Art. XXXIII.—*Granite Bowlders in (?) the Pennsylvanian Strata of Kansas;* by W. H. Twenhofel.

Introduction.

From time to time granite has been reported from deep wells of different parts of east Kansas. On investigation many of the reported granites were found to be other kinds of rocks, or without basis in fact. In a few instances final judgment had to be reserved. The 1915 boom in oil development together with very conspicuous cases of granites reported from two wells near Zeandale, a small village about eight miles east of Manhattan, Kansas, brought so many inquiries to the Kansas University Geological Survey, and the possibility of encountering granites in drilling was having such a depreciative effect on further development, that Professor E. Haworth, the State Geologist, carefully investigated all of the reported cases of granite in order to definitely ascertain, if it were possible, whether such actually had been reached in any of the deep wells.*

In each of the Zeandale wells granite was reported at a stratigraphic level in the upper part of the interval between the Oread and Iola limestones. In one it was struck at nine hundred and fifty-eight feet and drilling was continued to one thousand and ninety-three feet without penetrating the granite, although curiously, the log of the well showed that thirty-two feet from the top of the granite the drill had passed through a twelve-inch bed of shale. In the other well granite was struck at nine hundred and forty-five feet and continued drilling encountered no lithic change. A careful examination of the cuttings which are said to have come from the wells showed unquestionable fragments of unweathered granite. Haworth's conclusions were to the effect that the granitic rocks which were derived from these two wells, and which perhaps had also been found in others, are probably firmly cemented sediments which came from rocks of a granitic character and, by way of illustration, he called attention to a rock of Tertiary age which occurs in Phillips County, Kansas, and is composed of firmly cemented granitic gravels derived from the Rocky Mountains. This rock resembles granite so closely that it has been quarried and used as paving blocks under that name.

During the field season of 1916, while examining territory in Wilson and Woodson counties in the interest of the Fredonia Gas Company, the present writer found granite bowlders which it is fairly certain came from Pennsylvanian strata.

* Haworth, Bull. 2, Kansas Univ. Geol. Sur., 1915.

The locality is in Eminence Township, Woodson County, about eight miles almost due south of Yates Center and one mile west and a half mile south of the Missouri Pacific Railway station, Rose, the locality being on the very headwaters of a small tributary of the Verdigris River, into which it empties about twelve miles to the southwest. The bowlders lie on the northern edge of a low hill which has been determined by a small anticlinal structure. A little valley extends almost entirely around the hill and beyond this valley other hills, immediately or ultimately, rise to higher elevations.

Since the occurrence is of interest not only because of the rocks themselves, their stratigraphic position and the geological history they reveal; but because their presence may help to explain the finding of granite in deep wells, a description of the lithology of the bowlders, of their manner of occurrence and of their relation to the strata with which they are associated is warranted. The facts will be given in considerable detail because of the uniqueness and importance of the subject.

The distribution, characteristics and lithology of the bowlders will first be given. This will be followed by an examination of every possible way by which the bowlders might have attained the positions where they are found. Then will be considered their stratigraphic position and a conclusion will be sought which satisfies the available data. Lastly, various deductions will be developed from the conclusions which have been reached.

For assistance in the field study of the bowlders, the writer is extremely grateful to one of his students, Mr. E. M. Stryker of Fredonia, Kansas, and also to Messrs. C. V. LaDow and Maurice Stryker of the same place, since it was largely through the aid of these three men that the territory within a radius of from ten to fifty miles of the place of occurrence of the bowlders was able to be examined.

Areal Distribution and Size of the Bowlders.

The bowlders are distributed over an area of about one hundred and twenty acres which are so placed that eighty acres in a tract eighty rods wide lie on the west side of the north–south road and forty acres on the opposite side of the road in a tract of the same width. Most of them and also the largest occur on the southwest twenty acres (1 on the map), where the greatest number are found on four low mounds or elevations which rise from four to six feet above the general level of the surface. The most western mound is the largest and highest and has an area of about an acre, and it also has the bowlders in far greater abundance than elsewhere. They are

FIG. 1.

