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This Thesis for the M.S. Degree, by
Thomas A. Hendricks
SOME DETAILS OF THE SEDIMENTATION OF THE MESAVERDE
FORMATION ON THE SOUTH SIDE OF THE
SAN JUAN BASIN, NEW MEXICO.

Department of

By

Thomas A. Hendricks, B.A.,

*Prof. George and
Staff of Department.*

A Thesis submitted to the Faculty of the Graduate
School of the University of Colorado in Partial Fulfill-
ment of the Requirements for the Degree M.S.

Department of Geology

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By

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ILLUSTRATIONS.

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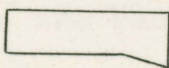
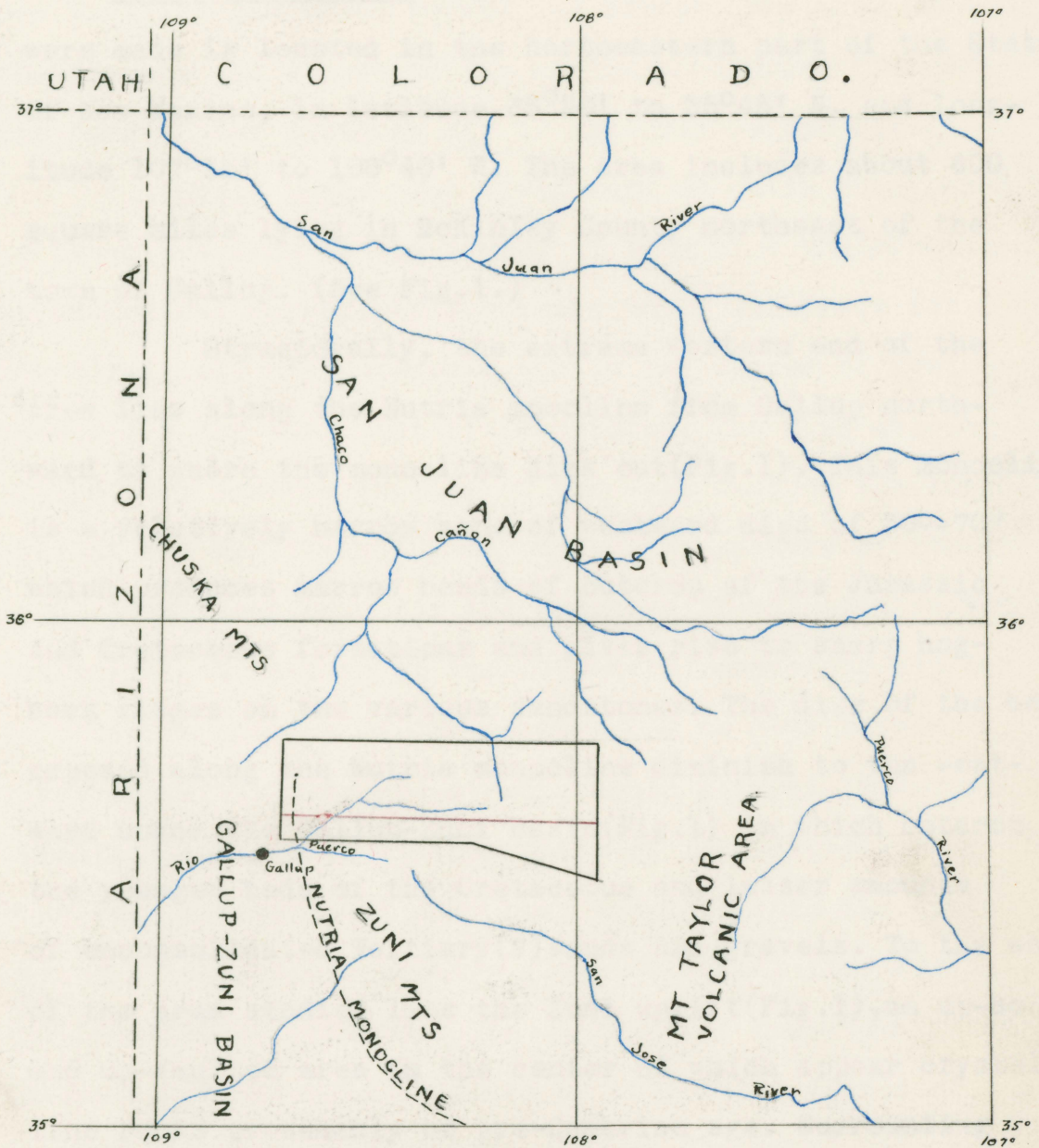
FIGURE 5a & 5b ----- 14

Area of studies on which
this paper is based.

