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THE STATE UNIVERSITY OF OKLAHOMA
RESEARCH BULLETIN

NOS. 1 AND 2

No. 1

SOME OBSERVATIONS ON THE HABITS
AND PLACENTATION OF
TATU NOVEMCINCTUM

No. 2

A SUGGESTED CLASSIFICATION OF
EDENTATES

BY

H. H. LANE

Professor of Zoology and Embryology

NORMAN

The University Press
October 30, 1909

ANNOUNCEMENT

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SOME OBSERVATIONS ON THE HABITS AND PLACENTATION OF TATU NOVEMCINCTUM.. * **

H. H. Lane.

A group of animals which has not received the attention it deserves is that ordinarily termed the EDENTATA. By most authors it has been accorded a lowly place among the Mammalia on account of several peculiarities of structure, notably the usually non-convoluted condition of the cerebrum, the rudimentary corpus callosum, the partial or total lack of teeth, and, in some species at least, a very generalized type of reproductive organs. More recently there has appeared a growing tendency to regard certain of these characteristics not as evidences of a primitive condition, but rather as expressions of adaptive specialization and hence indicative of a higher position than that usually accorded the order. In fact, it is more than likely that the various species of living Edentates, in the old sense of this term, are scattered remnants of what was once a large and widely distributed group, so greatly diversified as to transcend the limits of a single order.

In the light of these facts it is rather surprising that so little is known concerning the anatomy, habits, or distribution of that species of armadillo which constitutes the only living representative of Edentates native to the United States. This is the Nine-banded Armadillo, *Tatu novemcinctum* (Linn.), which Bailey (1) considers a subspecies, *texanum*, the Texan armadillo, to distinguish it from the more typical form living farther to the south in old Mexico. It is quite common in southern Texas from the Gulf coast, between the Rio Grande and Matagorda Bay, up the Pecos, Neuces, Colorado, and Brazos River valleys as far north as Austin and Llano and occasionally to Breckenridge in Stephens County, and

* Contribution No. 2, from the Department of Zoology and Embryology, State University of Oklahoma.

** For preliminary note, see Science, N. S., vol. xxix, No. 748, April 30, 1909, p. 715.

southeastward to Antioch, Houston County, in the valley of the Trinity River. On the west it has been taken in Loving County, near the New Mexico line. It is reported to me as very common around Uvalde. Bailey records the general belief "that they are spreading eastward and northward," which, if true, is a rather unusual condition of things. One would expect it to disappear before the rapid advance of human settlement, especially as its flesh is regarded as an excellent article of diet, its armored skin is being turned into baskets at the rate of several thousand a year, and its reputation as a robber of freshly made graves leads to a more or less persistent persecution. Whatever may be the truth regarding this accusation, its burrowing habit is forcibly suggested by possession of long strong claws on its fore feet and by the excessively developed musculature of the thoracic and upper arm regions.

Early in April, 1908, through the kindness of Dr. C. F. Darnall, a physician of Llano, Texas, the writer came into the possession of a living adult female armadillo of this species, which had been taken a few days previously near the town mentioned. In captivity this specimen was a most harmless and inoffensive creature. It made no attempt to defend itself in any way except by "humping" its back and "bucking" like a broncho. This motion was so violent that it was almost impossible to pick up the creature while the movements were in progress. Additional protection was afforded by the smoothly worn condition of the carapace which rendered one's hold all the more precarious. Whenever an attempt was made to hold it or to drive it from one place to another it indulged in a series of grunts very closely resembling the sounds made by domestic swine when threatening an attack. This, with a slight squeal of fright or pain, constituted the only vocal sound made by this individual while under observation. It made no attempt to roll itself up into a ball, as it has been reported to do, but rather flattened itself out on the floor leaving no part of its unprotected ventral surface exposed.

Early on the morning of April 23, it gave birth to four young, which averaged about 25 cm., in length from tip to tip.

The mother, owing doubtless to her imprisonment, would have nothing whatever to do with the young ones, and an attempt to rear them by hand proved a failure within a few days. Except for size and color, they were identical in appearance with the adult. The dermal armor, of course, was not so hard, and the color was much lighter, being a light brown or brownish yellow, whereas the mother was more of a drab or gray. The long tail was about two thirds the length of the body. The nine bands of movable plates were even more distinctly differentiated in the young than in the adult. A comparison of the number of these movable plates in the mother and the young gave the following results:

	1	2	3	4	5	6	7	8	9	Totals
Mother	61	59	61	61	60	60	63	61	61	547
I	60	62	61	59	61	60	64	64	65	556
II	63	63	62	62	62	61	65	66	64	568
III	63	62	63	61	62	60	64	65	66	566
IV	63	63	62	58	61	62	63	63	64	559

The significance of these figures is discussed below in another connection.

The mammae of the mother were four in number, one pair pectoral and the other inguinal in position. The secretion in this case was almost nil, probably due to the conditions of confinement. The number of young and the number of mammae (four) coinciding may indicate the probable number of young usual to a litter in this species of armadillo. This conclusion is strengthened by the observation of another litter of four born in captivity on or about April 21 of this present year (1909), but from a different mother. Both A. Milne-Edwards (14) and Koelliker (11) report finding four embryos in utero, in this species. In a recent paper Newman and Patterson (15) make the statement that "there are always four embryos, corresponding in number to the two pairs of mammae," though Flower and Lydekker (6) say that four to ten are produced at a time.

The simple globular uterus, preserved in formalin within a week after parturition, is 4 cm. long by 3 cm. broad at a point 2 cm. anterior to the os uteri; its dorso-ventral thickness

is 2 cm. in the sagittal plane and it rounds off rather regularly towards the sides. Externally its dorsal and ventral surfaces are marked along the median line by a prominent ridge which passes through the apex of the uterus at right angles to the plane of the oviducts. The ridge on the dorsal surface is more pronounced than that on the ventral side. The cavity of this uterus was occupied by a large blood clot and has an antero-posterior length of 3 cm., a dorso-ventral diameter of 1 cm., and a greatest right to left diameter of 13 mm. The uterus gives no indication of a duplex or even a bicornuate condition such as is found in certain other Edentates.

The oviducts are only very slightly convoluted and are approximately 4 cm. in length. They are attached to the surface of the uterus itself for approximately 2 cm. and enter the latter at points 1 cm. apart and about equidistant from the apex of the fundus.

The placentation presents some very interesting features. In my preliminary note (12) I stated that "there was a complete fusion of the four chorionic vesicles into one," common to all the foetuses, each of which had originally its own separate amnion. Newman and Patterson (*loc. cit.* p. 185) hold from the evidence of somewhat earlier stages that there is never but a single chorionic vesicle. To quote: "We say single chorion advisedly, because its surface gives no indication of being a multiple structure, that is, the product of the fusion of four chorionic vesicles at an earlier period, as suggested by Lane; nor do the facts revealed by a study of sections of the chorionic wall seem to bear out such an interpretation. One must admit, however, the great difficulty of any attempt at a correct interpretation of the exact relationship existing between the foetal membranes as seen in these advanced stages. The solution of that problem must be sought in a study of young stages, when the membranes are in process of formation." (*Italics mine—Lane.*)

Thus until the study is made of these very early stages direct evidence cannot be forthcoming to settle the differences

between the hypothesis incidentally set forth in my brief note in Science and that advanced by Newman and Patterson. However, in all fairness, I must admit the probability of the correctness of their view as an inference from the fact that, so far as has been observed, "the embryos of any given set are always practically identical and of the same sex." Thus from the table given above it is evident that while there is no exact identity, there is a fairly close resemblance in the number of plates. This is more marked when attention is directed to the totals than when the different bands are examined separately. Newman and Patterson give the total counts only in two cases under their observation and point out a remarkable division of the four fetuses of each litter into two pairs, corresponding to their respective positions within the chorionic vesicle. Of course it was impossible in the case of my specimen to determine from what quadrant each had been derived. Beyond the fact that number I of the table was the first one of the litter born, nothing is known even concerning the order in which they were delivered. According to the hypothesis of Newman and Patterson, however, I and IV with 556 and 559 plates each may be assigned to one pair, while II and III with 568 and 566 respectively form the other pair, each member of which more closely resembles its fellow than it does either member of the other pair. But let us see whether further analysis of the figures given in the table warrants this conclusion. More significant even than the totals, are the figures for the corresponding bands in each pair. Especially striking are the two cases in which the number of plates in a single band falls below 60. Counting from the cephalic margin of the belt of movable plates, it is found that the fourth band in I and IV has 59 and 58 plates respectively, while in the other pair the corresponding numbers are 62 and 61. Band 5 in I and IV shows 61 and 61, while the same band in II and III has 62 in each case. On the other hand it should be pointed out that this resemblance may be merely accidental for in several cases I (or IV) resembles II or III more nearly than it does its fellow. For instance, in the first band I has but 60 plates while IV has 63—exactly the number found also in both II and III. If

this difference be the result of chance why may not the same be true of the likenesses just pointed out? Again in the second band II and IV have exactly the same number of plates, 63 in each, while I and III likewise form a pair with 62 in each. In the third band II and IV again form a perfect pair with 62 plates in each, but I and III agree neither with each other nor with II and IV, for I has 61, while III has 63. In the sixth band exactly the reverse condition obtains, I and III forming a perfect pair with 60 plates each, while II and IV have 61 and 62 respectively. An examination of the table further will show similar discrepancies in the remaining bands. With such a showing it certainly becomes very difficult to decide which foetuses form the pair derived from a certain one of the first two blastomeres. However, they are all females and all near enough alike to have been derived from the same ovum, so that the main proposition still holds.

Proceeding to "conjecture as to the manner in which the conditions seen in the older stages have arisen," Newman and Patterson offer (*loc. cit.* p. 186) as a "tentative" hypothesis the following:—"It may be supposed, for example, that the developing egg, after it has reached a stage corresponding to that of an inner-cell mass and trophoblast in other mammals, has, in the case of *Dasyus* (sic!) four inner-cell masses—a cell mass for each quadrant; and furthermore that the cells of any given inner-cell mass together with the trophoblastic cells of its quadrant, are the lineal descendants of one of the blastomeres of the four-cell stage." While admitting the possibility of other interpretations they hold that none is so credible as this. Their arguments appear to me, on the whole, to be pretty conclusive, as well as the obvious bearing of their results upon the "problem of the identity of the embryos of a set, and its corollary that of sex determination." I most heartily join in the hope which they express "that a study of the early developmental stages will lend a solution to this problem, and also furnish a satisfactory explanation of the puzzling question of "identical twins;" and thus raise this explanation from the plane of conjecture to the dignity of observed fact."

It has been more than twenty years since this hypothesis

was first advanced by von Jhering (24) * from a study of a South American armadillo (*Tatusia* [*Praopus*] *hybrida*), in which, likewise he found all the fetuses (six or more) enveloped in a common chorion and the individual members of each litter always of the same sex. In this case also his evidence led him to conclude that all the young produced at a time by this armadillo were the products of a single fertilized egg, through the separation of the early blastomeres. As a result of his studies, von Jhering arranges different types of reproduction into several categories, of which that found in the armadillo he terms "temnogenesis."

It would be well worth while, therefore, by a study of very early stages, to confirm in our native species the conclusions to which von Jhering was led in his work upon this South American armadillo. In my own case while there is no positive evidence, there is at least nothing to negative the suggestion that the fetuses of *Tatu novemcinctum* are developed each from a single one of the first four blastomeres, and if so the sex is already determined in the oosperm, and the observation falls in line with many others recently made.

The amnia in my specimen, as in those studied by Newman and Patterson, had grown together so that the chorionic vesicle is divided lengthwise into four parallel chambers by their united walls (Fig. 1 am.). Within each of these amniotic chambers, naturally, is the attachment of a single umbilical cord (Fig. 1, um. c.)

Externally a superficial examination of the placenta gives the impression that it is of the zonary type, though much broader to be sure than the zone in the case of the Carnivores and still broader than that of *Orycteropus*. The villi are present in a wide band or girdle surrounding the chorionic vesicle, which is somewhat barrel-shaped and has its two ends thin, membranous, and entirely devoid of villi, though in earlier stages Newman and Patterson report the presence of a small tuft of villi, at each pole of the vesicle, in the centers of

* I wish here to express my thanks to Professor H. E. Jordan for kindly referring me to this paper.

these membranous, otherwise non-villous, areas. There is absolutely not the slightest trace of such a villous tuft in my specimen. (Fig. 2 and 3 a.)

The length of the chorionic vesicle in this case is approximately 12 cm., with a largest transverse diameter of approximately 7 cm., at the equator. A more careful examination shows that the villous band is far from similar throughout its entire extent. In fact, it is made up of two approximately disc-shaped areas, the limits between which are occupied by villi much shorter and perhaps less numerous than those composing the discs. (Fig.2).

The short villi form a band (Fig. 2,b) two and one half to four centimeters broad running lengthwise of the chorionic vesicle between the two discs of long villi (Fig 2 c) which have an average diameter of approximately 8 to 9 cm. At either end of the vesicle the band of short villi forks so as to surround the thin membranous acea occupying the pole (Figs. 2 and 3.) There is thus formed, as it were, at either pole, an island of thin non-villous membrane (Fig. 3, a) surrounded by the band of very short villi (Fig. 3,b). The boundaries between the disc-shaped areas with the long villi and the bands of short villi are very sharp and distinct; the transition is so very sudden that there can be no mistake in the observation. The short villi forming the bands are only one or two millimeters long, while the long, highly arborescent ones occupying the disc-shaped areas have a length of fifteen to eighteen millimeters. The two disc-shaped areas, in turn, when examined on the amniotic surface prove to be compound, that is to say, each has attached to it two umbilical cords which arise at about equal distances from the opposite margins of the villous areas though nearer one pole (distal) than the other of the chorionic vesicle (Fig. 1).

Newman and Patterson describe quite a different condition in their specimens. They say (loc. cit., p. 182): "An examination of the external villous layer of the chorion shows that placentation is unique in that areas of villi, although apparently forming a complete zone about the equatorial region of the uterine wall, are in reality arranged in four closely ap-

proximated ovoid areas, two large and lateral in position, and two smaller, one dorsal and the other ventral. The proximal (i. e., the posterior of vaginal) and distal ends of the chorionic vesicle are practically free of villi, except at each pole, where the presence of a small tuft of villi causes the chorion to adhere very firmly to the uterine wall. . . . The villous zone composed as it is of four ovoid areas, extends into the polar regions in the form of four scallops at each end, and on the amniotic side of the four scallops are situated the points of attachment of the four umbilical cords."

They further state (loc. cit., p. 184) that the difference between their account and mine lies "chiefly in [Lane] locating the points of attachment of the two umbilical cords on each of the large 'disc-shaped' areas and none on the smaller areas." It is not surprising that they further assert that "This condition is certainly not found in our material," for it is evident that they have confused what I have described as a "band of short villi" (Fig. 2, b) with two of their four villous areas. In my specimen the bands of short villi were lateral, while the disc-shaped areas were respectively dorsal and ventral in position as is shown by their areas of contact with the uterine wall, which appear as two much-pitted circular spaces, one on the dorsal and the other on the ventral inner surface of the fundus. There are no "scallops" in the two disc-shaped areas though the membranous portion of the anterior pole is somewhat crescentic with a slight projection on its concave side into the adjoining band of short villi (Fig. 3, a). This is evidently the vestige of the earlier scalloped condition described by Newman and Patterson, but the reduction of the villi has gone so far in this case that the disc-shaped areas are no longer affected.

