INSOLUBLE RESIDUE STUDIES OF THE COLUMBUS AND DELAWARE LIMESTONES IN OHIO

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INTRODUCTION

Several generations of geologists have contributed to our knowledge of the Columbus and Delaware limestones of Ohio. Their studies include lithologic and paleontologic descriptions of these formations and, to some extent, attempt to subdivide them into smaller units. However, the work has been confined largely to areas of outcrop; little has been done on the subsurface identity and extent of these limestones. The purpose of this report is to describe, from insoluble residue studies of the outcrop areas, certain details of the petrography that may be used as criteria to aid in the correlation of the sections along the outcrop with those in the subsurface.

AREA STUDIED

The outcrop areas of the Columbus and Delaware limestones in Ohio are as follows (fig. 1): (1) a long, narrow belt extending north from northwestern Pickaway County to the region of Kelley's Island in Lake Erie; (2) an outlier in west central Ohio, mainly in Logan County; and (3) a strip in northwestern Ohio, west of the Cincinnati Arch, which includes beds of approximately Columbus and Delaware age. Locations of the sections studied are indicated on the map (fig. 1) and described in the appendix. Because most of these sections have been adequately described in previously published reports (Stauffer, 1909; Ehlers, Stumm and Kesling, 1951), they are not repeated in this paper. Reference to the published description of each section is included with its location in the appendix.

STRATIGRAPHY

The Columbus and Delaware limestones are commonly correlated with the Onondaga and Hamilton, respectively, of New York. In early geological reports on Ohio, this Devonian limestone section was referred to as the "Corniferous"; with later division of the section the term Columbus was introduced for the lower portion, and Delaware for the upper. A complete account of the origin, definition and use of the terms may be found in Stauffer (1909) and Stewart (1955). In his work on the Middle Devonian of Ohio, Stauffer divided the Columbus and Delaware limestones into zones based on lithologic and paleontologic characteristics. Since then, most workers have attempted some form of subdivision of the Columbus limestone but have left the Delaware a single unit. Subdivisions of the Columbus have generally included 2 or 3 units rather than the several zones of Stauffer, which are difficult to recognize except in central Ohio. Several names with various meanings have been used for these subdivisions; because of duplication and incomplete description, a summary of their history, with a suggested preference, is given here.

Bellepoint member, Columbus limestone

There is general agreement on the term Bellepoint member as applied to the lower Columbus of Ohio. Named by Swartz in 1907, from exposures in a quarry

and along Mill Creek at Bellepoint in southwest Delaware County, it consists of the brown dolomitic portion of the Columbus. The best exposures now are along the south bank of Mill Creek, about 200 yards east of an iron bridge 1½ miles above the mouth. The base of the section is a conglomeratic layer, 6 inches to 1 foot thick, disconformably overlying Bass Islands dolomite. The top of the unit was placed by Swartz and Stauffer at the top of a coral-stromatoporoid biostrome, where it is present; the unit includes Stauffer's zones A, B, and C.

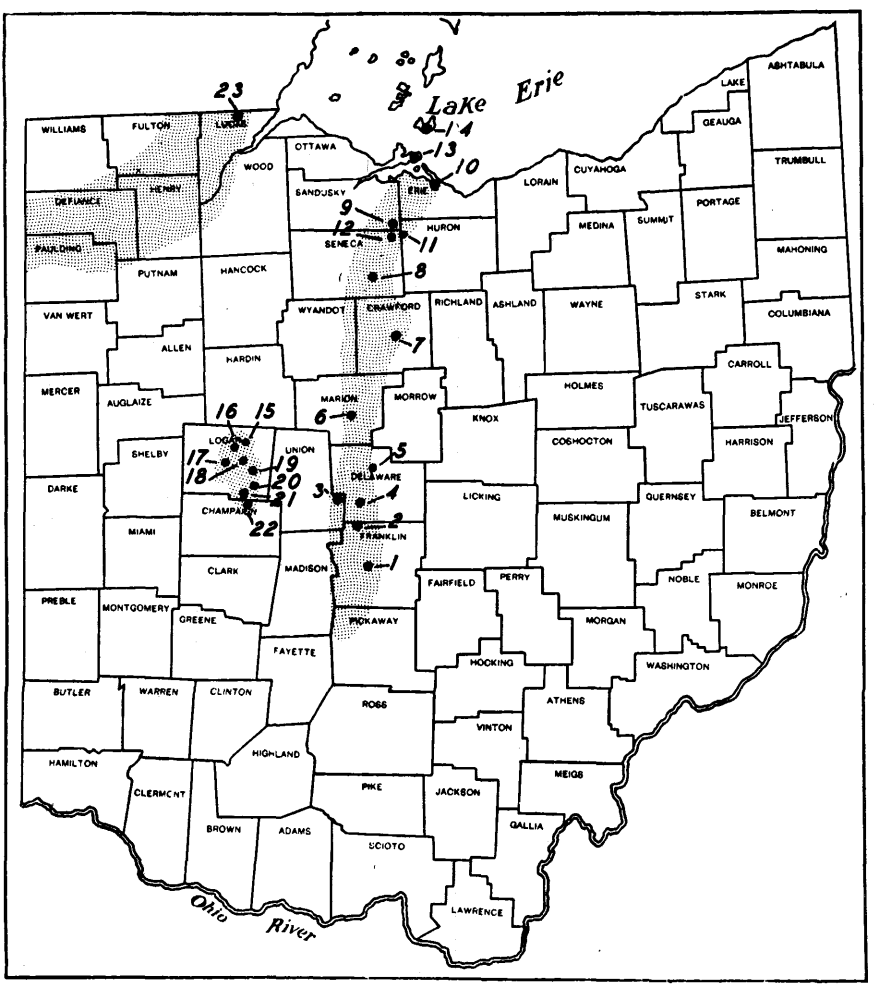

FIGURE 1. Map showing area of outcrop of Columbus and Delaware limestones and location of sections studied.

Delhi member, Columbus limestone

The designation of the upper member of the Columbus has had a more varied history.

The base of the upper part is a cherty limestone or a tan to gray crystalline limestone. The chert zone, also called the "gastropod zone," was named the

Eversole member by Stauffer, but he seems to have used the term more as one of convenience than as reference to a formal stratigraphic unit. This zone is not extensive in central Ohio. It is suggested here that the unit (Stauffer's D zone) be referred to as the gastropod or chert zone, where present, but not given a formal name.

In 1874 Winchell used the term Delhi for the high calcium limestone in the upper Columbus quarried near the village of Delhi (now Radnor) just northwest of Delaware, Delaware County. Winchell's description gave an erroneous impression of the thickness of the upper Columbus, as Stauffer later pointed out. Westgate (1926), in a report on the geology of Delaware County, called the upper Columbus Klondike, for exposures at Klondike quarry. However, he placed the base of the Klondike member about 6 feet above the top of the coral zone. He used the term "coral zone" for the biostrome layer, and "heavy limestone layer" or "*Spirifer macrothyris*" zone for the next 6 feet. In later papers Wells (1944, 1947) used first Klondike, then Delhi, for the upper member.

Swartz (1907) applied the term Marblehead member to the gray limestone in the Lake Erie area and Venice member to the overlying blue limestone. These two units, according to present interpretations, approximate the upper Columbus of central Ohio.

The Devonian limestone in the outlier in Logan County has been described by Stauffer (1909) and by Moses (1922). Stauffer identified the Monroe limestone, the Columbus limestone, and some Delaware (?) limestone overlain by the Ohio shale. In summarizing his results he indicated (1) a reduction or disappearance of the Bellepoint member, (2) a greatly reduced fauna, (3) a sandy upper zone in the limestone which may be Delaware, (4) the absence of a "bone bed" or other horizon marker for the separation of the Columbus and Delaware limestones, and (5) the absence of the Olentangy shale. He concluded that probably no separation of the Columbus limestone should be made. In the later study, Moses (1922) identified the Lucas dolomite, the Columbus limestone, and the Ohio shale. He divided the Columbus of the outlier into three parts on the basis of fossils and lithology, and suggested that the lowest part might be equivalent to Stauffer's zones A through D, and the middle part equivalent to the middle Columbus elsewhere. For lack of faunal evidence, Moses did not correlate the top part of the Columbus in the outlier.

