STATE GEOLOGICAL SURVEY *of* KANSAS
RAYMOND C. MOORE, State Geologist

BULLETIN 11

GEOLOGIC INVESTIGATIONS IN WESTERN KANSAS

With Special Reference to Oil and Gas Possibilities

I. Geology of Ellis County
II. Geology of Hamilton County
III. Geologic structure of the Dakota sandstone
IV. Structure and limits of the Kansas salt beds

By N. W. BASS

Prepared in coöperation with
The United States Geological Survey

Printed by authority of the State of Kansas

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PART I
GEOLOGY OF ELLIS COUNTY

PART II
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PART III
GEOLOGIC STRUCTURE OF THE DAKOTA SANDSTONE

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Geologic Investigations in Western Kansas.

INTRODUCTION.

By Raymond C. Moore.

THE report which is here offered by Mr. N. W. Bass does not undertake to consider exhaustively the oil possibilities of the entire western portion of Kansas, but presents rather the results of some months of field and office work on the subject of oil possibilities in western Kansas, continuing studies begun in Russell county by Messrs. Rubey and Bass[1] after commercial quantities of oil were discovered in this part of the state. The present investigation has involved special study of two counties—Ellis, which borders Russell county on the west, and Hamilton, which adjoins the Colorado boundary where the Arkansas river enters Kansas. In addition, a rapid reconnaissance of most of the remainder of western Kansas has been made in connection with the preparation of a regional structure map on the Dakota sandstone and to supplement other work on the subsurface geology of the region. The exposed formations in the vicinity of deep borings have been examined as an aid in making correlations of the rock formations penetrated in these borings. Thus, Mr. Bass' report presents, first, relatively detailed information concerning the stratigraphy, structure, underground geology and oil possibilities of two typical parts of western Kansas; and second, broad regional studies of a reconnaissance nature on the structure of the Dakota sandstone and the distribution and structure of the Permian salt.

One of the objects of the geologic investigation of Russell county was the determination of reliable key beds for structural mapping in areas where Cretaceous formations other than the hard Greenhorn limestone beds are exposed. The Greenhorn beds make persistent escarpments and can be followed by the geologist in determining the local geologic structure in essentially the same fashion as the limestones in the oil fields of eastern Kansas and Oklahoma. It was found that there are traceable key beds in other Cretaceous formations, although in general these beds are not so easily followed as the resistant limestones in the Greenhorn. With reference

1. Rubey, W. W., and Bass, N. W., The geology of Russell county, with special reference to oil and gas resources: Kansas Geol. Survey Bull. 10, 1925.

to oil and gas possibilities in other parts of western Kansas, it was also important to learn the nature of the fold along which oil was found in Russell county and the age and structural relations of the rocks underground where the oil occurs.

The investigations undertaken in Ellis county are a logical continuation of the Russell county studies. The Graneros, Greenhorn and Carlile formations are widely exposed in the southern, eastern and northern parts of Ellis county, and the surface structure should be rather readily determinable here, as in the Russell county district. In the central and northwestern parts of Ellis county, however, are areas covering many square miles which are underlain by higher Cretaceous rocks belonging to the Niobrara formation. Several anticlinal folds have been mapped by geologists in the Niobrara beds of Trego, Gove and Logan counties, but a question has been raised as to whether these anticlinal folds really exist or whether their supposed occurrence is based on misinterpretation of local dips that result from slumping or local faulting. Definite mappable key beds appear to be lacking in the chalk, and the determination of the supposed anticlinal folds was based on observation of dips rather than the mapping of persistent identifiable beds.

In the Ellis county district, where both the Niobrara formation and the underlying mappable beds in the Carlile, Greenhorn and Graneros formations are exposed, opportunity is probably afforded to determine, at least in some localities, whether the chalk beds are actually folded in such a way as to make observations of dip and strike reliable in determining underground structure, or whether owing to slumping and more or less intricate irregular faulting, such observations have little or no value. An important part of Mr. Bass' work in Ellis county was therefore directed to a study of the Niobrara formation. Is there pronounced slumping along the borders of the chalk, where the presence of weak shale outcropping in a slope underneath the chalk affords the best opportunity for slumping? Are there numerous faults in the chalk that are not present in the adjacent shale and thin limestone, showing that the chalk has responded to deformation in a very different way from associated beds? If this is the case, what is the explanation of the faulting? Is there a systematic arrangement of the faults, so that their trends and the amount of their throw may be used to interpret regional deformation of the underlying strata? Especially, is it possible to find in the chalk any means by which exact horizons may be recognized and traced in mapping?

As outlined in Mr. Bass' report on Ellis county, more or less satisfactory answers to these questions have been obtained. Probably the most valuable results of the Ellis county investigation will appear not simply in the discussion of oil and gas possibilities in this particular county, but in the application of observations made here to the several other counties in which the same rock formations are exposed at the surface. In this way, the Ellis county and also the Hamilton county investigations apply to most of western Kansas.

The selection of Hamilton county for special field study was based primarily on the known occurrence southwest of Syracuse of an anticlinal fold mapped by N. H. Darton, of the United States Geological Survey.[2] Cretaceous rocks corresponding in a general way to those studied in Russell and Ellis counties are exposed along the Arkansas river and locally elsewhere in the county. Most of the rock exposures, however, are small. Because each part of the rock series more or less closely resembles another, especially in the shale areas, no effort had been made previously to present detailed correlations and to determine exact stratigraphic equivalence between isolated outcrops. After the discovery that in Russell and Ellis counties thin beds of bentonite in the beds beneath the chalk may be used in the identification of exact horizons, it seemed desirable to apply methods of precise correlation and mapping to this western area, and to determine as accurately as possible the nature of the anticlinal fold reported by Darton. This investigation was the more important in connection with the study of western Kansas conditions in general, because the drilling of a deep test was in progress on this anticline. Through the courtesy of the operators samples of drill cuttings were procured and have been studied in the laboratory of the Kansas Geological Survey. The Hamilton county report thus presents information concerning a typical part of extreme western Kansas, and the knowledge of surface and underground geologic conditions in that county may be used in studying adjoining districts.

The regional map of the Dakota sandstone is an important contribution to the study of oil and gas possibilities in the western part of the state, for the reason that this rather readily traceable geologic unit affords one of the most satisfactory datum planes for the determination of geologic structure in a broad way. The map that

2. Darton, N. H., Structure of a part of the Great Plains: U. S. Geol. Survey Bull. 691, p. 7, 1918; U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin folio (No. 212), 1920.

has been prepared by Mr. Bass shows several modifications from the older, generalized map prepared on much less detailed information by N. H. Darton.[3] As explained by Mr. Bass, evidences of anticlinal folding in certain parts of the state seem to offer possibilities for oil and gas production that are comparable to those in Russell county and perhaps along the buried granite ridge farther east.

A study of the distribution of the salt and its structure is very interesting in that it affords a comparison of the structure in the older rocks with that in the series that crops out at the surface. The fact that salt appears to be absent in the region of the apparent axis of the fold extending west of south from Decatur and Norton counties seems to indicate the persistence of a structurally high area in the older rocks across which the salt either was not deposited, or, if deposited, was removed by subsequent erosion due to local uplift along this line. In view of the well-known oil and gas developments of the Amarillo district, in the panhandle of Texas, the finding of gas in Seward county, Kansas, and the observations of structure that are here presented, the possibilities of commercial production of oil and gas in this part of western Kansas seem promising.

3. Op. cit., pl. 1.

PART I.

The Geology of Ellis County, Kansas.

FIELD WORK.

THE field work on which the report on Ellis county is based was done between the first of July and the middle of August, 1924. Inasmuch as the details of much of the stratigraphic section below the Niobrara formation exposed in Ellis county are similar to those in the area adjacent on the east, which was known to the writer from his work there with W. W. Rubey in the spring of 1924, the necessity for a great number of detailed geologic sections of these rocks in Ellis county was eliminated. Many sections of parts of the Niobrara formation were measured, however, in order to determine whether persistent recognizable units are present. The area was traversed by automobile, driven along section-line roads, and although all the lines are not open the county was covered with a fair degree of thoroughness. In this traverse the boundaries of the several formations and members and other key beds were sketched throughout the county, the topographic maps of the United States Geological Survey being used as a base.

ACKNOWLEDGMENTS.

During the field investigation county officers and other residents of Ellis county gave all possible assistance in supplying records of water wells and other information. The writer is indebted to C. J. Helms, of Ellis, for records of a large number of water wells drilled in Ellis county and elsewhere in western Kansas; and to J. F. Kinkel, geologist of the Keys Petroleum Co., for core-drill records and stratigraphic information on the Niobrara formation in near-by areas, and to H. L. Baldwin of the Mississippi Valley Oil Co., for detailed sections of the Smoky Hill chalk member in Trego county. Appreciation is expressed to Mrs. N. W. Bass for her assistance in the field mapping, and to W. C. Mendenhall and R. C. Moore, who spent a few days in the field, for many helpful discussions and suggestions. J. B. Reeside, Jr., also visited the area in connection with work in Russell county earlier in the year and rendered valuable assistance in the identification of fossils and in the delimitation of

stratigraphic units. The writer is especially indebted to W. W. Rubey for his field work in parts of Ellis county, done in connection with a geologic study of Russell county, and his continued interest and valuable criticism in connection with the compilation of this report. Thanks are due also to W. T. Thom, Jr., R. C. Moore, and C. S. Corbett for criticisms and suggestions in the assembling of the data.

Geography, Location and Culture.

Ellis county is only a short distance west and north of the center of Kansas. (Fig. 1.) It is approximately 30 miles square and contains about 576,000 acres. The main line of the Union Pacific rail-

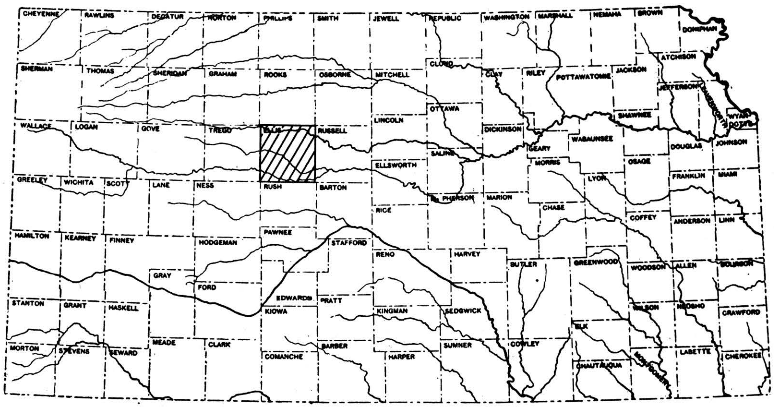

Fig. 1. Index map of Kansas showing location of Ellis county.

road between Kansas City and Denver crosses the middle part of the county in an east-west direction. Hays, the county seat, with a population of about 3,300 according to the census of 1920, is the largest town in the county, and Ellis, with 2,000, is the next. A state teachers college and a large agricultural experiment station are located at Hays. Ellis is a division point on the Union Pacific railroad, and the company maintains railroad shops there. There are nine small towns in the county, shown on the geologic map, Plate I. The U. P. Highway, a well-graded automobile road, parallels the railroad across the county, an excellent north-south highway passes through Hays, and well-graded roads throughout the county are kept in good repair and afford means of access to nearly all parts of the area. The only parts containing few roads are the rugged stretches along the outcrop of the Fort Hays limestone member of the Niobrara formation, north and south of Saline river in the northern part of the county and south of Smoky Hill river in the southwestern part.

The area is practically treeless except for narrow lines of trees along the principal streams and for small groves here and there surrounding farm buildings. The native soil covering is an excellent sod, predominantly of buffalo grasses and grama, growing on a dark brownish-gray silt loam.

Wheat raising is the chief industry, although there is an increasing tendency toward diversified farming with wheat as the principal crop. Substantial farm buildings, motor trucks, and pleasure cars indicate on the whole a fair degree of prosperity. Because of low rainfall, paying crops are not raised every year, and the wheat grower has become accustomed to experiencing crop failures to balance against bumper years.

TOPOGRAPHY.

Ellis county lies at the eastern margin of the High Plains. Its characteristic topographic features are broad, relatively flat upland benches, deeply incised by the main drainage channels; these main streams flow east, and their valleys are markedly steeper on the south sides than on the north sides. The broad benches rising gently westward, and margined by scarps that face eastward, are controlled by the harder rocks that crop out at the surface. The highest bench which occupies the high divides in the west half of the county, is supported by the relatively resistant Tertiary "mortar beds" of the Ogalalla formation; the next bench is held up by the Fort Hays limestone member of the Niobrara formation; and the lowest widespread bench by the top of the Greenhorn limestone.

The altitude of the surface above sea level ranges between 2,400 feet near the southwest corner of the county to 1,700 feet in the northeastern part, where Saline river crosses the county boundary. The maximum relief in the southwestern part of the county is 360 feet in 4 miles, and at places along the Saline in the northern part it is 200 feet in less than a mile. Both Saline and Smoky Hill rivers have an average fall in a straight line across the county of approximately 10 feet to the mile.

Stratigraphy.

The rocks exposed in Ellis county are of Quaternary, Tertiary, and Cretaceous age, and the drill has penetrated also Permian and Pennsylvanian rocks. The lowest rocks exposed appear along the Smoky Hill river in the southeastern part of the area. The thick shale members of the Cretaceous make gently graded, soil-mantled slopes over a large part of the county, but are well exposed in the extreme southwestern part and along Saline river in the northern part. The uppermost beds of the Cretaceous section represented here are best exposed in the northwestern part of the county, and the Tertiary rocks in the western part. The Quaternary deposits occupy the flood plains of the streams.

The following table gives the salient features of the formations exposed. More detailed descriptions follow this table.

TABLE I.—*Stratigraphic section of outcropping rocks in Ellis county, Kansas.*

AGE.	Formation and member.	Lithologic character.	Thickness (feet).
Recent.		Alluvium in stream flood plains.	0–40
Pleistocene (?).	McPherson (?) formation.	Gravel terraces along Smoky Hill and Saline rivers.	0–20
Pliocene and late Miocene.	Ogalalla formation.	Gravel, sand, clay, and "mortar beds" occurring on high divides throughout the county.	0–75
	——— Unconformity ———		
Upper Cretaceous.	Niobrara formation: Smoky Hill chalk member.	Chalky shale, interbedded with massive, brittle chalk. Weathers pure white, yellow, and orange. Forms badlands. Top not exposed.	100
	Fort Hays limestone member.	Massively bedded cream-colored chalky limestone. Makes prominent bluffs bordering main stream courses.	55
	Carlile shale: Blue Hill shale member.	Gray-black fissile clay shale, with Codell sandstone bed at top, and several layers of calcareous septarian concretions. Thins southwestward.	175–215
	Fairport chalky shale member.	Chalky shale interbedded with thin layers of chalky limestone, which increase in number toward the base. Thins northeastward.	85–115
	Greenhorn limestone: Pfeifer shale member.	Chalky shale interbedded with thin layers of soft chalky limestone. Top bed known as "fence-post limestone." Makes low bench.	20
	Jetmore chalk member.	Alternating thin beds of chalky limestone and chalky shale. Limestone in upper half abundantly fossiliferous. Makes pronounced bench.	20
	Hartland shale member.	Chalky shale with few thin beds of chalky limestone. Makes gentle slope.	35
	Lincoln limestone member.	Yellowish, tan-weathering chalky shale with hard thin-bedded, finely laminated crystalline limestone at top and base. A few thin beds of chalky limestone. Makes low bench.	20
	Graneros shale.	Dark bluish-black shale with bed of sandy ironstone near base and a few sandy calcareous lenses above. Shale has bitter taste.	32–40
	Dakota sandstone.	Fine-grained white sandstone, irregularly bedded, and red, white, and mottled clay and sandy shale. Base not exposed.	20+

Quarternary System.

Recent Series.

Accumulations of alluvium of Recent age cover a narrow zone constituting the present flood plain and low terraces in the valleys of the major streams.

Pleistocene (?) Series.

A higher, rather distinct terrace occurs on the south side of Smoky Hill river, 80 to 120 feet above the present stream level, in the southwestern part of the county, and extends westward on both sides of the river entirely across Trego county which is adjacent to Ellis county on the west. This terrace is covered with relatively coarse gravel, much of which consists of fragments of chalk, chert, *Inoceramus* shells, and material derived from the Ogalalla formation. Gravel composed of similar material occupies a large area of the surface in T. 13 S., Rs. 16 and 17 W., and on the divide sloping southeastward between Big Creek and its North Fork. Pleistocene fossils indicating a correlation with the McPherson formation were found along Smoky Hill river in Russell county [1] in a gravel that is probably continuous with these gravel beds in Ellis county. A prominent terrace that lies 50 to 75 feet above the present grade of Saline river in the north-central and northeastern parts of the county was possibly developed at the same time as the one on Smoky Hill river.

Tertiary System.

Ogalalla Formation.[2]

Long tongues of sand, gravel and clay, in part cemented with lime, having a maximum thickness of 75 feet, cap the highest divides throughout the northwestern half of the county and mark the eastern margin of the High Plains. The character and physiographic relations [3] of these deposits indicate that they belong to the Ogalalla formation, which is widespread throughout western Kansas and Nebraska.[4] This formation unconformably overlies the Smoky Hill chalk member of the Niobrara formation in Ellis county, and in other parts of western Kansas it overlaps Cretaceous rocks from

1. Kansas Geol. Survey Bull. 10, p. 21, 1925.
2. The spelling of Ogalalla here used, is that adopted by the United States Geographic Board.
3. See Kansas Geol. Survey Bull. 10, p. 23, 1925, for a discussion of the application of these criteria to outliers of the Ogalalla formation in central Kansas.
4. Darton, N. H., U. S. Geol. Survey, Geol. Atlas, Syracuse-Lakin folio (No. 212), 1920.

the Pierre shale to the Dakota sandstone. The surface of the southward-facing slopes grades so evenly into that of the underlying formation and is so completely mantled by soil that the contact between the two is difficult to determine. On the northward-facing slopes, however, bluffs, usually with two benches, constitute the characteristic topographic expression of the formation.

Owing to the cementation of some of the beds with lime carbonate they greatly resemble a mortar of coarse material, and these harder portions have long been called "mortar beds."[5] (Fig. 3.) The material other than the "mortar beds" is uncemented or very loosely cemented intermixed and interbedded sand, clay, and gravel, containing some lime. Johnson,[6] in the first part of his treatise on the High Plains, discusses the origin of these "mortar beds" and concludes that they mark old stands of the ground-water table. River waters carrying small amounts of calcium carbonate, upon entering lakes such as Great Salt Lake, in which the water is salty and concentrated, throw down much of their calcium carbonate. Johnson thinks that the Ogalalla formation at the time of its deposition (by drying streams) contained a ground water with appreciable amounts of dissolved salts other than calcium carbonate; he likens this ground water to that of such salty lakes, and the surface waters charged with calcium carbonate that percolated downward at that time to such river waters. Under these conditions calcium carbonate was accumulated in sheet form in the gravel, sand, and clay at the old ground-water levels. Although the "mortar beds" cut horizontally across lenses of fine as well as coarse material, they occur in greatest amount in the coarser sand and gravel, because it is in such material that the freest circulation of water would occur, and consequently the greatest amounts of calcium carbonate would be carried there.

In much of its area in Ellis county the Ogalalla formation contains two thick "mortar beds," and in some places three layers are present. Figure 3 shows a typical northward facing scarp of the formation. A prominent butte near the southwest corner of the county, in T. 15 S., R. 20 W., that is capped by the Ogalalla, shows three "mortar beds." The total thickness there is 55 feet; the two lower hard layers are each 8 to 10 feet thick, 8 feet of intervening softer material forms a gentle slope, and the uppermost hard layer caps the

5. Hay, Robt., U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 570, 1895.

6. Johnson, W. D., The High Plains and their Utilization: U. S. Geol. Survey, Twenty-first Ann. Rept., pt. 4, pp. 643-656, 1901.

KANSAS GEOLOGICAL SURVEY
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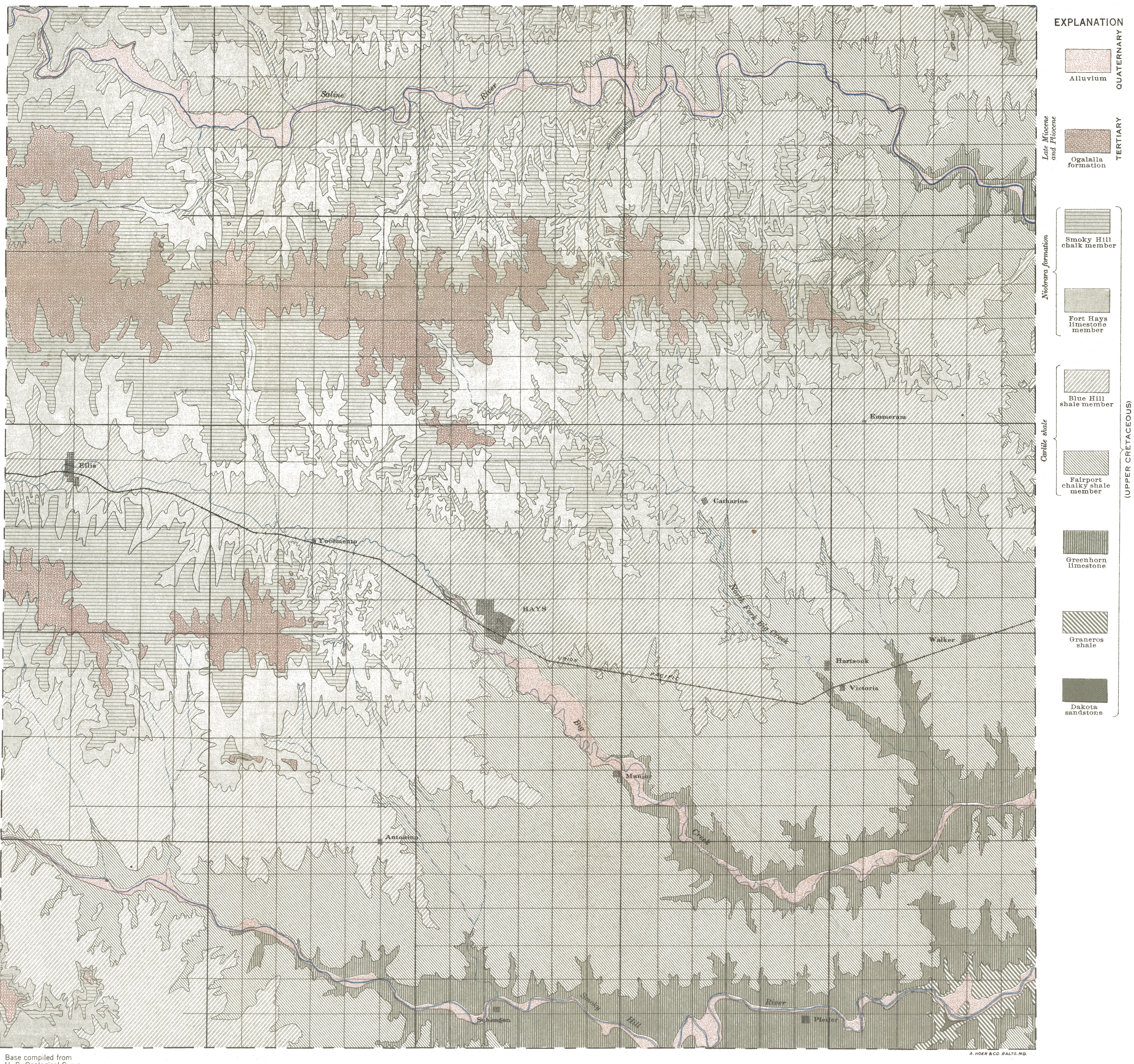
PLATE I.



Base compiled from
U. S. Geological Survey
Topographic maps.

A. HOEN & CO. BALTO. MD.

RECONNAISSANCE GEOLOGIC MAP OF ELLIS COUNTY, KANSAS
BY N. W. BASS

Scale 1/125000

1 ½ 0 1 2 3 4 5 Miles

hill. Nodules of chert ranging from a fraction of an inch to 2 inches in diameter are strewn upon the surface of each bench in this exposure and elsewhere in the county. The low knolls in the central part of T. 14 S., R. 19 W., are capped by chert derived from weathered "mortar beds."

FIG. 2. Cross-bedding in the Ogalalla formation. T. 26 S., R. 26 W., Ford county. View northeastward.

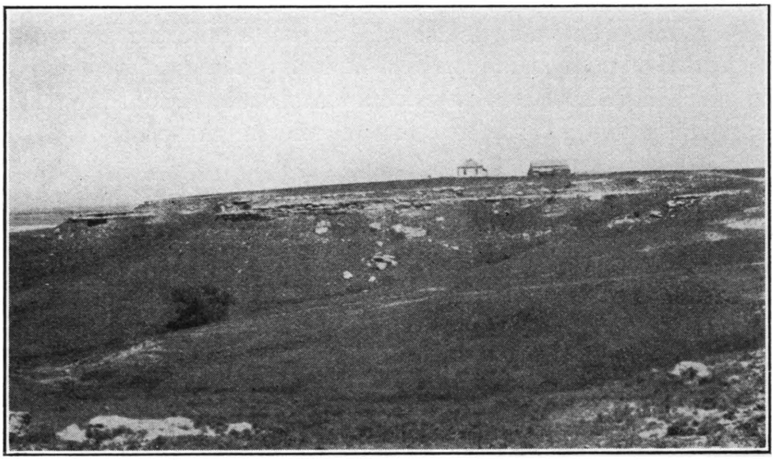


FIG. 3. Typical outcrop of "mortar beds" of Ogalalla formation on north facing slope. Sec. 3, T. 12 S., R. 20 W., Ellis county. View eastward.

Cretaceous System.

Niobrara Formation.

In western and northwestern Ellis county about 150 feet of the basal part of the Niobrara formation is in places excellently exposed in bare bluffs and badlands. In Kansas the formation has been separated into two readily recognizable members—the Smoky Hill chalk above and the Fort Hays limestone below.

Smoky Hill chalk member. About 100 feet of the basal part of the Smoky Hill chalk member is exposed below the overlapping Ogalalla formation in Ellis county. It consists of marl beds alternating with chalk and thin beds of clay. The member occupies a relatively broad area in the western part of the county, forming the gently rolling table-land above the Fort Hays limestone bench and below the Ogalalla formation. Because of the abundance of chalky shale and soft chalk it breaks down into smooth, gently graded slopes throughout most of its area of outcrop, but in some localities, particularly in the northward-facing slopes, it makes bare, intricately dissected badlands. There the more calcareous beds caseharden upon weathering and form protecting caps for the softer silty parts. This differential weathering results in buttes and scarps of fantastic shapes that range in color from a dazzling white through yellows to orange and orange-red. The harder chalk beds range in thickness from an inch to more than 1½ feet. A marked characteristic of the exposed Smoky Hill beds is the abundance of flat, circular limonitic concretions averaging about 10 or 12 inches in diameter, many of which have central cores of pyrite that occupy molds of fossil shells of *Inoceramus* (*Haploscapha*) *grandis*. Unaltered specimens of these large *Inoceramus* shells covered with masses of *Ostrea congesta* are quite as common as the limonitic concretions. In a few places lenses of a black, shiny carbonaceous, coaly-looking substance an eighth to a quarter of an inch thick and extending laterally for only a foot or two were seen in this member.

Because the member crops out over an extensive area, principally north and west of Ellis county, and presents the only possibilities for structural mapping throughout so much of western Kansas, the greater part of which is mantled by the Ogalalla formation, considerable stratigraphic detail was obtained in the hope that mappable marker beds might be found. The statement is frequently heard that the hard and soft beds in this member were not definitely stratified, but that the difference in hardness is merely a matter of weathering; in other words, that there are no beds in this member that can be traced reliably over distances sufficiently great to justify their use as key beds for structural mapping. Attempts have been made to follow bands of color in the weathered chalk, only to find that color changes transgress the bedding and are not confined within stratigraphic boundaries. Many domes and anticlines have been mapped in the areas of outcrop of the Smoky Hill member, in which the configuration of the contour lines has been based solely on dip readings. Because in the region of their outcrop the chalk beds are nearly everywhere intricately cut by faults, there appears to be at least some basis for doubt as to the value of this method of structural mapping in this region. Detailed study of the rocks lying within the interval of 70 feet above the base of the member afforded proof that there are two series of beds within these rocks that can be traced definitely. The outcrops of these two series of beds, usually the best-exposed parts of the member, were mapped throughout an area of 10 square miles in the northwestern part of Ellis county and were definitely recognized 10 miles or more farther away, but no attempt was made to trace the beds beyond the limits of the county. Although beds stratigraphically higher in the Smoky Hill member have not been studied in detail, reconnaissance observations of a series of hard and soft chalky shales and chalk with a few interlaminated bands of bentonitic clay, exposed in central and southern Logan county, 100 miles west of the area here discussed, lead the writer to the belief that key beds are present also within the higher portion of the Smoky Hill member.

