as great or more. Frequently no definite arrangement can be distinguished, but occasionally in favorable places one can demonstrate that the cells are grouped in colonies, which appear to be roughly spherical when small, elliptical or botryoidal when large. The cells are arranged so that their length is radial with regard to the colony, in which they form a peripheral layer, one or sometimes two or more cells thick. Their lateral distance from one another is variable but generally greater than their own diameter. When rather crowded, they are sometimes clearly arranged in pairs or groups of four. The substance in which the cells are embedded shows no structure and might well be the product of mucilage only. It is only here and there that colonies of definite shape can be distinguished; the scattered arrangement of the cells in other parts of the matrix may be explained as either due to flattening or distortion of colonies of similar form and size, or to the colonies having had indefinite growth, so that only young stages would show a regular form.

From such details as can be determined there seems to be no doubt that the matrix has been derived from

[28] Thiselton-Dyer, W. T., On a substance known as Australian caoutchouc: Jour. Bot., 1872, pp. 103–106.

[29] Boodle, L. A., N'hangellite and coorongite: Roy. Bot. Gardens, Kew, Bull. 5, pp. 146–151, 1907.

[30] Cumming, A. C., Coorongite, a South Australian elaterite: Chem. News, vol. 87, pp. 306–308, 1903.

[31] Höfer, Hans, Das Erdöl und seine Verwandten, pp. 262–264, 1922.

[32] Wiesner, Julius, reviewed by Höfer, op. cit.

[33] Hautpick, E. de, Coorongite, a petroleum product: Australian Min. Standard, 1923, pp. 1000–1001.

[34] Boodle, L. A., N'hangellite and coorongite: Roy. Bot. Gardens, Kew, Bull. 5, pp. 145–151, 1907.

a gelatinous organism belonging almost certainly to the blue-green algae, among which it would be classed under the Chroococcaceae. Prof. G. S. West, F. L. S., who kindly examined the organism for me, agrees that it certainly appears to be a blue-green alga and compares it with *Coelosphaerium* Naeg. but adds that it is not exactly like anything with which he is acquainted. Its precise determination must be reserved until living material, or such as represents early stages in the formation of n'hangellite, can be obtained. Conversion into bituminous substance must imply extensive chemical changes in the mucilage, whereby the original characters of the alga may have been altered to some extent as regards the spacing and form of the cells. Changes have no doubt also taken place in the cell contents; hence the occasional greenish color of the cells may be secondary and not a remnant of their original pigment. On soaking or boiling a section in water the cells undergo a curious change; their cavities become enlarged and often appear as though empty, but when transferred to strong glycerine they gradually regain their original appearance.

In some parts of the specimens the matrix shows no structure, but as the loss of structure is often not abrupt but preceded by a transitional boundary where the algal cells are collapsed or indistinct, it is probable that the structureless condition is secondary and due to more destructive changes than those which took place elsewhere. One may therefore assume that the whole of the matrix represents a gelatinous alga.

This description tallies very closely with that of coorongite.

CHEMICAL PROPERTIES.

When heated in a tube coorongite will all melt, forming a sirupy liquid, which remains viscous after cooling. On distillation it yields large quantities of oil.

An analysis made in a laboratory of the South Australian Government gave the following results:

Analysis of coorongite.

Moisture and volatile substances at 120° C	0. 8
Gaseous distillates with acid reaction	14. 0
Oily distillate	69. 2
Tarry matter and coke	10. 1
Mineral matter	5. 9
	100. 0

The oily distillate was redistilled and gave a series of oils of varying densities in the following fractions:

Results of redistillation of oily distillate from coorongite.

Fraction at 110° to 170° C	6. 7
170° to 240° C	27. 7
240° to 295° C	25. 3
295° to 300° C	27. 3
Residue	14. 0
	100. 0

An ultimate analysis gave the following results:

Ultimate analysis of coorongite.

Moisture	0. 46
Carbon	64. 73
Hydrogen	11. 63
Ash	1. 79
Fixed carbon	1. 005
Oxygen, etc	20. 375
	100. 00

Analyses made in the Bureau of Mines laboratory at Pittsburgh gave the following results:

Analyses of coorongite.

	As received.	Moisture free.	Moisture and ash free.
Proximate analysis:			
Moisture	1. 6		
Volatile matter	90. 1	91. 5	97. 2
Fixed carbon	2. 6	2. 7	2. 8
Ash	5. 7	5. 8	
	100. 0	100. 0	100. 0
Ultimate analysis:			
Hydrogen	11. 3	11. 3	12. 0
Carbon	73. 8	75. 1	79. 7
Nitrogen	. 7	. 7	. 7
Oxygen	8. 4	7. 0	7. 5
Sulphur	. 1	. 1	. 1
Ash	5. 7	5. 8	
	100. 0	100. 0	100. 0

These figures agree fairly well with a number of determinations made by other analysts.

Coorongite is partly soluble in carbon bisulphide, chloroform, ether, and benzol. A preliminary extraction with carbon bisulphide yielded about 70 per cent of soluble matter. The residue is of a tough, leathery consistency and has lost much of its elasticity. Besides the residue of the oil algae, it contains a few fragments of tissues and cuticles of higher plants, also mineral matter consisting of some diatoms and largely of sand. The ash amounts to 5.8 per cent in the untreated coorongite. All the insoluble extraneous substances have naturally been concentrated in the residue. The soluble matter is in the form of thick, viscous oil of a yellow color, which gradually turns darker on exposure to the air.

Cumming [35] carried the investigations on the extraction with carbon bisulphide further. He obtained 24 per cent extract, leaving a resi-

[35] Cumming, A. C., Coorongite, a South Australian elaterite: Chem. News, vol. 87, pp. 306–308, 1903.

due containing 30 to 40 per cent of ash. The soluble matter therefore amounted to about 33 per cent of the original coorongite. This consisted of a clear yellow, translucent, waxlike substance, which softened at 35° C. and was quite fluid at 42°. It was readily soluble in all proportions in benzene, ether, toluene, chloroform, and carbon bisulphide. Cumming was not able to saponify it and therefore concluded that it was of the nature of a mineral oil. Its composition (C, 77.92; H, 11.69; O, 10.39) and its molecular weight correspond to the formula $(C_{10}H_{18}O)_8$.

The insoluble constituent was an unelastic, tough substance, which burned with a luminous flame, melted before the flame, and had an odor like burning fat. It was saponifiable with alcoholic potash. Its composition (C, 64; H, 10.52; O, 25.26) and molecular weight conform to the formula $C_{10}H_{18}O_3$. The chemical examination of coorongite and the oil derived from it has not been completed.

CONCLUSIONS.

The study of *Elaeophyton* therefore furnishes proof of the theory of the algal orgin of the boghead coals. The plan of organization, the structure, and even the form and size of the organism agree so closely with the corresponding character of the yellow bodies that constitute the boghead coals as to leave no room for doubt of their close biologic relation and their similarity in composition. The chemical nature of these organisms is so resistant to the agencies of putrefaction as to enable them, in a favorable environment, to survive the coal-forming processes with more or less complete preservation in the forms found in the boghead coals.

The most important fact concerning *Elaeophyton* with reference to the formation of coorongite, in consideration of the theory that boghead coals owe their origin to similar organisms, is the chemical composition of its cell wall. The cell walls in the living organism are composed largely of oil or oily substances. No theory of chemical changes from cellulosic or mucous substances into an oil or fat is necessary. The oil is such in the living plant. There is probably a slight oxidation of some constituents but no radical change. The fact that the cell walls do not appear to putrefy nor undergo any further oxidation after the first change of color seems to account for the more or less complete preservation of the organisms in coorongite.

YELLOW BODIES OF BOGHEAD COALS COMPARED WITH ELAEOPHYTON.

In the light of the structure and other features of *Elaeophyton* as above set forth, we can now return to the boghead coals and by comparison and analogy get a more complete idea of the nature and the structure of the organisms that formed them, and so of the nature, structure, and origin of the fossil bogheads themselves. By comparison of horizontal sections at a lower magnification the similarity is evident. Plate XXXII, *B*, represents a horizontal section of the Australian kerosene shale containing *Reinschia australis*, and in comparing this with Plate XXVII, *B*, showing the living *Elaeophyton*, all magnified at 200 diameters, the resemblance is clearly shown. At a higher magnification, at which the cellular structure is more definitely brought out, the similarity is definitely shown and is seen to correspond to a striking degree. Although almost any of the illustrations will serve, the most surprising similarity is shown in Plate XXXI, *A*, representing the living organism, and Plate XXXIV, *A*, representing a section of the Australian kerosene shale. Plate XXXIII, *B*, illustrating *Reinschia*, also shows a striking resemblance.

It should be remembered that a photograph will not represent all the structural features as clearly as they can be seen directly under the microscope, where, by focusing up and down, the structure may be followed throughout. When the two forms are thus studied, and allowances are made for the changes resulting from coalification processes, no doubt is left as to their common origin.

The yellow bodies in the boghead coals can now be interpreted as colonies and compounds of colonies, exactly as in the living material. The smaller yellow bodies represent primary colonies in the central part of which the blank cells may often be discerned (see Pls. XXXIV, *A;* XXXV, *B;* and XXXVI, *A*); others are fusions of two, three, or four primary colonies, in which also the blank cells may be recognized (Pl. XXXVII, *A*). Probably most of the yellow bodies are of this kind; in others, the large yellow bodies, a large number of colonies are united. The outlines of the primary colonies can usually be distinguished in the compound colonies, as in the living material. (See Pls. XXXIII, *B;* XXXIV, *A;* XXXVI, *A;* XXXVII, *B;* XXXVIII, *A.*)

The protoplasmic or once living parts of the organisms are represented by the darker areas shown in the illustrations, most of them clearly of an oval outline, though some are contorted and disarranged. In thin sections of the boghead coals these portions are shown to be oval or ovoid sacks, or contorted or shriveled-up sacks that once were ovoid. Usually the contents are brown to dark brown. However, in the bogheads from different localities they may vary considerably in state of preservation, color, size, form, and definiteness of outline. In the Scotch torbanite examined, for example, the cell contents of *Pila*, the yellow body, are much lighter in color and may even be of the same color as the cell-wall matter, the coloring matter being absent, so that the cell wall is indicated merely by a line of different refraction. In the Australian kerosene shale the colonies of *Reinschia* are in many specimens particularly well preserved, and the sacks contain much brown coloring matter; for this reason these shales furnish most favorable material for study. Each of the brown sacks is surrounded by a light-colored, usually relatively thick wall, which in turn is embodied in a slightly darker material, the medium cementing the cells into colonies. The oval sacks with their surrounding cell walls are grouped in a zone toward the outside. This zone may be two or more cells deep. Their arrangement commonly is irregular—that is, there is generally no definite orderly arrangement. In this respect they are similar to the living form. At the central part of each of the multiple colonies is found a blank structure—that is, cells without the brown sacks. These undoubtedly are analogous to the blank cells of the living colonies of *Elaeophyton.*

COMPARISON OF THE BOGHEAD COALS EXAMINED.

In comparing with one another the boghead coals studied considerable differences in structure and the degree of preservation may be observed. Many of these differences are, however, possibly due to extrinsic causes and are not differences that existed in the organisms themselves when living.

AUSTRALIAN BOGHEAD, OR "KEROSENE SHALE."

The boghead coal from the Wolgan Valley, New South Wales, in a formation of Permian age, is compact and homogeneous in its outer appearance and shows but little stratification. It is of a dark or dull-brown color, breaks with a typical conchoidal fracture, and can not be made to split along any particular cleavage plane.

