

CHAPTER VI.

STRATIGRAPHY OF THE COAL MEASURES.

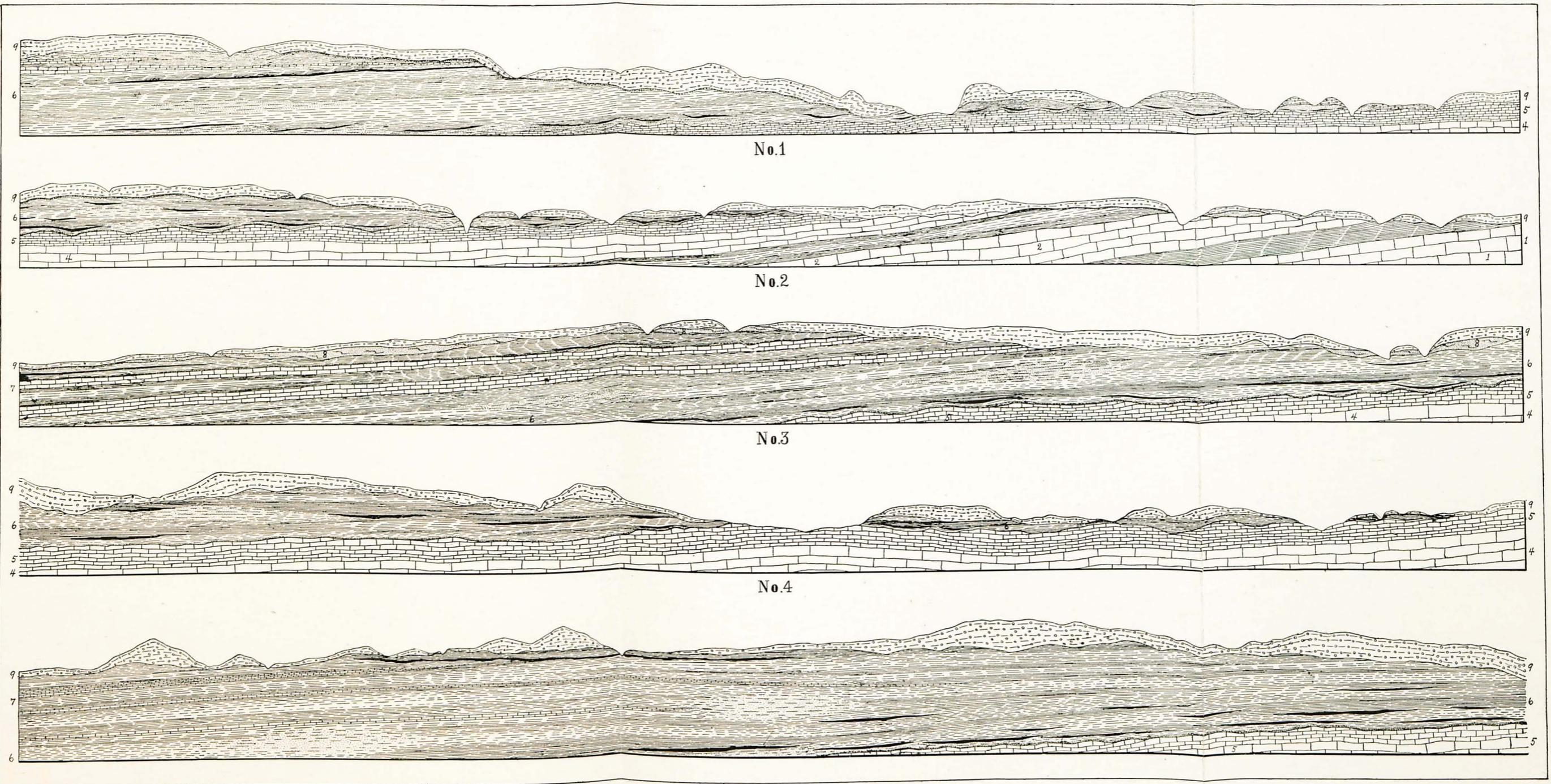
Introductory Remarks.—Iowa has been little affected by mountain-making forces. The rock strata are consequently largely undisturbed. As compared with mountainous regions, the arrangement of the successive layers of sediments is in a general way quite simple. Nevertheless when considered in detail there appears at the outset a complexity of structure in much of the coal producing area which is entirely unlooked for. Owing to particular conditions of deposition and to certain peculiarities of later erosion the relations of the different rock strata do not present the great simplicity that might be expected. According to the best information derived from a study of the rocks throughout the Coal Measure area of Iowa these beds were laid down along the coastal incline of an old Paleozoic continent. The various layers were formed on a low plain which, though remaining near sea-level most of the time, was sometimes elevated above the water and subjected to erosive agencies or depressed below the surface of the sea to be covered by new accumulations of sediments. With the erosion of the land and the action of ever varying currents the final disposition of the beds became more or less highly complicated.

The Iowa-Missouri coal basin represents a broad bay-like expansion opening toward the west, and in this direction, during later Paleozoic times, into the great interior