The foetuses escaped through the posterior non-villous pole of the chorionic vesicle, which lay near the os uteri. There was no indication of a decidua capsularis; the placenta, however, was truly deciduate.

Whether there was here an approach toward the zonary type through the fusion of four discoidal placentae, or a transition toward the discoidal or cotyledonary type by the seg-

regation of certain areas of a zonary placenta, could be determined certainly only by the examination of a series of early stages which I do not possess. However, the observation of Newman and Patterson of a chorionic vesicle, of an age estimated to be one month, with its "entire surface . . . covered with villi" is conclusively in favor of the latter hypothesis. And the discrepancies which have been pointed out between their description and mine are probably due to the fact that they were working with earlier stages in which the location of the villi into disc-shaped areas through their reduction or total disappearance in other parts of the chorionic surface, had not proceeded so far as in my specimen, which may with all probability be taken as representative of the last condition ordinarily attained in this species. The placenta was obtained immediately after its discharge and carefully preserved, so that it is perfect, save for the rupture of the chorionic vesicle and amnion by the birth of the foetuses.

At any event the type is an intermediate one between the zonary placenta of the Carnivores and the discoidal placenta of the Primates, Chiroptera, Rodents, and Insectivores.

Owen (16) and Koelliker (11) describe the placentation of the armadillo as truly discoidal and deciduate; Alf. Milne-Edwards (14) holds it to be zonary. Beddard (3) describes it as "dome-shaped and deciduate;" Flower and Lydekker (6) say: "Placenta discoidal;" but on the next page they add: "There is no reason to believe that the placentation [in the armadillo] is essentially different from that obtaining in the other groups" [of Edentata.]

The latest general account of placentation is that of Strahl (21) who recognizes as types of true placentae (1) *Placenta zonaria* with two varieties, (a) *simplex* and (b) *composita*; (2) *Placenta zono-discoidalis*; and (3) *Placenta discoidalis* with three varieties: (a) *simplex*; (b) *duplex*; and (c) *perforata*. Of these we may dismiss at once from our consideration as wholly inapplicable to the case in hand, *P. zonaria simplex* and *P. discoidalis simplex* and *perforata*. *P. zonaria composita* is the name applied to

EXPLANATION OF THE FIGURES.

Fig. 1. Diagram of equatorial cross-section of chorionic vesicle. The position of the umbilical cords (u m. c.) is indicated, though in fact they are not located at this level.

am, amnia, which divide the Chorionic Vesicle into four longitudinal chambers. b, band of short villi; c, area of long villi.

Fig. 2. Diagrammatic external lateral view of Chorionic Vesicle. a, non-villous area at pole; b, band of short villi separating the two disc-shaped areas of long villi, c.

Fig. 3. Diagrammatic external polar view of Chorionic Vesicle. Lettering, same as in Fig. 2.

Figures all natural size.

Fig. 1.

Fig. 2.

Fig. 3.

the placenta of the elephant in which "ausser dem Guertel Zottenbueschel nach Art von Kotyledonen und besondere Zottenfelder an den Polen des Chorionsackes vorhanden sind," a condition not at all similar to that in *Tatu. P. discoidalis duplex* really comprises two types. In the first of these, such as occurs in *Cercocebus* or *Semnopithecus*, there is a dorsal, or primary, and a ventral or secondary, discoidal placenta; the latter may exceptionally persist, though usually, at least in the *Anthropoidea*, it is transitory, disappearing later in gestation. The other type of duplex discoidal placenta occurs, for instance, in the mole (*Talpa europea*) and comprises what may be termed an omphaloidal and an allantoidal placenta. Obviously the armadillo under consideration does not conform to either of these types.

Strahl's remaining category, *Placenta zono-discoidalis*, is described as a placenta, "die als zonaria angelegert wirt, aber aus dieser in eine doppelt scheibenfoermige uebergeht." It occurs in the ferret (*Putorius furo*) and the weasel (*Putorius vulgaris*). It arises as an incomplete zone which later separates into two distinct disc-shaped areas, situated on opposite sides of the chorionic vesicle. The primary zone of separation is on the mesometral side, while the secondary is opposite the primary one. The placenta of *Tatu novemcinctum* bears somewhat of a resemblance to this type though the observations of Newman and Patterson establish very clearly that, from at first a totally villous state, the placenta becomes gradually approximately zonary in type, as A. Milne-Edwards described it, and later, according to my own observations, tends toward the double discoidal form, though it differs from that in the ferret and weasel in at least one important particular, since there are small villi present even at parturition in both zones of separation between the discoidal areas. It does not, therefore, find a place in Strahl's classification and I suggest that it be termed *Placenta zono-discoidalis indistincta*; the *Placenta zono-discoidalis* of Strahl being designated as variety *distincta*.

SUMMARY.

1. *Tatu novemcinctum*, var. *texanum*, the only Edentate living in the United States at the present time, gives birth usually to four young in a litter.

2. The uterus is simple and globular, 4 cm. long, 3 cm. broad, and 2 cm. thick. The oviducts are only slightly convoluted and are 4 cm. long.

3. Each foetus develops within its own amniotic sac, though a common chorionic vesicle serves for all.

4. While the evidence is not decisive, the fact that the young were all of the same sex and greatly resembled each other, as well as the fact that they were all contained in a common chorionic vesicle, lends probability to the view that in *Tatu* there is polyembryony (*temnogenesis*) as was suggested by von Jhering and later by Newman and Patterson, and that the sex is determined in the fertilized egg.

5. The chorionic villi vary from short simple ones, one or two millimeters long, to arborescent ones with a maximum length of 18 millimeters.

6. The short villi form two longitudinal bands separating two discoidal areas of the long villi.

7. The placenta is of a deciduate type intermediate in form between the zonary and the discoidal; not conforming exactly to Strahl's *Placenta zono-discoidalis* the placenta of *Tatu* is designated as *Placenta zono-discoidalis indistincta*.

8. There is no decidua capsularis.

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STATE UNIVERSITY OF OKLAHOMA,

Norman, Oklahoma,

October 1, 1909.

No. 2

A SUGGESTED CLASSIFICATION OF
EDENTATES

A SUGGESTED CLASSIFICATION OF THE EDENTATES. *

H. H. Lane.

It has long been conceded that the Edentata, in the broad sense, form a heterogeneous "order," but, mostly on account of the relatively small number of living species, "convenience" has been allowed to override weightier considerations, and has led to the retention of a confessedly artificial and unnatural allocation of the forms comprised in this group. If classification has any scientific significance at all it lies in the expression of natural relationships, and the accident of there being only a small number of species in a group should not for mere convenience' sake compel the adoption of an artificial rather than a natural arrangement of these species.

Most frequently of late years the division into the suborders, Xenarthra and Nomarthra, has been adopted, the former for the American and the latter for the Old World species. The Xenarthra constitute undoubtedly a rather natural group but the union of Manis and Orycteropus in the Nomarthra is decidedly artificial. A like result has been attained by those authors who recognize two "orders"—Edentata, in the stricter sense, with the limits of the Xenarthra, and the Effodientia, corresponding to the Nomarthra. The same objections may be urged against this plan as against the one previously mentioned. It does have the advantage, however, of better expressing the wide separation of the Old World from the New World species. Flower (4) retains the order Edentata, in the broad sense, but recognizes four suborders, (1) Pilosa including the Bradypodidae, Megatheriidae, and Myrmecophagidae; (2) Loricata for the Dasypodidae; (3) Squamata for the Manidae; and (4) Tubulidentata for the Orycteropodidae. The objection to this arrangement lies in the fact that the affinity of the Pilosa and Loricata is much closer than that of either of these

* Contribution No. 3, from the Department of Zoology and Embryology, State University of Oklahoma.

groups with the Squamata or the Tubulidentata. Moreover, the Squamata and the Tubulidentata are certainly as far removed from each other as either is from the Pilosa and Loricata.

Other authorities, e. g., Max Weber (14) and Elliot Smith(9), recognize three orders which they designate as the Xenarthra, Tubulidentata, and Squamata. This arrangement is undoubtedly correct in principle and agrees very closely with the conclusions set forth below. Oldfield Thomas (11) has gone farther and has proposed the formation of a subclass, which he terms the Paratheria, for the Edentata. There appears to be altogether inadequate reasons for such a radical step as this and it becomes impossible if the Taeniodonta are to be recognized as Edentata.

A comparison of the uterus and placenta of the different groups of living Edentates suggests very strongly the propriety of recognizing at least three distinct orders. Thus *Orycteropus* possesses a duplex uterus the two portions of which open separately into the vagina, as is the case in some Rodents. This is the most primitive type of uterus occurring among the Edentates and indeed is as primitive as any in the Mammalia. Turner (13) has shown that the zonary placenta of *Orycteropus*, unlike that of the Carnivora, has its arborescent chorionic villi diffusely arranged in a broad girdle whose width is equal to one half or more of the length of the chorionic vesicle. While the material and foetal parts are closely interlocked, Turner was unable to determine whether the placenta is truly deciduate.

In *Manis* the uterus is truly bicornuate, and is therefore of a distinct type though intermediate between the simple globular form of the Xenarthra and the duplex condition of the Tubulidentata. The placenta, as described by Sharpey, Turner, and Anderson (fide Balfour), is absolutely unique. It has its simple villi arranged in ridges radiating from a non-villous longitudinal strip on the concave surface of the chorionic vesicle, the whole placenta, however, being diffused over the surface both of the chorion and the uterine mucosa.

In all the Xenarthra, finally, the uterus is of the type de-

scribed in my previous paper for *Tatu novemcinctum*, viz., simple and globular, and represents a higher degree of advancement in this respect than that found in the other living Edentates. Correlated with this type of uterus, the placenta is deciduate, and either discoidal or indistinctly zono-discoidal, as shown in the article just cited.

If these characters be not sufficient for the erection of distinct orders, there are a number of others correlated with with them which certainly suffice. Thus in the Tubulidentata, along with the hairy covering, one finds numerous slightly heterodont, diphyodont teeth, which are formed apparently by the aggregation of parallel vertical columns of dentine, each column with its own pulp cavity, and the whole forming a tooth-structure utterly unlike anything found elsewhere among the Mammalia.

In the *Manidae* the external body covering consists of large imbricated horny scales in shape and arrangement such as to suggest the appearance of a huge pine cone. These scales are generally regarded as unique in structure being formed of masses of hairs cemented together by their superficial epidermal cells. *Manis* is toothless and shows an adaptive resemblance in the shape of the head and form of the tongue to other anteating, or perhaps more properly, termite-eating forms.

In the *Xenarthra* the body is covered by peculiar hair, which may be more or less replaced by dermal plates in the armadillos. They all possess the peculiar additional articulations on the vertebrae which suggested to Gill the name, *Xenarthra*. These articulations do not occur in *Manis* and *Orycteropus*. Teeth are totally lacking in the *Myrmecophagidae* which in that respect occupy the place of greatest specialization and complete the line of dental degeneration probably begun in the *Taeniodonts*. The teeth of the remaining *Xenarthra*, however, are homodont, and monophyodont, with the exception of certain of the armadillos, in which they are partially diphyodont. This group has, therefore, lagged behind its relatives in the degeneration of its dentition.

We feel justified, therefore, in recognizing three distinct

orders of living Edentates, agreeing in this with Elliott Smith, Max Weber, and Osborn (10). Despite the fact that these animals constitute several distinct orders, they are so widely separated from all other Mammalia and exhibit certain such general resemblances to each other, that it seems necessary to recognize a SUPERORDER EDENTATA. This leaves the term *Xenarthra* of Gill available for the American species. The term *Squamata* which has been frequently applied to the *Manidae* seems to have been antedated by *Squamata* (Oppel 1811), applied to an order or superorder (Osborn) of *Reptilia*, and should therefore be replaced by *Pholidota* of Weber, as, indeed, has been done by Osborn. *Tubulidentata* for *Orycteropus* stands.

Although denied by Scott it appears probable that Wortman (16) is correct in considering the *Taeniodonta* as ancestral Edentates, probably allied to the modern *Xenarthra*. As characterized by Smith-Woodward (15), they are an American group in which the more primitive forms were distinctly Eutherian, with a heterodont dentition. There were incisors both above and below, the cheek teeth were differentiated into molars and premolars, and the former had a tritubercular crown which in time became worn away leaving the dentine exposed. The earlier known species had teeth rooted and more or less covered with enamel, but in the later species there was a gradual diminution of the incisors and all the teeth became "hypsodont, rootless, and of persistent growth, while the enamel is limited to narrow vertical bands." In the *Stylinodontidae*, the skull and limbs are remarkably sloth-like, while in the *Conoryctidae* these characters point toward the armadillos. It seems clear, as Wortman has suggested, that the *Taeniodonta* are ancestral Edentates, i. e., ancestral to the *Xenarthra*, and that some of the living species are degenerate types from the same stock.

With these facts before us, the most natural arrangement appears to be as follows :

SUPERORDER EDENTATA (Vicq d'Azyr).

Order 1. TAENIODONTA Cope

Family Conoryctidae Wortman

Family Styliodontidae Marsh

Order 2. XENARTHRA Gill

Suborder Pilosa Flower

Family Bradypodidae Bonaparte

Family Megalonychidae Zittel

Family Megatheriidae Owen

Family Myrmecophagidae Bonaparte

Family Orophodontidae Ameghino

Suborder Loricata Flower

Family Dasypodidae Bonaparte

Family Glyptodontidae Burmeister

Order 3. PHOLIDOTA Weber

Family Manidae Gray

Order 4. TUBULIDENTATA Flower

Family Orycteropodidae Bonaparte

The arrangement of the families is not intended to be other than arbitrary. Likewise it is impossible to arrange the orders of living species in a linear series so as to show the relative degrees of specialization. On the basis of the form of the uterus, the relative positions would be: Tubulidentata, Pholidota, Xenarthra; using the form of the placenta as indicative of relative rank, the arrangement is: Pholidota, Tubulidentata, Xenarthra. While if the dentition be taken as the criterion quite a different arrangement would result. In short the three orders of living Edentates here recognized probably all arose about the same time as divergent lines from some ancestral group. The Taeniodonta were probably nearer the base of the Xenarthral line than to that of either the Pholidota or Tubulidentata.

SUMMARY.

1. A comparison of the placenta of Tatu with that of other Edentates leads to the conclusion, which is confirmed by a consideration of other structures, that the Edentata transcend the limits of a single "order."
2. Previous classifications being more or less artificial or otherwise unsatisfactory, suggestion is made of what is thought to be a more natural arrangement.
3. The Edentata are recognized as a superorder of Mammalia, comprising four orders: Taeniodonta Cope, Xenarthra Gill, Pholidota Weber, and Tubulidentata Flower, and reasons are given for these conclusions.
4. It is suggested that the orders diverged from some ancestral group at present unrecognized, the Taeniodontata being more nearly related to the Xenarthra than to the other orders.

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THE STATE UNIVERSITY OF OKLAHOMA
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NUMBER 3

PROPOSED GROUPS OF PENNSYLVANIAN
ROCKS OF EASTERN OKLAHOMA

BY
CHAS. N. GOULD, D. W. OHERN
AND L. L. HUTCHISON

NORMAN
The University Press
March 1, 1910

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INTRODUCTION

This paper embodies certain results of field work accomplished by the authors during the past twelve years. Mr. Gould first visited the region under discussion in 1897, and has done more or less work there each year since that time. Mr. Hutchison has spent five field seasons in the region, being employed chiefly in collecting data relating to oil and gas. In 1907 he wrote a thesis covering certain phases of the subject, which has, however, never been published. Mr. Ohern has been employed the past two seasons in the north-central part of the region doing detailed mapping.