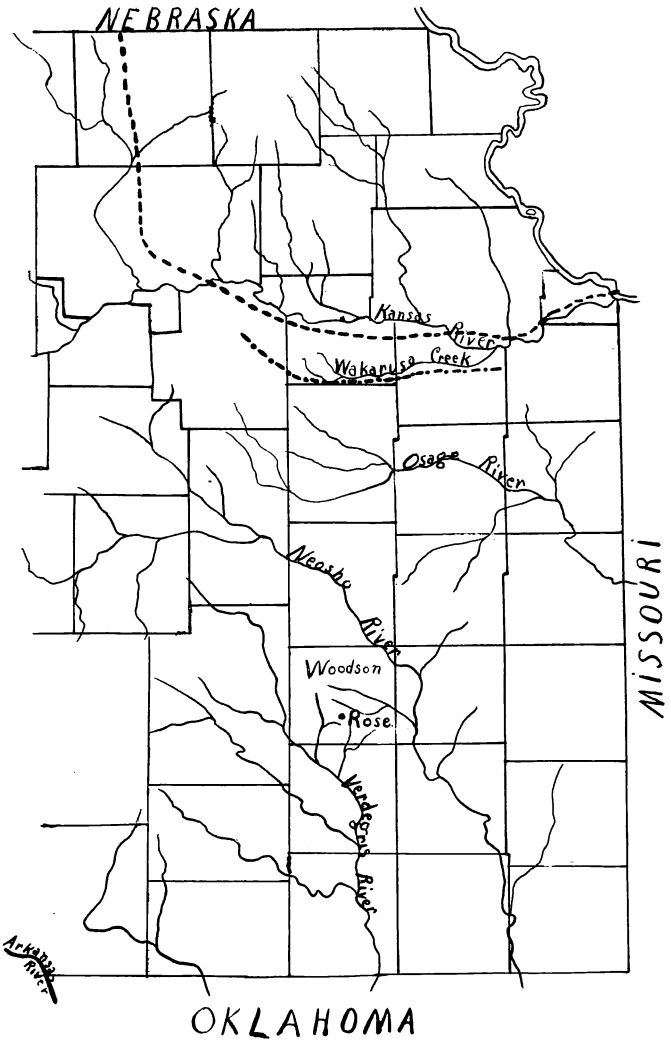

FIG. 1.—Outline map of eastern Kansas, showing the position of Rose and its relation to other parts of Kansas. The dashed line shows the approximate position of the southern limit of the Kansan ice sheet. The dot and dashed line shows the position of the southern limit of Kansan glacial bowlders. Glacial data are taken from Todd, Trans. Kan. Acad. Sci., vol. xxiv, 1910, pp. 211–218, and Science, vol. xxxix, Feb. 1914, pp. 263–274.

so numerous on this mound that about one-fourth of the surface is covered and they have made impossible its cultivation, so that at present it is given over to the growth of bushes, and such appears to have always been the case. None of the other mounds contains a twentieth as many bowlders as does this. In addition to the larger mounds, there are about a half dozen others of much smaller height and area which have not been mowed or plowed because of projecting bowlders. These smaller elevations are situated between and for about a hundred feet on either side of the larger and they also extend much

FIG. 2.

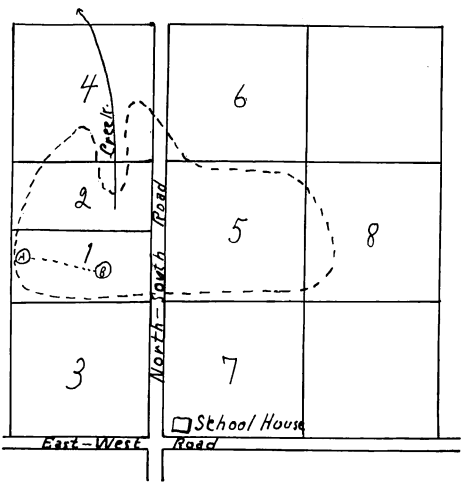

FIG. 2. Outline map of the region of the bowlders. Each square represents forty acres. The section on the right of the north-south road is T. 26 S., R. XVI E., S. 18, Eminence township; while the area on the left is in T. 26 S., R. XV E., S. 13. The area within the dashed line carries bowlders which appear to be in approximately natural position. The large mounds extend from A to B, A being the position of the most western mound.

farther east, but there are none toward the west. The four largest mounds are aligned in a direction a little south of east and they extend through about a thousand feet. The alignment coincides with the outcrop of the shales with which the bowlders are associated.

The most western of the large mounds has a dozen or more bowlders with diameters of about four feet and there are probably between fifty and a hundred that are more than a foot and a half in diameter. The largest bowlder observed is on one of the smaller mounds and it has a diameter of nearly seven feet.

Every one of the mounds owes its origin to the resistance of the bowlders as compared with the resistance of the surrounding and underlying rock, the former having been eroded away, while the latter was protected. It should be noted, however, that one of the larger mounds has no bowlders on it, but there are no reasons for disbelieving that they were once there, and have either crumbled under the forces of weathering, or perhaps some of the people of the region hauled them away. On this mound, the shales are at the surface.