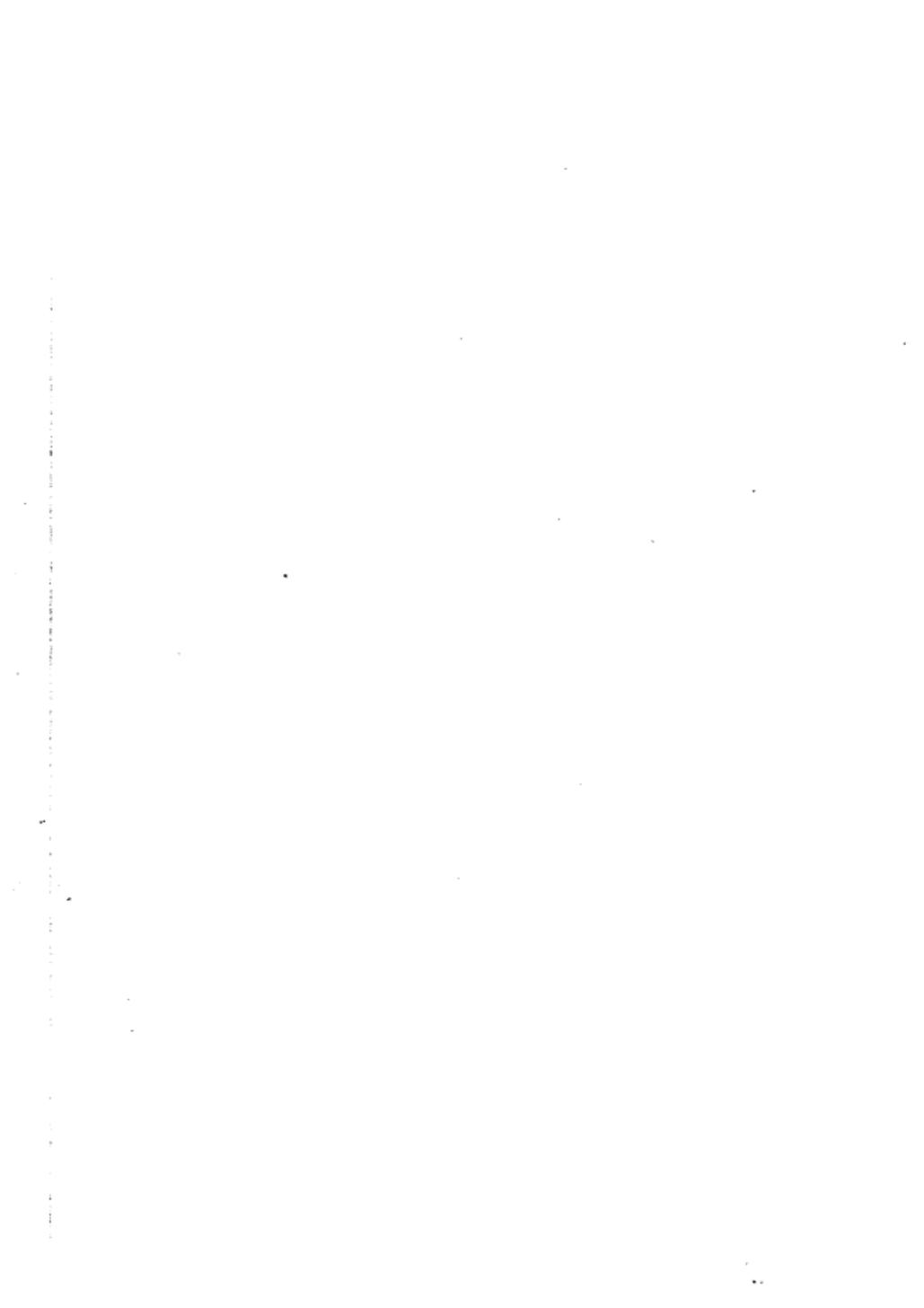
sea which occupied all the western half of the present continent of North America. The Iowa coal field may have been at one time connected with the Illinois area but the evidence now seems to indicate that if this was ever the case the belt now traversed by the Mississippi river was not far below sea-level and that the waters at all times were very shallow.

Regarding, then, the Iowa Coal basin as once forming a part of a large sheltered bay in which were deposited shore sediments along the marginal zone, and open sea beds in the interior or central portion, lines drawn perpendicular to the old shore-line would be directed westward in the southern portion of the state and southwestward and southward in the north-central and northwestern portions. Geological sections along the lines mentioned show that everywhere within the marginal zone of shore deposits there is a characteristic want of continuity of the different layers, while, as the interior district is approached, particular strata assume a wide geographical extent. As in lithological features, therefore, the stratigraphical characters of the Iowa Coal Measures exhibit in a general way two well marked phases, the one distinctive of the marginal belt which has heretofore been commonly known as the "Lower" division and the other of the central area or "Upper" portion of the coal-bearing series.

General Sections.—Several generalized sections crossing the central portion of the state are shown in the accompanying plate. In all of the sections the different geological formations are numbered like: 1 is Silurian; 2, Devonian; 3, Kinderhook; 4, Augusta; 5, Saint Louis; 6, Lower Coal Measures; 7, Upper Coal Measures; 8, Cretaceous; 9, Drift. Section number 1 is approximately



GENERAL CROSS SECTIONS OF COAL MEASURE BASIN IN IOWA.



along the line of the southwestern branch of the Chicago, Rock Island and Pacific railroad, from Washington to the south state line. At its northeastern limit only the St. Louis limestone is shown at the surface. For some distance the Coal Measures are quite thin and the Lower Carboniferous limestone appears in the beds of the streams. Section number 2 is in a northeast and southwest direction from Cedar Rapids to Chariton. The older formations are represented as having a general dip to the southwest and the Coal Measures as resting unconformably upon them. Section number 3 is from the southwestern corner of Webster county to the northeastern corner of Page and has nearly a north and south direction. The Cretaceous beds are seen lying unconformably upon both the upper and lower Coal Measures. Section number 4 is constructed in an east and west direction along the line of the Chicago, Burlington and Quincy railroad.

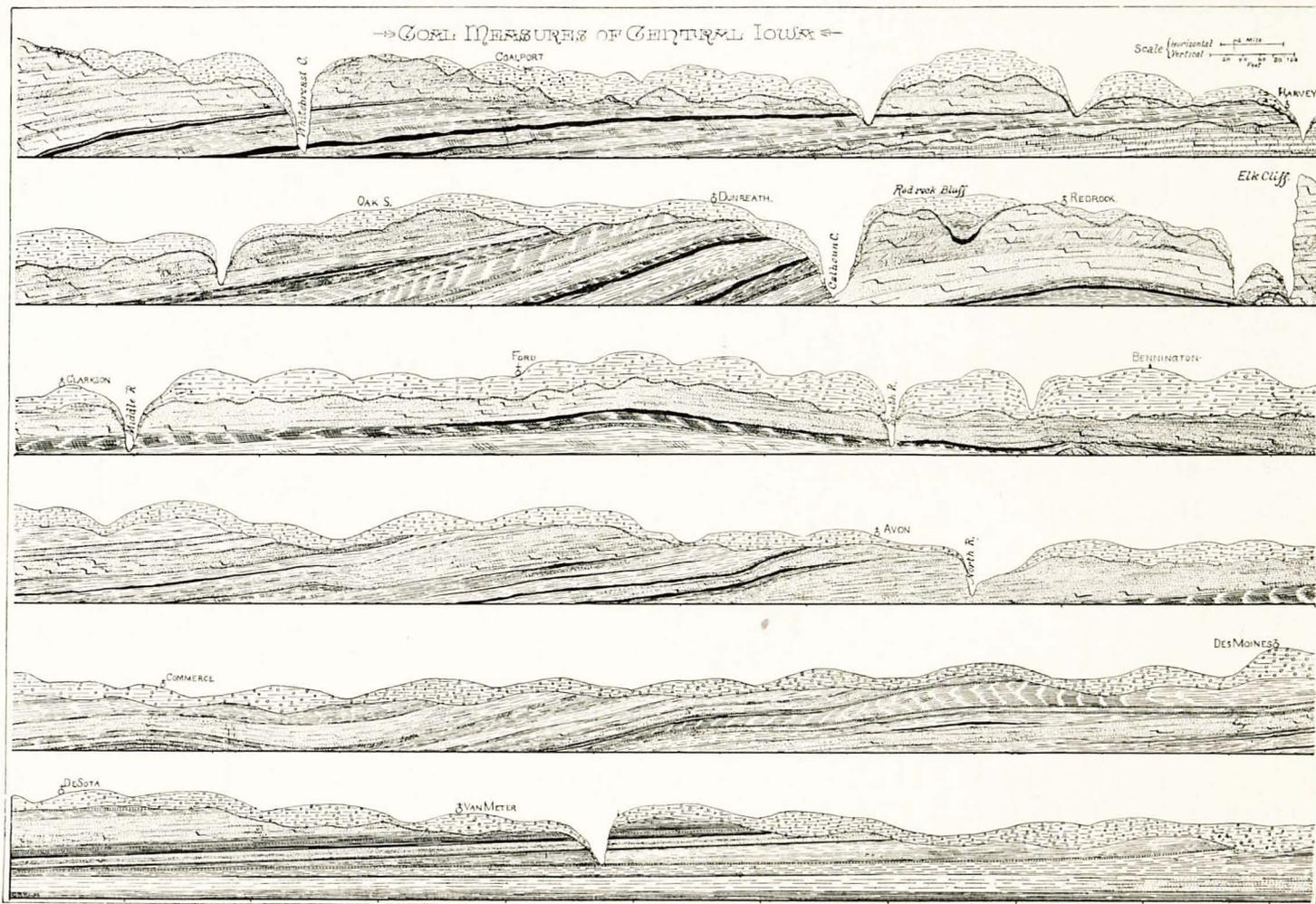
The sequence of strata, the succession of fire clay, coal, bituminous shale or slate, sandstone, or sandy shales is so frequently repeated everywhere throughout the coal region of Iowa that it often becomes a matter of extreme difficulty to detect the fact that workable coal beds operated only a short distance apart may be very distinct from one another and that each is a separate horizon. Thus, failure to recognize the details of the proper arrangement of the coal-carrying strata had led prospectors and miners to claim that the different coal seams worked in a given locality have a much wider distribution than they really possess.