Line of section. (Fig. 2.).

Scale-- 1 inch = 24 miles.

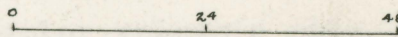
Fig. 1. INDEX MAP OF NORTHWEST NEW MEXICO; SHOWING LOCATION OF AREA AND RELATIONS TO THE SURROUNDING GEOLOGIC FEATURES.



Area of studies on which this paper is based.

Line of section, (Fig. 2.).

Scale-- 1 inch = 24 miles.



ed.

Introduction.

Location and area. The area in which these studies were made is located in the northeastern part of the State of New Mexico, in latitude $35^{\circ}30'$ to $35^{\circ}45'$ N. and longitude $107^{\circ}55'$ to $108^{\circ}40'$ W. The area includes about 600 square miles lying in McKinley County northeast of the town of Gallup. (See Fig.1.)

Structurally, the extreme western end of the area lies along the Nutria monocline from Gallup northward to where the monocline dies out (Fig.1). This monocline is a relatively narrow zone of westward dips of 30° - 70° which produces narrow bands of outcrop of the Jurassic and Cretaceous formations and gives rise to sharp hog-back ridges on the various sandstones. The dips of the beds exposed along the Nutria monocline diminish to the westward under the Gallup-Zuni Basin (Fig.1) in which outcrop the younger beds of the Cretaceous and lesser amounts of unconsolidated Tertiary(?) sands and gravels. To the south of the area studied lies the Zuni uplift (Fig.1), an up-bowed and up-faulted area in the center of which appear crystalline rocks presumably of pre-Cambrian age. Surrounding these are bands of outcrop of sedimentary formations ranging from Carboniferous to Cretaceous in age and dipping away from the uplift in all directions. To the east of the area lies the Mt. Taylor volcanic pile, made up of Tertiary basaltic extrusives and more acid intrusives. To the north-

ward lies the San Juan Basin (Fig.1) -a broad structural basin in which Cretaceous beds appear along the edges and Tertiary sediments toward the center. The area herein discussed is a part of the northward dipping Cretaceous beds of the southern rim of that basin.(See Fig.1)

Field work. The field work on which this paper is based was done in the summer of 1929 by a United States Geological Survey party, working under J.D.Sears for the first half of the summer and in the charge of the author for the last half of the summer. The main object of the work was the mapping of the coal beds of the lower part of the Mesaverde formation for the purpose of public land classification. For the purposes of correlation and determining structure it was necessary, however, to map certain barren members of the section and to note rather carefully lithologic and stratigraphic changes. Numerous detailed sections of various parts of the vertical section were measured and have been compiled into the composite stratigraphic section given in Fig.2. (See Fig.1 for location of section). The mapping was done with plane tables and telescopic alidades by either the stadia or the triangulation method, depending on the local nature of the topography and forest cover in the various parts of the area. Individual mapping was done by J.D.Sears, A.W. Quinn, W.S.Pike, Jr., Hubert O. DeBeck, and the author. Of

this, the greater part of the mapping and nearly all of the stratigraphic work was done by either Doctor Sears or the author, or one or both, working with other members of the party.

Previous work. The area has been discussed in varying detail by N.H.Darton, J.H.Gardner, H.E.Gregory, and C.E.Dutton. All these men did reconnaissance work and treated in no way the points discussed in this paper.

/ Darton, N.H., The "Red Beds" and associated formations in New Mexico: U.S. Geol. Survey Bull. 794, pp.179-183, 1928.

/ Gardner, J.H., The coal field between Gallup and San Mateo, New Mexico: U.S. Geol. Survey Bull. 341, pt. II, pp.364-378, 1907.