As seen in thin sections, the yellow bodies, the colonies of *Reinschia australis*, are somewhat loosely packed. This is shown in Plate XXXII, *A*, in which the bodies are represented by irregular, elongated patches and the groundmass by the black areas. There is, however, a considerable difference in this respect in different parts of the same sample or even in the same thin section. The colonies or yellow bodies have been flattened considerably, the larger ones more than the smaller ones. The ratio of the larger diameter to the shorter averages about 2:1; in the smaller bodies it is 3:1. Most of the smaller bodies represent single colonies; the larger ones represent compound colonies.

The colonies are embedded in an opaque, dirty-looking groundmass, which, in general, is composed of matter produced by organic degradation and a small amount of mineral matter. A large part of this organic matter is the result of degradation of the yellow bodies themselves; besides this, bits of plant tissues and plant fibers and remnants of cuticles form a very small part of it. Spores are not numerous in this boghead but are invariably present, as is to be expected.

The yellow bodies or colonies of *Reinschia* in this sample are the best preserved of all the algae in the boghead coals examined. There is, however, a considerable variation in their state of preservation. In some the structure is remarkably well preserved, every detail of the structure of the organism being intact; in others it is very obscure. Between these two extremes all shades of preservation may be observed. The sacks—that is, the once living protoplasmic contents—contain much brown coloring matter, which differentiates them clearly from the remainder of the cell and also lends the section as a whole a brown color under the microscope.

BOGHEAD COAL (TORBANITE) FROM TORBANE HILL, SCOTLAND.

In its outward appearance the sample of boghead coal from Torbane Hill, Scotland, resembles an ordinary spore cannel coal. It is slightly laminated, and although the cross and oblique fracture is conchoidal in general, it will split along certain horizontal bedding planes. It represents the celebrated deposit of torbanite found in the Calciferous sandstone series, of Mississippian age.

As seen in thin sections, the yellow bodies, the colonies described as *Pila scotica,* are a little more closely packed than the colonies in the Australian shales and are not nearly so much compressed. This is clearly shown in an examination of the photographs of the cross section reproduced in Plate XXXIV, *B*, and in a comparison with the horizontal section in Plate XXXV, *A*. The groundmass is of the same appearance and probably of the same composition as that in the Australian shales, though it is somewhat more opaque. The sacks, or once living protoplasmic parts of the cells, contain little or no brown coloring matter and hence are not well differentiated from the remainder of the cell. That they are present is clearly revealed through a difference in refraction of the cells along the borders of the sacks, although this may not be reproduced distinctly in the photographs; yet every photograph taken shows clear evidence of the structure. The lack of the brown coloring matter makes the sections of a much lighter color than those of the Australian boghead. The algal colonies appear to have suffered considerable changes during the peat stage and look as if they were waterworn. A careful comparison shows that their general structure was very similar to that of the Australian deposit.

Spores are invariably present in this coal, though in relatively small numbers.

BOGHEAD COAL FROM BATHGATE, SCOTLAND.

Only one small sample from the deposit at Bathgate, Scotland, has been examined. Experience shows, however, that one section is indicative of the characteristics of a deposit for a considerable space around the sample. The material is from the Calciferous sandstone series, of Mississippian age.

The yellow bodies (colonies referred to *Pila scotica*) in the Bathgate boghead coal are considerably more flattened than those in the Torbane Hill deposit and have a more pronounced brownish color. (See Pls. XXXVI, *B*, and XXXVII, *A*.) The embedding medium is of the same appearance as that in the Torbane Hill boghead. The structure is much better preserved than that in the Torbane Hill coal but not quite as well as that in the Australian shale. The sacks are well preserved and well differentiated from the cell walls, owing to their dark-brown contents. The structure is very similar to that in the Australian boghead. The differences in preservation are due to outside influences; evidently the organisms that gave rise to the deposit at Bathgate and Torbane Hill were very similar to those in the Australian deposits, to which they are most clearly related.

BOGHEAD COAL FROM ALASKA.

In outward appearance the Alaskan boghead, according to the one sample on hand, is very similar to an ordinary cannel coal. This sample came from a district drained by Colville River; the exact locality and the geologic age of the beds are not known. It is compact and dark grayish black. When examined at a low magnification (200 diameters), it presents the same general appearance as the boghead coals from Scotland and Australia and at once gives the impression that it is of the same kind. (See Pls. XXXVIII, *B*, and XXXIX, *A*.) But under a higher magnification it presents a marked difference, and offhand it gives the appearance of not belonging to the same kind at all. The yellow bodies on the whole are somewhat smaller than in the samples previously described, the large majority have no brown coloring matter in the sacks, and they reveal no definite structure or only a faint structure. But a careful survey of the sections, both horizontal and cross, discloses here and there yellow bodies whose structure has been well preserved and whose entire organization may be reconstructed. These show that the general structure is similar to that in the Australian boghead coal, if not the same, and that they must have been derived from an organism of the same nature as that which gave rise to that coal. Between those that are well preserved and those in which little or no structure has been retained all grades of transition are found; and as the general appearance, nature, and form of all the yellow bodies are the same, it must be concluded that all were derived from the same source.

The alga characterizing the Alaska boghead is almost certainly of the same nature and is probably closely related to those forming the yellow bodies in the other boghead coals here described, as well as the living *Elaeophyton.*

BOGHEAD COALS OF THE KISKIMINETAS REGION, PENNSYLVANIA.

The boghead coal at Kiskiminetas Junction, Pa., in the region where Kiskiminetas River joins Allegheny River, is found in a thin bed, not more than 2 feet in thickness, in the limestone between the Upper and Lower Freeport coals, in the Allegheny formation, of Pennsylvanian age. It begins with an ordinary shale at the bottom, which quickly changes into a bituminous "slate" and then within a few inches into a rich boghead coal. It much resembles a bituminous shale throughout its thickness. (See Pl. XXXIX, *B.*) It is laminated and will split horizontally along certain bedding planes.

In thin sections its resemblance to the other boghead coals is at once apparent. The yellow bodies are, on the whole, of the same size as those in the Alaskan boghead but smaller than those in the Scotch and Australian samples. In general form and appearance the yellow bodies (Pl. XL, *A*) are the same as those in the other bogheads, but on comparison of the minute structure they are found to differ markedly, showing very little organized structure or none at all. Here and there the microscopist may imagine that he recognizes the brown sacks, but in the last analysis there is no positive proof of them. If conclusions were to be based upon the structure of the bodies in this coal alone, they would be relegated at once to the category of the unknown; but in looking over the bogheads from different places and considering the varying state of preservation of the structure, a continuous series can be constructed—at one end those in which the structure is perfectly preserved, gradually and imperceptibly grading into those at the other end, in which no structure is observable, the same or very similar general form, color, and nature being maintained throughout the series. Such a result gives strong support to the reasoning that the whole series is of the same origin. Such a series comprises the Australian bogheads, with the structure in a perfect state of preservation, at one end, and the Pennsylvanian bogheads, with no structure preserved, at the other. In this light, until further evidence is found to the contrary, it may be assumed that the deposit at Kiskiminetas Junction is of the oil-algal origin and a true boghead coal.

CANNEL COAL FROM UPPER POTTSVILLE FORMATIONS IN WESTERN PENNSYLVANIA AND EASTERN KENTUCKY.

Samples of cannel coal from the upper Pottsville at Lesley, near Paintsville, Ky., were also examined. The bed at Lesley is approximately 5 feet 9 inches thick. At the bottom is a layer of ordinary bituminous coal about 2½ inches thick, changing soon into cannel coal, which continues to the top, with the exception of a 4-inch layer of stratified bituminous coal in the middle of the bed. The bed has a roof of rather gritty gray shale containing carbonized plant remnants and residues.

The cannel is black and tough and cleaves in slabs of varying thickness; but the cross and oblique fractures are distinctly conchoidal. The cannel is really a spore cannel coal, because by far the larger part of the organic matter consists of spore matter. Spore exines of a number of different kinds, both microspores and megaspores, enter into its composition. Much macerated spore matter and some cuticular matter are observed in the ground mass.[36]

Among the spore exines are peculiar yellow bodies in varying amounts, resembling those of the boghead coals in certain respects. No definite organized structure, however, can be discerned in them. These bodies have been described by the writer[36] as follows:

> The coal contains interesting objects that are very abundant in certain strata, where they constitute more

[36] White, David, and Thiessen, Reinhardt, The origin of coal: Bur. Mines Bull. 38, p. 253, 1914.

than half of the bulk. In other strata they are comparatively rare. On the whole, they constitute only a small proportion of the total mass. They are in general appearance distinctly similar to Renault's genus *Pila* of his supposed algae.

These bodies vary greatly in size, ranging roughly from 30 to 175 microns in diameter. In color they are almost of a paraffin-white, which in thicker sections becomes a light brass-yellow. Their form is roughly oval, with an irregular outline. This irregularity consists of processes, often pseudapoda-like, and irregular cavities or depressions, reaching often to the center or even through the body.

The structure of these bodies is, in fact, so irregular that an adequate description of it is difficult. It is probable that these yellow bodies had their origin in an organism similar to that which gave rise to the Australian and European boghead coals.

Numerous yellow bodies, apparently comparable to those described in the foregoing pages, are found in a cannel coal occurring in the Mercer shale on Neshannock Creek near Leesburg, in Springfield Township, Mercer County, Pa. As shown in Plate XL, *B*, this coal contains much material of humic origin. Besides the spore exines and the yellow bodies, of which the latter are plainly recognizable in the photograph, the section discloses large numbers of cuticular fragments and numerous lumps of resin, two kinds of which, one dark and the other lighter, are seen on the left.

It is likely that a close examination of cannel coals will reveal algal colonies in many of them, as is to be expected on account of the open-water environment in which they were laid down. In view of the interesting results of the present study of bogheads and cannel coals, a more systematic examination of the cannel series, of which abundant material is already in hand, is contemplated.

SUMMARY.

According to origin, bituminous shales and cannel coals may be classified into humic, spore, ceric, resinous, and algal deposits.

This paper endeavors to show that the yellow bodies of the boghead coals are not derived from spores but represent colonies of alga-like organisms heretofore not well known. In all the bogheads investigated these colonies, described as *Reinschia* and *Pila*, are similar to an organism now living in the salt lakes and salt lagoons of South Australia and neighboring islands. The living organism has been termed *Elaeophyton* because of the large amount of oil it contains.

Elaeophyton is a colonial organism in some respects resembling some of the blue-green algae, but its cell wall differs from that of the algae ordinarily described. The colonies, which are just visible to the naked eye, may be single or compound; they are solid and of globular form. Each colony is composed of an irregular outer zone of living cells, several cells deep, inclosing a core of irregular inner cells that lack protoplasmic contents. The living cell contents are of oval or ovoid form, are relatively small (about 3 microns in diameter and 5 microns long), and contain no definite nuclei. They are surrounded by a relatively thick cell wall of irregular thickness. The different cells are cemented together by a medium apparently similar to the cell walls. These colonies appear on the lakes and lagoons toward the end of winter, are blown to the shore, and there form a rubber-like mass called coorongite. Coorongite does not appear to decompose or oxidize further; it is rich in oil and volatile matter, burns with a bright, hot flame, and melts before burning. When heated in a closed test tube it melts into a sirupy liquid, becoming viscous on cooling. When distilled, it yields about 70 per cent of oils, some tarry matter, some gas, and very little solid residue. Coorongite is the peat stage of boghead coal.