The twenty acres due north of the tract just considered (2 on the map) were lower down the slope and hence lower in stratigraphic position. Through a portion of the northern edge a small creek has cut through the shales associated with the bowlders and has reached the underlying Stanton limestone. Bowlders, some of which are more than a foot in diameter, are scattered over the slopes on which the shales outcrop and a few are present in the bed of the small creek, where it is clear they were thrown to dispose of them. On the road to the east, where the land is nearly as high as at the mounds, several have been plowed out in the grading. There are not nearly so many bowlders on this tract as on the twenty acres due south.

On the forty acres to the south of the twenty first considered (3 on the map) bowlders are very rare. There are probably not a dozen on the whole tract; every one is small, none weighs over a pound, and there is little doubt that man is responsible for their occurrence on this field. On the forty acres to the north (4 on the map) granite bowlders up to eighteen inches in diameter occur quite thickly scattered over parts of the higher land on the southern side and are most abundant on the southeast corner of the area. On this corner the soil is extremely thin in many places and in some places it is altogether wanting and the shales, thickly studded with small granite bowlders, are at the surface. The small creek, which has already been noted, flows through this tract and has the Stanton limestone exposed in its bed. A few granite bowlders are present in the creek bed, but it is quite evident that they were thrown there to get rid of them.

It is possible that there was at one time an extension of the bowlders to the west, since from the top of the largest mound there is a comparatively rapid descent—a grade of five to six per cent—to exposures of the Stanton limestone which outcrops about three hundred feet beyond the western edge of the mound. No bowlders, however, are present within about one hundred and fifty feet of the outcrop, so that it is quite probable that the bowlders in their distribution ended abruptly westward.

On the forty acres east of the road (5 on the map) small granite bowlders are not uncommon and a few large chunks were seen in the hollows and hedges where it is clear they had been thrown. No one of these exceeded a weight estimated at twenty-five pounds. The forty acres to the north (6 on the map) has the Stanton limestone over most of its area as the surface rock and, save for the southwest corner, no bowlders are present, while the tract of forty acres to the south has a very few small ones and these were probably carried through human agencies to the places where they occur. On the forty acres to the east of 5 (8 on the map) a few small bowlders are

FIG. 3.

FIG. 3. View of one group of bowlders on the most western mound. Bowlders are quite thick in the bushes on the right background. The handle of the hammer is sixteen inches long.

present which have been brought there in cultivation, or they may be the last surviving fragments of large bowlders which may once have been over the field. It is deeply eroded so far as the shales are concerned and the surface is nearly on the Stanton limestone, which is also true of 7.

These are all the places where granite bowlders were observed. The surrounding country for from ten to fifty miles in every direction was quite thoroughly examined and at no place was a single granite bowlder found, and, so far as the writer is aware, none has ever been reported, and the nearest locality where such are known to occur is about seventy-five miles to the north in the drift of the Kansas ice sheet.

Characteristics and Lithology of the Bowlders.

Many of the bowlders are almost completely decayed and are so soft that they can be dug through with a spade, Mr. E. M. Stryker having thus dug about fifteen inches into one which was buried in the ground. The most badly decayed ones are in the ground; but, as shown by fragments, there were others in the midst of the solid bowlders now on the surface which fell to pieces as fast as they became exposed. Some of those on the surface have the constituent minerals so poorly held together that they can be crumbled with the hands. Others which are still compact have deep corrosion pits which reach into the stone for six or more inches. It appears quite probable that the greater number of the smaller bowlders have been produced by the breaking up since deposition of the larger, for in many instances the former have the minerals poorly held together and are of angular and irregular outlines. They have the appearance of having been separated from larger pieces and where the bowlders are numerous there are not a great many small ones except in those places where a large one is crumbling to pieces. It is plainly evident that the granite bowlders are very old and have been where they now occur a very long time.

The minerals composing the rock of the Rose bowlders are glassy white and pale bluish-white quartz and gray orthoclase and oligoclase feldspar, considerable proportions of the latter being present as phenocrysts, of which some are fully three-fourths of an inch across in their greatest dimension. Quartz is also present as phenocrysts of which the largest are about half an inch across. Compared to the quartz, the feldspars predominate in a proportion estimated at about two to one. A few grains of magnetite are present together with a few grains of some ferro-magnesian mineral which has been chloritized so as to be unrecognizable. Originally it was probably either hornblende or biotite. Professor Joseph Barrell, to whom some of the specimens were submitted for examination, confirmed the identifications and stated that "the rock has been shattered, but the fragments are still largely in their original juxtaposition. In connection with this shattering there was a recementation with fine-grained quartz and feldspar showing a trace of poikilitic tendency."* The shattering of the rock is not apparent on all of the granite bowlders although it is plain from every one that they are closely related and were evidently derived from the same mass of rock. The intimate dovetailing of the minerals absolutely puts out of consideration any possibility that the rock is an arkose or a breccia.

