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RESINS IN PALEOZOIC PLANTS AND IN COALS OF HIGH RANK

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By David White.

INTRODUCTION.

The theory that coal is but peat, mainly of swamp types of formation, that has been transformed by normal geologic processes seems to have been completely demonstrated, though it is not fully accepted by many geologists and chemists. Examinations have shown that the coal substance is made up of plant débris, more or less decomposed and altered, mingled with and perhaps permeated by the now hardened but once liquid products of organic decomposition. Such being the case, we may conclude that all the parts and products of the plants were originally contributed to the peat formation and, either as fragmental remains or perhaps as chemical products of the decomposition of portions of the vegetal substance, may have entered into the composition of the peat. The evidence shows that varying proportions, in places nearly all, of the contributed plant materials were structurally obliterated before the peat-forming process terminated.

Naturally, in the process of building up peat those plant parts and products which were most resistant to the decomposing agents, principally bacteria and fungi, would survive longest and, other things being equal, would be most easily recognized in the undestroyed débris remaining in the coal. Among these decay-resisting products are the resins, waxes, spore covers, cuticles, seed coats, and bast of the plants of numerous kinds that are contributed to the peat.

Plants of types that produce resins and waxes are present in every region where peat is now in process of formation. Their fossil remains are present also in nearly every swamp that is found buried in the formations of later geologic ages, and in the low-rank coals found in these formations. Yet, because the presence of resins in the coals of higher rank has not been sufficiently demonstrated, it is believed by many, perhaps by most geologists and chemists, and even by some paleontologists, that resins never entered into the composition of these coals; that the higher-rank coals of all ages owe their very differences in rank to differences in the types of the plants from which they were formed, the absence of resin-producing plants being regarded as one of the conspicuous characteristics of the floras producing these coals; and that the great coal-forming floras of the Carboniferous period, to which the bituminous and higher-rank coals of most parts of the world belong, were destitute of resin-bearing plants. It is also urged by many foreign writers that the coals of high rank have not at any time existed as peats.

The fact that the presence both of the remains of resin-bearing plants and of resin itself in the high-rank coals of the Paleozoic and Mesozoic formations has not been generally recognized is due to the nature of the evidence rather than to the lack of it. The purpose of the present paper is (1) to show that resins have been contributed to the high-rank coals of the Cretaceous and Tertiary periods as well as to the coals of low rank which are characteristic of those periods; (2) to point out the evidence that the Carboniferous floras were possibly as richly productive of resins or resinous substances as the floras of later periods; and (3) to demonstrate, with illustrations of material both common and unique, the presence of abundant resinous material in Paleozoic coals. Observations as to the physical changes in the resins consequent on the alteration of the coals to successively higher ranks are given. Incidentally the paper sets forth further proof (which apparently is not superfluous) of the origin of high-rank coals as peats.

RESINS IN COALS OF LOW RANK.

The occurrence of fossil resins in the lignites of the Cretaceous period is known to all who have closely observed these fuels. They are present in almost all deposits of these lignites and are in some places so abundant as to constitute an appreciable portion of the coal. These resins have been derived, for the most part at least, from coniferous trees that have been contributed to the original peat from which the lignites or coals of higher rank were formed.

As ordinarily observed, without the aid of the microscope, the resins consist of very irregular lumps ranging from the smallest particles to fragments over an inch in diameter. Usually the larger pieces are more or less elongated and variously flattened or shapeless. Sometimes they are found in their original positions with reference to the remains of the trunks, branches, or organs which bore them as surface exudates or to cover wounds, but generally they appear to be scattered in a medium of more or less promiscuously mingled plant débris or vestiges, all cemented in a dark humic matrix ("carbohumin"), though in fact the débris is apt to be more or less distinctly stratified and assorted as to kind, size, and state of preservation in the strata of the coal bed. Thus the resins are much more abundant in some layers of the coal than in others, according to the kinds of ingredient plant material contributed to form these layers and the conditions attending their deposition in the peat swamp. The conditions of deposition controlled both the extent of decay of the variable plant débris and the disposition of the decomposition products, portions of which were usually carried in solution by water from the areas of peat formation.

The resins are generally yellowish, brownish, or amber-colored, translucent, and vitreously conchoidal in fracture, though some of the material is pale yellow and apparently granulose in texture. As is well known, the amber of the arts and most of the copal of commerce are merely fossil resins, the greater part of the trade supply of amber having been produced by several Tertiary species of pines now found fossil in the rocks bordering the Baltic Sea in eastern Prussia.

Substances regarded by certain authors as fossil resins have been described under many names, some of which follow:[1] Amber, ambrosine, ajkite, ambrite, berengelite, bucaramangite, brücknerellite, caproline, chemawinite, duxite, dinite, euosmite, fichtelite, gedanite, glessite, guayaquillite, hatchetine, hartite, kranzite, jaulingite, könlite, köflachite, leucopetrite, middletonite, muckite, neudorfite, piauzite, pyroretin, phylloretin, retinite, retinellite, refikite, rosthornite, rümanite, reussinite, scheererite, schleretinite, succinite, schraufite, sieburgite, simetite, walchowite, xyloretinite.

By far the greater part of these resins or doubtful supposed resins are from coals of Cretaceous and Tertiary ages or from peats.

Although at some localities and in certain layers of the lignites and subbituminous coals[2] small lumps of resin may be so numerous as to be conspicuous on the bedding planes or cross fractures of the coal, these are, after all, insignificant in quantity as compared with the resin in particles of microscopic size contained in the same layers or even in layers that reveal no resin at all to the unaided eye. These microscopic fragments are present in varying amounts in practically all the low-rank coals of Cretaceous or Tertiary age that have been microscopically examined. In some places they are so abundant as to impart a yellowish or brownish color to the layer. The relative amounts of these resins and resin compounds affect certain important qualities of the fuels, as will later be noted. The microscopic resins are numerous in kind and mode of occurrence, having been deposited in the cells and vessels of wood, bark, leaves, and seed coats and in the outer envelopes of spores and pollen grains. In the plant world of to-day they are produced by many different kinds of vegetation belonging to widely different classes of vascular plant life. A large percentage of the dry wood of certain conifers consists of resin. On the other hand, many types of plants, especially among the angiosperms, produce little or none.

[1] See Leonhard, Gustav, Grundzüge der Mineralogie, 2d ed., pp. 381-383, 1860; also Dana, J. D., Mineralogy, 6th ed., pp. 996-1024, 1892.

[2] As defined by M. R. Campbell (Econ. Geology, vol. 3, p. 134, 1908), the subbituminous coals are distinguished from the bituminous by their mode of weathering, their less developed jointing and cleavage, and their higher moisture. On exposure to the atmosphere the lumps check irregularly, the resultant fragments, however small, being irregular in outline and having rough faces instead of cleavage planes. Weathering is characterized (very conspicuously in the longer-exposed fragments) by separation of the coal in plates parallel to the bedding, this process continuing to invisible limits. They were formerly called "black lignites." The name lignite is now restricted by the United States Geological Survey to brown coals.

CONCENTRATION OF RESINS IN COALS.

The principle proposed by many of the older paleobotanists and emphatically reiterated by Renault and Bertrand, that the vestiges or remains of the plant structures contained in the coals represent, in general, those parts of the plant or those kinds of tissue which were most resistant to decay, is exceptionally well illustrated by the resins. It is well known that the delicate and soft structures of the plant, such as the parenchymatous and medullary tissues, are the first to disappear in the putrefactive processes necessary to the formation of peat, and that according to the duration of these processes, which is a variable factor, and to the agents, mainly bacterial, engaged, the decomposition becomes more and more complete, extending to the more resistant elements or tissues. Thus the decay of the less resistant starchy and cellulosic compounds is followed by that of the more resistant; the wood succumbs before the corky bark; the proteids disappear in advance of the waxes, and so on, until in the most "mature" and "amorphous" peats little is left except the most indestructible parts, such as the resin particles, fragments of cuticles that are composed of very resistant substances, and the resinous or waxy coverings of spores and pollen grains. Of these persistent portions of the plant the resins generally survive to the last the subaqueous biochemical or putrefactive processes concerned in the formation of peats.

From the foregoing statements it will be seen at once that the amount of resin in a coal, though varying of course according to the kinds of plants contributed to the formation of the mother peat, is largely determined by the extent to which the decay of the vegetal débris progressed. For, as the resin is the most resistant to decay, it obviously will, other things being equal, survive to form the largest percentages in those peats (coals) in which the decay of the plant débris has gone farthest. The successive decay of the less resistant enveloping and associated tissues gradually frees the resin particles, which, with the disappearance of the other plant materials, settle together in an accumulation, really a natural concentration. Hence a mature or "amorphous" peat formed by the far advanced decay of plants that have a comparatively low resin content may actually be much more resinous, as the result of such concentration, than another peat of the xyloid type, composed largely of wood which, though relatively rich in resin, has undergone comparatively slight decay.

What is said above as to the genesis of peats may be affirmed also of lignites, subbituminous coals, and coals of higher grades, all of which are but lithified and altered peats.

In most coals, especially the woody types, the percentage in volume of the resin still resting in the original cells or vessels in a piece of wood is further relatively increased by the mere loss of moisture and the other cell contents, and by the contraction and collapse of the cell walls under pressure, with the attending chemical changes. The great reduction in volume thus produced in the wood is accompanied, in the low-rank coals, by no observed shrinkage of the "rosin"-like resins. In the xyloid lignites—that is, lignites consisting largely of undestroyed or but partly decayed fragments of trunks, branches, or twigs—the amounts of resin may be very little if the woods represented were originally not very resinous; but in some coals highly resinous woods have been so reduced without obliteration of the cells that the volumetric percentage of resin therein has been more than doubled.

EFFECTS OF RESIN CONCENTRATION.

It has often happened during the formation of thick deposits of peat in a swamp that the water has in places been for a time too deep to be occupied by vascular plants growing in place. In these pools, sometimes small and irregular in form, where the water was temporarily open and the supply of oxygen was greater, the decomposition of the vegetal débris falling into the water could, if the water was not too stagnant, go so far as to leave only great quantities of resinous matter mingled with spore and pollen exines, wax residues, and cuticles. The same condition could exist also beneath the ordinary shallow-water cover in portions of the swamp if the oxygen supply was sufficient and the rate of accession of fresh plant débris was not too great. Layers of such matter may be recognized in many coals, though usually they are thin and obscured by underlying or superimposed, more or less coarse vestigial matter. They form the "fatty" parts of the bed. When the deeper water body was restricted, steady, and sufficiently stagnant to preclude both the inwash of considerable mineral sediments and the complete destruction of the organic vestiges, and the spore, pollen, wax, and resin concentrate was therefore low in ash and comparatively unstratified, the resultant "sapropelic" deposit is canneloid—that is, it forms canneloid layers or lenses—in the lignites, and these layers or beds, when the lignites were changed to coals of subbituminous and higher ranks, became cannel coals and oil rocks, though the latter, being generally formed in water bodies of greater extent and supposedly carrying innumerable algæ of low orders, and containing more mineral matter, are usually high in ash. The origin of the cannel type of coal is, in its essential features, the same without regard to the geologic age of its formation or the rank of the fuel, though the mutual proportions of the characteristic components, exines and resins,[1] may vary from place to place and from epoch to epoch. The concentrated resins and the resinous and waxy exines of the pollen and spores, variously mingled with microplankton vegetal elements, impart to the coals of the cannel and oil-rock group their high volatile, high heating, and high illuminating qualities and their tendency to fuse, even if they are of low rank, the resins and waxes being characteristically rich in hydrogen, the element of greatest calorific value, and relatively low in oxygen, the great heat neutralizer [2] in coals. The canneloid coal is high in volatile matter merely because its component plant remains or products are not only high in volatile but resistantly so.

The relative percentages of hydrogen and oxygen in the waxes and resins, as compared with the percentages of those elements in wood, peat, and lignite, are shown in the following table:[3]

Analyses of wood, resin, coals, etc.