Limestones that overlie the Detroit River group in Lucas County and adjoining areas of northwest Ohio have been called Columbus by Ohio geologists on the basis of (1) similar lithology, *i.e.*, dolomite in the lower part and limestone in the upper part; (2) similar sequence, *i.e.*, Detroit River, Columbus, and Traverse group of the west equivalent to Detroit River, Columbus, and Delaware-Olentangy of central Ohio; and (3) similar faunas. The "Columbus" of northwestern Ohio and the Dundee of Michigan are unquestionably the same unit; however, recent work on the fauna of this unit by Ehlers and Stumm (1951) and Ehlers, Stumm and Kesling (1951) suggests that the northwest Ohio "Columbus" is younger than the Columbus of central Ohio and therefore should be called Dundee. Stewart (1955), on the basis of an analysis of faunas, correlates the Dundee with the Delaware and leaves the Columbus interval unrepresented in the northwest Ohio section.

Since geologists generally agree to divide the Columbus limestone into two units, the following usage is suggested: Bellepoint member for the brown dolomitic, sparingly fossiliferous beds commonly called the lower Columbus, including Stauffer's zones A and B; Delhi member for the tan, gray, and blue fossiliferous limestone usually called the upper Columbus, including Stauffer's zones C through H. The coral, gastropod, and chert zones are considered zones in an informal sense. Because of its calcareous nature, abundant fossils, and sharp contact with the Bellepoint member, the coral zone is included in the Delhi member.

INSOLUBLE RESIDUE PROCEDURE

The thickest and most complete sections of the Columbus and Delaware limestones were selected for sampling and study. These sections were measured, and samples were taken at one-foot intervals. Most samples were selected from the limestone matrix rather than from a chert nodule, a coral, a stromatoporoid, or a clayey layer. Residues from the samples not thus selected contain a large amount of chert or clay, most of the latter reflecting the position of a clayey bedding plane or a stylolitic surface. Wherever possible, samples were selected from fresh rock.

Laboratory processing for the insoluble residues followed generally a technique used at the Illinois State Geological Survey by L. E. Workman (personal communication). A 20- to 25-gram sample of approximately pea-sized fragments was dissolved in a beaker of dilute hydrochloric acid. Some samples required heating in a sand bath for complete digestion of dolomite. The liquid was decanted and the residue washed to remove the acid. In the process of washing, agitation, and decanting, the portion of the residue finer than about 0.01 mm. was collected on filter paper. By careful and consistent handling, this size separation was kept reasonably constant. The coarse and fine residues were weighed and the quantity of each shown on graphs (see Moore, 1951; Jackson, 1952; and Struble, 1952). The coarse residue was described in detail. Although in the solution of many of the samples, an organic residue collected on the surface of the acid, no effort was made to determine its nature or quantity, and in the removal of this rather gummy substance undoubtedly some of the inorganic particles were lost. A generalized summary graph for each area studied is included here (fig. 2, 3, 4, 5).

LITHOLOGIC DESCRIPTION

A generalized section is briefly described for each of the outcrop areas. Outcrop sections of the Columbus limestone are thickest in central Ohio. The thickness has been variously reported: Stauffer (1909) estimated 105 feet; Carman (1927) measured 87 feet at O'Shaughnessy Dam; Westgate (1926) estimated 85 feet in the Delaware County area.

The Bellepoint member lies disconformably on the Bass Islands group, as can be seen at the type locality along Mill Creek in southwest Delaware County. The Bellepoint is a porous brown medium-grained dolomite. At the base is a conglomeratic interval of 6 to 8 inches, containing pebbles of tan to gray fine-grained dolomite and chert up to 3 inches in diameter. The pebbles are lithologically like the immediately underlying Bass Islands and Detroit River groups. The matrix of the conglomeratic interval is very sandy in most places, the sandiness persisting upward for 2 to 3 feet. The major portion of the Bellepoint member consists of brown and tan medium-grained dolomite in beds 6 inches to 3 feet thick, containing many well-developed stylolites whose surfaces are covered by a black asphaltic residue. Considerable recrystallization is indicated by ghost outlines of fossils and large areas of uniformly oriented grains having a common cleavage direction. Nodules of white to gray chert are present, usually scattered but occasionally in layers. The upper portion of the Bellepoint is more calcareous, and a clayey band makes a sharp break between it and the overlying Delhi.

Ranging in thickness from about 55 to 65 feet, the Delhi member in central Ohio is a medium to coarsely crystalline fossiliferous limestone containing chert in layers and scattered nodules, and numerous stylolites. The color varies from almost white through gray to tan. The lithology of the base of the Delhi is variable: In some areas it is a coral-stromatoporoid biostrome up to 4½ feet thick; the matrix is light brown fine-grained limestone with clayey layers at top and bottom and occasionally scattered through the unit; in places the corals are highly stained with petroleum residue, and heavy black residues are found on

some bedding surfaces. In other areas the lowest Delhi beds contain up to 8 feet of white to gray chert, in nodules, layers, or large masses, some of which are brecciated; they are also fossiliferous, with gastropods particularly common. In still other areas the base of the Delhi is tan fine- to medium- grained limestone.