* Personal communication, August 17, 1916.

There is much variation in texture, but every specimen is porphyritic. In some the texture is very coarse with the average grain approximating one fourth inch and in no bowlder was a microscopic texture observed. Bowlders of coarse and fine grain occur together and some are coarse-grained on one portion and fine on another with the dividing line between the two textures quite sharply defined. This juxtaposition of the two textures may have been produced by the recementation following the shattering, the fine-grained granite being the cement.

In addition to the granite porphyry bowlders, three or four of chert were seen and on the most western mound were found two of quartzite of which the larger is about two feet in diameter and is composed of glassy gray sands of fine grain. Most of this bowlder is still on the mound. The smaller of the two bowlders weighs about half a pound and, while the quartz is of the glassy type, it is of a greenish shade. This bowlder is in the writer's collection. The larger quartzite bowlder is so deeply corroded as to have a spongy appearance.

Every one of the porphyry bowlders is more or less obscurely subangular in shape; but, as previously stated, the surface of every one of them is much weathered and, hence, rough and pitted, so that little data relating to the character of the original surface could be obtained. In fact, the original shapes may have been anything, while the present shapes may be altogether due to weathering. The smaller quartzite bowlder appears originally to have had one side flat.

Possible Methods of Origin of the Bowlders.

Four hypotheses may be considered. They are as follows: (1) the bowlders are firmly cemented masses of coarser sediments in which large unworn crystals of feldspar were important as constituents; (2) they are bowlders of weathering derived from a sheet, dike, or flow of igneous rock which is there enclosed in the sediments; (3) they were carried to their present positions by streams; (4) ice was the transporting agent.

The disposition of three of these hypotheses is readily accomplished. The bowlders are certainly not firmly cemented coarse sediments, for such a possibility is precluded by the absence of rounded fragments, the presence of well-formed crystals of feldspar, the intimate dovetailing of the minerals and the total absence of any signs of deposition in the material composing the bowlders. Every one of the granitic bowlders is true granite and each was directly derived from a common parent igneous mass. It is absolutely impossible to hold to the first hypothesis.

The only thing supporting the hypothesis that the bowlders are the surface exposures of an intrusion or extrusion is the alignment of the large mounds, which is linear and, therefore, in harmony with the idea that the bowlders came from either a dike, sheet or flow. A sheet or flow is the more probable because of the correspondence between strike of strata and alignment of mounds. However, if an intrusion be responsible for the bowlders, it must have been large, if coarse-grained textures be criteria of size of intrusion, and this fact of coarse texture thoroughly disposes of any possibility that the large mounds are the outcroppings of a flow. If an intrusion be present, the shales ought to be modified to some extent, especially if the intrusion be large, as must have been the case. There is, however, absolutely no evidence of any alteration. Furthermore, the presence of the flint and quartzite bowlders offers difficulties to this hypothesis. Lastly, if either a dike, sheet, or flow exist here, somewhere the parent rock ought to have been seen in place; but so far as observed, every bowlder rests on shales. It appears quite positively certain, therefore, that this hypothesis can not be held.

The hypothesis that the bowlders are water-borne makes necessary an inquiry as to the sources from which they might have been so carried and the competency of present and past streams to have brought about the transportation. The present streams of Kansas are not of high gradient and throughout this region they do not appear to have been so since their origin. The drainage is eastward and such has been its direction since early in the Tertiary. Prior to the Tertiary the drainage was westward. The nearest western points from which granite bowlders might have been carried by streams since the beginning of the Tertiary are in the Rocky Mountains, fully five hundred miles away, and for streams of such gradient as those of Kansas possess, or have possessed since the early Tertiary, the task would have been an absolutely impossible one. Moreover, not one of the present large streams of Kansas, which heads in regions of igneous rocks, flows within seventy-five miles of the locality of the bowlders which, as previously stated, lie on the extreme headwaters of a small tributary of the Verdigris. If a Tertiary or later stream deposited the bowlders where they now occur, very great changes of drainage must be assumed and this necessitates such great erosion that it is difficult to understand how the bowlders could have avoided destruction. The Rocky Mountains as a source for the bowlders, hence, can be eliminated, and all Kansas streams which head, or since early Tertiary times have headed in the Rocky Mountains, as transporting agents, must be eliminated from consideration.

A possible source for the bowlders is the drift of the Kansan ice sheet. The nearest locality of its occurrence is about seventy-five miles to the north, where bowlders are present in considerable numbers in the valley of Wakarusa Creek and a few occur on the hill slopes which limit the valley on the south. The map, fig. 1, shows the general facts of the distribution of the Kansan drift and the nearest southern limit of the ice. Between the Wakarusa Valley and Rose there are no bowlders, the bowlders at the former place are dominantly red quartzite and there is no drainage from the former to the latter and has been none since the Kansan glacial advance. This must also, therefore, be eliminated as a source.