	C.	H.	O.	N.	Available hydrogen.	H:O.
1. Wood	49.31	6.29	a 44.20	(a)	0.77+	0.14+
2. Peat	55.65	6.48	36.43	1.44	1.93	.18
3. Dopplerite	56.46	5.48	a 38.06	(a)	.73+	....
4. Lignite	74.86	5.32	18.51	1.31	3.01	.29
5. Fossil resin	78.61	9.52	11.77	....	8.05	.81
6. Wax	80.33	13.07	6.6	....	12.25	1.98
7. Bituminous coal	82.91	5.70	9.90	1.49	4.46	.58
8. Bituminous coal	87.52	5.26	7.22	....	4.36	.73
9. Semibituminous coal	91.62	4.85	2.32	1.21	4.56	2.09
10. Cannel	84.52	7.67	7.81	....	6.69	.98
11. Torbanite	84.56	10.99	a 4.45	....	10.43+	2.46+

a Nitrogen included with oxygen.

1. Petersen and Schädler, Liebig's Annalen, vol. 17, p. 179, 1836. Average of 24 woods.
2. Roth, Justus, Allgemeine und chemische Geologie, vol. 2, p. 642. Average of 10 analyses.
3. Kaufmann, F. G., K.-k. geol. Reichsanstalt Jahrb., vol. 15, p. 283, 1885.
4. Clarke, F. W., The data of geochemistry, 2d ed.: U. S. Geol. Survey Bull. 491, p. 714, 1911. Average of 10 analyses.
5. Gies, W. J., Science, vol. 25, 1897, p. 462. Resin, Amboy (Cretaceous) clays, Staten Island, New York.
6. Cornuba wax.
7. Clarke, F. W., op. cit., p. 718. Average of 40 analyses of coals from Ohio, Indiana, Illinois, Iowa, and Missouri.
8. Bureau of Mines Bull. 22, Upper Cretaceous coal, coking coal, Sopris, Colo. Fixed carbon (in "pure coal"), 62.3 per cent.
9. Idem, Pocahontas coal, Elkhorn, W. Va. Fixed carbon (in "pure coal"), 85.75 per cent.
10. Idem, Lesley, Johnson County, Ky. Cannel coal.

It will readily be seen that the presence of resins and spore and pollen exines must have its effect on all coals, the result being more conspicuous when the proportion of cannel-forming elements is greater. A high hydrogen-oxygen ratio ("pure coal" basis) in a coal below the semianthracite rank is to be regarded as indicating a more distinctly "bituminous" type of coal, for the bitumens are especially characterized by their very high hydrogen and their correspondingly low oxygen content. In the latter respect certain waxes approach the bitumens even more closely than do the resins, as is indicated by the wax analysis in the table. In this connection mention should be made of Hatchett's conclusions,[4] reached in 1804, that the resins and waxes were the sources of the bituminous quality in coals.

[1] The term "resins" is here used in the broad sense, though in the descriptions of fossil specimens on later pages it signifies the characteristic "rosin"-like and amber-like resins.

[2] See White, David, The effect of oxygen in coal: U. S. Geol. Survey Bull. 382, 1909; Bureau of Mines Bull. 29, 1911.

[3] A larger series of ultimate analyses of coals of varying ranks may be found for comparison in the bulletins just cited and in Bureau of Mines Bull. 22.

[4] Hatchett, Charles, Roy. Soc. London Philos. Trans., 1804, p. 385; 1806, p. 109.

THE OBLITERATION OF THE RESINS.

It has been urged elsewhere [1] that it is important when discussing the origin of coal to recognize the operation of two great and fundamentally distinct processes or stages. The first process is the biochemical, which accomplishes the transformation of miscellaneous vegetal débris into peat. The second process, which follows or perhaps slightly overlaps the first, antedating the complete cessation of anaerobic bacterial action, is dynamo-chemical. Both processes are complex. Through the action of the dynamo-chemical agencies, apparently initiated and dominated in general by pressure but sometimes immediately controlled by contact-metamorphic heat, the peats have been transformed to lignites and coals of all higher ranks, being compressed, dehydrated, lithified, and partly devolatilized—that is, distilled. The progressive loss of volatile matter, which is still going on in most coals, is marked in particular by the elimination of oxygen in amounts relatively so much greater than the accompanying losses of carbon and hydrogen as to accomplish, in effect, a concentration of these two great fuel-producing elements that becomes more and more noticeable until the fuel approaches the anthracitic rank. The elimination of the oxygen permits a most important increase of the calorific value of the coal. The physical changes accompanying the dynamo-chemical process—that is, the effects of the pressure metamorphism—are found in the deformation of the plant remains, and the darkened color, reduction in volume, and increase of luster, jointing, friability, and even schistosity in the coal, as well as of cleavage and silicification in the surrounding strata.

The progress of the dynamo-chemical process is most conveniently gaged by the extent of the devolatilization (carbonization) of the fuel, as somewhat crudely determined by the conventional method of "approximate analysis" of the coal, the result being expressed in the ratios of the fixed carbon and volatile matter. Neither the initial organic chemical compounds nor those actually existing in any coal are fully known. The end product of the dynamo-chemical process is the approximate elimination of the volatile matter, the residue being graphite or, under conditions of intrusive contact, coke.

In the progressive transformation of peats, lignites, and subbituminous coals to fuels of higher rank, what becomes of the resins and waxes? For the answer to this question we are compelled, for the present, to depend largely on optical evidence.

The following observations relate, first, to the disappearance of the resins in the transformation of the Cretaceous and Tertiary coals. Later the question of the presence of resins in the coals of Paleozoic age will be considered.

Lump resins in widely varying amounts were found in all the lignites and subbituminous coals examined, though in many coals the pieces were very small. This is true of the xyloid lignites in the Fort Union Tertiary of North Dakota and Montana, the Cretaceous lignites of the Atlantic Coastal Plain, the Tertiary lignites of Arkansas and Texas, the subbituminous coals of the Cretaceous in the Denver Basin and in the Gallup district, New Mexico, the Eocene coals of the Cascade region of Washington, and the Cretaceous coals of the Hanna district of Wyoming. In all the coals of the lignitic and subbituminous ranks the resins have been found to retain the ordinary resin color, and apparently their other physical characteristics, although in some of the subbituminous coals the lumps show unmistakable effects of pressure, which has distorted them and here and there partly squeezed them into the joints of the bed. It is not probable, however, that the resins of these coals have remained wholly without chemical change from their original composition, notwithstanding their typically resinous appearance.

In the higher-rank coals—that is, in those grading through the lower bituminous ranks—the resins are found to have changed very greatly, having evidently undergone both physical and chemical alteration. This is shown in general, first, by the darkening of the color to a smoky brown; later, by the further blackening, crackling, and shrinkage of the lumps, which at a still later stage appear to be reduced to dark brownish-black spongy or granular residues, and still later, if the observations are correct, to a thin, fine, powdery black scale. The last state

[1] White, David, Econ. Geology, vol. 3, No. 4, p. 303, 1908; U. S. Geol. Survey Bull. 382, p. 62, 1909.

is difficult of recognition, and its correlation with the resin lumps is not without question. This change of the resins, which constitutes in effect a reduction (carbonization) of the substance, appears to have proceeded rapidly at a stage less than midway in the progress of the coals through the bituminous rank.

The behavior of the resins in the coals that are undergoing the somewhat advanced stages of dynamo-chemical alteration is suggestive of the action of recent resins when heated. In the highest ranks of the bituminous coals the resins are no longer recognizable as such to the unaided eye, and the identification of their residues in these fuels is at the present time wholly uncertain. They seem to have been practically obliterated, and the phenomena of their disappearance strongly suggest a mode of devolatilization under conditions favoring the retention of at least a part of their carbon in the coal. It is probably safe to infer that in the reduction of the resin, as well as in that of the other plant materials, the losses of oxygen are disproportionately large. The reduction of the resins appears to be coincident with a corresponding comparatively rapid deoxygenation of the coals themselves.

Without giving detailed observations regarding the fuels in the various coal fields, I will mention only a number of somewhat typical localities, where the successive stages in the alteration of resin may be well seen in the corresponding successive ranks of coal. It is understood that the "resins" here meant are the ordinary "rosin"-like or amber-like lumps. The rank of the coal will be, in a general way, shown by the accompanying percentage number, which indicates approximately the fixed carbon of the coal on the "pure coal" basis (ash, moisture, and sulphur free).[1] There is some variance in the degree of alteration in the resins at some mines and localities, just as there is variance (perhaps mutually corresponding) in the percentage of fixed carbon at the same points. These variations may be due to local differences in the stresses, to the advantageous position of the fuel at a certain point with reference to a fold, or even to the comparative resistance of the enveloping strata. The coals here discussed are all of Cretaceous or Tertiary age.

Among the subbituminous coals, in which the resins, though retaining their colors and general physical features, are more or less squeezed into the joints, especially in folded regions, mention may be made of the coals at Gallup, N. Mex.; Lafayette, Colo.; Renton and Centralia, Wash.; Red Lodge, Mont.; and the Sheridan and Hanna districts, Wyo.

In the low-rank bituminous coals the results of the dynamic influences are more evident, though there is but little visible evidence other than more advanced deformation and local discoloration. Thus the resins are generally more apt to be squeezed into the joints or along the bedding planes, in some places spreading out in large thin scales, although most of the lumps seem to retain their characteristic resinous aspect, in the low-rank bituminous coals of the Canon City field, Colo. (for example, Coal Creek, Radiant, or Fremont, averaging about 56 per cent fixed carbon); Shumway (55), Strong (56), Pictou and Walsenburg (58), in the Trinidad field, Colo.; Roslyn, Wash. (58); and New Castle (58), South Canyon (58), Black Diamond (59), and Sunlight (59), in the Glenwood Springs field, Colo. In some of these coals the lumps and scales of resin are in places turned more or less smoky brownish.

In the bituminous coals of slightly higher rank (fixed carbon averaging 60 per cent or a little higher) the resin lumps are not only deformed, being mostly flattened out as thin scales in the joints and bedding planes, but they have generally become of a dark sooty-brown color, most of them being more or less completely reduced to a brownish-black granular residue and some apparently to a mere black powdery film. The transitional stages from the smoky-brown or lighter-colored vitreous, conchoidal, semitransparent, and sometimes crackled lumps and scales to the reduced granular carbonaceous residues appear to be complete and abundantly illustrated. Examples of this later stage are found at Durango (Porter's), Colo. (61); the C. F. & I. mine at Crested Butte, Colo. (62); Carbonado, Wash. (62); Van Houten, N. Mex. (61); and Gulch, Colo. (63). In the coals of this rank (61 to 63 per cent fixed carbon in "pure coal") lumps retaining even

[1] These percentages, while probably fairly representative, are not to be regarded as showing with accuracy the average fixed carbon in the coal at the point mentioned. More exact estimates of the average percentages may be gained from the examination of the tables of analyses contained in Bulletin 22 of the Bureau of Mines.

in part the typical resin aspect are rarely to be found, though the very dark smoky-brown and largely reduced phases verging into the granular carbonaceous residues are seen at most of the localities mentioned.

In coals of a still higher rank the resins are apparently obliterated and no longer recognizable to the unaided eye. This is illustrated in the high-rank bituminous coals of Eocene age at Fairfax, Wash. (74); the Upper Cretaceous coal at Coal Basin, Colo. (76); the Eocene coal at Montezuma, Wash. (82); and the anthracites north of Crested Butte and at Floresta, Colo. In fact, I do not recall observing any material retaining megascopic resinous secretions in the high-rank bituminous coals (65 to 68 per cent fixed carbon) in the vicinity of Trinidad, Colo. (Sopris, Starkville, Cokedale, and Engleville), though carbonaceous traces, probably correctly identified as resin residues, are present. Fragments may, however, rarely be present here, especially in "bony" layers of the coal beds.