The rocks that occupy the stratigraphic interval, from 70 to 100 feet above the base of the member, are not well exposed in the area studied in Ellis county, and little detailed information as to their character was obtained. The beds from 55 to 70 feet above the base are well exposed on the west side of the road in the SE¼ NE¼, sec. 14, T. 12 S., R. 20 W. where they consist for the most part of very soft dull orange-colored chalk that weathers into cavernous-walled ledges with thinner layers of harder chalk interbedded with shale in the basal few feet. These rocks are sparingly fossiliferous and include a few limonitic concretions. The next lower 10 feet of the member is well exposed in many places and forms one of the readily traceable units, here termed group A. From 20 to 45 feet above the base of the member and in its lowest 10 feet the beds are poorly exposed, but from 10 to 20 feet above the base occurs another series of beds (group B) that can be followed throughout the area.

The upper group of readily traceable beds in the Smoky Hill member exposed in Ellis county lies from 45 to 55 feet above the base of the member. For convenience of reference these beds are here designated "Group A" beds. A typical section follows:

Section of "group A" beds in sec. 2, T. 12 S., R. 20 W.

	Ft.	In.
8. Massive, brittle chalk nearly pure white; forms bench with surface strewn with white chalk chips; caps buttes	1	10
7. Soft chalky clay shale, dull gray to slightly tannish gray; weathers readily and forms an indentation in bluffs	..	6
6. Bluish-gray chalky shale, harder than shale above and below it	..	6
5. Soft, chalky clay shale; weathers dull dark gray; is slightly indented in weathered bluffs	..	3
4. Very chalky shale, drab to blue-gray; in many places weathers yellowish gray	1	2
3. Soft clay shale; weathers dull dark gray; makes prominent indentation in bluff	..	3
2. Drab chalky shale; weathers to light cream color; in places shows indistinct darker clay layer near middle	2	2
1. Dark dull-gray clay shale, usually including near middle a bed of very chalky and harder shale 2 to 3 inches thick. In all exposures measured a layer of yellow bentonitic clay one-fourth inch thick was found 2 inches above the base	..	8

Below this is more chalky shale that is a little harder than No. 1 and includes bands of softer clay shale, but it is so commonly covered in moderately gentle slopes that details of its parts are of little value. These slopes are typically strewn with the flat, circular limonitic concretions. The rocks of the section given above commonly crop out in almost vertical cliffs that are capped by the chalk bed No. 8. Figure 4A is a diagrammatic sketch of the section here described. A view of a typical exposure is shown in Figure 5.

West of the area mapped, in northeastern Trego county, some of the distinguishing features mentioned here appear to be lacking. The dark band recorded as No. 5 in the section is only faintly distinguishable, and No. 3 is likewise rarely well developed. The bentonitic clay of No. 1 in a zone of soft shale is present, however, and about a foot below it is a white chalk that shows in some of the sections measured in the vicinity of the one described above.

At the foot of the gentle shale slope that extends for 25 feet below the base of the "group A" beds is a second bench, terminating in low bluffs, that can be followed quite as definitely as the "group A" beds. In general its hard beds weather to a much deeper orange color than the "group A" beds, although its color can not be relied upon as a criterion to distinguish it. The following is a typical section of these beds, which are herein designated "group B" beds. Their top is 22 feet above the base of the Smoky Hill member.

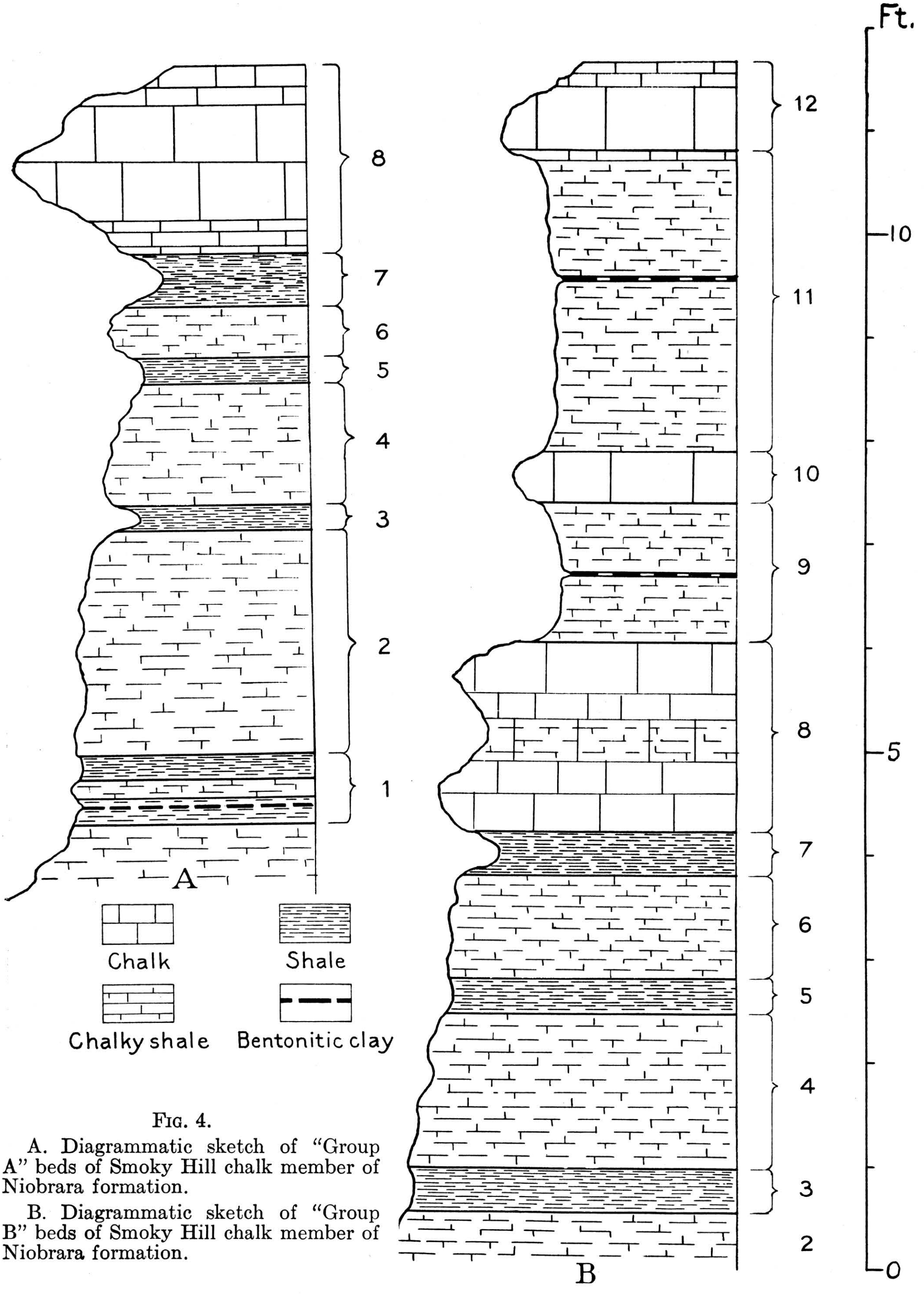


FIG. 4.

A. Diagrammatic sketch of "Group A" beds of Smoky Hill chalk member of Niobrara formation.

B. Diagrammatic sketch of "Group B" beds of Smoky Hill chalk member of Niobrara formation.

Section of "group B" beds in sec. 2, T. 12 S., R. 20 W.

		Ft.	In.
12.	Chalk, cream-colored, brittle, massive in lower two-thirds; weathers thin bedded in upper part	..	10
11.	Chalky shale; weathers to a deep yellow; includes an ocherous bentonitic clay band one-fourth inch thick, 1 foot 3 inches below the top. Upper 6 inches in places more chalky and not distinguishable from No. 12	2	11
10.	Chalk, brittle, from orange-yellow to cream-colored; makes slightly projecting ledge, in places jagged but generally blocky	..	3–8
9.	Chalky shale, dull drab to blue; in places weathers to a dull ocherous tan; includes an ocherous bentonitic clay band one-fourth inch thick, 8 inches above base	1	5
8.	Chalk, relatively soft but hard enough to form small rounded ledge. In places a soft band near middle makes of the unit a double-edged minor ledge projecting over the underlying beds. It ranges from dull orange-tan to cream-colored	1	10
7.	Soft, chalky clay shale, reddish tan; weathers into a pronounced indentation in bluff walls	..	4–6
6.	Chalky shale, harder than No. 7; weathers to a dull tan to cream-color; bluish when fresh	1	..
5.	Soft clay shale; weathers to dull gray or tan; makes a dark band slightly indented in bluff	..	4
4.	Shale like No. 6	1	6
3.	Soft shale like No. 5	..	5
2.	Shale like No. 6	1	9
1.	Soft chalky shale containing a yellow bentonitic clay band a quarter-inch thick	..	3–4

Figure 4B shows a diagrammatic sketch of the part from Nos. 3 to 12 of the section just described. Below No. 1 of the section is soft chalky shale, containing an abundance of large, flat limonitic concretions, which weathers readily to a gently inclined slope terminating at its base in the top bench of the Fort Hays limestone.

The "group B" beds can be distinguished from the "group A" beds by the thickness of the harder shales between the soft shale beds and by the occurrence of the two bands of bentonitic clay in the upper part, which are absent in "group A," and the occurrence of a bentonitic clay band in No. 1 of "group A" that is absent in "group B." The clay shale beds Nos. 3 and 7 are the most prominent soft members of the "group A" beds, and No. 7 is the most prominent soft layer in the "group B" beds.

Fossils collected from the Smoky Hill chalk member are listed below. The fish was identified by J. W. Gidley, of the United States National Museum, and the remainder by J. B. Reeside, Jr., of the United States Geological Survey.

Tooth of the large fish *Hypsodon* (*Portheus*) sp.
Globigerina bulloides D'Orbigny.
Inoceramus (*Haploscapha*) *grandis* Conrad.
Textularia sp.
Ostrea congesta.

Fort Hays limestone member. Massively bedded cream-colored chalk or very chalky limestone, aggregating 55 feet in thickness, constitutes the Fort Hays limestone member of the Niobrara formation in Ellis county. The individual beds of chalky limestone range in thickness from 6 inches to 6 feet and average about 2½ to 3 feet; these beds are separated by thin layers, 1 to 4 inches thick, of light gray to dark gray chalky clay shale. The bedding is thinner toward the top of the member, and the upper beds commonly weather almost pure white. In contrast with the chalk of the overlying Smoky Hill member the rock of the Fort Hays member appears slightly coarser in texture and somewhat harder. The individual beds are much thicker than those of the Smoky Hill, and weathered exposures of the two members show a marked contrast in the relative amounts of shale and hard beds, the Smoky Hill member having much the greater shale content. Rounded, coarsely ribbed shells of the pelecypod *Inoceramus deformis* are fairly abundant in the harder beds of the Fort Hays member. Individual beds and series of beds are persistent, with but little change in thickness over extensive areas. In many exposures that have been not long subjected to weathering thin bands of dark clay shale that separate the massive limestone beds differ from the adjacent beds only in being slightly softer, and some of the very thin layers appear only as cracks or joints along bedding planes. On weathered exposures, however, differences of hardness and general lithology are emphasized.

The uppermost few feet of the member contains more shale than the remainder, constituting in a measure a series of transition beds into the overlying Smoky Hill member. The following is a compiled detailed section of the Fort Hays limestone member. The topmost 8 feet of the section was measured in the NE¼ NW¼ NW¼, sec. 2, T. 12 S., R. 20 W., and the remainder in sec. 36, T. 11 S., R. 19 W., Ellis county.

Section of Fort Hays limestone member in T. 12 S., R. 20 W., and T. 11 S., R. 19 W.

			Ft.	In.
42.	Chalky limestone, soft; some clay shale	Forms bench strewn with white chalk chips.	2	..
41.	Shale, chalky, gray		1	..
40.	White chalk		1	..
39.	Tan clay shale		..	2
38.	White chalk, rather soft		1	2
37.	Black clay shale; makes conspicuous band		..	2
36.	White chalk and dark-gray chalky shale interbedded, in layers 2 to 6 inches thick		3	8
35.	Chalky limestone, massive, light cream-colored		1	4
34.	Clay shale; in places contains two ½-inch bands of yellow bentonitic clay		..	4

		Ft.	In.
33.	Chalky limestone, cream-colored on weathered surface and very light cream-colored on fresh fracture; weathered surface is slightly hardened; massive	2	4
32.	Dark-gray fissile clay shale	..	1
31.	Chalky limestone, like No. 35	1	2
30.	Shale, like No. 32	..	1
29.	Chalky limestone, like No. 35	..	4
28.	Shale, like No. 32	..	1
27.	Chalky limestone, Like No. 35	1	1
26.	Shale, like No. 32	..	1
25.	Chalky limestone, like No. 35	2	6
24.	Shale, like No. 32	..	2
23.	Chalky limestone like No. 35	..	6
22.	Shale, dark gray to black; includes in some localities a band of yellow clay about one-half inch thick	..	3
21.	Chalky limestone, like No. 35	3	..
20.	Clay shale, tan, fissile	..	1
19.	Chalky limestone, like No. 35; a bedding plane 1 foot 4 inches above base may represent horizon of shale break in much weathered exposures	3	2
18.	Clay shale, black, fissile	..	1
17.	Chalky limestone, like No. 35	1	11
16.	Shale, like No. 18; includes thin band of light-colored clay at top,	..	6
15.	Chalky limestone, like No. 35	4	..
14.	Dark-gray fissile shale, separated a little above middle by chalky limestone bed 2 inches thick	..	8
13.	Chalky limestone, like No. 35	2	6
12.	Clay shale, tan to gray	..	4
11.	Chalky limestone, like No. 35	1	7
10.	Clay shale, dark gray	..	3
9.	Chalky limestone, like No. 35	2	11
8.	Shale, like No. 10	..	2
7.	Chalky limestone, like No. 35	4	..
6.	Shale, like No. 10	..	2
5.	Chalky limestone, like No. 35	3	9
4.	Clay shale, tan	..	2
3.	Chalky limestone, like No. 35; includes a narrow band a little softer than remainder 2½ feet above base	6	3
2.	Clay shale, dark tan to black, fissile	..	1
1.	Chalky limestone, like No. 33	1	9
	Blue Hill shale member of Carlile shale.		
	Total Fort Hays member	56	

Shells of the large pelecypod *Inoceramus deformis* and the small *Ostrea congesta* occur throughout the section, except possibly in the upper few feet.

Beds Nos. 42 to 36 are in few places well exposed, as they normally form a sparsely grassed slope strewn with white chalk chips that recedes from the cliff of harder beds below. Because of this tendency to break down into gentle slopes, the exact position of the contact of the Fort Hays member with the overlying Smoky Hill member is less readily determinable than the basal boundary of the Fort Hays. The chalky shale near the base of the Smoky Hill member, immediately above the white chip bench, however, weathers to a deep yellow or orange color, which delimits the position of the contact within a few feet.

Because it is considerably harder than the underlying Carlile shale, the Fort Hays limestone commonly stands in vertical bluffs that cap a steep, barren shale slope. In Ellis county the valley of Saline river is bordered with such bluffs throughout the area of outcrop of the Fort Hays member. The tributary streams have carved and intricately serrated the valley walls, leaving a myriad of long, narrow spurs capped by cliffs of Fort Hays limestone that extend toward the main valley.

This member of the Niobrara is remarkably persistent and regular in its thickness and general character throughout western Kansas. It is readily identified in drilling, and is recognizable in the logs of nearly all wells that penetrate it. In its exposures in northern Hamilton county, near the Colorado line, the thin shale beds are more numerous and make up a little larger percentage of the member than they do in Ellis county. The chalky limestone beds also are somewhat softer, but on the whole the member has much the same appearance that it has in Ellis county. Its total thickness in Hamilton county is 60 feet. In the log of the Midfield No. 2 well, near Wray, Colo., a few miles west of the northwest corner of Kansas, it is recorded as 53 feet of white limestone.

Carlile Shale.

Chalky and clay shale, about 300 feet thick, that contains thin beds of chalk near its base, numerous zones of septarian lime concretions in its upper half, and a unit of fine-grained sandstone at its top, constitutes the Carlile shale. The upper two-thirds is made up predominantly of gray-black fissile clay shale, and the lower third of chalky shale and thin beds of chalky limestone. In Ellis county it is separable into the Blue Hill shale member above and the Fairport chalky shale member below.[7]

Blue Hill shale member. Ranging between a thickness of 215 feet near the northeast corner of the county and 175 feet near the southwest corner, the Blue Hill shale member occupies a broad belt of gently graded, grassed slopes in southern and eastern Ellis county and a narrow band of bare, steep slopes along Saline river in the northern part. The member is made up of gray-black noncalcareous clay shale, which at several horizons contains large calcareous or

7. Rubey, W. W., and Bass, N. W., op. cit., p. 33.

small ferruginous concretions, and in the uppermost 25 feet of gritty shale or sandstone.

At the top of the Blue Hill shale member is a very fine grained

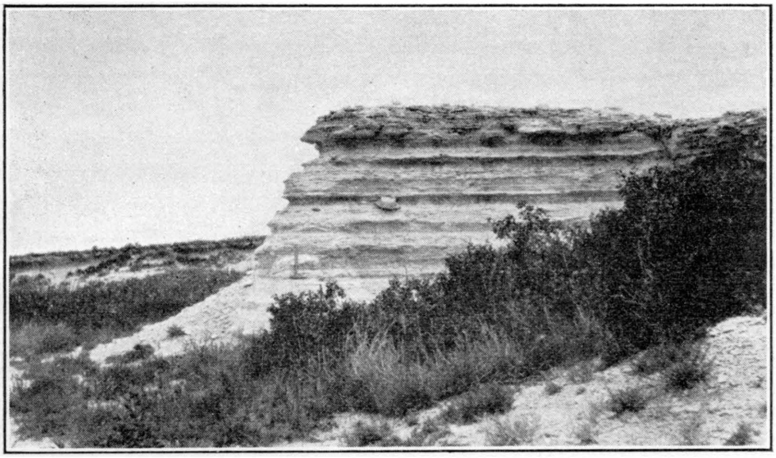


Fig. 5. "Group A" beds of Smoky Hill chalk member. Hammer head is on bentonitic clay of No. 1, hat is on No. 3, and uppermost chalk is No. 8 of Fig. 4A.

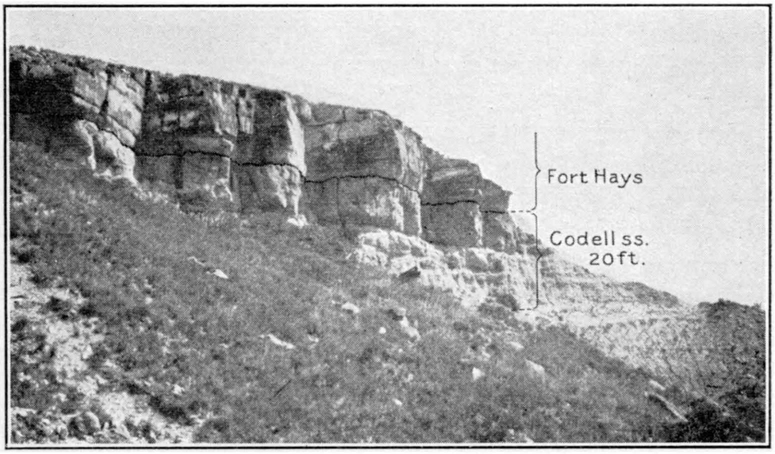


Fig. 6. Codell sandstone bed of Blue Hill shale member of Carlile shale. NW¼, sec. 26, T. 11 S., R. 18 W., Ellis county.

sandstone, including a few layers of sandy shale. In northern Ellis county, where this unit is thick, the uppermost few inches contains considerable clay that erodes easily and forms a small notch in the cliff produced by the overlying Fort Hays limestone. Below this clay is an indurated sandstone bed 5 to 6 feet thick that weathers to a bright tan color and forms a curved cliff face. (Fig. 6.) About 1 foot of shaly sandstone separates this 5- to 6-foot bed from an underlying gray indurated sandstone 3 to 5 feet thick that stands in a vertical cliff. The basal sandy material grades into the shale below and in most of its outcrops form gentle slopes. Because of its unusually thick development in a series of excellent exposures in the bluffs along Saline valley in Ellis County 5 miles south and a little west of Codell, this sandy unit of the Blue Hill shale member is here named the *Codell sandstone bed.* It is well exposed in a road cut near the north boundary of Ellis county in the NE¼, sec. 3, T. 11 S., R. 17 W., where it is 22 feet thick. Farther west, north of Saline river, from 10 to 13 feet of the upper part of the sandstone is exposed at several localities. It is 20 feet thick in the NW¼, sec. 26, T. 11 S., R. 18 W. The lower part of the Codell bed becomes less sandy southward, and at Yocemento, in T. 13 S., R. 19 W., it consists of but 3½ feet of sandstone underlain by 6 feet of sandy shale. Near the southwest corner of the county, in sec. 21, T. 15 S., R. 20 W., the sandstone material is only 3½ feet thick, but the shale for a considerable thickness below it includes numerous thin layers of sand and sandy shale.

Well logs show the Codell sandstone bed to be present over a considerable part of western Kansas. Its outcrop is characteristically marked by water seeps. Many drilled wells in Ellis county and counties adjacent on the north and west derive water from it. About 80 miles to the west, near Russell Springs, water wells have been drilled to depths of about 800 feet to this sandstone. The water from these wells has a foul taste and although good enough for stock is rarely used for drinking. The Codell sandstone is present near the Colorado state line in Hamilton county, where it consists of sandstone about 2 feet thick in the upper part underlain by 20 feet of gritty shale that contains very thin streaks of shaly sandstone.

Gray-black fissile noncalcareous clay shale containing several layers of calcareous concretions makes up the remainder of the Blue Hill shale member. Crystals of selenite are commonly strewn upon the weathered surface, especially in the lower part of the member. The uppermost concretion layer occurs just beneath the Codell sandstone bed, about 25 feet below the top of the Blue Hill member. The concretions at this horizon are not numerous, occurring 15 to

25 feet apart horizontally. They have the appearance of slightly flattened spheres averaging 2 to 3 feet in diameter, are of a steel-gray color, have a coarsely granular texture, and contain relatively

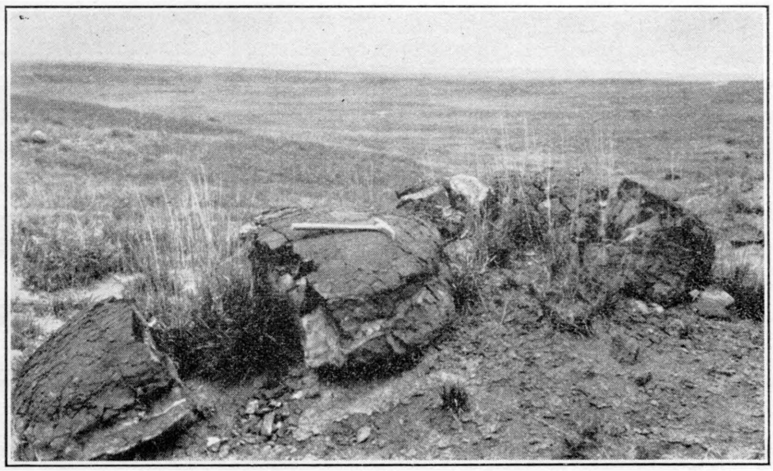


FIG. 7. Weathered septarian concretion in Blue Hill shale member of Carlile shale. Sec. 21, T. 15 S., R. 20 W., Ellis county.

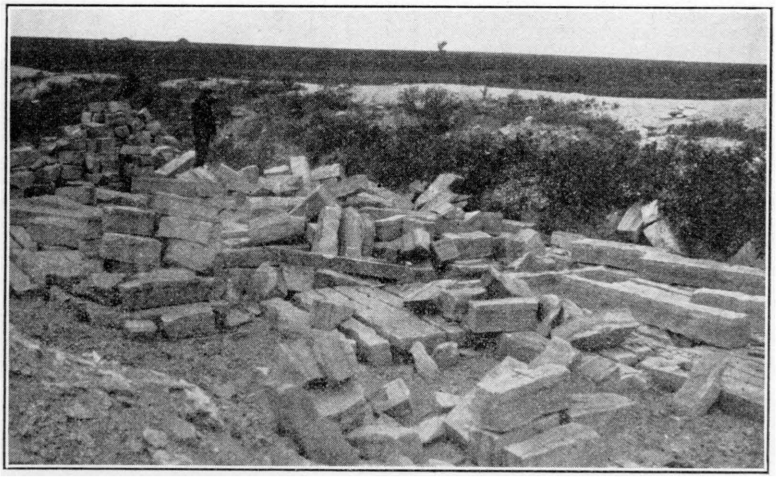


FIG. 8. Quarry in the "fence-post limestone" bed of the Pfeifer shale member of the Greenhorn limestone. Sec. 27, T. 17 S., R. 15 W., Barton county.

few thin septæ filled with crystalline calcite veins. In general they are more smoothly rounded than those found at lower horizons. In the southwestern part of the county the interval between 45 and 85 feet below the top of the member is strewn with large septarian concretions shaped for the most part like flattened spheres, but many are of odd nodular shapes. (Fig. 7.) The topmost and lowest concretions of this group, which apparently occur at definite stratigraphic horizons, are readily distinguished from the others by their very red weathered surfaces. The concretions of the other horizons weather to a dull gray or brown color. It is probable that the concretions that appear to occur heterogeneously throughout the interval between the two layers of red ones are likewise definitely stratified, but because of their persistent habit of slumping on a weathered slope true stratigraphic positions of individual concretions cannot be determined. Two layers of similar large reddish-brown concretions, the upper about 100 feet and the lower 135 feet below the top of the member, occur in northeastern Ellis county and northwestern Russell county, but concretions at these horizons were not seen in the exposures in southwestern Ellis county. There a definite layer of septarian concretions ranging in diameter from 6 inches to 2 feet occurs about 45 feet above the base of the member. Gypsum crystals are most abundant in the shales below this concretion bed. In northeastern Ellis county and northwestern Russell county, at 31 feet above the base of the member, is a concretionary ironstone bed 1 to 2 inches thick, and 16 feet above it is a layer of small flat septarian concretions.

Fairport chalky shale member. Increasing from a thickness of 85 feet in the northeastern part of Ellis county to 115 feet near the southwest corner, the Fairport chalky shale member of the Carlile shale occupies a broad area of low relief in the southern and eastern parts of the county. It is composed throughout of calcareous shale, including thin beds of chalky limestone, which occur in greatest abundance toward the base of the member. On fresh exposures it is bluish, but its weathered surface is a light orange-tan. The lower half characteristically has in addition a pink tinge, which gives it a flesh color. The individual thin beds of chalky limestone in the lower part of the Fairport are very persistent laterally, and the series of chalky limestones and shales in the basal 25 feet of the member were noted at many localities in Russell and Ellis counties, and were found to remain practically constant in their relative positions and intervals above the Greenhorn.[8]

The limestones and shales are abundantly fossiliferous, the fos-

8. A detailed stratigraphic section of this member is given in Kansas Geol. Survey Bul. 10, p. 40, 1925.

sils being more perfectly preserved in the limestones. Thin smooth shells of the small oyster *Ostrea congesta* occur abundantly in the shales, however, and are in many places thickly strewn upon the weathered slopes of the member.