Other sources from which the bowlders might have come are the Arbuckle and Wichita mountains of Oklahoma, and the old mountains of southeastern Missouri, the former being about two hundred and twenty-five miles away and the latter more than three hundred. There has been no drainage in the direction of Rose from these regions since the Cretaceous. The reverse was true during parts of the Mesozoic, but there is no evidence that any of these ancient streams were of high gradient in the region of Rose and hence it is quite improbable that the bowlders could have been carried by them, and, if so carried, unless they were covered by Mesozoic sediments, for which there is no evidence whatever, it is impossible to explain how they could have been preserved through the long interval of time which has elapsed since the drainage was reversed and through the erosion which the region has undergone. They might have been deposited by streams of Pennsylvanian age and subsequently covered by Pennsylvanian sediments. In this way they could have been preserved. The sediments, however, with which they appear to be associated were deposited in quiet waters—waters absolutely unable to transport bowlders of the sizes of those which are present. Streams, hence, must be discarded as possible agents of deposition.

It may be assumed that somewhere in this region in Pennsylvanian times there rose a granite mass from which bowlders rolled as talus to the places where they are now found. The strata of the region are almost horizontal and if a granite mass projecting above the present level of the bowlders were once present, it seems that somewhere in the region it should still project through the sediments which lie at the same level as the bowlders. There is absolutely no evidence that such is the case.

The last possibility is that ice was the agent of transportation. This alone appears to be competent to carry bowlders of the sizes which are present. Ice could have brought about the transportation either in the form of a glacier or as floating

ice. If the bowlders are in the Pennsylvanian strata, then they must have been deposited by floating ice, for only in such a way could the very local distribution have been effected and the deposition have been made in the midst of muds laid down in quiet waters. If the bowlders are of comparatively recent time, that is Tertiary or early Pleistocene, they must have been laid down either by a glacier or ice floating in a stream flowing from its margin.

In seeking for the place of origin of the bowlders, comparison was made with specimens of Missouri and Lake Superior granites of which the University of Wisconsin has collections containing about all the varieties, while the literature was examined for data relating to the granites of the Wichita and Arbuckle mountains. This search has yielded negative or uncertain results. In addition, Professor E. Haworth very kindly loaned for comparison a specimen of the rock which was reported to have come from one of the Zeandale wells. The latter, mineralogically and texturally, is altogether unlike the Rose bowlders and the same is essentially the case with respect to the Missouri granites. So far as the literature is concerned, it appears quite unlikely that a granite of the characteristics of that composing the Rose bowlders is present in either the Arbuckle or Wichita mountains.

In respect to the granites of the Lake Superior region, the examination was limited to those of the Vermilion Range of northern Minnesota which Doctor C. K. Leith suggested most nearly resembled that of the Rose bowlders. The specimens which are most similar came from the recomposed granite of Lake Saganaga. According to Grant, the original Saganaga granite "is coarse-grained gray to reddish granite . . . . of which the chief constituents are quartz, orthoclase, acid plagioclase and hornblende. A peculiar and characteristic feature of this granite is in its large grains of quartz, which are conspicuous on weathered surfaces. The quartzes are commonly a quarter of an inch in diameter and they frequently become larger." In the recomposed granites which developed from these "the hornblende of the true granite is wanting."* This description approximates that of the Rose bowlders, but the similarity comes far from approaching identity, and the examination of specimens of the recomposed granite made this much clearer since the textures of the two rocks are quite different. In the Rose bowlders the phenocrysts of quartz are larger and this mineral has a different appearance, the proportion of quartz is less, the average grain is larger, while there are no large phenocrysts of feldspar in the recomposed Saganaga

* Grant, Geol. and Nat. Hist. Surv. Minn., vol. iv, p. 322, 1897.

granites. Furthermore, the general appearance of the two rocks is quite different, and the recementation appears to have been accomplished by different methods.

The Rocky Mountain granites were not examined since it does not seem likely that any of the known conditions of present and past drainage would permit the bowlders to be derived therefrom.*

Stratigraphic Position of the Bowlders.

The local section of the region under consideration belongs to the Douglas and Pottawatomie formations of the Pennsylvanian system and consists at the base of the Stanton-Allen limestones with a thickness estimated at about fifty feet. The former limestone is above the latter and there is generally a separating shale. Overlying the limestones are the LeRoy shales and sandstones. The local thickness of this member slightly exceeds two hundred feet. These two divisions are the only ones exposed on the hills at Rose. To the east lower strata appear and to the west higher ones. The LeRoy shales and sandstones consist of black shales throughout the basal eighty or ninety feet while the upper portion is composed of red and yellow sandstones and sandy shales. These sediments are probably of deltaic and fluvial origin in the region under consideration.