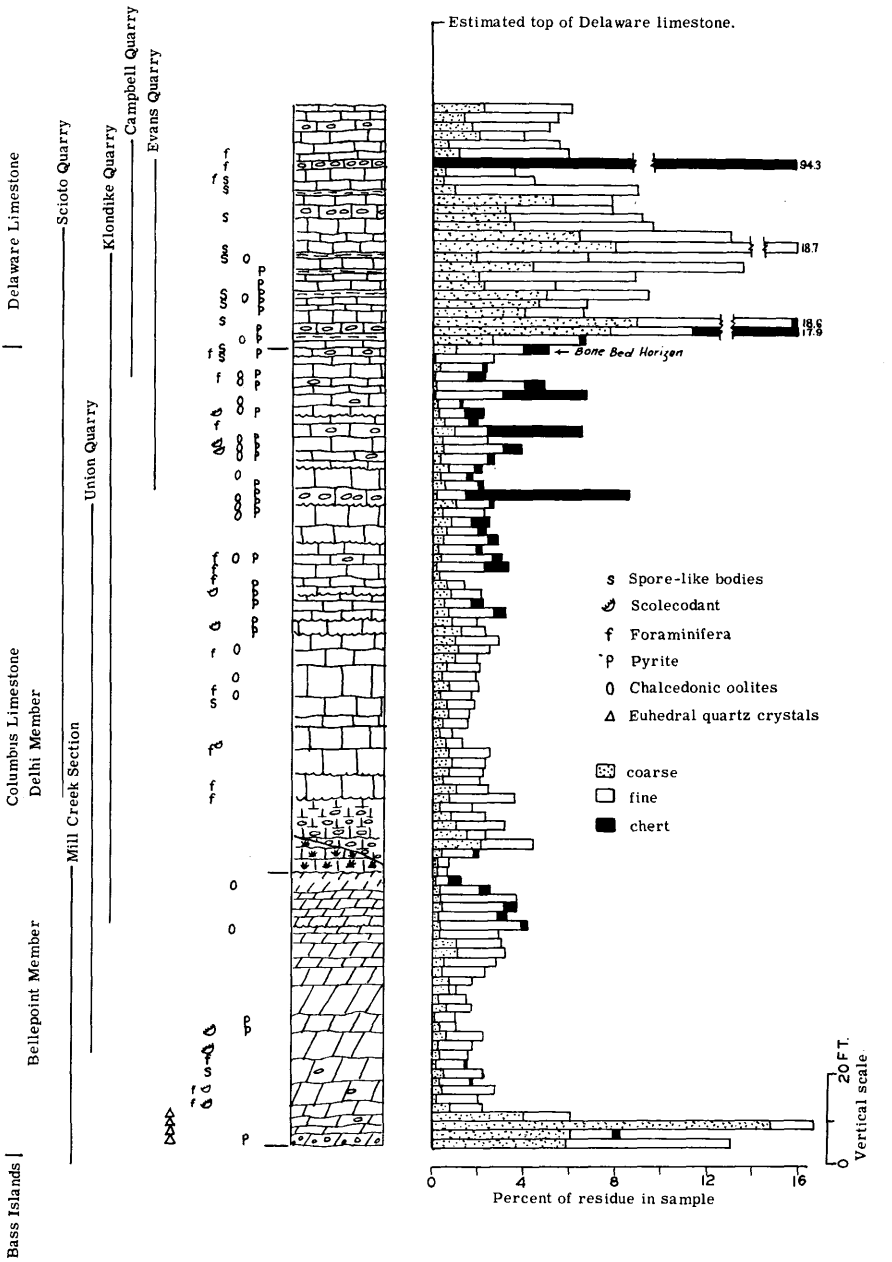

FIGURE 2. Generalized section of the Columbus and Delaware limestones in central Ohio, showing the distribution of insoluble residues.

These lower beds are overlain by light tan to gray thick-bedded limestone containing many fossils. Some layers, notably Stauffer's "*Spirifer gregarious*" zone, are almost a coquina. The upper 15 to 20 feet of the Delhi is somewhat less fossiliferous, medium to massive bedded with prominent oblique joints and scattered white to buff nodules near the top. At many localities the top of the Delhi member is marked by a "bone bed," described in detail by Wells (1944). This bed is approximately 6 to 10 inches thick, but bone material is abundant in places as much as 2 feet below the top of the member. The matrix is tan to gray coarsely crystalline limestone, in some places crinoidal.

Disconformably overlying the Columbus limestone is the Delaware limestone, which in central Ohio is approximately 35 feet thick. At the base of the Delaware in the Columbus area, the limestone is fine grained, bluish gray, and shaly, with a prominent chert interval about 8 feet above the base. Higher in the section the chert is less prominent, and most of it occurs as regular nodular layers about 1 inch thick. The formation contains less chert northward from the Columbus area. The major portion of the Delaware is fine- to medium-grained blue-gray fossiliferous limestone. Occasional layers of crinoidal limestone occur, one of which is at the position of Stauffer's *Hadrophyllum* zone, also the horizon of a bone bed. Upon weathering, the blue-gray color of the fresh limestone typically becomes brown, and originally massive-appearing beds separate into thin beds. The Delaware limestone is disconformably overlain by the Olentangy shale.

The Columbus limestone changes in character and thickness northward toward the Bellevue-Sandusky area. The basal beds of the Columbus, where it disconformably overlies the Lucas dolomite, are less conglomeratic and less sandy than those in central Ohio. These beds are tan to gray limestone or dolomitic limestone and are coarser grained than the light, fine-grained Lucas beneath. The lower and middle portions of the Columbus in the Bellevue-Sandusky area are similar to corresponding portions of the Delhi member of central Ohio. The upper 20 feet, however, is blue-gray, and is less fossiliferous and more compactly crystalline than that to the south. The Columbus limestone of northern Ohio is nowhere completely exposed; from the correlation of several quarry sections, it is estimated to be about 60 feet. The decrease in thickness is interpreted as the result of overlap from the south, with loss of the Bellepoint member; paleontologic evidence supporting this interpretation is discussed in Ehlers and Stumm (1951). Thus the Columbus limestone of the northern area is thought to be the equivalent of the Delhi member of central Ohio.

The overlying Delaware limestone also changes toward the north. It is thin to medium bedded, blue to blue-gray, medium grained, and fossiliferous. Here the lithology of the lower portion of the Delaware is similar to that of the underlying upper portion of the Columbus. Interbedded with the crystalline limestone are numerous layers of crinoidal limestone, occasionally shaly. Most of the chert is gray to black and in nodular layers; some is white and usually fossiliferous. Stauffer identified the Columbus-Delaware contact at several localities on the basis of a "bone bed" horizon, which is not so well developed as the one in the Columbus area, but seems to be in about the same position. The complete Delaware section is not exposed; an estimate of the thickness, based on correlation among several quarries, is 60 to 70 feet. It is overlain by the Plum Brook shale.

Devonian rocks of the Bellefontaine outlier include Lucas dolomite, Columbus limestone, and Ohio shale. Stauffer reported questionable Delaware limestone in several places, but his identification does not seem warranted. The total thickness of the Columbus in the outlier is estimated to be approximately 85 feet. This is the interpretation of Moses (1922), who, on the basis of fossils, placed the section at Cable below the sections at Bellefontaine and East Liberty. The maximum known thickness at any one place is approximately 65 feet, based on an interpretation of cuttings from a water well at a military installation on Campbell Hill (cuttings are on file at the Ohio Geological Survey).

The lower part of the Columbus section at Cable consists of a sandy, somewhat conglomeratic interval at the base of light brown fine- to medium-grained dolomite, with a well-developed chert interval a few feet above the base. The chert is somewhat massive, white to tan, and fossiliferous. The remainder of the section is gray medium-grained dolomite and dolomitic limestone, with some fossiliferous limestone toward the top. This section overlaps a fine-grained dolomite identified as Lucas.

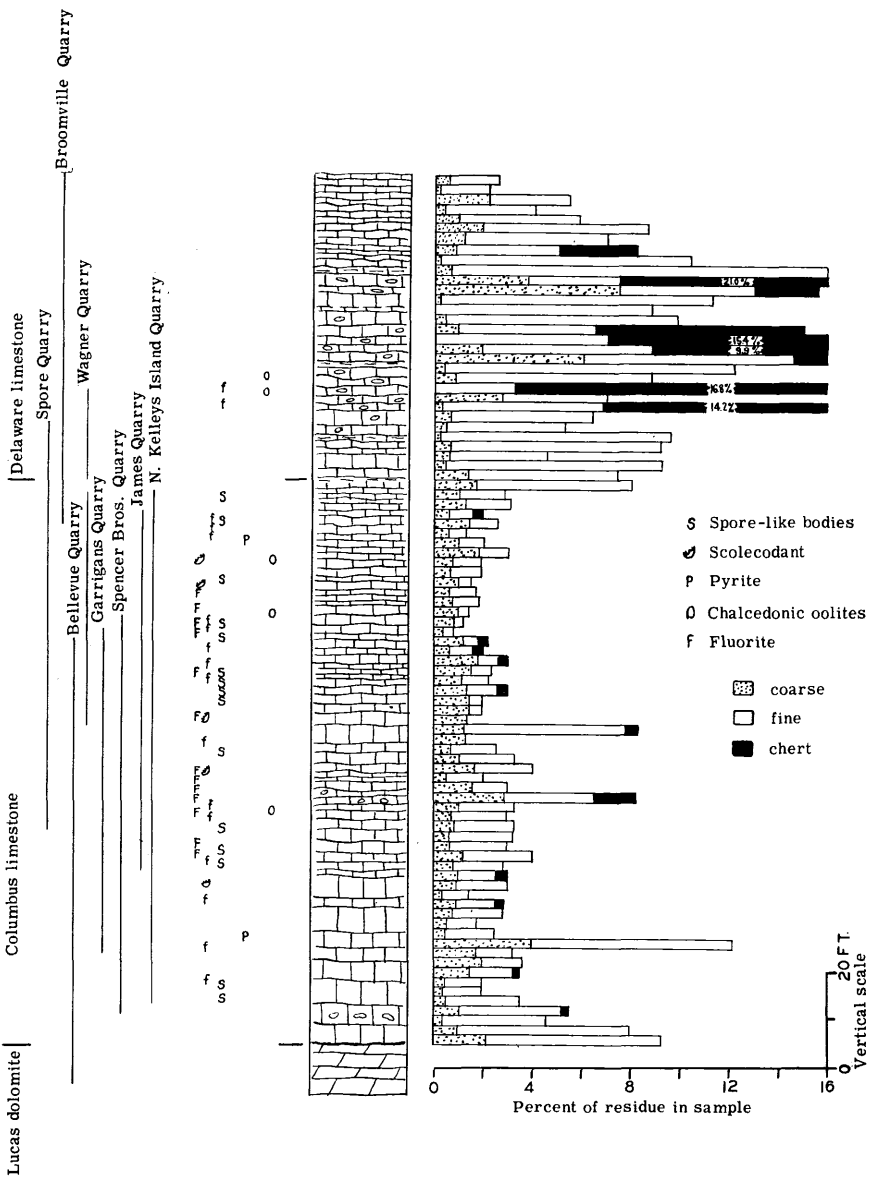

FIGURE 3. Generalized section of the Columbus and Delaware limestones in northern Ohio, showing the distribution of insoluble residues.

