OKLAHOMA
GEOLOGY
NOTES

Cover Picture

Lithostrotionella FROM THE PENNSYLVANIAN OF OKLAHOMA

   Colonial rugose corals are common in rocks of Mississippian age in the central part of the United States but have been previously unreported in this region from rocks of Pennsylvanian age. Recently specimens of the genus *Lithostrotionella* have been found to occur commonly in the Bloyd Formation (Lower Pennsylvanian, Morrowan) in northeastern Oklahoma. Colonies up to 1.5 feet in diameter have been observed and in some localities closely spaced colonies occurring in growing positions extend laterally along a bedding plane for 4 to 5 feet. A study of these and other Morrowan corals in Oklahoma is in progress.
   The cover picture is a photomicrograph (x2.3) showing a section of a typical specimen. Note the marked variation in the development of the columella from one corallite to another.

   --Patrick K. Sutherland

Techniques of Pollen and Spore Electron Microscopy
Part I.—Staining, Dehydration, and Embedding

John J. Skvarla

INTRODUCTION

The high resolution attainable with the electron microscope has revealed morphological detail in pollen and spore walls (exines) that cannot be elucidated by light microscopy (Afzelius, Erdtman, and Sjöstrand, 1954; Rowley, 1959, 1960; Skvarla and Larson, 1965a). Published procedures for preparing pollen and spores for electron microscopy are derived from a few basic techniques, which are set forth in the present section. Prior to application of these techniques, the pollen or spores should be processed through acetolysis by standard palynological methods, and a portion of the acetolyzed sample should be set aside for light-microscopic analysis (Wilson and Goodman, 1963, 1964).

The present paper describes the procedures to be followed from the time of acetolysis through embedment in resins for ultramicrotomy, and subsequent papers will deal with ultramicrotomy, section staining, surface shadowing techniques, electron micrography, and interpretation.

OSMIUM TETROXIDE TREATMENT

The use of osmium tetroxide (OsO_4) is optional and can be omitted, if desired. It is employed in our laboratory because it assists in contributing to a more consistent quality of electron microscopic image.

The osmium is prepared as a stock 4-percent aqueous solution, which is combined with an equal volume of buffer to give a final concentration of 2 percent OsO_4. Osmium is a highly toxic, volatile substance; therefore, appropriate precautions and handling techniques should be strictly observed (Pease, 1964). Osmium is obtained in a crystalline form, packaged within sealed glass ampules. The steps in preparing a 4-percent aqueous solution of osmium from a 1-gm ampule are as follows:

(1) Soak ampule in water to remove outer gummed labels.
(2) Place ampule (after the exterior has been thoroughly cleaned) into a reagent bottle.
(3) Add 25 ml of distilled water.
(4) With a clean, solid glass rod, smash the ampule.

The osmium will dissolve at room temperature within 24 hours. A mild warming will reduce solution time to a few hours. If desired, the broken ampule can be removed by filtration, but meticulous care must be taken to eliminate introduction of contaminants. Also, filtration should be done as rapidly as possible to avoid weakening the mixture. This procedure must be carried out in a fume hood for reasons of safety.

The use of a buffer is necessary to avoid excessive osmium precipi-

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tation within and upon the exine. Although a number of buffer solutions are available, those most commonly used are sodium cacodylate, veronal acetate, and Sorenson's phosphate. The buffer is prepared as a stock solution and is mixed with the osmium when ready for use. The buffers are prepared as follows:

(1) Veronal acetate buffer (Palade, 1952)
Solution A

Sodium veronal (barbital)	14.7 gm
Sodium acetate	9.7 gm
Distilled water to make	500.0 ml

Solution B
0.1N HCl — prepared by diluting 8.6 ml of concentrated HCl (36%, 11.6 M) in distilled water to make 1 liter.

The stock buffer at pH 7.2 is prepared as follows:

Solution A	2.0 ml
Solution B	2.0 ml (enough solution B is added to adjust pH to 7.2).
Distilled water to make 5 ml	$\sim$ 1.0 ml

(2) Phosphate buffer (Sorenson, in Gomori, 1955)
Solution A
0.2M Monobasic sodium phosphate $(NaH_2PO_4 \cdot H_2O)$ — prepared by dissolving 27.8 gm in 1 liter distilled water.
Solution B
0.2M Dibasic sodium phosphate (Na_2HPO_4) — prepared by dissolving 28.4 gm in 1 liter distilled water.