Succeeding the LeRoy shales are the Iatan (Kickapoo) limestone and the Lawrence shales and sandstones. Below the Allen limestone are the Lane shales and this is preceded by the Iola limestone.

At present the bowlders are on the surface of a hill at a level varying from eight or ten feet above the Stanton limestone to about fifteen feet above, the largest and best preserved being at the latter level and the large mounds previously described lie at this upper level. The associated strata belong to the black shale division of the LeRoy shales and sandstones and these shales underlie the entire hill top on which the bowlders were seen, the shales immediately underlying the bowlders being nearly the highest exposed on the hill. The nearer the surface is to the top of the Stanton limestone, the fewer, the smaller and the more poorly preserved are the granite bowlders, and where the shales are altogether removed

* It was also considered whether the bowlders might not have been brought to their present position by man. The hypothesis was rejected as altogether untenable.

(Since going to press, cuttings from three other recently drilled wells of central Kansas which have been reported to have reached granites have been sent to the writer for examination. There is no resemblance between the materials from these wells and the granite of the Rose bowlders.)

there are no granitic fragments excepting such as have clearly been carried down the slope and they, in general, are so rare as to be negligible. On the south, east and west sides of the anticlinal structure no bowlders were observed, although exposures are equally as good as on the north side, since erosion in numerous places has reached the Stanton limestone. Stating the matter differently, the large bowlders occur over a quite limited area and appear to coincide with a definite and limited horizon in the LeRoy shales. In every instance they rest on shales and shales arise around some of them, but in no instance were shales seen to overlie bowlders. A few quartz veins were observed in the shales just in front of the school house (see map, fig. 2), but these can have no significance in relation to the granite bowlders.

Two alternative views are therefore presented; namely, the bowlders are not in the Pennsylvanian strata and are of comparatively recent age, or the bowlders are in the Pennsylvanian strata and are contemporaneous in origin with the shales on which they rest and which in some instances rise above their bases. Each of these two views will be examined in detail.

The evidence for the first view is that the bowlders lie on the surface and that in no instance were shales seen to cover them. Not even a small bowlder was seen overlain by shales; but, as already has been stated, it appears quite probable that no or few small bowlders were originally present. Opposing this view are the facts favoring the other, which will be considered in a subsequent paragraph, and the difficulty of explaining how the bowlders attained their present positions on the headwaters of a very small stream. As has already been shown, ice was in all probability the agent of transportation, but the bowlders are not of the same age as the Kansan glacial bowlders farther north. They are certainly older. The bowlders of the Kansan ice sheet are dominantly red quartzite, probably seventy-five per cent of them being composed of that rock, but not a single red quartzite bowlder occurs at Rose, while the two quartzite bowlders which were seen there resemble quartzites which outcrop near the village of Middletown, five or six miles to the southwest, and they may have come from there; but the resemblance is not sufficiently close to say positively that they do. Perhaps the Rose bowlders are the deposits of a glacial advance of pre-Kansan time, that is, very early Pleistocene—the sub-Aftonian,—or perhaps Tertiary. In that case, the ice advancing from the north crossed and filled the valleys of the Wakarusa, Osage and Neosho rivers, each of which is now trenched from one hundred to two hundred feet below the level of the uplands; or perhaps these valleys were not in existence at that time. On this

view the bowlders may be considered either a remnant of a once extensive sheet of drift, or a local deposit of ice floating from the glacial margin with the main body of the drift lying a little farther to the north.

If the bowlders are a remnant of a once extensive sheet of drift, then the rest of it has been altogether removed from the surrounding country without leaving a single trace of its one time presence and all marks of glacial erosion have been completely effaced so that the valleys mentioned above show no evidence whatever of having been filled and crossed by glaciers. If the bowlders are the deposits of early Pleistocene or Tertiary floating ice, the problem is rendered no simpler, since the drift-covered and glacier-eroded area lay but a short distance to the north.

This view postulates great erosion, which took place in such a way so as not to destroy the Rose bowlders, but at the same time altogether swept away similar deposits from neighboring areas, some of which were higher and others apparently lower than the hill at Rose. Such preservation calls for extremely special conditions and there is nothing in the region that lends itself to the view that such were present. It would appear that the final stages of removal of the supposed drift sheet would be marked by gravels of small size remaining here and there over a great stretch of country instead of a well-preserved deposit in one place.

