ART. XXVII.—*The Chert of the Wreford and Foraker Limestones along the State Line of Kansas and Oklahoma*; by W. H. TWENHOFEL.

Introduction.

The Foraker limestone member.

The Wreford limestone member.

Relations of the cherts to the associated limestones.

Description of the cherts.

Source of the silica.

Time and method of origin of the chert.

Theory that the chert is a consequence of weathering.

Theory that the chert developed through filling of cavities, or replacement of solid rock.

Theory that the chert nodules resulted from direct precipitation of silica from sea water.

Theory of partial replacement of unconsolidated lime sediments either before or during the process of consolidation.

Résumé of facts and conclusions.

Introduction.

Chert is abundantly distributed throughout the Pennsylvanian and lower Permian strata of Kansas and Oklahoma, and its presence scarcely ever fails to attract the observer's attention, even though he is not a geologist. In some sections it so thoroughly litters the fields as to make them unfit for cultivation. There are other sections where it is extremely abundant; but not sufficiently so to prohibit cultivation. Over these areas the chert has been gathered into heaps in the hollows or along the borders of the parts cultivated. It is used as road material in many of the counties in which it occurs, and its use for this purpose is certain to be more extensive in the future.

It is quite probable that some chert is present in practically every important limestone member of the Pennsylvanian and Permian systems of Kansas and adjacent states and it is extremely common or abundant in many members; the Winterset, Oread, Foraker and Wreford limestones containing it in large quantities. In this paper only those cherts are considered which occur in the Foraker and Wreford members.

For the opportunity of studying these cherts in the field the writer is indebted to Mr. B. E. LaDow of Fredonia, Kansas. The suggestions and criticisms of the writer's colleagues, Professors Winchell and Mead, have greatly aided in the preparation of the article.

The Foraker Limestone Member.

The Foraker limestone forms the summit of an important escarpment in southeastern Cowley County, Kansas, and western Osage County, Oklahoma. Its correlative in the Kansas River section has not been determined.

The thickness of the limestone averages about seventy-five feet. There is some variation in the thickness, which in places rises to one hundred feet, but whether there is a systematic increase or decrease in any direction has not been determined.

The greater part of the member consists of limestone, but thin beds of shale and shale partings are present. Much of the limestone is not very resistant and these portions are commonly covered with soil, or weathered products from overlying strata. Exposures of the strong thick beds, in particular their upper portions, are of abundant occurrence.

The Foraker limestone is extremely fossiliferous, but the number of common species is few. Some beds are literally jammed with *Fusulina*, others have them in a few individuals. An interesting feature connected with the occurrence of *Fusulina* is that in some beds the shells are enclosed in a coating of calcium carbonate. This, however, is not peculiar to this horizon. The incrustation is believed to be of algal origin. Other fossils which are not uncommon are *Aulopora* (?) *anna*, *Composita subtilita*, species of *Productus*, species of bryozoa, and fragments of crinoids.

Some beds of the member contain numerous chert nodules, the exact horizons of which in many instances are not readily determinable. On fresh surfaces the chert nodules are not particularly conspicuous, but little difficulty is experienced in finding them. Weathering of the limestones brings the chert into relief and ultimately concentrates it on the surface. The chert is abundantly fossiliferous at all localities where it was examined,—some four or five hundred. Nodules in which fossils are not present apparently are extremely rare. The nodules do not appear to attain a great size—five to six inches being about the average—and they are of irregular shapes. The chert is quite porous, the cavities in large part appearing to be molds of small fragments of fossils.

The Wreford Limestone Member.

The Wreford limestone is known to extend from northern Kansas into central Oklahoma. Throughout the Flint Hills of Kansas (The Wreford limestone member in considerable part yielded the flint after which the hills are named) the thickness varies from thirty-five to fifty-five feet.¹ Near the Kansas-Oklahoma line it is much thinner. Its base is pretty sharply delimited from the underlying shales, the change from shale to limestone being quite abrupt. The upper limit of the formation does not appear to be quite so sharply defined.

Of the descending sections which follow, the first was measured about one mile east of the little village of Otto, Cowley County, Kansas. The second section was measured about eight miles nearly due north of the first. The two sections serve to show the persistence of the individual units of the member and also their variations.

11. Slabby gray limestone weathering into rounded dome-shaped surfaces. Not well exposed at the base. Upper layer one foot thick3 feet.

10. Gray limestone with yellow and gray chert in lenticular masses parallel to the bedding planes. Not well exposed at the base4 feet.

9. Compact gray limestone, coarser grained than that of zone 8. This zone contains an abundance of chert concretions of which many attain diameters exceeding two feet. The concretions have odd and peculiar shapes. Many of them have their longest axes parallel to the bedding planes. Others have them vertical or inclined to these planes. Locally, the concretions are connected with those adjacent, and places have been observed where the chert composes nearly the whole of the zone. The chert thoroughly litters the ground over the outcrop of the zone which, as a general feature, occurs on the rim of a well-defined rock terrace. Both chert and limestone are fossiliferous, the fossils for the most part being fragments of shells3 feet.