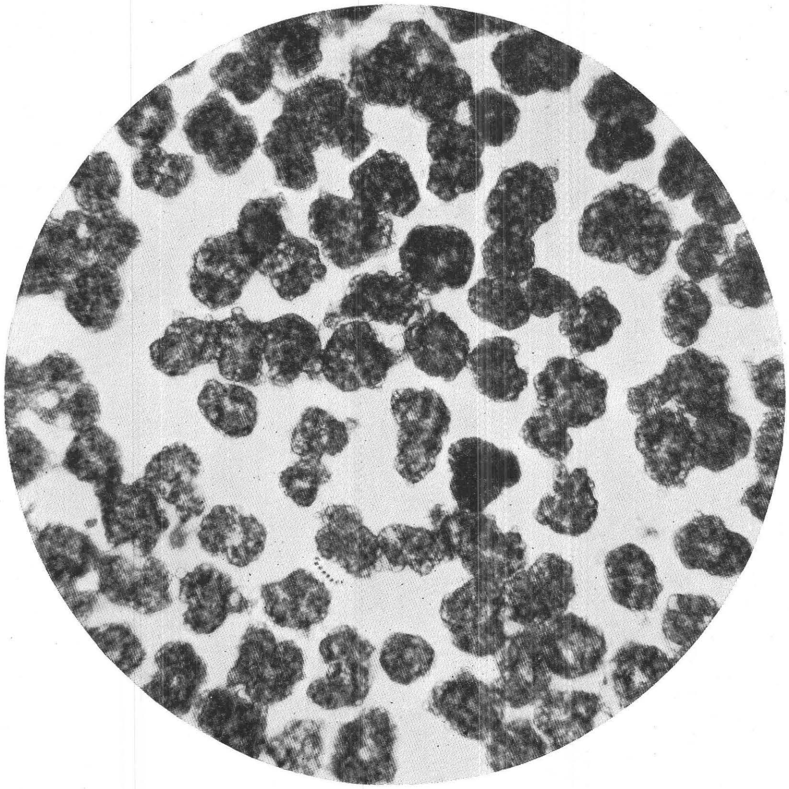
The structure and size of the yellow bodies in the boghead coals examined correspond closely to those of the colonies of *Elaeophyton*. The yellow bodies contain an outer zone of thick-walled cells inclosing oval sacks, most of which have brown contents. These sacks represent the once living protoplasmic contents of the cell. The preservation of the structure as a whole differs in deposits at different localities, the coals examined showing a range from a very well preserved structure to a condition in which the structure has been completely effaced. A similar range occurs to some extent

in the deposits of well-preserved material. By analogy and through the similarity in structure, appearance, and qualities of the yellow bodies in the boghead series, it is concluded that all had a similar source—that is, colonial algae of the same general nature and of a composition similar to that of the colonies of the living *Elaeophyton*.

ACKNOWLEDGMENTS.

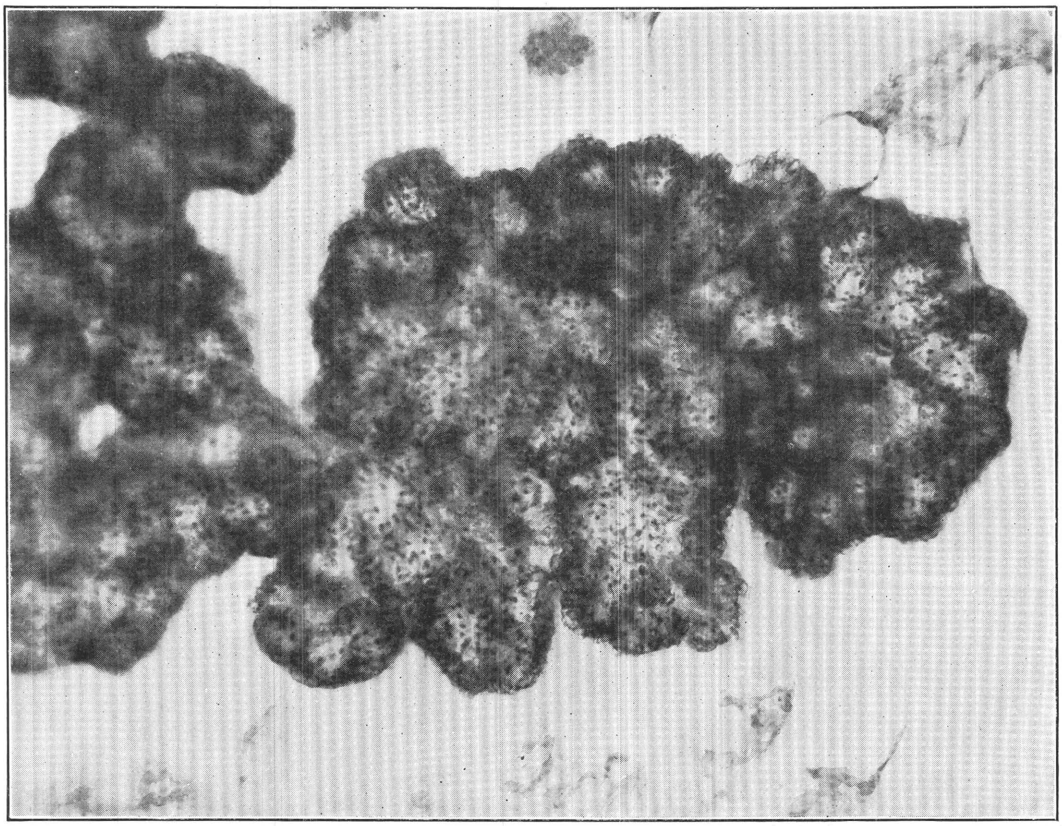
In addition to numerous suggestions made by members of the Bureau of Mines staff, whose names need not be mentioned, the writer is indebted for extensive and constructive criticism to David White, most of whose suggestions have been incorporated in these notes.

PLATES XXVII—XL



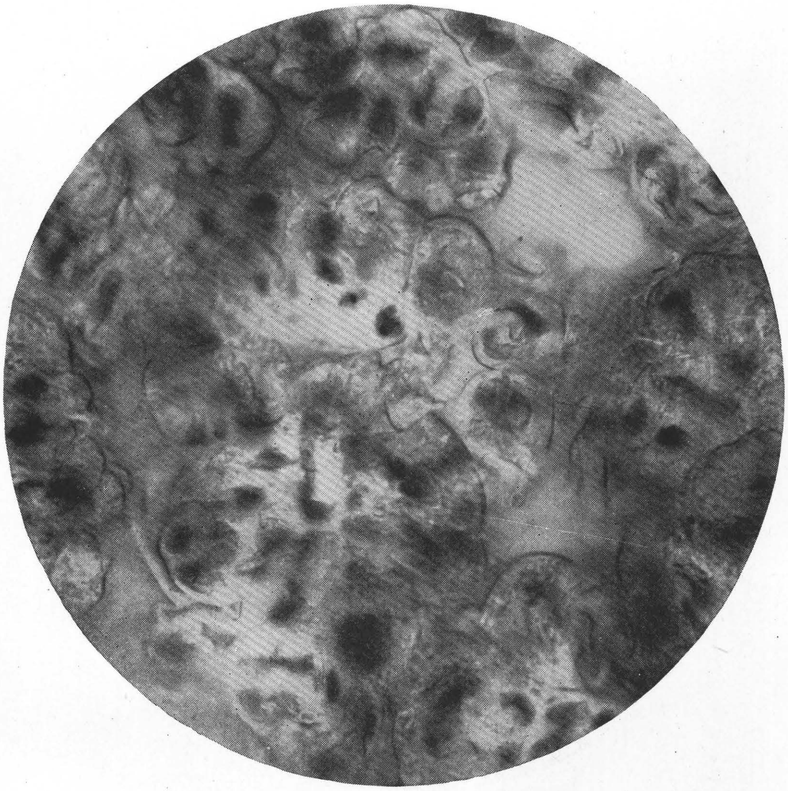
A. COLONIES OF THE LIVING ONE-CELLED ALGA, ELAEOPHYTON N. GEN., FROM THE COORONG DISTRICT, SOUTH AUSTRALIA

Single as well as compound colonies are shown. The size of the compound colonies depends on the number of primary colonies in them. The small bodies are apt to be single colonies, the larger ones compound colonies. × 200



B. A NUMBER OF COLONIES OF ELAEOPHYTON MERGING INTO A LARGER MASS

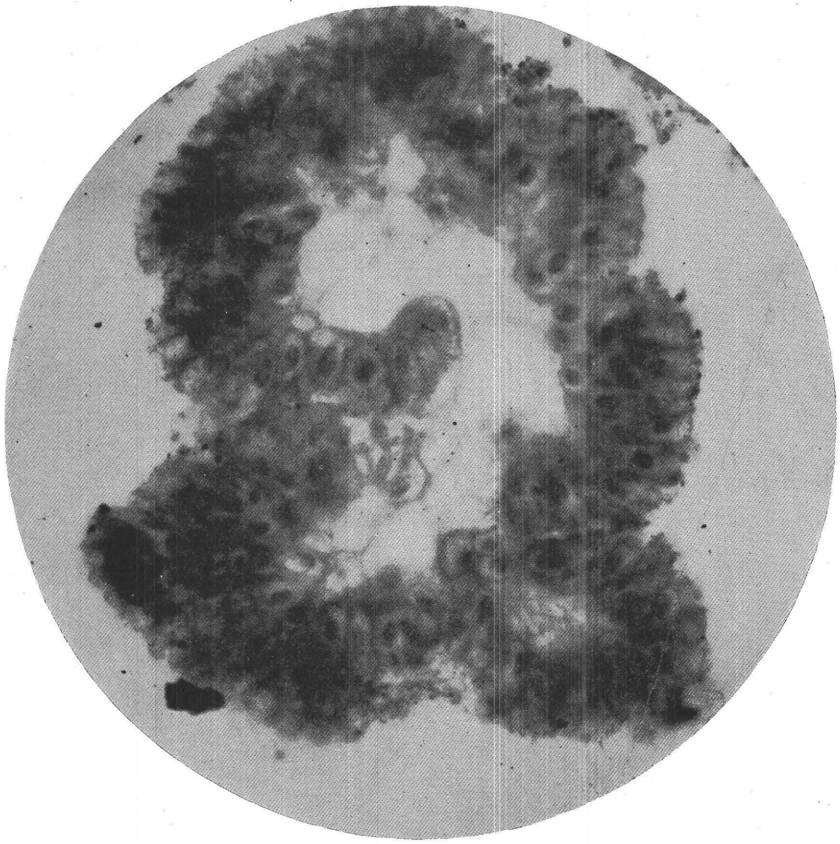
The black specks represent the living cell contents. × 200



A. A COLONY OF THE LIVING ELAEOPHYTON, COMPRESSED UNDER THE COVER GLASS AFTER STAINING WITH SAFRANIN

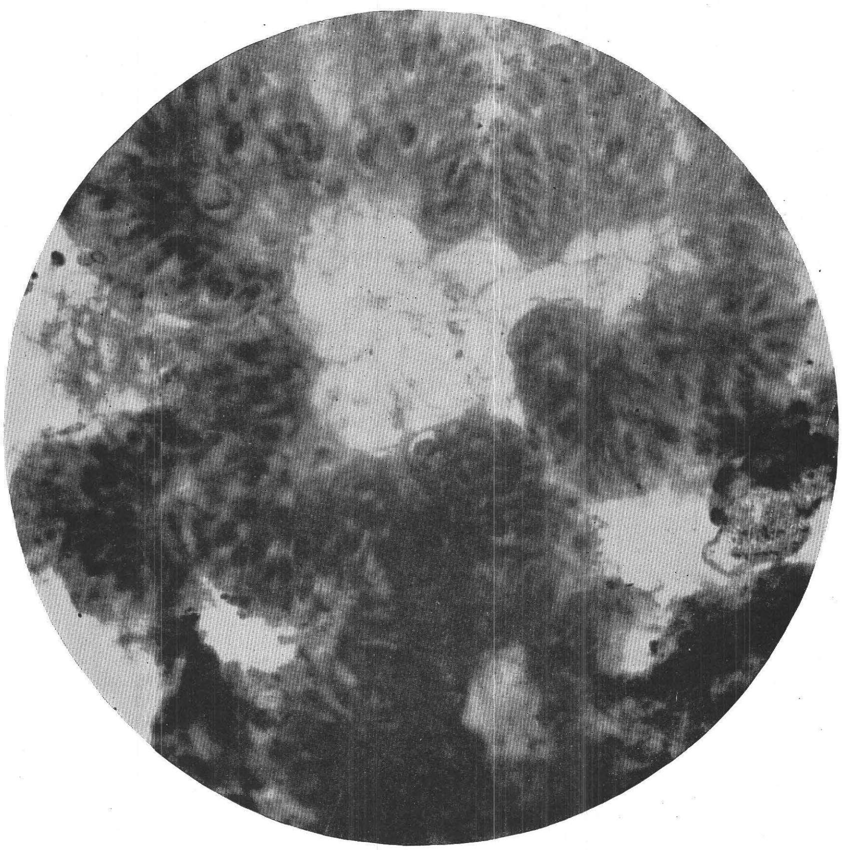
The dark oval or ovoid spots represent the living cell contents. At many points the outlines of the cell walls are shown. × 1,000