/ Gregory, H.E., Geology of the Navajo country: U.S. Geol. Survey Prof. Paper 93, pp.75-79, 1917.

/ Dutton, C.E., Mt. Taylor and the Zuni Plateau: U.S. Geol. Survey Sixth Ann. Rept., pp.111-183, 1885.

However, it seems appropriate to mention the work of Clark, Reeside, Sears and Bradley, and Stebinger in other

/ Clark, F.R., Economic geology of the Castlegate, Wellington, and Sunnyside quadrangles, Carbon County, Utah: U.S. Geol. Survey Bull. 793, pp.13-20, 113-119, and pls. 4 and 13, 1928.

Stephenson, L.W., Tongue, a new stratigraphic term,
 / Reeside, J.B.Kr., Upper Cretaceous and Tertiary formations
 of the western part of the San Juan Basin, Colorado and New
 Mexico.: U.S. Geol. Survey Prof. Paper 134, pp. 49-53, and fig.
 3, 1924.

/ Sears, J.D., and Bradley, W.H., Relations of the Wasatch
 and Green River formations in northwestern Colorado and
 southern Wyoming: U.S. Geol. Survey Prof. Paper 132-f, pp. 94-
 100, 1924.

/ Stebinger, Eugene, The Montana group in northwestern
 Montana: U.S. Geol. Survey Prof. Paper 90-g, pp. 61-68, 1914.

areas where they found similar conditions in beds of the
 same general age. Study of their reports indicates that
 the type of stratigraphic variation described here is not
 peculiar to this area but seems to have characterized the
 regional conditions in the widespread inland Cretaceous
 sea. This short dissertation is merely the construction of
 one small block which may later be fitted into a complete
 mosaic of the sedimentation throughout the entire Cretace-
 ous sea during the whole time of its existence, so far as
 those conditions are recorded in existing rocks available
 for study.

Attention is called to publications of A.W. Grabau/
 and L.W. Stephenson/ in which are stated some of

/ Grabau, A.W., Principles of Stratigraphy; A.G. Seiler and
 Co., pp. 723-745, 1924.

_/ Stephenson, L.W., Tongue, a new stratigraphic term, with illustrations from the Mississippi Cretaceous: Washington Acad. Sci. Jour. 7, pp. 243-250, 1917.

the principles so clearly illustrated in the stratigraphy of this area.

Limitations of the work. The outcrops in the area studied are in a series of east-west bands. Consequently, the observations given here are essentially two dimensional - vertical and east-west. The observed fact that lithologic changes were somewhat more rapid along a north-south line wherever observations could be made indicates that, unfortunately, the studies herein described were made on outcrops trending at an angle of about 30° to the shore-line at the time of deposition. These facts should be borne in mind while reading the observations and interpretations of the various stratigraphic features

Acknowledgments. The author wishes to express his thanks to Doctor Sears of the United States Geological Survey for the generous contribution of material, suggestions, and criticism in the process of compiling and analyzing field observations. He wishes also to express his appreciation to the other members of the field party for collecting data and to those of his associates who have added helpful suggestions and criticism.

Fig 2. Diagram showing stratigraphic variations from west to east across area. Top of I sandstone arbitrarily drawn level.
 Horizontal scale 1/62,500
 Vertical scale 1/62,500

Explanation

- | | | |
|---|---|--|
| J J coal measures | G G barren measures | C C sandstone |
| I I sandstone | F F sandstone | B
A A and B sandstones. |
| H H coal measures | D D sandstone | Marine shale |

1, 2, 3, etc. Approximate locations of chief stratigraphic changes.

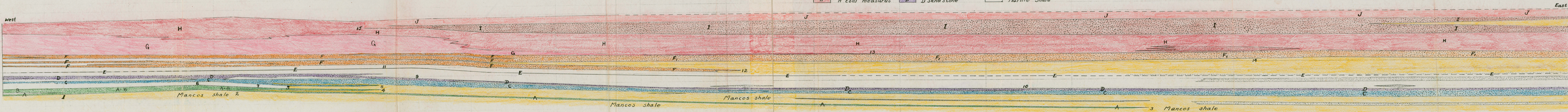


Fig 2

Stratigraphy and Sedimentation.