8. Compact, fine-grained, yellowish gray limestone, containing a great deal of pale blue and yellow chert which is thoroughly and intimately intergrown with the limestone. The chert composes about fifty per cent of the rock, but the ratio varies somewhat with locality. On weathered surfaces it stands out in irregular relief. Both chert and limestone contain many fragments of fossils2 feet, 8 inches.

¹ Prosser, C. S.: Jour. Geol. vol. 10, p. 713, 1902.

7. Limestone having a rotten appearance, yellow when weathered, light colored on fresh fracture. Contains considerable argillaceous material and, if much weathered, has the appearance of shale. Fragments of fossils are present..2 feet.

6. Compact gray limestone containing numerous silicified (chert) fossils, the greatest number being those of *Composita subtilita*. The beds are six inches to one foot thick and are separated by partings of thin limy shale. In some exposures this zone has a chalky appearance3 feet, 10 inches.

5. Light yellow shale with thin, compact, bluish-gray limestone. About one-third is shale. Numerous *Productus nebraskensis*, together with other fossils, are present. The fossils are not silicified. Base of the Wreford limestone..1 foot, 8 inches.

4. Light yellow shale with thin gray limestones ..6 inches.

3. Light brown and yellow shale with thin ($\frac{1}{2}$ inch) lenticular limestones8 inches.

2. Light blue shale in lower six inches, upper foot composed of yellow shale1 foot, 6 inches.

1. Red gritty shale4 feet.

The second section was measured about a mile north-east of the town of Dexter. It is as follows:

10. Gray limestone weathering into rounded blocks of about eight inches in diameter. Base not exposed4 feet.

9. Gray limestone which on exposure occurs as large slabs on the slope. Contains many round vertical holes which vary between three and six inches in diameter. Chert occurs in this zone but its relation to the limestone has not been determined1 foot, 5 inches.

8. Gray limestone, not honeycombed. Separates into slabs with diameters of from three to four feet1 foot, 6 inches.

7. Gray limestone (one bed) in which are many vertical circular holes of about one inch in diameter, giving it a honeycomb appearance. Fresh exposures show that these, in all probability, were originally worm burrows which were about as deep as the rock is thick, since passing nearly vertically through the fresh rock are tube-like structures of three-eighths to one-half inch in diameter which are composed of material—chiefly mud and fragments of fossils—which is less resistant than the surrounding limestone. In some exposures this zone is united to the overlying, the two zones in such exposures making a single bed2 feet, 3 inches.

6. Gray limestone in two- to six-inch beds..2 feet, 3 inches.

5. Gray limestone with little chert in the upper portion, but with an abundance of large brown-surfaced chert nodules in the lower half. Some of the nodules are as great as three and a half feet in their greatest horizontal diameters. The vertical diameters do not exceed a foot2 feet, 4 inches.

4. One bed of intimately intergrown yellowish-gray limestone and pale blue chert2 feet, 2 inches.
3. Thin white limestone with an abundance of silicified (chert) *Composita subtilita* and, more rarely, *Derbya*, fenesteloid bryozoa and other fossils2 feet, 4 inches.
2. White, somewhat chalky limestone. Contains silicified (chert) echinoderm spines (*Archæocidaris*) and bryozoa6 inches.
1. Thin, compact, gray limestone with poorly defined bedding planes1 foot, 3 inches.

Relation of the Cherts to the Limestones.

The sections show that the chert occurs in four more or less distinct relations.

In the Foraker limestone it is present as isolated nodules, of which the average is about five or six inches in diameter. These nodules commonly, but not always, have their longest axes parallel to the bedding planes and in places the chert and limestone are quite intimately intergrown.

The first zone of the Wreford which contains chert has it only in the fossils. The main body of the zone consists of limestone.

The second zone which carries chert has it intergrown with the limestone in an exceedingly intricate and labyrinthine way, so that in any one mass of rock the chert is essentially one piece, which is also true of the limestone. On weathered surfaces the division between the chert and the limestone is extremely sharply defined and no difficulty exists in stating where the chert begins and the limestone ends. Freshly fractured surfaces, however, show that there is a zone of about one-half inch in width between the chert and the limestone, in which there is a minute intergrowth of calcite and silica.

The third chert of the Wreford occurs in large irregularly shaped nodules of marked concentric structure, the nodules in considerable, and probably greater, part being elongated parallel to the bedding. There are many nodules of a spherical shape in which no longest axis exists, and there are numerous others which have their longest axes transverse to the bedding. The nodules are not sharply delimited from the enclosing limestone.

A fourth chert zone is known to occur in the Wreford, and there may be others. This has the chert in lenticular

masses and also like that of the third zone of chert. These may represent two zones and, as they have not been well enough seen to place them in the section with sufficient definiteness, they will not be further considered.

Description of the Cherts.

The chert of the Foraker limestone is quite porous, most of the pores appearing to have resulted from the removal of an organic fragment. The color is either some shade of gray, a pale gray blue, or a mottled gray and blue. Yellowish-gray shades are not uncommon. The abundant fossils are commonly of a different color from the surrounding material. In most instances they are lighter than the matrix; in some instances they are darker.