In certain of the coal fields where the alteration of the coals is regional the disappearance of the resin may be noticed in a restricted area, and even in a single very restricted coal group or possibly in a single bed, as, for example, in the Trinidad-Walsenburg-Raton field. In the Walsenburg district, at the northern end of this field, the low-rank bituminous coals of Upper Cretaceous age contain abundant resins, generally preserving their physical characteristics, though locally squeezed, but farther south along the same strata the resins are badly altered or apparently much reduced in the area of low-rank coking coal reached at Hastings and Berwind, about halfway to Trinidad, while still farther south, in the vicinity of Trinidad, the resins in the same coals are practically obliterated, the carbonaceous residues being seemingly lost in the finely jointed, granular high-grade coking coal. Other excellent areas for study are the Glenwood Springs coal field (also Upper Cretaceous) and the vicinity of Crested Butte, both in Colorado, where the regional differences in the fixed carbon are strongly marked. Another good region for observation is offered by the Tertiary coal areas of the Cascade field, in Washington.

My observations are less complete than is desirable and need confirmation. This may easily be accomplished by persistent and close field examination, which should take particularly into view also the precise stages of resin reduction corresponding to the respective stages of alteration in the coals themselves. However, the data now in hand appear to show that when the ordinary types (humic) of bituminous coals approach a rank roughly indicated by the development of 59 or 60 per cent of fixed carbon ("pure coal" basis), the megascopic resins contained therein reach a critical point, at which they begin rapidly to lose their resinous aspect and suffer reduction; and that before the coal has been carried by the dynamo-chemical process to 65 per cent fixed carbon the resin darkens, crackles, and shrivels, losing its characteristic features and apparently becoming reduced to a small coaly residue.

The period of marked alteration and reduction (carbonization) of the normal megascopic resins in the coals of Cretaceous and Tertiary age seems in general to coincide with that point in the devolatilization of the fuels which leads (other things being equal) to the development of the qualities essential to the production of high-standard commercial coke.

Whether the microscopic particles of resin still contained in the cells and canals of the plant or strewn about, freed by the decay of the surrounding tissues, on the ancient peat and mud layers have simultaneously undergone the same alteration and reduction as is observed in the readily visible lumps is yet to be determined by microscopical examination. It seems, however, fairly safe to assume that the internal resin secretions of the plants, which presumably are chemically identical with the wound resins, have similarly and contemporaneously suffered reduction and carbonization.

The typical coking quality, once developed, continues until the coal is carried approximately to the semianthracite rank, or, apparently, as long as sufficient volatile carbon and hydrogen remain in the fuel. Whether resins of any kind or any allied substances survive during this period remains to be determined. Their persistence, except as coalified residues, through the coals of semibituminous rank seems highly improbable. In this connection it will be remembered that the progressive deoxygenation of coals brought about by the dynamo-chemical processes results in the development in the higher bituminous ranks[1] of hydrogen-oxygen ratios (dry coal basis) similar to the ratios found in the resins. As already noted, the resins tend to impart a high hydrogen-oxygen ratio to the otherwise high-oxygen coals of the lower ranks, the highest ratios in these coals being found in the canneloid types. In the high-rank coals the high hydrogen-oxygen ratio necessary for successful and practicable coking is developed in the process of normal progressive devolatilization.

The period of coal alteration that is marked by the reduction of the resins appears to comprehend also a "deadening" of the cannel coals associated in the same groups of strata, as is to be expected. The apparent lack of cannel coals retaining their characteristic cannel qualities in the regions of semibituminous and higher-rank coals seems to be due to the reduction of the resins and other related canneloid elements. Beds or lenses, apparently deposited under cannel-forming conditions and probably once cannels, are present in the regions of semibituminous and anthracite coals, but though they retain a semblance to their original aspect and the massive conchoidal structure of cannels they have lost the special cannel qualities and are now often classed as "bone." I know of no occurrence of typical cannel coals or oil accumulations in formations and districts where the regional devolatilization of the coals has brought the humic coals to the rank characterized by 70 per cent of fixed carbon.

A question to be determined by chemical investigation is whether the reduction or carbonization (presumably a smothered devolatilization) of the resins has not aided in the deoxygenation of the remaining substance of the coal.

In areas like the Cascade coal field of Washington or the Glenwood Springs, Crested Butte, and Trinidad fields in Colorado, where in passing from one side of the field to another the coals are found to be progressively more and more altered through the dynamo-chemical process, there is no evidence whatever to serve as the basis for a belief that the plants growing in the district of low-rank coals differed essentially either in kinds or in resin content from those contributed to the original peat in the district of high-rank coals. The coals, some of which are practically continuous from area to area, are accompanied by similarly formed underclays, mostly containing roots in place, are similarly layered in benches apparently similarly composed, and are covered by shales or sandstones which, so far as observed, contain identical floras, thus showing approximate identity in the conditions of deposition of the fuel. It also must be remembered that the high-rank coals are similar in their mechanical constitution to those of low rank, containing fully as much woody matter, either in its jetlike condition of coalification or as "mineral charcoal," or, on the other hand, fully as much spore and vestigial material as the lower-rank coals in the same formation and basin. The progressive reduction (carbonization) of the cell walls, the dehydration of the remaining tissues, and the reduction of the resins or allied substances have naturally produced a decrease in the size of the wood fragments, but it is probable that the other material in the coal has suffered similar reduction, so that the proportions remain nearly the same. The progressively developed pressure cleavage, usually with more or less deformation, which on the whole becomes more and more evident in the more highly altered coals, not only tends to mask the texture of the woods, which are at the same time slightly reduced as the result of devolatilization, but tends in particular to crush and obliterate the mineral charcoal, which consequently contributes mainly to the dust and smut of the high-rank coal when it is mined and prepared for market. This is true also of the anthracites and other high-rank coals of the Paleozoic coal fields.

The observations as to the disappearance of the resins accord fully with the theory of the devolatilization (carbonization) of the coals as the result of thrust-pressure metamorphism, the coals being most altered, except in the vicinity of intrusives, where the pressure has been most intense and longest sustained, with variable but increasing strains.

[1] U. S. Geol. Survey Bull. 382, pp. 53, 54, 1909.

RESINS IN PALEOZOIC PLANTS AND COALS.

The preceding discussion concerns mainly the coals of the Cretaceous and Tertiary periods, in which resin-bearing types of vegetation are known to have been abundant, as is shown by the fossil remains, and which, wherever they have not been too far altered by the dynamo-chemical process, are conclusively shown to contain resins of various kinds in microscopic deposits if not in plainly visible aggregations. We pass now to the consideration of the Paleozoic coals, in which the original occurrence as well as the present existence of resins has generally been doubted.

Most geologists and chemists seem inclined to the belief that the great differences which are almost universally supposed to exist between the Paleozoic coals (the so-called "stone coals"), on the one hand, and the Tertiary and Cretaceous coals (generally taken for granted to be lignites or brown coals), on the other, are due mainly to differences in the composition of the plants contributed to the formation of the coal in each great era. Prominent if not chief among these assumed differences is the supposed absence of resins in the coal-forming vegetation of the more ancient periods. The fact that in the apparent absence of resins visible to the unaided eye the Paleozoic coals strongly contrast with the characteristic low-rank coals of the later epochs, in which resins are so commonly obvious or are at least nearly always to be found if sought, has seemed strongly to support this theory. The persistent adherence to this conclusion is, however, remarkable in view of the well-known occurrences in the younger formations of whole areas and groups of high-rank coals. Neither the ultimate nor the proximate analyses of the high-rank bituminous Tertiary and Cretaceous coals afford any criteria for a chemical distinction between these coals and those of the same rank but of Paleozoic age. This circumstance harmonizes with the fact, well known to those having wide knowledge of coals of different ages, that at least very many specimens representing the higher ranks of Tertiary or Mesozoic coals are indistinguishable, to the unaided eye, from similar specimens of Paleozoic coals of the same rank, the identity of bedding, lamination, jetty layers, charcoal layers, and woody or minute débris being so complete that only by paleobotanic examination can the age of the sample be detected. The plant materials originally forming the high-rank Cretaceous and Tertiary coals were not less resinous than those entering the coals of lower rank in the same geologic group and province.

The criteria which serve as the basis for the belief, on purely paleobotanic grounds, that resins and waxes were present in the peat-forming vegetation of the Carboniferous period may be summarized as follows:

1. The dominant types of the Carboniferous vegetation, such as the lycopods, ferns, Calamariales, Cycadofilices, and Cordaitales, though mostly of lower orders than the dominant types of the Cretaceous and Tertiary coal fields, are hardly inferior to the latter in magnitude nor in their highly developed organization, as is shown by the anatomical structure of petrified material representing many of the forms. A great number of the lycopods, Cycadofilices, and Calamites were not only trees in size but were also provided with exogenous woody trunks and cortical developments equaling in complication of structure the plants of the present day. The inference is reasonable and justifiable that the terrestrial vascular plants growing under similar environmental conditions in the different geologic epochs have been subject to the same vital principles, have carried on the same functions, and have been composed of similar plant compounds, and that they have accordingly contributed plant products, including carbohydrates, proteins, fats, oils, waxes, and resins, similar, if not essentially the same, both in variety and in chemical composition, in all the epochs of great coal formation. Evidence is also found in the presence of secretory canals and cells in the nearest living relatives of the ancient plants, and in the occurrence in certain cannel coals of microscopic bodies which, though untested chemically, have an aspect so resin-like as to lead to their interpretation as probably resins.

2. The microscopic studies carried on by Renault, Williamson, Scott, Zeiller, Seward, C. E. Bertrand, and others, of petrified fragments of Carboniferous plants, some of which occur silicified or calcified in the midst of the beds of coal, have revealed the presence, in most of the

Carboniferous vascular plant types, of canals and cells that have been interpreted as secretory, though few of them have been regarded with confidence as resin-containing and none seem to have offered criteria decisive as to this point. It is worth while in this place to cite some of the most important paleobotanic data bearing on the problem.

The Stigmaria roots which are so nearly omnipresent in the underclays of the Carboniferous coals and even in the layers of the coals themselves contain certain strands described [1] as "secretory." The Stigmaria are the roots of Sigillaria and Lepidodendron. It is therefore interesting to note the presence of secretory cells filled with dark-brown residues, associated with the transpiration tracts in the cortical tissues of Sigillaria [2] found silicified in the Permian at Autun, France. The structures are regarded by Renault as "gum cells with sheaths" and by Seward as "secretory strands." Seward [3] notes the occurrence in Lepidodendron of a secretory zone outside of the cylinder of secondary wood, embracing an "association of small cells, large spaces, and a certain amount of dark-colored material suggestive of tissue disorganization and secreted products." In the silicified material it is perhaps impossible to determine whether the residues noted in these fossil lycopods included resins.

Among the Paleozoic ferns numerous sacs supposed to have been of a "secretory nature" found in the inner zone of the cortex of the trunks of Zygopteris have been described by Scott,[4] and "gum canals" in Psaronius are pointed out by Zeiller.[5] The latter were the tree-fern trunks which bore the typical Pecopteris fronds so abundant and omnipresent in the higher coal measures.

In the Cycadofilices, which combine structures characteristic of the primitive gymnosperms, particularly the cycads, with others characteristic of ferns, especially the Marrattiaceæ, secretory structures have been observed in many types and are perhaps present throughout the group; thus Scott [6] notes that in Lyginodendron, the best-known type of the group, "sacs with dark contents, probably representing some kind of secretory organ, are frequent in all the soft tissues of the plant." The occurrence of secretory glands at the apices of the spines is characteristic of the fronds of this genus. In Ptychoxylon Renault [7] found in the outer cylinder of the cortex numerous elongated cells, many of them hypertrophied and filled with brown matter, "perhaps a gummy substance." The characters of the American material later to be described make it seem probable that these may be resin cells. "Numerous secretory canals much resembling the gum canals of recent cycads," and interpreted by both Renault [8] and Scott [9] as probably gum canals, are scattered throughout the thick cortical tissues of both the trunks and the petioles belonging to the genus Medullosa. To this genus probably pertain the petioles to be described later in this paper as containing a resinous substance. Secretory sacs or canals have been found also in the thick cortical tissues of Cycadoxylon and the Poroxylon type, and "gum canals" are reported as abundant and large in the hypodermal bands of Colpoxylon,[10] where they are sometimes filled with a brown substance thought to be possibly resin. Likewise Retinodendron, a type close to Cordaites, is said by Renault [11] to have abundant "resin tubes" and "secretory cells" in alternating zones of the cortex. The Cycadofilices embrace many of the commonest fernlike genera of the Carboniferous, including Neuropteris, Alethopteris, Odontopteris, Callipteris, Linopteris, and Mariopteris.