The stock buffer at pH 7.2 is prepared as follows:

Solution A	7 ml
Solution B	18 ml
Distilled water	25 ml

(3) Cacodylate buffer (Plumel, in Gomori, 1955)
Solution A
0.2M Cacodylic acid, sodium salt $(Na(CH_3)_2AsO_2 \cdot 3H_2O)$ — prepared by dissolving 42.8 gm in 1 liter distilled water.
Solution B
0.2M HCl — prepared by diluting 7.6 ml conc. HCl with distilled water to make 1 liter.

The stock buffer at pH 7.2 is prepared as follows:

Solution A	50.0 ml
Solution B	4.2 ml
Distilled water to make a total of 200.0 ml	

Under a fume hood, the 2-percent buffered osmium is poured into the glass test tube containing the acetolyzed exines. A drop of wetting agent (e. g., Aerosol OT 85%) is added to aid in dispersion and immersion of the exines in the osmium. The test tube is then stoppered to prevent escape of osmium fumes.

After two hours at room temperature, the suspension is centrifuged (using a standard-model clinical centrifuge) and the osmium

is decanted. Distilled water is added, the mixture is centrifuged to sediment the exines, and the water is decanted. This process is repeated (generally three times) until all excess osmium has been removed.

Uranyl acetate is commonly used as a section stain following ultramicrotomy (to be discussed in Part II); however, exine staining has been found to be more effective when it is employed immediately after osmium treatment. If osmium is omitted, the uranyl acetate is used immediately after acetolysis.

Stain is prepared by adding powdered uranyl acetate to distilled water to make a 5-percent solution. Occasional shaking or placing of the mixture on a shaker-apparatus will insure saturation. Because uranyl acetate contains uranium and is radioactive, any part of the body splashed by the solution should be washed immediately.

Following the final distilled-water wash to remove the acetolysis mixture, or the osmium if osmication is used, sufficient uranyl acetate (3-5 ml) is added to submerge the exines. After one hour at room temperature, and with intermittent stirring with a wood applicator to facilitate exine dispersion, the mixture is centrifuged and the uranyl acetate solution is discarded. Excess solution is removed by three or four rinses in distilled water followed by centrifugation.

After removal of the uranyl acetate, one has the option of concentrating the exines into pellets by agar embedding (Rowley, 1959) or of processing them in a loose, unconcentrated state. The advantage of the former method is that numerous exines can be sectioned at one time and various orientations can thus be obtained. The latter method has the advantage of more effective infiltration by embedding resins, thus being less susceptible to thin-sectioning difficulties. As a general practice, it is recommended that exines of small and intermediate diameters be embedded in agar, but for large pollen grains such as those of the Graminae and Malvaceae and large spores such as those of the Selaginellaceae and Isoetaceae, better results are generally achieved without agar.

When agar embedding is used, a 1-percent concentration is prepared by adding the appropriate proportion of a standard brand of agar (e. g., Difco-Bacto) to a flask containing distilled water. The flask is placed in a pan of boiling water until the agar is dissolved. The completeness of solution can be assessed by the increased transparency and smooth consistency of the liquid; agar melts at $98°$ C and boils violently at $100°$ C, so it is necessary to use care at this stage. When dissolved, the agar is ready for immediate use, or it can be refrigerated for future use.

A few drops (3 ml) of viscous agar solution are transferred into the test tube containing the exines, and then the mixture is stirred rapidly with a wood applicator and immediately centrifuged. The

tendency of the agar to solidify quickly requires that centrifugation be done as rapidly as possible.

If a stock supply of refrigerated agar gel is used, a small agar wedge is removed with a metal spatula and dropped into the test tube containing the exines; the mixture is warmed until the agar is fluid enough to be stirred. The subsequent steps are as discussed for the viscous agar technique.

Centrifugation for approximately five minutes results in the compacting of agar-infiltrated exines at the tip of the test tube. Subsequently, the mixture is allowed to stand at room temperature or placed under refrigeration until solidification is complete (usually 15-30 minutes).

A solidified agar-exine pellet can be removed easily from the test tube by inserting a pipette (Pasteur disposable pipette) down the side of the test tube and blowing; this will dislodge the pellet and allow it to slide freely from the test tube. The blunt tip of the pellet containing the exines is sliced with a razor blade into thin transverse disks. The disks then are cut into small cubes (approximately 2-5 mm), which are returned to the test tube.