Little concentric arrangement of material is shown in these cherts, but the peripheral portions of each nodule have a more porous texture and lighter color than the interior portions. The interiors also have a conchoidal fracture, which is not true of the peripheral portions. These differences are probably due to leaching of the exterior portions of the nodules.

Fossils, chiefly *Fusulina*, are abundantly scattered throughout the chert, their cross-sections making from ten to fifteen per cent of the areas of the thin sections and fracture surfaces. The distribution is quite uniform. While there are patches where they are not abundant, these relatively barren portions are not confined to any particular parts of the nodules, so that as many fossils are in the bottom portions of a nodule as in the top. There is no arrangement of the fossils into bands, and the fusiform shells of *Fusulina* are oriented so that the axes of symmetry are parallel neither to a line, plane, or curved surface, the shells being oriented in every possible direction. The fossils are also composed of chert.

The preservation of the *Fusulina* is extremely excellent, being generally better in the cherts than the enclosing limestone, and some of the most delicate details of structure are shown. The concentric walls of the shells are perpendicularly perforated by small threads of limonite. These thread-like structures are considered to be fillings of the original pseudopedial openings of the test. They are wanting in the radial portions. The material composing the main body of both types of wall is of a

pale yellow color which between crossed nicols breaks up into a mosaic of fine grains of chalcedony and quartz. The material filling the cavities of the shells has a radiate or dove-tailed structure, and consists of colorless chalcedony or of small units of quartz and chalcedony of irregular shapes in irregular arrangement. The material surrounding the shells is an aggregate of tiny units of limonite, quartz and chalcedony. No amorphous silica was observed. Small crystals of calcite are commonly present.

The lowest chert zone of the Wreford, that in which the fossils alone are composed of silica, has the chert only as a replacement of the original matter of the shells. Many of the fossils have the silica in rosette arrangement, while in others it duplicates to a greater or less extent the original structures of the shells. The chert is commonly of a gray color. The interiors of the shells are filled with intergrown calcite and glassy quartz which in many instances are discolored by iron oxide. Shells in which the interiors are composed of chert are quite rare.

The zone in which the silicified fossils occur was seen in fully five hundred exposures over an area of about one hundred square miles, so the silicification in this zone is quite general. Many of the exposures are in deep stream-cuttings and were fresh, and one is in the bottom of a recently dug well, the shells coming from about twelve feet below the surface of the ground, so that it is quite certain that the fossils in this zone are silicified beneath the surface. No exposure was found where the shells are composed of lime carbonate.

In the second chert zone of the Wreford, the chert, except for peripheral portions, is of gray-blue, yellowish-gray, dark gray, and mottled gray and blue color. The peripheral portions are more granulated than the interiors and do not have the conchoidal fracture which is characteristic of the latter. The outer portions are also minutely porous and the colors are shades of yellow and brown. Except for this peripheral portion the chert shows no concentric banding. There is, however, a rude banding parallel to the bedding of the limestones. The inner portions are composed of dense, compact chert which in some specimens is minutely porous. Fossils are present in both the limestone and the chert. They are

commonly fragments and young shells. *Fusulina* is extremely rare. The fossils have the appearance of being most abundant in the outer granular portions of the chert, but in reality such is not the case. Many of those in the limestone are composed of chert. The preservation in the chert is as good as in the limestone.

The chert masses, in general, are elongated parallel to the bedding but they also cut across the bedding and go from slightly lower to slightly higher levels. In addition, fingers of chert go out in every possible direction, so that each unit—if a unit may be said to be present—is united to chert above, below, and laterally.

The groundmass of the chert of this zone consists of exceedingly minute grains of chalcedony, quartz, and limonite, limonite and limonite staining being quite abundant. Amorphous silica does not appear to be present. In the groundmass are many minute fragments of fossils of which the most conspicuous are of needle-like shape. As these are not parallel in arrangement, it results that a thin section shows them with different outlines. Those whose axes are parallel to the surface of the thin section have needle-like outlines; those whose axes are perpendicular appear as circles; while those transverse give ellipses. The needle-like structures are of light color in thin section and each of them appears to have had a central axial canal or filament, which is indicated by a thread-like portion of different color, a pale yellow being most common. These needle structures appear to be almost wholly composed of chalcedony, very little, if any, quartz being present, and are believed to be monaxial sponge spicules. They are about one-tenth of a millimeter in diameter and one millimeter long. Bryozoa have also been recognized among the minute fragments of other fossils which are present. A cylindrical rod-like structure is present in one section which may have come from one of the calcareous algae. This is peculiar in that it appears to have the remains of a small coiled organism in its interior. If *Fusulina* be present in this chert, it is extremely rare.

The chert of the third zone of the Wreford (see fig. 1) is in the form of large and small nodules of variable and peculiar shapes. Maximum diameters equal and perhaps exceed four feet. The surfaces are extremely irregular by reason of dome-shaped protuberances which appear

to have developed as secondary centers of secretion. Tangential sections across these protuberances indicate that at these places there is a bulging outward of the concentric bands. The interior in every specimen studied is of banded concentric structure, the structural bands being commonly wider on the top of a nodule than on the bottom side, and laterally generally wider than on top. The bands are not always the same widths on horizontally opposite sides; one nodule which was studied having sixteen bands on one side extending through three and one-half inches of radius. On the other side these merge and

FIG. 1.