Especially interesting is the fact that Renault [12] observed in the branches of Arthropitus, a type supposed to be related to Calamites, many short longitudinal cells containing dark-colored bodies resembling resins, and many tubes interpreted by him as "gum reservoirs." The outer

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1 Seward, A. C., Fossil plants, vol. 2, pp. 158, 159, 1910.
2 Renault, Bernard, Bassin houiller et permien d'Autun et d'Épinac, vol. 4, Flore fossile, pt. 2, pp. 222, 224, Pl. XLI, figs. 9 and 10, 1896.
3 Op. cit., pp. 114, 145, 146, 168, fig. 183.
4 Scott, D. H., Studies in fossil botany, 2d ed., vol. 1, p. 315, 1908.
5 Zeiller, René, Bassin houiller et permien d'Autun et d'Épinac, vol. 1, Flore fossile, pt. 1, Pl. XXI, 1890.
6 Op. cit., p. 368.
7 Op. cit., p. 322.
8 Idem, p. 295, Pl. LXX, figs. 1 and 2.
9 Op. cit., pp. 434, 437.
10 Renault, Bernard, op. cit., Pl. LXVIII, figs. 2 and 7; p. 203.
11 Idem, Pl. LXXVII, figs. 10, 13, 14.
12 Idem, Pl. XLVII, figs. 2, 3; Pl. XLVIII, fig. 2; Pl. LV, figs. 6, 7; Pl. LVI, figs. 6, 7; p. 91.

fleshy coats of the seeds of Cordaites are provided with canals which have been supposed to be intended for the storage of gum or tannin, and the parenchyma of the primary cortex of the trunks of the tree is said to envelop secretory sacs.

Mention should be made of the large canals and reservoirs and of unequal rounded granular bodies in the cortex of Hapaloxylon; of supposed gum cells near the nerve strands in Calamodendron and Dolerophyllum; and particularly of the occurrence of wood cells containing products regarded by Renault [1] as resinous, and of groups of cells full of "resin" in the large pith of the stems of Cedroxylon.

Finally it is important to note the occurrence, as described by both Renault [2] and Zeiller,[3] of numerous "gum tubes" filled with dark residues, associated with the sclerenchymatous hypodermal strands of the petioles known as Myelopteris and Myeloxylon. The suggestion that these canals are possibly resin-bearing appears to be fully justified, as will be pointed out in the description of carbonized remains from Montana, possibly belonging to the same genus. Before passing from the subject, it should be noted that the spore exines of the Paleozoic pteridophytes are generally believed, for good reasons, to have been protected by waxy, resinous, or gummy coverings like those of their living successors.

Many of the structures noted above are very likely mucilage or gum receptacles, but it is highly probable that some, at least, of the types were resin-secreting, and there is little doubt that they would have been so interpreted by paleobotanists had the occurrence of lump resins in the Carboniferous coals been fully recognized.

For many years I have observed in most of the Paleozoic coals of moderate or low bituminous rank the presence of great numbers of slender, rigid, glossy, cylindrical, needle-like rods of varying sizes, longitudinally embedded in very many of the fragments of mineral charcoal ("mother of coal"). Such carbonized fragments of wood are especially abundant in the Carboniferous coals of the interior basins, in places forming layers of considerable thickness. The slender rods, varying in diameter apparently according to the kind of tree, protrude from the macerated edges of the wood like the ends of broken needles. When examined closely they are found to be discontinuous. (See Pl. XI, fig. 4.) Even when the surrounding tracheids or wood cells did not completely decay away during the process of peat formation so as to expose them or leave them isolated, the collapse and reduction of the wood when partly macerated and under pressure was so complete and the wasted cell walls are so closely flattened that the slender parallel rods produce ridges where they lie near the surface of the "charcoal" fragments, which are usually reduced to a thin scale.

A typical example of a fragment of a compressed stem preserved as "mineral charcoal," from coal "No. 2," near Gerlaw, in western Illinois, is shown in figure 1, Plate IX. This fragment, which is split along the bedding plane, is but a portion of large piece of carbonized wood over 2 feet in length and several inches in width, lying in the midst of a well-laminated coal. Under the lens the very slender needle-like or rodlike casts are seen lying on or partly freed in the longitudinal grain of the wood. Many of the casts come very obliquely to the surface, and some are exposed for long distances. Others appear only as ridges in the "charcoal" scale to which the surrounding collapsed, softened, and wasted woody tissues were reduced. Numerous broken fragments of isolated casts lie strewn among vestiges of cuticles and other comminuted vegetal débris on the right, as may clearly be seen under the lens. A clearer presentation of the needle-like rods contained in this fragment of flattened carbonized wood is given in the four times enlarged figure of a portion of the same specimen (Pl. XI, fig. 4). In the inspection of this and the other figured examples of a common type of mineral charcoal the following points should be noted: (1) The needle-like rods lie in their original position in and parallel to the grain (tracheids) of the log; (2) they were hard and terete before the partial maceration of the surrounding wood cells, or, conversely, the tracheids collapsed and rotted away, while the rods were hard and resistant to pressure; (3) they were resistant to the bio-

[1] Op. cit., p. 368.
[2] Renault, Bernard, Acad. sci. Paris Mém. sav. étrang., vol. 22, No. 10, p. 17, Pl. V, fig. 40, 1875.
[3] Op. cit., p. 284, Pl. XXVII.

chemical agencies of decay, which liberated great numbers of them to be washed or strewn about on the mud or peat surfaces; and (4) they appear to have largely retained their form and their rigid though fragile character, while the peat has been altered by the dynamo-chemical process to coal of bituminous rank. These features leave no room for doubt that the rods are in fact but the casts or fillings of canals longitudinally traversing the tissues of the woods and petioles of some of the coal-forming plants. Their rigidity when existing in the fresh vegetation points to their nature as hard, brittle resins, gums, or waxes, but their resistance to the agents of decay and to the dynamic action argues against the interpretation of them as gums, while their mode of occurrence in internal canals points most strongly to their being resins instead of waxes.

The aspect and mode of occurrence of the fragments of carbonized wood ("mineral charcoal") so common on the bedding planes of coal is well shown in the piece of bituminous coal from the midst of the bed mined near Exeter, Ill., illustrated in figure 2, Plate IX. In this fragment, a part of which is shown enlarged four diameters in Plate X, the vessel casts, though of a type more slender than in the other specimen, are distinct. In some of the "charcoal"[1] fragments, like that in the upper left corner of the photograph, which nearly cover the bedding plane of the specimen, the fracture is closely parallel to the grain; but several of the other pieces are either macerated or abraded obliquely to the grain, so that the vessel casts protrude from the worn ends. It will be noticed further that many segments of the casts, completely released by decay of the wood, lie scattered here and there like fragments of broken needles. Some of them are but slightly moved from their original attitude as they were left by the decay of the surrounding tissues. Most of the large wood fragments on this piece of coal contain the needle-like vessel casts, though vestiges of wood in which none are seen are also present here, as in very many specimens and in most coals. It is probable that in the older peat swamps, just as in those of to-day, the resinous woods were more resistant to decay than the other types and therefore more likely to escape decomposition.

Many specimens are found in which the decay of the wood has been practically complete, so as to free the casts entirely. A good example of such isolated and broken casts is shown in figure 3, Plate IX, and four times enlarged in Plate XII. In this fragment, from a thin bony layer in the coal at Colchester, Ill., the rods are mingled with comparatively small numbers of large megaspore exines, minute fragments of cuticles, and scattered remains of the resinous or waxy, very resistant envelopes of certain seeds, particularly Cardiocarpon, two of which are present on the fragment illustrated. The casts, which vary in diameter and probably belong to several species of plants, at first glance suggest sponge spicules, but their ready combustibility betrays their vegetal origin. The specimen illustrated, which is about a quarter of an inch in thickness, is somewhat minutely laminated, some of the laminæ containing extremely thin layers of nearly amorphous carbonaceous silt. Between some of these laminæ are thin lenses and streaks of jetlike wood, all very much flattened. The layer here represented contains, as already explained (p. 68), much cannel-forming material, though the lamination with fine mineral sediment and stems gives it a "bony" character.

Carbonized wood fragments containing terete, brittle, decay-resistant vessel fillings, such as those shown in the accompanying plates, are abundant in most Paleozoic coals, at least in the interior basins of the United States, except where they are too far altered by dynamo-chemical agencies. A slight curvation sometimes noted possibly indicates a degree of elasticity or toughness in the original substance, but a degree of fragility in these fillings is shown by the ready fracture of the casts isolated by the decay of the rest of the tissues in the waters of the peat-forming swamp. That the contents of the canals were hard and round when the fresh wood fell to the surface of the swamp is shown by the maintenance of their tereteness while the surrounding tissues were undergoing maceration and deformation in the peat. Their free combustion, apparently with high volatile matter, plainly shows that they were not produced by occupation of the vessels by fine silts or other inorganic mineral matter. Their hardness

[1] In another place (Bureau of Mines Bull. 38, 1913) I urge that these "mineral charcoal" fragments are not cinders nor fragments, charred by burning at the surface of the swamp.

and moderate rigidity at the time the woods decayed show, on the other hand, that they can not be merely hardened organic solutions occupying the canals after the woods became immersed in the swamp; otherwise they would have suffered deformation or perhaps would have again entered solution when freed from the rotting tissue. The waste of the cell walls on account of chemical reduction and the collapse of the partly macerated cells under pressure to a thickness of one-fifth to one-fifteenth, or possibly less, of their original diameter bring the rods into prominence, even where they are not actually exposed at the surface of the carbonized wood, now generally reduced to a thin scale. In this way the cast material is effectually concentrated.

A close examination of the casts under low magnification shows that they resemble very dark brown or slightly orange-brown vulcanized rubber, the fracture being conchoidal and somewhat vitreous. Under stronger magnification the casts are found to be composed of an orange-russet or more or less yellowish semitranslucent substance. Cross sections, rounded or oval in form, of amber-like substance, similar to and probably identical with those composing the casts, are to be observed in thinly ground sections of coals from the same group, prepared and described by Thiessen,[1] and are regarded by him as probably transverse or oblique sections of resin vessel casts.

The cannel coals from the basal coal measures of Missouri and from the upper Pottsville in eastern Kentucky, examined by Thiessen, contain, in addition to the usual varied spore exines, numerous small irregular lumps of highly refractive substances slightly varying in their orange or yellow tones, which are interpreted by him, rightly, I believe, as resins. It will also be noted that in a recent important paper on the explosive elements in coals James Lomax[2] has described the occurrence of several microscopic bodies which, on account of their form and aspect, he regards as resins.

As in the Cretaceous and Tertiary coals the resins have persisted in form recognizable as resins until the coals have advanced some distance into the bituminous rank, it follows that remains of resins, if they were ever present and if they were similarly resistant to the biochemical agencies of coal formation, should similarly be found in Paleozoic bituminous coals of the same rank.

Accordingly they should be present in such Paleozoic coals as those of western Illinois, Iowa, and western Missouri. In 1908, immediately after an examination of the coals in several of the western coal fields, I was engaged in the eastern interior coal fields, where the comparatively low rank of the Paleozoic coals seemed favorable for resin survival. As a result of a close inspection, resin in small lumps was found in the coal at several of the comparatively few mines visited.