The contact of the Lucas dolomite and the Columbus limestone is exposed in the lower part of a quarry at the west edge of Bellefontaine. In this quarry the Columbus is massive, tan to gray, medium-grained dolomite with scattered chert nodules and fossils and with a 4-inch chert layer at the base. Fish teeth are common in the lower 2 to 3 feet. The upper part of the Columbus is best exposed in the East Liberty quarry. It is medium-grained, tan to gray-buff dolomite, dolomitic limestone, and limestone, somewhat massive but weathering into thin beds. It contains numerous stylolites and white and buff chert nodules scattered or in layers. Toward the top is a 1- to 2-feet bed of white to purplish fossiliferous chert associated with layers of crinoidal limestone. The upper 1 to 3 feet are gray to brown and sandy, with occasional bone fragments. The top surface has large areas of pyrite 1 to 2 inches thick, overlain by Ohio shale.

The Columbus(?) (Dundee) of the Lucas County area was studied only at the France Stone Company quarry at Silica, Ohio, where it is approximately 60 to 65 feet thick. It disconformably overlies the Detroit River group (Anderdon) and at the top is transitional with the overlying beds, which are called the "Blue" limestone member (Carman, personal communication) of the Silica formation. The lower 20 feet of the formation in the quarry are tan to gray thick-bedded medium-grained dolomite and dolomitic limestone, with scattered fossils, some stylolites, and chert. The chert is especially abundant in the lower 4 to 5 feet; it is nodular, white, and fossiliferous in places. The middle part of the section is buff and gray medium-bedded fossiliferous limestone with scattered chert nodules. The upper portion is thin- to medium-bedded tan and gray fossiliferous limestone. The general lithologic appearance of the formation is similar to that of the Columbus of central Ohio, but the faunal interpretation of Ehlers, Stumm, and Kesling (1951) correlates it with the Delaware.

DISTRIBUTION AND DESCRIPTION OF INSOLUBLE RESIDUES

The insoluble residues are discussed in somewhat arbitrary groups: detrital minerals—fine and coarse fractions; secondary minerals—chert, euhedral quartz, pyrite, and fluorite; and organic materials. The stratigraphic distribution of residue by percentage is summarized in figures 2, 3, 4, and 5, in generalized columns for each area studied. Graphs of the residues show the percentages of fine clastics, coarse clastics, chert, and pyrite; symbols indicate the distribution of pyrite in small quantities and of arenaceous foraminifera, scolecodonts, and spore-like bodies. Detailed descriptions of the residues by section are available in the theses of Jackson (1952), Moore (1951), and Struble (1952).

Detrital minerals—The detrital minerals of the residues were separated into fine and coarse fractions.

The fine residue consists of clay and fine silt-size grains of quartz, chert, and clay minerals; no attempt was made to identify it further. Quantities of fine residue from the Columbus limestone vary as follows: in most samples they range from 2 to 4 percent; individual samples, however, run as high as 8 percent, the cause in most cases being a clayey bedding plane or stylolitic surface at the position where the sample was taken. Clayey layers in the coral zone may run higher than 10 percent. Quantities of fine residue vary little between the upper and lower Columbus. A slight increase exists in the Columbus of the outlier, the general range there being from 3 to 5 percent. Quantities of fine residue in most samples from the Delaware limestone range from about 8 to 10 percent; individual samples contain as much as 20 percent. Since both a greater quantity and a greater range in quantity of fine material are found in the Delaware than in the Columbus, the contact between the two limestones is well marked.

The detrital portion of the coarse residue is made up of binodal quartz sand with traces of accessory minerals. The sand is of two types, with a distinct size separation. The coarser type (fig. 6, A) is fine to medium, well rounded, and

frosted, and contains some inclusions; the finer (fig. 6, B) ranges from medium silt to very fine sand and is angular to subangular. The stratigraphic positions of the coarser type are distinctive: it occurs at the base of the Devonian, whether the lowest Devonian formation be Detroit River or Columbus; at the base of the coral zone (base of upper Columbus); and at the top of the Columbus in the East Liberty quarry of the outlier. It is generally best developed at the base of the Devonian, where it is as much as 3 feet thick; an exception, however, is at the Piatt quarry in Logan County, where the sandy character persists throughout the 23 exposed feet of the Lucas formation. The sandy interval at the base of

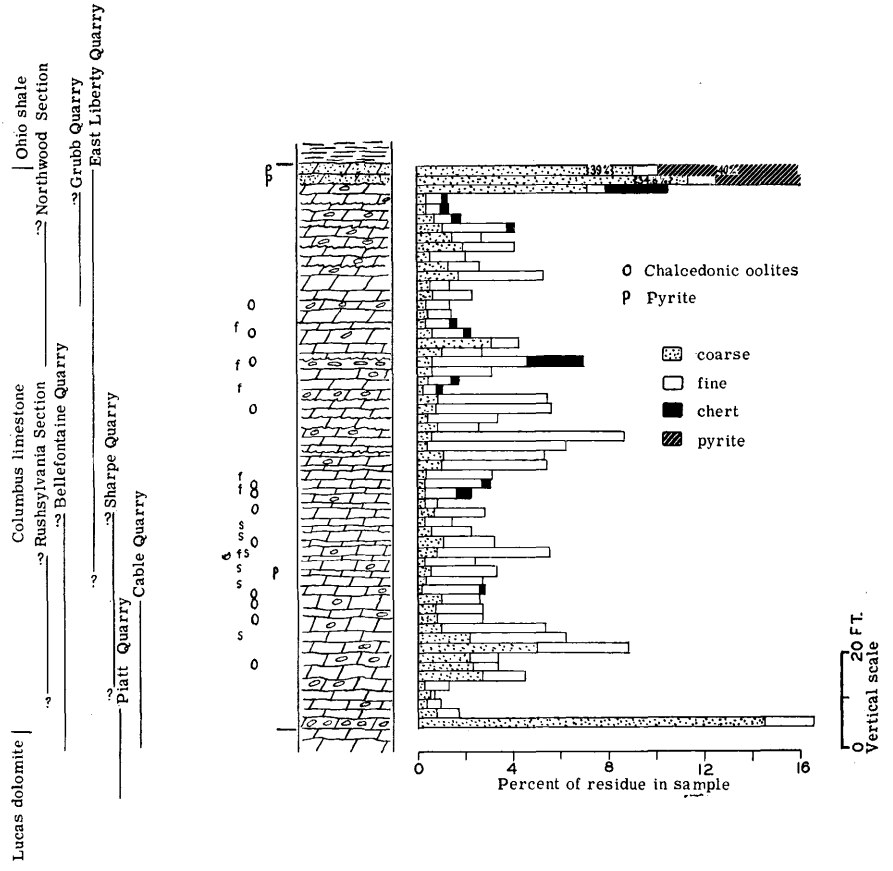

FIGURE 4. Generalized section of the Columbus limestone in the region of the Bellefontaine outlier, showing the distribution of insoluble residues.

the Columbus where it overlies the Detroit River is 1 to 2 feet thick. These intervals at the base of the Lucas and at the base of the Columbus are well shown in the section from a water well on Campbell Hill in the area of the Bellefontaine outlier (see O.G.S. well sample No. 475). Coarse frosted sand was found at the coral zone, *i.e.*, the contact between the upper and lower Columbus, in two sections in central Ohio, but there is less there than in the lower sand intervals. In the East Liberty quarry section in the outlier, frosted grains are present in the top 2 feet, where the limestone becomes impure. This is the position of the beds which Stauffer suggested might possibly represent the Delaware. In other than

these intervals, one to five coarse frosted grains per sample were found in scattered samples throughout the Columbus, but none were in those from the Delaware.