FIG. 1. The specimen on the right is from the second chert zone of the Wreford limestone. The irregular mass crossing the center is limestone, the rest is chert. Two small nodules of chert are shown in the limestone. The specimen on the left is from the third chert of the Wreford. The dark blocks are chert, one with its longest diameter parallel to the bedding, the other with its longest diameter transverse thereto. Each specimen is adjusted so that the bedding planes are in horizontal position. These two chert zones are known to extend over more than a hundred square miles and are not more than 5 feet from each other vertically. Except that each is composed of silica, they have no other common feature. The dimensions are shown by the 6-inch rule.

extend through only five-eighths of an inch of radius. In any radial section the bands are not the same width, varying in one specimen from three-fourths to one-fourth of an inch. The exteriors of exposed nodules are of a brown color due to oxidation. The color of the weathered interiors is a striped blue and gray, the shades varying, depending on degree of exposure. Interiors of freshly broken specimens do not have the banding so plainly shown and are commonly of dark gray-blue color. Weathered nodules are porous, the gray areas more than

the blue, and on much exposure to the weather the gray portions become yellow or some shade of brown. Little distinction can be made between the peripheral portions and the interior. No parts of these nodules have a distinct conchoidal fracture.

Fossils are scattered throughout the chert and occur on the surface, many being represented by cavities. A form quite common in some nodules is a fenestelloid bryozoan. The fossils in the chert are as good as, and apparently a little better than, those in the limestone. The chert on weathered surfaces is sharply separated from the limestone, but fresh fractures across both chert and limestone show that each is intergrown with the other. Nodules were observed with masses of limestone almost completely surrounded by chert, so that it is quite probable that nodules exist in which masses of limestone are completely enclosed. Quite fresh chert contains a great deal of calcite—at least twenty-five per cent—scattered throughout, and the solution of this is believed to be largely responsible for the cavities in weathered nodules, these in places making from twenty-five to fifty per cent of the surface of a thin section, the lighter colored bands of the chert appearing to be largely due to their presence; since, except for the cavities, there is little microscopic difference between the lighter and darker bands.

The groundmass consists of an aggregate of microscopic grains of quartz, chalcedony, calcite and limonite. The last occurs both as stains and little particles, and in places is so abundant as to render the thin sections nearly opaque. It is present both in weathered and unweathered chert. A little siderite also appears to be present, but the quantity is not great. Sections from unweathered chert contain much calcite. Some of the cavities are lined with minute crystals of quartz and chalcedony, making them microscopic geodes. No amorphous silica was observed.

Source of the Silica.

Respecting the source of the silica from which cherts are formed, there are three general theories, namely: (1) the silica is directly derived from the shells and supporting structures of organisms, such as spicules of sponges and shells of radiolarians and diatoms, these organisms

largely obtaining it from silica dissolved in the waters of the ocean in which they live, or from silicates held in suspension; (2) the silica is precipitated directly from the sea water through chemical processes; (3) the silica is deposited with the sediments as a mechanical precipitate of finely divided silica or silicates carried in suspension in the sea water, and is subsequently segregated to form nodules.

That organic silica in great abundance is deposited with sediments hardly needs statement. The immense deposits of diatom and radiolarian ooze show the extent to which silica now accumulates and nearly all bottom deposits appear to contain siliceous tests in greater or less abundance.

That silica is carried by the rivers to the sea in great abundance is now well known. River water that does not have some silica in solution is extremely rare and great quantities of silica are annually delivered to the ocean. Of the solid matter in solution in average river water, 11.67 per cent consists of silica,² and the rivers of the world annually deliver to the sea dissolved silica to the extent of a little more than 223 million tons.³ As there is very little silica solution in the ocean water,⁴ it follows that essentially all of this is precipitated, and that, too, before going very far from the shore. Some of it is taken out by organisms, but it seems quite certain that considerable quantities are chemically precipitated. Tarr has demonstrated⁵ that this precipitation is accomplished in ordinary sea water by the salts which are in solution therein. The silica probably reaches the bottom as extremely tiny particles and is mingled in that form with the sediments.

The abrasion brought about by wind and the corrasive work of water and ice certainly produce a great deal of finely divided silica. Much of this reaches the sea and is deposited with other sediments. Possibly this may be dissolved and segregated to form chert.

It is certain, therefore, that there is no dearth of silica brought to the sea, and that some of this silica ultimately becomes segregated to form the chert nodules is equally

² Clarke, F. W., *Data of Geochemistry*, U. S. Geol. Survey, Bull. 616, 116, 1916.

³ Clarke, *ibid.*, 115.

⁴ Clarke, *ibid.*, 123-125.

⁵ Tarr, W. A., *this Journal*, 44, 409-445, 1917.

certain. Respecting the time and method of segregation there is considerable diversity of opinion.

Time and Method of Origin of the Chert Nodules.