B. SECTIONS OF SEVERAL COLONIES OF ELAEOPHYTON, TWO OF WHICH SHOW THE CORE OF INNER BLANK CELLS. × 600



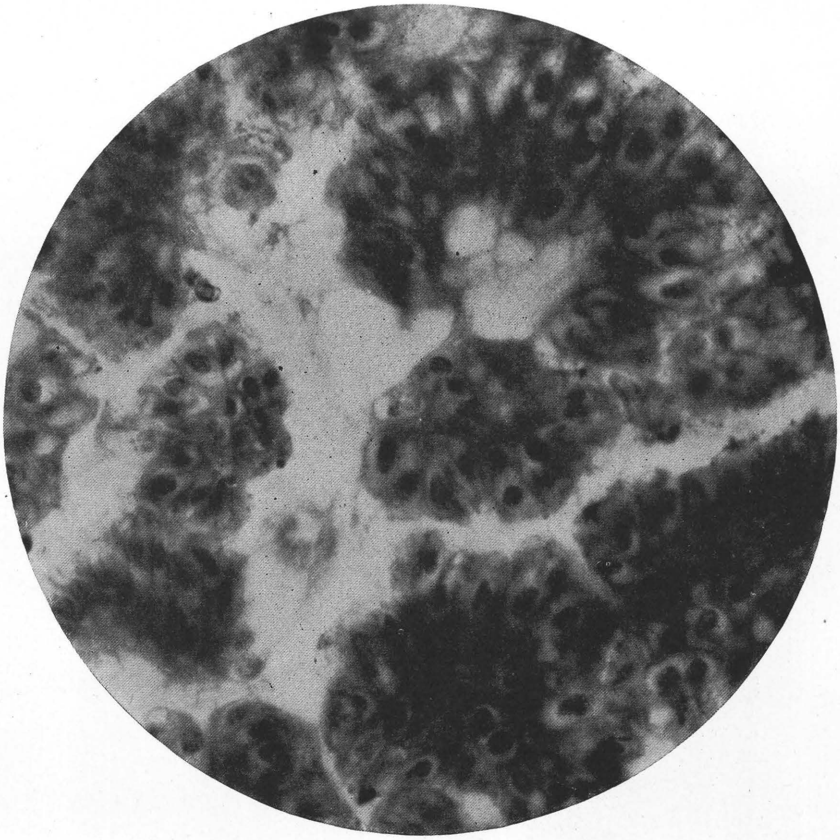
A. SECTION OF A SMALL COMPOUND COLONY OF ELAEOPHYTON

Showing the thick zone or shell of living cells, and the structure of the inner core of blank cells. × 600



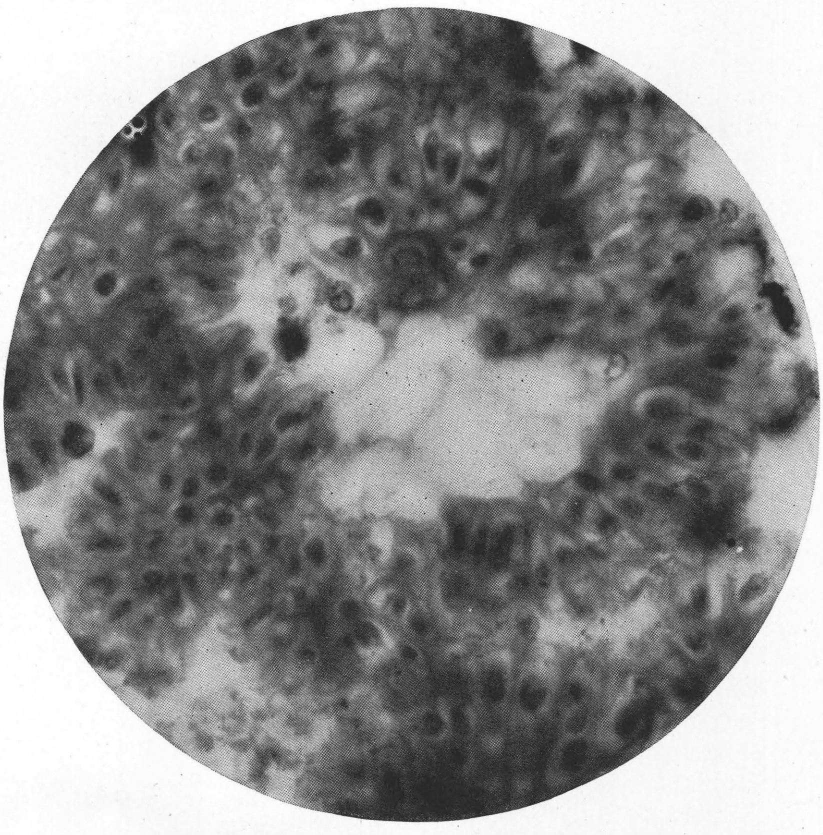
B. SECTION OF COMPOUND COLONY OF ELAEOPHYTON AND OF AN ADJOINING SINGLE COLONY

Showing the blank inner tissue surrounded by an outer zone of living cells. × 600



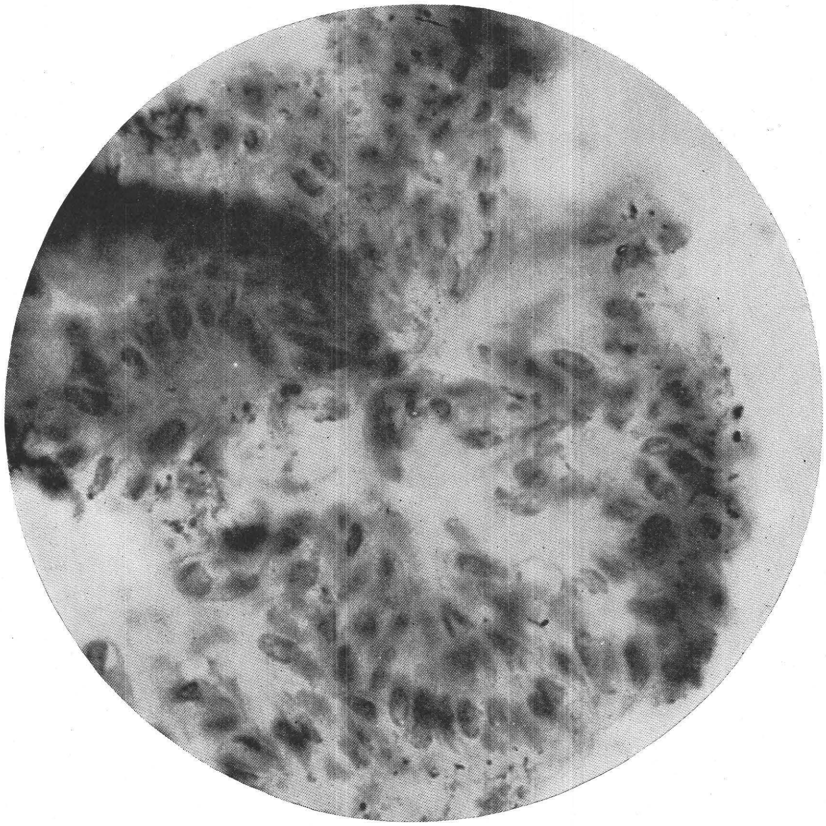
A. SECTION OF COMPOUND COLONY OF ELAEOPHYTON AND PARTS OF NEAR-BY COLONIES AT A HIGHER MAGNIFICATION

Plates XXX and XXXI show more definitely the organization of the individual cells. The oval dark spots represent the contents of the living cell, the lighter area bordering each of these spots represents the reinforcement of fatty or oily matter deposited inward on the primary cell wall, and the darker heavy lines surrounding the cells and uniting them represent the cementing matter. The lighter areas of irregular structural pattern represent the blank cells. The irregular light strips represent open spaces between the colonies. × 1,000



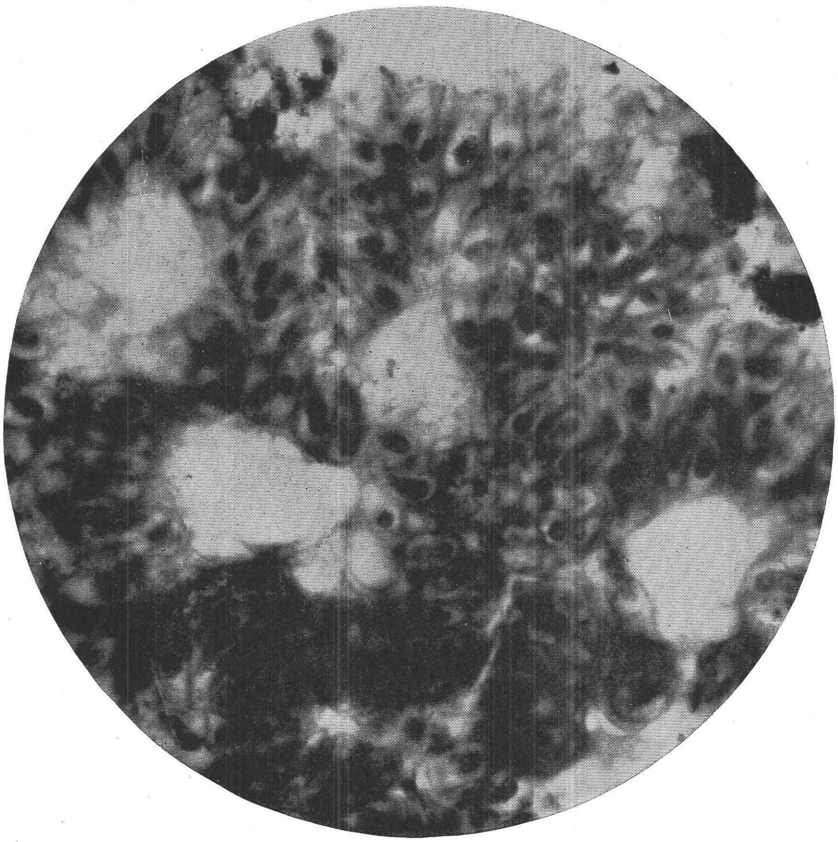
B. SECTION OF COMPOUND COLONY OF ELAEOPHYTON

Showing in particular the aspect and variation of the blank cells in the center of the colony. × 1,000



