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have modified but slightly the topographic forms of its surface, adding only the last touches to the features which the region presents to-day.

A POSSIBLE ORIGIN FOR THE LIGNITES OF NORTH DAKOTA.

BY FRANK A. WILDER.

The lignite of North Dakota occupies part of an area that is shared by the neighboring states of Montana, Wyoming, and South Dakota, and by Assiniboia on the north. The total area of this lignite field in the United States alone is 70,000 square miles, apportioned as follows:

North Dakota	31,500
Montana	25,000
Wyoming	9,000
South Dakota	4,500

It is probable that all of this field does not contain lignite beds of workable thickness, but studies carried on in North Dakota and Montana during the past summer indicate that thick beds are very general, and that often a series of four or five are separated by relatively thin strata of clay. Some of the beds are very thick, one which outcrops near the Little Missouri in southwestern North Dakota measuring forty feet, while twenty-foot beds are not uncommon.

Analyses of samples taken from more than sixty points in North Dakota show that, except for the high percentage of moisture that they contain, they might be ranked as semi-bituminous coal, since the amount of fixed carbon is unusually high for lignite. The average North Dakota lignite contains thirty-two per cent of moisture. When this is driven off by heating to 100 C., analyses show that the average lignite is composed of:

	Per cent.
Volatile matter	41.5
Fixed carbon	51.
Ash	7.5

The beds, as a rule, show no great lateral persistence. Mining operations have demonstrated that one bed in Ward county underlies fifty square miles of country, but this is believed to be much more extensive than the average. Observations along the Little Missouri and in the Bad Lands, where the lignite beds are often exposed along ravines and canyons for miles continuously, show that the floor on which they were laid down was often uneven, and that they are inclined to thicken or thin out rapidly. While one bed is thinning another may develop above or below it, so that the lignite is continuous through large areas, though there is diversity of beds.

All of the workable lignite beds of North Dakota are regarded as Laramie, though beds a few inches in thickness in the eastern part of the state occur in the Benton. Fossil shells which included three gasteropod and one pelecypod species, collected during the past summer at three points—the same species being found at each point—in clays intimately associated with the lignite, were identified by Mr. Charles Schuchert, of the Smithsonian Institution, who reports that while the range of the species is somewhat extensive, all are indicative of the Laramie. Similar determinations have been made in former years by members of the staff of the United States Geological Survey. As it exists in North Dakota the Laramie consists mainly of clays which are never fissile or shale-like in character. From fat and joint clays they may gradually become arenaceous till they pass into unconsolidated sand. This is locally hardened into solid beds. The most extensive sandstone in the state caps the high buttes in Billings county, and is fifty feet thick. Most of the sandstones are micaceous, the common mica being biotite. Strata which are widely separated laterally and in the vertical scale as well, often show great similarity in composition. They are commonly cross-bedded. The clay strata are marked

by strong individuality in color, and display all shades of gray, brown, red, and yellow, producing effects in the canyons of the Bad Lands that are often exceedingly beautiful. Beds of high grade fire clay which have a fusing point above 3,500° F., are common. A series of clay strata may dip at an angle of ten degrees or more, while those above and below are horizontal. The effect to the eye is not unlike that of cross-bedding.

The lignite is commonly brown in color and exceedingly woody in structure. Tree trunks many feet long and from one to two feet in diameter are often found lying prone in the lignite bed. Unfortunately the bark is never preserved or other characteristics by which they can be identified without the microscope, and as yet microscopic studies have not been undertaken. Small masses of a rosinous-like substance are often distributed through the lignite. Leaf prints and delicate forms have not been found in the lignite itself, but in the associated clays they are well preserved. Specimens taken from a clay which lies between two lignite beds in Ward county were sent to the Smithsonian Institution for identification, and were determined to be:

Sequoia langsdorfii (Brongniart) Heer.
Sequoia brevifolia Lesq.
Sequoia angustifolia Lesq.

Sequoia cones, finely fossilized, were found in great abundance in Morton county. Leaf prints of *Viburnum* perfectly preserved in thin bands of clay-ironstone were found at a number of points.

Unusual opportunities to study the relations of the lignite to the under clay are given, since a great deal of mining is done by the strip-pit system, which leaves the clay bare and shows exactly the line of contact between clay and coal. The extensive exposures in the bluffs of the Bad Lands are instructive in the same way. The underlying clay is practically free from roots. It may contain limbs or trunks, which are scattered irregularly here and there, but these are not uncommon anywhere in the Laramie clays. In not a single instance was a stump found with

roots in the clay under the coal, nor was a case reported by any of the miners interviewed. The clay floor is often uneven. It may dip as much as five degrees when the structure of the overlying clays shows that there has been no folding. It is dotted with low, broad mounds at times and is rarely level.

The purity of some beds is very constant, while the amount of ash in the lignite from others will increase ten per cent and even more in a lateral distance of two hundred yards. So great a change in quality, however, is unusual. Often the upper two or three feet, or even all of a thin bed seems to have decayed, as though after the woody matter had accumulated under water, the lake or swamp under which it was deposited had been partly drained and the lignite exposed to the air for a time before it was covered by silt. The ash in this "soft" lignite is often twenty per cent and it is worthless as fuel. This is as apt to be true of beds low in the Laramie as of those that are near the top.