Views relating to the time and method of origin of chert nodules fall into two general classes, namely: (1) the cherts develop subsequent to the solidification of the strata in which they are imbedded through replacement of certain parts or through the filling of cavities; and (2) the cherts develop prior to, or contemporaneous with, the solidification of the containing strata, either as original precipitates or as segregations in the unconsolidated sediments.

Of those who hold that the chert develops subsequent to the solidification of the containing strata, one group maintains that the chert forms in the zone of cementation through replacement of the carbonates or through filling of cavities, the silica being derived from that held in solution in ground water. Another group maintains that chert develops as a consequence of weathering and that it is far more abundant in exposed strata, or strata which at one time have been exposed, than in strata which have not been subjected to weathering agencies; it being rare or wanting in the latter.

Likewise there are two groups of those who consider that chert is formed prior to, or contemporaneous with, the solidification of the containing strata. According to one group the cherts are deposited contemporaneously with the associated materials; according to the other the nodules develop by segregation of silica in the sediments before the latter become consolidated and cemented, or while this is being accomplished.

It is quite possible, and even probable, that chert has been formed in each of the ways postulated. Furthermore, it is but fair to state that it is certain that the students who hold to the several theories which have been outlined do not insist that chert originates in any one particular way. Each of these theories will now be examined with particular reference to the cherts which are considered in this paper.

Theory that the chert is a consequence of weathering.—This view appears to have been developed by Dr. E. O. Ulrich,⁶ who considered that the chert in the Potosi group

⁶ Bain, H. F. and Ulrich, E. O., U. S. Geol. Survey, Bull. 267, 27, 1905.

of southeastern Missouri developed "largely as the result of segregation of siliceous matter under conditions of slow subaerial decomposition of the limestone." The present writer believes that some chert has been developed in this way, observations made at fossil localities suggesting that in some cases the replacement of fossils by silica is consequent to weathering.

It is quite certain, however, that none of the chert which is considered in this article developed in this fashion. As has already been stated, the chert has been observed under essentially every condition of exposure, and in fresh rock it is just as abundant and, except for oxidation, of the same character as in that in which it has been exposed to weathering agents. The test would come more particularly in the case of the first chert zone of the Wreford limestone, that in which the chert occurs in fossils (chiefly *Composita subtilita*). This zone was seen in hundreds of places under all conditions, and invariably the shells are composed of silica, while the material filling the hollow interiors is composed of calcite and quartz. Had the silicification been a consequence of weathering, it would seem that somewhere the specimens of *Composita* should have been composed of calcium carbonate, especially as places were observed where the immediately underlying bed has its fossils in that form.

It may be argued that the exposure antedated the present and that the cherts lie along disconformities or old erosion surfaces. This view can not be sustained.

Theory that the chert developed through filling of cavities, or replacement of solid rock.—That some chert occurs as fillings of cavities and fissures rests on many observations, so there is no doubt that it is of quite common occurrence,⁷ but that the chert under consideration did not develop through filling of cavities is quite evident from the distribution of fossils therein. In no instance were these found to be confined to the lower portions of the nodules; but, so far as observed, and fully a thousand nodules were examined in the field, they are uniformly distributed throughout. Furthermore, none of the cherts shows any relations to fractures and not a single fracture was observed which had been filled by chert.

That chert may develop as a replacement of solid limestone through replacement of the carbonate by silica held

⁷ Van Tuyl, F. M., this Journal, 44, 450, 1918.

in solution in water has been demonstrated,⁸ and it is quite probable that a great deal of chert develops in this way. When solid limestone or dolomite is thus replaced by silica, the original structures of the replaced rock should be duplicated, or be less perfect, in the resulting chert. Original structures would include bedding, lamination, fossils, etc. It is impossible that they could be better and it is more than likely that they should have lost something in the process of replacement. As a substance of which fossils may be composed, silica is about but hardly quite so good as calcite. If the fossils held in the cherts are of better preservation than those in the limestone, it should be considered positive evidence that the chert is not a replacement of solidified limestone. Cherts which are replacements of solid limestone should have bedding and lamination planes continued from the limestone into the chert and, if these structures end abruptly at the chert, the latter could hardly be considered of this origin. The conclusion would be stronger if the cherts were fossiliferous, as it does not appear possible that in the same chert fossils could be retained and bedding planes eliminated. Replacements of this kind should be related to fractures and should also give the same character of chert in vertical distribution in beds which are essentially similar—quite similar limestones within less than five feet of each other vertically should have similar cherts—, while in horizontal distribution the chert should be considerably localized.

The cherts of the Foraker limestone appear to be confined to certain beds of this member and in these there seems to be general horizontal distribution. The *Fusulinas* of these cherts are exquisitely preserved and, in general, they are of better preservation than are those of the enclosing limestone; in collecting, few of the latter were considered of much value. Not only is the detail of the interior much better shown in the silicified fossils, but also the character of the surface. Few traces of bedding are shown in the specimens which have been studied. On a basis of these characteristics it is considered that these cherts are not replacements of solid limestone.