Lump resin was found in a dense, hard, bony layer in which very little woody matter was visible and the canneloid concentrates were mingled with a large percentage of mineral sediments at the Rutledge mine, a few miles northwest of Ottumwa, Iowa. At the La Salle shaft, in the eastern edge of La Salle, on the northern border of the Illinois coal field, the coal derived from bed "No. 2" (the bed from which the wood shown in fig. 1, Pl. IX, was taken) reveals a few small fragments of resin. One of these is shown, five times enlarged, in Plate XI, figure 1. The same block, about 5 inches in cube, of typical laminated bituminous coal, shows at different levels two other fragments of resin, one of which, exposed on the "butt" of the coal, is seen similarly enlarged in figure 3 of the same plate.

During a casual examination of the coal of upper Pottsville age at a small mine in one of the lower block coals near Brazil, Ind., the small but somewhat conspicuous fragment of resin shown five times enlarged in figure 2, Plate XI, was observed. It will be noted that the resin in this specimen, which comes from the midst of the bed, has been squeezed along both the bedding and the joint planes, so that its cross section has a "step" structure. A vertical joint just to the left of the resin lump is indicated in the illustration by the filling of narrow "white

[1] White, David, and Thiessen, Reinhardt, The origin of coal: Bureau of Mines Bull. 38, 1913.
[2] Inst. Min. Eng. [London] Trans., vol. 42, p. 2, 1911.

scale," whose irregular line in the photograph is due to the uneven fracture of the coal and the obliquity of the view. The opening of the joint and the deposition of the salts are probably of late date, while the deformation of the resin, which is squeezed along the bedding and vertical joint planes, probably dates from the post-Paleozoic uplift. The deformation of the resin is exactly comparable to that so familiar in the high-rank subbituminous and lower-rank bituminous coals of Cretaceous age in the western United States.

In all the specimens noted in the Paleozoic coal fields in the upper Mississippi Valley the substance retains its russet-amber, vitreous, translucent, resinous aspect, appearing exactly like some of the resins in the younger coals. One of the fragments from La Salle is slightly yellowish, granular, and more opaque than the others in the same fragment of coal. Another is somewhat irregularly pitted or hollowed, as is indistinctly shown in figure 1, Plate XI. The resin lumps in these coals are friable and have a conchoidal fracture. Fragments from the Indiana specimen illustrated in figure 2, Plate XI, when burned on the platinum spoon by Chase Palmer, of the Geological Survey, were found to fuse readily, gradually turning brown, while emitting resinous odors. At higher temperatures they became dark and pitchy, emitting resin fumes before bursting into a light-yellow flame. A trace of grayish ash remained on the platinum after combustion. A very small quantity of this resin examined by David T. Day was found to be hardly soluble in alcohol, though it was partly dissolved in chloroform.

As already remarked, no systematic search for resin in the Paleozoic coals of the eastern interior basin or any other Paleozoic region has been made. It is probable, however, that resins will be found to be widespread in those Paleozoic coals that are not too far altered, in accordance with the observations of the Tertiary and Cretaceous coals of corresponding rank. The amount of wound or surface-exudate resin secreted by the Paleozoic plant types appears to have been small compared with that secreted by the later plants, but it is probable that the Paleozoic plants had ample canal storage.

Regarding the probably resinous nature of the canal casts so abundant in many of the carbonized woods in the Paleozoic bituminous coals of the interior fields, as described and illustrated on previous pages, I have recently learned of criteria of a novel and interesting character.

The occurrence of Paleozoic fossil plants on Big Spring Creek, 20 miles southeast of Lewiston, Mont., having been reported, specimens were, at my request, gathered in 1911 by Dr. A. C. Peale, of the United States National Museum, with whom was associated Mr. A. C. Silberling. The material collected was found on examination to consist mostly of the remnants of very badly macerated fragments of ferns, lycopods, and Calamariæ, carbonized and confusedly mingled with sufficient extremely fine gray argillaceous silt not only to destroy its value as coal, but even to impart to some of the layers a soiled, dark, sooty gray color. Though petioles of several types are abundant in this material, no filicoid pinnules are distinguishable, they having apparently disappeared by decay. Carbonized stem fragments of Sphenophyllum, Asterophyllites, Calamites, and Lepidodendron are mingled with megaspore exines, sporangia, and seed coats of Cardiocarpon.

The strata of this vicinity are said by W. R. Calvert, who in 1911 made a reconnaissance examination of the geology of this part of Montana, to belong to the upper part of the Quadrant formation, the geologic age of which has been questioned. Numerous petioles, exhibiting the characteristic superficial features of *Sphenopteris* (*Lyginodendron*) *hoeninghausii*, associated with *Lepidodendron obovatum* in the collection show that at least this part of the Quadrant formation is of Pottsville (Westphalian) age.

On examining the fossils from Big Spring Creek I was greatly astonished to see flat bunches of parallel, flexible, threadlike fibrils, suggesting the raveled edge of some textile fabric, protruding from the edges of the rock and from the ends of some of the carbonized plant fragments. A close examination of these singular fibrils showed them to issue from the ends of carbonized fragments of certain narrow, slender stems or petioles, apparently of a filicoid type, that were most abundant in the coaly shale. The scalelike coaly residues of these petioles (as I prefer to regard them) are longitudinally traversed by the parallel fibrils, which are completely enveloped by the carbon, though between many of the fibrils the carbon, representing the remaining undestroyed substance of the petiole, is thinner than the diameter of a fibril; consequently the fibrils produce prominent ridges in the carbon. On account of the hardness and tenacity of the fibrils, they may not only be readily stripped from the carbonaceous matrix but some of them may be pulled in segments of considerable length from the broken edges of the shale. Segments over 8 centimeters in length may be obtained without great difficulty. The aspect and mode of occurrence of these most interesting features can, however, be best comprehended on examining the accompanying illustrations.

In the small fragment photographed natural size shown in figure 1, Plate XIII, is seen the carbonized residue of a petiole transversely crossing the shale fragment. The petiole evidently was much macerated and is now flattened to a very thin layer, less than 0.3 millimeter thick, of glistening black, imperfectly cubical but quite friable coal. This is longitudinally traversed by the parallel fibers, whose continuity and strength have enabled them to tear a part of the petiole, on the left, from the adjoining shale. This part of the petiole is now held suspended by the fibrils, which are still "in place." The appearance of the specimen is better shown in figure 1, Plate XIV, photographed twice the natural size. Obviously we have here the homologue of the needle-like casts of the canals already described as occurring in the flattened and reduced carbonized woods from the coals of the Mississippi Valley. However, in the Montana material, which is less altered, the fibrils are still somewhat flexible and tough. When the canal fillings are isolated the adhering fragments of coal and shale may be mostly removed by careful crushing or rubbing between the fingers, leaving the dark, threadlike casts free, whereupon, if long and unsupported, they are apt to droop slightly by their own weight, as shown in figure 3, Plate XIII, and figure 2, Plate XIV.

The parallelism and regularity of the canal casts and their relation to the carbonized residues, which often lie compactly superposed in varying directions, are better seen in figure 2, Plate XIII, which represents a thin layer of the shaly bone. Examination of the photographic enlargement of a part of the same specimen, shown in figure 3, Plate XIV, shows the casts to be nearly cylindrical, though slightly variable in cross section. Notwithstanding a degree of flexibility (see fig. 3, Pl. XIII), which enables the threadlike casts to be bent and twisted to a certain extent, and a toughness which enables one actually to pull them out to the edges of the shaly bone (so friable is the environing coaly scale), they are brittle, usually fracturing squarely, though minutely conchoidal. In many specimens the fragments of carbonaceous shale are, when broken, held together by the canal casts, as illustrated in figure 2, Plate XIV. In most of the petioles the maceration and decay of the plant tissues at the time of their deposition in the muddy water of the swamp were not so complete as to leave the casts without support. In other fragments, however, as illustrated in figure 4, Plate XIV, the decay extended to more resistant cortical tissues, so that the casts were left free and unsupported within the sheath maintained by the cuticle. This is shown not only by the nearly complete absence of environing coaly residue, but also by the lax, irregular attitudes of the released fillings of the canals, which curve and overlap in slight confusion, although their general longitudinal direction is preserved. Frequently the casts were entirely freed by the decay of the stems or petioles, so that they are left isolated and drifted about in various positions, as is shown in portions of the same figure. It is to be noted that the isolated and probably slightly drifted casts were at the time of the deposition of the plant débris so brittle that they were broken into fragments comparable to those of the isolated rods seen in the coals of Illinois, Iowa, Missouri, and Indiana, though in the Montana specimens they seem to have been slightly less friable and more flexible and are usually found in greater lengths where isolated and tangled in the surrounding clay or débris.

Like the secretions from the coals of the Mississippi Valley already described, the Montana rods appear amorphous, to the naked eye resembling vulcanized rubber. When freed from the surrounding carbon or adhering clay by gentle rubbing between the fingers or by treatment in hot nitric acid, the isolated threads may be manipulated with ease and mounted for examination under the microscope. They are then found to be composed of a russet-yellow, semi-translucent substance resembling resin. The thinner sections presented by the more slender threads approach an orange-yellow. It is to be noted also that many of the canals were, for apparently short distances, not completely filled by the substance, which seems to have been deposited on the walls so as to form a hollow cylinder. Some of the cylinders were crushed or caved in on one side. The attempt to discern the configuration of the contact cells forming the walls of the vessel has not yet been wholly successful, though some of the rods have the aspect of having been bounded by longitudinally short, small cells, roughly quadrilateral in outline. The evidence, so far as it goes, points, therefore, to the typical canal structure for the container of the resin-like secretion.

As previously noted, the canals varied considerably in diameter, some of the plants having comparatively large rods like those shown in figure 2, Plate XIII, and figure 3, Plate XIV, while in others, such as are seen in figure 1, Plate XIII, the rods are relatively slender. Some difference in size is to be observed even in the fibrils lying in a single petiole. In this connection it may be remarked that similar differences may be noted in the Myelopteris petioles described by Renault and Zeiller, previously mentioned.

The examination of the Montana material leaves scarcely room for doubt that it is of the same general nature as the secretions filling the canals in the carbonized woods or freed as needle-like fragments in the vegetable débris or carbonaceous muds of the Illinois coal field. It will have been noted that in both regions the fillings or rods were evidently approximately cylindrical in form and of nearly uniform diameter throughout great lengths; that most of them were hard enough successfully to resist the pressure of overlying vegetable débris and muds, not only during the peat-forming process, but also during later periods; that they appear to have been largely if not completely resistant to the biochemical processes which accomplished the partial decomposition and transformation of the vegetal débris into peat; and that they have survived the subsequent dynamic and chemical agencies which transformed the original peaty substance into a cubical laminated coal of low bituminous rank. The conditions of their release from the freshly rotting stems and petioles in the water of the peat-forming swamps and the mode of their deposition in the peat absolutely preclude all hypotheses explaining their origin as infiltrations of vessels or canals subsequent to the burial of the stems in the peat.

The isolated rods ignite readily and burn freely with a bright-yellow flame and a moderate amount of smoke in the open air, leaving a small amount of dark-gray residue. Small quantities of the threads, after isolation and such imperfect cleaning as could be given by moderate rubbing between the fingers, were, through the courtesy of Mr. J. D. Davis, of the Bureau of Mines, subjected by him to ultimate analysis, with the following result:

Analysis of resinous vessel casts from Montana.

C	72.69
H	8.85
O	13.61
Ash	4.85
Ash-free:	
C	76.40
H	9.30
O	14.30

It is probable that the ash of the sample is slightly high on account of the method of cleaning, which possibly also affected the other percentages to a slight extent, though presumably in no important way. Mr. Davis states that very little of the substance has been dissolved by acetone during about five months. The analysis of the Montana resinoid secretions may profitably be compared with some of the analyses given on page 68. It is particularly comparable to the analysis of the lump resins from the Upper Cretaceous coals in northern New Mexico, described by Loew[1] as wheelerite.

[1] Loew, Oscar, Am. Jour. Sci., 3d ser., vol. 7, p. 571, 1874. Specimens probably from the Cretaceous of northwestern New Mexico.