It is difficult to formulate an hypothesis for the origin of the lignite that is in harmony with all of the facts cited. The ordinary explanation for coal deposits seems inadequate since nearly all of the phenomena on which it is based are absent in this field. There are no roots in, nor stumps rising out of the underlying clays; nor are there delicate leaf prints preserved in the body of the coal, indicating deposition in quiet water. Moreover, the flora of the Laramie, or at least those forms that have been collected from the lignite area and in close connection with the lignite, are of genera which to-day live on dry ground. Many of the beds seem to be made up entirely of wood, with no addition of leaves or the finer forms of vegetation. This wood has suffered so little decay that it is hard to think that the material that forms the upper part of the bed grew upon or derived nourishment from that below, and where the beds are twenty feet thick, not an uncommon occurrence, it is equally hard to conceive of trees growing on ten feet or more of fallen but undecayed trunks, and striking root down into the underlying clay.

In considering drift material deposited in deltas as an origin for coal deposits, the question arises whether sufficient stress has been laid on the probability that considerable quantities of silt and sand would be deposited with the vegetable matter. The conditions must have been unique under which drift timber sufficient to make twenty feet of lignite could accumulate, and yet so little silt be deposited with it that the ash of the lignite is but one or two per cent higher than the percentage of mineral matter in the wood. A second point that demands consideration is the origin of this vast amount of drift material.

The Laramie beds are regarded as accumulations in fresh water. The great fresh water lakes of the present do not seem to present conditions which, though operative for a long period of time, would give rise to similar deposits, for the amount of drift material that becomes waterlogged in them and sinks to the bottom far from the shore where it could accumulate without addition of silt, is probably small. Strong currents and winds either carry most of the drift wood out of the lake or crowd it to shore where it is buried in sand. In the smaller lakes of northern Michigan and Minnesota, located in the heart of the timber country, conditions are different. Vegetation is abundant to the water's edge and sand beaches are rare. Any one who has seen certain of them during logging time can readily believe that, if by natural conditions logs were poured into the lakes as they are yearly during the logging season and became waterlogged there, woody beds equal to those of the Laramie lignites would result. Perfectly natural conditions as they exist to-day, operating through a very long period of time, would doubtless contribute to one of these lakes enough material for a lignite bed, but as the time in which the accumulation takes place is increased, the probability of a large admixture of foreign matter is increased. It is true that the forest conditions that exist around these lakes prevent the carrying in of large quantities of sand and dust by wind, but tributary streams that are active enough to bring down considerable quantities of timber would contribute to the lake a good

deal of silt as well. This would be deposited near the mouths of the streams for the most part. It is conceivable that many logs would drift beyond the zone of heavy silt deposit, and that a woody deposit highly mixed with silt near the stream delta, and growing purer with distance or other conditions that diminished current action, might arise. Nevertheless, it is plain that if conditions which would hasten the accumulation of woody matter may be assumed, the problem will be simplified.

The Rocky mountain uplift is generally credited to the Laramie, for Laramie strata are found well upon the mountain slopes. No evidence is at hand, however, to show that the late Laramie ever wholly covered the Rocky mountain area. If the uplift occurred all through the Laramie, the explanation that has been offered for the lignites receives material aid. The uplift, it may be conceived, began with the region that is now the heart of the Rockies, and continued till the region as far east as western Dakota was slightly affected. The effect of the earliest movement would be to quicken erosion in the region of uplift and increase deposition at its edge, in the central and eastern Montana country. Here the disturbance in the west would manifest itself in abnormal drainage conditions. Lakes would arise, fed by the streams coming from the west. Streams thus rapidly quickened in a forest country would carry much drift timber, for during the former period of relative inactivity forest conditions would have crept down close to the stream banks. Undercutting, with landslides, would throw into the valleys the giant redwoods, which the next flood would carry to the lakes. As the uplift continued and its axis widened, the region of deposition would be carried farther and farther east, and there would be a gradual shifting of the lake country in that direction. The Laramie strata to the west would be tilted and faulted as they are to-day, and those farther from the center of upward movement would lie practically horizontal.

Such an hypothesis seems to fit the nature of the Laramie clays and sandstones, as well as the peculiarities of

the interbedded lignite. The cross-bedded sandstone which passes gradually into clay; the clay beds that are sometimes remarkably persistent in color and texture, and at other times extremely variable, passing abruptly into carbonaceous clay and on into lignite; the large tree trunks that are scattered through all of the clay beds; all suggest the former presence of shifting lakes fed by streams laden with silt and timber. In one instance stumps three and four feet in diameter and fifteen feet high, silicified, were found over an extensive area standing upright. They were not associated with a lignite bed, and seem to represent part of a forest that was silted under by the shifting of a lake bed.

This view of the origin of the lignites is admittedly hypothetical. It seems, however, to present a reasonable line for study, to form a working hypothesis, to use the admirable term of Professor Chamberlin. To prove or disprove it, additional study will be directed to the following points: To determine whether the Laramie of the mountains is older than that of the plains; to show whether in the main the wood from which the lignite was derived was of land growth and to determine the habitat of the species, and to see what light the fauna of the Laramie throws on the relation of land to water at that time.