This member, particularly the lower half, is lithologically not unlike the underlying Greenhorn limestone, but its contained fossils furnish the basis for separation. The boundary between the Fairport member and the Greenhorn limestone is placed on paleontologic grounds at the top of the "fence-post limestone" bed. The upper boundary of the Fairport member is not so sharply defined throughout the county as the base. In good exposures it can readily be determined within a few feet by the calcareous character of the Fairport shales and their weathered orange-tan color, in contrast with the noncalcareous character and gray-black color of the overlying shales and their increased stickiness when wet. Seeps of water commonly occur at or near this contact.

This lower member of the Carlile shale continues to increase in thickness westward beyond the boundaries of this county. In Hamilton county, less than 5 miles from the Colorado line, it is approximately 150 feet thick and maintains in general the characteristics described above. There, as in Ellis county, the basal part of the member is lithologically very similar to the underlying Greenhorn limestone and is separable from it chiefly by a change in the contained fossils.

The following fossils collected from the member were identified by J. B. Reeside, Jr., of the United States Geological Survey:

Prionotropis woolgari (Mantell).
Serpula plana Logan.
Inoceramus fragilis Hall and Meek.
Globigerina bulloides D'Orbigny.
Textularia sp.
Ostrea congesta.

Greenhorn Limestone.

The four members of the Greenhorn limestone described in the Russell county report[9] are readily recognizable in Ellis county, where they have a total thickness of nearly 100 feet. The entire formation occupies but little more than 15 per cent of the surface of Ellis county, largely because of the steepness of its slopes. It is extensively exposed in the southern and southeastern parts of the

9. Rubey, W. W., and Bass, N. W., op. cit., p. 45.

county, and extends a few miles up Saline river in the northeastern part.

Pfeifer shale member. The uppermost member—here named Pfeifer shale member for its exposures near Pfeifer, Ellis county—is capped by the "fencepost limestone" bed, so called because it is extensively quarried and used for fence posts throughout the region of its outcrop. (Fig. 8.) The Pfeifer member is 19 to 21 feet thick and consists of alternating layers of chalky shale and chalky limestone, the latter in beds from 3 to 8 inches thick. On fresh exposure the entire mass presents a blue color, but on weathering it becomes a light tan or cream. In general the member produces gently graded slopes, the topmost bed forming a slight shoulder. Its outcrop throughout this region is commonly marked by white mounds of the overburden removed in quarrying the "fence-post limestone" bed. The following section was measured 2½ miles northwest of Pfeifer:

Section of Pfeifer shale member in road cut in SE¼ sec. 21, T. 15 S., R. 17 W.

	Ft.	In.
24. "Fence-post limestone," chalky limestone, light tan, even grained, including near the middle a rusty band about an inch wide and a little lower another rather indistinct band. Contains a few well-preserved fossils (*Inoceramus labiatus*). Top bed of Pfeifer member	..	8½
23. Soft chalky shale, cream to flesh colored	..	11
22. Chalky limestone, somewhat concretionary; weathers white; contains a few fossils	..	1
21. Chalky shale like No. 23	..	10
20. Concretionary chalky limestone, fossiliferous; weathers white	..	4
19. Shale, like No. 23	1	2
18. Chalky limestone, with no fossils; weathers white	..	1
17. Chalky shale, like No. 23	..	11
16. Chalky limestone, like No. 18	..	4
15. Shale, like No. 23, with a band of bentonitic clay 4 inches thick at its top. Upper part of clay band gritty and shows orange color	1	2
14. Concretionary fossiliferous chalky limestone	..	2
13. Chalky shale; weathers flaky; light tan; in places contains a thin discontinuous bed of somewhat fossiliferous concretionary chalky limestone	1	6
12. White chalky limestone, very few fossils	..	3
11. Shale, like No. 13, somewhat fossiliferous; in places has two thin discontinuous beds of fossiliferous concretionary chalky limestone,	2	4
10. Chalky limestone; weathers to rusty brown; ferruginous band near middle; contains many fossils	..	2
9. Shale, like No. 13	..	10
8. Chalky limestone; very few fossils	..	3
7. Shale, like No. 13	1	..
6. Concretionary chalky limestone, fossiliferous	..	2
5. Shale like No. 13	..	9
4. Concretionary chalky limestone; fossils abundant	..	2½
3. Shale like No. 13	1	4
2. Concretionary chalky limestone; fossils abundant	..	4
1. Shale like No. 13	3	1
Total thickness of Pfeifer shale member	18	11

Jetmore chalk member. Underlying the Pfeifer shale member is 20 feet of interbedded chalky shale and chalky limestone known as the Jetmore chalk member.[10] The chalky limestone beds of this member are harder than those of the overlying Pfeifer member, and the uppermost bed, which approaches a foot in thickness, is hard, inclined to be concretionary, and characteristically forms a bench, with its blocks scattered along the edge. (Fig. 9.) The hard beds of the upper half of the member are much more abundantly fossiliferous than those above and below, many of them being composed almost entirely of shells of the pelecypod *Inoceramus labiatus.* The base of the member is not sharply defined in Ellis and Russell counties. The chalky limestone beds become thinner and less numerous in the lower part of the Jetmore member and grade into the calcareous shale of the underlying Hartland member. Because of the predominance of beds of hard, white, chalky limestone, the member weathers in steep, almost bare, light-colored slopes.

Hartland shale member. Below the Jetmore chalk member is a series, about 35 feet thick, of chalky shales that contain a few thin beds of soft chalky limestone and a few thin layers of bentonitic clay. In Ellis and Russell counties these beds, which are herein named Hartland shale member, from exposures near Hartland, Kearny county, Kansas, grade into the overlying Jetmore member with no sharp change in lithology, and are defined somewhat more distinctly below by the hard, thin-bedded, finely banded, dark-colored limestone of the basal member (Lincoln limestone) of the Greenhorn limestone.

Lincoln limestone member. The basal or Lincoln limestone member[11] of the Greenhorn limestone consists of about 20 feet of chalky shales with thin beds of light-gray chalky limestone and of hard, finely banded, dark-colored crystalline limestone. The beds of crystalline limestone are most abundant at the base and top of the member, are fossiliferous, and emit a strong bituminous odor when broken. Several thin layers of bentonitic clay that weather to an orange color are contained in the shales. The color of these layers and the brown of the weathered crystalline limestones give the member on the whole a much yellower color than other members of the Greenhorn limestone.

Comparison with Greenhorn limestone exposed in other localities. The four divisions within the Greenhorn limestone are readily rec-

10. Rubey, W. W., and Bass, N. W., op. cit., p. 46.
11. Rubey, W. W., and Bass, N. W., op. cit., p. 47.

ognizable and persistent both southwest and northeast of Ellis county, throughout an extensive area along the outcrop of the formation. Nearly 150 miles southwest of Ellis county where the

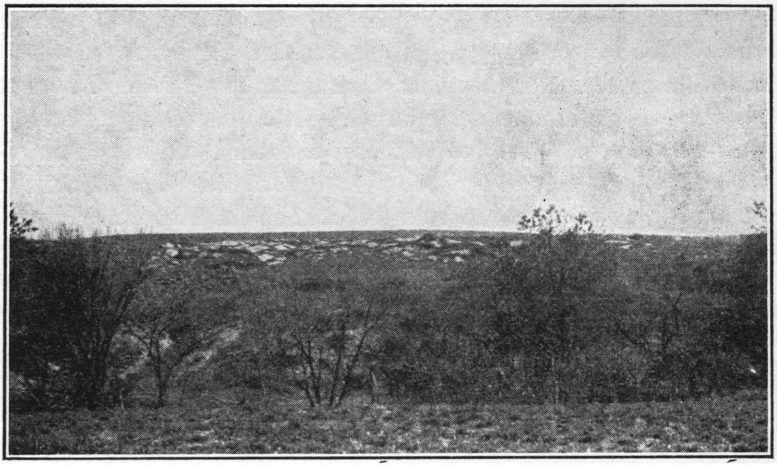


FIG. 9. Typical outcrop of the uppermost chalk bed in the Jetmore chalk member of the Greenhorn limestone. Sec. 8, T. 23 S., R. 24 W., Hodgeman county. View southward.

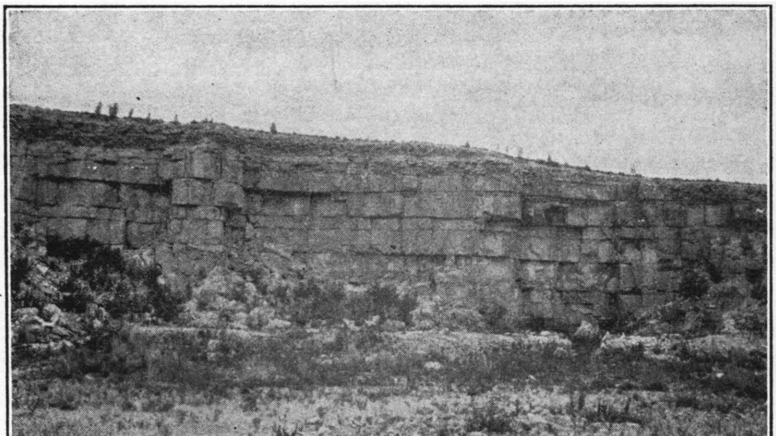


FIG. 10. Bluff of Fort Hays limestone member of Niobrara formation at old quarry at Yocemento, Ellis county.

Greenhorn limestone is exposed along the Arkansas valley in Kearny and Hamilton counties, similar divisions can be recognized, but the upper two are less easily distinguishable. There the entire formation has a thickness of 130 feet, the upper 74 feet of which is made up of alternating chalky shale and chalky limestone beds corresponding to the Pfeifer and Jetmore members—the top 25 feet representing the Pfeifer and the remainder, which contains layers of abundantly fossiliferous chalky limestone, the Jetmore. This 74 feet of chalky and limy beds in Hamilton and Kearny counties is herein named Bridge Creek limestone member of Greenhorn limestone, from exposures on Bridge creek, northwest of Medway, Hamilton county. It is immediately underlain by chalky shale 23 feet thick. This shale unit, herein named Hartland shale member, is in turn underlain by the Lincoln limestone member, which consists of 35 feet of chalky shale alternating with thin beds of chalky limestone and of finely banded crystalline limestone.

Graneros Shale.

A narrow strip in the southeastern part of Ellis county along Smoky Hill river is occupied by the Graneros shale. It is made up predominantly of blue-black fissile noncalcareous clay shale. Numerous thin lenses of sandy shale, sandstone, sandy limestone, and ironstone concretions are interbedded with the shale. Selenite crystals are commonly strewn over the surface, and the shale has a bitter taste. The following section was measured in the south bank of Smoky Hill river:

Section of Graneros shale in the NE¼ sec. 34, T. 15 S., R. 16 W.

	Ft.	In.
14. Black or gray-black fissile clay shale	2	..
13. Grayish-tan sandy shale, with interlaminated thin stringers of sandstone and shale; about 60 per cent sandstone and 40 per cent shale	3	6
12. Shale, similar to No. 14	5	..
11. Very shaly fossiliferous limonitic sandstone	1	..
10. Shale, like No. 14, but containing a small amount of gypsum crystals on the surface	1	6
9. Very limonitic and gypsiferous sandy shale and sandstone interlaminated. Estimated lower half 95 per cent sandstone and upper half 50 per cent	1	..
8. Black gritless bitter-tasting noncalareous paper shale; selenite crystals abundant on surface	5	..
7. Reddish-brown limonitic sandstone with an abundance of fossils,	..	¾
6. Shale, like No. 8	2	6
5. Irregularly interlaminated sandstone and shale and thin stringers of gypsum. Sandstone estimated at four-fifths of whole. Basal 2 inches weathers to tan-brown color and remainder to red-brown. Makes slight irregularity in shale slope. One sandstone layer strongly ripple marked	1	..
4. Gray-black fissile noncalcareous shale, in part slightly gritty, with a bitter taste	3	6

	Ft.	In.
3. Dark-gray sandy shale, increasing in sandiness to top. Ironstone concretion bed at base averaging 2 inches thick. One irregular concretion 6 inches thick and 1 foot 6 inches in horizontal dimensions was noted	1	..
2. Black to gray-black, slightly gritty shale with bitter taste	2	..
1. Black to gray-black bitter-tasting shale, sandy at top and containing a thin layer of limonite concretions. Decreases in sandiness downward, and basal part only slightly gritty	3	..
Dakota sandstone	..	..
Total thickness of Granerous shale	32	..

The Graneros is somewhat thinner in this section than in near-by places where it was measured. The average thickness of the formation in Russell county is about 40 feet.[12] In sec. 23, T. 22 S., R. 22 W., Hodgeman county, nearly 50 miles southwest of the locality of the above section, the formation has a total thickness of 38 feet and is made up of black fissile clay shale that contains numerous thin beds of rusty-colored sandstone and ironstone and considerable gypsum in the lower 8 feet and a rusty-colored sandy shale bed, 10 inches thick, about 23 feet above the base. In a compiled section measured in western Kearny and Hamilton counties, near the west edge of the state, the formation has a total thickness of 61 feet and consists largely of blue-black fissile clay shale. Ironstone concretions and impure sandstone lenses are present in the basal few feet, and at 23 feet above the base is a zone about 5 feet thick containing thin-bedded sandy fossiliferous limestone. A persistent bed of white bentonitic clay occurs 11 feet below the top.

Dakota Sandstone.

Only the uppermost 18 to 20 feet of the Dakota sandstone is exposed in Ellis county and that in an area of only a few acres. It rises from beneath the level of Smoky Hill river in the NW¼, sec. 35, T. 15 S., R. 16 W., and arches over the axis of a northeastward trending fold here called the Pfeifer anticline. In this exposure the Dakota sandstone consists, from the top down, of 5 feet of massively bedded fine-grained light-gray sandstone, containing an abundance of carbonized plant fragments; a zone 1 foot thick, of pyrite concretions embedded in sandstone; and 8 feet of massive fine-grained sandstone. These rocks represent the upper regularly bedded sandstone unit of the Dakota sandstone described in Bulletin 10[13] of this survey. The rocks between the base of the sandstone and the river bed are concealed by alluvium.

12. Rubey, W. W., and Bass, N. W., op. cit., p. 51.
13. Rubey, W. W., and Bass, N. W., op. cit., p. 54.

The log of a well drilled in sec. 3, T. 16 S., R. 16 W., Rush county, about a mile south of this exposure records 140 feet of white sand in the upper part of the Dakota. The logs of the three wells drilled for oil in the northeast quarter of the county bear out the fact noted in the Russell county outcrops that individual beds or groups of beds in the Dakota are extremely lenticular and variable. These logs, however, in general show from the top down 25 to 85 feet of sandstone that carries water, 100 to 130 feet of material recorded largely as red rock, a light-colored water-bearing sandstone 50 to 100 feet thick, a little more than 100 feet of dark shale, and about 100 feet of white sandstone. The log of the Smith well, in sec. 14, T. 12 S., R. 16 W., shows the basal sandstone absent there. The lower black shale and sandstone units very probably constitute the Comanche rocks, which crop out in central and south-central Kansas.

Many wells throughout the county obtain water from the Dakota; this water is commonly too salty for domestic use but is used for stock.

Rocks Not Exposed.

M. N. Bramlette made microscopic studies of drill cuttings from wells drilled in and to the east of Russell county for the purpose of tracing westward the formations that crop out in eastern Kansas. In his description he separated the rocks into units, most of which included several formations. The detailed results of Mr. Bramlett's studies are published in Part II of Kansas Geological Survey Bulletin 10, pages 87-93.

Solely on the basis of the drillers' logs, for no well cuttings were available, the buried rocks in Ellis and Trego counties have been correlated with those in Russell county. Plate II shows a correlation table of wells in a line westward from the Russell pool, including two wells in Ellis county and two in Trego county. So far as possible Bramlette's groupings are followed.

Unit 1. All rocks younger than the Dakota sandstone are included in unit 1, for few of the formation boundaries are recognizable in the logs. In Ellis county this unit contains only parts of the Carlile, Greenhorn, and Graneros formations, but the Trego county wells penetrate several hundred feet of the Niobrara formation, the basal member of which, the Fort Hays limestone, is recorded as white limestone from 50 to 60 feet thick.

Unit 2. The next unit contains the Dakota sandstone and very probably in its basal part rocks of Comanche age. Light-colored to white sandstone and shale, irregularly bedded with red and mottled shale, are characteristic of the upper half of the unit, and dark shale and white to yellow sandstone of the lower half. The sandstones commonly carry water, which in most wells in this region is salty.[14] W. H. Twenhofel and W. L. Stryker in their report of studies of the subsurface distribution of the Comanche rocks in western Kansas[15] describe the Comanche beds in two of the wells included in Plate II, Nos. 1 and 5. In well No. 1 they placed the top of the Comanche at a depth of 372 feet, at the top of a bed of soft red sandstone, and the base at 560 feet. In the Davidson well, No. 5 of Plate II, the rocks between 1,240 and 1,325 feet are assigned to the Comanche, the sandstone occupying the lowermost 85 feet of this unit being the Cheyenne sandstone. This assignment shows a thickening of the Comanche westward, which is in harmony with Twenhofel and Stryker's observation that these rocks thicken westward and southward from the Russell oil field, where they are about 200 feet thick.

Unit 3. Ranging in thickness from 600 feet in the east to 900 feet in the west, unit 3 forms a rather clearly defined division constituting the Cimarron group of the Permian "Red Beds."[16] The rocks of this group are largely red siltstones with minor amounts of sand in Russell and Ellis counties, but the proportions of sand—much of it white rather than red—increases greatly westward, according to the logs of the Trego county wells. A widespread marker bed that is recorded as "gray lime," about 50 feet thick, occurs in the basal part of the unit. Bramlette states that the cuttings from this bed in wells in and east of Russell county are anhydrate, and a specimen taken in the Polifka well, in central Ellis county, is anhydrite. A bed of blue shale 65 feet thick that occurs about 100 feet below the anhydrite bed in the Bemis well, in northeastern Ellis county, can be followed westward to the Keyser well, in Trego county, where it has thinned to 5 feet, and eastward into Russell county.

Unit 4. The fourth unit includes from 60 to 220 feet of beds that are usually recorded as blue shale and salt beds ranging in thickness from 21 feet in the Bemis well to 227 feet in the Smith well. The log of the Polifka well (not shown in the correlation table, Pl. II), near the center of Ellis county and only 12 miles south of the Bemis

14. For a description of surface exposures of the Comanche in Kansas, see Twenhofel, W. H., The Comanche of Kansas: Kansas Geol. Survey Bull. 9, 1924.

15. Am. Assoc. Petroleum Geologists, Bull., vol. 9., pp. 1105-1114, 1925.

16. Moore, R. C., Oil and gas resources of Kansas: Kansas Geol. Survey Bull. 6, pt. 2, pp. 64-73, 1920.

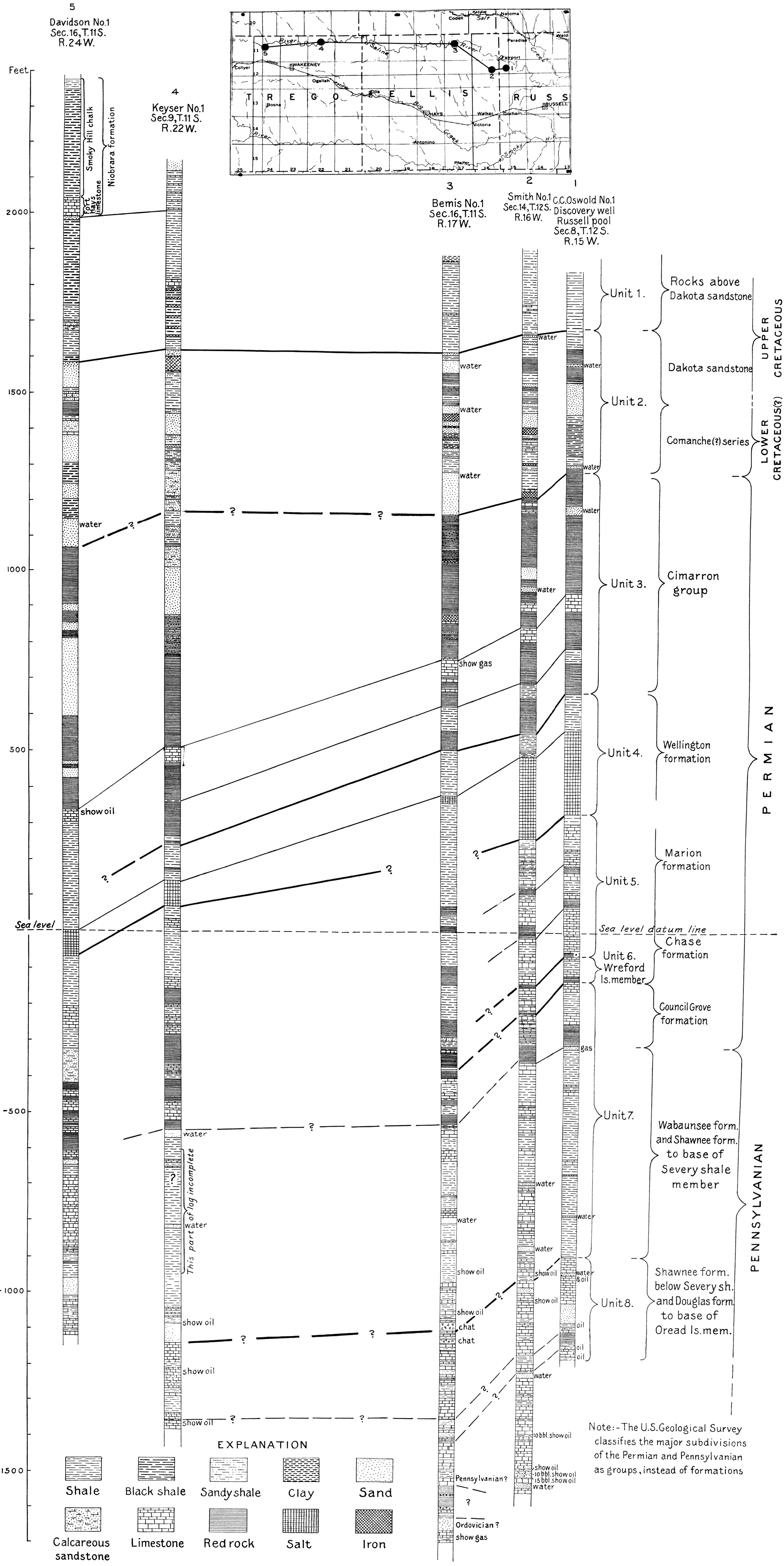


Plate II. Correlation of well records in Russell, Ellis and Trego counties, Kansas.

well, reported 230 feet of salt. Inasmuch as this series of salt beds is very widespread and of rather uniform thickness throughout many counties in west-central Kansas, its reported thinning in the Bemis well is noteworthy. This unit is a part of the Wellington formation.

Units 5 and 6. Bramlette's separation of units 5 and 6 was based largely on a microscopic study of cuttings, and the projection of the units into Ellis county by log correlations is exceedingly difficult. Its position as indicated on Plate II is, therefore, subject to question. The basal limit of unit 5 is likewise indefinite. The two units, probably all in the Permian, include a series of rocks recorded by drillers as interbedded shale and limestone with much red material. Bramlette correlated unit 6 with the Wreford limestone.

Units 7 and 8. Unit 7, probably including rocks from a horizon a little above the base of the Permian through the Severy shale of the Pennsylvanian, is composed largely of shale with a few beds of limestone. Individual beds in the unit cannot be traced in the logs of wells in Ellis county and Trego county. Unit 8 includes mostly limestone, and in its lower part, thin beds of sandy shale; at its base is the original "pay sand" of the Russell oil pool. This unit probably represents limestones of the lower part of the Shawnee formation and includes at its base the Oread limestone.

Approximately 350 feet of thick limestone beds, the lower 50 feet reported to contain much sand, were penetrated in the Smith well below the horizon of the original "pay sand" of the Russell field, but in the absence of cuttings from these rocks, few inferences can be ventured as to their probable stratigraphic position. So few identifiable marker beds of the Oswald and Smith logs can be definitely correlated with the strata recorded in the Bemis log that considerable doubt must be expressed as to the correctness of the correlations of the lower rocks shown on Plate II.

The presence of an unconformity in the buried rocks of the region situated 400 feet more or less below the Russell oil-producing beds was indicated by the record of the Phillips well of the M. M. Valerins Oil & Gas Co., drilled in sec. 3, T. 13 S., R. 13 W., 25 to 30 miles southeast of the Bemis well. In material from the Phillips well Pennsylvanian fossils[17] were identified from rocks that lie between the horizon of the Russell oil sands and a series of red rocks about 350 feet lower, and fossils of Ordovician age were identified from rocks below this red-rock series. The general sequence of

17. Bramlette, M. N., op. cit., p. 93.

beds below the horizon of the Russell oil-producing beds in the Bemis well appears to correspond to that in the Phillips well. On this basis tentative well-log correlation indicates that the series of limestone and shale about 100 feet thick immediately below the horizon of the Russell producing beds in the Bemis well is of Pennsylvanian age, that the series of red beds lying next below is in part of early Pennsylvanian age and probably in part older, and that the sandy limestone in the basal part of the well is of Ordovician age. Logs of other wells drilled recently in this part of the state indicate that this unconformity is present throughout an area embracing several counties.

The chief events that appear to have taken place in the formation of this series of beds may be briefly set forth. The lowermost beds penetrated in the Bemis well were deposited on the sea bottom in Ordovician time, and other deposits accumulated above them. The region was later elevated above the sea, and the land thus formed was subjected throughout a long period of time to the agencies of erosion. The red beds and gravel recorded in the log were accumulated on this old land surface. Later, in Pennsylvanian time, the sea again covered the land, and shale and limestone were alternately laid down, layer upon layer.

Beds Useful for Structural Mapping.

The Dakota sandstone occupies so small a part of the surface of Ellis county that its importance as a key bed suitable for structural control is slight. Furthermore, because of its irregular, lenticular bedding, it is not believed to be reliable for such mapping except in a regional study covering relatively large areas. The few hard layers in the Graneros shale may be valuable as key beds in a few places, but in the main they will never be used. The Lincoln limestone member of the Greenhorn limestone, which immediately overlies the Graneros, is commonly well exposed and forms ledges that in a horizontal plan almost coincide with the outcrop of the hard beds in the Graneros, a fact which largely vitiates the usefulness of the beds in the lower formation. In many localities, however, both the basal and the topmost beds of the Lincoln member constitute excellent key beds.

The two markers most widely used in this part of the state for structural mapping are the uppermost beds of the Jetmore and Pfeifer members of the Greenhorn limestone. The top bed of the Jetmore member is slightly thicker and harder than the other beds, has a slightly concretionary tendency, and weathers into gray-white blocks that lie strewn along the edge of a steep-sided bench. (Fig. 9.) Its position above the abundantly fossiliferous limestone beds that occur in the Jetmore member and below the relatively soft shale and thin soft chalky limestone of the overlying Pfeifer member aids in its recognition. The "fence-post limestone" —the top bed of the Pfeifer member—is marked along much of its outcrop by small white mounds of chalky shale, the overburden that has been removed from old stone quarries. Its uniform thickness, ranging between 8 and 9 inches, and its even texture assist in its recognition. It caps a gentle slope that rises for 20 feet above the weathered blocks of the topmost bed of the Jetmore member. In clean exposures three layers of thin, flat chalky limestone concretions can be seen in the 4½ feet of shale immediately above the "fence-post" bed.

In the Carlile shale a chalky limestone bed 4 to 5 inches thick that occurs 5½ feet above the base of the Fairport member is readily recognizable by the presence immediately below it of an orange-yellow bentonitic clay bed 5 inches thick. At 11 feet above the base of the Fairport member is a layer of ellipsoidal chalky limestone concretions averaging about 8 inches in thickness and a foot in diameter that readily distinguishes the limestone beds that occur stratigraphically near it. The three thin beds of chalky limestone that occur in the interval from 20 to 25 feet above the base of the member and weather to a red-brown to tan color may be recognized, and are sufficiently hard to form minor benches and make useful key beds for mapping. Although the upper part of this member is not so extensively exposed as the basal 25 feet, higher groups of chalky limestone are recognizable from place to place by the thin layers of bentonitic clay in the shales associated with the hard beds and can be traced in the clean exposures along Smoky Hill river. The contact between the two members of the Carlile shale is difficult to follow in detailed mapping, although usable in many places for reconnaissance work. The several layers of concretions in the Blue Hill member can not be used over extensive areas. The large concretions slump so readily in the soft shale in which they are embedded that little confidence can be felt as to their being in their true stratigraphic position. The ironstone bed 31 feet above the base, however, can be traced readily throughout much of its outcrop in the northeastern part of the county.