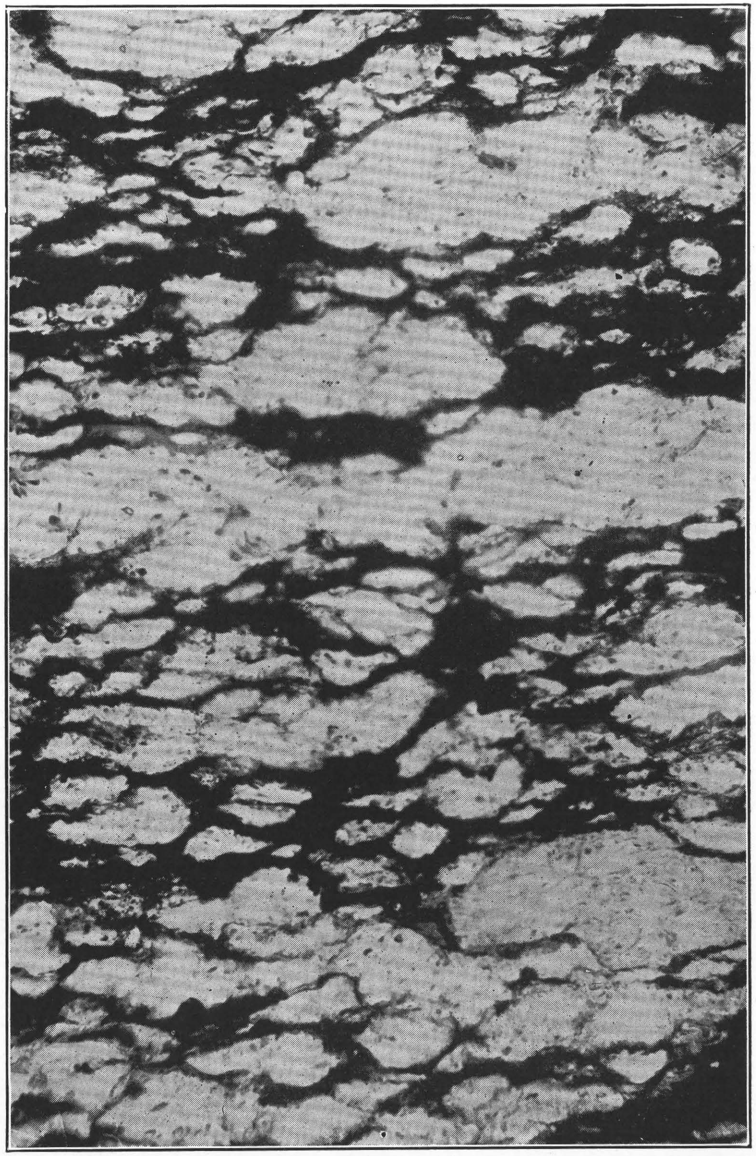
A. SECTION OF COMPOUND COLONY OF ELAEOPHYTON

Showing the thick fatty matter deposited about the cavity of the cell and forming its thick wall. Compare this figure with Plate XXXIV, *A.* × 1,000



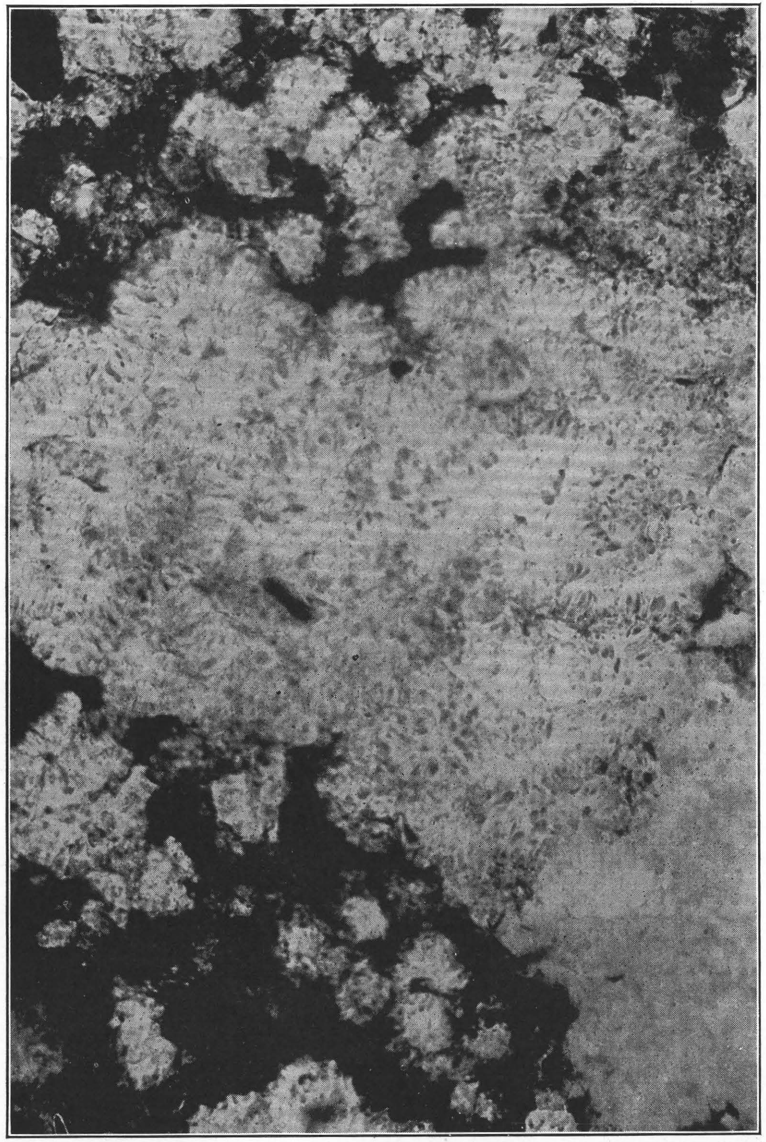
B. SECTION OF COMPOUND COLONY OF ELAEOPHYTON

Showing variability in size, form, and aspect of blank cells; also relations of fatty inner cell thickening about the central cavity to the cementing matter and the blank cells. × 1,000



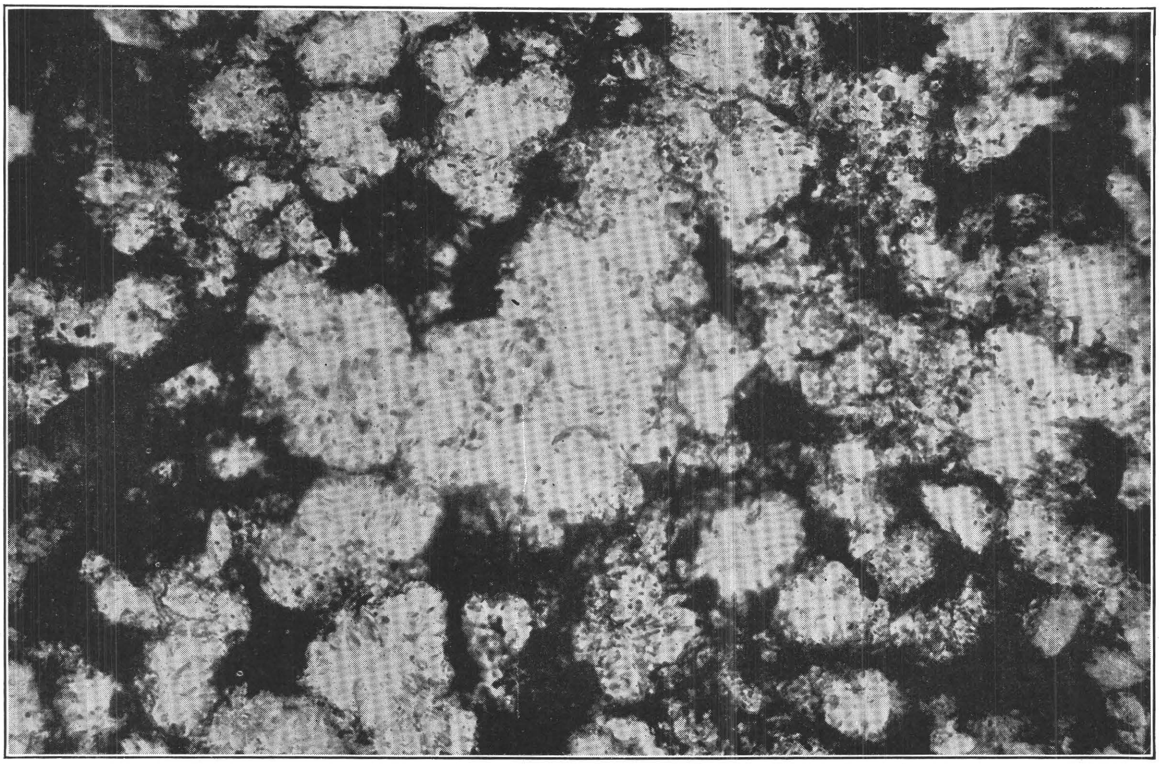
A. CROSS SECTION OF BOGHEAD COAL (THE SO-CALLED KEROSENE SHALE) OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

The irregular, light, somewhat spongy masses that form "yellow bodies" in this fossil deposit are the compound colonies of the one-celled alga Reinschia australis B. Renault. × 200



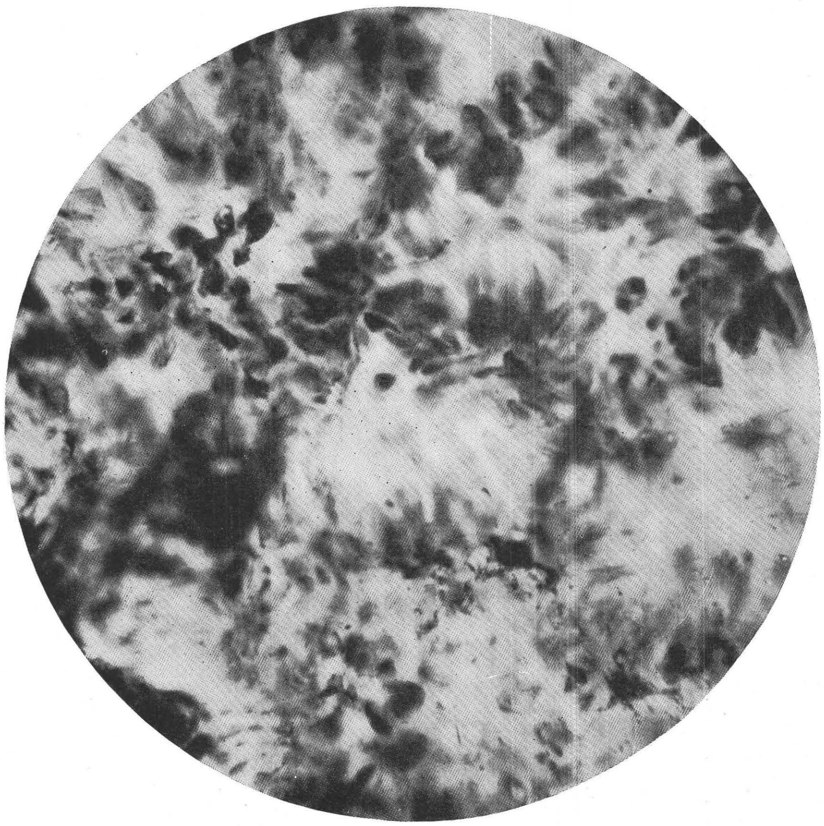
B. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES

The section shows large and small colonies of Reinschia australis B. Renault. × 200