The impossible, however, in the past has not infrequently been proved the possible and it may be that the Rose bowlders are of early Pleistocene or Tertiary age. If such be the case, the only early Pleistocene glacial material with which it is possible to compare them is the sub-Aftonian drift of Iowa. Beyer,* in his description of the Oelwein section, characterized the sub-Aftonian drift sheet as "a massive gray-blue till with a marked greenish tone when unoxidized. The upper portion contains much humus and gives off a characteristic marsh-like odor when wet. The distinctive characters which serve to distinguish the bowlder clay from the preceding (*Kansan*) are its color, the predominance of greenstone, and vein quartz pebbles and a less tendency to joint on exposure. Granitic pebbles and bowlders are almost if not entirely wanting." Savage who studied the same section, in his description says substantially the same things.† The sub-Aftonian drift of the Grand River section was described by Bain as "Boulder clay . . . containing mainly small pebbles, predominantly of vein quartz, but with a fair proportion of granite"‡ while

* Beyer, Proc. Iowa Acad. Sci., vol. iv, pp. 58–62, 1897.

† Savage, Ann. Rept. Iowa Geol. Surv., vol. xv, p. 522, 1904.

‡ Bain, Proc. Iowa Acad. Sc., vol. v, p. 97, 1898; Am. Geol., vol. xxi, p. 255, 1898.

Chamberlin and Salisbury, in a general statement of the sub-Aftonian drift, describe it as "typical sheet of till notable for the relatively high percentage of its greenstone erratics."*

It is significant that while greenstone and vein quartz pebbles and bowlders are very prominent among those of the sub-Aftonian drift, not a single greenstone or vein quartz pebble or bowlder occurs among the many observed in the locality under consideration, and if the material of the latter were related in time and origin to the bowlders of the sub-Aftonian drift there should be present some material of the character typical of that drift. The greenstones might have decayed, but the vein quartzes should certainly have outlasted the granites. Furthermore, so far as published descriptions observed by the writer are concerned, not a single one of the sub-Aftonian bowlders is anyways nearly so large as the large bowlders of the Rose region. There is no Tertiary material on the western plains with which the Rose bowlders can be compared, nor is there any evidence that such was ever present.

It is therefore considered that the hypothesis that the bowlders are of early Pleistocene or Tertiary age is not in harmony with the available facts, and while it still must be considered as a possibility, it does not appear that it can be strongly maintained.

The chief evidence for the second view is the close correspondence between the outcrop of the shales and the distribution of the large bowlders. As already noted, the large bowlders occur on the surface following the outcrop of a definite and relatively narrow horizon in the shales. Also along the north–south road decayed bowlders are present which lie almost surrounded by decayed shales. Residual soil is not meant when delayed shales are referred to, but shales in which the bedding has not been entirely obliterated. Furthermore, in every instance where a bowlder was observed in undisturbed position it rested on shales without an intervening soil. In no instance, however, were shales seen overlying bowlders. Could this observation have been made, it would, of course, have definitely decided the problem; but it was not observed and probably never will be since the bowlders are local and the cover, if once present, in the immediate vicinity has been totally removed. Higher shales are present on the hill, but they are a little farther south.

If the bowlders are in the shales, the explanation of how they reached their present positions is quite simple. The LeRoy shales have been stated to be deltaic in origin, and in strata a little above the horizon of the bowlders there is decisive evidence of deposition in tumultuous non-marine waters. This

*Chamberlin and Salisbury, Geology, vol. iii, p. 384, 1907.

evidence is both in the manner of deposition and the deposits themselves. Somewhere near the headwaters of the stream which brought in the sediments and which are believed to have been to the south or southeast, there were highlands on some of which snow and ice may have accumulated to form glaciers. Masses of ice breaking away from these floated down stream to become stranded or stopped in quiet waters where they melted and deposited the débris which they carried. Murray and Hjort have stated that bowlders dropped from floating ice take position in the muds into which they fall with the long axes in perpendicular position.* It is not possible to apply this test to the Rose bowlders since erosion has warped all of those which were elongated out of what may have been their original positions so that they now lie with the greatest areas downward.

To the extent that the facts are available it appears that the more probable view of the position of the bowlders is that they are in the shales and contemporaneous therewith.

If the second view outlined above be correct, the sequence of events, so far as the Rose bowlders are concerned, must have been something as follows: (a) In Pennsylvanian times the region of Rose was on a broad delta or river flood plain on which masses of ice becoming detached from glaciers which lay on high lands assumed to have been situated to the south or east from time to time became lodged in local areas and melted there. (b) Long afterward, probably about the close of the Permian, the strata of the region of eastern Kansas were warped and numerous low anticlinal structures were developed, one of which involved the strata containing the Rose bowlders. (c) A long period of erosion followed. The anticlinal structure gave erosion favorable points of attack which led to the rapid removal of the less resistant strata so that the area of structural elevation became from time to time a topographic depression, these times coinciding with the appearance of weak strata at the surface. The LeRoy shales and sandstones constitute one of the weak members and they were removed to the bowlders whose comparative resistance retarded erosion. When the Stanton limestone was reached, the streams followed it down the structural slope and thus was developed the valley which practically surrounds the Rose hill.