The base of the Fort Hays limestone member is sharply defined and is an admirable key horizon if certain precautions are taken. On many long, narrow tongues of outcrop left by erosion the member has slumped below its true level, owing to the giving way of the soft shale below, and its altitude in such places must be disregarded. Individual beds in the Fort Hays member can be identified by careful measurement of sequences of beds. Although rarely well exposed, the contact between this member and the overlying Smoky Hill member is in many places sufficiently well marked for reconnaissance mapping. The top beds of the Fort Hays member weather into white chalk chips and form a low bench, above which is a gentle slope of dark-yellow chalky shale constituting the basal beds of the Smoky Hill member. The rocks designated "group A" beds and "group B" beds in the description of the Smoky Hill member (pp. 19-23) are series of soft and hard beds that can be traced extensively and be used as key beds. It is thought very probable that detailed study of beds in the Smoky Hill member stratigraphically higher than those exposed in Ellis county will reveal other groups sufficiently distinctive to serve as key beds in extensive areas farther west in Kansas.

Structure.

Attitude of the Greenhorn Limestone.

The Cretaceous rocks in Ellis county have a regional dip of about 10 feet to the mile in a direction slightly east of north. A series of broad, gently arched northeastward-trending noses form gentle undulations on the northward-dipping surface. The more prominent structural features of the area are shown on Plate III, by contours drawn on the top of the Greenhorn limestone. The map was made from the reconnaissance geologic sketch map, for which the Hays, Ellis, Plainville, and Hill City topographic maps were used as a base. Dashed contour lines are drawn in smooth curves across broad areas mantled by Tertiary rocks, although the true structure is probably much more irregular. The representation of structure here given is of course not accurate in detail, but it is believed to present a true picture of the regional features.

The most pronounced structural feature of Ellis county is a northeastward-trending fold that crosses the southeast corner of the county and extends into Russell county. This fold, here called the Pfeifer anticline, appears to be in general alignment with the Fair-

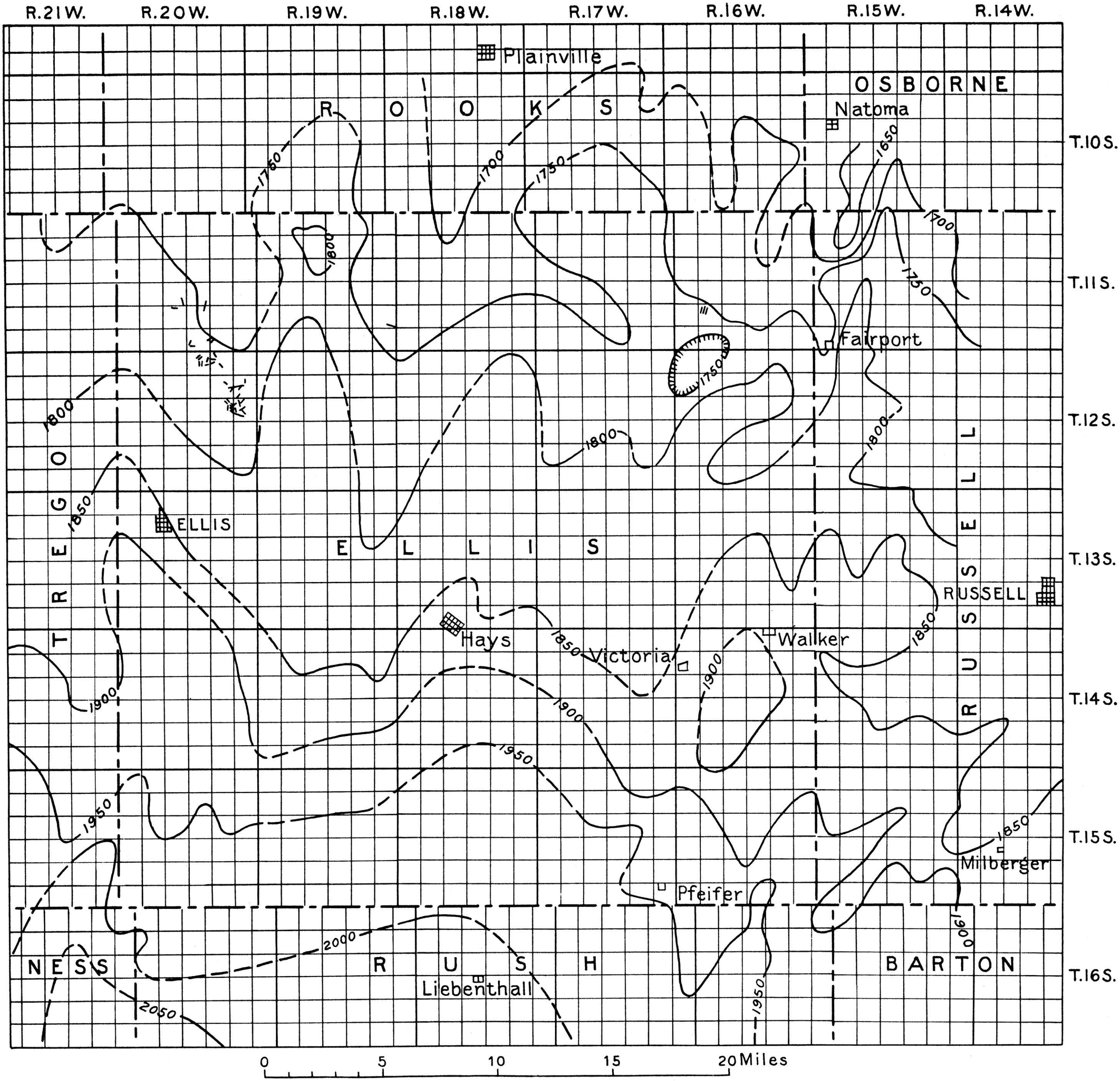


PLATE III. Reconnaissance structural contour map of Ellis county, Kansas.

port-Natoma anticline of Russell and Osborne counties. It may not, however, be a direct continuation of that anticline, but rather lie somewhat *en échelon* to it. Like the Fairport Natoma anticline, it is steeper on the west flank, where dip readings as great as 3½ degrees were noted.

A rather sharp syncline parallels the Fairport-Natoma and Pfeifer anticlines on their west side and is in turn paralleled on the west by a series of "structural highs," much less pronounced than the Fairport-Natoma and Pfeifer anticlines, that extend from the northeast corner of Ellis county southward to Pfeifer. A broad nose strikes northward across the middle of the county and turns slightly to the east in the northern half. A rather pronounced anticline, trending a little east of north, extends from the northwestern part of Ellis county into Rooks county in R. 19 W. A northeastward-trending nose is present in the southwest corner of the county. These two folds in the western part of Ellis county show alignments nearly parallel to those of the Fairport-Natoma and Pfeifer anticlines respectively (Plate III) and may possibly represent a similar but less strongly folded series of anticlines.

Structure of the Pre-Cretaceous Rocks.

Rocks lying below those of Cretaceous age have a regional inclination slightly north of west in Ellis and Trego counties. (Fig. 11.) The average rate of slope in the eastern half of the county is 10 feet to the mile and in the western half a little less than 7 feet to the mile. The "Red Beds" were subjected to erosion prior to the deposition of the Cretaceous rocks, and about 400 feet more of "Red Beds" material was removed from the eastern part of Ellis county than from the western part of Trego county. Well logs consequently show a thickening of the "Red Beds" westward. If this westward thickening of the "Red Beds" is assumed to take place at a uniform rate, a well drilled near the west edge of Ellis county would have to penetrate 200 feet of sediments below the Cretaceous beds that are not present in the eastern part of the county. Wells drilled on the Fairport-Natoma anticline in western Russell county show that the degree of deformation of the rocks involved in the fold increases in depth,[18] and it is to be expected that structural features shown at the surface in Ellis county are likewise accentuated in depth.

18. Rubey, W. W., and Bass, N. W., op. cit., p. 71.

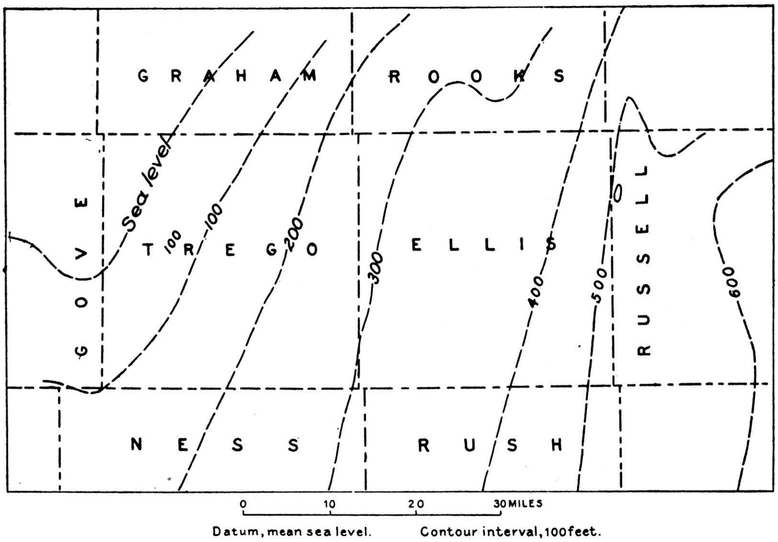


FIG. 11. Altitude of the top of the salt beds of the Wellington formation in Ellis and adjacent counties.

Faults.

In reconnaissance mapping of the type carried on in Ellis county it is not possible to detect all faults; in general only those that occur near the roads are noted. Plate IV shows a small tract in the northwestern part of the county in which more detailed mapping was done, disclosing a total of 76 faults. In this tract the Smoky Hill member of the Niobrara formation occupies about 80 per cent of the area that contains Cretaceous rocks at the surface and in it are found 97 per cent of the observed faults. Because of the difficulty of identifying marker beds in the faulted chalk, on many of the faults it was impossible to determine the amount of displacement. The faults show no predominant direction of trend. Of the forty-four in which the amount of displacement was determined, twenty-seven have an apparent throw of 5 feet or less, seven range between 5 and 10 feet, five range between 10 and 15 feet, four range between 15 and 25 feet, and one has an apparent throw of 80 feet. About two-fifths of these forty-four faults are downthrown toward the south, about two-fifths toward the west, southwest or northwest, and about one-fifth toward the east, southeast or northeast. The fault planes dip at steep angles and are commonly marked with veins of calcite that range in thickness between that of a knife-edge

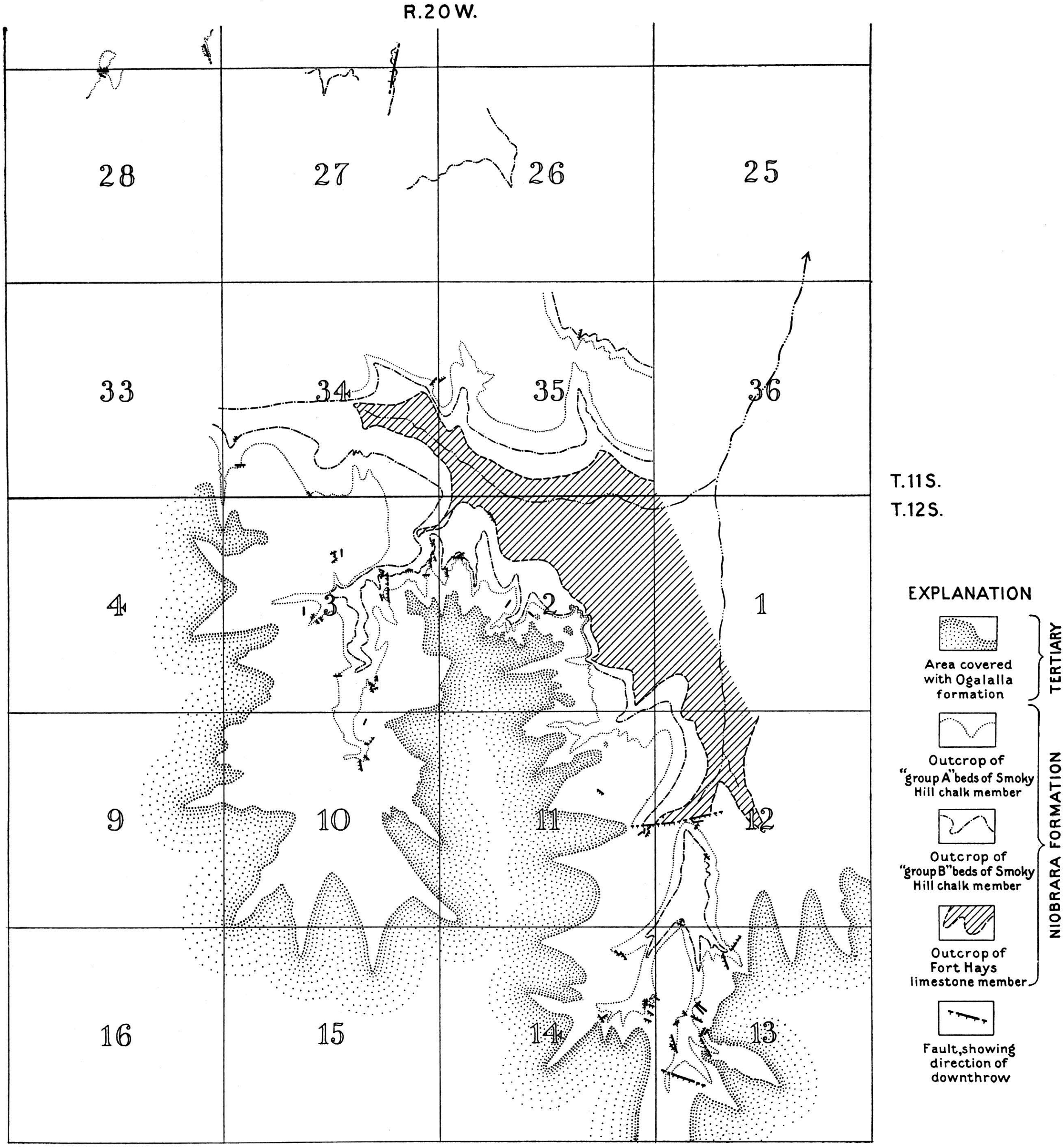


PLATE IV. Map of a faulted area in northwestern Ellis county.

and 6 inches. These veins commonly have slickensided surfaces, and some of them are slickensided within the vein itself, possibly indicating repetition of faulting. Only a few of the fault lines can be traced for more than 200 or 300 feet, and many of them can be traced less than 50 feet.

The fault of greatest magnitude noted in the tract examined in detail trends a little north of east near the common quarter corner of secs. 11 and 12, T. 12 S., R. 20 W. (Pl. IV.) The beds are dropped on the south 80 feet, so that the top of the "group A" beds of the Smoky Hill member is brought into contact with rocks well below the top of the Fort Hays limestone member. Beds on the upthrown side dip at a low angle to the north, and those on the south dip 19° N., into the fault. Two faults, of parallel trend and of less than 5 feet displacement, occur just south of the large fault in the Smoky Hill member. It seems probable that the steep dip south of the large fault terminates in other faults now concealed by alluvium.

A few faults other than those shown on Plate IV were seen in Ellis county. The Fort Hays limestone member and the upper part of the Blue Hill member are cut by a fault trending N. 80° W., in which the beds are dropped 23 feet on the north near the southeast corner of sec. 25, T. 11 S., R. 19 W. The fault plane dips 60° N. The beds on both sides of the fault plane are essentially flat, and no vein calcite fills the fracture. Three parallel faults, trending N. 10° E., in each of which the beds are dropped a few feet on the west, appear in the Fairport member of the Carlile shale in the NW¼, sec. 29, T. 11 S., R. 16 W. Slickensided crystalline calcite veins fill these fractures. About 8 miles south of Hays, in the SE¼, sec. 17, T. 15 S., R. 18 W., the lower beds of the Fairport member are faulted. The fault strikes N. 60° E., and the beds are dropped 3½ feet on the southeast. A vein of slickensided crystalline calcite 6 to 8 inches thick fills the fracture.

Of the eighty-one faults noted in the county, seventy-four were seen in the Smoky Hill chalk member of the Niobrara formation, three in the Fort Hays limestone member, and four in the Fairport member. As the seventy-four faults in the Smoky Hill member were found in the course of work that was far more detailed than that in the lower beds, the relation is probably not nearly so striking as here indicated. However, the evidence indicates that faults are more abundant in the Smoky Hill member than in the other members. Only one fault has an apparent throw greater than 25 feet.

No system as to direction of fault planes is discernible, and the dips of the fault planes are steep. As a rule the fault planes are marked by slickensided vein calcite, and in some places the chalk beds near the fault plane on the downthrown side are intricately cut by thin calcite veins that are nearly vertical or dip slightly toward the fault plane. On the downthrown side of many but not all of the faults the beds dip into the fault plane.

Twenhofel[19] has studied faults in the Niobrara formation at numerous localities in counties north and west of Ellis county and accounts for them under four possible methods of origin, as follows, stating that most of the faults are probably due to the cause first mentioned: (1) Settling of brittle chalk to conform to adjustments attending unequal compression of the thick body of shale over the irregularities of the Permian-Comanche unconformity and over sand lenses in the Comanche and Dakota; (2) surficial slumping on the slopes of present stream valleys; (3) slumping into solution cavities within the chalk; (4) faulting in conjunction with regional structural movement.

Adjustments attending unequal compression of sediments. Observations made in Ellis county are not inharmonious with Twenhofel's conclusion that the greater number of these faults can be attributed to unequal compression of sediments over sand lenses in the Comanche and Dakota and irregularities in the Permian surface. Recent drilling has revealed another unconformity lying about 3,500 feet beneath the surface of Ellis county over which this process may have also operated to some extent. It has been pointed out by several writers that irregularities in such an old eroded land surface as that marked by this unconformity form cores over which the sediments are unequally compressed,[20] the clay deposits for instance being more readily compactible than limestones and sandstones.

The chalk beds of the Niobrara formation are exceedingly brittle and are consequently susceptible to only slight deformation except by breaking. These brittle beds immediately overlie a deposit consisting predominantly of soft clay shale a little more than 400 feet thick, which is in turn underlain by the Dakota sandstone and

19. Twenhofel, W. H., Surface structures of Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 9, pp. 1064-1069, 1925.

20. Blackwelder, Eliot, The origin of the Central Kansas oil domes: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 89-94, 1920.
Mehl, M. G., The influence of the differential compression of sediments on the attitude of bedded rocks: Science, new ser., vol. 51, p. 520, 1920 (abstract).
Powers, Sidney, Reflected buried hills and their importance in petroleum geology: Econ. Geology, vol. 17, pp. 233-259, 1922.

Comanche beds which contain lenticular sand bodies, and overlie the irregularly eroded surface of the Permian rocks. This order of succession of beds appears to be ideal for securing faulting in the Niobrara chalk. The thick clay beds are compressed over the less compactible sandstone beds of the Dakota and Comanche and the less readily compactible beds of the Permian, and because of the lenticular character of the sand bodies and the irregularities in the Permian surface are compacted unequally. The chalk beds of the Niobrara formation, which overlie the clay body, because of their

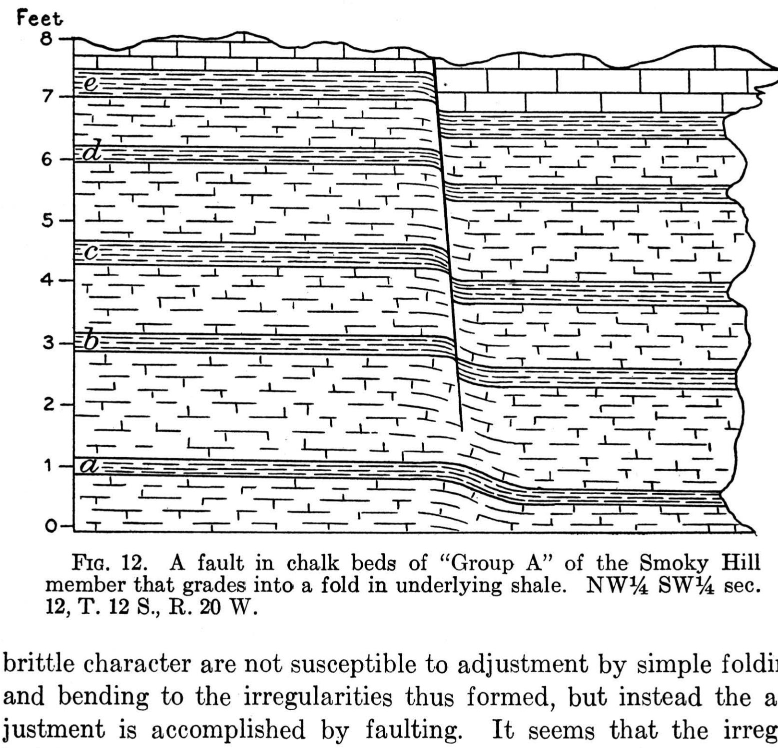


FIG. 12. A fault in chalk beds of "Group A" of the Smoky Hill member that grades into a fold in underlying shale. NW¼ SW¼ sec. 12, T. 12 S., R. 20 W.

brittle character are not susceptible to adjustment by simple folding and bending to the irregularities thus formed, but instead the adjustment is accomplished by faulting. It seems that the irregularities at the top of the thick shale body resulting from such a process would likely be for the most part undulatory in type favoring the production of many faults accompanied by small displacement of the beds rather than a few breaks of great magnitude. The large number of faults with small displacement of the rocks found in Ellis county is in harmony with this hypothesis.

The presence of faults in the Greenhorn limestone which is separated from the Dakota sandstone by only about 40 feet of clay shale and is below much of the soft clay unit that immediately underlies the Niobrara beds suggests that the nucleus about which the settling has taken place to produce these faults (assuming this to be their origin), must lie well down in the Dakota or Comanche rocks, or below. It may be that the base over which this process of unequal compression has operated is in some cases even below the upper Permian surface, perhaps the old erosion surface that lies at a depth of about 3,500 feet.

An illustration of the general process of folding of soft beds accompanied by faulting in overlying brittle beds was seen in the field. The brittle chalk beds of "group A" beds of the Smoky Hill member are cut by a fault of small displacement which is resolved into a fold in the shales of the lower part of the group, in the NW¼ of the SW¼, sec. 12, T. 12 S., R. 20 W., as illustrated in Figure 12.

Surficial slumping. Although recent slumping of large blocks of Fort Hays limestone has occurred at many localities where erosion has been rapid and the limestone caps steep shale slopes, no evidence that this process has operated to cause any of the faults mapped in Ellis county was seen. Furthermore, in Ellis county no appreciable number of the fault blocks dip into the slope, which is the usual attitude assumed as the result of slumping of this character. However, the slope of the pre-Ogalalla surface may be quite different from the present slope and it is possible that a relationship between the faults and that slope might be established.

Slumping into solution cavities. If all the faults seen in the region are to be attributed to unequal compression of sediments, it should be expected that the Fort Hays limestone member of the Niobrara formation would contain as many faults as the overlying beds of the Smoky Hill member, as the Fort Hays is composed of brittle chalk with much less shale content than the Smoky Hill. Observations in the field, however, show that all but seven of the eighty-one faults observed are in the rocks of the Smoky Hill member, and that only three are in the Fort Hays limestone. However, the Smoky Hill member occupied the greater part of the surface of the area examined in detail for faults. A larger number of faults were seen in the "group A" beds of the Smoky Hill member than in the underlying "group B" beds. This difference suggests that the faults increase in number upward. Although the type of field mapping carried on did not permit the detection of all faults, the fact that the faults seen in the Smoky Hill member are much more numerous than those observed in the Fort Hays member indicates that all the faults in the Smoky Hill beds do not extend into beds in the Fort

Hays, and that the causes operating to produce some of the faults in the Smoky Hill member did not similarly affect the Fort Hays member. The abundance of calcite vein material filling the fault fractures indicates solution and redeposition of considerable material by circulating ground water within the Smoky Hill member. However, this might be expected in such readily soluble material as chalky limestone and shale, whatever the cause of the faults. The prevailing habit of the beds on the downthrown side of the faults to dip steeply into the fault planes suggests the former presence of cavities, the roofs of which have failed, allowing the overlying rocks to slump down. It is concluded, therefore, that some of the faults in the Smoky Hill member may have been formed in this manner.

Faults resulting from regional crustal deformation. If any appreciable number of the faults described were formed in connection with the structural deformation of the rocks of the region they would show more or less regularity as to habit or plan of occurrence, trend, direction of displacement, and distribution with relation to structure. Few data concerning their distribution with relation to the structure were obtained, but their utter lack of any regular plan, trend, and direction of displacement indicates that for the most part the faults are not related primarily to the structure of the region.

To summarize, no definite conclusion as to the origin of the faulting in this region can be drawn from the data at hand, but the evidence appears to suggest that most of the faults may be accounted for by unequal compression of sediments over buried irregularities on old erosion surfaces, or sand lenses; some by failure of roofs of cavities formed by circulating ground water within the Niobrara formation; a very few may be related to regional crustal deformation; and it is not impossible that a few may be the result of slumping into present stream channels.

Economic Products.

At present the greatest interest in the mineral resources of Ellis county is centered on the possible presence of oil and gas, and if either should be found within the county it will for a time overshadow all other mineral products, but others, including building stone, gravel, cement, and salt are nevertheless important. The bentonitic clay beds mentioned in the stratigraphic description are too thin and impure to be of any economic value as a source of bentonite.

Oil and gas prospecting. In 1903 a well was drilled near the center of sec. 10, T. 15 S., R. 20 W.,[21] in search of gas for use in mills that were being erected for the extraction of gold from the Carlile shale.[22] No shows of gas or oil were recorded and the well stopped in the "Red Bed" at a depth of 1,177 feet. Artesian water was struck at several depths. Recently a well was drilled for oil in the northwest corner of sec. 14, T. 12 S., R. 16 W., 3 miles west of the Russell pool, on one of the most prominent of the minor anticlines of the county. Several good shows of oil were encountered, but the well was abandoned after testing rocks that lie about 300 feet below the producing horizon of the Fairport-Natoma anticline. A well drilled to a depth of about 3,500 feet on the Polifka farm, in sec. 18, T. 13 S., R. 17 W., found several shows of oil but failed to yield in commercial quantity. The Bemis well, drilled in 1925, in sec. 16, T. 11 S., R. 17 W., to a depth of 3,570 feet, struck several shows of oil and gas. A derrick is built in sec. 33, T. 15 S., R. 20 W. A well is being drilled in sec. 25, T. 10 S., R. 19 W., a little more than 2 miles north of the county boundary. A show of oil was obtained north of Ogallah, about 10 miles west of the county boundary, in sec. 9, T. 11 S., R. 22 W. Wells in Russell county, within a mile of the Ellis county line, are producing oil. A well drilled in the SW¼ sec. 3, T. 16 S., R. 16 W., Rush county, less than 1 mile south of Ellis county, on the Pfeifer anticline, found shows of oil but failed to obtain commercial quantities of oil. This anticline is similar to the Fairport-Natoma anticline, which produces oil in Russell county, in being steeper on the west flank than on the east, but the reconnaissance mapping (Pl. III) indicates that the area of westward dip is somewhat less extensive than that of the Fairport-Natoma fold.

The anticline in T. 11 S., R. 19 W., shown on Plate III, although less steeply folded, is believed to be a part of an extensive series of structural "highs" that extends northward from Ness county into Phillips county. This anticline is now being tested for oil and gas by wells that are being drilled north of Ellis county. A well drilled in 1925 in sec. 25, T. 10 S., R. 19 W., a little more than 2 miles north of the Ellis county boundary, is reported to have encountered two or more strong shows of oil. Other wells drilled farther north, in general alinement with this fold, have obtained shows of oil.