In addition to data collected by the authors, the results of other investigators in the field have been freely used. Joseph A. Taff, for many years connected with the United States Geological Survey, spent a number of field seasons in the coal fields of Oklahoma, and has published several reports and folios dealing with the southern portion of the region. N. F. Drake, Geo. I. Adams and C. E. Siebenthal have each made reconnaissances in the region, and their results have been utilized as far as possible. The reports and papers of Haworth, Beede, Prosser, Rogers, Bennett, Adams, Schrader, Shaler and others, in Kansas, and the works of Branner, Collier and Purdue in Arkansas have been drawn upon.

THE PROBLEM

The rocks in the area under discussion consist of a thickness of from 10,000 to 12,000 feet of sediments of Pennsylvanian age extending from the Mississippian to the Permian. In general these rocks consist of alternating layers of shale and sandstone. The shales greatly predominate, making up approximately three-fourths, or possibly nine-tenths of the entire thickness of the strata. In the northern part of the State

there is a number of ledges of limestone, but even in this region, shales constitute more than three-fourths of the strata, the remainder being about equally divided between sandstone and limestone. Farther north, in east-central Kansas, the limestone ledges are not only more numerous (no fewer than twenty distinct ledges having been recognized) but they are thicker, while sandstones make up a relatively small per cent. of the entire series.

In Kansas it has been noted that on passing from the center of the State to the Oklahoma line, the various limestone ledges frequently thin out, and some of them disappear before the line is reached. Others pass for several miles into Oklahoma before disappearing, but, except in eastern Kay County, comparatively few limestones reach the Arkansas River. Of the half dozen or more which persist south of that stream, only one ledge, so far as known, exceeds ten feet in thickness.

It has also been found that as the limestones thin out to the south and finally disappear, sandstones often come in, usually either just above or just below the limestone. In other cases the ledges become more arenaceous to the south, until finally the ledge which was a limestone has become a sandstone. It frequently happens, also, that additional sandstone ledges come in, first as mere arenaceous bands in the shales, then as thin lenses which thicken to the south, and finally become ledges of hard sandstone twenty to fifty feet thick, which resist erosion and give rise to pronounced escarpments. In a number of instances, however, the thinning out of the limestone ledges is to the north. This fact is particularly well exemplified in the case of several limestone ledges in the region about Bartlesville, and between that city and Arkansas River above Tulsa. Here, at least two heavy ledges of limestone disappear to the north. Many of the ledges, both limestone and sandstone, when traced for any considerable distance are found to be local lenses. The general rule throughout the area is, however, that limestones "finger out" to the south and sandstones to the north, while the intervening shales coalesce.

Another factor which complicates the difficulty of the

situation is the gradual thickening of the entire series to the south, particularly near their base. For instance the basal group, to be hereinafter described as the Muskogee group, is about 450 feet thick at the Kansas-Oklahoma line, but in the region north of the Choctaw fault, in the eastern part of the State, the same group has an approximate thickness of 9,000 feet. Part of the apparent thickening in this instance is probably caused by unconformity by overlap on the Mississippian, but much of it is doubtless caused by normal thickening of strata southward. The thickening of other groups from north to south, while not so conspicuous as in the case mentioned, is nevertheless often obvious.

From what has preceded, it will be evident that the problem of the proper division and correlation of the various beds is, in the absence of paleontological data, at best difficult. In rare cases only, may any single ledge of either limestone or sandstone be traced from Kansas line southward for any considerable distance. As has been stated, many of the sandstones and a few of the limestones are lenticular, and have but a comparatively limited areal extent. These conditions have already given rise to considerable confusion in folio and economic mapping, and it is feared that, as this work progresses, the complications may be augmented. It is with the hope of lessening the possibility of confusion in the application of stratigraphic terms and the needless multiplication of names in the future that this article has been prepared.

PROPOSED SOLUTION

The authors are convinced that the problem of the future division and correlation of the various beds may be greatly simplified by dividing all the rocks in the region into a few general groups, the limits of which may be demarked by certain conspicuous ledges of limestone and sandstone which extend southward from the Kansas line. After studying the region in considerable detail, it has been found that there are at least four of these ledges of sufficient importance and linear extent along the line of outcrop to serve as adequate group

markers, which groups must, of course, be confirmed by paleontological evidence. Beginning on the east, these ledges are as follows:

1. **The Claremore formation**, the approximate equivalent of the Fort Scott limestone of Kansas, which is correlated with the Calvin sandstone in the Coalgate folio.

2. **The Lenapah limestone**, which lies at the approximate horizon of the Upper Parsons, or Coffeyville, limestone of Kansas.

3. **The Pawhuska formation**, which is believed to be the equivalent of the Deer Creek and Hartford limestones of Kansas.

4. **The Wreford limestone**, which, south of the Cimarron River, gives way to the Payne sandstone.

From the study of the map it will be seen that these four formations trend approximately parallel northeast and southwest, from the Kansas line toward the region of the Arbuckle Mountains. The southern extension of none of them has been definitely located, but it is believed that accurate field studies will fix the position of each formation.

PROPOSED GROUPS

It is therefore proposed to demark the limits of four general groups of the Pennsylvanian rocks of eastern Oklahoma as follows:

1. **The Muskogee Group**, including all the rocks from the base of the Pennsylvanian series to the base of the Claremore formation. The name proposed is that of Muskogee County which lies near the center of the area occupied by the group.

2. **The Tulsa Group**, including everything from the base of the Claremore formation to the base of the Lenapah limestone. The name is from Tulsa County, in the eastern part of which the rocks of the group are well exposed.

3. **The Sapulpa Group**, including the rocks between the base of the Lenapah limestone and the base of the Pawhuska formation. The name is from Sapulpa, the county seat of Creek County.

4. **The Ralston Group**, including everything from the base of the Pawhuska to the base of the Wreford, which has usually been considered the base of the Permian. The name here proposed is from the town of Ralston in northern Pawnee County.

In proposing these groups, the authors do not wish to be understood as attempting to fix definitely the nomenclature of the region. The purpose is merely to provide a comprehensive yet simple scheme of classification which may be followed in future mapping. The classification is made entirely upon stratigraphic and lithologic data.

DESCRIPTION OF GROUPS

THE MUSKOGEE GROUP

Area. The Muskogee group includes a series of rocks, chiefly sandstones and shales, extending from an unconformity at the top of the Mississippian series on the east, to the base of the Claremore formation and its approximate southern equivalent, the Calvin sandstone, on the west. In the northern part of the State it includes the approximate area occupied by the southern continuation of the Cherokee shales of Kansas; in its southern extension it includes the great coal region of Oklahoma. The area included in this group in Oklahoma is bounded on the north by the Kansas line, and on the northeast by the areas occupied by Mississippian rocks. On the east the Arkansas line is the boundary. The Choctaw fault, the Cretaceous overlap in Atoka County, and the Arbuckle Mountains demark the southern limit. It includes all or part of the following counties in Oklahoma: Ottawa, Craig, Mayes, Rogers, Wagoner, Cherokee, Okmulgee, Muskogee, Sequoyah, Le Flore, Haskell, McIntosh, Okfuskee, Hughes, Latimer, Pittsburg, Coal, Pontotoc and Atoka.

Stratigraphy. Near the Kansas line, in which state the name Cherokee shales has been applied to the rocks of the group, the approximate thickness of the strata is 450 feet and consists largely of shales, with local beds of sandstone and limestone and several thin beds of coal. The following sec-

tion from Pryor Creek to Claremore made by Messrs. Ohern and Wolf will give a fairly comprehensive idea of the stratigraphy at that place.

SECTION, Pryor Creek to Claremore

14.	Shale with a few interbedded sandstones..	135 feet.
13.	Massive, medium-grained sandstone.....	17 feet.
12.	Shaly sandstone.....	3 feet.
11.	Argillaceous, heavily-bedded, fossiliferous limestone	2½ feet.
10.	Bluish shale.....	35 feet.
9.	Carbonaceous shale capped by six inches of ferruginous, siliceous limestone.....	3 feet.
8.	Gray, fine-grained sandstone.....	7 feet.
7.	Arenaceous shale.....	70 feet.
6.	Alternating shales and sandstones.....	70 feet.
5.	Argillaceous, fossiliferous limestone.....	8 feet.
4.	Massive, medium-grained sandstone.....	37 feet.
3.	Shaly sandstone.....	8 feet.
2.	Massive, medium-grained sandstone.....	14 feet.
1.	Bluish shale, weathering to light yellow, and a few inter-stratified sandstones.....	550 feet.
		<hr/> 960 feet.

In the Muskogee folio, Mr. Taff describes two formations, the Boggy and the Winslow, the latter being the equivalent of the Hartshorne, McAlester and Savannah formations as exposed in the coal fields farther south. The formations above the Boggy have not been described in Muskogee, Okmulgee and McIntosh counties.

The stratigraphy of the southern part of the Muskogee group is better understood than that of any other part of the Pennsylvanian series in Oklahoma. Numerous reports and folios bearing upon the subject, chiefly from the pen of Mr. Taff, whose work in the region continued almost without interruption from 1895 to 1908, have given us a very comprehensive idea of the stratigraphy, structure, and economic re-

sources of the coal fields of the State. The general sequence of the formations with their approximate thickness as shown in Coal and Hughes counties is here given, the oldest below :

Calvin sandstones.....	200 feet.
Senora formation.....	500 feet.
Stuart shale.....	250 feet.
Thurman sandstone.....	200 feet.
Boggy shale.....	2000 feet.
Savanna sandstone.....	1200 feet.
McAlester shales.....	2000 feet.
Hartshorne sandstone.....	200 feet.
Atoka formation.....	3000 feet.
Total.....	<hr/> 9550 feet.

This entire series of strata is coal-bearing. In Arkansas beds of considerable thickness occur in the Atoka formation, but in Oklahoma these beds are usually thin and inconspicuous. The McAlester formation contains four beds of workable coal and a number which may eventually be developed. The Savanna contains at least three and the Boggy formation two workable beds. Several occur in the higher formations of the series, particularly one in the upper part of the Senora which is mined at Henryetta, Schalter and Morris. In the southeastern part of the area occupied by rocks of the Muskogee group the strata have been extensively folded, and in certain places faulted. A series of anticlines and synclines have their axes extending northeast-southwest.

It is not the purpose in this connection to discuss the problem of the cause of the thickening of the various beds of the Muskogee group to the south, or what amounts to the same thing, the thinning of the beds to the north. It has usually been assumed that the change in the thickness is due largely to unconformity by overlap. While in the present state of our knowledge, particularly in the absence of complete paleontological evidence, it would be extremely unwise to say that this cause did not obtain, at least in part, still in the light of accumulating evidence it seems very probable that

we must look elsewhere for reasons to account for a considerable part of the southern thickening of the beds.

THE TULSA GROUP

Area. This group includes all the rocks lying between the base of the Calvin-Claremore formation and the base of the ledge which in Kansas has been known as the Upper Parsons or Coffeyville limestone, but which in a paper by Ohern, now in press, is designated as the Lenapah limestone. The rocks of the group outcrop on the surface as a band, averaging 20 miles in width, and extending from the Kansas line south to the region of the Arbuckle Mountains. The Lenapah limestone has not been certainly located south of the North Canadian River, although there is reason for believing that it will eventually be correlated with a limestone in the upper part of the Holdenville formation, which outcrops not far from the town of Holdenville in Hughes County, and which probably extends nearly to Ada. The rocks of the Tulsa group occupy all or part of the following counties: Craig, Nowata, Rogers, Tulsa, Wagoner, Okmulgee, Okfuskee, Coal, Hughes and Pontotoc.

Stratigraphy. The rocks of the Tulsa group as exposed in the northern part of the State, include formations which in Kansas have been described under the names Fort Scott limestone, Labette shales, Pawnee limestone, Bandera shales, Altamont limestone and Walnut shales. The combined thickness of these rocks at the Kansas line is about 250 feet; farther south this thickness is much greater.

The Fort Scott limestone, known to the oil drillers of Kansas and Oklahoma as the Oswego lime, was first described in Kansas, where it consists typically of two limestone members and an intervening shale member. Ohern, however, finds that in northern Oklahoma a third limestone member comes in below the Fort Scott of Kansas, and persists at least as far south as the Arkansas River. For this formation, consisting of three limestones with two intervening shale beds, each containing coal, in a paper now in press, he is proposing to use the name Claremore.

The Labette shales, named and described in Kansas, extend from the Kansas line southward across Oklahoma, finally, on the disappearance of the higher limestones, coalescing with other shales. The Pawnee and Altamont (Lower Parsons) limestone, which at the Kansas line are separated by the Bandera shales, come together in southern Nowata County and form a single ledge, the Oologah, the "Big lime" of the drillers. The ledge extends southward, crosses the Arkansas River near Broken Arrow and disappears in the vicinity of the Concharty Mountains.

From the Arkansas River south the rocks of the Tulsa group consist of sandstones and shales with an occasional lentil of limestone. In the Coalgate folio Mr. Taff has described the following formations beginning with the Calvin:

Seminole conglomerate.....	150 feet
Holdenville shale.....	250 feet
Wewoka formation.....	700 feet
Wetumpka shale.....	120 feet
Calvin sandstone.....	200 feet

If, in the above section, the Tulsa group includes the Calvin, Wetumpka, and Wewoka formations, and probably 200 feet or more of the Holdenville formation, this would indicate that the rocks of the group as exposed in the region south of the Canadian River reach a thickness of approximately 1200 feet.

THE SAPULPA GROUP

Area. The rocks which constitute the Sapulpa group include everything from the base of the Lenapah limestone to the base of the Pawhuska formation (as that term was used by J. P. Smith) as these formations are exposed in the northern part of the State. Neither the Lenapah nor the Pawhuska has been definitely located south of the North Canadian River and for that reason the southern limits of the group cannot now be accurately demarked.

The area included in the group averages 35 miles in width, extending from the Kansas line south to the vicinity of the

Arbuckle Mountains. It includes all or part of Nowata, Washington, Osage, Pawnee, Creek, Tulsa, Okmulgee, Payne, Lincoln, Okfuskee, Pottawatomie, Seminole, Pontotoc and probably McClain, Garvin and Murray counties.

Stratigraphy. Included in the Sapulpa group in Oklahoma are rocks which in Kansas have been described under the following formation names: Coffeyville limestone, Pleasanton shales, Bethany Falls limestone, Ladore shales, Mound Valley limestone, Galesburg shales, Dennis limestone, Cherryvale shales, Drum limestone, Chanute shales, Iola limestone, Lane shales, Stanton limestone, LeRoy shales, Kickapoo limestone, Lawrence shales, Oread limestone, Kanwaka shales.

The approximate combined thickness of these rocks as exposed in southern Kansas is 1000 feet. In Oklahoma the thickness of the group gradually increases until at the Arkansas River it is probably 1200 feet or more.

So far as known, with the exception of the Lenapah, none of the limestone ledges exposed in Kansas persist as far south as the Arkansas River. The Drum limestone splits near the Kansas line, and the lower member, which Ohern calls the Hogshooter, disappears some twenty miles north of Tulsa. The upper member of the Drum disappears soon after crossing the State line. Two limestone lentils, the Dewey and Avant, come in not far from Bartlesville and persist beyond the Arkansas River where they also disappear. As the limestones disappear near the Kansas line, sandstones become prominent and farther south increase in thickness until they make up a considerable part of the rocks of the group, although, as in other parts of the general region occupied by Pennsylvanian deposits, shales are the predominating rock.