Underlying the Mesaverde formation in the Gallup-Zuni Basin is about 700 feet of Mancos shale- bluish gray, calcareous, fossiliferous marine shale, becoming sandy and less fossiliferous toward the top. Resting on the Mancos shale on the northeast side of the Gallup-Zuni Basin is the basal sandstone of the Mesaverde (Sand A fig. 2), a soft, buff sandstone, overlain in turn by continental shales. Since the Mancos shale- Mesaverde sandstone contact is gradational and since the basal Mesaverde sandstone is overlain by continental shales, the sandstone apparently is a regressive sandstone representing the final filling of the marine basin at that point. As the A sandstone is traced northward and eastward the overlying continental shale disappears and the B sandstone above it merges with the A sandstone. (Point 1, fig. 2). This suggests that the complete filling of the marine basin was not accomplished by the A sandstone and that the combined sandstone A and B represent the regressive sand of the Mancos sea for several miles. As the combined sandstone A-B is traced farther eastward, it is seen to be split by a tongue of marine shale. (Point 2, fig. 2). The lower of the sandstone tongues thus formed can be traced about twenty-five miles to the eastward (Point 3, fig. 2) to where it dies out into the Mancos shale. The upper sandstone tongue, which is the regressive sandstone of the Mancos

sea for a part of that distance, continues only a few miles to the eastward (Point 4, fig. 2) to where it also dies out into Mancos shale.

The succession of observations listed above indicates that deposition from the continental mass to the southwest was sufficiently more rapid than subsidence to force the margin of the Mancos sea eastward. However, subsidence was probably continuous, as continental beds to the westward grade, at the same horizon, eastward into marine beds.

Overlying the B sandstone at the west edge of the area is a sequence of continental shales. Traced eastward, they seem to thin and then grade into marine shales. (Point 5, fig. 2). This gradation was not observed, however.

The next higher bed at the west side of the area is the middle sandstone of the Gallup member of the Mesa-verde. (Sand C, fig. 2). Overlying it is a zone of continental shales--carbonaceous, sandy, non-fossiliferous shale locally containing beds of coal. Above this shale is the upper sandstone of the Gallup member. (Sand D, fig. 2). Both the middle and upper sandstones of the Gallup are at this point medium to coarse-grained, white to buff to red, irregularly bedded to massive sandstones, apparently of continental origin. As this three-fold sandstone-shale-sandstone group is traced eastward, the upper sandstone is seen to cut out the shale and merge with the lower sandstone for a short distance. (Point 6, fig. 2). Farther to the eastward (Point 7, fig. 2) the C sandstone thickens rather abruptly

and a tongue of marine shale wedges into the lower part. The tongue of sand thus formed dies out in a short distance into Mancos shale. (Point 8, fig.2). This C sandstone grades downward into the marine Mancos shale, is fine-grained, buff, and rather uniformly bedded; this would indicate that it is a marine sand. The D sandstone - white, in coarse-grained, cross-bedded, and sun cracked (east of point 6, fig.2) - is in contact with the C sandstone at point 9, (Fig.2) and almost continuously from point 10 (Fig.2) to the east side of the area. However, between points 9 and one 10 (Fig.2) the two sandstones are separated by continental shales bearing local coals, and continental shales and coals appear locally between the two from point 10 (Fig.2) to the east side of the area. Thus, sandstone C appears to be the local regressional sandstone of the Mancos sea between point 7 (Fig.2) and the east side of the area. The local areas of continental shale and coal indicate that swamps in which peat accumulated were developed on the top of this sandstone. Following the accumulation of the peat, accelerated subsidence caused a slight advance of the sea, resulting in the formation of sandstone D which from the characteristics listed above seems to have been a beach sand. One interesting feature is that the D sandstone is consistently a beach sand for a distance of at least 35 miles along the present outcrop. This suggests that the present line of outcrop of D sandstone is essentially along what was the shore line at the time of deposition of the sandstone.

Following the deposition of sandstone D was a period of slow subsidence during which peat formation took

ce following the deposition of the continental beds above place. At that time, the lower coal measures were formed in a continuous zone across the area. The highest coal or coal zone of this group is represented by some E (Fig.2).