Building stone. Building stone is plentiful in Ellis county. The "fence-post limestone," the top bed of the Greenhorn limestone, has been extensively quarried along its outcrop in the southeast quarter

21. Darton, N. H., Geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, p. 295, 1905.
22. Lindgren, Waldemar, U. S. Geol. Survey Bull. 202, 1902.

of the county and used as fence posts, bridge stone, and building stone. Most of the large churches in the county are built of this stone. It is estimated that the present cost of fence posts at the quarry is about 50 cents each.[23] The Fort Hays limestone also has been used for building, although it is softer and weathers more rapidly than the "fence-post limestone." Several public buildings and numerous farm buildings have been constructed of the harder chalk beds of the Smoky Hill member of the Niobrara formation in counties west of Ellis. The chalk beds of the two members of the Niobrara formation appear to be useful for the manufacture of whiting, and the numerous thick exposures that lie directly along the Union Pacific railroad may in the course of time be so used.

Gravel. Gravel suitable for use in masonry, street paving, and road surfacing is abundant along the flood plains and higher terraces of the streams. Recently a large amount of gravel for street construction has been taken from the valley of Big Creek, about one mile west of Hays. Road materials are obtained from the Tertiary rocks in some localities in western Kansas, particularly from areas where the Tertiary gravel is cemented with silica so as to form a very hard quartzitic rock. Quartzitic tertiary rocks occur half a mile south of the southwest corner of the county, in sec. 6, T. 16 S., R. 20 W.

Cement. The raw ingredients for the manufacture of cement are abundant in Ellis county. The idle plant of one unsuccessful attempt to manufacture cement stands at Yocemento, on the Union Pacific Railroad. The history of this enterprise was not learned, but the remoteness from fuel and large markets must have contributed to its failure. The production of oil and gas near by solves the fuel problem in part, but the remoteness from large markets still remains.

Ground water. Although in parts of the county the principal water-bearing strata lie at considerable depth, little difficulty is experienced in obtaining ample water for stock, but potable water for domestic use is lacking in some places. Several wells drilled in Ellis county to the contact of the Fairport and Blue Hill members of the Carlile shale obtained potable water, and the Codell sandstone bed, forming the top of the Blue Hill member, also furnishes satisfactory supplies. On the High Plains excellent water is found in abundance in the Ogalalla formation. Along the larger stream valleys shallow water may be found in the gravel of the alluvium.

23. Loreditsch, C. J., county engineer of Ellis county, personal communication.

However, to obtain water in sufficient quantity for stock and of a quality suitable for domestic use is a real problem in much of the county. In areas lying below the outcrop of the base of the Blue Hill member and away from the larger stream courses it is necessary to drill to the Dakota sandstone, which unfortunately in many places yields water that is too salty for domestic use. In many wells, however, the water in the uppermost water-bearing stratum of the Dakota is not so highly saturated with salts as that in the lower porous strata of the formation and can be used for domestic purposes.

Salt. The records of recent deep wells show that Ellis county, like most of the counties of western Kansas, is underlain by an enormous deposit of salt, ranging in total thickness from 21 feet as reported in the Bemis well, in sec. 16, T. 11 S., R. 17 W., to 230 feet in the Polifka and Smith wells, in sec. 18, T. 13 S., R. 17 W., and sec. 14, T. 12 S., R. 16 W., respectively. These wells, together with others in Trego, Ness, Rush and Russell counties, furnish data for a calculation of the amount of salt underlying Ellis county. If it is assumed that 30 per cent of the salt thickness as reported by drillers is occupied by shale, mud, or other rocks than salt, that is, using but 70 per cent of the thickness actually reported in the well logs, and that the thickness of the salt beds varies at a uniform rate between the wells, a rough estimate indicates that Ellis county contains more than 200 billion tons of salt. Built in a prism standing upright, its base occupying one square mile, this quantity of salt would tower into the air about 2 miles. The top of the salt series lies approximately 1,400 feet below the surface in the eastern part of Ellis county and increases in depth westward. (Fig. 11.) As thick salt deposits lie nearer the surface farther east in Kansas and are therefore more easily accessible, the salt in Ellis county is only a potential resource and is of little economic value at present.

PART II.

The Geology of Hamilton County, Kansas.

Field Work.

A FEW weeks in August and September, 1924, were spent in and near Hamilton county obtaining the data upon which this report is based. Inasmuch as the south half of the area is within the boundaries of the Syracuse and Lakin quadrangles, which were described by Darton[1] in 1920, much time in searching for outcrops in the field was saved by reference to Darton's geologic map. The purpose of the field study was to determine as nearly as possible the configuration of the Syracuse anticline shown in a generalized sketch map by Darton. There are few exposures of the rocks involved in the Syracuse fold, the surface being occupied by unconsolidated sediments that are unconformable with the folded strata and were deposited subsequent to the time of folding. It was therefore necessary to determine the stratigraphic section in detail in order that the available outcrops might be correctly assigned in the stratigraphic column.

A detailed section of the rocks was measured, in part in Kearny county on the north side of Arkansas river, in part in southern Hamilton county in T. 26 S., R. 41 W., and in part farther north in Hamilton county in Ts. 22 and 23 S., R. 42 W., and T. 22 S., R. 43 W. Altitudes were determined in Ts. 25 and 26 S., R. 41 W., in T. 26 S., R. 42 W., and in the eastern part of Ts. 22 and 23 S., R. 42 W., by telescopic alidade and plane table. In the remainder of the south half of the county the locations of outcropping strata were sketched on the United States Geological Survey's topographic map of the Syracuse quadrangle. No topographic survey of the north half of the county has been made, and so in that area outcrop locations were sketched on a map (scale 1 inch to 2⅝ miles) issued by the county clerk's office at Syracuse, and altitudes were determined by aneroid readings. For the determination of structure a large number of water wells drilled to the Dakota sandstone in the south half of the county were visited and located on the Syracuse topographic

1. Darton, N. H., U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin folio (No. 212), 1920.

map. Records of a few wells in the north half of the county were obtained.

No attempt was made to visit every outcrop in the north half of the area nor to determine accurately the areal distribution of the formations. The field work was done to determine the structure of the region, and the areal geologic map (Pl. V) was compiled in the office from the data gathered in the course of the structural work. This map is consequently of a distinctly reconnaissance type.

Samples of drill cuttings from the Wood Oil Co.'s well, in sec. 5, T. 26 S., R. 41 W., Hamilton county, were studied during the winter of 1924-'25, as drilling progressed. Temperature readings in the well were taken the first week in April, 1925, when the drill had reached a depth of 4,650 feet.

ACKNOWLEDGMENTS.

Splendid coöperation in the field work was given by a great number of ranchers in the county, residents of Syracuse, and the county officers. Special thanks are due to Fred Hoppe, of Syracuse, who assisted in the plane-table work and part of the time in collecting water-well records. Appreciation of the many courtesies accorded by W. S. McCray, Clyde Smith, and E. L. Orr, of the Wood Oil Co., and the drillers and tool dressers of the same company, particularly for their painstaking care in saving complete sets of samples of drill cuttings from their well is gladly expressed. The writer is indebted to W. C. Mendenhall for suggestions during a short visit to the area while field work was in progress, and to W. T. Thom, Jr., and R. C. Moore for valuable criticisms in the compilation of the data.

LOCATION, TOPOGRAPHY, AND CULTURE.

Hamilton county, comprising an area 25 miles from east to west by 36 miles from north to south, is in the third tier of counties north of the south boundary of Kansas and is adjacent to the Colorado line. (Fig. 13.) It is within the High Plains division of the Great Plains province, and its surface presents in general a broad, flat table-land (Fig. 14B), interrupted by the drainage channel of Arkansas river, which flows in a southeastward direction across the middle of the county, and modified to a much less marked degree by the North Fork of Bear creek, in the southern part of the county. The plains have a gentle eastward inclination, the highest parts of the county being near its west boundary. In the southwestern part the maximum altitude above sea level is slightly below 3,700 feet, and in the northwest corner the surface rises about 300 feet higher. Arkansas river has an average grade of about 8 feet to the mile across

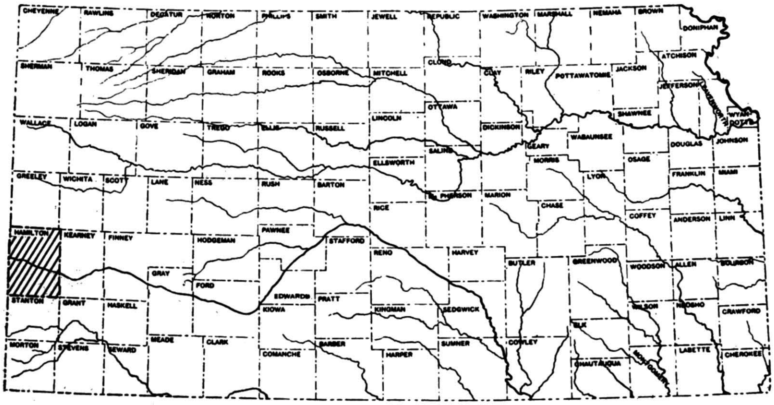


FIG. 13. Index map of Kansas showing location of Hamilton county.

the county, and its bed is at an altitude of 3,100 feet where it crosses the east boundary.

Because of low annual rainfall (average 15.59 inches) and hot

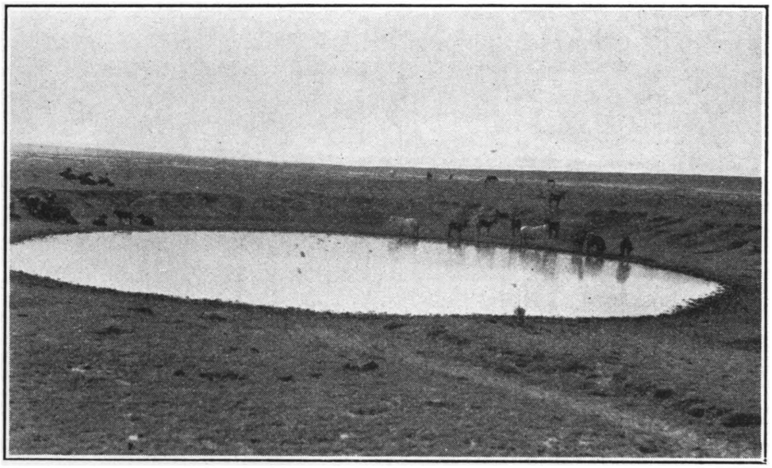


FIG. 14 A. Water hole on the High Plains, sec. 25, T. 25 S., R. 43 W., Hamilton county.

winds, the raising of crops is in general difficult. A small percentage of the total area is farmed with mediocre success, but the greater part is given over to the grazing of cattle. Short grasses, of which buffalo and grama are most abundant, form a dense sod that covers the surface. The observations of this one summer indicate that broom corn, wheat, and drought-resistant sorghums are the prin-

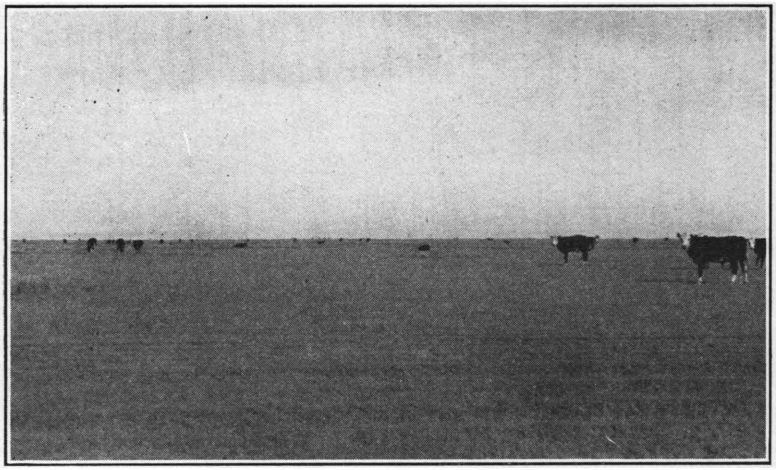
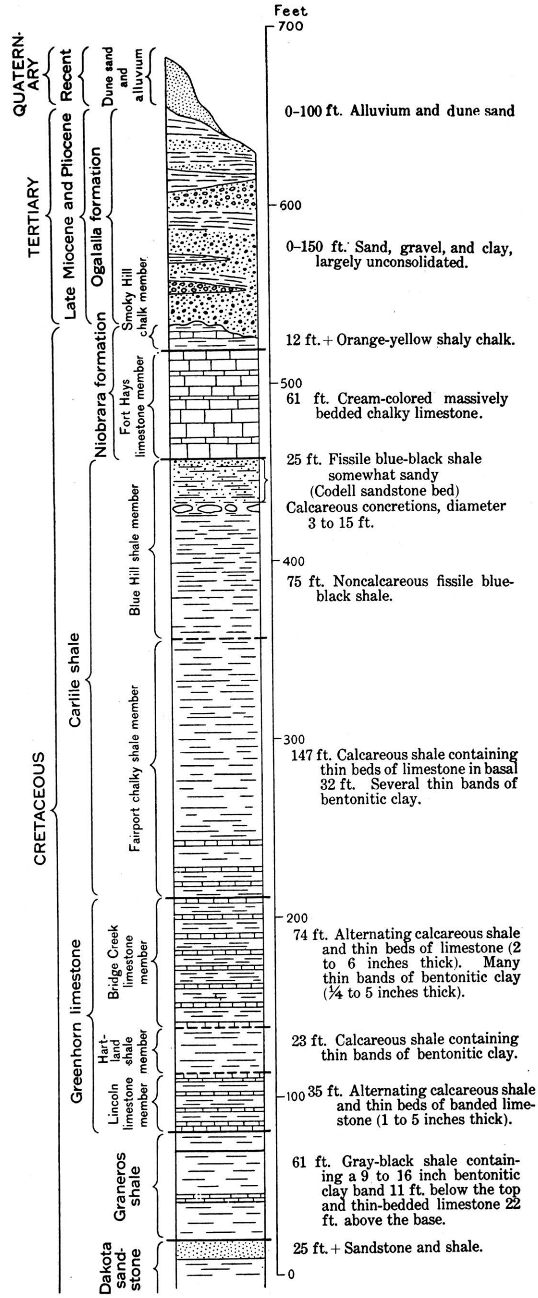


FIG. 14 B. View on the High Plains, sec. 26, T. 25 S., R. 41 W., Hamilton county.

FIG. 15. Outcrop of volcanic ash in sec. 13, T. 26 S., R. 41 W., Hamilton county.

cipal crops raised on the farms. A narrow irrigated strip along Arkansas river produces excellent crops, among which alfalfa hay is probably of the greatest value. The farms are thinly scattered, particularly north of the Arkansas valley, and there are but a few small towns in the county, the total population being 2,500 in 1925.



COLUMNAR SECTION OF ROCKS EXPOSED IN AND NEAR HAMILTON COUNTY, KANSAS.

FIG. 16.

The main line of the Atchison, Topeka & Santa Fe railway crosses the county and Syracuse is a division point, where a hotel and small shops are maintained. The Santa Fe automobile trail parallels the railroad, and a graded road crosses the county from north to south. The used roads throughout the area are for the most part not graded, but because the surface is exceedingly level and is underlain by materials that form an excellent natural road bed, and the rainfall is low, they are in fair condition throughout most of the year.

Stratigraphy.

A little more than 500 feet of rocks of Cretaceous age, about 150 feet of Tertiary sediments, 25 feet of Quaternary alluvium, and dune sand of an unknown thickness are exposed in Hamilton county (Fig. 16), and nearly 5,000 feet of older rocks have been penetrated by the drill. Except in a few scattered localities (see Pl. V) the Cretaceous rocks are effectively concealed by a mantle of Tertiary and Quaternary deposits spread over their eroded edges. A generalized section of the rock formations is given below.

Stratigraphic section in Hamilton county, Kansas.

AGE.	Formation and member.	Lithologic character.	Thickness (feet).
Recent.		Alluvium along Arkansas river and other streams. Dune sand.	0–100+
Pleistocene (?).		Volcanic ash in southern part of county.	0–2½
Pliocene and late Miocene.	Ogalalla formation.	Sand, clay, gravel, and "mortar beds."	0–150
	Unconformity		
Upper Cretaceous.	Niobrara formation: Smoky Hill chalk member.	Soft shaly chalk with limonitic concretions. Top not exposed.	12
	Fort Hays limestone member.	Light cream-colored thick-bedded chalky limestone containing thin partings of dark-gray chalky shale.	61
	Carlile shale: Blue Hill shale member.	Blue-black fissile shale, slightly sandy in top 25 feet (Codell sandstone bed). Contains layer of calcareous concretions just below the Codell sandstone bed.	100
	Fairport chalky shale member.	Calcareous shale with thin bedded chalky limestone near base.	147
	Greenhorn limestone: Bridge Creek limestone member.	Alternating limy shale and thin chalky limestone.	74
	Hartland shale member.	Limy shale.	23
	Lincoln limestone member.	Limy shale; thin-bedded, finely banded limestone; and thin chalky limestone.	35
	Graneros shale.	Gray-black fissile clay shale, with thin-bedded limestone 22 feet above base.	61
Lower Cretaceous (?).	Dakota sandstone and possible representatives of Lower Cretaceous Purgatoire formation and Lower Cretaceous (?) Morrison formation.	Irregularly bedded light-colored fine-grained sandstone, sandy shale, and shale in upper part; dark shales near middle; and light-tan sandstone at base. Upper 25 feet exposed.	400+
Permian (?).		Red shale, sandy shale, anhydrite, gypsum, salt, and a little limestone.	2,200+
Pennsylvanian.		Interbedded dark-gray cherty limestone and shale. Shale red and brown in upper half and dark-gray in lower half.	1,000
		Light-gray oölitic limestone containing a few thin breaks of dark-gray shale.	500
		Dark-gray to black shale.	800+

Quarternary System.

A belt of Recent alluvium averaging about 2 miles in width and about 25 feet in thickness borders Arkansas river, the greater part of it north of the present river channel. Paralleling the alluvium on the south is a belt of dune sand of unknown thickness, probably not more than 75 feet, composed largely of quartz sand. This belt is 3 to 5 miles wide. The surface of the greater part of the dune area is covered with coarse grasses such as are common to dune-sand regions of the West, but there are considerable areas of bare dunes that shift their positions with every wind storm. Beds of volcanic ash as much as 2½ feet thick, of Pleistocene (?) age, occur in southern Hamilton county. (Fig. 15.)

Tertiary System.

Ogalalla Formation.

The Ogalalla formation, which has a maximum thickness of 150 feet and consists of lenses of gravel, sand and clay intricately overlapping one another, all unconsolidated except for a few layers cemented with lime carbonate, occupies the greater part of the surface of Hamilton county. It was spread upon the eroded floor of Cretaceous rocks by aggrading streams of Pliocene and late Miocene time.[2] The greatest amount of the material in the formation is unconsolidated sand of a reddish-brown color. Numerous thick lenses of dark clay and muck are reported in the logs of drilled water wells, and thin layers of gravel are common. Here and there are layers of sand and gravel that are cemented by abundant lime carbonate into a comparatively hard rock having much the appearance of old mortar and commonly known as "mortar beds."[3] The ridge south of Coolidge and Medway, constituting the divide between Arkansas river and the North Fork of Bear creek, is capped by "mortar beds." The gravel beds and coarse sands of the formation carry water throughout much of western Kansas and are consequently the main source of well-water supply over a wide area.

2. Darton, N. H., U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin folio (No. 212), 1920.
3. Hay, Robert, U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 570, 1895.

Cretaceous System.

NIOBRARA FORMATION.

Smoky Hill chalk member. An unknown thickness of the lower part of the Smoky Hill chalk member of the Niobrara formation unconformably underlies the Tertiary rocks in the northern part

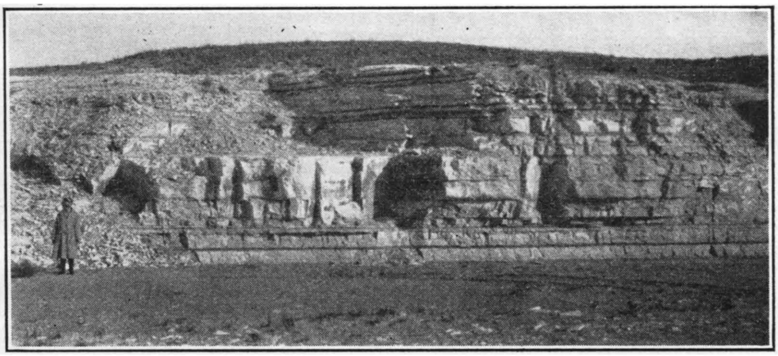


FIG. 17. The upper 15 to 20 feet of the Fort Hays limestone member of the Niobrara formation, sec. 3, T. 22 S., R. 43 W., Hamilton county. View southeastward.

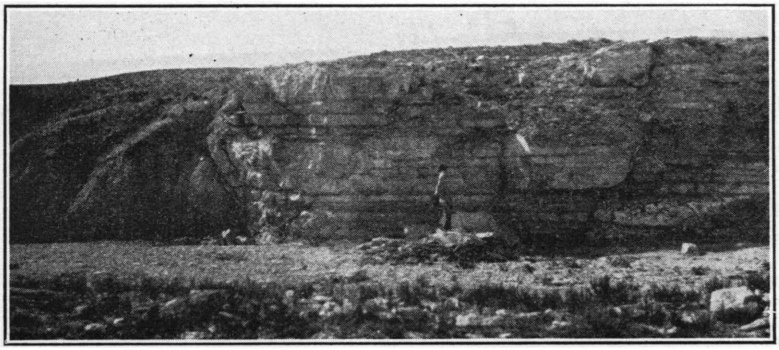


FIG. 18. Fault in sec. 29, T. 22 S., R. 42 W., Hamilton county. Beds of the Fort Hays limestone member of the Niobrara formation show on the right side of the main fault and the topmost 25 feet (Codell sandstone bed) of the Blue Hill shale member of the Carlile shale are on the south. A second fault having a small throw shows near the right end of the picture. View westward.

of Hamilton county. The basal 12 feet of the member, which consists of orange-yellow soft shaly chalk, is exposed in the NW¼, sec. 3, T. 22 S., R. 43 W., and a thin remnant of the basal beds shows in the creek bank in sec. 14, T. 22 S., R. 42 W. These rocks contain numerous flat circular limonitic concretions and many flat circular shells of the bivalve *Inoceramus* (*Haploscapha*) *grandis* Conrad, plastered with oyster shells. The limonitic concretions fill casts of specimens of the *Inoceramus* shells. Numerous partly replaced shells were seen in the Smoky Hill chalk member in Ellis and Trego counties, which lie east of Hamilton county.

Fort Hays limestone member. A thickness of 61 feet of cream-colored chalky limestone, in massive beds ranging from a few inches to 3½ feet in thickness, separated by thin layers of dark-gray clay shale, constitutes the Fort Hays limestone member of the Niobrara formation. (Fig. 17.) In this respect the member maintains in remarkable degree the characteristics exhibited in Ellis county and neighboring parts of central western Kansas, where it is so extensively exposed. The shale bands are more numerous and the limestone beds appear to be slightly softer and chalkier in Hamilton county than in the areas to the east, although these characteristics may be due to the more recent exposure of the outcrops seen in Hamilton county. Practically the entire member contains in fair abundance specimens of the coarse-ribbed, rounded shells of *Inoceramus deformis,* and associated with them are shells of *Ostrea congesta.* The topmost few feet of the member is more shaly than the remainder. These top beds form a rather distinct bench, however, and in the few exposures seen are whiter and harder than the overlying beds, and they do not contain the flat circular limonitic concretions and flat *Inoceramus* (*Haploscapha*) *grandis* shells so common in the Smoky Hill member.

The base of the member is quite sharply defined from the underlying Carlile shale. The contact is in many places marked by a hard, dark blue gray, fossiliferous limestone only a few inches thick that emits a strong odor of petroleum when broken. Individual beds in the member are difficultly traceable, but a series of limestone beds can be correlated readily from one exposure to another.

Exposures of the Fort Hays limestone member are limited to the northwest part of the county, where tributaries of Arkansas river cutting headward have laid bare in their steep walls limited areas of these beds underlying the Tertiary deposits. It is probable that exposures other than those shown in Plate I exist in the gulches in the south part of T. 22 S., R. 42 W., for this area was not visited.

Fossils from the Fort Hays limestone from bluff of the limestone on Bridge creek in sec. 25, T. 22 S., R 42 W., were identified by J.

B. Reeside, Jr., of the United States Geological Survey, lot 12793. The only species identified was *Inoceramus deformis* Meek.

Carlile Shale.

A body of shale that is noncalcareous, blue black and fissile in its upper 100 feet and limy and lighter colored, increasingly so downward, in its lower part, the whole comprising a total thickness of about 250 feet (based in part on the log of a water well) constitutes the Carlile shale. It was divided into two members in Russell county,[4] the Blue Hill shale member above and the Fairport chalky shale member below. These subdivisions are readily determinable in the outcrops in Hamilton county, for in general they maintain here the characteristics exhibited in Russell county, nearly 150 miles to the northeast.

Blue Hill shale member. Blue-black noncalcareous fissile clay shale; sandy in its upper part and containing a layer of calcareous concretions 25 feet below the top, constitutes the Blue Hill shale member. The uppermost 25 feet consists of gritty shale containing very thin streaks of silty sandstone, and the top 2 feet is largely sand. This sandy zone constitutes the Codell sandstone bed described in Part I. At 25 feet below the top of the member, or just beneath the Codell bed, is a layer of calcareous concretions which are commonly 4 to 5 feet in diameter, though some attain a diameter of 15 feet. These concretions crop out along many of the gulches in northwestern Hamilton county and are especially abundant on Bridge creek in the NE¼ sec. 35 and the NW¼ sec. 36, T. 22 S., R. 42 W., west of Brower's ranch house. Figure 19 is a view of a few of the concretions at this locality. Many individuals exhibit a marked cone-in-cone structure in their upper weathered surfaces and contain a few septa filled with vein calcite. One concretion unusually well exposed near Brower's ranch passes laterally into a thin calcareous shaly sandstone which contains numerous casts of mud cracks on its upper surface. Below the concretions is 75 feet of blue-black fissile clay shale that is exposed in its entire thickness in sec. 29, T. 22 S., R. 42 W.

The Blue Hill member has thinned westward from the region of Ellis and Russell counties, where it ranges in thickness between 175 and 215 feet, to a thickness of 100 feet in Hamilton county. In Ellis and Russell counties it contains numerous layers of septarian lime concretions, but in Hamilton county it contains only one. The

4. Rubey, W. W., and Bass, N. W., The geology of Russell county, Kansas: Kansas Geol. Survey Bull. 10, p. 33, 1925.

Codell sandstone bed is present in the uppermost part of the member but contains much more intermixed and interlaminated clay than in the areas farther east.

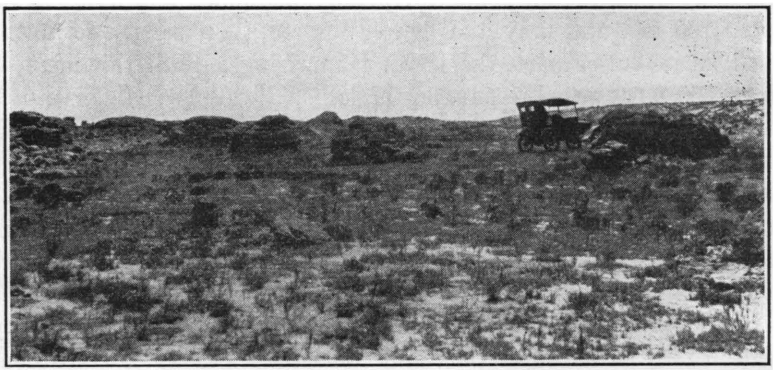


FIG. 19. Calcareous concretions in the Blue Hills shale member of the Carlile shale on Brower's ranch, sec. 36, T. 22 S., R. 42 W., Hamilton county.