The relation that the Rose bowlders bear to the occurrence of granitic material in the Zeandale wells is still problematical. It may be that the latter reached its position in the same manner as did the bowlders at Rose. Evidence, however, has lately come to the writer from many sources that granitic

* Murray and Hjort, Depths of the Ocean, London, 1912, p. 207.

rocks in place locally underlie the Pennsylvanian strata of central Kansas and it is possible that the Zeandale granites hold a similar position. Furthermore, the evidence in the writer's possession, which has been derived from at least five independent sources, points to the conclusion that these granites are older than the overlying strata. If this view be correct, and the Rose bowlders be of the origin indicated by the available data, it follows that there is no connection between the two occurrences.

Conclusions from the Known Data.

(1) The bowlders reached the positions where they are found through the agency of ice, either glacial or floating; but more probably the latter.

(2) The view is strongly favored that they are of the same age and hold the same stratigraphic position as the shales with which they are associated, that is, they are the deposits of Pennsylvanian floating ice.

(3) It is barely possible that they are a remnant of an early Pleistocene or Tertiary drift deposit which resulted from a great glacial advance in pre-Kansan times, or the bowlders may have been laid down by floating ice derived from the glacier's margin.

Corollaries of the Conclusions.

(1) If the bowlders are not of Pennsylvanian age, they may belong to the sub-Aftonian drift, to the bowlders of which, however, they bear little resemblance. Should they belong therewith, it follows that the sub-Aftonian stage of glaciation in Kansas extended farther south than the glaciers of any other stage are known to have done. If not of sub-Aftonian age, then perhaps they should be correlated with the Tertiary glacial deposits of southwestern Colorado, recently described by Atwood;* but, so far as known, there is no information whatever on which to base a synchrony.

If the bowlders are in the LeRoy shales and sandstones and are of Pennsylvanian age, as appears the more probable view, they add another link to the chain of evidence for cool climates in Pennsylvanian times. In the Old World and South America the evidence for such cool climates is fairly complete, but for North America it has been more or less scanty. The finding of bowlders, probably ice transported, in the base of the Caney shale of Oklahoma,† which Ulrich considers of Pottsvillian

* Atwood, U. S. Geol., Prof. Paper 9 5-B, 1916.

† Taff, Science, vol. xxix, p. 637, April 1909. Bull. Geol. Soc. Am., vol. xx, p. 701, 1910. Woodworth, Bull. Geol. Soc. Am., vol. xxiii, p. 457, 1913.

age,* extended the probability of cool climates for this continent to the early Pennsylvanian. It is not possible to correlate the Rose bowlders with those in the Caney shale, but it is possible that they may be correlated with the Squantum tillite near Boston.† This is a part of the Roxbury conglomerate and supposedly of Permian age, although the age determination is based merely on the resemblance that this conglomerate bears to Permo-Carboniferous conglomerates of the Narragansett and Norfolk basins, an extremely hazardous feature on which to base a correlation. If the correlation of the Rose bowlders with the Squantum tillite can be made, the position of the former, if they are situated where this article assumes, definitely fixes the age of both and also the time relations of the beginning of the Permo-Carboniferous cold climates so far as the North American continent is concerned. The LeRoy shales have been correlated in a general way by Schuchert‡ with the Conemaugh of Pennsylvania. The cold conditions of the late Paleozoic have usually been assumed to have occurred during the Permian which for the Kansas section is generally not considered to have begun until the close of Wabaunsee deposition, which is separated from what is considered the probable stratigraphic position of the bowlders by between thirteen and fourteen feet of sediments.§ Some writers have begun the Permian at a slightly lower position, but no one has attempted to include the Douglas formation of which the LeRoy member is a part, since the faunas of that and the two overlying formations are typically upper Pennsylvanian. It follows, therefore, if the assumptions which have been made respecting the stratigraphic position of the bowlders be correct, that glaciers existed over the higher lands during parts of the later half of Pennsylvanian time.

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* Ulrich, Bull. Geol. Soc. Am., vol. xxii, pl. 29.

† Sayles, Bull. Mus. Comp. Zool., vol. lvi, No. 2, Geol. Ser., vol. x, pp. 141-175, 1914.

‡ Schuchert, Bull. Geol. Soc. Am., vol. xx, p. 558, 1909.

§ Haworth, Kan. Univ. Geol. Surv., vol. ix, pl. III, 1908.