DEHYDRATION

The agar-exine cubes (or, in the absence of agar, the loose exines) are next passed through a graded series of 10-, 25-, 50-, 70-, and 95-percent ethyl alcohol, at room temperature, for 5 to 10 minutes in each concentration. If it is necessary to interrupt the procedure for any length of time, the 70-percent alcohol solution can be used to retain the exines. The exines are then given three 10- to 15-minute rinses in absolute alcohol to remove all traces of water. Because the agar-exine cubes sink to the bottom of the test tube in the alcohol concentrations, centrifugation of the mixture is not necessary and the alcohols can be changed by simple decanting. However, if the exines are not perfused with agar, centrifugation will be necessary.

EMBEDDING

Although several embedding resins are available, Araldite-Epon has given the best results for pollen and spores (Mollenhauer, 1964). The resin is prepared in stock quantities as follows:

Stock A
25 ml Epon 812 ⎫
15 ml Araldite casting resin M ⎬ the preparation should be
4 ml Dibutyl phthlate ⎭ thoroughly mixed
Stock B
Dodecenyl succinic anhydride (DDSA)

When ready for use, 1.8 cc of stock A is added to 2.2 cc of stock B in a disposable plastic syringe. The mixture is transferred to a disposable glass test tube and thoroughly mixed. The miscibility of the stocks can be enhanced by placement in an 80° C oven. After 5 to 10 minutes the resins are heated sufficiently and will mix readily. At this time 1- to 2-percent tridimethylaminomethylphenol (DMP-

TABLE I.—CHECK LIST FOR PREPARATION OF ACETOLYZED POLLEN
AND SPORES FOR ELECTRON MICROSCOPY

1. 2-percent buffered OsO_4 (1 hour) (optional)
   (Rinse in distilled water until free of osmium fumes)
2. 5-percent uranyl acetate (2 hours)
   (Rinse in distilled water 3-4 times)
3. 1-percent agar embedding (for small and intermediate-
   sized pollen and spores). Cut pellet into small cubes
4. Alcohol dehydration (10, 25, 50, 70, 95, 100%) (5-10
   minutes)
5. Reagent-grade acetone infiltration (2 treatments) (10
   minutes)
6. Araldite-Epon embedding:
   2 parts acetone + 1 part Araldite-Epon (1 hour)
   1 part acetone + 2 parts Araldite-Epon (1 hour)
         100% Araldite-Epon (1 hour)
7. Aluminum trays or capsules
8. Heated vacuum desiccator (80-90° C)
9. Laboratory oven (80° C) (6-12 hours)

30) is added. As this ingredient will determine the final hardness of
the resin, considerable caution must be exercised in estimating the
proper amount to be added; too little DMP-30 will result in a soft
resin and make ultramicrotomy difficult or impossible; too much
DMP-30 will cause the resin to become brittle and can damage the
diamond knives used in ultramicrotomy. As the shelf life of DMP-30
is only a few months, it is generally good practice to make an initial
test without exines, in order to determine the proper resin hardness.
For fresh DMP-30, 1 to 4 drops are added to every 4 cc of resin; for
older DMP-30, 6 to 10 drops are used.

After the DP-30 is added to the warmed resin, the mixture is
again thoroughly shaken. The easiest way to insure mixing is to place
the test tube on an automatic mixer (e. g., Vortex-Genie).

The steps in embedding:

(1) Immediately following the final alcohol rinse, the
    exines are given two 10-minute soakings in reagent-
    grade acetone.
(2) After decanting the last acetone rinse, the resin
    mixture described above is diluted in a ratio of 2
    parts acetone to 1 part resin, and is added to the
    exine preparation.
(3) After one hour at room temperature, the solution is
    decanted (exines not embedded with agar must be
    centrifuged) and an acetone-resin mixture in a ratio
    of 1:2 is added.
(4) After one hour the solution is again discarded and
    100-percent resin is added.
(5) After one hour the entire mixture (i. e., 100% resin
    and agar-exine cubes) is poured into aluminum trays
    (see appendix for preparation of trays). For loose
    spores and pollen the mixture also can be poured into
    aluminum trays, but the exines are better concen-

trated by pouring into "OO" gelatin capsules or special plastic capsules (Beem capsules) having a fine blunt tip.

(6) The aluminum trays (or capsules) are placed in a vacuum desiccator heated to 80-90° C and allowed to warm for 5 minutes at atmospheric pressure.

(7) Vacuum is then applied. Special care is required to avoid excessive boiling with ensuing loss of agar-exine cubes from the containers. Such loss can be prevented by intermittent evacuation, allowing a few seconds for the bubbling to subside each time before applying further vacuum.

(8) When the bubbling has ceased, indicating that all traces of air or water are removed from the exines, atmospheric air is admitted to the desiccator. The containers are then placed in an 80° C laboratory oven. After 6 to 12 hours the resin is hardened sufficiently and is ready for ultramicrotomy.