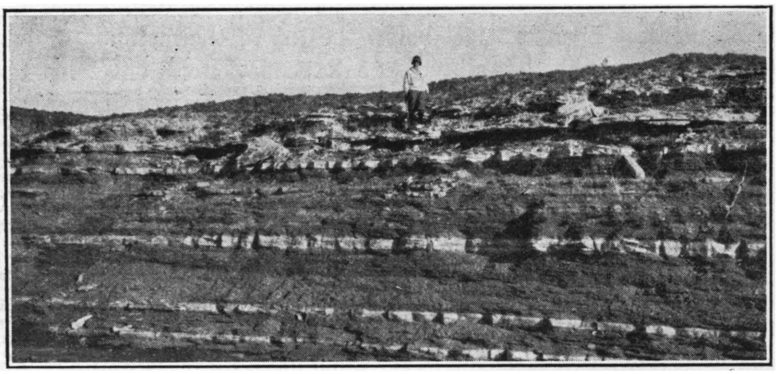


FIG. 20. A part of the Bridge Creek limestone member of the Greenhorn limestone, in the east bank of Bridge creek, sec. 14, T. 23 S., R. 42 W., Hamilton county. The abundantly fossiliferous limestone beds of the member occur near the top of the exposure.

The fossils from the Blue Hill member, as reported by J. B. Reeside, Jr., of the United States Geological Survey, consist of the following:

Lot 12762, NW¼ sec. 32, T. 22 S., R. 42 W.:
Inoceramus sp., fragments.
Prionocyclus wyomingensis Meek (upper Carlile fauna).

Lot 12769, sec. 36, T. 22 S., R. 42 W.:
Prionocyclus wyomingensis Meek.
Lot 12770, sec. 36, T. 22 S., R. 42 W. Top of Codell sandstone bed:
Ostrea congesta Conrad (float?).
Ptychodus sp.
Lamna? sp.
Corax? sp.
Coprolites and phosphate nodules.

"If the idea is correct that a phosphate nodule and fishbone horizon represents a suspension of sedimentation, this horizon offers an interesting and useful place for a sedimentary boundary."

Lot 12772, from very top of member, at contact with Fort Hays limestone, sec. 36, T. 22 S., R. 42 W.:
Inoceramus fragilis Hall and Meek.
Prionocyclus wyomingensis Meek (upper Carlile fauna).

Fairport chalky shale member. Calcareous blue-black shale in the upper part, becoming more limy and somewhat lighter in color downward, and thin chalky limestone beds alternating with limy shales in the basal 35 feet, the whole having a thickness of 147 feet (based on the log of a water well), make up the Fairport chalky shale member of the Carlile shale. Its contact with the overlying Blue Hill member is not sharply defined. It can be fairly definitely differentiated, however, in sec. 32, T. 22 S., R. 42 W., by the lack of calcareousness in the shale of the overlying member. Fossils collected a short distance below the contact are diagnostic of the lower Carlile. The upper three-quarters of the member is only partly exposed in the region, but on the basis of the few exposures seen and its gently sloping topographic expression it is believed to be practically all calcareous shale with a very few beds of shaly limestone 1 to 2 inches thick. The lower one-fourth of the unit contains eleven beds of light-gray generally fossiliferous chalky limestone, relatively soft on fresh exposure, averaging 3 to 4 inches in thickness, no bed exceeding 6 inches. The lower shales are very calcareous and likewise fossiliferous. Many thin layers of bentonitic clay, one-quarter to 1 inch thick, are present throughout the member, though they decrease in number upward. One layer of orange-colored bentonitic clay 8 inches thick occurs 32 feet above the base. The entire member is of a bluish color on fresh exposure and weathers to a cream-gray, becoming lighter in color downward.

The fossils from the Fairport member, as reported by J. B. Reeside, Jr., of the United States Geological Survey, are listed below. The positions of the collections in the stratigraphic section are shown in Figure 21 by numbers corresponding to the lot numbers given here.

Lot 12785, sec. 14, T. 23 S., R. 42 W., from chalky limestone bed 18 feet above base of member:

Inoceramus labiatus Schlotheim, broad variety (lower Carlile fauna).

Lot 12788, sec. 7, T. 23 S., R. 42 W., from chalky limestone bed 5 feet above base of member:

Inoceramus labiatus Schlotheim, broad variety (lower Carlile fauna).

Lot 12814, sec. 7, T. 23 S., R. 42 W., from chalky limestone bed 16 feet above base of member:

Ostrea cf. *O. congesta* Conrad.
Inoceramus labiatus Schlotheim, broad variety.
Baculites gracilis Shumard.
Prionotropis woolgari (Mantell).
Ichthyodectes? sp.

Lot 12784, sec. 7, T. 23 S., R. 42 W., from chalky limestone bed 12 feet above base of member:

Globigerina bulloides.
Ostrea cf. *O. congesta* Conrad.
Inoceramus labiatus Schlotheim, broad variety.
Inoceramus fragilis Hall and Meek.
Prionotropis woolgari (Mantell).
Ichthyodectes? sp.
(Lower Carlile fauna.)

Lot 12824, sec. 14, T. 22 S., R. 42 W., from chalky limestone bed 11 feet above base of member:

Globigerina bulloides D'Orbigny.
Inoceramus labiatus Schlotheim, broad variety.
Inoceramus fragilis Hall and Meek.
Baculites sp.
Prionotropis woolgari (Mantell).
(Carlile fauna.)

Greenhorn Limestone.

The Greenhorn limestone, consisting of calerous shale interbedded with thin layers of chalky and crystalline limestone and bentonitic clay, is sharply defined from the underlying Graneros shale, but merges into the overlying Carlile shale with no apparent lithologic change. Its separation from the basal member of the Carlile shale is made on the evidence of the fossils that occur abundantly above and below the contact of the two formations. The Greenhorn limestone is 132 feet thick and is readily divisible into three members in the Hamilton county region—an upper member of alternating chalky limestone and shale, herein named Bridge Creek limestone member; a middle member of limy shale, herein named Hartland shale member; and a basal member of interbedded limy shale, chalky limestone, and thin-bedded hard crystalline limestone that represents the Lincoln limestone member of counties to the east.

Bridge Creek limestone member. Alternately bedded limy shale and chalky limestone, having a total thickness of 74 feet, four-fifths of which consists of shale, constitute the Bridge Creek limestone member of the Greenhorn limestone. These beds are excellently exposed on Bridge creek northwest of Medway, in sec. 14, T. 23 S., R. 42 W. The member as a whole is harder than the overlying and underlying beds and characteristically forms low bluffs or terraces. It is this member that forms the relatively steep slope bordering the Arkansas river bottoms on the north. (Plate V.) The chalky limestone, which constitutes scarcely one-fifth of the total thickness of the member, occurs in somewhat equally spaced beds averaging 4 inches in thickness, no single bed exceeding 10 inches. A view of a part of the member cropping out on Bridge creek is shown in Figure 20. Ten or more bands of bentonitic clay are present, ranging from a quarter of an inch to 5 inches in thickness. Although fossils are rare in the lower third of the member, they are abundant in the shale and limestone of the upper two-thirds and are much better preserved in the limestone than in the shale. The limestone beds occurring from 40 to 50 feet above the base are composed almost entirely of fossil shells of *Inoceramus labiatus,* a characteristic species of the Greenhorn limestone. Because the individual beds of limestone and layers of bentonitic clay of the member are so persistent laterally, a detailed section of the stratigraphic sequence of beds was measured in order that the very meager exposures of parts of the member that occur on the flanks of the Syracuse anticline might be compared with this section and properly allocated in the stratigraphic column. Figure 21 shows a detailed section of the Bridge Creek limestone member and the lower part of the overlying Fairport chalky shale member. The limestones of the Bridge Creek member terminate abruptly at the base in a relatively thick bed split near the middle by a thin bed of shale. The double limestone bed thus formed, because of its superior hardness over the underlying soft shale, forms a bench that terminates below in a steep slope and rises more gradually to a series of very minor terraces formed by the several limestone layers above. A thick layer of bentonitic clay (Fig. 21) that occurs above the basal limestone weathers into an ocherous clay soil spread upon the lowest terrace, and the white chips of the basal limestone lie immediately below it and form the cap to the steep slope of the succeeding Hartland shale member.

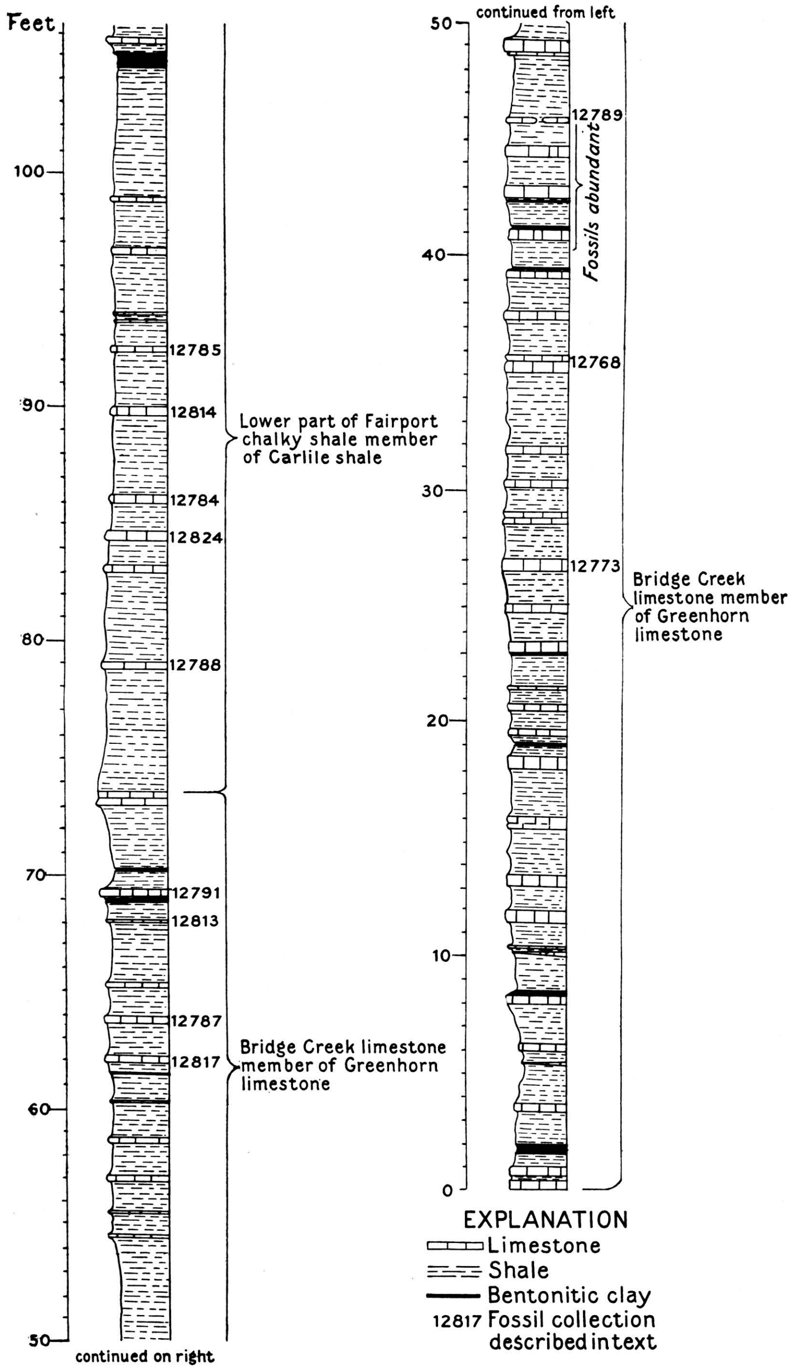
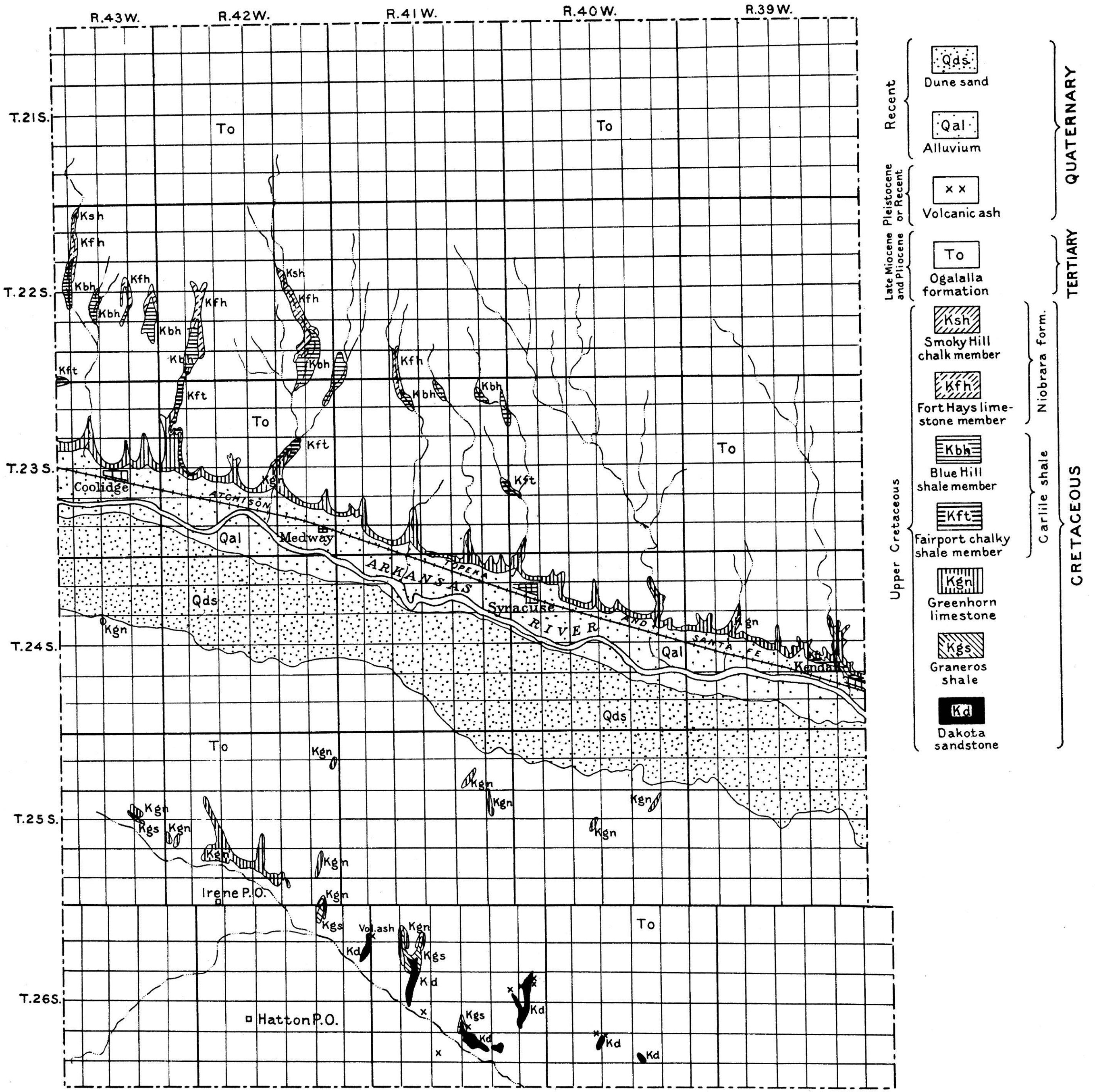


FIG. 21. Graphic detailed section of the lower part of the Fairport member, and the Bridge Creek member of the Greenhorn limestone.



RECONNAISSANCE GEOLOGIC MAP OF HAMILTON COUNTY, KANSAS

By N. W. Bass.

Much of south half of area after N. H. Darton, U.S. Geological Survey Folio 212.

0 5 10 MILES

PLATE V.

These characteristics are excellently shown in the low bluff paralleling Arkansas river on its north side from Kendall southeastward for several miles in western Kearny county.

The field work in Hamilton county was done after the writer had become acquainted with the Greenhorn limestone in Ellis and Russell counties in central Kansas, where the upper half of the formation is divided into the Pfeifer shale member and Jetmore chalk member. These subdivisions can be recognized in Hamilton county, although less distinctly. The uppermost 25 feet of the Bridge Creek member of Hamilton county is almost certainly the equivalent of the Pfeifer shale member of Ellis county, the topmost bed being the "fence-post limestone." The remainder of the Bridge Creek member apparently represents the Jetmore chalk member of central western Kansas. In Hamilton county, as in Russell and Ellis counties, this part of the member is capped by a relatively thick limestone bed that is slightly harder than those above it, although not conspicuously different from the others, and the limestone beds of the upper part of the member are composed almost entirely of fossil shells of *Inoceramus labiatus*. The top 5 feet of this member and the basal 8 feet of the overlying member are exposed in Beeler's pasture, about half a mile south of the ranch house. This occurrence is one of the few good exposures on the north flank of the Syracuse anticline and is consequently the best-known outcrop in the region. In this exposure the thick limestone bed that shows in the creek bank a little more than 2 feet above a concretionary bed and forms a prominent shelf about 2 feet above the level of the creek is believed to be the equivalent of the top bed of the Jetmore member and is 49 feet above the base of the Bridge Creek member.

Hartland shale member. Below the Bridge Creek member is a unit of calcareous shale 23 feet thick that is almost devoid of limestone and contains numerous layers of bentonitic clay ranging from a quarter of an inch to 2 inches in thickness. This shale weathers to a tannish gray or flesh color. The entire unit is clearly exposed in western Kearny county, in the bluff on the north side of the old Santa Fe trail, from a point a short distance west of Hartland to Kendall, where the member forms a slope between a cap of white chips formed by the basal limestone beds of the Bridge Creek limestone and a lower bench made by the thin, hard layers in the upper part of the Lincoln limestone member. A section measured in Kearny county, about half way between Sutton and Kendall, shows the Hartland member to be composed of calcareous shale with very thin layers of bentonitic clay at intervals of 8 inches, 2 feet 6 inches, 2 feet 10 inches, 6 feet 6 inches, 7 feet 3 inches, 10 feet 6 inches, 11 feet 4 inches, 15 feet 6 inches, 16 feet, and 17 feet above the base, and four thin layers of ocherous clay in the top 1½ feet of the member. A few lenses of very dark gray fossiliferous limestone a quarter of an inch to 1 inch thick occur in the member.

The Hartland shale member is lithologically similar to the unnamed member between the Jetmore and Lincoln limestone members of the Greenhorn limestone in Russell county,[5] and occurs in the same stratigraphic position.

Lincoln limestone member. The basal 35 feet of the Greenhorn limestone is also predominantly calcareous shale, and only about one-tenth of its thickness is made up of beds of limestone, which occur in thin layers half an inch to 4 inches thick, averaging about 2 inches. These limestone beds are hard, finely banded, and in part crystalline, have a dark-gray color but weather brown, and are present in most abundance near the base and top of the member. They typically weather into hard, banded, brownish slabs that emit a petroliferous odor on fresh fracture. The unit as a whole, although of bluish color on fresh exposure, weathers to a much darker tan or orange-tan color than other members of the Greenhorn. Its lower beds are well exposed in the railroad cut 1 mile east of Sutton siding, in western Kearny county, and the beds of its upper part crop out 2 miles east of Kendall, on the north side of the road. This series of beds corresponds so closely in lithology and stratigraphic position to the Lincoln limestone member of the Greenhorn limestone of Lincoln and Russell counties that, although it is impossible to trace the beds throughout most of the intervening area, because of the overlap of Tertiary sediments, little hesitancy is felt as to their correlation. Its dominant characteristics—hard, finely banded, thin-bedded crystalline limestone at the top and base, with chalky shale and soft chalky limestones constituting the mass of the unit are alike in each region.

Fossils. The fossils from the Greenhorn limestone, as reported by J. B. Reeside, Jr., of the United States Geological Survey, are listed below. The stratigraphic position of the collections from the Bridge Creek limestone member are shown in Figure 21 by numbers corresponding to the lot numbers given here:

5. Kansas Geol. Survey Bull. 10, p. 47, 1925.

Lot 12761, near quarter corner between secs. 27 and 28, T. 25 S., R. 42 W., from Bridge Creek limestone member:

Inoceramus labiatus Schlotheim.

(Greenhorn fauna.)

Lot 12768, SW¼ sec. 14, T. 23 S., R. 42 W., from limestone bed 36 feet above base of Bridge Creek limestone member:

Inoceramus labiatus Schlotheim.

Baculites? sp.

Puzosia n. sp., identical with species found in the NW¼ sec. 12, T. 14 S., R. 13 W., Russell County, and related to a species in the lower Carlile of the Black Hills.

(Greenhorn fauna.)

Lot 12773, SW¼ sec. 14, T. 23 S., R. 42 W., from limestone bed 27 feet above base of Bridge Creek limestone member:

Inoceramus labiatus Schlotheim.

Thomasites n. sp., a genus reported once previously in North America from the Greenhorn of the Front Range in Colorado. It is known in the lower Turonian of southern Europe and Africa.

(Greenhorn fauna.)

Lot 12787, sec. 14, T. 23 S., R. 42 W., from limestone bed 9 feet below top of Bridge Creek limestone member:

Inoceramus labiatus Schlotheim, broader than typical form, though it does not seem to be the broad variety.

Lot 12791, sec. 7, T. 23 S., R. 42 W., from limestone bed 4 feet below top of Bridge Creek limestone member:

Prionotropis? n. sp., same as specimen from locality 12540, in Ellis county, and probably same as one from Huerfano Park, Colo.

Lots 12817 and 12822, sec. 14, T. 23 S., R. 42 W., from limestone bed 11 feet below top of Bridge Creek limestone member:

Ostrea cf. *O. congesta* Conrad.

Inoceramus labiatus Schlotheim.

Textularia sp.

Globigerina bulloides D'Orbigny.

Inoceramus labiatus Schlotheim.

(Greenhorn fauna.)

Lot 12760, NE¼, sec. 32, T. 24 S., R. 38 W., about 2 miles southeast of Kendall, Kearny county, from bed near top of Lincoln limestone member:

Globigerina bulloides D'Orbigny.

Inoceramus labiatus Schlotheim.

(Greenhorn fauna.)

Lot 12765, sec. 2, T. 25 S., R. 38 W., half a mile east of Sutton siding, Kearny county, from bed near base of Lincoln limestone member:

Inoceramus labiatus Schlotheim.

Echidnocepthalus? sp.

(Greenhorn fauna.)

Graneros Shale.

Gray-black fissile argillaceous shale, sharply separated at the top from the banded limestone slabs of the basal (Lincoln) member of the Greenhorn limestone and less sharply separated at the base from the underlying Dakota sandstone, with a thickness of 60 to 65 feet, constitutes the Graneros shale. At 10 feet below its top is a prominent and persistent bed of bentonitic clay that ranges from 5 to 16 inches in thickness. The upper half of the formation is well exposed in the railroad cut a mile east of Sutton siding, in western Kearny county. (Fig. 22.) At 20 to 22 feet above the base of the

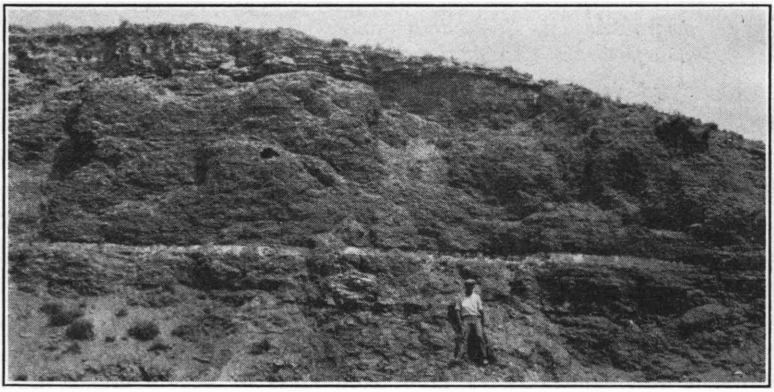


Fig. 22. Graneros shale capped by basal beds of Lincoln limestone member of Greenhorn limestone in cut bank on north side of Arkansas river, 1½ miles east of Sutton Siding, Kearny county. Bentonitic clay band 9 inches thick a few feet above man's head.

formation a zone 5 to 6 feet thick contains thin-bedded fossiliferous sandy limestones that weather to a rusty-colored rough surface. These beds crop out in the irrigation canal a mile west of Hartland, Kearny county, just west of the ditch crossing of the old Santa Fe trail. They crop out also in the NW¼, sec. 8, T. 26 S., R. 41 W., 1¼ miles south of the Wood Oil Co.'s well. A log of a water well drilled by the Atchison, Topeka & Santa Fe Railway Co. at Coolidge shows limestone 1 foot thick at this horizon. The basal 8 or 10 feet of the formation characteristically contains lenses of impure sandstone and sandy shale and layers of iron concretions 2 to 8 inches in diameter, constituting transition beds from the underlying Dakota sandstone. The basal beds of the Graneros are exposed in the SW¼, sec. 22, and the SW¼, sec. 8, T. 26 S., R. 41 W.

The fossils, as reported by J. B. Reeside, Jr., of the United States Geological Survey, consist of the following:

Lot 12764, sec. 2, T. 25 S., R. 38 W., three-quarters of a mile east of Sutton siding, Kearny county:

Ostrea n. sp., small single type, found at several localities in the Graneros of Kansas.

Lot 12767, SE¼, sec. 7, T. 25 S., R. 37 W., 3 miles southeast of Sutton siding, Kearny county:

Ostrea n. sp. small single type found at several localities in the Graneros of Kansas.

Inoceramus n. sp. (?) related to *I. fragilis* Hall and Meek.

DAKOTA SANDSTONE.

The upper 25 to 30 feet of the Dakota sandstone consists of light tan or buff fine-grained irregularly bedded sandstone and shale, and crops out in several small areas in southern Hamilton county. The topmost beds, which grade into the overlying Graneros shale, are commonly very ferruginous, very fine-grained, and in places cross-bedded, and layer upon layer are strongly ripple marked. The sandstone lenses interfinger with the shale. (Fig. 23.) In places the top sandstone of the formation is a relatively massive bed about 3 feet thick, which weathers into large blocks and is composed of very fine-grained quartz sand, the whole presenting a light tan color. Commonly above this are thin-bedded ironstone layers embedded in the basal part of the Graneros shale, or very ferruginous sandstone or ironstone concretions. In other exposures irregularly cross-bedded, poorly sorted rusty-brown sandstone and dark-gray to light shale aggregating 10 feet in thickness overlie this massive bed. (Fig. 24.)

South of Hamilton county, in Stanton and Morton counties and near Hartland in Kearny county, parts of the Dakota sandstone have been recemented with silica to form steel-gray dense quartzite that weathers brown and dark gray. In many exposures this rock occurs in rudely spherical or concretionary forms that weather out on the surface. In other exposures gradations from sandstone to quartzite are exposed. Because of their superior hardness these quartzite masses cap many rounded knolls in the area of their outcrop. The quartzite boulders are often encountered in drilling water wells in the region, and great difficulty is experienced in drilling through them. The Dakota sandstone carries an abundant supply of water, and it furnishes most of the stock water for the ranches of southern Hamilton county and supplies the flowing wells in the vicinity of Coolidge. It is reported that a few water wells penetrated thin coal beds near the top of the formation.

Rocks penetrated by the Wood Oil Co.'s well. The unusually deep test well of the Wood Oil Co. in the northwest corner of sec. 5,

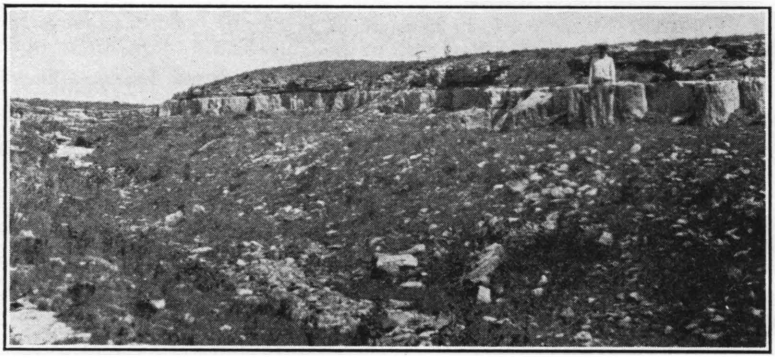
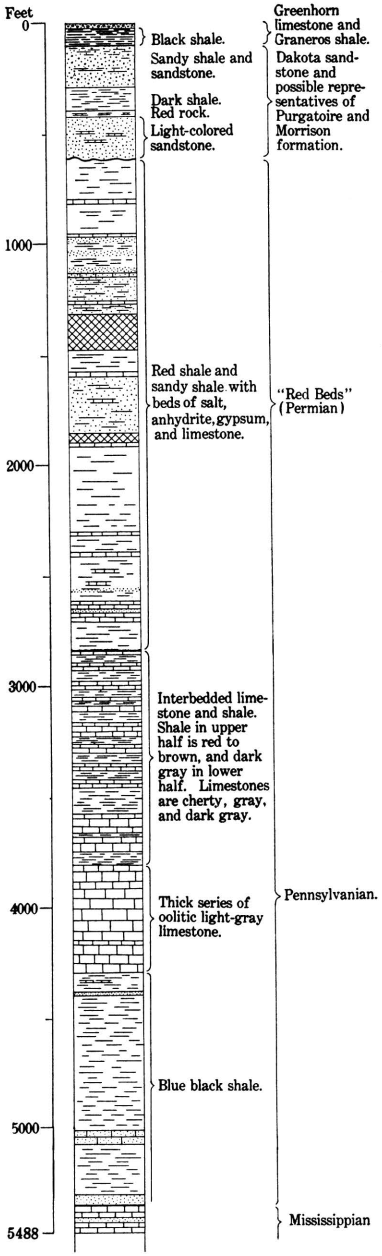


FIG. 23. Cross-bedded sandstone interfingering with shale and overlying massive sandstone bed near the top of the Dakota sandstone. Sec. 27, T. 26 S., R. 41 W., Hamilton county.