The finer silts and sands of the coarse residue range from less than 1 to 2 percent in most residues of the Columbus limestone; a few samples contain as much as 5 percent. In the Delaware limestone, the finer sand and silt fraction increases sharply to an average of 4 to 6 percent; in some samples it is more than 10 percent. This increase in quantity of the silt to fine sand parallels the increase of the finer (clay to fine silt) fraction in the Delaware residues.

Included with the detrital grains are a number of accessory minerals, most of fine sand and silt size, some angular and some rounded. The more common of these, in order of decreasing quantity, are zircon, tourmaline, feldspar, leucoxene, ilmenite, limonite, hematite, magnetite, and garnet. None of these minerals are present in quantities greater than a trace, and no identifiable pattern appeared in their distribution, either laterally or vertically.

Secondary minerals—Secondary minerals in the residues include various forms of chert, euhedral quartz, pyrite, and fluorite.

The term chert is used here to refer to mixtures of several varieties of silica, from chalcedony to cryptocrystalline quartz to macrocrystalline quartz. Chert is present in about half of the residues studied. The quantity varies widely from sample to sample. Since deliberate effort was made to avoid the larger masses of chert in sampling, percentages given here do not represent completely the distribution of chert in the formations. It was noted in the field that chert horizons vary even within a single quarry. A few observations on the general character and distribution of the larger chert nodules can be made here, but further study of the chert is needed.

In general, chert of the Columbus is light, varying from light gray to white and from cream to buff. More often than not it occurs as scattered, discontinuous nodules. Much of it is fossiliferous. In the Columbus of central Ohio, chert is found near the base and the top of the Bellepoint member, in the "chert zone," and near the top of the Delhi member. In the "chert zone" it is gray to white, massive, fossiliferous, and in many places brecciated. The Columbus of the outlier seems to contain more chert than does that of central Ohio, and more of it occurs in layers. A well-developed fossiliferous chert layer is present near the base of the Cable section, and another near the top of the Columbus in the East Liberty quarry. Chert is found in the lower part of the Columbus in northern Ohio and in the lower part of the Columbus(?) in Lucas County.

The chert of the Delaware is in well-defined, nodular layers, more continuous than those of the Columbus. It is typically gray to black, although some of it is lighter in the middle and upper parts of the formation. One type of nodule, particularly characteristic of the Delaware, is composed almost wholly of fossil fragments, largely bryozoa. Less chert is found in the Delaware of northern Ohio than in that of central Ohio.

Chert in the residues occurs in a number of forms: as massive chert fragments, some of which contain fossils; as porcelaneous, porous, white chalcedony; as chalcedonic oolites; as fossil casts of granular quartz; and as fossil casts of massive quartz.

The massive chert fragments vary in color and structure; they are white to gray to tan, and many contain small druse-filled cavities. They occur irregularly in the residues from both formations, representing portions of larger nodules which were included in the original sampling.

The white porous chalcedony occurs as fossil replacements, usually fragmentary; as large, irregular masses; and as fine sand- and silt-size fragments. This type of chert occurs in both the Columbus and the Delaware limestones but is more common in the Delaware.

Chalcedonic oolites (fig. 6, C) are well developed in many of the samples from all sections of the Columbus. Many of the oolites are clustered; some individuals

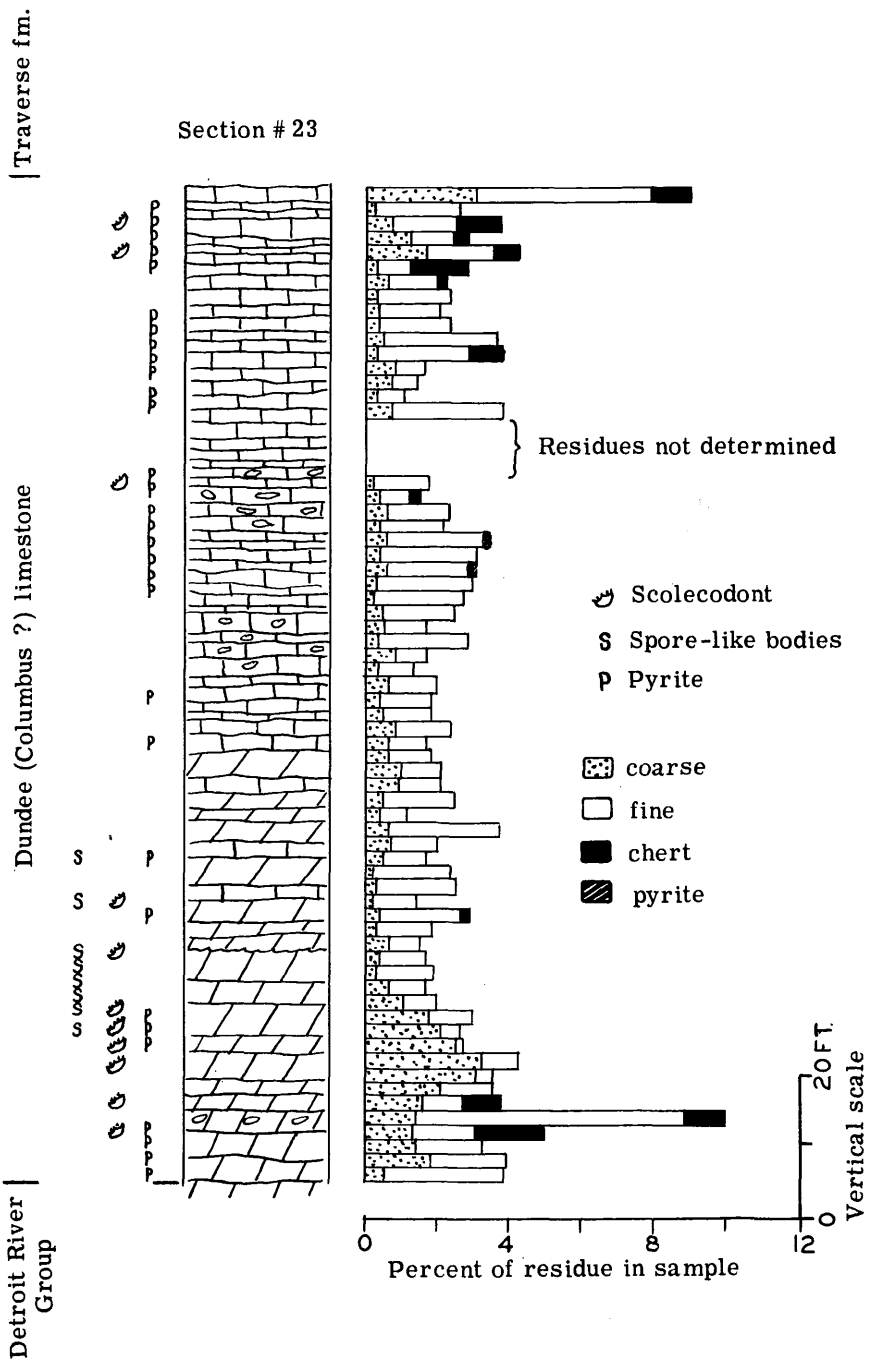

FIGURE 5. Generalized section of the Dundee (Columbus?) limestone from the Silica quarry, Lucas County, Ohio.

are large enough to be called pisolites. Some are light gray, waxy, semi-translucent chalcedony; others are varying shades of porcelaneous white chalcedony; still others are altered to spheres of clear granular quartz. These oolites and pisolites are believed to be of primary origin, for the samples contained no evidence of calcareous forms. In many of the larger fossil fragments the structure of the main mass is of massive quartz; the borders are chalcedonic and have a concentric structure like that of oolites, thereby suggesting that they represent the most recent growth (fig. 6, D). Both clustered oolites and fossil replacements were observed in residues from Mississippian limestones of Indiana by Martin (1931), who used the term "ooloid" to describe them. Although most authors believe that chalcedonic oolites are secondary replacements of original calcareous forms, both the Columbus forms described here and the Mississippian forms described by Martin suggest that these are primary structures. There appears to be a sequence of changes from the chalcedonic form to the granular silica in many of the oolitic clusters and fossil casts in the residues.