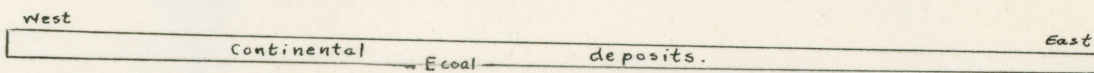
After the accumulation of the peat which later became coal E deposition of continental shales continued in the western part of the area up to the continental Otero sandstone group (Group F, fig.2). The Otero group is a series of continental sandstones, shales, and thin coals. To the eastward, the amount of sandstone increases, the shales become more sandy, and the coals thin out, until at point 11 (Fig. 2) there is an almost unbroken continental sandstone sequence. In a short distance to the east of point 11, however, marine shale splits the sandstone group, both the upper and lower resultant sandstones become marine, and the lower one tongues out into marine shale. (Point 12, fig.2) From point 12 eastward thick marine shale is present and grades upward into a regressive marine sandstone (Sandstone F₁, fig.2). This regressive F₁ sandstone is immediately overlain by coal measures from point 13 (Fig.2) eastward.

The sequence of events following the formation of the E coal group may be explained in two ways, depending on the method of formation of the regressive sandstone F₁. The interval between the E coal horizon and the top of the F₁ sandstone at point 11 is 220 feet, while 30 miles to the eastward, at point 14, the interval is 340 feet. This divergence may be explained on the assumption that the subsiden-

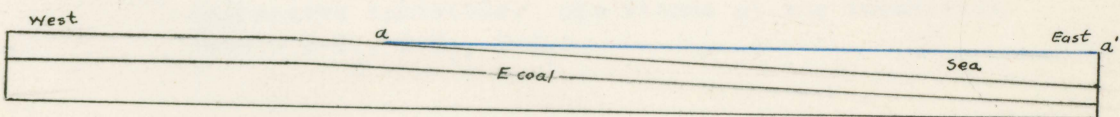
11.

ce following the deposition of the continental beds above the E coal group was differential and that the eastern part of the area was depressed more than the western part. (See fig.3). While this subsidence was progressing, marine shales were being formed to the northeastward and long enough period of time for the shore sands to build outward and cause the restriction of the sea. Such a sand

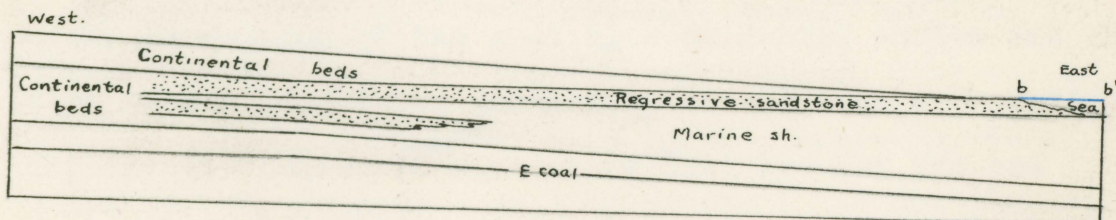
Fig. 3. Diagram illustrating successive steps in the formation of a regressive sandstone with a varying interval to a coal bed below.



a. Deposition of E coal and overlying beds.



b. Differential subsidence, greater toward east.



c. Continued subsidence until level b-b' is reached, with the sea becoming stationary at that point and then forming a regressive sandstone.

marine shale to the eastward, due to minor fluctuations in the rates of deposition and subsidence. However, after continental beds to the southwestward, while marine sands the level B-B₁ was reached, the rate of deposition was more were being formed in a narrow zone along the shore. Following that came a period of stability during which the land sank, the sand accumulation not only continued upward sea stood at a single level (level b-b' in fig.3b) for a but was able to encroach on the sea as well, so that by the long enough period of time for the shore sands to build time the sea had reached the level G-G₁, the shore line had outward and cause the restriction of the sea. Such a sand moved upward and seaward along the line B-G and regressive would be expected to have a level top. (See Fig.3 c).