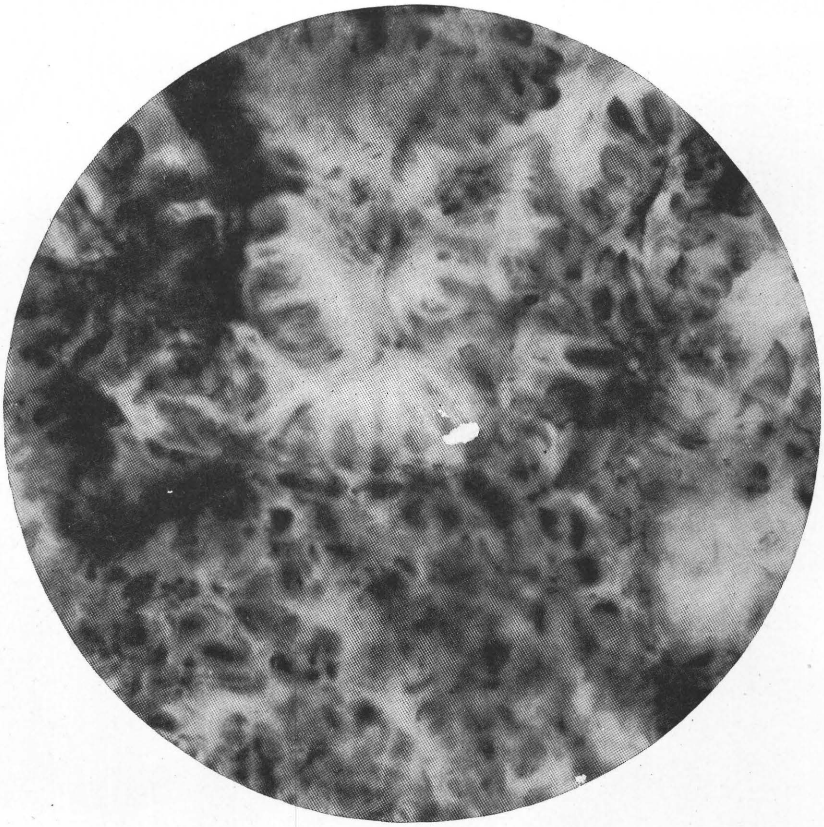
A. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

This section shows compound colonies, mostly of rather small size, of the fossil alga Reinschia australis B. Renault. × 200



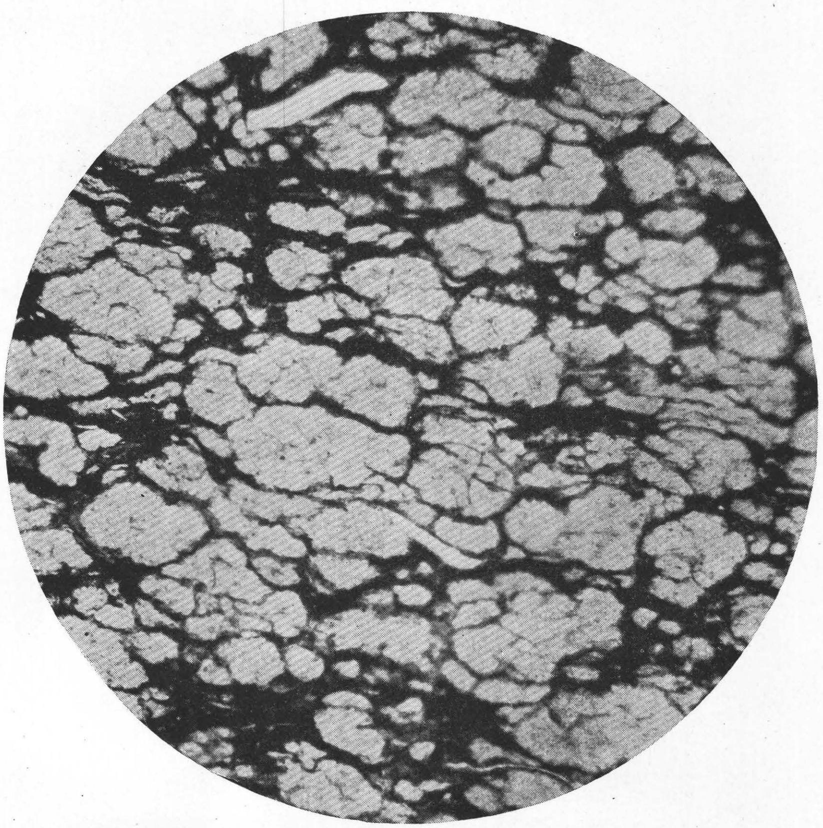
B. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

More highly magnified to show a number of primary colonies of the fossil alga Reinschia australis B. Renault. The dark oblong spots represent the remains of the contents of the living cells, now stained dark by biochemical decomposition products more or less distinctly humic. × 1,000



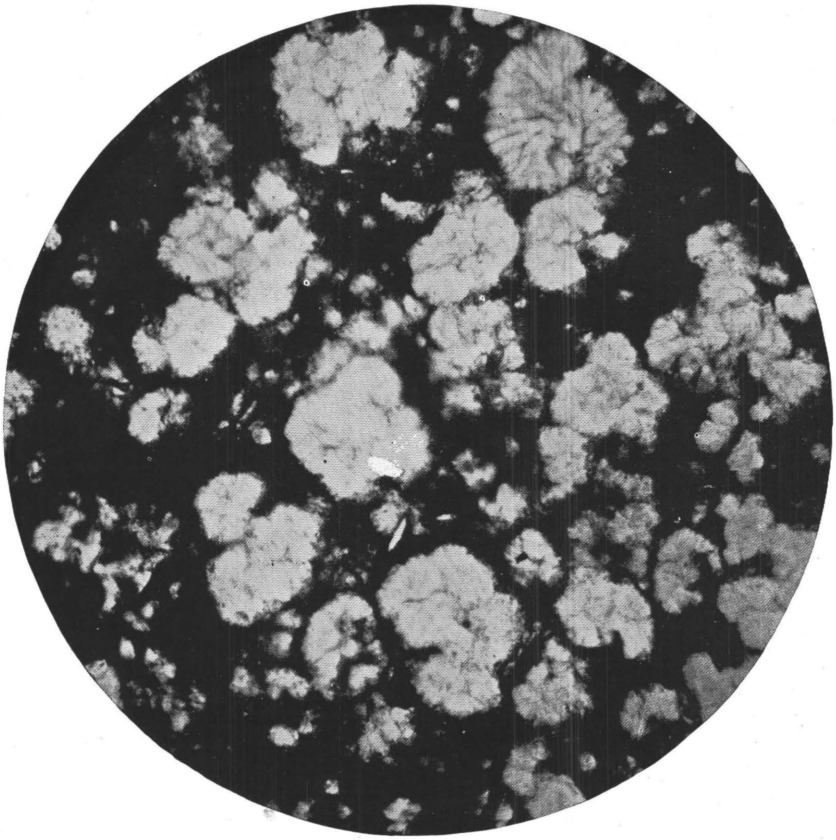
A. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

Showing colonies varying in size of the fossil alga Reinschia australis B. Renault, characteristic of the kerosene shale. The more completely the rock is made up of these colonies of fatty algæ the more voluminous the distillate and the better its quality. × 1,000



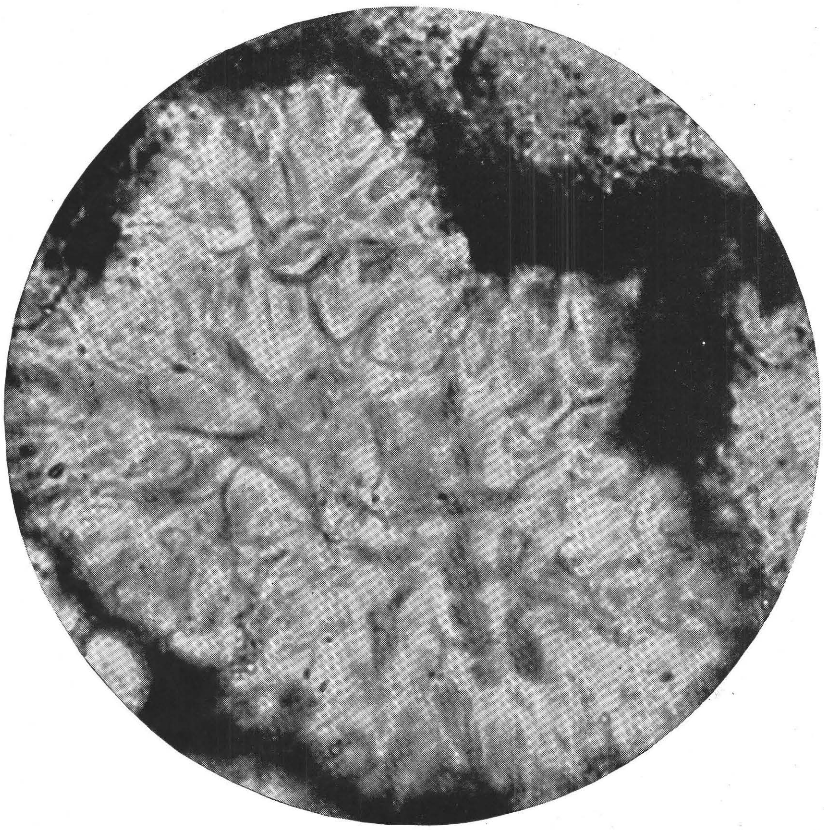
B. CROSS SECTION OF BOGHEAD COAL (TORBANITE) OF MISSISSIPPIAN AGE FROM TORBANE HILL, SCOTLAND

The section shows the colonies of the one-celled alga Pila scotica B. Renault, now fossil and embedded in a general attritus of dark-brown color. But little flattening has taken place. × 200



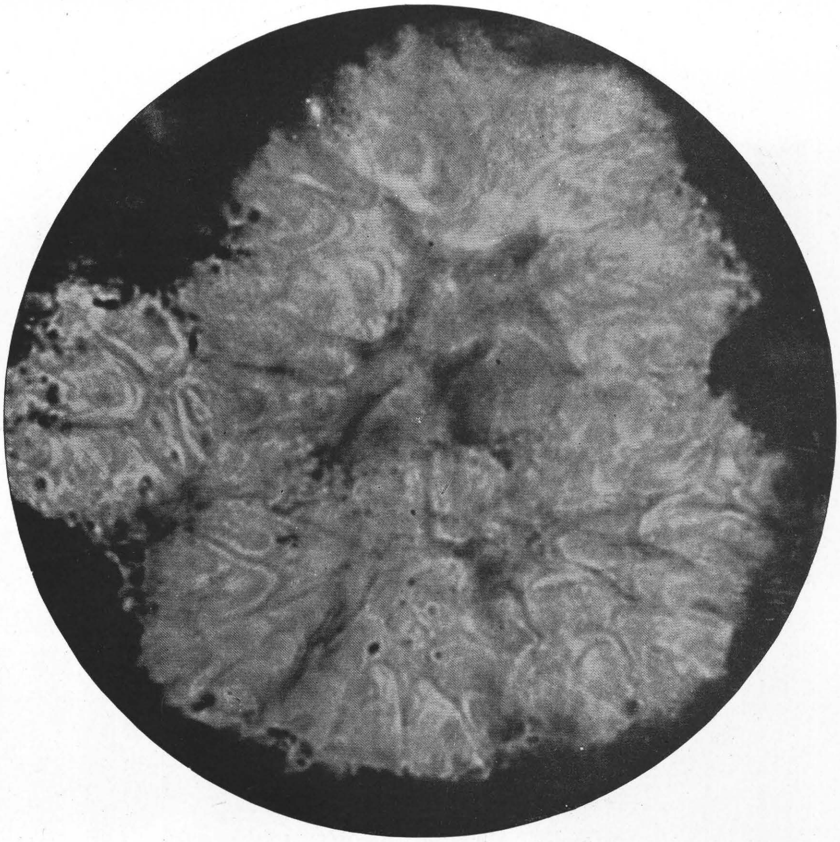
A. HORIZONTAL SECTION OF BOGHEAD COAL (TORBANITE) OF MISSISSIPPIAN AGE FROM TORBANE HILL, SCOTLAND