Form of the Coal Basin.—The northward extension of the great Interior coal basin of Iowa and Missouri occupies a broad, shallow depression deepening to the

westward. Its thickest portion is centrally about at the present Iowa-Missouri boundary line, on the Missouri river. The vertical measurement at this place is variously estimated from 1,200 to 2,000 feet; but from that point it becomes attenuated toward the east and north, and thins out completely before reaching the Mississippi river in the one direction, or the northern boundary of Iowa in the other. The general relations of the Iowa Coal Measures to the underlying strata are those of a coal-bearing series of rocks reclining unconformably upon its limestone floor and therefore presenting some stratigraphical peculiarities not commonly met with among the other geological formations of the state; for the deeply eroded surface of the basement renders the disposition of the beds much more irregular than if it was an ordinary overlap of strata on a level area.

LOWER COAL MEASURES (DES MOINES BEDS).

Of all the Iowa Coal Measure districts that part in the central portion of the state in Marion, Polk and Dallas counties is perhaps better understood geologically than any other. Both the phenomena of structure and arrangement of the coal-bearing strata presented by this region may be taken as typical of a greater part of the Iowa Coal field. The leading facts are shown in a very detailed section from Harvey, in the southwestern part of Marion county, along the line of the Des Moines river to the Capital City, and thence up the Raccoon river to DeSoto in Dallas county, a distance of about sixty miles. The construction of the section has been greatly facilitated by the numerous excellent exposures afforded by railway lines that have been built nearly the entire distance on each side of the two streams. These railway cuts taken



GEOLOGICAL SECTION ALONG DES MOINES AND RACCOON RIVERS IN CENTRAL IOWA.

together with the natural outcrops on the rivers, permit the stratigraphy of the district to be very satisfactorily traced in all the minor particulars.

Along the line just specified, several hundred exposures were examined and measured, the different beds being carefully correlated in the field by direct passage from point to point. Out of the entire number of measurements made, ten of the most instructive and typical sections were recently selected and fully described. Accompanying the notes was a general section, the base of which was the low-water limit in the Des Moines river and on which was marked each of the localities considered. The Pleistocene deposits were not differentiated with sufficient care to warrant the separation, on the general section, of the drift sheets and loess.

Detailed Section in Central Iowa.—Passing westward from Harvey, at the southern extremity of the section, the St. Louis limestone, overlain at frequent intervals by white, fossiliferous marls from a few inches to fifteen or twenty feet in thickness, disappears below the water level in the Des Moines river at the bridge spanning the stream on the Pella and Knoxville road. This limestone appears again at Elk Cliff just below the town of Redrock in a low anticline exposed for a few hundred yards. At various places this limestone shows its upper surface channeled and unevenly eroded, the soft white clays which form the superior member of the formation in the district being completely removed. Coal Measure clays or sands fill these ancient ravines. The extent of the erosive action that took place prior to the deposition of the Coal Measures has not as yet been accurately made out. In a distance of ten miles, between Harvey and Elk Cliff where careful and satisfactory measurements have been taken,

it is known that not less than seventy-five feet of shales intervene between the two horizons of the Lower Coal Measure sediments in contact with the Saint Louis limestone of the two places.

The exposure at Elk Cliff is very instructive for other reasons than those here mentioned. A small but deep ravine divides the section. On the left is the concretionary limestone, the last outcrop of the Saint Louis in Central Iowa to be noted in the ascent of the Des Moines river. At this place it rises in a low arch about fifteen feet above low-water. Overlying it are marly and somewhat sandy shales which have a vertical exposure of sixteen feet. The Redrock sandstone rises in vertical cliffs to a height of 150 feet. The inclination is 5° to the westward; but the dip is perhaps even greater to the southeast. The strata are visible down to the water's edge. The direct line of contact between the arenaceous and calcareous beds is not shown, as the detritus brought down by the streamlet, and the alluvial material deposited at its mouth by the Des Moines river during high water, completely conceal the stratified rocks for several yards on each side of the entrance. In his ascent of the Des Moines river in 1852, Owen observed the same exposure and thought that it indicated a fault of 150 feet or more. It is probable, however, that the case is one similar to that exhibited at the Redrock quarry; and that the limestone area at the time of deposition of the sandy material was a slowly sinking island or low promontory, which was eventually completely covered by the arenaceous deposit.

At Redrock cliff the stone is for the most part massive, with a dip everywhere to the south and west; and a short distance above the quarry just alluded to, the inclination is very considerable. A mile beyond, the

sandstone has disappeared completely and the section shows only shales and clays. The space between the latter exposure and the last known outcrop of the sandstone is, perhaps, half a mile, the interval being largely hidden by Pleistocene deposits down to the water-level. The abrupt change in the lithological characters of the rocks in so short a distance has been mentioned by Owen and by Worthen but the explanation is entirely different from that offered by these writers.