An alternative explanation of the conditions of formation of these particular beds is given by Fig.4. Contemporaneous with that was the accumulation of marine sands and silts in the zone GG₁F₁F. Also contemporaneous

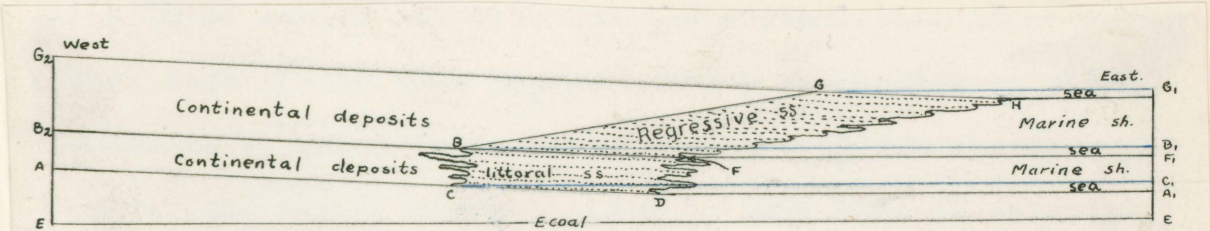


Fig. 4. Alternative explanation of method of formation of a regressive sandstone. Sea stands at the successive levels C-C₁, B-B₁, G-G₁.

during the period of sand deposition.

Returning to Fig.2, the regressive sandstone F₁ After deposition of the coal E, continental shales and sands overlies the marine shales and is overlain by coal-bearing were deposited, sloping seaward, up to the line A-C. Following that was increased subsidence that brought the sea in to the west of this is a zone of barren continental non-fossiliferous sands (Group G, fig.2) which were probably formed by stream deposition prior to the beginning of the retreat of the sea. However, as the regressive sandstone F₁ was building the shore line outward, the gradients of the rivers were marine sand accumulation would be in a zone CBFD, with an intertonguing of continental beds to the westward and of

marine shale to the eastward, due to minor fluctuations in the rates of deposition and subsidence. However, after the level $B-B_1$ was reached, the rate of deposition was more rapid than the rate of subsidence. This means that as the land sank, the sand accumulation not only continued upward but was able to encroach on the sea as well, so that by the time the sea had reached the level $G-G_1$ the shore line had moved upward and seaward along the line $B-G$ and regressive marine sand accumulation had taken place in the zone $BGHF$. Contemporaneous with that was the accumulation of marine muds and silts in the zone GG_1F_1F . Also contemporaneous with these marine deposits was the accumulation of continental beds in the zone BB_2G_2G . Such a regressive sandstone would be expected to be intertongued with the marine shale. However, the top of the sandstone in this case is relatively smooth and shows no intertonguing, which indicates that the rates of deposition and subsidence were remarkably constant during the period of sand deposition.

Returning to Fig. 2, the regressive sandstone F_1 overlies the marine shales and is overlain by coal-bearing beds. Apparently continuous with these continental beds and to the west of them is a zone of barren continental non-fossiliferous shales (Group G , fig. 2) which were probably formed by stream deposition prior to the beginning of the retreat of the sea. However, as the regressive sandstone F_1 was building the shore line outward, the gradients of the rivers were

naturally being decreased and swampy conditions were becoming prevalent. Consequently, the coal zone H was developed on top of the barren zone G and later on top of the regressive sandstone F₁.

The period of regression gave way in time to advance of the sea onto the coal measures H, and the transgressive sandstone I was formed. Just below this sandstone, in the top of the coal measures H, were occasional brackish-water oyster beds of very local extent, and occasional beds of coal are found in the base of the sandstone, which is rather an indistinct boundary at many places. These features indicate that the transgression was relatively slow, and that with the accelerated subsidence, peat accumulation was continuing to the westward simultaneously with the formation of the transgressive marine sandstone. (Fig. 5a). Farther seaward to the northeast, marine shales were being formed contemporaneously with this sand and were resting on the part of the transgressive sandstone formed at a lower stage of the sea. (Fig. 5a).