The colonies of the fossil one-celled alga Pila scotica B. Renault, which form the "yellow bodies," are embedded in an attrital matrix of dark-brown color, "the groundmass," in which is mingled a considerable amount of dirt. The large macerated body at the top appears to represent the fossil organism described by B. Renault as Cladiscothallus, a fungus. × 200



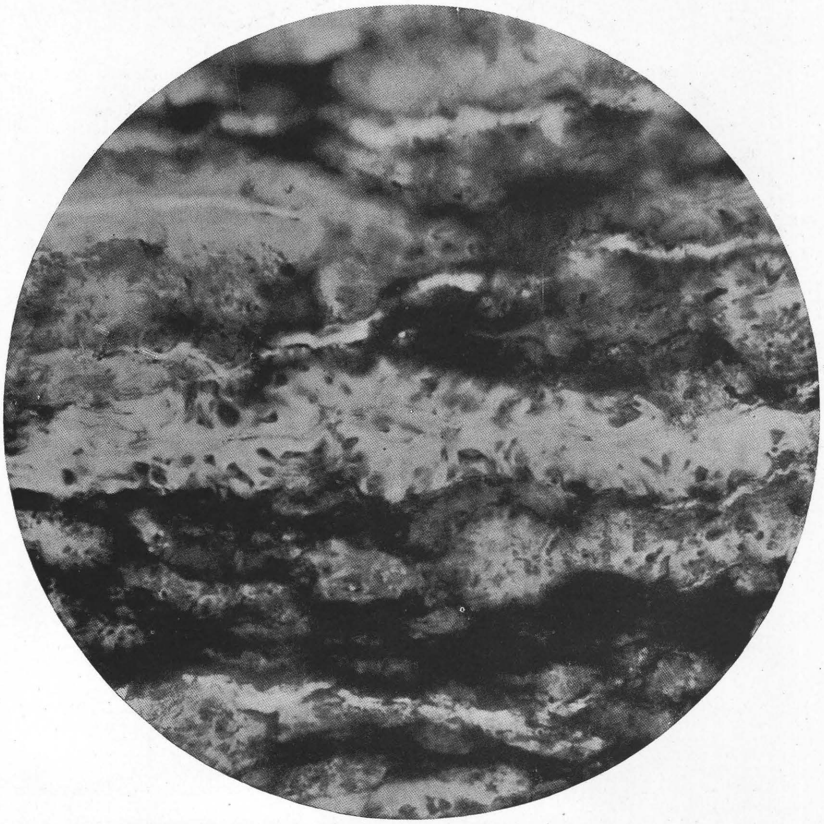
B. HORIZONTAL SECTION OF A COLONY OF PILA SCOTICA B. RENAULT FROM THE SAME LOCALITY AND DEPOSIT AS THE SPECIMEN ILLUSTRATED IN *A*

Shows an outer zone of cells surrounding the inner core of blank cells in the fossil species just as in the living Elaeophyton. The brown cell contents of some of the cells are distinguishable. The algae of the colonies are slightly decomposed around the edges of the colonies. × 1,000



A. HORIZONTAL SECTION OF AN ALGA COLONY, PILA SCOTICA B. RENAULT, IN THE BOGHEAD COAL (TORBANITE) OF MISSISSIPPIAN AGE FROM TORBANE HILL, SCOTLAND

The primary colonies are easily distinguishable; also the inner core of blank cells. The brown oval contents of the cells have largely disappeared, as is common in this boghead coal, but the outlines of the cells are still visible through a difference in refraction. × 1,000

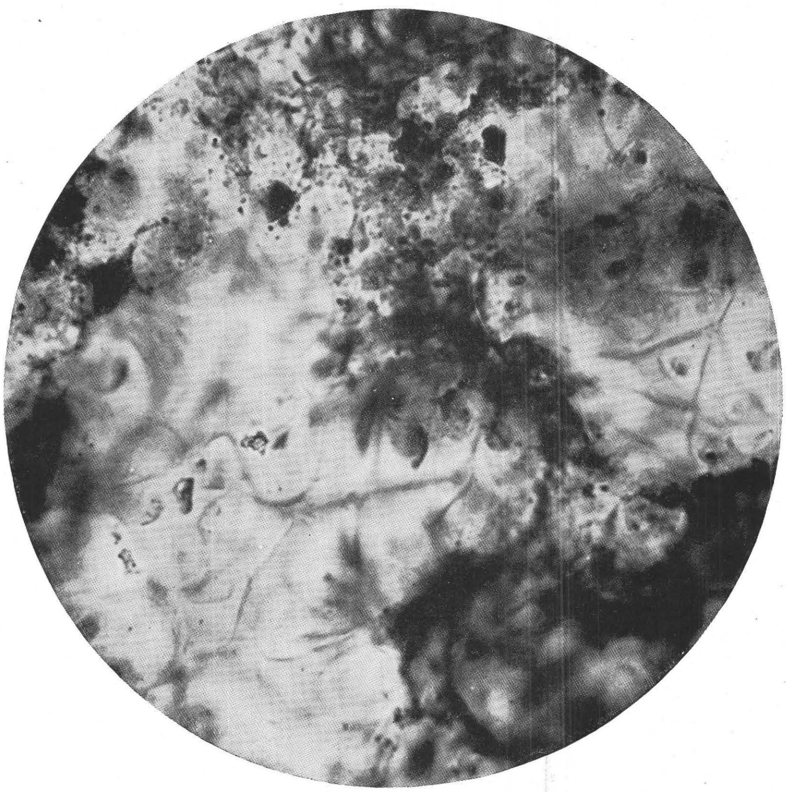


B. CROSS SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

The "yellow bodies," compound colonies of the one-celled alga Pila scotica B. Renault, have been much more flattened than are those in the deposit at Torbane Hill. (See Pl. XXXV.) The blank cells of the core of the colony have been more flattened than the individual algae, thus giving the colony the appearance of a highly sculptured spore exine. × 1,000

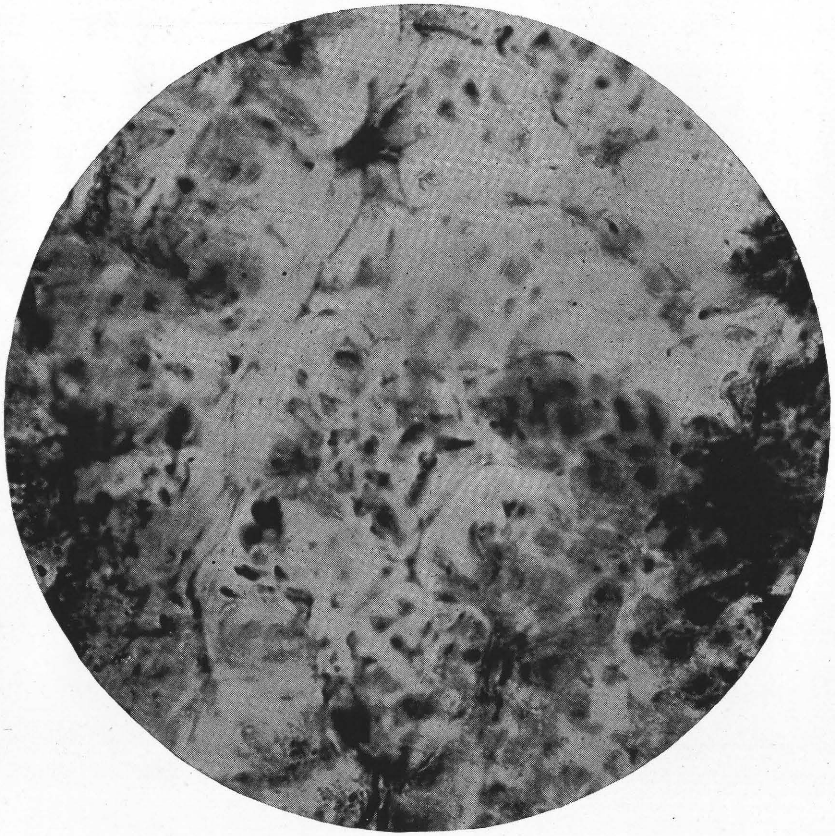
A. CROSS SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

The "yellow body" in the central part of the photograph is clearly shown to be a compound colony of the one-celled fossil alga Pila scotica B. Renault. The primary colonies are well marked off. × 1,000



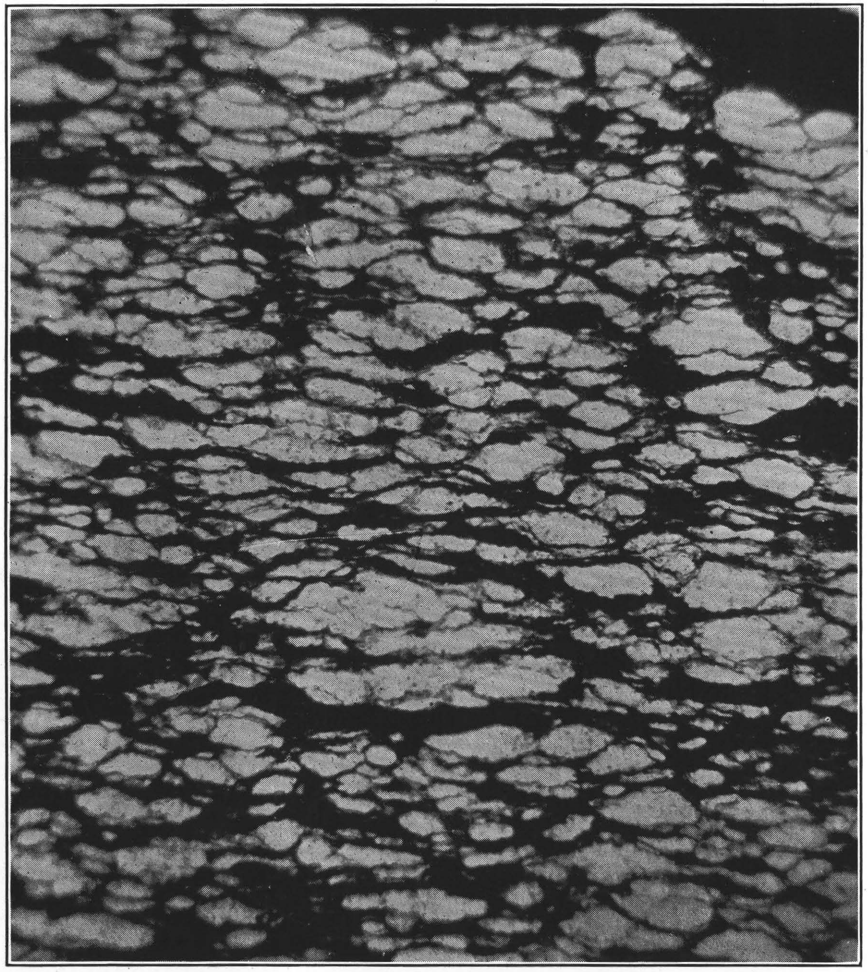
B. HORIZONTAL SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

The outlines of the cells of the individual algae (Pila scotica B. Renault) in this highly magnified thin section are rather clearly shown, and the brown oval cavity which once contained the protoplasm of the alga is shown distinctly. × 1,000