The upper limit of the Redrock sandstone as disclosed in the quarry is very uneven and paved everywhere with rounded waterworn boulders and pebbles, derived from the sandstone itself. A fire clay covers this pavement and upon it rests a coal bed having a thickness of six feet centrally, but rapidly thinning out laterally in both directions to an unimportant, scarcely recognizable bituminous seam. Northward, or at right angles to the face of the section, the coal is thicker. Superimposed upon the coal are drab and ash colored clayey shales having an exposed thickness of thirty feet but which are manifestly much more extensive. From a consideration of this section, then, it is clear that before the superimposing coal seam was formed the vast sand bed had been raised above the surface of the waters, consolidated, and was then subjected to considerable denudation. In a small trough or ravine, excavated in the sandstone, the Carboniferous material was deposited as the land was again being submerged. Immediately to the north of the section represented in the figure (which faces the south) the corrasion acted much more vigorously, as is shown by the rapid inclination of the axis of the trough in that direction; so that the section is actually across a tributary ravine opening into a large basin in which the coal is now mined in

large quantities. The inference is, then, that the abrupt disappearance of the great bed of sandstone in such a short distance as half a mile above the quarry where it has an exposure of more than one hundred feet, is not due wholly to inclination of the stratum, but it is the result of great erosion in that direction, previous to the deposition of the shales and clays; and that the massive sandstone really formed a bare hill of considerable height against which the subsequent deposits were laid, when the conditions for such a change occurred.

[Here, to all appearances is an extensive sandstone formation with a maximum thickness of more than one hundred and fifty feet, lying unconformably upon the St. Louis limestone and with coal bearing strata imposed unconformably upon it. At one time it was thought the sandy member represented shore or estuary deposits of the Kaskaskia sea. Such, however, was found not to be the case. A few miles below Elk Cliff, as already remarked, exposures were observed showing fully seventy-five feet of dark sandy, clayey and bituminous shales between the sandstone and the concretionary limestone. The shales carry at least two workable seams of good coal, one of which attains a thickness of five to seven feet and has a very considerable geographical extent.

The recent observations therefore have cleared up many of the hitherto doubtful points concerning the geological history of the Redrock sandstone. It is not the basal member of the Coal Measures as was regarded by Worthen; nor is it a shore extension of the Kaskaskia limestone; neither is its geographical extent as limited as has been supposed. Twenty miles to the southeast of Redrock a sandstone of great thickness, having identical lithological characters and with a similar stratigraphical

position, is believed to be its extension southward. And it may also rise a few feet above low-water in the north-west corner of Marion county. The most interesting consideration in regard to this Redrock sandstone is the fact of its considerable elevation above the surface of the sea and its subjection to subaerial erosive agencies for a long period of time before the submergence again took place. During the interval the great thickness of sandstone probably was almost entirely removed in places.

A short distance above the Redrock cliff where the great sandstone completely disappears the sandstones,

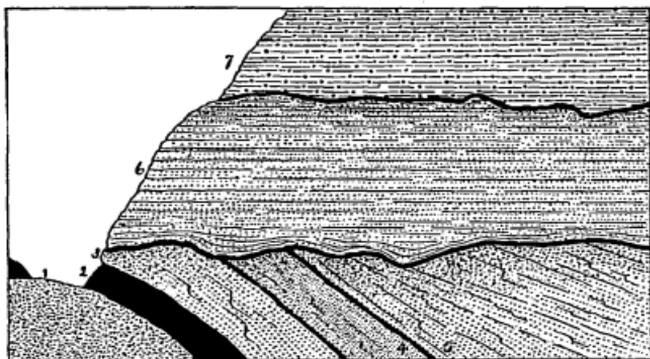


Figure 6. Bennington Section (Marion County), showing Inclination of Coal Strata.

coals and shales laid down are inclined toward the west forming part of a shallow syncline as seen along the river. Eight miles above, near the old village of Bennington, the strata have already begun to rise considerably. At this place a very instructive section is exposed along the river bank. A small portion is shown in the accompanying figure 6.

In this section number 1 is a massive, compact sandstone somewhat concretionary in places. It appears to be

a small knoll, rising scarcely ten feet above the water level of the river and exposed horizontally only about a dozen yards. Its rounded surface is considerably hardened and more or less ferruginous. In lithological characters this rock is identical in all respects with the Red-rock sandstone and may represent the summit of an eroded elevation of that great sand stratum. Immediately overlying the sandstone and inclined at a considerable angle is a bed of coal two feet in thickness (number 2). Above the coal is a heavily bedded yellow sandstone (number 3) having a measurement of four feet. This is followed by a soft blue sandrock about three feet in thickness. Next comes a buff, rather soft sandstone, heavily bedded at first, but gradually becoming more and more thinly bedded eastward. This formation is at first inclined about the same as the coal bed, but in passing down the stream the dip acquires a lower and lower angle, until a quarter of a mile away the planes of stratification are nearly horizontal. Number 6 is a thin ferruginous band about two inches in thickness, very irregular and cutting across the underlying beds obliquely. It is manifestly an old eroded surface. Above it are ten feet of thin clayey sandstone layers and sandy shales, the bedding planes following the sinuosities of the irregular band at first but quickly assuming a straight horizontal position. The sandy shales were evidently more extensive but were probably removed largely through glacial action. More than forty feet of drift cover them.

From Bennington to Des Moines the strata are very undulatory, sometimes rising, sometimes sinking. Beyond Des Moines westward, the layers become nearly horizontal with little or no change in the dip. This very noticeable difference in the laying down of the beds marks the



Figure 7. Composite Section showing Structure of Lower Coal Measures of Iowa.

passage from the "Lower" to the "Upper" Coal Measures—a transition from the marginal or coastal sediments to the more open sea deposits.

The geological cross section of the Carboniferous in central Iowa may be taken as representative of the Lower Coal Measures of the state. A summary of the facts brought out may be graphically given in a generalized, or rather composite, section, as shown in figure 7.

There is in the Lower Coal Measures one notable exception to the general arrangement of the coal seams and associated strata in limited interlocking beds. This is the Mystic coal vein which simulates the even character of the Upper Division. While properly belonging to the marginal deposits it is quite probable that it was formed in a more open part of the coastal zone under

conditions much like those prevailing in the formation of the Upper Coal Series. The coal seam and two beds of heavy limestone, thirty feet apart and some distance above the coal, are found to extend with little or no change of relations for a distance of fifty miles in one direction and forty in another. Wherever the strata in this area are penetrated the same succession of layers is passed through. The strata are very regular and dip slightly to the south and west, so that in crossing the county of Appanoose there is a fall of about one hundred and twenty-five feet.