The siliceous fossils in the lower chert zone of the Wreford are without doubt replacements of solid material. That point is settled, but whether this replacement occurred before or after the solidification of the sedi-

⁸ Church, A. H., *Journ. Chem. Soc.*, 15, 107, 1862.

ments from which the limestone was formed remains to be decided. It is difficult to understand how a replacement of shells could have been so general in horizontal distribution, and so slight in vertical distribution, as the bed immediately below contains its fossils still almost wholly in carbonate form. The fact that the shells were replaced while the surrounding limestone was not affected might be explained on the ground that the shells were composed of a less stable form of calcium carbonate than that of the surrounding limestone. It would seem, however, that in the recrystallization of the sediments to form the limestone the shells would also have assumed the stable form of lime carbonate. An additional source of difficulty is how to account for the entrance of water to the shells, as the enclosing limestone is quite fine-grained, without being affected in any apparent degree and without any nodules forming. These difficulties have led to the rejection of the theory that the chert fossils are replacements subsequent to solidification of the limestone.

The cherts of the second zone of the Wreford and those of the third are totally different in appearance and structure. In fact, they are about as different as any two cherts could very well be. The distribution of each of these cherts is horizontally uniform over an area of at least one hundred square miles, with the probability that the horizontal distribution far exceeds this figure. In the upper zone there is no trace of the bedding of the limestone in the chert, while fossils are preserved therein. The second zone shows faint traces of bedding, but fossils are as a rule better preserved in the chert than in the limestone. No chert of the character of that of the third zone is found in the second zone and the reciprocal is also true.

These facts strongly militate against the view that these cherts developed through replacement of limestone; in fact, they prove the contrary. It is therefore concluded that the cherts being considered did not develop subsequent to the solidification of the containing strata. The alternative is that they are antecedent in origin to solidification or contemporaneous therewith.

Theory that the chert nodules originated from direct precipitation of silica from sea water.—This theory, first enunciated by Prestwich,⁹ has lately been independently

⁹ Prestwich, J.. *Geology, Chemical, Physical, and Stratigraphical*, vol. 2, 320-324. Oxford, 1887.

elaborated by Tarr,¹⁰ who came to the conclusion that the Burlington chert nodules resulted from direct precipitation of silica and that these nodules were subsequently buried in the sediments. "The silica," he says, "is believed to have been derived from the land by chemical weathering and transported to the sea by the streams as colloidal silica," where "it is believed to have been precipitated by the alkali salts in the sea water after it had undergone considerable dispersion and a certain amount of concentration—; the silica thus precipitated on the sea bottom would tend to assume more or less globular or elliptical forms. Upon burial these forms would become compressed into their elliptical or lenticular shapes by weight of the accumulating sediments. Fossils falling into this soft colloidal mass would be perfectly preserved" (p. 428). It is argued that the "gel-mass" was for a while carried about by currents, until its mass had become sufficiently great to cause it to sink to the bottom. "If the waters were shallow, currents and waves might have shifted and rolled the masses of gel about, thus tending to form larger aggregates. This rolling aided in producing the banding of the chert, but only the relatively small masses were rolled about. Circular bands are found only in the smaller aggregates, those not exceeding eight to ten inches in diameter." "If the currents were unable to move the masses, the latter would have grown through mass action, the larger aggregates attracting the smaller ones. As growth proceeded, the banding and mottling of the chert was developed, due to carbonaceous materials that are believed to have been included in the chert as it grew" (p. 437). "When several nodules were formed close together they united to form a larger mass which shows a lobed circular outline from the flattening of the several spherical aggregates" (p. 439).

Certain other characteristics of cherts which might have developed in this manner may be suggested. If the postulated masses of "gel" were rolled around by waves and currents so as to develop the banding through the inclusion of carbonaceous matter, there would also be included the shells of small organisms which lay upon the sea bottom, and as a consequence there ought to be some sort of banded arrangement in the distribution of the fossils, and their longer axes should be parallel to the tan-

¹⁰ Tarr, *op. cit.*

gents of the globular masses. If the globules developed without rolling, the shells of organisms would be largely those of pelagic habitat, and it would seem that this should have led to the arrangement of the long axes of the shells parallel to the upper surfaces of the "gel-masses." If "gel-masses" of the characteristics postulated were formed and rolled about by wave and current, it would appear that not uncommonly some, and quite likely many, would ultimately have reached places of deposition of clastic sediments. This would occur quite commonly in such a series of sediments as compose the Pennsylvanian and Permian strata of Kansas, Oklahoma, Missouri, etc., in which lateral gradation from one to the other type of sediment is extremely common and occurs within short distances. This, apparently, has not occurred.

If the circular banding of cherts developed through rolling about, with banded chert nodules of large size there should be an abundance of evidence of wave activity. If the banding developed in this way, the bands of the top and bottom should be of about the same width and number and the bands of the horizontally opposite sides should also be of about the same width and number, for it does not appear reasonable to suppose that the included material which developed the banding would have accumulated in the process of rolling to a much greater extent on one side than on the other, while the silica which was being added apparently would have been distributed quite uniformly along every radius. The greater width of the bands laterally, as compared to their widths in the vertical direction, might have developed as a consequence of their flattening through their own weight or the weight of the overlying sediments, because of silica moving from the top to the sides.