The transgressive sandstone I advanced to the position 15 (Fig. 2). When the sea had reached that point, however, the balance again swung so that deposition progressed more rapidly than subsidence, and the sea was again forced eastward. (Fig. 5b). Thus, while the base of the sandstone I is transgressive, the top is regressive. In this regressive sandstone show the typical characteristics of a late as the sea was forced eastward by the sediments. Also,

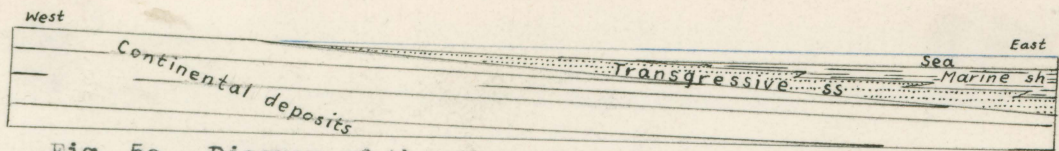


Fig. 5a. Diagram of the contemporaneous formation of transgressive sandstone, marine shale, and continental beds.

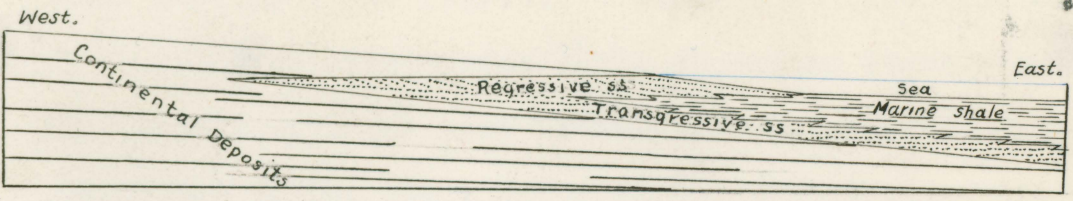


Fig. 5b. Diagram of the formation of a transgressive sandstone changing upward into a regressive sandstone. Also shows the contemporaneity of several types of beds.

beach or littoral sand. It is white, apparently rather pure, ripple-marked, cross-bedded, and sun-cracked, while less striking farther to the eastward, some of these characteristics are present across the entire area.

The renewed dominance of deposition over subsidence did not interrupt the accumulation of peat on the continental area as the coal measures J were formed (Fig. 2). Therefore, the coal measures over which the transgressive sandstone advanced and which were being accumulated to the westward simultaneously with the formation of the sandstone to the east (Fig. 5a), continued to accumulate as the sea was forced eastward by the sediments. Also,

as the regressive sandstone was formed farther and farther eastward, the coal measures advanced eastward on top of it. (Fig. 5a). Thus, the coal measures are continuous to the west of the area of formation of the transgressive and regressive sandstones. (Fig. 2). However, the coal zone is split eastward by those sandstones, the lower coals being overlain by the transgressive sandstone, and the upper coals overlying the regressive sandstone. (See Fig. 5b).

Similarly, marine shale deposited seaward contemporaneously with one part of the transgressive sandstone and on top of the older parts of the sandstone, advanced westward with the transgression of the sea. Also, these shales continued to be formed seaward as the regressive sandstone was deposited, but retreated progressively eastward with the recession of the coast line. That means that the marine shale has the form of a westward pointing wedge, overlying and intertongued with the regressive sandstone, and being absent where the transgressive and regressive sandstones have coalesced. (Fig. 5b).

Above the coal measures J resting on the regressive sandstone is a great thickness of barren continental siltstones or mudstones, including some irregular sandstones and thin coals. Since these beds were not studied in detail, the conditions under which they were formed will not be discussed.

Synopsis.

The area in which these studies were made was on or near the southwestern shoreline of the Cretaceous sea during late Mancos-early Mesaverde time. The area was one of progressive but variable subsidence that may have been somewhat greater to the east than to the west or may have been essentially the same over the entire area. However, as the subsidence progressed, the balance between the rate of subsidence and the rate of deposition fluctuated so that the shoreline migrated seaward as deposition became dominant and landward as subsidence became dominant. In general, however, deposition was more rapid than subsidence. These conditions produced an intertonguing of marine and continental beds, a series of transgressive and regressive sandstones, and a general eastward migration of the shoreline of the Cretaceous sea.

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