T. 26 S., R. 41 W., affords some information regarding the beds below the Dakota sandstone in Hamilton county. This well starts 105 feet above the top of the Dakota sandstone. The rocks between depths of 105 and 612 feet as recorded in the log are principally

FIG. 24. Cross-bedding in the upper part of the Dakota sandstone. Sec. 17, T. 26 S., R. 41 W., Hamilton county. View southwestward.

light-colored sandstones and shales, which carry considerable water. (Fig. 25.) From 105 to 290 feet is sandy shale and sandstone; from 290 to 400 feet is shale, below which is 30 feet of red rock



GENERALIZED STRATIGRAPHIC SECTION OF BURIED ROCKS OF HAMILTON COUNTY, KANSAS, AS SHOWN IN LOG OF WELL DRILLED IN SEC. 5, T. 26 S., R. 41 W.

FIG. 25.

and pink limestone underlain by 180 feet of sandstone with 50 feet of sandy limestone near the top. It cannot be determined from the log how much of this is in the Dakota sandstone and how much represents older strata. Darton[6] suggests that the lower parts of this sandy unit may include representatives of the Lower Cretaceous Purgatoire formation and the underlying Lower Cretaceous (?) Morrison formation. Between the depths of 612 and 2,832 feet the well penetrated a series of red shales and sandstones with a few layers of anhydrite and gypsum; about 100 feet of salt which occurs principally in two beds; and some limestone, most of which is in the lower part. The greater part of these rocks is probably of Permian age, although the lower beds may be Pennsylvanian. For a thousand feet below this red series are limestones and shales. The shales are brown to red-brown in the upper half and become dark gray to black below. The limestones are gray, are very commonly cherty, and contain microscopic fossils of Pennsylvanian age at several horizons. About 450 feet of dark gray oolitic limestone that contains a few thin breaks of shale occurs beneath this group. Although long-range well-log correlations are likely to be in error, the great thickness of oolitic limestone underlying a series of alternating limestone and shale appears from a study of logs of wells scattered throughout Kansas to correspond in general to a thick series of limestone occurring above the Cherokee shale in the eastern part of the state. From 4,300 feet to 5,350 feet the drill passed through dense blue-black shale that contains a few thin breaks of limestone, mostly in the upper part; a very fine sandy shale between 4,370 and 4,390 feet; and fine sharp sand in the lowermost 50 feet. This thick shale series occupies the stratigraphic position of the Cherokee shale of eastern Kansas. At a depth of 5,350 feet gray cherty limestone of probable Mississippian age was struck, and the hole was continued in limestone and sand to a depth of 5,488 feet, where it was abandoned.

6. Darton, N. H., U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin folio (No. 212), 1920.

Brief Geologic History, with Special Reference to Structural Mapping.

Long before the deposition of the Tertiary rocks that now occupy the greater part of the surface of Hamilton county (Plate V) the underlying stratified beds were arched or gently folded into the Syracuse anticline and for a long period of time were eroded by streams. Probably thousands of feet of sediments were removed, until on the top of the Syracuse anticline only the Graneros shale and the lower part of the Greenhorn limestone remained, and on the southeast slope of the anticline streams had removed these rocks also and had cut into the underlying Dakota sandstone. Then the Tertiary sand, gravel, and clay of the Ogalalla formation were spread out over the folded beds by streams heavily laden with débris from the recently formed highlands to the west, in Colorado. These aggrading streams of late Tertiary (Miocene and Pliocene) time continued building until the old stream channels were deeply buried and a gently inclined, almost plane surface (Fig. 14B), high above the old valleys and covering also the old divides, occupied an extensive area east of the mountain front reaching from the Dakotas into Texas. Later, as a result of climate change,[7] erosion again set in and has continued to the present time. At a few localities in Hamilton county it has progressed so far as to lay bare the rocks underlying the Tertiary beds, revealing in part their structure.

This brief geologic history of the region will make it apparent to the layman as well as to one trained in the science of geology that the features of geologic structure—that is, irregularities in the position of the strata such as anticlines, synclines, and domes—cannot be determined by observations taken in this locality in the rocks of Tertiary age. It is only in those areas where the older rocks are exposed at the surface that the geologist can make observations to determine the inclination of the beds.

Because so much of western Kansas is thoroughly mantled by sand, gravel and clay of Tertiary age, it is important that the residents of the region should know that structural geologic mapping from observations of surface outcropping rocks is impossible in such areas. The state geologist is frequently asked by residents of this part of the state to confirm reports of "geologists" or others that

7. Johnson, W. D., The High Plains and their Utilization: U. S. Geol. Survey 21st Ann. Report, pt. 4, pp. 601-741, 1901.

structural features favorable for the accumulation of oil exist on their ranches. It is regrettable that ignorant or unscrupulous men posing as "oil finders" are not rare, and that they frequently mislead unwary citizens to make investments that have small chance of any return. In the hope of curtailing in part the operations of

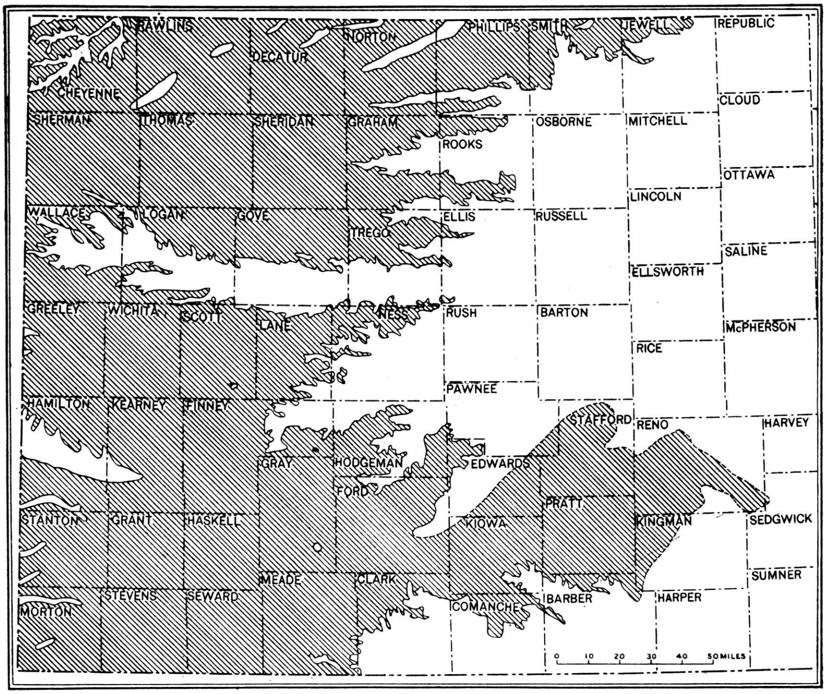


FIG. 26. Map of western Kansas, showing areas covered by Tertiary rocks. (After Haworth.)

those engaged in this unworthy enterprise Figure 26 is presented, showing the general areas in western Kansas which are mantled by these Tertiary deposits and for which structure contour maps, unless based on data from a series of deep water wells or test borings that go down to a readily recognizable stratum older than the Tertiary, are not worth the paper upon which they are shown.

Structure.

Folding.

The accompanying sketch map (Plate VI) is drawn on the basis of the meager data afforded by the few outcrops of Cretaceous rocks, together with information supplied by the local ranchers as to depths to the Dakota sandstone in water wells. Most of the well records were given from memory. The ownership of many wells has changed, and the only available records are those handed down by memory from one owner or his neighbor to another. Plane table and telescopic alidade control was used only for the few outcrops near the Syracuse anticline. Altitudes of the water wells were obtained from the topographic map of the Syracuse quadrangle. The altitudes indicated for the outcrops in the northern part of Hamilton county were taken from aneroid readings. Because of the scarcity of data available from surface rock exposures the map compiled from the field survey may not show all the structural features in this area, and even of the known anticlinal folds it is not possible to determine certain details from surface evidence. Therefore, any more drilling for oil and gas in the area should be preceded by the drilling of several shallow wells to the Dakota sandstone to determine structural details. The axis of the main anticline is thought to trend southeastward, as shown on Plate VI, with a "high" centering in the SW¼, sec. 6, T. 26 S., R. 41 W., where the top of the Dakota sandstone is believed to be slightly more than 3,400 feet above sea level. It is very probable that a saddle trending northwestward crosses the fold near the northwest corner of sec. 2, T. 26 S., R. 42 W., thus forming a closure of approximately 50 feet on the west side of the dome. Prior to the drilling of other tests for oil on the "high" in the SW¼, sec. 6, however, a well should be drilled to the Dakota sandstone in the SE¼, sec. 36, T. 25 S., R. 42 W., and perhaps a second one in the section adjacent on the east, to determine if the saddle and consequently the closure on the west actually exist.

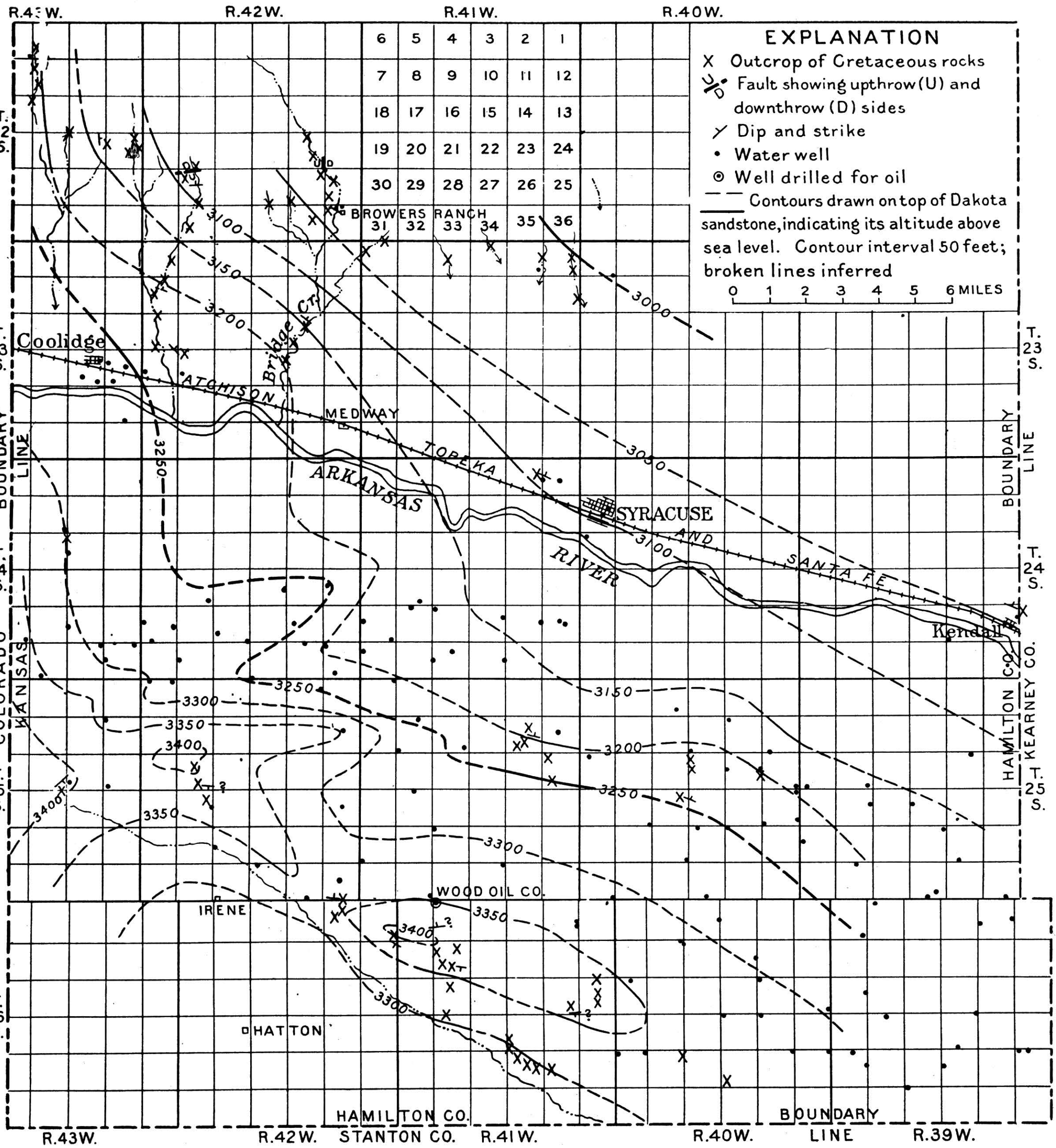
The intersection of an eastward-trending nose with the main anticline indicates a possible "high" about the common corner of secs. 7, 8, 17 and 18, T. 25 S., R. 42 W. There may be a slight dome near the quarter corner common to secs. 1 and 2, T. 25 S., R. 43 W., where a northeastward-trending nose intersects with the Syracuse fold. These two domes are indicated merely by scattered and somewhat conflicting records of water wells and should be regarded as only possible "highs." They should not be tested for oil or gas unless first accurately defined by shallow drilling to the Dakota sandstone.

The well drilled in the northwest corner of sec. 5, T. 26 S., R. 41 W., is on the northeast flank of the fold, according to the interpretation of the structure presented on Plate VI. The well was abandoned at a depth of 5,488 feet, having encountered no encouraging shows of oil and only a little gas. The strata penetrated by the drill below the red beds contain no rocks laid down near shore but appear to represent limestone and mud originating far from the shore line. Practically no sand was found in this entire series, except a little exceedingly fine-grained sand at a depth of 4,370 feet. It is generally believed that the greatest abundance of oil-forming organisms live and accumulate in mud not far off shore in marine waters. Here, too, deposits of porous sand are laid down alternately with the mud, later to serve as reservoirs for the oil. These conditions appear not to have prevailed in the region of Hamilton county for any lengthy period within Pennsylvanian time. Consequently both a source for the oil and reservoir rocks to contain it are lacking to a depth of a little more than 5,000 feet.

If other test holes are to be drilled, however, it is recommended, that the area be first covered by a sufficient number of shallow drill holes to determine accurately the local structural conditions. Because the Wood Oil Co.'s well has shown that anyone contemplating a test boring should be prepared to go more than 5,000 feet deep to test all the Pennsylvanian rocks and even deeper to penetrate underlying beds, the preliminary expense of shallow drilling does not appear unwise in this area, where any structural interpretation of the meager data available at the surface will of necessity contain many errors and may even misinterpret the main features.

Joints and Faults.

In the exposures in the southern part of T. 22 S., R. 42 W., and the northwestern part of T. 22 S., R. 43 W., the Fort Hays limestone member of the Niobrara formation contains well-developed joints, the most pronounced of which in the eastermost exposures trend in general a few degrees south of east and in the westermost exposure a few degrees north of east. The western exposures show also a second set of joints, much less strongly developed, trending N. 10° to 14° W. No definite set of secondary joints was noted in the eastern exposures, although a few trending in general about N. 35° E. were seen.



SKETCH MAP SHOWING GEOLOGIC STRUCTURE OF SOUTHERN PART OF HAMILTON COUNTY, KANSAS

PLATE VI.

In the NE¼ NW¼, sec. 29, T. 22 S., R. 42 W., the basal beds of the Fort Hays limestone are faulted into contact with the upper part of the Carlile shale. The fault plane is clearly defined where it appears in the west bank of the creek (Fig. 18) and can be traced westward by the outcrop of slickensided calcite vein material that fills the fracture for 350 feet to a point where it goes under cover of the soil. The fault plane trends N. 85° E. and dips 72° N. The rocks are dropped on the north, the amount of throw being about 35 feet. About 25 feet farther north is a second fault with a displacement of 2½ feet in which the beds are dropped on the south, and the fault plane dips 55°. A fault in the Fort Hays limestone member that appears in the creek bank in the SE¼, sec. 23, T. 22 S., R. 42 W., trends N. 10° W., has a throw of 15 feet 8 inches, and drops the beds on the east. The dip of the fault plane is 55° NE. The rocks on the upthrown side 50 feet southwest of the fault plane dip about 1° W., and within 10 to 15 feet of the fault plane they flatten and may be very slightly inclined toward the fault.

A small exposure of thin-bedded hard limestone and soft shale of the Lincoln member of the Greenhorn limestone near the east quarter corner of sec. 14, T. 25 S., R. 40 W., shows a fault trending N. 75° E. The fault plane, which is marked by a calcite vein 2 inches thick dips 60° SE., and the rocks are dropped on the southeast 1½ feet. The thin-bedded limestone and shale that occupy a horizontal distance of 3 to 4 feet north of the fault plane on the upthrown side are strongly crumpled into a series of minor anticlinal and synclinal folds.

Economic Products.

Sand and gravel for concrete construction occur in abundance in the alluvium along Arkansas river and in the Ogalalla formation at many places throughout the county. Material for the manufacture of cement is abundant in the area occupied by the Greenhorn limestone bordering the river flood plain on the north (Pl. V) and in the northwestern part of the county in the area of outcrop of the Fort Hays limestone. On Bridge creek in the southwestern part of T. 22 S., R. 42 W., 25 to 30 feet of the Fort Hays limestone underlain by a great thickness of shale is exposed. Stone for building has been quarried in years past from the massive sandstone beds of the Dakota in the southwestern part of the county, in secs. 22 and 27, T. 26 S., R. 41 W., and sec. 27, T. 26 S., R. 40 W. Many buildings in Coolidge, Syracuse, and Kendall are constructed from stone quarried from the Bridge Creek member of the Greenhorn limestone at localities 1 to 2 miles northwest of Syracuse, immediately north and northeast of Coolidge, and a mile northeast of Kendall. Several ranch buildings have been built from rock quarried from the Fort Hays limestone. The principal quarries are on Bridge creek in the southwestern part of T. 22 S., R. 42 W.

Volcanic ash of value as cleaning powder was noted at several localities in the county. A bed 1½ feet thick occurs near the east quarter corner of sec. 20, T. 26 S., R. 41 W. It is at least 1½ feet thick in the SW¼ SW¼, sec. 22, and 2½ feet thick near the center of sec. 13, T. 26 S., R. 41 W., where it is extensively exposed. (Fig. 15.) Other exposures occur in the SE¼ SE¼, sec. 1, T. 26 S., R. 42 W.; the SW¼, sec. 28, and SE¼, sec. 14, T. 26 S., R. 41 W.; and the NE¼, sec. 29, T. 26 S., R. 40 W.

Well water of excellent quality and in great abundance is to be had throughout the south half of the county by drilling into the Dakota sandstone. Artesian water is obtained from sandstones in the Dakota near Coolidge, and the water rises high in the wells in other parts of the area. Good water at shallow depth is obtained in the alluvium and dune-sand area bordering Arkansas river, and an abundance of water occurs in the sand and gravel deposits of the Ogalalla formation in the northern part of the county. Wells drilled in the shale areas north of the Arkansas and in the western part of the county have found no water in the shale series more than 400 feet thick that lies between the Fort Hays limestone member of the Niobrara formation and the Dakota sandstone, except in the sandy zone at the top of the shale and immediately below the Fort Hays. Live springs occur in the gulches where this sandy unit crops out in secs. 25 and 29, T. 22 S., R. 42 W., sec. 24, T. 22 S., R. 43 W., and elsewhere in this vicinity. Wells located immediately below this sandy zone will have to be drilled to a depth greater than 400 feet to reach the Dakota sandstone and an abundant supply of water. The record of J. Behrendt's well, in the SE¼, sec. 4, T. 22 S., R. 43 W., as furnished by the driller, P. A. Bauer, indicates the thickness of the shales that are barren of water.

Record of Behrendt well, sec. 4, T. 22 S., R. 43 W.

	Thickness (feet).	Depth (feet).
Rock	5	5
White clay (Fort Hays limestone)	35	40
Black shale barren of water (Carlile, Greenhorn and Graneros)	440	480
Dakota sandstone, waterbearing	36	516

TEMPERATURE READINGS IN THE WOOD OIL CO.'S WELL.

During the first week in April, 1925, the writer took the following temperature readings in the well drilled by the Wood Oil Co. in sec. 5, T. 26 S., R. 41 W. The well had at that time reached a depth of 4,650 feet. Water stood in the hole within 2,000 feet of the surface. Three maximum mercury thermometers were used. They were incased in a water-tight steel tube for readings taken in water. and a perforated brass tube for readings taken above the water level. The tube containing the thermometer was set in a notch in a wooden block, and this in turn was attached to the bailer, which was lowered and raised as slowly as the well machinery would run smoothly. The thermometers were allowed to remain 3 hours for each reading made in the water and 1½ hours for each reading above the water surface.

Temperature readings in Wood Oil Co.'s well.

[Altitude of surface, 3,460 feet; total depth of well at date of reading, 4,650 feet; mean annual temperature, 53.8° Fahrenheit.]

Depth (feet).	Temperature (deg. F.).	Depth (feet).	Temperature (deg. F.).
100*	58.1	2,500	88.7
	58.1		88.8
	57.9		88.7
500	63.1	3,000	95.7
	63.1		95.7
	63.0		95.7
1,000	66.1	3,500	103.9
	66.1		103.9
	66.0		103.8
1,500	75.1	4,000	111.7
	75.1		111.7
	†75.2		111.8
2,000	79.0	4,600	123.1
	79.0		123.1
	‡79.0		123.2

These data show a lower rate of increase in temperature than the average for Kansas. Darton[8] states that in southeastern Kansas the average rate of increase of temperature with depth in seven wells tested is 1° in slightly less than 60 feet, and the average rate in four wells in the western part of the state is 1° in 49 feet. The average rate of increase in the Wood Oil Co.'s well is 1° in about 69½ feet.

* Temperature at derrick floor 50°. Thermometers were chilled in ice water and the mercury was lowered to 43° before test was made.

† In air.

‡ In water.

8. Darton, N. H., Geothermal data of the United States: U. S. Geol. Survey Bull. 701, p. 45, 1920.

PART III.

Geologic Structure of the Dakota Sandstone of Western Kansas.

PROSPECTORS for new oil and gas pools are diligently at work in many localities in western Kansas. The Russell oil field, in northwestern Russell county, was discovered late in the fall of 1923, through their efforts, and is now producing about 5,000 barrels of high-grade oil a day, and many wells are being drilled in the field. Encouraging shows of oil or gas have been reported in wells drilled in no less than eighteen counties; oil has been produced a few miles north of Hutchinson; and gas has been found in a well now capped, at Liberal, near the southwest corner of the state, and in four wells about 15 miles south of Wray, Colo., within 5 miles of the west boundary of Kansas. Two wells in the western part of the state have gone below a depth of 5,000 feet; one in Hamilton county was drilled to 5,488 feet, and one in Clark county had reached a depth of more than a mile by the end of 1925.

Many of the wells of western Kansas have been drilled subsequent to the compilation by Darton[1] of a preliminary map of the central Great Plains, showing the structure of the Dakota sandstone, and these wells have made available additional structural data. The writer spent about three weeks in October and November, 1924, collecting many of these recently available data. Every county in western Kansas was visited, and drilled wells were located and their altitude determined by aneroid in much of the area, and by the topographic maps of the Geological Survey in the areas for which such maps were available. All outcrops of known key beds in the Cretaceous rocks that were seen along the route were sketched, and their altitude determined in the same manner as that of the wells. Reconnaissance structural data that were obtained earlier in the year in Russell county by W. W. Rubey and the writer and in Ellis and Hamilton counties by the writer are incorporated in the regional map. Information on file by oil companies operating in the region was used wherever available. The

1. Darton, N. H., The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, pp. 1-26, 1918.

records of the Keys Petroleum Co., of Wakeeney, were of particular value, and the writer is glad of this opportunity to acknowledge the courtesies shown by this company and others, and by many individuals, too numerous to mention. It is regrettable that sufficient time to get records of all water wells was not available, and that much other work which should be done cannot be under-

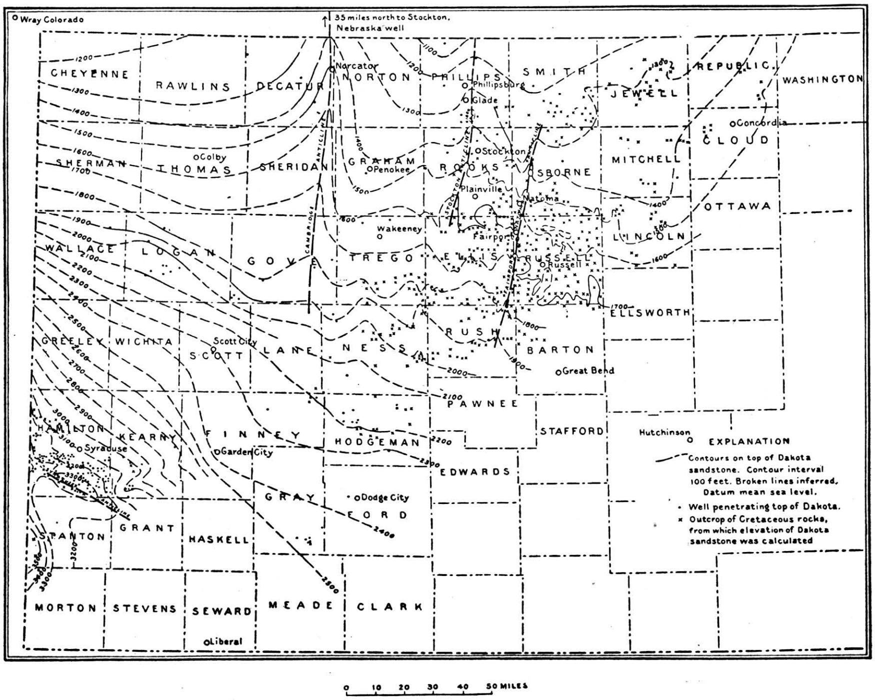


PLATE VII. Reconnaissance map of western Kansas showing structure of the Dakota sandstone.

ERRATA: Top center of map in margin above Norton county, read "Stockville" instead of "Stockton."

taken because of lack of state funds. Consequently, the structural features as shown might be modified somewhat by information from existing deep water wells, but it is believed that the map presents a sufficiently accurate regional picture of the structural conditions of western Kansas to justify its publication, although much improvement is no doubt possible.

The rocks exposed in that part of western Kansas shown in Plate VII have at their base the Dakota sandstone, a formation about 300 feet thick consisting of sandstone, sandy shale, and clay shale. It crops out in a broad band extending northeastward from Edwards and Stafford counties to Washington county. Overlying the Dakota sandstone, and with outcrops paralleling it on the west, are the Graneros shale, which consists of dark gray to black clay shale 35 to 40 feet thick in the eastern part and 60 feet thick in the southwestern part of the area; the Greenhorn limestone, composed of alternately bedded thin limestone and limy shale, having a thickness of 100 feet in the eastern part and 130 feet in the southwestern part; the Carlile shale, consisting of an upper division of non-calcareous dark-gray shale with the Codell sandstone bed at the top, and a lower division of calcareous shale alternating with thin limestone, ranging in thickness between 300 feet in the eastern part and 250 feet in the southwest; and the Niobrara formation, which consists of about 700 feet of chalk beds and chalky shale, the basal 60 feet being distinguishable from the remainder by its superior hardness and small content of shale. (Logs of several wells drilled in Logan county a few miles south of Russell Springs show the Niobrara formation to be about 700 feet thick.) An unknown thickness of the gray Pierre shale occupies the extreme northwestern part of the state. According to a calculation based upon figures given by Mather[2] the Pierre shale is about 2,000 feet thick in the Wray gas field, Colorado, about 5 miles west of the Kansas boundary. Overlapping the eroded edges of the formations above named from the Pierre shale to the Dakota sandstone is a series of sand, gravel, and clay beds of late Tertiary age (Ogalalla formation) that occupies the surface of the greater part of the western half of the area and extends far to the east on the high drainage divides. (Fig. 26.)