No accurate section has ever been made across the southern part of the region occupied by rocks of the Sapulpa group, and for that reason it is impossible to do more than to approximate the thickness of the group along the Canadian River, but it is probable that in this region it is somewhere between 1500 and 2000 feet.

In its southwestern extension, the Sapulpa group passes into and includes the eastern part of the Oklahoma Redbeds,

being part of the so-called Chandler beds. The approximate line of transition from non-red to red rocks, in other words the eastern line of the Redbeds, is indicated on the map.

THE RALSTON GROUP

Area. The Ralston group includes the rocks in the upper part of the Pennsylvanian series, beginning at the base of the Pawhuska formation and extending to the base of the Wreford limestone and its southern continuation, the Payne sandstone, which has usually been considered the base of the Permian.¹ The group is exposed as a band averaging 30 miles in width extending parallel to the other groups described in this paper, from the Kansas line south toward the Arbuckle Mountains.

Neither the Pawhuska formation nor the Payne sandstone has been definitely located as far south as the North Canadian River and consequently the limits of the southern part of the Ralston group which is exposed in Lincoln, Oklahoma, Pottawatomie, Cleveland, McClain and Garvin counties, can not be accurately demarked. In the northern part of the State, this group is exposed in Osage, Kay, Pawnee, Payne and Lincoln counties.

Stratigraphy. The equivalents of the following formations in Kansas, the combined thickness of which is approximately 800 feet, are included in the Ralston group as the latter is exposed in northern Oklahoma:

Lecompton limestone, Tecumseh shales, Deer Creek limestone, Calhoun shales, Topeka limestone, Severy shales, Howard limestone, Scranton shales, Burlingame limestone, Willard shales, Emporia limestone, Admire shales, Americus limestone, Elmdale formation, Neva limestone, Eskridge shales, Cottonwood limestone, Florena shales, Neosho formation.

These formations are exposed along the Flint Hills in southern Kansas, but near the Oklahoma line most of the limestone members thin out and disappear, while sandstones

1. Beede now considers the Elmdale as the provisional base of the Permian.

come in and thicken to the south. No accurate section across the group has been made in Oklahoma but it is probable that the group does not thicken to the south as rapidly as do the groups heretofore described. In fact, there is some evidence which indicates that in Lincoln, Pottawatomie and Cleveland counties the rocks representing the southern extension of the Ralston group are not so thick as they are farther north.

In southern Pawnee and northern Payne counties, the color of the rocks in the Ralston group changes and becomes a deep brick-red and so continues to the southern limits. This area includes the greater part of the so-called Chandler beds mentioned above.

HIGHER ROCKS

Above the Ralston group, the sequence of limestones and shales with occasional sandstones continues uninterruptedly for several hundred feet. The Kansas geologists have described these rocks under the following names, the oldest below:

- Wellington shales
- Marion formation
- Winfield limestone
- Doyle shales
- Fort Riley limestone
- Florence flint
- Matfield shales
- Wreford limestone

The limestones contain much flint, which, being resistant, withstands erosion, giving rise to a series of pronounced escarpments, which, in southern Kansas, constitute the Flint Hills. The rocks of the Marion are less resistant, and form few pronounced escarpments. The Wellington shales are all soft rocks and weather into a flat plain.

In Oklahoma, all these formations pass into the Redbeds along the line indicated on the map. Several of the limestones, particularly the Wreford, the Florence and the Fort Riley, extend several miles into the Redbeds before finally

losing their color and merging with red sandstones and shales.

This peculiarity of relations is represented on the map in Kay and adjoining counties, where there is exposed an area of non-red Permian rocks, triangular in shape, bounded by the Kansas line, the Wreford limestone and the eastern margin of the Redbeds.

University Geological Laboratory,
March 1, 1910.

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THE STATE UNIVERSITY OF OKLAHOMA
RESEARCH BULLETIN

NUMBER 4

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THE STRATIGRAPHY OF THE OLDER
PENNSYLVAINAN ROCKS OF
NORTHEASTERN OKLAHOMA

BY

D. W. OHERN

NORMAN
THE UNIVERSITY PRESS
DECEMBER 1, 1910

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The STATE UNIVERSITY OF OKLAHOMA RESEARCH BULLETIN is issued at irregular intervals. It is devoted to the publication of the results of research by members of the university. One paper constitutes an issue and the different issues are numbered consecutively in the order of their appearance. Exchanges with other institutions and learned societies everywhere are solicited. All EXCHANGES should be addressed to the LIBRARY OF THE STATE UNIVERSITY OF OKLAHOMA, NORMAN, OKLA., U. S. A.

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INTRODUCTION.

Rocks of Pennsylvanian age outcrop in most of eastern Oklahoma. The region discussed in this contribution lies principally north of the Arkansas River and between the western limit of the Boone chert and the ninety-sixth meridian. It is geologically continuous with the area occupied by rocks of the same age in southeastern Kansas. Very little systematic work had been done in this region until that undertaken by the writer in the field seasons of 1908 and 1909. During this time considerable advance was made in the study of these rocks and it is hoped that the results herein set forth will, in a measure, contribute to our knowledge of the geology of this area.

It is impossible to discuss the history of geological work in northeastern Oklahoma, without constant reference to that done in contiguous territory in Kansas. The geology of the Carboniferous of the two states is inseparable, and while it is not possible here to refer in detail to the work done by each investigator in Kansas, it should be borne in mind that each contributed to the geology of Oklahoma whether he actually worked in the State or not.

The writer wishes to acknowledge his indebtedness to Chas. N. Gould, director of the Oklahoma Geological Survey, for courtesies shown and valuable assistance given in the preparation of this paper. Acknowledgements are due also to L. L. Hutchison and Chas. H. Taylor who have made valuable suggestions. Gould and Taylor have read the manuscript and offered criticisms.

WORK DONE BY PREVIOUS WRITERS

Probably the earliest published account of the geology of the region is by Jules Marcou in 1855. (1) This writer spent from 1848 to 1854 in this country and a small part of this period was devoted to the study of what is now Oklahoma. The geological map accompanying his brief treatise represents in a general way the occurrence of the Lower and Upper Carboniferous as they exist in the eastern part of the State. In

1. Published by permission of the Director of the Oklahoma Geological Survey.

1. La Terrain Carbonifere dans L'Amerique du Nord. Geneva, June, 1855.

writing of the Upper Carboniferous west of the Mississippi River, he says: ".....ses limites.....sont basees sur les observations faites dans diverses des ses parties par Nicolet, D. D. Owen, H. King, G. G. Shumard et par moi." (2)

In 1897, N. F. Drake published a reconnaissance map of the then Indian Territory coal field. The rocks referred by him to the Upper Carboniferous were divided into the "Lower Coal Measures," the "Cavaniol group" and the "Poteau group." (3) The base of the Permian he has drawn apparently at the lower limit of the Pawhuska limestone, although his map is sadly in discord with his section given on page 279. But even the Pawhuska limestone is far below the Wreford limestone whose base is now believed to be the lower Permian. (4) His contact lines, also, have been shown to be erroneous, not following the strike. (5) His work is so general and inaccurate as to be of little value for the region under discussion.

G. I. Adams in 1901 made a preliminary study of the geology of northeastern Oklahoma but the work was subsidiary to the elucidation of the geology of the Upper Carboniferous of Kansas. His observations in Oklahoma were confined largely to the Claremore formation and Hogshooter limestone. The results are embodied in Bulletin 211 of the United States Geological Survey.

From 1900 to 1907, C. N. Gould made several excursions into the region, chiefly for the purpose of ascertaining the conditions of underground water. While the area he studied lies largely to the west of that here considered, he nevertheless made a number of observations of prime importance to the present discussion. (6)

6. Water Supply and Irrigation paper No. 148, U. S. G. S., 1905, pp. 28 et seq. Am. Jour. Sci. 4 ser., Vol. XI, 1901, pp. 185-190.

2. Loc. cit. pp. 20, 21.

3. A Geological Reconnaissance of the Coal Field of the Indian Territory. Proc. Am. Phil. Soc., Vol. XXXVI, 1897, pp. 326-419.

4. Prosser, C. S., Review of the Classification of the Upper Paleozoic Formations of Kansas. Jour. Geol., Vol. 10, 1902, table op. p. 718. (See Beede, J. W., Jour. Geol., Vol. XVII, p. 710, for revision of data.)

5. Adams, G. I. Bul. 184, U. S. G. S., 1902, p. 158.

C. E. Siebenthal, of the United States Geological Survey, spent about six weeks in 1907 doing reconnaissance work in the region. The object of his observations was, however, chiefly economic, but he made some substantial contributions to the stratigraphy and structure of the region.

Up to the present, considerable confusion has existed as to the continuity of the Drum limestone of the Kansas geologists. Siebenthal believed that this limestone does not extend south of Opposum Creek. (7) This is a very natural inference on first studying the region; and the same conclusion was reached by the writer when a preliminary study was made of this formation; but subsequent detailed work demonstrates this to be an error, as will be shown later.

The same author believed that the limestone at the Portland cement plant at Dewey is the Piqua of the Independence quadrangle. (3) It will be shown hereafter that this limestone lies far below the horizon of the Piqua. The grounds upon which Siebenthal stated his belief seem to be that the limestone which is being quarried at the cement plant at Dewey lies above the shaly sandstone which he took to be the Wilson of the United States Geological Survey. However, it will be shown that the prominent escarpment running southward from the Kansas line just west of Coffeyville and extending to a point west of Nowata is not formed by the Wilson but by a thickened member of the Coffeyville formation of the Independence quadrangle.

During the field seasons of 1905 and 1906, L. L. Hutchison, at that time a student in the Oklahoma State University, made further advance in our knowledge of these rocks. His results may be found in his dissertation in the University library.

The work by the writer covered the field seasons of 1908 and 1909 and several periods of shorter duration. He has been ably assisted by several of the advanced students of the department of geology in Oklahoma State University.

In the autumn of 1908, Rev. John Bennett spent several weeks in the region in the employ of the Oklahoma Geological Survey. His results are not published but the writer is indebted to him for several disclosures, more especially in connection with the stratigraphy of the horizon of the Drum and succeeding limestones.

7. Bul. 340 U. S. G. S., p. 195.

8. *Ib.*, pp. 195, 220.

GEOGRAPHY AND TOPOGRAPHY

Practically the entire region under discussion is drained by the Verdigris and Grand rivers and their tributaries. In Oklahoma, the latter stream derives its waters principally from the area underlaid by the Boone chert and the Vinita formation, while the former drains chiefly higher formations.

Speaking generally, the region consists of broad, flat valleys near the major streams and rather high, rough areas on the divides. Owing to the alternation of hard and soft strata, the former being sandstones and limestones, and to the low westward dip of the rocks, several prominent escarpments result. The most eastward of these is that made by the heavy sandstones lying somewhat above the middle of the Vinita formation. It is well seen in the vicinity of Vinita and especially just west of the town of Pryor Creek.

The second escarpment, usually fairly well defined, is made by a series of limestones and sandstones with some intervening shales, for which the name Claremore formation is herein proposed. This escarpment crosses the state line about five miles west of Grand River and runs southwestwardly, passing about two miles east of Centralia, thence to Chelsea and Claremore. South of Catoosa it loses its sharpness of definition, owing to the pronounced development of resistant strata both above and below.

The Pawnee limestone and its southern extension, the Oologah, also make a prominent escarpment lying to the westward of that just outlined. It is very marked in the northern part of the area, especially at the head of Big Creek. It crosses the Verdigris River just northeast of Nowata and makes the lower part of the west bluff of that stream southward to Catoosa. Here the stream veers to the eastward while the bluff can be traced southward to the vicinity of Broken Arrow. Beyond, it, in turn, becomes indistinct for the same reason as does the escarpment caused by the Claremore formation.

The fourth marked escarpment crosses the state line about two miles west of Coffeyville, Kansas, and continues southward a few miles beyond a point west of Nowata. There it turns westward around the head waters of Hogshooter, Cedar and Coon creeks. West of Caney River and south of Bartlesville, its effect is blended with that of associated strata.

This escarpment at the Kansas line is formed by the Drum limestone and overlying sandstones; and while it is continuous to Nowata, it is there due, as previously mentioned, to

the marked development of subjacent sandstones. A fuller discussion of the stratigraphic relations will be given in proper order.

West of Little Caney River, a marked escarpment is made by a series of massive, thick-bedded sandstones and limestones. It crosses the Caney River in the Osage region several miles above Bartlesville and continues southward along the 96th meridian to and beyond Tulsa. South of the limit of the Nowata quadrangle, its line becomes very irregular, owing to streams of some magnitude which flow against the dip of the strata.

Early in his studies the writer discovered that southward from a point some miles north of Ochelata this escarpment is due to successively lower strata. C. D. Smith, of the United States Geological Survey, demonstrated to the writer that the same is true to the north also. Successive sandstones turn westward to be placed by others which develop below them and continue the bluff southward.

In addition to the escarpments thus briefly described, the divides between the more prominent streams are characterized by rolling or rough topography. In practically every instance this is due to the incisions made by the smaller streams through the more resistant strata into the softer subjacent shales. A marked feature of this rolling topography is that it is to be found chiefly just to the eastward of the major streams. It is due to the fact that the gradient of the smaller streams, near their sources, is greater than the dip of the rocks. Thus, the drainage channels cut through the hard strata which make the eastward facing escarpments and form the rough topography of much of the region. This situation is especially marked east of the Verdigris River in the northern part of the area under consideration.

The incisions described make the interpretation of the structure of the region a much simpler task than is the case when the dip of the rocks exceeds the gradient of the streams. For in not a few instances the strata may be traced for several miles along the banks of one of these minor streams, enabling the observer thus to determine precisely the amount and variation of the dip. In view of the fact that the occurrence of oil and gas is so closely related to the structure, a study of the outcrops along these small streams is deemed of great importance.

The major streams, as a whole, make a feeble attempt to run parallel to the strike of the rocks, following the soft strata. When they cross the more resistant rock, they follow the

shortest line. A close study of the streams thus assists one in an interpretation of the structure of the region. This feature becomes all the more important when it is remembered that along the channels of these streams the older rocks are almost entirely concealed by river deposits. Seldom can any of the limestones be traced across the floodplains and channels of the major streams, especially in times of high water; but one is usually safe in saying that a resistant stratum crosses the stream where the latter turns suddenly to the eastward.

The striking feature of practically all the streams is that they occupy very deep channels. In dry seasons many of these may be seen to be holding stagnant water of considerable depth, showing that the streams, where they flow on the softer rock, scoop out excavations below the general bed. These deep channels control to a marked degree the cross-country travel of the entire region, for it is only at favored places that a crossing can be made by ford.

GENERAL STRUCTURE

The low, westward dip prevailing in the Upper Carboniferous region of Kansas obtains also for rocks of the same age in Oklahoma. This rarely exceeds 60 feet to the mile and generally is much less, 15 or 20 feet being perhaps the average. Occasionally slight easterly dips are to be detected. More often, however, this usual westerly dip is varied by northeast-southwest anticlines. In a few instances these can be observed by the eye or detected by a clinometer; but more often observation over a considerable area is required to reveal them. It is along these anticlines that the great oil pools of the region are located. A detailed discussion of the structure will be made in a succeeding paper on this area.