The evidence, as the present writer sees it, does not favor the view that the cherts which are considered in this article were formed in the manner which has just been outlined.

The *Fusulinas* of the Foraker cherts are uniformly distributed and show no concentration in any way whatever. The greater number of modern species of Foraminifera¹¹ are bottom-dwellers—only about twenty-five species being pelagic—and the chances are that large forms like

¹¹ Cushman, J. A., Bull. 71, U. S. Nat. Museum, 8, 1916.

Fusulina had a similar habitat. If this were true, they could hardly have dropped into the coagulating masses of silica, and, if these were rolled around on the sea bottom, some sort of banded arrangement in their distribution in the nodules ought to have developed. As these cherts are little banded, the implication would be that they had not been rolled about; such being the case, the *Fusulinas* must have dropped into, or crawled upon, the "gel-masses." If they lived on the bottom the former was not possible. If the *Fusulinas* were indeed pelagic in habitat and fell upon the coagulated chert, or were bottom-dwellers and crawled upon it, it would seem that the long axes of the tests would be tangent to the upper surface or sides of the "gel." Such, however, is not the case, as the axes of these shells are oriented in every possible direction.

For the basal chert of the Wreford—that in which the chert occurs only as a replacement of the shells of organisms—the explanation of original precipitation has no application. These are obviously replacements.

The second chert of the Wreford, in which there is the intricate intergrowth of limestone and chert, is also difficult to explain on the theory of original precipitation. These cherts do not have an elliptical globular shape, and to the writer it does not appear possible that the intricate intermingling of the limestone and the chert could have developed through the confluence of any number of coagulated globular or elliptical masses of silica, since the chert has ramifications in every direction which are confluent with neighboring masses laterally and vertically and has all sorts of projections and embayments. Furthermore, the sponge spicules which are present in this chert offer difficulty. It is possible that they might have floated to the masses and adhered to them and subsequently been covered by more silica. Three thin sections made from the associated limestone where it occurs in the same block from which a thin section of the chert was made, and within one and six inches of the place where the fragment for the thin section of chert was derived, do not show a single thing which can be positively identified as a sponge spicule, although other fossils are present. It may be that sponge spicules were once present in the limestone and have been dissolved, otherwise there must have been some selective action of the objects to

which they may have floated. If they were dissolved and precipitated about other sponge spicules, those in the chert, for instance, a method of origin considered in the succeeding topic is approximated.

The third chert zone of the Wreford, that in which the large banded nodules occur, is also difficult to explain on the theory of original deposition. According to this theory, the nodules should be flattened parallel to the bedding, and this is true for many and perhaps most of them; but there are many others which are globular and not flattened at all. Others are of irregular shapes and still others have their longest axes perpendicular to the bedding. In places the chert composes the entire zone. Many of the nodules have diameters of three feet or more, and these, like the small ones, have concentric structure. If these were once "gel-masses" of silica which were rolled around so as to give them concentric structure, it implies rather strong currents for which the associated material gives no evidence whatever. If they were not rolled around, the greater additions of silica should have been from above and laterally and, if this could have been deposited in banded form, the banding which is present in these nodules would have been realized. At the lateral peripheries, the bands are two to three times as wide as on top. This might have been brought about by the flattening through their own weight or the overburden; but, as will be shown subsequently, the banding may be explained equally as well in another way. The somewhat botryoidal aspect of the exterior shows the development of many centers of accretion; but these, too, have a concentric structure which appears to be no more than an outpushing of the interior bands. These could not have been developed through any process of rolling or by the cohering of one "gel-mass" to another.

The observed facts relating to the cherts under consideration do not favor an origin through direct precipitation from silica in solution in the sea water, the precipitation and formation of the nodules taking place in accordance with the theory outlined in this topic. That processes of the nature considered may have assisted in the formation is quite possible. Furthermore, the writer considers it extremely improbable that large "gel-masses" could have developed in the manner postulated, and more probable that the silica is precipi-

tated in extremely small particles and that these are buried with other sediments. No such "gel-masses" appear to have been reported from ocean waters or ocean sediments.

Theory of partial replacement of unconsolidated lime sediments either before or during the process of consolidation

This theory in its broadest statement maintains that the silica replaced unconsolidated sediments either before or during the process of consolidation, the silica being derived from organic and other silica mingled with the sediments, either in solid form or in solution. The silica in solution in the sea water is not excluded from aiding in the formation of the chert. The term replacement is used not only to include actual substitution of the lime sediments, but also replacement of the space held by them through their being pushed out of the way. Organic substances and organic silica are believed to have quite commonly served as nuclei for the nodules.