Variability of Strata.—In considering the stratigraphical features of the Lower Coal Measures the conclusion will probably have been reached that the beds present great variability. Such indeed is found to be the case. In fact it is one of the most striking characteristics of the formation represented in Iowa. The rapid passage from one bed to another lithologically very distinct is everywhere apparent, the transition taking place vertically in different layers or laterally in the same horizon. The stages and manner of gradation of the various beds from one to another have already been described sufficiently.

Unconformities in the Coal Measures.—Local unconformities in the Iowa Coal Measures are well shown in a number of places. Those noticed in connection with the Redrock sandstone, already described in the geological cross section of the Coal Measures in central Iowa, is perhaps the most prominent now known. It is fully 200 feet above the Lower Carboniferous limestone, and sections show the entire thickness of more than 100 feet of the Redrock sandstone to be removed through erosion. In some places coal beds fill old gorges. Other physical breaks in the Coal Measures are indicated elsewhere along the same stream but at present they are more or less

completely obscured by débris. These phenomena go to show that during the deposition of the coal bearing strata numerous minor oscillations of the shore-line occurred allowing the waters to recede slightly and then again advance inland.

Thickness of the Lower Coal Measures.—In connection with the brief account of the leading geological features of central Iowa as brought out by an examination of some of the natural exposures, allusion should be made to the information pertaining to the Carboniferous rocks below the datum line of the general section. All attempts to secure reliable accounts of the strata passed through in the borings and the sinking of mine shafts have availed but little, since such information is almost invariably withheld by the parties in charge of the operations. For this reason the difficulties of working out the structural details of this part of the Carboniferous group were somewhat greater than they otherwise would have been; and the final results are thus considerably delayed.

As already stated the general dip of the strata along the principal line of investigation is southwestward. The mean thickness of the Lower Coal Measures, as shown by careful measurement of the various members, must originally have been considerably more than seven hundred feet. This determination was arrived at in the following way. At the most easterly exposure of the section, the distance from the St. Louis limestone to an easily recognizable bed near the top of the bluff was perhaps fifty feet in a direction normal to the dip and strike. This particular layer was then traced to the point where it disappeared below the datum line and the measurement was repeated in the same manner as before. Of course it is not to be supposed that the present thickness of the Lower Coal Measures

in central Iowa is nearly so great as the figures above given would suggest; for in reality the maximum vertical measurement of the beds is probably a little over one-half that estimate or not far from four hundred feet as is fully attested by borings. Erosion has largely removed the coal bearing strata of the district, and therefore the original thickness of these rocks is not preserved in any one place.

Summary.—Briefly stated the leading stratigraphical features of the Lower Coal Measures may be summarized as follows:

(1) The Coal Measures of Iowa were laid down over an ancient surface with hills and vales, ridges and gorges, the line of overlap passing over Lower Carboniferous, Devonian or even Silurian rocks.

(2) The unconformity of the Lower Coal Measures of Iowa upon limestones of the Lower Carboniferous is much more pronounced than has been generally suspected. The confirmation of this statement is found in observations recently made at Elk Cliff, Harvey, and Maryville, in Marion county, at Fairfield, in Jefferson county, at What Cheer, in Keokuk county, and at many other points.

(3) The striking unconformities in the Lower Coal Measures have never been so apparent as at present. The most remarkable instance of this sort is the case of the Redrock sandstone. The thick sand bed was manifestly consolidated and elevated above the surface of the sea for a considerable distance, then it was subjected to long denudation as is shown in the deep gorges and ravines which are still preserved in the hard sandstone. So wide spread was the action of the erosive agencies that the great sandstone more than one hundred and fifty feet in thickness, was largely removed, so that at present only a

few isolated outliers tell of its former great extent. When regional submergence again set in, the old gorges and shore depressions were occupied by small swamps.

(4) With a few exceptions the earliest formed coal seams are far more extensive both geographically and vertically than later ones.

(5) The coal of Iowa may be regarded as distributed in innumerable lenticular basins, sometimes several miles in diameter and six or seven feet in thickness centrally, sometimes only a few hundred yards in extent. These occur at many different horizons and interlock with one another, so that a boring may pass through a score or more coal horizons without meeting more than one or two veins of sufficient thickness for profitable working.

UPPER COAL MEASURES (MISSOURI FORMATION).

In contradistinction with the stratigraphy of the Lower Coal Measures that of the Upper Division is remarkably regular, in this respect closely resembling the Lower Carboniferous. The stratigraphical continuity is therefore very much more pronounced than in the case of the marginal zone. This fact is due chiefly to the different conditions under which the two formations were laid down, the Upper Coal Measures being essentially open sea deposits for the most part. As already seen the lithological characters are also less changeable than they are in the Lower productive measures. The greater prevalence of limestones, which are among the most persistent of strata, gives a continuity of horizons not met elsewhere in the Coal Measures. The different layers are capable of being traced long distances.

Typical Section.—Perhaps the best sections of the Upper Coal Measure rocks are exposed along the Nodaway

river in Page, Montgomery, Adams and Adair counties, along the Nishnabotna in Page and Montgomery counties and along the Missouri from Council Bluffs to the southern boundary of the state. On the two former streams the horizons appear very even and seem to dip with the stream and at about the same angle. The principal coal vein is exposed in many places and always at nearly the same distance above the water level. In the northern part of Adams county the seam apparently passes beneath the bed of the water course. The remarkable uniformity in the low inclination of the strata in the Nodaway river section may be due to the fact that this river flows approximately parallel to a shallow synclinal axis; for there are known to be well defined folds in the Carboniferous strata of southwestern Iowa.

Deformations.— Along the Missouri river very considerable dips in the beds are noticeable at various places. The most conspicuous inclination is near Jones Point where a thickness of more than one hundred feet of strata is carried below the water level within the distance of a mile. Certain of the thick limestone beds are easily recognizable for miles along the stream. Todd, who has given careful attention to the section, has recently shown that there are a number of these corrugations whose axes trend north 60 degrees east or approximately parallel to the northwestern boundary of the Iowa coal field. Measurements show that the crest of one of the anticlines is nearly five hundred feet above the trough of an adjoining syncline. The recognition of regular folds in the Carboniferous strata of the state has a very important bearing upon the explanation of certain geological phenomena in different parts of the coal field which are not easy to understand otherwise. In the Lower Coal Measures the

entire absence of persistent horizons over wide areas has prevented deformations of this kind from being studied satisfactorily. A number of well marked anticlines and synclines in the strata older than the Carboniferous has been known for some time, though their exact boundaries and amplitude are not as yet definitely known. With the presence of these folds in the formations above and below the coal bearing rocks it is to be inferred with but little doubt that the bending has been also imparted to these border layers in which it has not heretofore been recognized. The bearing of this observation upon the possible occurrence of natural oil and gas in commercial quantities in Iowa is very important. It is known now that all of the conditions for a successful flow are present in the state, but the exact extent to which each of these conditions are satisfied yet remains to be determined. The crest of the anticlines must be penetrated in order to obtain a proper flowing. It therefore is of prime importance to have the different folds located accurately, but this requires time and careful study of the geological structure before outlays of money should be made in prospecting. When this work is accomplished a few tests will soon disclose whether or not Iowa is to become a gas and oil center.