STRATIGRAPHY

General Features: The lower Pennsylvanian rocks of northeastern Oklahoma are a series of shales, limestones and sandstones. While the latter play a leading role in the topography, they are usually thin and lenticular except in the southern part of the region. Owing to their massive character, polygonal fragments of widely varying sizes are to be found over areas that are altogether out of proportion to the relative thickness of the beds. These fragments find their way down the slopes and give the appearance of vast thicknesses of strata. Not infrequently a bed of only a foot or

two in thickness may be the cause of a ridge or hill of considerable magnitude.

Perhaps the most striking lithologic feature of the sandstones as a whole is their sameness. Only in a few instances has the writer been able to use lithologic character as a means of identification of beds. Generally they are medium- to fine-grained, light colored when fresh, but becoming reddish or brownish on weathering. Some of the more massive beds show a marked tendency toward concentric weathering. This is the case especially with the younger sandstones here discussed.

Likewise the limestones, when fresh, show a marked sameness in color and texture. On weathering, however, changes result which are of great value in identifying individual beds. Since it is by means of limestones almost wholly that contact lines are drawn, this value greatly increases.

It is perhaps in the shales that the greatest diversity of lithologic character is to be found. But they are seldom exposed. Only rarely can they be found capping eminences. For the most part, the sandstones and limestones effectually conceal the subjacent shales. Although the latter occupy the surface over considerable areas in the lower stretches of country, unaltered shales are seldom seen. While, therefore, they are of first importance as regards thickness, they can rarely be used as criteria in mapping.

The Pennsylvanian rocks of eastern Oklahoma have been tentatively divided by Gould, Ohern and Hutchison into four groups, the Muskogee, the Tulsa, the Sapulpa and the Ralston. (9) Of these, the last does not occur in the region under discussion. The others will be treated in order.

MUSKOGEE GROUP

Under the term Muskogee Group are included "All the rocks from the base of the Pennsylvanian series to the base of the Claremore formation." The rocks are chiefly shales and sandstones. The lower limit is sharply marked by an unconformity, below which lies the Boone chert, or the Pitkin limestone or its equivalent. The fauna of the Pitkin is shown by Girty, and the view is supported by Ulrich, to be Mississippian, while that of the limestone lenses in the superjacent Morrow formation is Pennsylvanian. (19)

The stratigraphy of this group is but imperfectly known

9. This series No. 3.

10. Folio 122, U. S. G. S., 1905, p. 5.

north of the Arkansas river. Of the fauna little or nothing is known. All things considered it is thought best to include all the rocks under one formation for the present.

Vinita Formation

Definition: At the base of the Pennsylvanian series in northeastern Oklahoma, lies a succession of shales with interstratified sandstones, thin beds of coal and lenticular limestones. For this series the term Vinita formation is here proposed from the town of Vinita where it is well developed. (11) As here defined it includes all the rocks of the Muskogee group. It should be clearly understood, however, that this definition is not intended to apply south of the Arkansas River, and even for some miles north of that stream little is known concerning the lower beds of the Vinita.

The Vinita formation is the approximate equivalent of the Cherokee shales of Kansas. But it is believed that the upper limit here defined is below the upper limit of the Cherokee. Sufficient detailed work has not yet been done to discuss the formation in full and certain statements here made must be regarded as tentative.

Area: The Vinita formation occupies a belt varying in width from twelve to thirty miles and extending from the Kansas line near Chetopa southwest to the Arkansas River. It is widely exposed in the vicinity of Vinita, Claremore, Wagoner and along the lower course of the Verdigris River. Its areal extent exceeds that of any other formation under discussion. Over much of the area is to be found a rough surface due to heavy sandstones.

Thickness: The Cherokee shales at the southern Kansas line have a thickness of 450 feet. (12) The maximum in Kansas is about 650 feet, the average being about 450. (13) Southward the Vinita formation appears to thicken rapidly. At Pryor Creek it is about 1,000 feet. The writer and Key Wolf made the following section beginning at the cemetery one mile east of the town of Pryor Creek and extending to Claremore:

14. Shale, with a few interbedded sandstones.....135 feet

11. Hutchison suggests this name in his unpublished work.

12. Siebenthal, C. E. Bul. 340, U. S. G. S., 1908, p. 191.

13. Adams, G. I. Bul. 211, U. S. G. S., 1903, p. 28; Haworth and Bennett, Univ. Geol. Sur. of Kan., Vol. IX, 1908, (distributed November, 1909), pp. 76, 77.

13. Massive, medium-grained sandstone.....	17 feet
12. Shaly sandstone	3 feet
11. Argillaceous, heavily-bedded, fossiliferous limestone	2½ feet
10. Bluish shale	35 feet
9. Carbonaceous shale, capped by six inches of ferruginous, siliceous limestone.....	3 feet
8. Gray, fine-grained sandstone.....	7 feet
7. Arenaceous shale	70 feet
6. Alternating shales and sandstones.....	70 feet
5. Argillaceous, fossiliferous limestone.....	8 feet
4. Massive, medium-grained sandstone.....	37 feet
3. Shaly sandstone	8 feet
2. Massive, medium-grained sandstone.....	14 feet
1. Bluish shale, weathering to a light-yellow, and a few interstratified sandstones.....	550 feet
<hr/>	
960 feet	

Discussion of the Pryor Creek-Claremore Section: No 1 is well exposed in the vicinity of the town of Pryor Creek. The thickness was ascertained by careful determination of the dip of its upper surface and of the distance between its eastern and western limits. It may be called the Pryor Creek shale and is probably the approximate equivalent of Drake's Lower Coal Measures.

Excellent exposures of No. 2 may be seen on the high point five miles due west of the town of Pryor Creek. It makes the lower part of the escarpment running north and south from this point.

No. 3 is to be seen on the hill just to the south of the one just mentioned and is scarcely more than a shaly phase of Nos. 2 and 4. At its base is a stratum of carbonaceous shale which may accompany coal.

In view of the fact that it is in the Vinita formation that practically all the oil in the northeastern Oklahoma field occurs, it is surprising that so little work has been done on the stratigraphy. As appears from the section there are two sandstones which stand out prominently, Nos. 2 to 4 inclusive (which may be regarded as a unit) and No. 13. While sandstones are lenticular, yet one might naturally expect these to be petroliferous horizons.

No. 4 is well seen in the same place as No. 2 and is one of the most massive sandstones of the entire older Pennsylvanian rocks of the region.

No. 5 is observed to lie in fragments on the top of the hill

above mentioned. A better exposure may be seen on the east section line of Sec. 13, T. 12 N., R. 17 E. It is also exposed in a ravine in the S. E. 1-4 of the same section.

No. 6 contains at least four beds of sandstone whose thickness could not be determined but each is seemingly three or four feet thick. The upper one is somewhat concretionary and weathers into a red soil. It may be seen at the base of the hill on the northeast corner of Sec. 15, T. 21 N., R. 17 E.

Much of No. 7 is exposed on the hill just mentioned, the top having been removed.

No. 8 caps the mound on the north side of Sec. 16.

No. 9 is seen in the same place. It is a hard ferruginous siliceous limestone with a jasperoid appearance. It contains an abundance of small fossils which have not yet been determined.

No. 10 is to be seen here, also, immediately overlying No. 9.

A good exposure of No. 11 is on the top of the hill on Sec. 7, T. 21 N., R. 17 E. Other exposures occur along the section line westward. It seems to be absent on Dog Creek, two miles northeast of Claremore.

No. 13 is exposed along Dog Creek two or three miles northeast of Claremore. It may be regarded as not improbable that this sandstone is oil-bearing farther west along its dip.

No. 14 underlies the city of Claremore. Its relatively homogeneous character gives rise to the broad flat valley which is delimited on the east by the sandstone just mentioned and on the west by the escarpment formed by the Claremore formation.

Stratigraphy: Much work remains to be done on this formation. At present the writer is strongly of the opinion that subsequent study will show it to be composed of at least four units. These will probably be a lower shale, a massive sandstone, a succession of shales and sandstones, and upper shale. Lenses of limestone, other than those of the above section are not lacking. Usually such beds are highly fossiliferous and, collectively, will no doubt furnish an abundant fauna. Beds of coal are also to be found but further work is necessary to show their position and value. One lies a few feet beneath the Claremore formation.

I cannot agree with Siebenthal in saying that in the Coalgate and Atoka quadrangles "These 9,000 feet of Pennsylvanian shales and sandstones is represented at the Kansas line by a thickness of but 500 feet of Cherokee." (14) Assuming

the verity of his correlation of the Fort Scott of Kansas with the Calvin sandstone of Coalgate quadrangle, still his statement is probably not correct; for the relation of the Vinita formation to the Mississippian below is for the most part, at least, one of overlap. (15) Thus as one follows the Mississippian-Pennsylvanian contact line southward and eastward from the Kansas line, successively older formations appear from beneath those overlying. At most, then, the Cherokee shales can be the equivalent of only a part of the 9,000 feet of Pennsylvanian sediments near Coalgate.

Correlation: As has been said, sufficient detailed work has not been done on the Vinita formation to warrant many precise statements. However, on the principle of continuity, the Vinita is believed to be roughly the equivalent of the Cherokee shales of Kansas, but, as noted above, the upper limit of the Cherokee lies somewhat above that of the Vinita. This point will be noted again under the succeeding formation.

To the south the Vinita formation is the approximate equivalent of the Winslow and Boggy formations of the Muskogee quadrangle and of certain higher unnamed formations exposed in the eastern part of the Okmulgee quadrangle.

In view of the fact that the relation of the Vinita to the subjacent formations is one of overlap, it is probable that the base of the former in its southern extension is older than that of the Cherokee of Kansas.

TULSA GROUP

This group includes all the rocks between the base of the Claremore-Calvin formation and that of the Lenapah limestone. It consists of several well defined and mapable units to which the following names are applied: Claremore formation, Labette shales, Oologah formation, and Nowata shales. These will be taken up in succession.

Claremore Formation

Lying above the Vinita formation is a succession of limestones and shales, with a single sandstone of prominence, and two or more beds of coal. For this formation the name Claremore is proposed. As here defined, it includes all strata between the subjacent Vinita formation and the overlying Labette shales. From a consideration of the stratigraphy and

14. Bul. 340, U. S. G. S., 1908, p. 191.

15. Bul. 260, U. S. G. S., Pl. I. p. 382.

lithology it forms a well-defined unit. The name is from the town of Claremore where the formation is well exposed and typically developed.

Area: The Claremore formation outcrops over a belt running southwwest from the Kansas line near Chetopa and varying in width from one mile, or even less, to ten. This belt extends past the vicinity of Centralia and thence to the westward of Chelsea. From here to near Catoosa it lies largely between the Frisco railway and the Verdigris River. Here the strike changes to nearly north-south and the belt extends to Broken Arrow and southward to the Arkansas River. The eastward limit, especially to the northward, is usually well defined, the basal limestone being usually found at or near the top of the escarpment already mentioned. The westward limit is not so obvious but it can usually be easily traced. Small streams are working slowly down the westward dip of the uppermost limestone. By observing these closely the contact may be determined with considerable readiness.

Thickness: The thickness of the Claremore formation is variable. At Claremore it is about 50 feet. But this is probably less than the average for the formation; thicknesses of 135 feet have been reported by Wolf. But where measurements were made the surface usually had been removed so that the average thickness probably exceeds the figures given.

Stratigraphy: Typically this formation consists of a lower, a middle and an upper limestone, with intervening clastic sediments and coal. The interval between the lower and middle limestones is mostly shale. A well-defined and persistent bed of sandstone lies a few feet below the middle limestone and is an excellent guide in mapping. It weathers to yellow or buff and the lower limestone can always be found some 15 feet below it. Perhaps a good section would show the interval between the middle and upper limestones to be mostly shale also; but good, sharp exposures are lacking so that one is compelled to estimate the relative thickness of shale and sandstone.

The following section was made by Wolf and the writer three miles west of Claremore, beginning at the base of the formation which is to be seen in contact with the Vinita in the ravine about one-fourth mile north of the school house. The section was made along the public highway and while the thicknesses and successions here given may not be correct in detail, they are sufficiently accurate to give a fair representation of the stratigraphy of the formatin in this region:

	Feet	Inches
10. Massive, fossiliferous limestone, top eroded in front of school house.....	5	3
9. Carbonaceous shale, seen at cross roads....	2	6
8. Cherty limestone, weathering to yellowish, spongy, siliceous fragments, fossils abundant	2	8
7. White, massive, fossiliferous sandstone....	4	8
6. Shale	5	6
5. Hard sandstone	2	
4. Shale	21	6
3. Chert, giving polygonal fragments on surface		4
2. Shale, weathering to a buff.....		10
1. Massive, bluish, fossiliferous limestone.....	3	
	48	3

Vinita

The chert of No. 3 of the above section, makes another very convenient horizon marker and is of prime importance to one tracing the lower limit of the formation. The cherty fragments are usually very abundant on the surface and their extremely dark or even jet color serves to distinguish them at sight.

The three principal limestones of the Claremore formation give rather abundant chert on the surface where sufficiently weathered. The same is true of the Pawnee, Oologah and Lenapah above. Limestones above the last mentioned generally give much less chert on weathering but aside from the color and abundance of the chert in the lower part of the Claremore formation, I know of no reliable lithologic feature that will serve to distinguish the several limestones of this horizon. In its northward extension, even the lower Claremore does not give this characteristic chert, but it is a constant feature for many miles north and south of the latitude of the town of Claremore.

Correlation: As already indicated, the base of the Claremore is believed to lie below that of the Fort Scott of Kansas, while the upper limestone of the Claremore is thought to be the equivalent of the upper of the Fort Scott limestones. Assuming the correctness of both ideas, the Claremore would be the equivalent of the Fort Scott limestone and the upper most part of the Cherokee shales of Kansas.

Labette Shales

The term Labette was first used by Adams for shales which in Kansas lie immediately above the Fort Scott lime-

stone and below the Pawnee limestone. These shales extend south from Kansas into Oklahoma and are as sharply defined in the latter state as in the former. As used in this paper, the term Labette applies to 100 feet or more of shales which lie above the Claremore formation and below the Oologah, of which the Pawnee limestone or its southern extension is the lower member. Both above and below, therefore, they are sharply delimited by limestones.

Area: The Labette shales occupy generally the topographic depression between the limestones just mentioned. As shown on the map, they extend in a broad belt southward from the Kansas line along the waters of Big Creek in the Vinita quadrangle as far as the latitude of Nowata. From this point southward, the Verdigris River flows along the line of their outcrop as far approximately as Catoosa, where the river turns sharply to the eastward, while the outcrop of shales continues southward past Broken Arrow to the Arkansas River. Beyond this stream the eastern limit is traceable by a limestone, probably the upper of the three mentioned in the discussion of the Claremore formation. This has been followed far to the southward by Hutchison and others. It appears at Wealaka Mission. Farther to the southward the limestone disappears and the horizon is occupied by sandstone.

The width of the belt occupied by the shales varies within rather wide limits, being in some places very narrow, especially when their outcrop is confined to the west bank of streams. Not infrequently, however, larger areas lie to the eastward of Big Creek and the Verdigris River, being separated from each other by incisions made by smaller streams.