As conditions on the sea bottom change from time to time, and as each bed represents a somewhat different condition from that obtaining during the formation of a previous or subsequent bed, it readily follows that the chert of each bed may be quite different from that of any other bed. Each separate band probably represents a separate period of accretion under slightly different conditions, and if the bands show a rhythmic character, such as exists in the third chert zone of the Wreford, it points to a recurrence of similar conditions which may well have been seasonal. If the recent suggestion of Barrell,¹² that geologic time should be expanded in large multiples and that each bed represents a much longer time than has previously been supposed, approximate a correct estimate of geologic time and the duration of sedimentary processes, there would be given time for as many periods of accretion as one could well wish. At any rate, not more than one hundred years would be required for the development of a Wreford nodule of the largest size on the assumption that each band is an annual accretion, and a much shorter time would be required if the bands represent seasonal accretions. Since the sediments were still soft while the nodules were growing, there would be

¹² Barrell, J., Bull. Geol. Soc. America, 28, 884, 1917.

no good reason for the preservation of structures which were not yet in solid form, and these might, or might not, appear in the cherts. Fossils would quite certainly be preserved and the preservation could be better than, as good as, or worse than, that of those in the associated materials.

The process of the growth of a nodule is thought to have been something as follows. As silica in solution was carried through the sediments by diffusion, it is believed to have been precipitated about centers, such as small pieces of silica, fragments or organic matter, and, slightly extending previous conceptions, perhaps a very small "gel-mass" of the type postulated by Tarr. The dominating factor in the process of nodule growth was the attraction exercised on the dissolved silica by the growing nodule. As silica was taken from solution, it destroyed the equilibrium of the solute, resulting in more silica being diffused toward the nodule. A relatively sharp boundary was maintained between the limestone and the chert by the pressure which the growing nodule exercised on the associated lime sediments and which favored their going into solution.¹³ That this boundary is gradative so far as the two substances are concerned is shown by the cherts which have been described in this article. In the development of the nodule any organic substances could become incorporated and these could be oriented in any direction. Masses of lime sediments, crystals of calcite, and all sorts of material could and should be present. As the movement of silica through the sediments would be greatest laterally because of bedding and lamination planes, and least from below because of greater pressure and hence less permeability in that direction, the greater width of the bands laterally and their least width below is readily explained. The different widths of bands on opposite sides would arise from differences in the quantity of silica supplied from different directions, while the different widths of the bands in radial section could be referred to differences in the quantity of silica supplied from period to period.

The chert of the Foraker limestone is believed to have developed as outlined. The theory harmonizes with the facts as they relate to this chert and fully explains the distribution and preservation of *Fusulina*.

¹³ Faber, S., this Journal, 41, 555, 1916.

It hardly needs to be stated that the fossils in the basal chert layer of the Wreford are replacements, and the theory that this replacement preceded, or was contemporaneous with, the solidification, encounters none of the objections urged against the others. This theory also quite readily explains the labyrinthine intergrowth of limestone and chert in the second chert zone of the Wreford, as well as the fact that the chert contains an abundance of spicules, though there are few in the limestone. That this chert is not concentrically banded may be referred to a continuity of uniform conditions. The obscure horizontal banding is an inheritance of banding in the unconsolidated lime sediments.

The facts relating to the third chert of the Wreford also harmonize with the theory. All the characteristics are readily explained, and the globular and irregular nodules offer no difficulty; neither do those whose long axes are perpendicular or transverse to the bedding. The abundant calcite in this chert is thus easily accounted for.

It may well be, however, that original precipitation and also other processes played some part in the development of these nodules. Nature forms the same things in different ways and rare indeed is the occurrence of a geological result which was produced through the operation of a single factor. History, beginning with the founders of geology, notably Werner, has recorded the errors of those who have thus assumed.

One other theory deserves consideration, and this concerns the method of origin of the concentric structure of the nodules of the third chert zone of the Wreford limestone. While studying these nodules in the field and in the laboratory, the suggestion recurred again and again: Might not these structures be of organic origin? They are not markedly different in general outward appearance, irregularities of the surface, and microscopic internal structure from *Cryptozoa*. Moreover, algae are known to have existed in large numbers in some parts of the world during the Carboniferous.¹⁴ Search for microscopic structures of a type approximating those possessed by algae has, however, been absolutely barren of results. If ever present, they have been totally

¹⁴ Garwood, E. J., *Geol. Mag.*, Dec. V, 10, 497-498, 1913; Dec. VI, 1, 265-271, 1914.

destroyed. If these nodules are of algal origin, they were probably calcareous in the beginning and were subsequently changed to chert by replacement.

Résumé of Facts and Conclusions

1. The cherts of the Foraker and Wreford limestones in the outcrops in the vicinity of the state line of Kansas and Oklahoma are quite varied in character and the different varieties are confined to distinct zones of wide horizontal distribution.

2. The observed facts do not harmonize with theories postulating an origin for these cherts consequential to weathering, or one of replacement, or of cavity-filling in solid rocks. It is not disputed, however, that chert develops in such ways.

3. It is possible that these cherts developed through direct precipitation of silica in solution in the sea water, but it is not believed that the facts support such an origin. That some silica may have been added to the nodules from silica in solution in the sea water is considered quite possible.

4. The chert is believed in major part to have resulted from replacement of unconsolidated limestone, the silica being derived from silica in solution which was mingled with the sediments, from silica in solution in the sea water, and from solution of organic or other silica, or silicates deposited in some form with the sediments.

5. The suggestion is made that the banded nodules occurring in one of the zones may have had an algal origin, but no microscopic structures similar to those occurring in algæ have been found.

University of Wisconsin,
Madison, Wis.