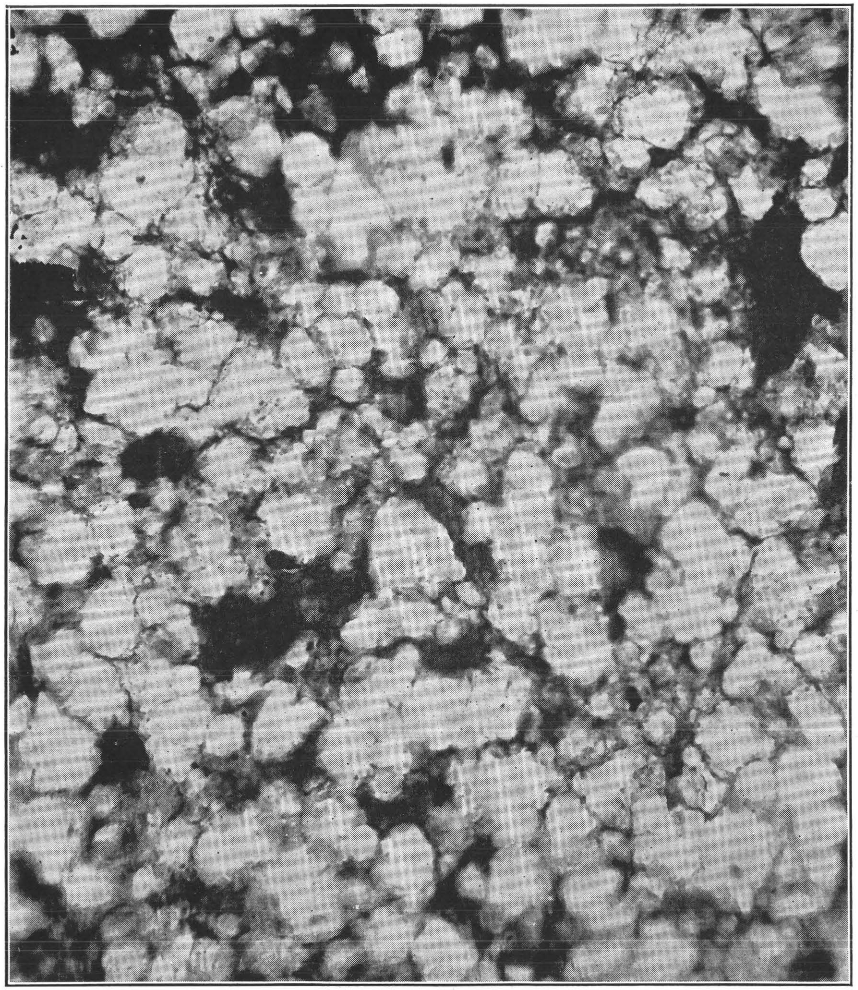
A. HORIZONTAL SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

This section outlines the primary colonies of the oil-forming fossil alga Pila scotica B. Renault, and the brown cell contents are clearly distinguishable. This and the four preceding illustrations should be compared with the photographs of the living Elaeophyton shown in Plates XXIX, XXX, and XXXI. × 1,000



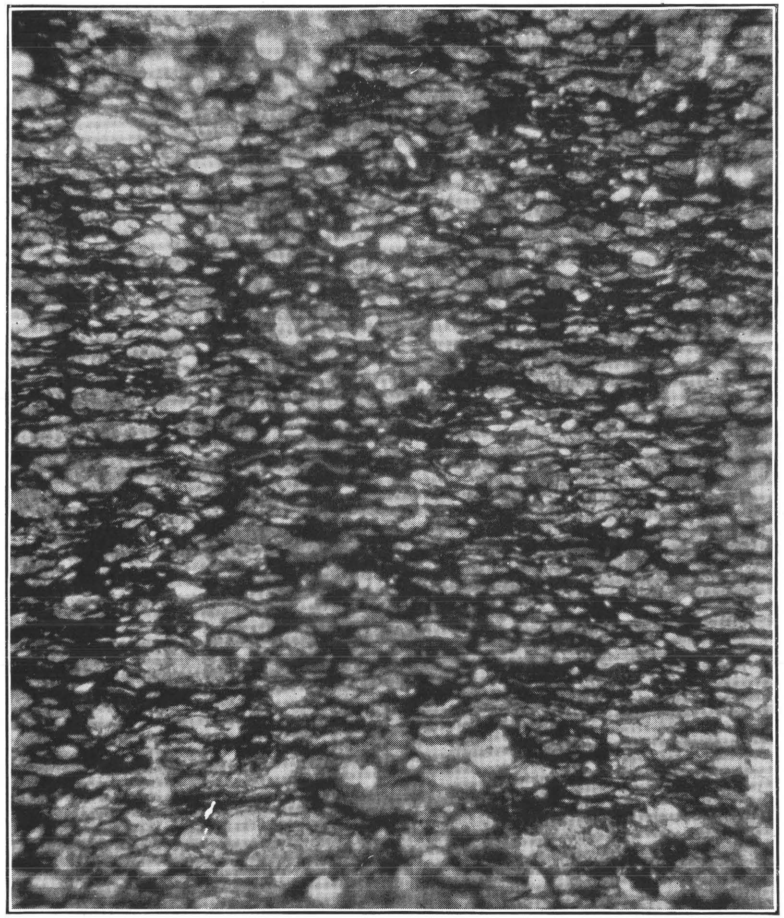
B. CROSS SECTION OF A BOGHEAD COAL FROM COLVILLE RIVER, ALASKA, SHOWING YELLOW BODIES

The obscurely indicated structure is comparable to that of the living Elaeophyton and to the fossil alga colonies characteristic of the kerosene shale (torbinate) and other bogheads. The Alaska yellow bodies also are probably compound colonies of a related alga. × 209



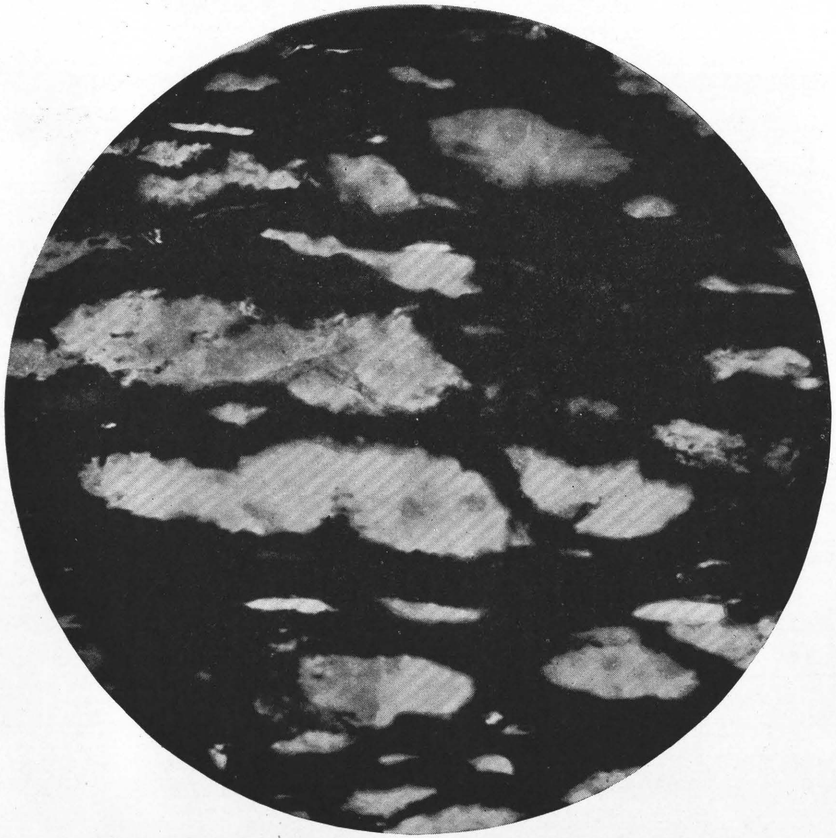
A. HORIZONTAL SECTION OF BOGHEAD COAL FROM COLVILLE RIVER, ALASKA

The similarity between the yellow bodies in this fossil deposit of unknown age in Alaska to the compound colonies of Elaeophyton (see Pl. XXVII) and to the fossil boghead algae of different ages is at once apparent. × 200



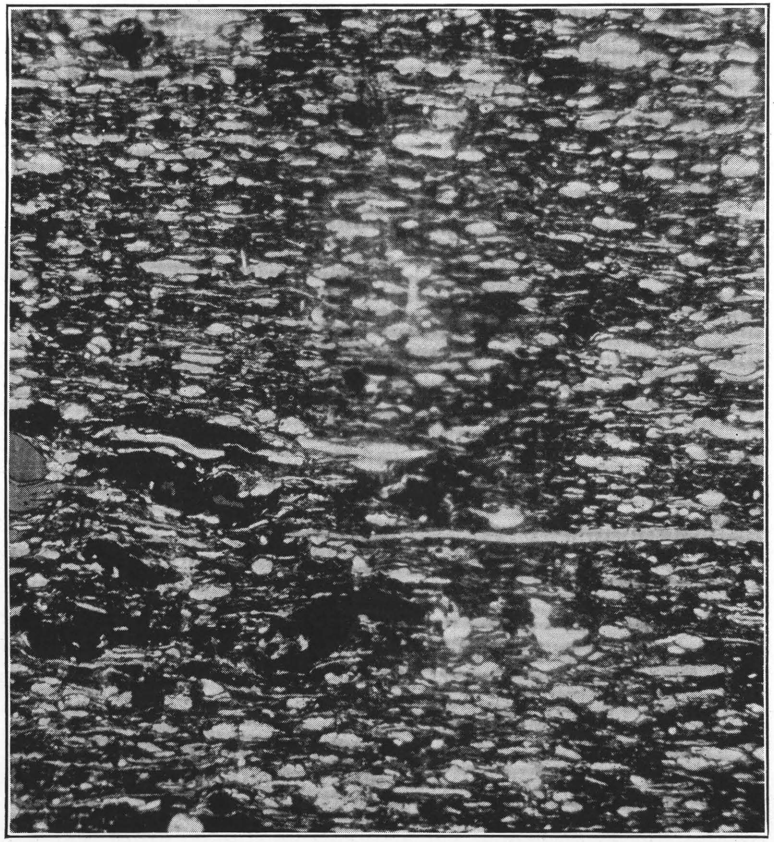
B. VERTICAL SECTION OF BOGHEAD COAL, LYING MIDWAY BETWEEN THE UPPER AND LOWER FREEPORT COALS, IN THE ALLEGHENY FORMATION AT KISKIMINETAS JUNCTION, WESTMORELAND COUNTY, PA.

The organic matter in this deposit is composed very largely of yellow bodies, apparently comprising algal colonies closely comparable in general aspect and to a degree at least in structure with Elaeophyton and the fossil types of boghead colonial algae. Relatively very few spores are present. The deposit begins with an ordinary shale at the bottom, which first gradually and then quickly changes into a rich boghead coal. × 200



A. CROSS (VERTICAL) SECTION OF CANNEL COAL FROM A FREEPORT BED OF THE ALLEGHENY FORMATION AT KISKIMINETAS JUNCTION, WESTMORELAND COUNTY, PA.

The yellow bodies in this section, here seen in greater enlargement, are strongly suggestive of Elaeophyton and are probably alga colonies similar in general composition to the living and the fossil forms shown in the preceding illustrations. × 1,000



B. CROSS (VERTICAL) SECTION OF CANNEL COAL FROM THE MERCER SHALE (UPPER POTTSVILLE) ON NESHANNOCK CREEK NEAR LEESBURG STATION, PA.

This section shows spore exines, lumps of resin (at left), and a number of yellow bodies, probably colonial algae related by nature and composition to Elaeophyton. The section exhibits the characteristic aspect and constitution of a cannel coal in which spore exines predominate and in which occur also minor amounts of resin lumps, alga colonies, fragments of cuticle, etc. × 200