Thickness: The thickness of the Labette shales in Kansas was said by Bennett to vary between 30 and 80 feet. (16) Haworth and Bennett later (17) give the variation as between 20 feet on the north side of the Marmaton River, near Fort Scott, and 60 feet a few miles west of that city. Near the Kansas line, the thickness appears to be only a few feet. A decrease in thickness is likewise noted in Kansas along the dip to the westward. (18)

As a whole, these shales are thicker in Oklahoma than in Kansas. From a few feet near the Kansas line, they thicken

16. Univ. Geol. Sur. of Kan., Vol. I, 1896, p. 91.

17. Univ. Geol. Sur. of Kan., Vol. IX, 1908, p. 83.

18. Uni. Geol. Sur. of Kan., Vol. III, 1898, p. 36.

rapidly to the southward, although this increase is by no means regular or constant, thinning sometimes taking place. Wolf and the writer ascertained the thickness to be 137 feet on Claremore Mound, a few miles northwest of Claremore. From the log of a well about two miles north of Albright's store near Coody's Bluff, the thickness would appear to be about 200 feet and Hutchison states in his unpublished work that to the southward the thickness continues to increase.

Stratigraphy: A fairly constant stratigraphic feature of the Labette shales is a sandstone which lies in the upper part. This is perhaps best seen in the vicinity of Coody's Bluff, where it has a considerable thickness, which increases to the southward. Everywhere along its extent this sandstone serves admirably as a guide in marking approach to the upper limit of the formation. Usually it is fine grained and of a yellowish or buff color. With this exception all the beds are shales.

Correlation: The correlation of the Labette with the Kansas section is perhaps as simple as that of any other formation in the lower Pennsylvanian of the region. Few fossils have been found and these have not been determined but the data at hand show that the Labette as here defined is practically the equivalent of the Kansas formation of the same name. It should be clearly understood, however, that with this, as with other formations here discussed, sufficient data are not at hand to make final statements on correlation; but that here given, will, in the judgment of the writer, eventually prove in the main correct.

Oologah Formation

The Oologah formation includes all rocks lying above the Labette shales and below the Nowata shales. The term was first used by Drake (19) for the massive limestone so well exposed on the west bank of the Verdigris River at Oologah and known as the "Big Lime" among drillers. The name has also been used by Adams, Siebenthal and others.

Area: Just south of the Kansas line the Oologah formation occupies a belt about ten miles wide, but this width decreases southward along the west bank of Big Creek to the Verdigris River northeast of Nowata. From here to the southern limits of the Nowata quadrangle it occupies a narrow band on the west bank of the river, but near Oologah the western limit recedes and the belt becomes some six or seven miles wide opposite Claremore and near Catoosa; narrows again northwest of Broken Arrow and so continues to the

Arkansas River. Near this stream the limits of the formation are poorly defined, the limestone giving way to shales and sandstones which can be separated from those above and below only with difficulty. The lines on the accompanying map are largely hypothetical south of Broken Arrow.

Thickness: The thickness of the Oologah, by measurement, in the type locality is about 100 feet. This is approximately the same as that given by well logs in the region. Exposures northwest of Nowata show 80 feet, the upper part being removed by erosion, while at the Kansas line a thickness of about 145 feet is shown.

Stratigraphy: The stratigraphy of the Oologah formation presents some interesting and unique features. Near Oologah the whole is a succession of bluish, cherty limestone beds, separated by thin bands of black, fissile shale. Except where exposures are sharp, however, the shale cannot be detected and the whole may be regarded as a limestone. Near Broken Arrow the surface fragments show a considerable content of silica, and these fragments may be, and have been, mistaken for sandstone, the buff color being common in the sandstones of the region.

Near Talala the limestone is split by a black, fissile, carbonaceous shale, which is well seen on Talala Creek just east of the railroad. This shale thickens slowly to the northward and is seen to be continuous with the Bandera shale of Kansas. This feature of a limestone splitting to the northward is unique in the region and was first discovered by Adams who says: (20) "From the vicinity of Oologah the formation was traced northeastward to the Kansas line. It is conspicuous along the Verdigris east of Nowata all the way to the Kansas line. In this interval there are two limestones separated by an interval of shale which thickens northward until it is approximately 100 feet on the head of Big Creek. The upper member of the limestone was determined by Bennett to be the equivalent of the lower member of the Parsons formation, as mapped and defined by Adams. The equivalency of the lower member of the Oologah has not been definitely determined. It is not impossible that it may prove to be a continuation of the Pawnee."

The writer finds that Adams was correct in thinking the lower limestone to be the continuation of the Pawnee of Kansas. It makes a prominent escarpment along the west bank of Big Creek and is the lower of the two making the bluff

20. Bul. 211, U. S. G. S., 1903, p. 62.

along the Verdigris from Nowata to Oologah. It is a hard, massive, bluish limestone, with a rather high content of silica and yields abundant chert fragments on weathering. The thickness is fairly constant being usually about 30 feet, while that of the Pawnee in Kansas varies between 8 and 52 feet. (21) Such variation in Kansas is said to be due to erosion of the upper surface, but this has not been observed in Oklahoma.

The shale lens, as already stated, increases in thickness from nothing at Oologah to about 100 feet at the Kansas line. Four miles northeast of Nowata the following section of the entire formation was made:

6. Bluish limestone	2 to 10 feet
5. Bluish to black shale.....	35 feet
4. Massive, fine-grained limestone.....	6 feet
3. Black, carbonaceous, fissile shale.....	5 feet
2. Bluish limestone, shaly in lower part.....	14 feet
1. Black shale, base not seen.....	11 feet

In the above section No. 1 is the top of the Labette. Nos. 2, 3, and 4 are the lower or Pawnee limestone. No. 5 is the Bandera lens, while No. 6 is the lower part of the upper limestone of the formation, the upper part having been removed by erosion.

The shale lens is fairly homogenous throughout. It is generally a blue or black clay shale, slightly arenaceous in places and is greenish or somewhat yellowish on weathering. Sharp exposures are rare, fragments of the superjacent limestones usually effectually concealing it. The exposure northeast of Nowata shows an abundance of an undetermined species of a brachiopod of the *Streptorhynchus* type. Other than these the writer knows of no fossils from this shale in Oklahoma.

The upper part of the northern extension of the Oologah is continuous with the Altamont (Lower Parsons) of Kansas and the latter name has hitherto applied to it in Oklahoma. It forms an escarpment west of that caused by the lower part of the formation and is separated from it a half mile, more or less. As the intervening shale thins to the south, the two escarpments coalesce. Where the two are distinct, the outcrop of the upper part varies in width from one half to three miles in the northwest part of the Vinita quadrangle, to about two and one half miles opposite Watova. Near Nowata it con-

21. Haworth and Bennett, Univ. Geol. Sur. of Kan., Vol. IX, 1908, p. 83.

spires with the lower part to form the prominent bluff along the river.

The nomenclature of the continuation of this bed in Kansas is in a somewhat confused state. It was designated the Altamont limestone by Adams. (22) Later that author called it the Parsons limestone and said that it consists of two distinct ledges. (23) Evidently he changed the name because "The Altamont limestone is not well exposed in the vicinity of Altamont."

Schrader and Haworth, in 1906, adopted the nomenclature of Adams' later work and described under the name Coffeyville a thick series of heterogeneous strata lying above the Upper Parsons. (24) (25)

Still later Haworth and Bennett (26) returned to the name Altamont as applying to the lower part of Adams' Parsons limestone, while to the upper part they applied the term Coffeyville. Adams held that the two limestones unite to the northeastward while Haworth and Bennett maintained that they do not, but are separate and distinct entirely across the corner of the State.

The thickness of the Altamont in Kansas is given as "nowhere more than 10 feet." (28) Previously, Schrader and Haworth (29) had given 15 feet as the thickness in the Inde-

22. Kan. Univ. Geol. Sur., Vol. I, 1896, p. 22.

23. Bul. 211, U. S. G. S., 1903, p. 33.

24. Bul. 296, U. S. G. S., 1906, p. 16.

25. Note: It is obvious that the term Coffeyville as used by Haworth and Bennett can not hold since it was previously used in a vastly different sense by Schrader and Haworth. The same may be said of the term Walnut, which the former authors apply to the shales immediately overlying the Altamont. The name is pre-occupied in the Austin folio.

26. Univ. Geol. Sur. of Kan., Vol. IX, 1909, p. 85.

27. *Ib.*, p. 87.

28. Haworth and Bennett, Univ. Geol. Sur. of Kan., Vol. IX, 1908, p. 85.

29. Bul. 296, U. S. G. S., 1906, p. 16.

pendence quadrangle. The latter figure represents the average thickness in the northern extension in Oklahoma, but this increases southward till, as it coalesces with the representative of the Pawnee, it is not less than thirty feet.

The fauna of the Oologah formation is less prolific than that of the equivalents in Kansas. However, in both limestones, brachiopods and corals are fairly abundant. Representative collections have been made by A. C. Reeds, but a critical study has not been made. The shale lens, as above noted, contains, as far as known, only a few fossils. A closer study may reveal others.

Correlation: The correlation of the Oologah has already been indicated. Until a critical study of the fauna is made it is to be regarded as the equivalent of the Pawnee, Bandera and Altamont (Lower Parsons) of Kansas.

Nowata Shales

Lying above the Oologah formation and constituting the highest beds of the Tulsa Group, is a series of shales with a few interstratified sandstones and at least one bed of coal, for which the name Nowata shales is here proposed. The name is from the town of Nowata where the shales are widely exposed and well developed. It is used by Hutchison in his unpublished work.

Area: Near the Kansas line and east of the Verdigris River, the Nowata shales occupy but a narrow band between the escarpments of the subjacent and superjacent limestones. They also occupy irregular areas along Snow, Crow Hollow and Cedar creeks, generally lying on the slopes of elevations which are capped by the Lenapah limestone. West of the Verdigris they are first seen near the mouth of Hickory Creek three miles north of Lenapah, where, as shown on the map, they occupy but a narrow zone. The width of the outcrop at Nowata is two miles or more; is greater at Watova, and in the vicinity of Talala is five miles. In the Claremore quadrangle the width is still greater, the area being the most conspicuous in the quadrangle. East of Tulsa, it is eight miles, and not less than ten at the Arkansas River.

This belt is a broad, flat plain whose monotony of surface is broken occasionally by the effect of thin sandstones. South of Nowata the belt is united with that formed by the shales lying near the base of the Sapulpa Group, the Lenapah limestone offering but feeble resistance to erosion.

Thickness: The Nowata shales in their northward extension in Oklahoma are probably less than 50 feet thick, although Siebenthal gives the thickness as 55 feet near Coffey-

ville. At Nowata the drill shows that the thickness has increased to 130 feet. This increase continues until at Tulsa it is about 600 feet and probably still greater south of the Arkansas River.

For the most part the Nowata shales have no lithologic feature which is not possessed by others of the region. They generally are bluish or greenish in color, but give almost always, on weathering, a soil, green or buff according to the stage of oxidation of the iron. They are essentially clay shales but not infrequently are highly arenaceous.

Stratigraphy: The stratigraphy of the Nowata shales is simple. The lower part is almost wholly a mass of shale. Near Oologah a massive sandstone about three feet thick lies about 35 feet above the base. This makes a well marked scarp which can be traced for a considerable distance along the strike.

In the vicinity of the mouth of Rabb Creek other sandstones make noticeable escarpments but sufficient data are not at hand to say whether they are more than mere local lenses.

One of the most persistent stratigraphic features of the Nowata shales is a bed of coal. The most northerly point at which it was observed by the writer is about midway between Talala and Watova and two miles west of the railroad. From here southward, its outcrop follows a sinuous course passing just west of Talala and three miles west of Oologah. Outcrops are frequent near Collinsville where the coal is mined, as well as in the vicinity of Coal Creek and near Dawson whence it is usually called the Dawson coal.

In its northward extension the coal lies about 100 feet above the top of the Oologah limestone, or about the middle of the Nowata shales, and maintains this relative position somewhat persistently. Hence its outcrop lies about midway between those of the Oologah and Lenapah limestones.

The coal is from 20 to 30 inches thick and seems to extend far to the southward of the Arkansas River as shown by Taff. (30)

Correlation: The Nowata shales are at present to be correlated with the Walnut shales of Kansas. Whether the former are the exact equivalent of the latter, paleontological evidence must determine. But the limestones which limit the Nowata above and below are continuous with those which demark the Walnut shales in Kansas.

30. Bul. 260, U. S. G. S., 1905, pp. 396, 397.

SAPULPA GROUP

The name Sapulpa Group was proposed by Gould, Ohern and Hutchison for those rocks which in Oklahoma lie between the base of the Lenapah limestones and the lower limit of the Pawhuska formation as that term was used by J. P. Smith. (31).

The area of this group is about 40 miles in width and occupies a trapezoidal region covering all of Washington and a large part of Nowata, Rogers and Tulsa counties and the eastern half of the Osage Nation. The western part of this area lies beyond the region under discussion. In the eastern part the writer finds it impossible to adopt any line that can be readily followed in the field from the Kansas line to the Arkansas River. The limestones and sandstones are lenticular, the former thinning out in both directions and the latter disappearing to the north. For this reason the only feasible plan for this discussion seems to be to consider the northern and southern parts separately; and inasmuch as final publications will in all probability be in folio form it seems best to let the latitude of the Nowata-Claremore quadrangle line be the approximate line of division between these arbitrarily constructed parts. Fortunately, the situation in the field makes this line a somewhat natural one. Two limestones are confined to the north of it and a third to the south, all serving admirably as limits of mapable units. The northern of these two areas will be considered first.

THE NORTHERN AREA

Lenapah Limestone

The term Lenapah limestone is here proposed for a conspicuous limestone which lies at the base of the Tulsa group, occupying the interval between the Nowata shales and the Curl formation. The name is from the town of Lenapah in Nowata county where the limestone is typically developed and widely exposed.

Area: The area occupied by the Lenapah limestone lies, near the Kansas line, entirely east of the Verdigris River. Making as it does a dip slope, the width of outcrop is here out of proportion to the thickness of the bed. It is the cap rock of most of the hills in the northeast part of the Nowata quadrangle. West of the river the first exposure worthy of note is on Hickory Creek three miles north of Lenapah. East

31. Jour. Geol. Vol. II, 1894, p. 199.

of this town it is widely exposed. Thence it extends to Delaware and south to Nowata where it is to be seen capping the bluff in the west part of the town. Most writers speak of it as disappearing here but the writer and his assistants succeeded in tracing it to Tulsa. However, south of Nowata its area is a mere line as shown on the map, and while the exposure is by no means continuous, enough outcrops can be seen to map it with considerable accuracy. In the southern part of the Nowata quadrangle it is seen west of Rabb Creek and on both banks of Buck Creek.

Thickness: In southern Kansas the thickness of the equivalent of the Lenapah is given as 8 to 10 feet. (32) In northern Oklahoma it is not less than 20 feet. This is the approximate thickness in the quarry 3 miles north of Lenapah. At Nowata this thickness has decreased to about 6 or 8 feet. South of Nowata a thickness of more than 30 inches has not been observed and this is maintained with little variation to Tulsa and beyond. Considering its thickness this limestone is remarkable for persistency.

The lithologic character of the Lenapah is very constant. It is, when unaltered, a dense, blue, partly crystalline limestone, usually containing an abundance of fossils, especially of brachiopods. On weathering it gives little or no chert, thus differing markedly from similar beds below it.

Stratigraphy: The stratigraphy may be summed up in the statement that the limestone consists of a single bed. In the northern part of the Nowata quadrangle there are a few inconspicuous beds of shale but south of Nowata these are absent.

Correlation: All data at hand go to show that the Lenapah limestone is the approximate equivalent of the Upper Parsons of Adams and of Schrader and Haworth in Kansas, which is the Coffeyville of Haworth and Bennett. (33) What the equivalency beyond Coffeyville is, I shall not attempt to say, as the synonymy is in deplorable shape and each succeeding contribution seems to contribute to the difficulty rather than to its solution.