Rock oil is an almost universally distributed substance ; but for the successful production in commercial quantities four conditions must be fulfilled. The absence of any one of these must result in the failure of any enterprise of this kind undertaken. There must be :

- (1) A suitable receptacle or reservoir in which the oil or gas may accumulate.
- (2) A non-porous cover to retain these substances.

(3) A particular geological structure or arrangement of strata.

(4) A pressure sufficient to force the oil or gas to the surface.

The first of these conditions is commonly fulfilled by a coarse sandstone, conglomerate or porous limestone. The rocks allow the ready transmission of liquids or gases from one part of a stratum to another. The second condition is satisfied by some close-grained rock overlying the porous stratum. This impermeable layer is usually found in a shale. Both of these requirements are found almost everywhere on the globe to a greater or less extent wherever stratified rocks are laid down.

The third requirement is that the rocks must be tilted. In the porous layer this permits of a movement of the water, oil and gas particles—a free mechanical rearrangement. The accumulation is in order of the respective specific gravities, the water at the bottom, then the oil and finally the gas at the top. The particular geological structure requisite is ordinarily the arch, fold or anticline. It is readily understood that having arranged themselves according to their respective specific gravities the gas occupies the central portion of the arch, the water the bottom and the oil a space between. When the top of the dome is pierced gas escapes; when the arch a little farther down is drilled into oil flows out, while if the strata near the base of the bow are penetrated only salt water appears. The formation of the arch is due to the same causes which elevate the mountains. Consequently in mountainous regions the folding is more pronounced than in districts little affected by the forces named. In those portions of the continent that are remote from mountain ranges the bending of the strata is not so striking and

the determination of the extent of the folding is much more difficult than in regions that have suffered greater disturbance. The folds when they appear are not so extensive, but in many cases they are still sufficiently great to satisfy one of the most important conditions for a successful flow of oil or gas. The fourth or last condition to be considered is the presence of rock pressure which is essentially artesian or hydrostatic and is measured by the height of a column of salt water which would rise in any well were water struck instead of gas.

Thickness of the Upper Coal Measures.—The thickness of the Carboniferous strata of southwestern Iowa and the adjoining parts of Missouri has been variously estimated. Broadhead was of the opinion that the Upper Coal Measures were between 1,300 and 1,400 feet in thickness. White regards them as only 200 feet thick. Todd, who has made some careful measurements along the Missouri river, has shown that no less than 350 feet are represented. Winslow recently making an investigation of deep drillings in northwestern Missouri is led to believe that the thickness of the beds is even greater than any of the figures here given. Deep borings at Red Oak, in Montgomery county, seem to indicate that the thickness of the Upper Coal Measures strata at that point is more than 500 feet. Putting together all the data upon which these various estimates have been made, and taking into consideration recent observations in the southwestern part of the state, it is probable that the greatest thickness of the Coal Measures is in the neighborhood of 800 feet. This latter estimate includes also most of the so-called Middle Coal Measures of White, which were regarded by him as having a thickness of 200 feet, but which later were shown to be considerably less.

GENERAL CONCLUSIONS CONCERNING THE LOCAL STRATIGRAPHY OF THE IOWA COAL MEASURES.

Heretofore the general impression has been that the "Lower" Coal Measures of the state were deposited prior to the laying down of the rocks of the Upper Division. Recent investigation seems to show that the two were formed contemporaneously; and that the former is to be regarded as a marginal or shore formation while the latter is the more open sea deposit.

It has already been shown that, just previous to the deposition of the Coal Measures in Iowa, Missouri and Kansas, continental movements caused the shore-line of this region to recede several hundred miles to the southward. For a considerable period—during the Kaskaskia epoch—erosive agencies were actively at work on the land surface which extended southward about as far as the present city of Saint Louis. Shore deposits—sands and clays—were laid down immediately beyond the place just mentioned, while farther southward marine beds continued to be formed one above another conformably.

When a new period of depression set in, coal marshes were formed along the landward creeping shore-line. The more strictly marine deposits began to slowly extend farther and farther northward resting on the older calcareous beds as well as the earlier formed marginal areas of sands, clays and accumulated vegetation. This process with many brief interruptions continued until the old shore-line had again gained its former place near the present Iowa-Minnesota boundary. As represented in the accompanying figure 8 it will be seen that the coal or marginal beds were formed at the same time as certain limy layers farther outward; and that all formations along any

given horizontal line (nearly horizontal but having a slight inclination to the southwest) were deposited contemporaneously. On a sinking coast the marginal sediments would have continually the later open sea deposits laid down upon them. The covering of the coal bearing strata by the calcareous beds would constantly take place as long as the depression of the shore continued.



Figure 8. Ideal Cross-section of the Iowa Carboniferous Rocks.

The "Lower" Coal Measures are not then a series of beds laid down previous to the deposition of the "Upper" Coal Measures. Each particular part of the former was deposited at the same time as portions of the latter farther seaward; the lines of contemporaneous deposition being nearly horizontal, yet having a common though slight seaward tilt. As a whole the "Lower" Coal Measures do actually lie beneath the "Upper" Coal Measures; but the line of separation is not a line drawn parallel, but obliquely to the planes of sedimentation.

The essential difference between the two ideas is graphically shown in the following diagrams. (Figures 9 and 10.)

Beyond the point of the southernmost extension of the ancient shore line (a little beyond the left hand terminus of the cut perhaps, figure 10) the limestones of the Upper Carboniferous would lie upon the Lower with practically no evidence of any physical break. The fauna of the

latter would continue into the former with little or no change or inconvenience.

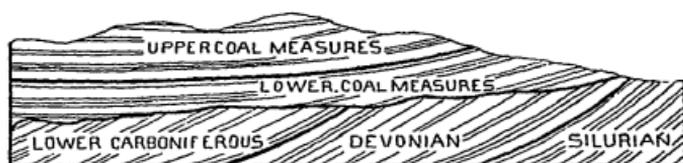


Figure 9. Popular Idea of the Relations of the Lower and Upper Coal Measures.