Although such oolites are occasionally found in the lower Columbus, they are particularly characteristic in the upper Columbus of all areas. Fragmentary fossil casts, usually made up of somewhat massive crystalline quartz or granular quartz (fig. 6, E), are numerous. Both types may be a result of recrystallization of "ooloids" of chalcedony. These fossil casts are one of the most common forms of chert in the residues. They occur in all units, but are especially characteristic of the upper Columbus, where they constitute the major portion of many of the coarse residues. Because the quantity of chert varies so greatly, composition, color and structure of the chert are more distinctive than amount.

Euhedral quartz is present as regenerated rounded detrital grains and as authigenic crystals, doubly terminated or in clusters (fig. 6, F). Secondary growth exists on the finer, subangular grains of the residues, but no pattern of distribution has been recognized. Grains showing secondary growth are common in the sandy Lucas dolomite in the Piatt quarry. Authigenic quartz is found in the sandy interval at the base of the Columbus in three localities.

Pyrite occurs in crystals from 0.01 to 0.1 mm., crystal aggregates, mat-like masses, and partial replacements of fossils. Its distribution in the formations is irregular both vertically and horizontally. In about half the samples it occurs as a trace of very small crystals; more rarely, as larger crystals or fossil replacements. It is most abundant at the top of the Columbus in the Bellefontaine outlier and near the contact of the Columbus-Delaware limestones elsewhere. In places the lower third of the Delaware has a slightly larger pyrite content than is generally found in the Columbus. Pyrite in small crystal particles and crystal aggregates is common in the northwest Ohio section.

Fluorite occurs in many of the residues from northern Ohio in the form of irregular crystalline masses, inclusions in chalcedony, and crystalline clusters with well-developed cubes (fig. 6, G). It is light purplish-tan to light purple. Fluorite is most common in the more porous, fossiliferous beds of the middle and upper parts of the Columbus. Distribution is not limited to any specific horizon; occurrence, however, is limited to the northern area.

EXPLANATION OF FIGURE

FIGURE 6. Examples of some characteristic materials found in the residues from Columbus and Delaware limestones. (All photographs X13.) **A.** Frosted sand. **B.** Fine angular sand. **C.** Chalcedonic oolites. **D.** Ooloid structures partially replacing brachiopod shell. **E.** Granular quartz casts of sponge spicule, bryozoan, and crinoid plates. **F.** Euhedral quartz. **G.** Crystal clusters of fluorite. **H.** Arenaceous foraminifera. **I.** Scolecodonts. **J.** Unidentified spore-like bodies.

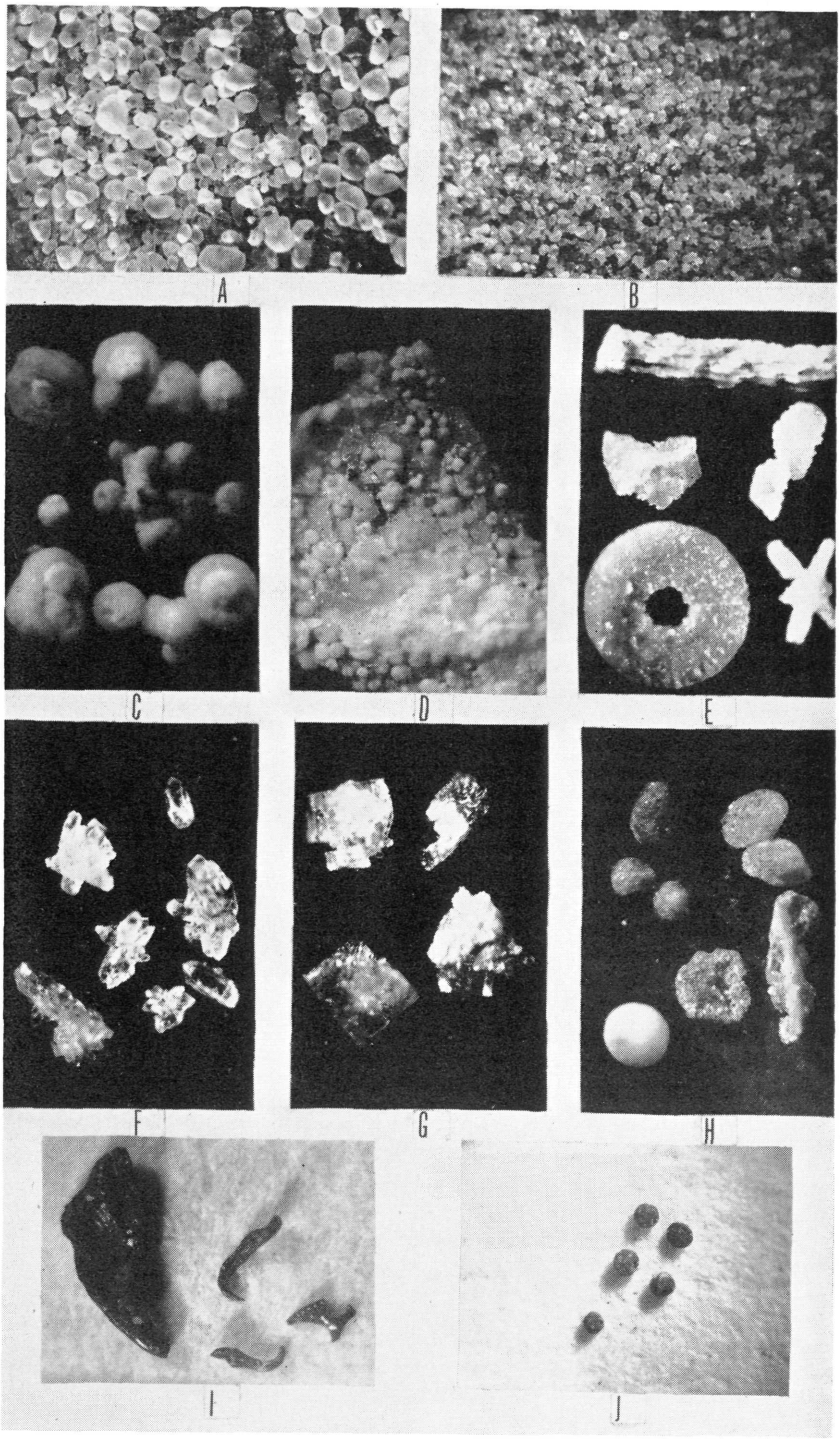

FIGURE 6

The organic portion of the residues includes bituminous material and fossils. Bituminous material emerges as a scum on the acid of a majority of the samples. It also occurs in small plate-like masses in a mixture with clay and silt fragments; in this form it is found spottily throughout both formations, but is most common in the lower Columbus and the Delaware. Fossils in the residues include arenaceous forminifera, scolecodonts, fish plates, unidentified spore-like bodies, and chalcedonic or quartz aggregate casts of crinoid parts, corals, brachiopods, sponge spicules and others. Arenaceous foraminifera (fig. 6, H), although more numerous in the central and northern areas than in the outlier, are fairly common throughout the Columbus; they represent several genera and species, including some that are new. Only a single small flattish form was found in the Delaware. Scolecodonts (fig. 6, I) show no strong stratigraphic or areal distribution. The unidentified spore-like bodies (fig. 6, J) are small brown to black hollow spheres approximately 0.03 mm. in diameter. They are abundant in certain samples from both the Columbus and the Delaware, particularly those of northern Ohio and Lucas County. Similar forms have been observed in the Onondaga of New York by J. F. Pepper (personal communication). The residues contain a few fish plates, most frequently from the position of the Columbus-Delaware boundary.