Curl Formation

Lying above the Lenapah limestone is a series of shales and sandstones for which the name Curl formation is here proposed, the name being taken from Curl Creek in the Nowa-

32. Haworth and Bennett, Univ. Geol. Sur. of Kan., Vol. IX, p. 87.

33. Univ. Geol. Sur. of Kan., Vol. IX, 1908, p. 87.

ta quadrangle along which the formation is well exposed and typically developed. It applies to all strata lying above the Lenapah and below the Hogshooter limestone.

Area: The area occupied by the Curl formation averages about 6 miles in width, the maximum being 10 miles. It extends in a broad, conspicuous band from the Kansas line near Coffeyville south and somewhat west past Lenapah, Delaware, Nowata and Oglesby to the west-central part of the Nowata quadrangle.

Thickness: The thickness of the Curl is not easy to ascertain on account of the difficulty of determining the precise dip on the one hand, and of lack of faith in the interpretation of well logs on the other. However, careful estimates give a thickness of about 300 feet from the northern Oklahoma line south to the latitude of Nowata or somewhat beyond. In the southern part of the Nowata quadrangle the thickness seems to be somewhat in excess of this figure. These estimates would indicate that the formation has about the same thickness as the equivalents in Kansas.

Stratigraphy: The lower part of the Curl formation is a mass of homogeneous clay shale of bluish or greenish color. On weathering the usual yellow or greenish soil results, covering vast flat areas on the eastern side of the belt described above.

In the upper part of the formation sandstones appear just south of the Kansas line and increase in thickness southward. These conspire with the Hogshooter limestone to form the prominent scarp which lies at or near the western limit of outcrop. It is probable that there is but one of these sandstone beds which is seemingly only a few feet thick; but because of its massiveness, the abundance of fragments and topographic effect are out of all proportion to the thickness of the bed. In the southern part of the Nowata quadrangle the sandstones are present but inconspicuous, partly owing to the thinning out of the Hogshooter limestone.

Correlation: The Curl formation is continuous with those formations which in Kansas lie between the top of the Parsons of Adams (Coffeyville limestone of Haworth and Bennett) and the base of the Drum. These formations are, Pleasanton shales, Bethany Falls limestone, Ladore shales, Mound Valley limestone, Galesburg shales, Dennis limestone, Cherryvale shales. (34) These or their equivalents comprise the Coffeyville formation of the Independence quadrangle. (35)

34. Haworth and Bennett, Loc. cit. p. 88 et seq.

The lower part of the Drum of Kansas being continuous with the Hogshooter of Oklahoma, the Curl formation must be considered tentatively the equivalent of the above formations.

Wann Formation

The term Wann formation is proposed for a series of shales, sandstones and limestones which occupy the interval between the top of the Curl formation and that of the Stanton limestone as that term is used by Haworth and Bennett. (36) It is the youngest formation in the Nowata quadrangle with the exception of some small areas which will not be discussed. It is composed of three members, the Hogshooter limestone member, the Copan member and the Stanton limestone member.

Hogshooter Limestone Member

This name is proposed for the limestone which lies immediately above the Curl formation in the Nowata quadrangle. The name is from Hogshooter Creek along whose west bank the limestone is well exposed.

Area: The area occupied by the Hogshooter limestone enters Oklahoma from Kansas about two miles west of Coffeyville. It re-enters that state several times before crossing Opossum Creek. Thence it continues as a narrow band south to a point opposite Delaware. In the northeast corner T. 26 N., R. 14 E., it spreads over a wide area, making a dip slope westward to Hogshooter Creek and continuing down the west bank of that stream. It crosses Caney River 3 miles northeast of Ochelata and extends due south to Ramona. Here it may be seen in the railroad cut at the section line south of the village. It is traceable to the southern limits of the quadrangle but has not been positively identified beyond. Near Ramona it is so thin that its area is a mere line.

Thickness: The thickness of the Hogshooter at the state line is about 10 feet. (37) To the southward it thins slowly, being 6 or 8 feet along Hogshooter Creek and 4 feet at Ramona. At the extreme southern limits of the Nowata quadrangle it is not over 3 feet and is thin bedded. In the valley of Opossum Creek it is almost wholly concealed by fragments of the sandstone above, but careful search always reveals its presence.

35. Schrader and Haworth, Bul. 296, U. S. G. S., 1906, p. 14.

36. Loc. cit. p. 104.

37. cf. Schrader and Haworth, Bul. 296, U. S. G. S., 1906, p. 14.

Stratigraphy: The Hogshooter consists essentially of a single bed of limestone. This in its northern extension is heavily bedded and massive but to the southward it is thin bedded and argillaceous. Usually fossils are fairly abundant.

Correlation: Considerable confusion exists as to the identity of the Drum of Kansas in Oklahoma, no less than four different limestones in the latter State having been correlated with it. Careful detailed mapping shows that the Hogshooter, as here defined and as shown on the map, is continuous with the lower part of the Drum. The upper part so far as known disappears just south of the Kansas line. This point will again be taken up under the discussion of the Dewey limestone lentil.

Copan Member

Lying between the Hogshooter and Stanton limestones is a thick succession of shales, heavily bedded sandstones and limestone lentils of which two are very conspicuous. For this series the name Copan is proposed from the town of that name in the vicinity of which the member is widely exposed. The name is not intended to apply beyond the limits of the Nowata quadrangle.

Area: Near the Kansas line the Copan beds outcrop over an area about 12 miles wide. The extreme width is not due to thickness alone but also to the fact that for about two-thirds of the distance the beds form essentially a dip slope westward to Little Caney River. Should the western limit be prolonged into the Pawhuska quadrangle the width of the outcrop would probably be less. From Dewey southward the Dewey limestone lentil breaks the monotonous succession of shales and sandstones. The member occupies practically all the region around Dewey, Bartlesville, Ochelata and Ramona.

Thickness: To the northward, careful measurements of the Copan gave a thickness of 250 feet near Wann. This is nearly the same as that shown in drill holes farther to the southwest, although a slight increase is shown. It is about the same as the thickness of the equivalents in Kansas. (38)

Stratigraphy: In the vicinity of Wann, the Copan beds show considerable thicknesses of fine-grained, massive sandstones in the lower part. The middle part is largely shale, which is well exposed on the slopes of the hills north and west of the village, and whose chief exposures lie between Coon Creek and Little Caney River. Three miles southeast of

38. Schrader and Haworth, loc. cit., p. 12.

Wann a bed of coal about 14 inches thick was observed lying about 50 feet above the Dewey limestone lens. Massive sandstones are prominent along Cotton Creek and along the 96th meridian south of Bartlesville. But the most prominent stratigraphic feature is certain limestone lentils which merit separate discussion.

Dewey Limestone Lentil

The most striking stratigraphic feature of the Copan beds is a lentil of limestone which is continuous and prominent from a point two miles east of Wann, south and west to and beyond the limits of the Nowata quadrangle. The name is from the town of Dewey where the limestone is admirably exposed in the quarry of the cement plant.

Where first seen, in the center of Sec. 13, T. 28 N., R. 14 E., the limestone is shaly and but 3 feet thick. Southward it thickens rapidly. It spreads over wide areas east of Dewey and Bartlesville, its continuity of outcrop being broken by the streams cutting through it and by concealment under isolated areas of superjacent shale. Outcrops are conspicuous about Bartlesville, especially at the bridge in the northern part of the city. By an anticline, the outcrop extends southwest of the city along the Missouri, Kansas and Texas Railway to and beyond the 96th Meridian. In the vicinity of Caney River it is quite concealed beneath alluvium. South of the river it occupies a narrow, sinuous band along Keeler Creek, circles east of Ochelata and is well exposed in North Fork one mile south of town. Continuing to the latitude of Ramona it unites with younger sandstones and limestones to form the prominent escarpments southwest of town.

As already mentioned, in its northern extension the lens is but 3 feet thick; at the cement plant at Dewey it is not less than 20 feet, the upper part being removed by erosion. In the vicinity of Ochelata and Ramona it is about 15 feet thick, although accurate measurements are difficult to obtain.

The Dewey lens is a bluish, semi-crystalline limestone, usually somewhat shaly but often massively bedded. On weathering it gives surface fragments which abound in seams of calcite which resist solution more effectually than the non-crystalline mass. Wherever examined the Dewey abounds in fossils, *Campophyllum torquium* being especially abundant. The interval between the Hogshooter and Dewey increases from 50 feet near Wann to about 100 at Ramona.

More confusion exists regarding the correlation of this limestone with others of the region and of Kansas than that of

any other formation in the area. Gould thought it continuous with the Drum, (39) as did also Hutchison in his unpublished work. Siebenthal believed the limestone quarried at Dewey to be the Piqua. (40) It has also been identified with the massive limestone at Avant, but this will be shown later to be above the Dewey; and further, the limestone at Lost City on the Arkansas River, 6 miles above Tulsa has been correlated with that at Dewey and Bartlesville. This also is incorrect, for, as subsequently shown, the limestone at Lost City lies far below the horizon of the Dewey.

Bennett was the first to discover that there are two limestones in the region east of Dewey. But he thought, after a somewhat hurried reconnaissance, that the upper one is continuous with the upper part of the Drum of Kansas. It is, however, impossible to establish any physical connection between the two, though a faunal study may show such relationship. At present the writer holds that the Dewey is above the horizon of the upper part of the Drum.

Avant Limestone Lentil

The term Avant limestone is here given to a lentil which lies about 85 feet above the Dewey along the 96th meridian south of Bartlesville. Certain exposures of this limestone in the hills about 5 miles south of that town are probably the most northerly extension of the lentil. It is fairly well developed in the three hills north of Ochelata and makes bold bluffs just southwest of the town along North Fork. The two hills south of town are due to a capping of the limestone. In the extreme southwest part of the quadrangle and in contiguous territory to the south, it caps the mesas and is the most effectual cliff-maker along the valleys. It extends west along Bird Creek to Avant, whence the name. Here superb exposures are offered and the typical development is to be found. Its southward extension will be given under the discussion of the southern part of the area.

Except west and southwest of Ramona as just noted, the area of the outcrop is a narrow band, so narrow that it is a mere line on the map.

In its most northern extension this limestone is only a few feet thick, but at Ochelata it is about 20 feet and the thickness increases southwest to Avant where the maximum

39. W. S. Paper, 148, U. S. G. S., 1905, p. 31.

40. Bul. 340, U. S. G. S., 1907, p. 195.

of 40 feet is attained as exposed at the quarry 2 miles southeast of the village.

The Avant in general character is very similar to the Dewey. It is a semi-crystalline limestone, of bluish color, often thin-bedded to the north but near Ramona and Avant it forms bold precipitous cliffs. The interval between the Avant and the Dewey is usually about 85 feet but near Ramona it is less than half the amount. The calcite seams so abundant in surface fragments of the Dewey are abundant here also. Fossils, too, are quite as common.

As above mentioned, the limestone at Avant has been correlated with the Dewey and with the Drum of Kansas. Careful mapping, however, shows these three are quite distinct each from the others. Nor is the massive limestone at Lost City in the same horizon. A faunal study may show the Avant to be related to one of the numerous ledges in Kansas but the data at hand show no such relationship.

Other Lentils

North and northeast of Wann are numerous exposures of thin beds of limestone which, so far as known, are not to be correlated with others of the region. At least two are present, separated by an interval of about 50 feet. The upper is strikingly oolitic, making in this respect a sharp contrast with others of the region. The lower is argillaceous and flaggy. Both are believed to be local.

Correlation: If the writer is correct in correlating the Hogshooter with the lower part of the Drum of Kansas and if, as indicated below, the Stanton of the writer is the equivalent of that of the Kansas geologists, then obviously the Copan is the equivalent of the upper part of the Drum limestone, Chanute shales, Iola limestone, Lane shales, Allen limestone and Vilas shales.

Stanton Limestone Member

The Stanton limestone of Kansas extends several miles into Oklahoma and the name will be retained. It was so named by Swallow. (41) Adams introduced the term Piqua (42) and this name was retained by Schrader and Harworth for the Independence quadrangle, (43) and also by Sie-

41. Prelim. Rep. Geol. Sur. of Kan., 1866, p. 20.

42. Bul. 238, U. S. G. S., 1904, p. 20.

43. Bul. 296, U. S. G. S., 1906, p. 12, and Independence folio.

benthal. (44) The Kansas Survey returns to the term Stanton. (45)

Area: The Stanton limestone outcrops on the slopes of the hills at and 2 miles west of Wann. Due north of the village it is well exposed on the slopes of the hills at, and extending three miles south of, the state line. Four miles southeast of Caney, Kansas, it is again exposed on the state line and also one mile south of that line on the hill just east of the Santa Fe railway. Good exposures are also offered on the four hills 2 miles north of Copan. But the best exposures in the region are on Twin Mounds 3 miles southeast of Copan where twelve feet of limestone caps the hills. Considering that these hills are so conspicuous, it is strange that no mention is made of these exposures in the literature.

West of Little Caney Creek, the northernmost exposure of the Stanton is seen three miles south of the state line and one mile west of the creek, alluvium covering it north of this point. It extends along the brow of the bluff south 4 miles, and west into the Pawhuska quadrangle in the middle of T. 28 N. The bluff re-enters the Nowata quadrangle south of Caney River and the limestone lies somewhat above the middle of the slope. The peaks 3 miles northwest of Bartlesville offer sharp exposures.

Along these bluffs the fragments of superjacent sandstones usually effectually conceal the limestone but it can always be found if diligent search is made.

So far as the writer knows, the Stanton has not been detected south of the latitude of Bartlesville and it probably disappears near the last point named.

The exposures of this limestone have thus been given somewhat in detail, first, because it has sometimes been considered as not extending into Oklahoma and, secondly, because it forms the most convenient horizon marker in the entire northwestern part of the Nowata quadrangle.

The bluffs along the 96th meridian south of Sand Creek are due to ledges lying below the horizon of the Stanton. Early in his work, the writer discovered that the continuity of the bluff south of Ochelata to Tulsa and beyond, is due to successively lower ledges which develop, become cliff-makers and, giving way to others, swing to the westward. C. D. Smith, of the United States Geological Survey, pointed out to

44. Bul. 340, U. S. G. S., 1908, p. 195.

45. Univ. Geol. Sur. of Kan., Vol. IX, 1908, p. 104.

the writer that the same situation obtains north of Ochelata to the Kansas line. This peculiar relationship of resistant strata to topography has been the chief cause of several erroneous correlations of limestones.

Thickness: The Stanton at the Kansas line is said to be only 1 or 2 feet thick. (46) The writer and Wolf, however, found it to be about 8 feet and fairly constant. On the Twin Mounds it is more than 12 feet, the upper surface having been removed by erosion. Northwest of Bartlesville it is 3 or 4 feet.

As seen in Oklahoma, the Stanton is a massive, bluish limestone always abounding in fossils. It gives little chert on weathering. Near the state line it is often highly arenaceous and not infrequently oolitic. Southward it becomes argillaceous and flaggy.

Correlation: The Stanton, as above discussed, is in many places continuous with exposures in Kansas. The writer feels little hesitancy in referring all exposures above given to a single ledge. The physical and paleontological characters all point to this and there is but little doubt that a critical study of the fauna will confirm it.

Higher Rocks.

As shown on the map, small areas of rocks above the Stanton exist in the northwestern part of the Nowata quadrangle. These are chiefly on the summits of the hills mentioned in connection with the Stanton limestone, and along the 96th meridian north of Bartlesville. Since quadrangle limits, however, are only incidental in this discussion and since the United States Geological Survey has studied the contiguous territory to the west, and will, no doubt publish shortly, it is the part of wisdom as well as of courtesy to close this part of the discussion with the Stanton.