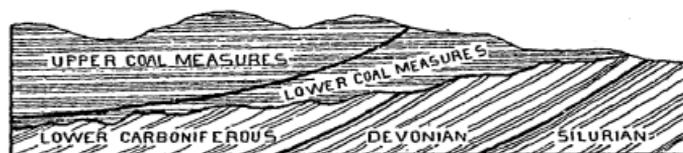


Figure 10. Actual Relations of Lower and Upper Coal Measures as now Understood.

COAL HORIZONS.

From what has been said it will be readily inferred that the Western Interior coal field at the time of its deposition was for the most part a broad shallow bay opening to the westward into the great continental sea, which then occupied most of what is now western North America. That the Coal Measures of the region were laid down during a period of gradual, prolonged, though often checked, subsidence is evidenced by all stratigraphical and lithological details, as well as by the characteristic faunal peculiarities. That the coal beds originated largely in coastal swamps of limited breadth but, with some interruptions, of very considerable length, stretching out near sea level for long distances and sending out minor extensions into the old rivers and estuaries is fully warranted by the facts disclosed everywhere. On the low slowly sinking shores there prevailed at certain times a similarity of physical conditions especially favorable to coal formation.

During these intervals unusual amounts of coaly material were allowed to accumulate and to be preserved in places, the period being pre-eminently one of coal growth, at least for a given province. The great stratigraphic plane marking the record may be appropriately termed a "Coal Horizon."

In stratigraphy, a geological horizon is a level recognizable over a considerable geographical extent, having a more or less well defined stratigraphical position, distinctive as to lithological features and characterized by a particular set of fossils. The term in a broad sense is almost equivalent to formation and has been used as indefinitely. In its more limited meaning it is applied properly to a minor part or zone of the smallest stratigraphical unit having a commonly accepted specific name. Understood in the same way, a coal horizon represents an even more limited expansion, where coal forming materials have accumulated. Practically it is one of the greater planes of sedimentation, marking a distinct episode in the deposition of a series of strata. Theoretically it represents not a phenomenon but rather a set of conditions, a period during which the physical circumstances were similar over a considerable marginal portion of a geological province. From an economic standpoint it stands not for a continuous bed of mineral fuel but a stratigraphical level where workable beds are more likely to occur than elsewhere and where the coal is to be especially sought for in a wide belt fringing a great coal basin. It is not to be inferred, then, that the mineral is equally developed on a given horizon in all portions of this marginal border. In some places the accumulations of plant remains are much greater than in others; limited basins and troughs of unusual thickness are there found.

Elsewhere the old vegetable materials are meagerly represented; only thin seams of coaly matter are preserved. Wide intervals of sandstone and shale often separate adjoining basins, or ancient land elevations may cut off one area from another. (See figure 1.) Yet through all of the many irregularities of deposition and subsequent deformation there are, nevertheless, discernible certain levels quite well defined at which coal beds are very much better developed than at others; clearly marked coal horizons they are, broad in extent and capable, in the case of the greater ones under favorable circumstances, of being traced over a large part of a given coal province. The coal may not be present in a continuous seam over the whole border district and probably never is; but along much of the margin of the coal horizon which at one time must have stood near the sea level for a considerable period, are innumerable basins separated from one another perhaps, yet to all appearances formed contemporaneously. Now they may thicken into sharply defined lenticular beds; now thin out to mere films, or disappear altogether; and again farther on they assume the form of extensive lens-shaped sheets. During deposition, as subsidence became too rapid or the sea too deep for the proper accumulation of vegetable material sediments were carried in, covering the plant beds. Or, if elevation took place, the old swamps, already shut off from free access to the sea, were subject to the agencies of denudation and were partially or entirely removed. As favorable physical conditions again set in the same course of events might be repeated.

In considering the relations of the different coal horizons to one another an approximate parallelism may be made out; not a strict parallelism of the nature which

Andrews* claimed to be true in Ohio, and which Newberry† subsequently stated to be entirely unsubstantiated by facts, but an approximate parallelism in a broad way.

There was apparently the germ of the truth in the idea of the first named author, though he was probably unfortunate in the choice of a name for his theory. Moreover, none of his writings indicate that he understood the problem in the way that recent investigations reveal it. His statements all seem to show that, while he was manifestly on the right path only one side of the subject had been presented to him, just as, quite recently, the question has been discussed from the opposite extreme. Andrews' views are perhaps best expressed in the following paragraph taken from his paper‡ on the subject :

“I have never found the slightest proof of the formation of a seam of coal over hills or high grounds. The parallelism of the seams, of which further mention will be made forbids it. * * * So far as my observations go, I have never found an instance where two distinct seams of coal came together, or conversely, where a seam became divided and its parts continued to diverge for a long or indefinite distance. It is not uncommon to find, in a seam of coal, proof that the coal marsh had in it local depressions, which were filled with sediments, making a soil on which new vegetation grew, and thus the seam shows two parts, separated by fire clay sometimes several feet thick; but in every instance when traced, I have found the parts to re-unite. The two parts never diverge indefinitely. From these statements we may infer a general law of parallelism. Such law is in harmony with

*Geol. Sur. Ohio, vol. I, p. 348. Columbus, 1873.

†Geol. Sur. Ohio, vol. II, p. 169. Columbus, 1874.

‡Geol. Sur. Ohio, vol. I, pp. 348-350. Columbus, 1873.

the belief of the most careful observers, that our productive Coal Period was characterized by great quietness and freedom from violent local disturbances."

This describes the apparent condition of things in Ohio, the same, with minor modifications and explanations, may be regarded as according fairly well with the facts observed in the Iowa-Missouri coal field.

On the other hand there are many who, with Newberry, have directly opposed any approach to the recognition of the parallelism of coal seams. Among the latest to express an opinion on this [side of the discussion is Winslow* who in considering the stratigraphy of Missouri

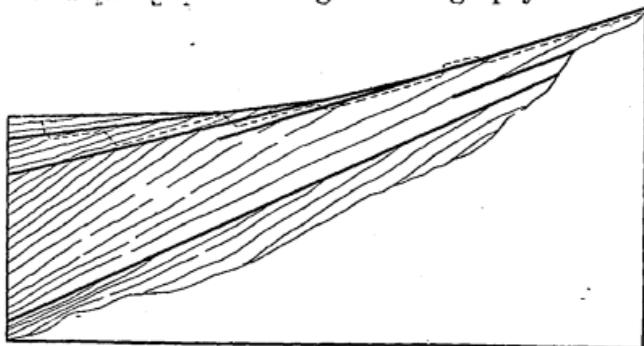


Figure 11. Stratigraphy of Coal Beds.

coal seams is lead to believe that the different veins diverge from one another in a manner best explained by the diagram given above, the dotted line representing Post-Carboniferous erosion. (Figure 11.)