Analysis of wheelerite from New Mexico.

C	73. 07
H	7. 95
O	18. 98

The highly "bituminous" character of the Montana Paleozoic material is conspicuously shown by its high "available" hydrogen ($H-\frac{O}{8}=7.5$ per cent) and its high hydrogen-oxygen ratio of 0.65, which, in a coal of the ordinary humic type, should place it within the coking class.[1] Obviously the effect of the presence of great numbers of these rods in a coal must be to "bituminize" it; to provide a high percentage of volatile matter; to impart a high calorific value to it; and, similarly, through the presence of so much hydrogen probably, to make the volatile highly illuminant. The rods are excellent cannel-forming ingredient matter.

In view of (1) the mode of occurrence of the secretions inclosed in the canals of the petioles and carbonized woods, as well as free in both the Montana and the eastern interior coal measures, (2) their resistance to the agencies of decay, (3) their aspect and state of preservation, (4) the microscopic characters of the substance composing the casts and its optical similarity to resin, (5) the close agreement, according to the chemical analysis, with the resins, and (6) the ascertained presence of lump resin in the Carboniferous coals of the upper Mississippi Valley, I have had little hesitation in regarding all these substances as resins, though not necessarily as identical resins. Not only is the Montana substance itself resin-like, but its mode of occurrence is a common mode of resin secretion in the plants of to-day. That it may be a gum seemed improbable, largely on account of its resistance to the agencies of alteration.

Feeling, however, that the Montana material, which is somewhat tougher and more elastic than the secretions found in the eastern coals (though it may not always have been so), might represent an unusual mode of occurrence of a resin-like wax rather than a typical resin, I submitted samples of the casts to Dr. C. L. Alsberg, then of the Bureau of Plant Industry in the Department of Agriculture, whose broad interest in problems of this kind and whose friendly courtesy prompted him to investigate the substance of the rods as thoroughly as the circumstances would permit. Dr. Alsberg's preliminary conclusion is that the substance from Montana is probably resinous. He says:

The fibrils were carefully separated from the matrix and freed from the latter as much as possible by rubbing between the fingers and by brushing with a camel's-hair brush. They were apparently insoluble in cold and hot water, in cold and hot alcohol, in chloroform, toluene, benzol, and boiling concentrated hydrochloric acid. Hot concentrated sulphuric acid caused them to disintegrate into many smaller fibrils without much charring. Hot 10 per cent potassium hydroxide caused the fibrils to swell somewhat, to soften, and, to a slight extent, to dissolve. Boiling with concentrated nitric acid caused rapid solution of the black outer layer, with evolution of gas, leaving a reddish, transparent, soft core. When cold this core became hard and flexible again. After the black coating had been dissolved by the nitric acid, the core apparently resisted further attack by the acid.

Thereupon 0.5537 gram was boiled with 95 per cent alcohol under a reflex condenser for several days. The material extracted weighed less than a milligram. The extraction was repeated with chloroform, which extracted but 2 milligrams. Then toluene was tried, yielding 1.2 centigrams of extracted material.

Since so little of the material was soluble in these organic solvents it was treated with concentrated hot nitric acid till the black outer layer was removed. It was then washed with water till all the acid was removed and dried. It was next extracted with ether under the reflex condenser. A small amount passed into solution. The extraction was repeated until no more was dissolved. It was then extracted in the same manner with chloroform; but only traces of material were dissolved in the course of several days. Thereupon the material was extracted with alcohol, which dissolved appreciable quantities. In the course of several weeks the boiling alcohol extracted about one-third of the material. After the alcohol extracted nothing more, the extraction was continued with toluene, which extracted a small amount. The residue which remained was partially soluble in a concentrated solution of chlorohydrate.

The different fractions into which the material was separated by these solvents are being investigated chemically. It is hoped that further data may in the future be published. At present from the data at hand it is possible to say that the indications are that the material is of a resinous nature. The solubilities point in this direction. Very few other substances have such solubilities. The solubility in chlorohydrate is particularly significant.

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[1] Bureau of Mines Bull. 29, p. 52, 1911.

CONCLUSIONS.

From the criteria reviewed it appears that at least a large part of the petioles and trunks of the Carboniferous coal-forming types of vegetation were provided, as described by several paleobotanists from petrified specimens, with numerous secretory canals and cells, in many of which residues, generally interpreted as gums but often suggesting resins and waxes, may still be seen. In the preceding pages evidence has been presented showing not only the presence of lump or exudate resins in Paleozoic coals of a somewhat low bituminous rank, but also the occurrence in these coals of great quantities of wood and petioles traversed by canals largely if not completely filled with secretions, whose mode of occurrence, optical characters, chemical composition, and resistance to decay under the conditions of coal formation seem to combine in proof of their resinous nature. These canal secretions were not only largely resistant to the biochemical processes of peat formation but they have withstood (though probably not without some chemical change) the ordinary dynamo-chemical processes of peat transformation, probably except contact metamorphism, until the coals attained at least a low bituminous rank. Their abundance in Paleozoic coals of this or lower ranks may readily be confirmed on close examination.

These resinous fillings have, as a result of the partial dehydration, the progressive chemical waste or reduction, and the pressure collapse of the environing undecayed plant tissues, been, in effect, concentrated in the coals, so that their proportionate volume is much increased even in the undestroyed wood. A great concentration results from the more advanced decay of the other plant tissues, so that the resinous rods or bodies are either separated only by extremely thin carbon residues representing the remaining portions of the plant, or they are completely freed and isolated and so permitted to lodge and accumulate, frequently in contact, in relatively large quantities. Such isolated resin fragments form a permanent and considerable ingredient of the coals of the cannel type, in some localities contributing largely to their physical and chemical qualities; and they are particularly characteristic of the canneloid fuels of the Cretaceous and Tertiary coal fields.

The amount of the wood and petioles probably containing resin found in the Paleozoic coal measures, both at the Montana locality and in the upper Mississippi Valley, justifies the conclusion that the quantity of resin contributed by the coal-forming plants and preserved either in place in the wood or as accumulations (concentrates) in various layers of the coal may, on the whole, have been as great in the Paleozoic era as in later epochs. Though the Paleozoic resins were probably secreted in lump or exudate form far less than the resins of the plants, especially the conifers, of the later formations, they were, I am inclined to believe, as important as contributions to the coal. Furthermore, it will be remembered that the aspect of the spore and pollen exines found in the coal, the characteristic features of the chemical analyses of the coal, and the fact that the exines have physically so far survived the decomposing agencies appear amply to sustain the belief that in both the Paleozoic and the Mesozoic plants the exines were, like their modern representatives, provided with protective wax, resin, and gum secretions. The amount of resinous and waxy material contributed by the highly varied and incredibly numerous spores in the Carboniferous coals was in itself undoubtedly large; and where, as in the cannel coals, such spores compose a large part of the fuel body, the resinous material, perhaps as much as the waxes, has produced the peculiar commercial and chemical qualities which characterize the coals of the cannel type. In this connection it may be remarked that some of the pinnules of cycadofilic types—such, for example, as *Neuropteris flexuosa* of the upper Pottsville or *Neuropteris gigantea* of the middle Pottsville—were probably provided with waxy coverings analogous to those borne by many leaves among living plants.

It is probable that in the Paleozoic as well as in the Cenozoic era many among the coal-forming species were not resin-producing, for many of the associated wood and petiole fragments found in the coal show no megascopic indications of such secretions. In the Montana material the resinous threads seem to be confined to petioles or slender stems, which, from the differences in the sizes of the canals, were presumably of more than one genus and species. At the Montana locality the resin-bearing plants, whether or not of several kinds, were very abundant, probably forming the larger part of the arborescent material contributed to the coaly shales at certain levels. There is reason to believe that in the Paleozoic, as in the later epochs, the resins produced by different plants varied in composition and qualities.

The evidence offered by the American material makes it seem not improbable that the dark-brown residues found in the canals of the silicified material from the French Permian also is resinous, as was suggested by Renault and Zeiller. The unquestionable presence of lump resin in the Paleozoic coals of the upper Mississippi Valley argues strongly also for the resinous nature of the dark contents of the secretory cells and canals of some of the other plants found petrified in the Carboniferous of Europe.[1]

The analogies to be drawn from the deformation, discoloration, alteration, and reduction (carbonization, involving loss of volatile) of the megascopic resin lumps as the coals of the Cretaceous and Tertiary in Colorado and Washington were brought from the lower-bituminous to the higher-bituminous ranks appear to offer a reasonable explanation for the failure hitherto to observe lump resin in the higher-rank bituminous coals of the Appalachian trough and for the probable absence of canal resin casts in the semibituminous coals of the same province. The question as to the extent of their survival (without doubt they were once present) in the areas of high-rank coal remains to be determined by observation, though it is probable that they are present in some of the lower-rank coals having a fixed carbon ("pure coal" basis) of less than 58 or 55 per cent in the western portion of the great Allegheny coal field.

A question which appears to deserve careful consideration is, What relation, if any, may the alteration or transformation (natural distillation) of these high-hydrogen and high-volatile fusible elements of the coals which appears to take place in a critical period (limited in round terms by the passage from 58 to 65 per cent of fixed carbon in "pure coal"), as the fuels are being brought by the dynamo-chemical agencies to the state of fitness, other things being equal, for the production of high-grade coke by the ordinary process, bear to the development of the coking quality itself in the coals?

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[1] The superficial aspect of the Montana petioles, the characters of their finely striated cuticles, and their mode of branching strongly suggest the petioles of Alethopteris and Neuropteris, to which I believe them probably to have belonged. The slightly irregular but generally parallel longitudinal lineation of the carbonized residues was presumably produced by hypodermal strands of thick-walled and slightly more resistant tissue, distributed mainly in a subperipheral zone. The secretory canals were most probably associated with such hypodermal strands, very much or perhaps identically as in the petrified stems described by Renault (Acad. sci. Paris Mém. sav. étrang., vol. 22, No. 10, p. 17, Pl. V, fig. 40, 1875) and Zeiller (Bassin houiller et permien d'Autun et d'Épinac, vol. 1, Flore fossile, pt. 1, Pl. XXVII, fig. 2, 1890) as Myelopteris and Myeloxylon.

PLATE IX.

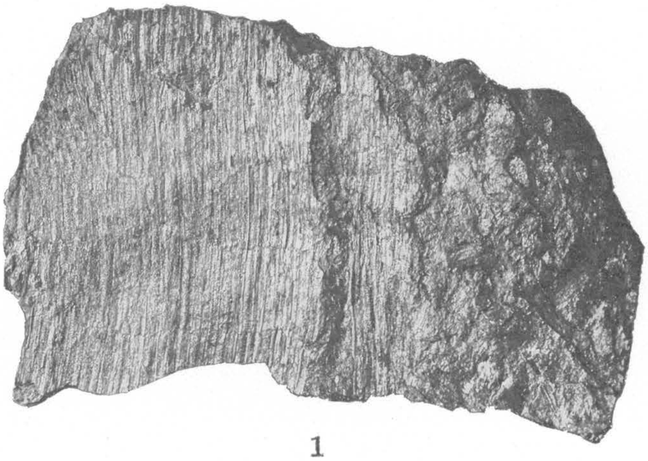
PLATE IX.

FRAGMENTS OF BITUMINOUS COAL SHOWING CARBONIZED WOOD, ETC.

FIGURE 1. Portion (natural size) of a large fragment of wood from the midst of the coal mined at Gerlaw, Ill. The wood, which is flattened comparatively thin, is traversed, parallel to the grain, by very slender needle-like casts, the remains of hard secretions, regarded as resinous, occupying the longitudinal canals. On the right are fragments of bark, cuticles, and small miscellaneous vegetal débris, all carbonized. A portion of the same specimen is shown four times enlarged in Plate XI, figure 4.