THE SOUTHERN AREA

The stratigraphy above the Lenapah limestone and between the Arkansas River and a line approximately coincident with the Claremore-Nowata quadrangle line, is markedly different from that of contiguous territory to the north. Hence it has been found necessary to establish different formations.

Skiatook Formation

The term Skiatook formation is proposed for those rocks

46. Schrader and Haworth, Bul. 296, U. S. G. S., 1906, p. 12.

which lie between the top of the Nowata shales, or the base of the Tulsa Group, and the base of the Ramona formation. This name is not intended to apply except between the north and south limits just given. The name is from the town of Skiatook in the northwest part of Tulsa County where the rocks outcrop over wide areas. Hutchison used the name in his unpublished work but in a slightly different sense.

Area: As shown on the map, the Skiatook formation occupies a wide zone in the northwest part of Tulsa County and extends southwest across the southeast part of the Osage Nation to the Arkansas River. This zone is 5 miles wide on the north but widens rapidly southwestward, partly owing to increase in thickness of the formation and partly to topography. The streams flow approximately along the line of dip, and along the valleys of Bird Creek and the Arkansas River the zone is no less than 15 miles wide, but much less on the divides.

Thickness: In the northwestern part of the Claremore quadrangle the Skiatook formation has a thickness of 250 to 300 feet. But along the Arkansas River it is probably not less than 500 feet although accurate measurements are lacking. This increase southward is seemingly due to the thickening of the sandstones.

Stratigraphy: Lying at the base of the Skiatook formation is a bed of dense, massive, bluish limestone, the southern extension of the Lenapah. It is well seen in the railroad cut one mile southwest of Vera; in several places on Secs. 2 and 17, T. 21 N., R. 13 E.; along the head waters of Rock Creek north of Tulsa; at the triple railway crossing in the northeast part of Tulsa; on the north bank of the Arkansas River just west of the Santa Fe bridge; and in many other places, though the outcrop is by no means continuous.

The greater part of the formation is composed of shale. A thickness of approximately 150 feet lies immediately above the Lenapah limestone. These beds outcrop in the western part of the broad flat plain stretching northeast from Tulsa, the eastern part being underlain by the Nowata shales. In the upper part of the Skiatook, heavy beds of sandstone come in and thicken enormously from north to south, thus throwing the upper contact line far to the west. These sandstones are exposed on the slopes of the hills in the vicinity of Hillside where the surface is in places covered with boulders of considerable dimensions. Across the valleys to the southward the sandstones seem less prominent, whether from decrease in thickness or from topographic causes does not appear. But

south of these streams the sandstones thicken at an astonishing rate and are very massive, making bold, rugged cliffs in the southeastern part of the Osage Nation toward Tulsa. Exposures along the Arkansas River show no less than three of these sandstones. In the hills to the north of the river single beds 85 feet thick are exposed.

A very prominent feature of the stratigraphy of the Skiatook is a limestone lens which is best exposed at Lost City on the south side of the Arkansas river 6 miles above Tulsa. Here a thickness of 40 feet is shown at the quarry. On the north bank of the river the writer did not see any exposures, alluvial deposits covering the slope to a considerable height above the present river bed, but Hutchison reports its presence. To the northward the limestone thins rapidly. On the Tulsa Road 8 miles northwest of the city, it is but 6 feet thick and about the same in the hills 6 miles north. The upper part in these latter places is essentially a crinoidal limestone. In the hills just mentioned the limestone is almost always concealed by fragments and boulders of a massive sandstone which lies a few feet above it.

As previously noted, this limestone has been correlated with the Avant, the Dewey and the Drum. To attempt a correlation with data at hand is hazardous to say the least. It seems on stratigraphic grounds to lie at about the horizon of the Hogshooter but any further statement would be a mere guess.

Correlation: Until paleontological data are secured for the correlation of the Dewey limestone, that of the Skiatook can be given only in general terms. Evidence at hand indicates that the Skiatook is the equivalent of the Lenapah limestone, Nowata shales, Hogshooter limestone and the lower 50 feet more or less of the Copan, of the northern part of this region. Of the Kansas section, then, it is roughly the equivalent of the Coffeyville limestone, Pleasanton shales, Bethany Falls limestone, Ladore shales, Mound Valley limestone, Galesburg shales, Dennis limestone, Cherrydale shales, Drum limestone and 50 feet more or less of the Chanute shales. (47)

RAMONA FORMATION

The name Ramona is here applied to those strata which lie between the top of the Skiatook formation and that of the Avant limestone. The name is from the town of Ramona in

47. Haworth and Bennett, Univ. Geol. Sur. of Kan., Vol. IX. 1908, pp. 87-98.

the southwest part of Washington County. In the hills just southwest of the town superb exposures are to be seen and here the formation exhibits its typical development.

Area: In the extreme northwest corner of the Claremore quadrangle the Ramona formation shows its widest outcrop. In the hills the superjacent strata have been removed and the upper limestone member caps many of the mesas, while the middle shale lies on the slopes and the lower limestone at or near the base. The outcrop thence extends as a narrow band westward to Avant. The limestones of the formation should here not be confused with others of which there are several and which occur higher up. After crossing Bird Creek the outcrop extends, as a mere ribbon but sharply defined, southwest to the bluffs on either side of the Arkansas River one mile west of Wekiwa. The low dip causes the outcrop to extend far up the river, the point of crossing not being known, but it is probably not far from the mouth of the Cimarron River. On account of lack of adequate maps, no attempt was made at detailed mapping in the Osage Nation.

Stratigraphy: The Ramona formation consists of three members, a lower and an upper limestone and intervening shales and sandstones. The limestone members are continuous with the Dewey and Avant lenses, respectively, of the northern part of the region and the names will be retained. Since the beds are constant concomitants they are best discussed together.

From a point about one mile west of Skiatook southwest to the Arkansas River, the formation makes a well defined escarpment. The Dewey limestone usually lies at the base and the Avant at or near the top. The best exposures in the southern extension are to be seen north of the school house of district number 52; here the Dewey makes, in Rock Creek, a beautiful little cataract known as Limestone Falls, while the Avant is conspicuously exposed in the bluff one-half mile further north. The former has in this vicinity a thickness of 6 feet to 8 feet. It is frequently highly arenaceous and can, in several places, be seen lying immediately on the sandstone of the Skiatook. The Avant member is about 12 feet thick on an average but this thickness decreases southward. An almost constant lithologic feature is its highly ferruginous aspect. Frequently large red boulders, which contrast sharply with associated rocks, can be seen adorning the slopes. This ferruginous character is mostly only superficial. Both the limestones and especially the Avant, carry abundant fossils, some being of a distinctly Permian aspect.

The term Ochelata, from the town in southern Washington County, is applied to the middle member of the Ramona formation. It consists largely of shale but a persistent sandstone, varying in thickness from 5 to 12 feet, lies somewhat above the middle of the shale. The thickness of the whole member is about 85 feet on an average; but west of Ramona it is but 20 feet.

Thickness: The total thickness of the Ramona is not far from 100 feet. Several measurements north of Hillside gave approximately this figure, and the southern extension varies but little from this.

Correlation: In the absence of paleontological data an attempt at a correlation is hazardous. However, a few remarks of an extremely general nature may not be out of place.

If, as above noted, the Skiatook includes some 50 feet of the Chanute shales, then it is not improbable that the Ramona may be the equivalent of the remainder of the interval to the top of the Allen limestone of the Kansas section. Further, it may be regarded as not improbable that the Dewey may be eventually correlated with the Iola, and the Avant with the Allen.

CORRELATION

In the discussion of the several formations, the correlation of each has been indicated. The grounds upon which these correlations have been made are: continuity, similarity of stratigraphic sequence and lithologic similarity. The limestones are usually very fossiliferous but the fossils have not been studied. It remains, therefore, to be seen whether paleontological criteria will confirm correlations made on other grounds. Moreover, lithologic character being variable, one is dependent almost wholly upon criteria afforded by continuity and similarity of sequence. To speak of continuity is to speak of that of the limestones. In field operations the continuity of one of these beds being established, that of associated clastic rocks is taken as a consequence.

The attached table gives a summary of correlations, both with the Kansas sections and those made by various workers in Oklahoma. While it is not to be hoped that future investigations will necessitate no change, the writer believes that the major features will prove to be correct. In the construction of the correlation table, free use has been made of in the Independence folio.

CONDITIONS OF SEDIMENTATION AND SOURCE OF SEDIMENTS

It has been shown above that shales comprise by far the greater part of the sediments of the region. The few fossils contained in them are marine. These shales thicken to the southward and eventually give way to sandstones.

As shown by Gould, Ohern and Hutchison, (48) there are fewer limestones in Northern Oklahoma than in southern Kansas. Of those herein discussed few extend to the Arkansas River and only one or two beyond. All carry marine fossils.

The sandstones show a very pronounced thickening to the southward. Many show abundance of ripple marks and other evidences of shallow water conditions. Those in the Wann and Ramona formations frequently carry remains of marine organisms. Fossils are abundant in sandstones just above the youngest formations just described.

The presence of coal and carbonaceous shales shows swamps or shallow water. The fact that these coal beds, although thin, are usually of considerable extent along the strike, shows that the conditions under which the coal accumulated obtained over considerable areas.

From these and other considerations it is evident that the sediments accumulated in shallow sea and possibly on tidal flats. Rapid alternations of shales, limestones and sandstones, as exemplified in the Claremore formation, show frequent minor changes of conditions, probably caused by oscillations of the sea bottom.

The thinning of the limestones, the striking development of the arenaceous constituents, the thickening of the whole series to the southward points to land in that direction.

It is worthy of note, however, that there is a greater total thickness of limestone in an east-west zone some 25 miles wide, whose northern limit runs approximately from Dewey to Nowata and beyond, than there is at the Kansas line. This, however, does not invalidate the general statement that limestones thin southward.

Taff has shown (49) that early in Pennsylvanian time the Arbuckle mountains were uplifted and were subjected to erosion till after the beginning of Permian time. The term Arbuckle Mountains should not be understood as applying mere-

48. This series No. 3.

49. Folio No. 98, U. S. G. S., 1903, P. P. 31, U. S. G. S., 1901.

ly to the restricted area now standing above the surrounding plain. The whole uplift is tilted gently southeastward and the extension is concealed in that direction by Cretaceous sediments. How far the area subjected to erosion in late Palozoic time extends beneath these later sediments it is impossible to say. But all evidence points to a considerable land mass in the present southern Oklahoma and northern Texas. In discussing the Pennsylvanian and Permian Red Beds of Oklahoma Beede remarks that "The Arbuckle and Wichita mountains are probably the source of much of the red sediment, in which they are partially buried, and the former mountains are directly responsible for the eastern extension of those beds into central Oklahoma." (50) I see no reason for thinking the underlying lighter colored sediments came from a different source. At the same time it may be questioned whether the land mass, as it is believed to have existed, was large enough to supply the enormous thicknesses of shales and sandstones deposited in central Oklahoma and northern Texas in Pennsylvanian time. This point gains force when it is remembered that as Pennsylvanian time went on, the area of denudation was gradually lessened by encroaching sea.

If the Arbuckle mountains were the source of these beds, and if the lower limit of the Oklahoma Red Beds has been correctly mapped (51) one would expect that the line would lie at successively lower stratigraphic levels when followed southward. Such, however, seems not to be the case. On approaching the mountains, the line seems to rise stratigraphically. Personally I think there is considerable evidence in support of the view that much of the Pennsylvanian sediments of central Oklahoma were laid down in a large estuary whose axis lay well to the north of the Arbuckle mountains. Sufficient information is, however, not at hand to substantiate this statement.

50. Jour. Geol. Vol. XVII, 1909, p. 714.

51. See this Series No. 3, Pl. I.

University Geological Laboratory, April 20, 1910.

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TABLE OF FORMATION NAMES, SOUTHEASTERN KANSAS AND NORTHEASTERN OKLAHOMA.

EASTERN KANSAS, SWALLOW, 1898.	SOUTHEASTERN KANSAS, HAWORTH AND KIRK, 1894.	SOUTHEASTERN KANSAS, HAWORTH, 1896.	NORTHEASTERN OKLAHOMA, DRAKE, 1897.	SOUTHEASTERN KANSAS, HAWORTH, 1898.	SOUTHEASTERN KANSAS, Adams, Girty and White 1903.	IOLA QUADRANGLE, Adams, Haworth and Crane, 1904.	INDEPENDENCE QUADRANGLE, Schrader and Haworth, 1907-8.	NORTHEASTERN OKLAHOMA, NORTHERN AREA.	OHERN, 1910. SOUTHERN AREA.
Stanton limestone series: Stanton limestone, No. 151; shales; sandstone; and coal.	Carlyle limestone. Leroy shales. Carlyle limestone. Shale. Iola limestone. Chunute shales.	Garnett limestone (?). Iola limestone. Thayer shales. Lane shales. Garnett limestone, Iola limestone, Carlyle limestone. Thayer shales. Iola limestone. Thayer shales.		Garnett limestone. Lane shales. Earlton limestone. Iola limestone. Thayer shales. Vilas shales.	Iola limestone. Vilas shales. Earlton limestone. Stanton limestone. Lane shales. Earlton limestone. Iola limestone. Chanute shales. Vilas shales.	Piqua limestone. Vilas shale. Allen limestone. Concreto shale. Iola limestone.	Piqua limestone. Vilas shale. Allen limestone. Concreto shale. Iola limestone. Chanute shale (upper part).	Stanton limestone member. Avant limestone lentil.	Avant limestone member.
Marais de Cygnes Coal Series.	Erie limestone.	Shale. Limestone. Erie limestone. Shale. Altmont(?) limestone; Bethany Falls limestone.	Poteau group	Erie limestone.	Drum limestone. Cherryvale shales. Dennis limestone. Galesburg shales (?). Dennis limestone. Galesburg shales. Hertha limestone.	Chanut shale. Bronson limestone. Dudley shale.	Drum formation. Coffeyville formation.	Hogshooter limestone member.	Skiatook formation.
Bethany Falls limestone, No. 160.	Laneville shales.	Pleasanton shales.		Pleasanton shales.	Upper Parsons limestone. Parsons limestone.	Denais limestone. Galesburg shale. Mound Valley limestone. Ladore shale. Hertha limestone.	Upper limestone. Shale. Lower limestone.	Lenapah limestone.	(Lenapah limestone).
Pawnee limestone series, No. 103.	Oswego limestone.	Pawnee limestone. Shale. Oswego limestone.	Cavendish.	Pawnee limestone. Labette shales. Oswego limestone.	Bandera shales. Pawnee limestone. Labette shales. Fort Scott limestone.	Bandera shale. Pawnee limestone. Labette shale. Fort Scott limestone.	Bandera shale. Pawnee limestone. Labette shale. Fort Scott limestone.	Oologah formation.	Oologah formation.
Fort Scott coal series. Fort Scott marble series. Lower coal series.	Cherokee shales.	Cherokee shales.	Lower Coal Measures. Lower Carboniferous.	Cherokee shales.	Cherokee shales.	Cherokee shale.	Cherokee shale.	Labette shale.	Labette shale.
Lower Carboniferous.	Mississippian.	Mississippian.		Mississippian or sub-Carboniferous.	Mississippian series.	Boone formation.	Boone limestone.	Boone limestone.	Boone limestone.

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