These conditions also accord in the main with the facts observed in all the Western Interior coal field.

An attempt to harmonize the two seemingly very divergent and even contradictory theories is apparently fruitless. But a more careful examination of the subject

* Geol. Sur. Missouri, Prelim. Rep. Coal, pp. 28-30. Jefferson City, 1891.

shows that the two theories are manifestly not based upon facts taken from the same point of view, but from quite different positions. Andrews' idea may be regarded as representing cross sections of the coal bearing strata taken parallel to the general course of the shore; Winslow's a section at right angles.

In districts where mountains are being elevated orographic movements in the earth's crust continue to be felt for long distances from the line of maximum disturbance. If a great sea or an ocean occupies a region affected to a moderate extent by the oscillations, an extended shore-line trends approximately with the axis of the mountain system, for the more important minor corrugations commonly run in similar parallel lines. The direction of maximum change in the inclination of the strata is therefore at right angles to the axis of the folds and hence in a broad way perpendicular to the shore-line. The direction of minimum change in tilting is under ordinary conditions the same as the axes or parallel to the shore. Bearing these suggestions in mind geological cross sections, under favorable circumstances of examination, would show a general parallelism of coal beds when made in one way; a decided tendency to non-parallelism when constructed in the other.

Granting, then, an old uneven land surface such as is known to have existed in Carboniferous times in the upper Mississippi, with the waters of the sea and the marginal maritime flats gradually creeping inland, it would naturally be expected that in any one of the marshy plains skirting the shores for any great distance there would be a very tortuous boundary on the land side and a somewhat less sinuous line of the seaward side; on the one hand were probably low hills and uplands

sending out spurs here and there which cut off one marsh from another and often allowed long open stretches of low upland to reach out even to the waters of the sea itself (figure 12); on the other hand were often narrow



Figure 12. Coal Horizon at Time of Formation; Parallel to Shore-line.

coastal plains rising scarcely above sea level, but shutting off to a great extent very effectually the saline waters from the swamps. Viewed areally the productive part of a great coal horizon is a wide irregular zone running in a tortuous course around a more or less extensive portion of the margin of a coal bearing basin included within the limits of a geological province. Examined at the present time coal horizons present, with all the irregularities of original deposition, subsequent change and deformation, a quite different aspect from the ideally perfect level of the ancient surface, or zone, during the process of formation.

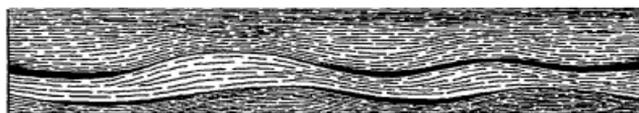


Figure 13. Coal Horizon as it Now Exists; Parallel to Shore-line.

In one direction parallel to the shore, there would be a series of minor saucer-shaped basins strung along on about the same great stratigraphical plane. (Figure 13.) They may rise or fall according as the other strata change in inclination. They may be separated by wide stretches of sandstones or shale or may come together in places. In

the different basins the original vegetable materials in becoming compact shrink most in bulk in the middle, thus allowing the margins to remain considerably higher than the center. This is more noticeable in small basins than in large ones. Then too the fact that the direction of minimum movement in the changes of level was, as has been shown, parallel to the prevailing trend of the shore does not preclude even in this direction a certain amount of tilting of the strata either by the rising or the sinking of one portion of the shore more rapidly than another; or by the passage of minor folds in directions not strictly harmonious with the general rising.

When a new cycle of vegetable accumulation took place the coastal swamps would again spread out at sea level, but not on plains exactly parallel to the horizon previously formed. Horizons which were separated to very considerable distances by shales or other strata probably are rarely exactly parallel to one another, or if so the parallelism is purely coincidental. There are other causes which also lead to the non-parallelism of the coal horizons. The original bottom of the shore may have been very uneven, as it is well shown in the very irregular surface of the Saint Louis limestone on which the Coal Measures of Iowa were laid down. Or, in two different areas the inequalities may be very great, the extremes often occurring in the same locality and thus presenting a much greater apparent unevenness than really exists. Erosion or currents may alter the position of the seams or parts of them. The top of the seams which were originally level become subsequently depressed in the center more than at the margins. There are also other causes tending to widen the seeming discrepancies.

In another direction, at right angles to the old shore, the minor basins along the different horizons may appear to show no tendency to parallelism at all. The approach to the parallel condition is inversely proportional to the amount of deformation occurring in the region at the time of the formation of the coal beds. Instead also of the seam being continuous for a considerable distance across the coal basins, as may be inferred from Winslow's graphic representation the productive coal strata should be confined to a limited marginal area and the coal horizon would only extend into the interior as a great stratigraphic

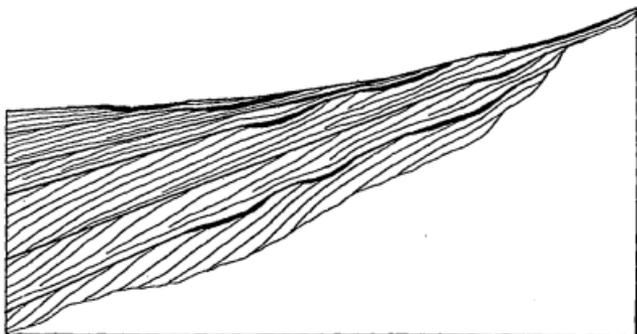


Figure 14. Coal Horizon Viewed at Right Angles to Shore-line.

ical plane, not easily recognizable perhaps, nor with any of the mineral itself to mark it. (Figure 14.)

The conditions described apply particularly to coal fields of Iowa and Missouri, where comparatively few disturbances of the strata have taken place. The relations are relatively simple. But in Ohio and Pennsylvania as the mountains are approached the structure increases rapidly in complexity, until in the highly folded and faulted districts attempts to follow out the original state of things may become utterly hopeless.

The majority of the larger coal deposits of the Western Interior field may be considered then as having been formed in swamps skirting a great shallow gulf, the extent of the productive portions of the different horizons being in a measure dependent upon the length of time the physical conditions were favorable to coal formation. Many short minor episodes doubtless existed between the larger ones during which comparatively small accumulations of vegetable material took place.

Another fact to be taken into consideration is that all the coal of the region was not formed in marine swamps, but that some of the minor basins were doubtless originally a very considerable distance from the sea, while certain others were formed with open sea conditions prevailing largely. A few seams also appear to have been formed as drift materials in estuaries at the mouths of streams.