Fossil replacements by quartz crystal aggregates and by chalcedony appear in many of the residues. Although several invertebrate groups are represented, the preservation is so incomplete as to make identification of genera or species unlikely. Most of the fossil casts are concentrated at certain horizons, but these horizons occur in both Columbus and Delaware limestones. Casts formed of quartz crystal aggregates are the more common; most of them are crinoid fragments. Typically, the casts occur in the more fossiliferous beds of the upper Columbus and, to a lesser degree, in the upper third of the Delaware. The more massive quartz and chalcedonic casts may be present at certain horizons in any part of either formation. Sponge spicules of quartz crystal aggregate are especially common in the horizon of the "bone bed."

Features of the residues that offer possible means of distinguishing between the Columbus and Delaware limestones can be summarized thus:

Residues of the Bellepoint member are rather consistent in quantity of fine detrital material, silt, and fine sand. An interval of frosted sand occurs at the base. Some chert and a few chalcedonic oolites are present. Bituminous stain is prevalent, and there are scattered arenaceous foraminifera and scolecodonts.

Residues of the Delhi member contain detrital material in quantities similar to those of the Bellepoint, with a less well-defined interval of frosted sand at the base. Chert is common in the form of chalcedonic oolites and fossil casts. Fossil casts composed of quartz crystal aggregates are characteristic of this member. Numerous and varied forms of arenaceous foraminifera are present.

Delaware residues show a marked increase in the amount of detrital material of clay, silt, and fine sand size. The increase is consistent throughout both the central and the northern areas. Detrital material is less, however, in the upper part of the formation, and a limited number of samples might therefore be confused with the Columbus. The Delaware is also distinguished by a near absence of foraminifera and chalcedonic oolites.

Residues of the Lucas County section studied as a basis for comparison include most of the characteristics of the upper Columbus residues. The overlying Blue limestone is an argillaceous unit, and although sampling was not continued beyond the top of the Columbus(?), this argillaceous character should result in an increase of detrital material at the Columbus(?)-Blue contact similar to the increase at the Columbus-Delaware contact elsewhere. Nothing in the characteristics of the residues suggests that the Lucas section could not be correlated with the upper Columbus of central Ohio, despite apparent absence of arenaceous foraminifera.

EVALUATION FOR POSSIBLE USE IN SUBSURFACE CORRELATION

Residues of the Columbus and Delaware formations contain enough characteristics in common that if one were given a single residue it would be difficult, if not impossible, to identify the formation from which it came. However, if a vertical sequence were available, a subdivision of the section could probably be established.

The materials described here have been from surface outcrops. What might be the potential use of the criteria given for each formation in subsurface correlation?

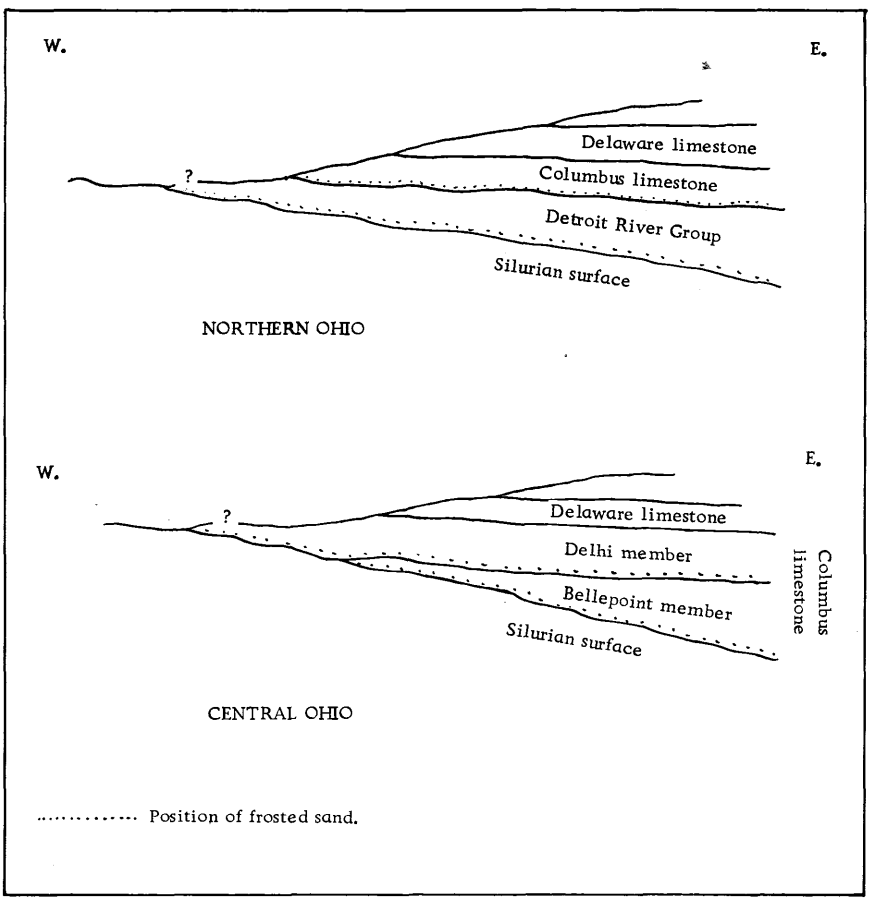

FIGURE 7. Diagram showing possible relationships of various frosted sand positions to the Silurian surface.

The stratigraphic positions of the frosted sand grains are the most outstanding feature of the residues. The origin of such grains in the Hillsboro and Sylvania sandstones has been discussed by Carman and Schillhahn (1930) and Carman (1936). The sandy interval at the base of the Devonian in central Ohio and northward to the Lake Erie islands is interpreted as a thin extension of the sand deposits of those two formations. Because of the relatively wide distribution of this sandy interval in surface exposures, it may be expected to persist for some distance in the subsurface.

A complication arises in that as many as three sandy intervals may have been developed; but, since the two additional intervals, at the base of the Columbus above the Detroit River and at the base of the upper Columbus, are probably less extensive, experience should allow one to distinguish among them. Although all of these sandy deposits represent further transgressions of Devonian seas (fig. 7), the lowest, marking the initial inundation of the sand-covered Silurian surface in this area, not only is the best developed but also should be the most extensive. The upper sand intervals representing westward overlap of successive Devonian seas probably had a more limited supply of sand and a more limited distribution into the basin. How far these intervals do extend and how they are related to the sand intervals reported as "Oriskany" in the well records remains to be determined.

The sandy character of the Lucas at the Piatt quarry and the sandy interval at the top of the Columbus at East Liberty, both in the outlier, have not been found in central and north central Ohio. Their location suggests a land area to the west and southwest that persisted to the end of Columbus time. This land might be an expression of the island referred to as Cincinnatia by Wells (1944). Sections throughout which sand is persistent, as in the Lucas of the Piatt quarry, can be explained by nearness to the shoreline, which remained in that locality throughout the deposition of the unit.

Other characteristics of the residues may also be pertinent to the problems of subsurface correlation:

First, the increase of detrital material at the Columbus-Delaware contact may be significant. If the generally accepted correlations of the Columbus with a portion of the Onondaga limestone sequence of New York and of the Delaware with the Hamilton shales and limestones of New York are correct, this difference in the detrital content of the two formations should not only persist but also increase to the east in the subsurface.

Second, although chalcedonic oolites may be of secondary origin and their distribution limited to the outcrop or near outcrop areas, it is also quite possible that they may be of diagenetic origin; if so, they may be widespread and therefore useful eastward in the subsurface. Newell (1953, p. 173) discusses this problem in relation to the siliceous replacement of fossils in the Permian limestones of West Texas.