FIGURE 2. Bedding-plane surface (natural size) of a block of coal from a mine in "coal No. 2," near Exeter, Ill. The surface is strewn with small pieces of wood now flattened and converted to mineral charcoal ("mother of coal"). Most of the pieces are traversed lengthwise of the grain by needle-like resinous canal casts, like those shown in figure 1, but much more slender. A part of this specimen is shown four times enlarged in Plate X.

FIGURE 3. Fragment (natural size) from a thin parting in the coal (No. 2) at Colchester, Ill., showing the very slender needle-like resin fillings of the canals, released by the decay of the surrounding tissues of the wood and now drifted in confusion. On the same specimen, as shown in bedding-plane view four times enlarged in Plate XII, are many megaspores and several envelopes of seeds all representing vegetal tissues most resistant to decay. Small particles of cuticle are also present.



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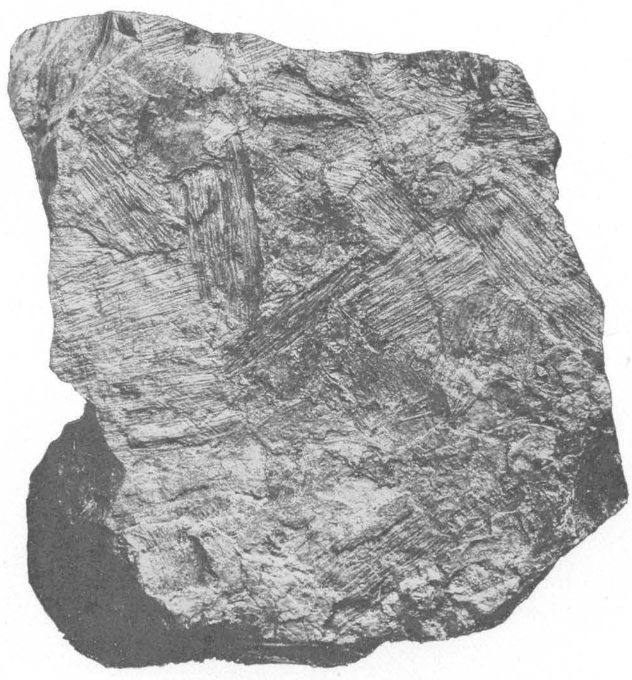

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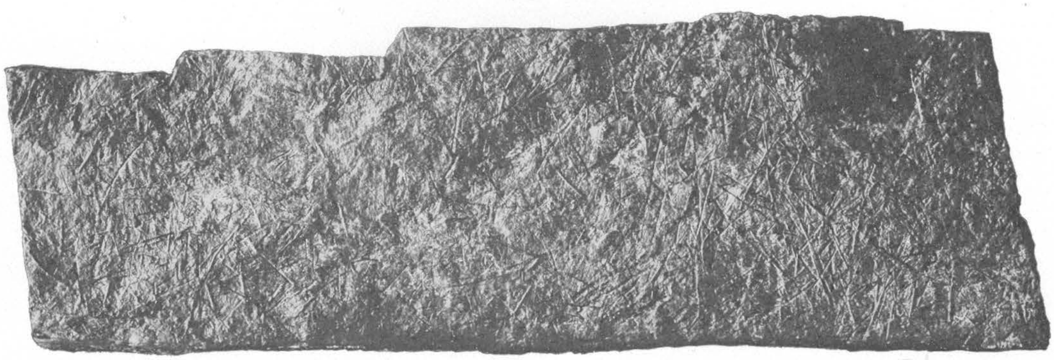

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FRAGMENTS OF BITUMINOUS COAL SHOWING CARBONIZED WOOD, ETC.

PLATE X.

PLATE X.

Bedding plane of coal from Exeter, Ill.

A portion of the block shown in Plate IX, figure 2, four times the natural size. The resinous casts of the canals longitudinally traversing the fragments of carbonized wood appear like needles or fine wires lying parallel to the surface or protruding obliquely and at the ends of the pieces of wood. In some places the wood has rotted so that the casts are left entirely freed and isolated. The surrounding wood cells were so macerated and compressed that many of the slender round casts stand out as ridges in the coaly residue even where they are not actually exposed.

BEDDING PLANE OF COAL FROM EXETER ILL.

PLATE XI.

PLATE XI.

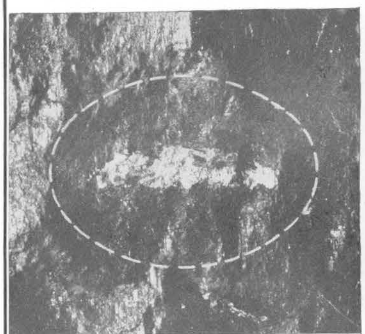
RESIN LUMPS IN PALEOZOIC COALS.

FIGURE 1. End view (five times enlarged) of a piece of coal from shaft at La Salle, Ill., showing a cross section of a flattened lump of rather dark amber-like resin. It is slightly pitted.

FIGURE 2. End view (five times enlarged) of a fragment of "block" coal from a mine near Brazil, Ind., showing a lump of resin. The resin has been squeezed both along the bedding plane and in the joints, so that its cross section exhibits a zigzag or "step" form. The light-colored spots above and below are mere reflections from fracture surfaces of the dense laminated coal, the photograph not being retouched. Fragments of the lump here shown have been subjected to combustion and chemical tests.

FIGURE 3. Another lump (five times enlarged) found on another side of the block of coal shown in figure 2. The lump is somewhat squeezed but retains its typical "rosin"-like translucent character. The outline of the section is crescentic, convex downward; the apparent extensions above and below are reflections from cleavage planes in the coal. The photograph is not retouched. The same specimen of coal exhibits a third resin lump.

FIGURE 4. Portion (four times enlarged) of the fragment from Gerlaw, Ill., shown in Plate IX, figure 1, showing the needle-like casts or resinous fillings of the canals in the wood, the grain of which runs vertically in the picture. The casts are in some places fully exposed, in others are protruding and broken off, and in still others appear only as ridges in the thin layer of mineral charcoal to which the wood is reduced.



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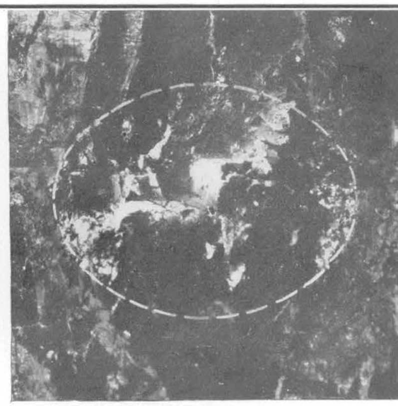

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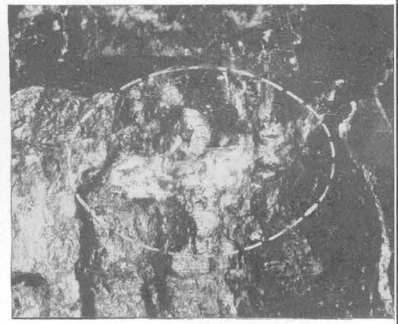


3

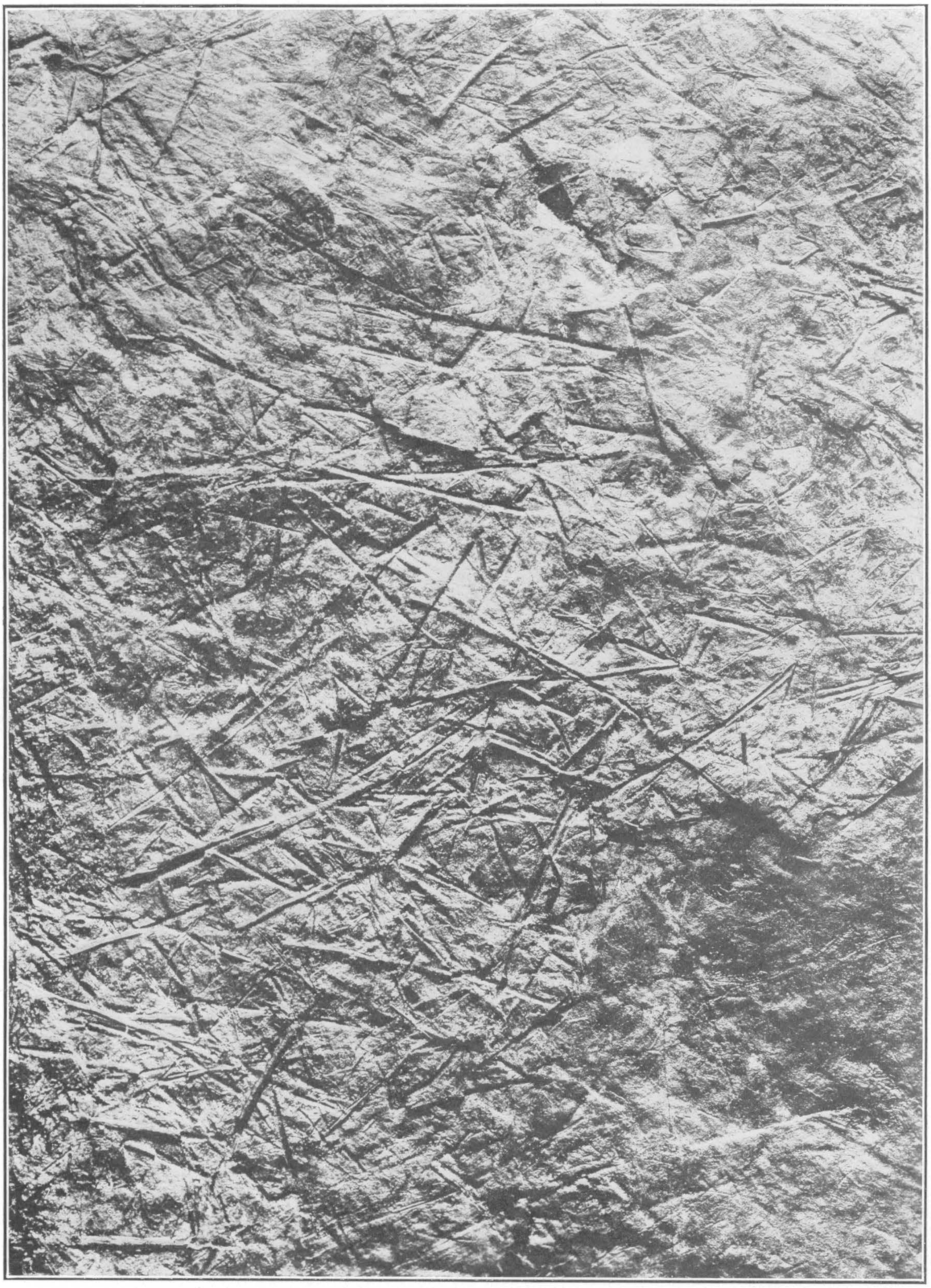
RESIN LUMPS IN PALEOZOIC COALS.

PLATE XII.

PLATE XII.

Fragment from thin parting in coal from Colchester, Ill.

Portion (four times enlarged) of the very thin parting shown in bedding-plane view in Plate IX, figure 3. Shows the round, slender, needle-like resinous casts from the canals of various woods. The casts, freed by the decay of the other tissues of the wood, have accumulated in great numbers, effecting a concentration of the resin substance. Fragments of cuticle, spore exines, and seed coats are also present.



FRAGMENT FROM THIN PARTING IN COAL FROM COLCHESTER, ILL.

PLATE XIII.

PLATE XIII.

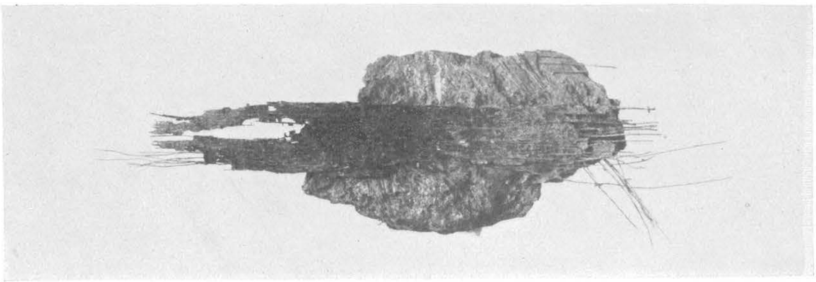
Resinous casts in stems or petioles.