In the logs of wells drilled in this region the Pierre shale is not readily distinguishable from the Niobrara formation. The basal member of the Niobrara, which is, except for the Dakota sandstone, the best marker recorded in the logs of wells, is nearly always logged as "white limestone," above the several hundred feet of blue or black shale comprising the Carlile shale, the Greenhorn limestone, and the Graneros shale. The Codell sandstone, at the top of the Carlile, is recorded in the logs of nearly all wells that reach its horizon. The shale unit (the Carlile, Greenhorn, and Graneros formations) thickens southeastward from the northwestern part of the state. Figure 27 shows the approximate thickness of this

2. Mather, K. F., U. S. Geol. Survey Press Notice, May 15, 1925.

unit in various parts of the region. However, at Wray, Colo., a few miles west of the northwest corner of Kansas, this unit is 400 feet thick, and it is known from numerous published reports that the Graneros shale thickens rapidly northwestward. The thinning in Kansas, therefore, cannot be projected northwestward. Moreover, the increase in thickness of the Graneros toward the north-

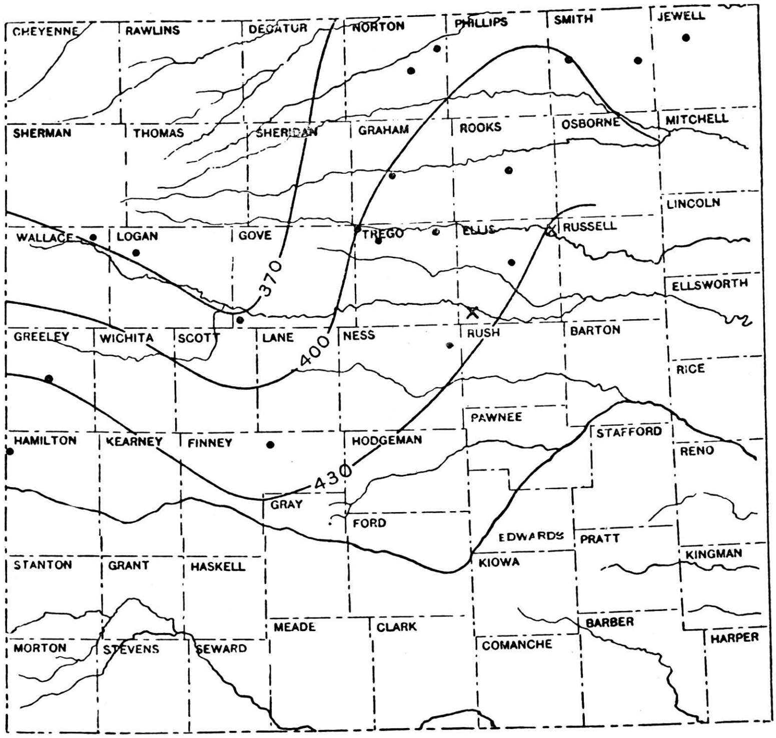


FIG. 27. Sketch map of western Kansas showing combined thickness of Carlile shale, Greenhorn limestone and Graneros shale.

•Well showing thickness
X Outcrop measurements

400 Lines of equal thickness

west indicates that the Carlile shale and Greenhorn limestone probably bear all the thinning shown in northwestern Kansas.

The Dakota sandstone is the best marker in the stratigraphic section for regional study, its top being logged as sandstone, sandy shale and in some wells as red rock. Below the Dakota are 100 to 200 feet of dark shale and light-colored sandstone of Comanche age that may not extend throughout the area but are present at least in the southern part; a series of red beds; largely of Permian age, that ranges from less than 1,000 to more than 2,000 feet in thickness; and a series of Pennsylvanian limestones and shales with a maximum thickness of more than 2,000 feet.

Structure.

The most pronounced feature shown in Kansas on the structure map (Pl. VII), as well as on Darton's maps of 1905 and 1918, is the Cambridge anticline, more generally known as Darton's arch, the axis of which trends northward through the eastern edge of Decatur county into Nebraska. The structure contours in Decatur county and western Norton and Graham counties are based on a number of control points, but the southern extension of the nose of the anticline through southern Sheridan and Gove counties is largely conjectural. Because of its greater size as compared with the other folds in Kansas it offers an attractive field for prospecting and should be thoroughly tested. A well was drilled in 1925 near Norcatur, on the crest of the fold, and found several strong shows of oil.

A rather pronounced and extensive series of structural "highs" extends from northwestern Ellis county north-northeastward across Rooks county, passing a few miles west of Stockton and thence into Phillips county near Phillipsburg. It is possible that the nose crossing the southeast corner of Trego county is the southward continuation of the Stockton fold or one *en échelon* with it. A well south of Glade in Phillips county, another north of Stockton, and one southwest of Plainville in Rooks county are being drilled on this regional "high." The Glade well has been reported shut down at a shallow depth for several months. Inasmuch as this well appears to be favorably located structurally, it is hope that the drilling will be continued. The Fairport-Natoma anticline, which is most prominent near the Russell oil field, extends north-northeastward from eastern Rush county into northern Osborne county.

In the southwestern part of the area the Syracuse anticline, in Hamilton county, is the most pronounced feature and is shown here much as presented on Darton's map, although some changes have been made. A well on the Syracuse anticline was drilled to a depth of 5,488 feet and encountered no encouraging shows of oil and only a small show of gas. The slight bending of the contours toward Scott City is based on a log of a water well given from memory, as a written record of the well could not be found. The position of the contours in this area is consequently subject to change.

It is hoped that the map here presented will not only be of some aid to the oil prospector in indicating the larger structural features of western Kansas, but may serve also the driller of water wells. For his benefit and guidance it may be said that the contours on the map show the approximate altitude above sea level of the top of the Dakota sandstone. The altitude of the surface of much of the area east of the one-hundredth meridian and south of the thirty-eighth parallel can be determined from topographic maps of the Geological Survey, which may be purchased at 10 cents a copy from the Director, U. S. Geological Survey, Washington, D. C., or the State Geologist, Lawrence, Kan.

In the northwestern part of the state, comprising some 13 counties and parts of others, no topographic surveys have been made. Altitude can be determined from railroad stations, the difference between the altitude of the particular section of land involved and that of the station being estimated. From these determinations and the altitude of the top of the Dakota, as shown on the map, a fair approximation of the depth necessary to drill to obtain water from the Dakota can be readily calculated.

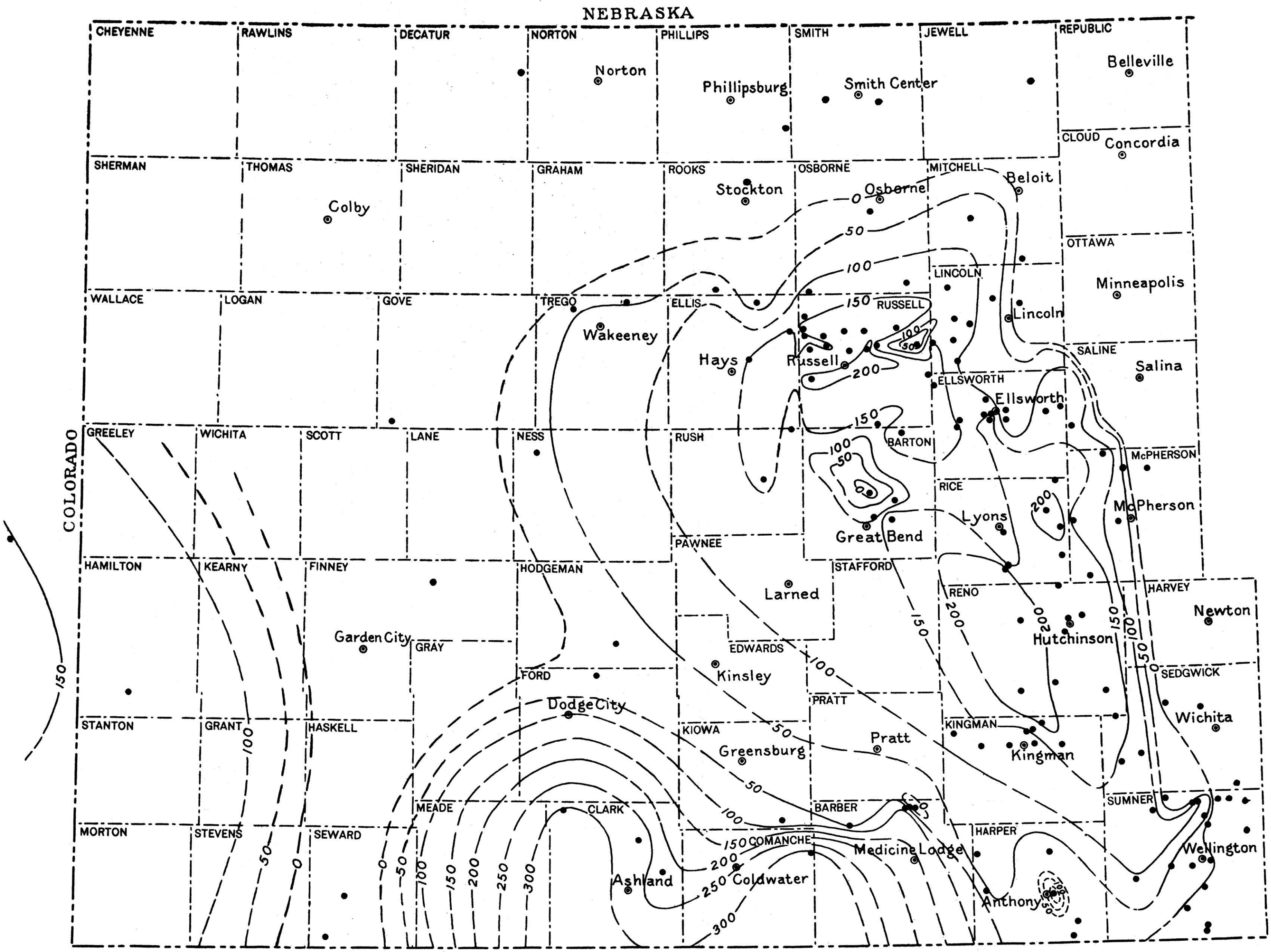
PART IV.

Structure and Limits of the Kansas Salt Beds.

RECENT prospecting for oil and gas in western Kansas, stimulated by the discovery of the Russell county oil field, and numerous wells put down prior to this recent drilling campaign, have afforded information as to the lateral extent and thickness of the Kansas salt deposits. In general, the area underlain by thick salt beds extends westward from a north-south line drawn a little west of the center of Sumner, Sedgwick, Harvey, McPherson and Saline counties and thence northwestward to the north-central part of Mitchell county. The accompanying sketch maps (Pls. VIII and IX) show the boundary of the salt deposit as defined by the present information. Although future drilling will make revisions necessary in many places, wells drilled in Rooks, Phillips and Decatur counties subsequent to the preparation of the map encountered no salt, and so indicate that the salt beds do not extend much farther north than the boundary shown on Plates VIII and IX.

The most widely spread zone of salt occurs in the Wellington formation (unit 4, Pl. II), of the Permian in Kansas. It is from this zone that commercial salt is produced at Hutchinson, Lyons, and Kanopolis. Throughout extensive areas the salt occurs in thick beds, and in other localities it is represented by thin layers intercalated with blue shale. A second deposit of salt about 200 feet thick a little more than 1,000 feet above the Wellington salt is shown by the logs of three wells in Clark county. (See Pl. VIII for location of wells.) It is to the presence of this upper salt that the greater part of the salt thickness in Clark, Meade, and Ford counties, shown on Plate VIII, is due. The principal salt recorded in the logs of the well in Hamilton county and in the well at Eads, Colo., about 30 miles west of the southwest corner of Greeley county, appears to represent more nearly the stratigraphic horizon of this upper salt, although it is probably not continuous throughout the region between Hamilton and Clark counties.

The structural attitude of the salt beds is shown on Plate IX by contours drawn on the top of the Wellington salt. These contours represent in general a board syncline, whose axis extends from



ISOPACHUS MAP SHOWING THICKNESS OF SALT IN WESTERN KANSAS

0 10 20 30 40 50 MILES

• Location of wells. Interval 50 feet.

Thickness used is in every case two-thirds of total thickness reported in log.

PLATE VIII.

southern Comanche county northward. The east limb of the syncline is relatively more steeply inclined at the eastern edge of the basin and has a tendency to flatten westward as it approaches the axis. The most prominent structural irregularity shown by the available information is the Fairport-Natoma anticline, on which the Russell oil field is located. This fold extends slightly east of north through the western edge of Russell county and into Osborne county. A northwestward anticlinal nose extends across Russell county and intersects the Fairport-Natoma anticline a little south of the northwest corner of the county. Altitudes determined in Kingman county indicate a westward-trending anticlinal nose in the northeastern part of the county, and an anticlinal nose alined in a northeasterly direction may be present in northeastern Clark county. Inasmuch as the presence of the two structural features just mentioned is inferred from data obtained from only a few wells, correspondingly less confidence can be placed in their existence and character. The irregularities shown in Russell and Ellsworth counties merely indicate that when more wells are drilled throughout western Kansas many changes can be made in the structural picture shown in Plate IX. In other words, smooth-flowing lines represent rather a lack of data than a true delineation of the actual structural conditions. As the meager data available indicate that the salt beds of the Wellington formation are absent in the westernmost four tiers of counties the general structure there can only be conjectured from other data. If the principal salt bed of the Wood Oil Co.'s Ranson No. 1 well, in the southern part of Hamilton county, is assumed to be at the stratigraphic horizon of the upper salt in the Clark county wells, these rocks are about 200 feet higher structurally in the Hamilton county well than in the Watchorn Oil & Gas Co.'s Morrison No. 1 well, in northeastern Clark county (the center one of the three shown in Pl. IX).

The existence of possible structural relations of the Cambridge anticline (Pl. VII); the occurrence of gas at Liberal, near the southwest corner of Seward county; and the oil and gas producing area near Amarillo, Tex., about 90 miles southwest of Liberal, have been mentioned by Pratt.[1]

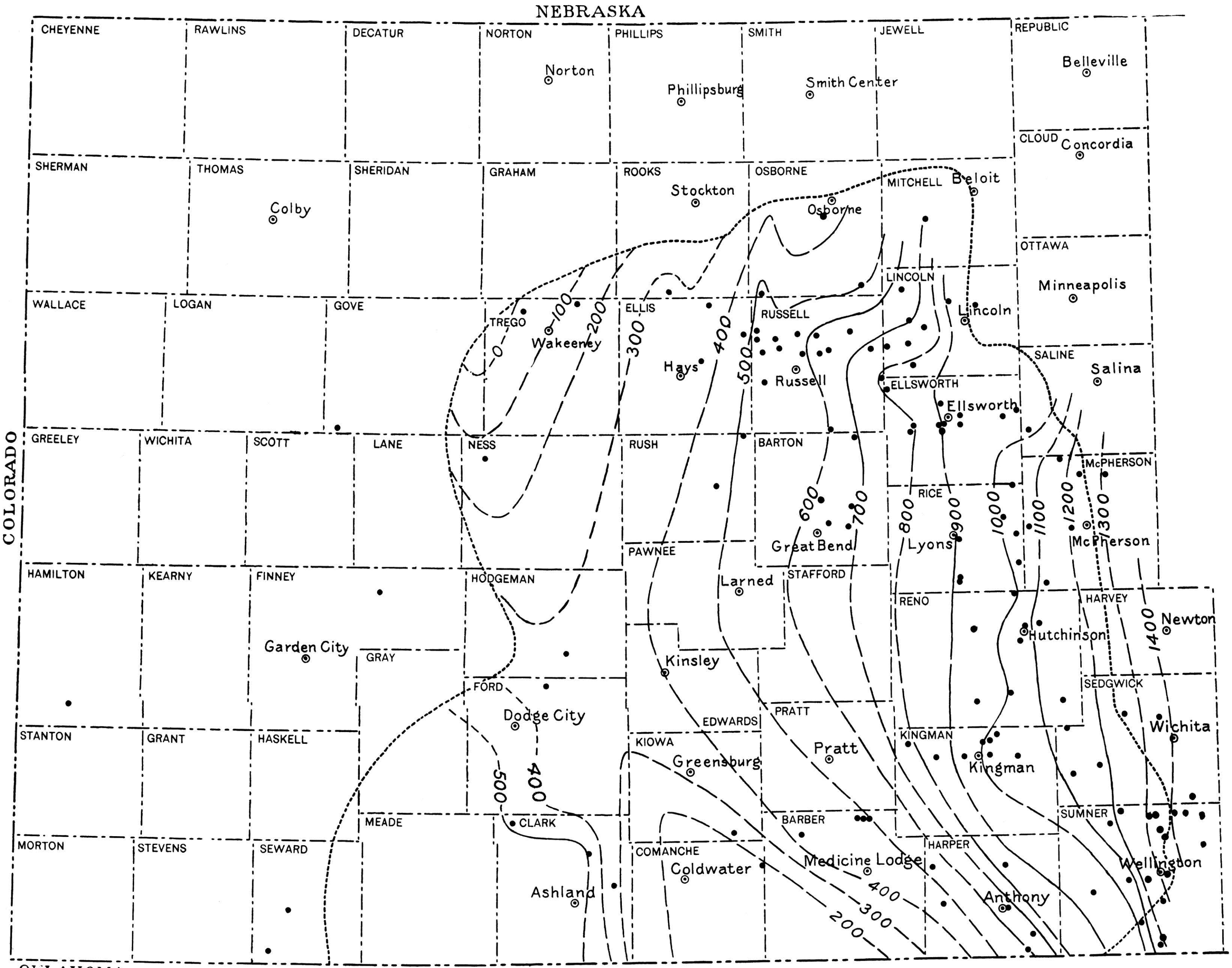
A show of gas was also reported in a well drilled in northeastern Finney county, and shows of oil were struck in a well drilled in eastern Decatur county, both of which are on this regional trend.

1. Pratt, Wallace E., Am. Assoc. Petroleum Geologists Bull., vol. 7, p. 245, 1923.

Thom[2] has suggested that the thinning of the Wellington salt westward in Kansas toward this possible regional "high," and its actual absence over the "high," together with the presence of a salt zone in Clark and Hamilton counties and its absence in intervening territory (the logs of the Seward county wells show no salt), tend to strengthen the supposition that an axis of uplift in this part of southern Kansas and northern Oklahoma may have formed a barrier between the basins where salt deposition was in progress in Permian time. Anticlinal folds overlying the buried Nemaha ridge in central Kansas; the Fairport-Natoma anticline, that crosses Russell and Osborne counties, on which granite has been struck; and a suggested buried ridge in northeastern New Mexico underlying prominent surface folds, suggest a regional structural pattern into which this possible structural "high" extending from Texas to Nebraska may fit. This alinement suggests that it, too, may overlie a granite ridge.

Plate VIII is a map showing the total thickness of the salt in western Kansas, as determined from well logs. Two-thirds of the salt as reported in the logs was assumed to be the total thickness of pure salt. The remaining third was discarded to allow for shale partings and other impurities not noted in the logs. Plate VIII is believed to represent in the main a fair picture of the thickness of the salt deposits in the area, although drastic revision can undoubtedly be made in places when more wells are drilled, and even with the data now at hand the map is in part subject to question. For example, the well in northeastern Comanche county is the sole basis for showing the salt to be so thick in that county and southwestern Barber county. Salt and shale are reported in the log of this well throughout a thickness of 550 feet, so that the amount assumed to be salt in compiling Plate VIII may be too great. The representation of an area of thick salt centering in Clark county is in part misleading, inasmuch as the thicknesses used there are based on two-thirds of the combined thickness of two salt zones that are separated stratigraphically by about 1,000 feet of red rock, while the thicknesses used north and east of this area represent only the lower salt zone, the upper zone not being present. If only the lower zone in Clark county wells is considered, the thickness of pure salt in the three wells would be, from the southeastern well northwestward, 130 feet, 60 feet, and 110 feet (in each two-thirds of the reported thickness).

2. Thom, W. T., Jr., informal communication.



ATTITUDE OF TOP OF SALT BEDS OF WELLINGTON FORMATION IN WESTERN KANSAS

0 10 20 30 40 50 MILES

Contour interval 100 feet. Datum is mean sea level.

• Location of wells. ------ Limit of salt.

PLATE IX.

As an acre-foot of pure salt weight approximately 3,000 tons, the total amount of salt in the area shown on Plate VIII is probably more than 5 trillion tons. This salt built into a prism with its base covering Grant county, which is 24 miles square, would be a little less than 1 mile high. Or it would be sufficient to build a wall a little more than 2 miles wide and 1,000 feet high entirely around the state of Kansas, a linear distance of 1,150 miles. The amount of normal sea water that would have to evaporated in order to form this amount of salt may be inferred from the fact that a thickness of about 3 feet of salt is deposited from a body of sea water about 100 feet deep.[3]

A study of the logs of wells drilled along the eastern margin of the salt area indicates that in the past salt beds extended farther eastward and that the present eastern boundary is largely the edge left by the dissolving away of this eastern portion. Comparison of the records of wells drilled in northern Sumner county on both sides of the margin of the salt shows a marked constriction in the eastern wells of the interval occupied elsewhere by the salt. A similar condition is shown by wells drilled in Lincoln county. Near this eastern margin wells reporting the salt to be more than 200 feet thick are only a few miles west of wells showing no salt. This abrupt change in thickness indicates that the margin of the salt represents an edge resulting from something comparable to erosion, rather than the shore line of an original salt deposit. The constriction of the salt interval in the eastern wells makes it appear very probable that as a result of the leaching and carrying away of the readily soluble salt beds by circulating ground waters near the outcrop, the overlying shale beds settled downward and filled in the cavities. It should be expected that settling on as large a scale as is postulated would be manifest in the topography of the surface, and inspection of the topographic maps that cover the marginal area for the most part corroborates this assumption. A narrow stretch of low-lying land, dotted with marshes, swamps, and lakes, extends northward from northwestern Sedgwick county across Harvey and McPherson counties, practically coinciding with the boundary of the salt area as shown by well logs. The fact that many of these lakes are salty[4] is further evidence that is considered corroborative of the explanation offered. The series of lakes and swamps cited is not continuous southward across Sedgwick county, but this fact is not necessarily

3. Darton, N. H., Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, pp. 222-223, 1921.

4. Moore, R. C., personal communication.

out of harmony with the reasoning developed, for the margin of the salt passes under the valley of Arkansas river, and the surface is largely occupied by alluvial fill and Tertiary deposits, which would have obliterated such features.

Other margins of the salt, however, indicate original shores. Wells showing no salt drilled in the vicinity of Wellington and southwestward in Sumner county do not show a constriction of the interval elsewhere occupied by the salt, but rather indicate that this interval has thickened slightly eastward, a relation that might be expected near shore where mud would very probably accumulate in greater thickness than farther out in the basin. The salt reported in wells in this part of the state shows a gradual thinning southeastward, almost certainly indicating an approach to the shore, in contrast to the abrupt termination noted along the east margin farther north. A like gradual thinning outward from the center is shown by wells in the northern and western part of the main salt area, indicating there an approach toward the shore of the depositional basin. These observations lead to the conclusion that the boundary of the salt beds as shown on Plate VIII represents the outer limit of salt deposition in southern Sumner county and along the northern and western boundaries, and that the eastern limit represents a position an unknown distance west of the original shore line. The recorded thicknesses indicate that the salt occurs chiefly in three rather distinct areas. One area lies in central Kansas and has its center near the western part of Rice county; another appears to lie chiefly in western Oklahoma, south of Clark county, Kansas, and a third is indicated in southeastern Colorado, west of Syracuse, Kan.[5] It seems probable that the latter two areas represent two different basins of salt accumulation or arms of one larger basin of later age than that centered near Rice county, the one south of Clark county overlapping the western edge of the Rice county basin.

The map of salt thicknesses (Pl. VIII) adds some data that tend to confirm W. D. Johnson's suggestion[6] that the origin of the Cheyenne Bottoms, in central Barton county, may be attributed to settling resulting from the removal of soluble masses of salt within the underlying rock. Johnson accounted for the Meade Basin, in Meade county, similarly and cited examples of caving and the formation of sink holes that are of historic record, as illustrations of

5. Darton, N. H., Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, pp. 205-223, 1921.

6. Johnson, W. D., The High Plains and their utilization: U. S. Geol. Survey 21st Ann. Rept., pt. 4, pp. 712-713, 1901.

the process. In March, 1897,[7] the surface of an area 175 feet in diameter which lay directly in the path of a cross-country trail near the margin of the Meade Basin slumped, and the hole thus formed filled with salt water. A similar phenomenon occurred in 1898[8] at the Rosel railroad station in western Pawnee county. Within a night an area of about an acre slumped, carrying down with it several station buildings and leaving in their place a lake surrounded by abrupt walls. No direct information is available on the thickness of the salt in Meade and Pawnee counties, but wells within the Cheyenne Bottoms show a marked thinning of the salt series as compared with logs of wells surrounding the area, suggesting that part of the original salt deposit may have been dissolved and carried away by circulating ground water.

The Kansas salt deposits constitute outliers of more extensive deposits in Texas and New Mexico where potash salts have recently been found associated with the salt beds—a fact which suggests that potash salts may exist in the Kansas deposits. Drillers of wells in this region are urged to collect samples from any salt beds penetrated. Inasmuch as most of the potash salts found in the Texas and New Mexico region are of pinkish or reddish color, it is particularly important to save any cuttings that contain red particles with the salt.[9]

Note on Subsidence Near Sharon Springs, Wallace County, Kansas.

By Raymond C. Moore.

On March 9, 1926, a very interesting subsidence occurred on the south side of the Smoky Hill river valley along the line between sections 33 and 34, T. 13 S., R. 39 W., about 5 miles east of Sharon Springs, in Wallace county. Because of the suddenness of the subsidence and the considerable depth of the resulting hole, widespread publicity in the press attended the phenomenon. A detailed report is not in place here, but supplementing notes on subsidence by Mr. Bass, essential facts gathered by the state geologist in a recent examination at the Sharon Springs locality may be of interest.

The present dimensions of the basin formed by the subsidence

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7. Idem, pp. 706-707.
8. Idem, p. 712.
9. Collecting sacks will be furnished upon application to the state geologist, Lawrence, Kan., and samples collected should be returned to the state geologist for chemical analysis.

are about 350 feet from east to west by 250 feet from north to south. At first the hole was much smaller, and it had a considerable but unmeasured depth, estimated by early visitors at 300 to 500 feet. Although Smoky Hill river is here dry, water from the underflow gradually filled the depression, forming a pond which, at the time of the writers' visit, was 75 feet below the adjacent upland to the east. Systematic soundings showed a gradual increase in depth of the water to about 50 feet, and then in the middle part of the depression a practically vertical-sided hole in which the depth of water was 165 to 170 feet. The computed volume of the depression is approximately 1½ million cubic feet.

Pierre shale is exposed in the walls of the sink, and near by there are very good exposures of this formation. The overlying Niobrara chalk is exposed a short distance east of the sink, south of Wallace. The structural relationships of the Cretaceous rocks show that water entering the Niobrara in eastern Colorado throughout a large area northeast of Las Animas may be expected to migrate down the dip of this soluble and more or less porous formation, emerging at the exposures 1,500 feet or more nearer sea level in Logan and other counties farther east in Kansas. It seems evident that the subsidence near Sharon Springs is due to the formation of a cavity of considerable size in the upper part of the chalk, following which, failure of the roof caused the cave-in.

The occurrence of crater-like depressions of varying size at several places in Wallace county under conditions that show clearly a depression of the Cretaceous rocks, the Tertiary being very thin or absent, indicates that solution of the chalk followed by subsidence of the overlying materials has taken place from time to time in the recent geologic history of the region.

□

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