Third, although the presence or absence of arenaceous foraminifera with chance recognition of them in the small samples from wells would hardly be very diagnostic in itself, as corroborative evidence it would be useful.

CONCLUSIONS

The insoluble residues of selected sections of the Columbus and Delaware limestones show that each formation has certain characteristics by which it can be recognized. Several lithologic features, particularly sand intervals and variation in quantity of clay-silt content, may be used to trace certain horizons eastward as an aid in subsurface correlation.

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APPENDIX

Locations of Sections Studied

The longer sections of the Columbus and Delaware formations are limited to quarries, and almost all sections studied have been described in previous publications. Therefore, to avoid repetition, only location and reference to sections are given here. Sections are in order of occurrence on the index map (fig. 1).

1. *Marble Cliff Quarries.* Section is in Marble Cliff Stone Company quarry north of Trabue Road, about a quarter of a mile west of Scioto River, west of tunnel connecting quarries north and south of Trabue Road, Norwich Township, Franklin County (West Columbus quadrangle). Section includes about 50 ft. of Columbus limestone and about 10 ft. of Delaware. It is the same as that described for the area by Stauffer (1909, pp. 44–49).

2. *Mill Creek Section.* Section is at a prominent bluff near an iron bridge across Mill Creek, 1 mile west of Bellepoint, Delaware County (Dublin-Delaware quadrangles). Section includes base of Columbus and approximately 30 ft. of Bellepoint member. Described by Stauffer (1909, pp. 73–74).

3. *Union Quarry.* Quarry is 2 miles east of Watkins, Mill Creek Township, Union County (Dublin Quadrangle). Section includes about 22 ft. of Bellepoint member and about 43 ft. of Delhi member. Coral zone is well developed at this locality.

4. *Klondike Quarry.* Quarry is on east side of Scioto River in Scioto Township, Delaware County, about 2 miles north of Bellepoint (Delaware quadrangle). Section starts in stream valley along south edge of quarry approximately at level of Scioto River and continues up valley and up face of quarry. It includes about 14 ft. of Bellepoint member and all of Delhi member of Columbus limestone. Described by Stauffer (1909, pp. 74–75).

5. *Campbell Quarry.* Section is in abandoned Campbell quarry at Delaware, Delaware County (Delaware quadrangle). Quarry is in center of west side of town, where abandoned Hocking Valley Railroad crosses Delaware Run. Twenty-five ft. section is all Delaware limestone. Described by Stauffer (1909, p. 87).

6. *John Evans Quarry.* Quarry is in northwest Marion, Marion County (Marion quadrangle), at intersection of Fairground Street and Hocking Valley Railroad. Quarry is partially filled with water, but about 34 ft. of section are exposed, including 13 ft. of Columbus and 21 ft. of Delaware. Described by Stauffer (1909, pp. 94–95).

7. *Spore Quarry.* Quarry, owned by Broken Sword Stone Company, is located along Broken Sword Creek about 6 miles northwest of Bucyrus, near Spore, Holmes Township, Crawford County (Sycamore quadrangle). Section includes some 42 ft., of which 36 are Columbus limestone, and the remainder Delaware limestone. Described by Stauffer (1909, pp. 109–110).

8. *Bloomville Quarry.* Section is in abandoned France Stone Company quarry about 1 mile north of Bloomville, Bloom Township, Seneca County (Tiffin quadrangle). Section contains about 36 ft., of which about 5 ft. are Columbus and the remainder Delaware. Described by Stauffer (1909, p. 111).

9. *Bellevue Stone Quarry.* Bellevue Stone Company quarry is located on north side of U. S. Highway 20, west of Bellevue, York Township, Sandusky County (Bellevue quadrangle). Section includes about 40 ft. of Columbus limestone, overlying probable Lucas dolomite. Described by Stauffer (1909, p. 114).

10. *Garrigan's Quarry.* Abandoned quarry is about 1½ miles west of Bellevue (Bellevue quadrangle) between U. S. Highway 20 and New York Central Railroad. Section consists of 31 ft. of Columbus limestone.

11. *Spencer Brothers Quarry.* Quarry is about 2 miles southwest of Bellevue along Nickle Plate Railroad in southwest quarter of Section 35, York Township, Sandusky County (Bellevue quadrangle). Section consists of about 40 ft. of Columbus limestone. Described by Stauffer (1909, p. 113).

12. *Wagner Quarry.* Wagner quarry section is located across road from south corner of Soldiers' Home in southeastern Sandusky, Erie County (Sandusky quadrangle). Section includes about 33 ft., of which upper 8 are Delaware and remainder Columbus limestone. Described by Stauffer (1909, pp. 125–126).

13. *James Quarry.* James quarry section is south of railroad station at Marblehead, Danbury Township, Ottawa County (Kelley's Island quadrangle). Section consists of 27 ft. of Columbus limestone. Described by Stauffer (1909, pp. 134–135).
14. *North Quarry.* North quarry section on Kelley's Island is at northern part of island near glacial grooves (Kelley's Island quadrangle). Section is about 53 ft. thick, all in Columbus limestone. Described by Stauffer (1909, p. 139).
15. *Rushsylvania Quarry.* Abandoned quarry is on the George J. Ansley farm 1½ miles east of Rushsylvania, Rush Creek Township, Logan County (East Liberty quadrangle). Section includes some 15 ft. of Columbus limestone; described by Stauffer (1909, p. 108).
16. *Northwood Quarry.* Section is in abandoned quarry on the Roberts farm, 2½ miles southwest of village of Northwood and 1½ miles south of State Route 274, in McArthur Township, Logan County (East Liberty quadrangle). Section includes about 16 ft. of Columbus limestone.
17. *Bellefontaine quarry.* Bellefontaine quarry section is south of Toledo and Ohio Central Railroad on west edge of Bellefontaine, Logan County (Bellefontaine quadrangle). Section includes about 25 ft., lowest 3 ft. being Lucas dolomite and remainder Columbus limestone. Described by Stauffer (1909, p. 103).
18. *Grubb Quarry.* Grubb quarry is on Raymond Road about half a mile east of Zanesfield, Jefferson Township, Logan County (East Liberty quadrangle). Section includes about 10 ft. of Columbus limestone. Described by Stauffer (1909, p. 103).
19. *East Liberty Quarry.* Quarry, owned by National Lime and Stone Company, is on State Route 33, 1½ miles southeast of East Liberty, Perry Township, Logan County (East Liberty quadrangle). Section includes about 40 ft. of Columbus limestone and the contact with Ohio shale. Described by Stauffer (1909, p. 106).
20. *Sharpe Quarry.* Quarry, abandoned, is on north side of Middlesburg, Zane Township, Logan County (East Liberty quadrangle). Section includes about 19 ft. of Columbus limestone. Described by Stauffer (1909, pp. 106–107).
21. *Piatt Quarry.* Quarry is located a third of a mile south of Machchee Creek on east side of Ludlow Line Road, about 2 miles east of West Liberty in Monroe Township, Logan County (East Liberty quadrangle). Section exposed includes about 23 ft. of Lucas dolomite and about 3 ft. of Columbus limestone. Described by Stauffer (1909, pp. 100–101).
22. *Cable Section.* Section is near State Route 290 half a mile south of Pennsylvania Railroad and 1½ miles west of Cable, Wayne Township, Champaign County (Mechanicsburg quadrangle). Section extends along a run to east of road on Powers farm. It consists of lower part of Columbus limestone, including a fossiliferous chert. Described by Stauffer (1909, pp. 98–99).
23. *Silica Quarry.* Section is exposed in west quarry of France Stone Company and south and north quarries of Medusa Portland Cement Company, Silica, Lucas County (Sylvania quadrangle). Section includes approximately 65 ft. of Columbus(?)-Dundee limestone. Described by Ehlers, Stumm and Kesling in the guidebook for The Geological Society of America, Detroit meeting (1951, pp. 17–18).

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