[From Big Spring Creek, 20 miles southeast of Lewiston, Mont. Quadrant formation; Pottsville age.]

Figure 1. Fragment of coaly shale crossed by the thin carbonized residue of a petiole, a portion of which (on the left) is held suspended by the very slender, threadlike resinous casts, which protrude at the ends like bristles or fibrils. The same specimen is shown twice enlarged in Plate XIV, figure 1.

Figure 2. Fragment of dark shaly coal or coaly shale, in which many of the petioles (or stems ?) are matted in various directions. The resinous casts of the canals, some of which are very large, make ridges in the very thin carbonized residues of the petioles, even where they are still enveloped by the coalified flattened remains of the surrounding tissue of the wood or bark. At several points casts isolated by the decay of the wood are seen. A portion of this specimen is shown twice enlarged in Plate XIV, figure 3.

Figure 3. Fragment of coaly shale from the edges of which protrude the parallel threadlike resinous vessel casts which have been pulled out of the carbonaceous residues in the adjoining fragments. The bands of casts lie in many directions and at many levels, according to the position of the containing carbonized wood.



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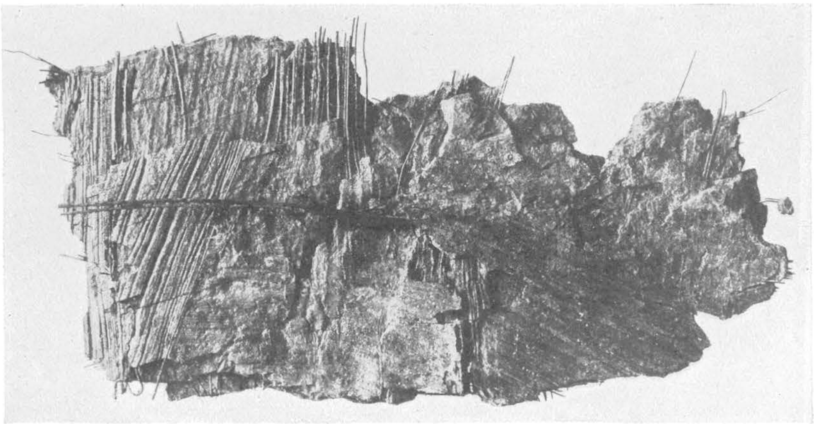

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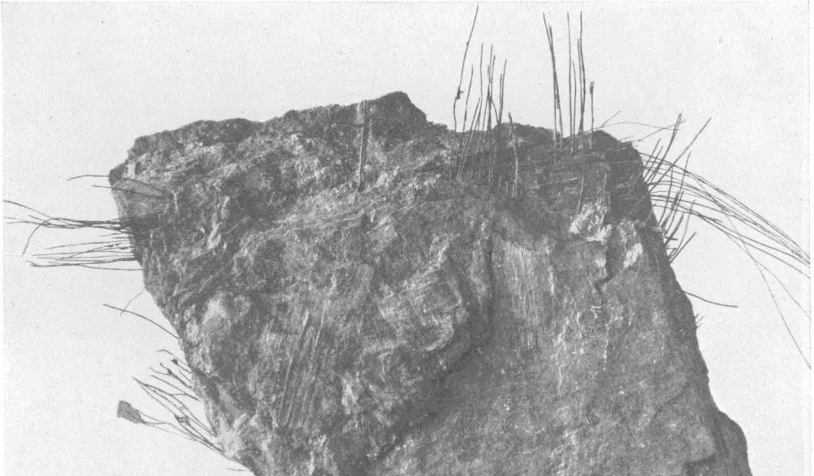

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RESINOUS CASTS IN STEMS OR PETIOLES.

PLATE XIV.

PLATE XIV.

THREADLIKE RESINOUS CASTS IN CARBONIZED WOODS.

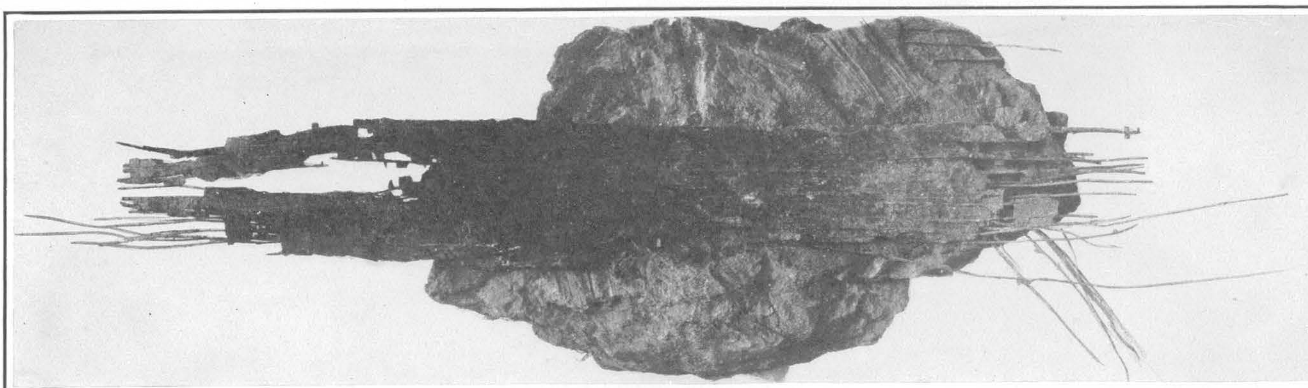
[From Big Spring Creek, 20 miles southeast of Lewiston, Mont. Quadrant formation; Pottsville age.]

FIGURE 1. Specimen shown in Plate XIII, figure 1 (enlarged two diameters), showing the cubical coal made from the remaining tissues of the petiole. The residue, which is less than 0.3 millimeter in diameter, is scarcely thicker than the resinous fibrils themselves. The cubically jointed coal has been lifted from the matrix and extends, sustained by the casts, on the left. Other stem fragments with casts lie in the same piece of coaly shale.

FIGURE 2. Fragment (twice natural size) in which the resinous casts, much greater in diameter, lie mostly in their original attitudes, the coal and mud having been partly removed.

FIGURE 3. Part of the specimen shown in Plate XIII, figure 2 (twice natural size), showing the parallelism and aspect of the resin canal casts, which in some of the petiolar fragments are very large. Regarding the relative diameter of the canals, compare this figure with a corresponding enlargement given as figure 1 above.

FIGURE 4. Piece of the coaly shale transversely crossed by a petiole or small stem which before burial in the carbonaceous mud had so far rotted that the resinous casts of the canals were left free and unsupported by intervening woody tissues. They lie longitudinally extended but lax and irregularly disposed within the thin outer sheath of the petiole. Many cast fragments wholly isolated by the decay of their enveloping stems are scattered in the richly carbonaceous mud.



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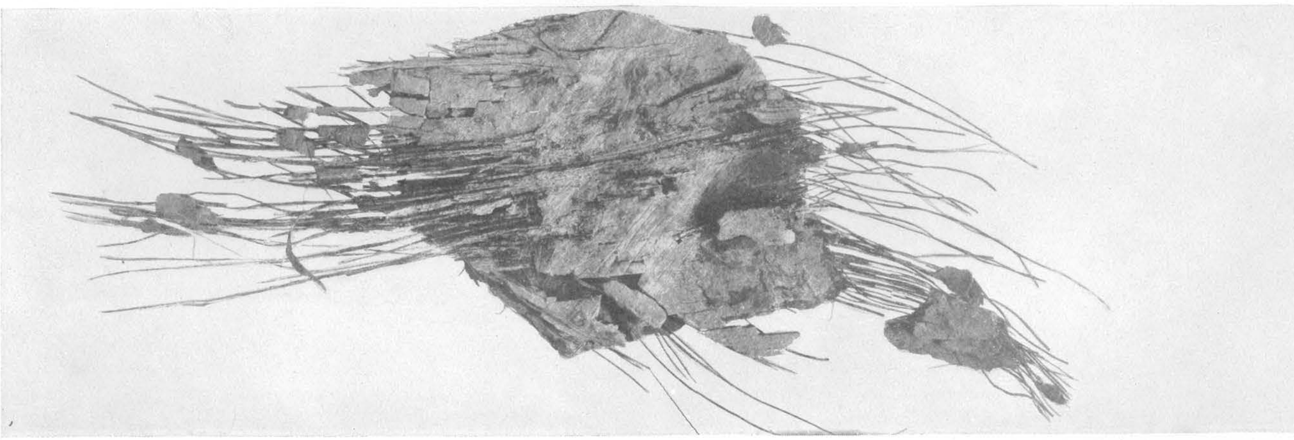

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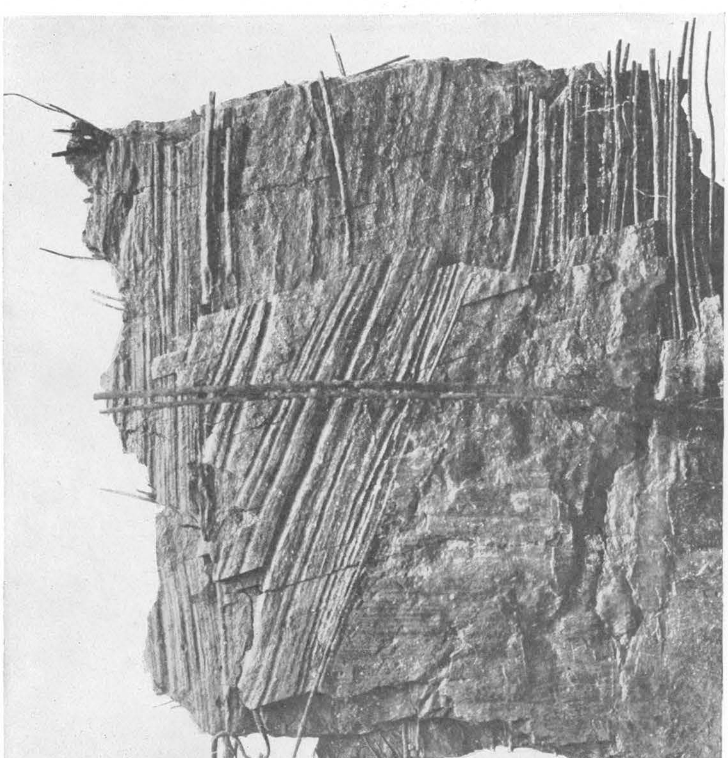

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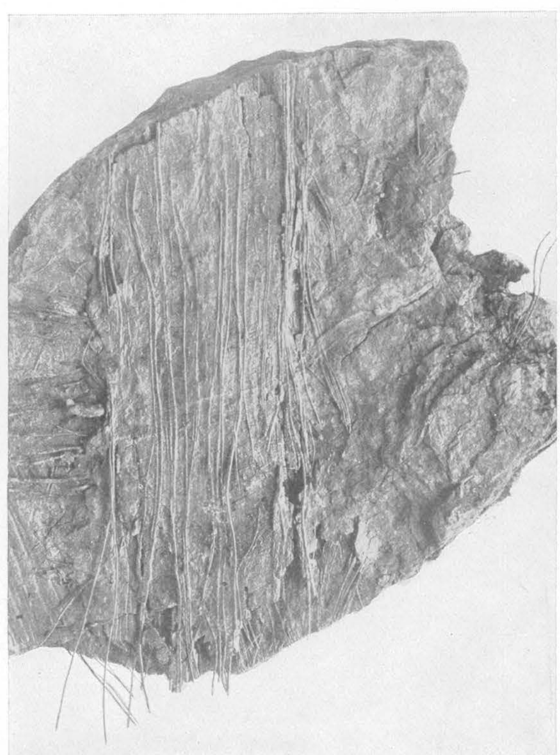

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THREADLIKE RESINOUS CASTS IN CARBONIZED WOODS.