DISCUSSION

Techniques described here have given sufficiently consistent results to warrant adoption as routine procedures in our laboratory. Other processing techniques, which are variations of that already described, also can be employed. The following discussion of these variations, with the reasons for using them, is aimed at providing the palynologist with sufficient understanding to cope with any special problems which may arise in exine analysis.

Osmium tetroxide is a standard fixative for biological tissues used to preserve the fine structure of the protoplasm. Because acetolyzed exines are devoid of protoplasm, some workers omit this treatment. It has been suggested that exine density yields an adequate image without osmium treatment (Afzelius, 1957, p. 126). Another observation is that the process of acetolysis, or of treatments prior to acetolysis (i. e., alcohol treatments involved with removal of pollen from herbarium sheets) may enhance staining propensity of the exines in much the same fashion as does osmium treatment (Larson, 1964).

Notwithstanding the merit of these opinions, osmium tetroxide is used in our laboratory because exines so treated react more favorably with stains containing heavy metal atoms, such as uranyl acetate and alkaline lead hydroxide section stains (the latter to be discussed in Part III), thus producing an image with over-all enrichment of contrast, as well as improving differential contrast between exine layers. Osmium apparently reacts with the exines and perhaps the embedding resins in such a way as to make ultramicrotomy less difficult (Larson, 1964), thus reducing sectioning time and perhaps extending the life of the knife edge whether it be diamond or glass.

A limited use has been made of treatments other than those employing buffered osmium, following acetolysis and prior to dehydration. Aqueous, unbuffered osmium has been found to accentuate certain exine features (Skvarla and Larson, 1965b) but has the disadvantage of producing excess precipitate. Another stain used at this stage,

aqueous, unbuffered 2-percent KMnO₄ (Mollenhauer, 1959), has questionable value for the palynologist; comparison of this stain with other staining techniques has shown that permanganate is an unreliable treatment for differentiating exine stratification layers, and may even introduce artifacts in the form of spurious stratifications in the exines.

The variety of resins commercially available has provided electron microscopists with a choice of several embedding mixtures (see Pease, 1964, for extensive lists). The first embedding resin used on palynological materials, and one which is still commonly used, is methacrylate (Mühlethaler, 1953; Afzelius, Erdtman, and Sjöstrand, 1954). Although methacrylate-embedded exines can be sectioned with relative facility, the methacrylate tends to vaporize under the electron beam, resulting in contamination of the microscope and introduction of specimen artifacts. Methacrylate also has the undesirable feature of requiring a 72- to 80-hour polymerization period before microtomy can be executed.

As an alternate approach, the aliphatic resin Epon 812 (Luft, 1961) was found to provide excellent image contrast for exines, while overcoming the contamination and polymerization difficulties characteristic of methacrylate. The only undesirable feature was the microtomy became unpredictable owing to the difficulty in controlling hardening properties of the Epon.

At present the most suitable embedment is one which combines Epon 812 with an aromatic resin, Araldite 502 or 6005 (Mollenhauer, 1964). This mixture is used routinely in our laboratory and has been found to give the most consistent results.

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Appendix

Preparation of Aluminum Embedding Trays

Embedding trays are made from heavy-weight household aluminum foil (e. g., Reynolds Wrap, Alcoa). By pressing small (i. e., 5-6 cm) squares of foil into a hand-operated die, as shown below, the appropriate shape can be fashioned. Such a die can be improvised from a wooden dowel or a hard rubber stopper and a metal cap, 3 to 4 mm deep, and only slightly larger in diameter than the dowel. (A more durable die may be machine tooled from solid aluminum cylinders.) Before the embedding resin is added, the interior of the boats should be swabbed with mold release (Marblette) in order to facilitate removal of the aluminum foil after polymerization of the resin.
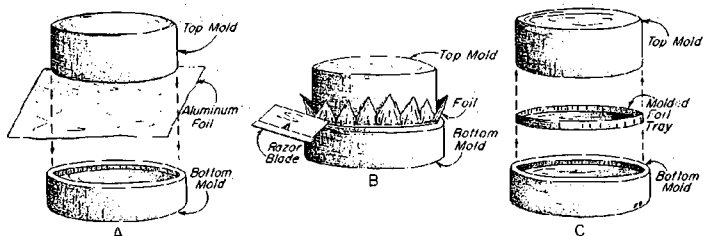
Certain types of flexible plastic bottle caps (available at pharmacies) can be used in place of aluminum foil as embedding trays. However, as some plastics soften and warp at polymerization temperatures, it is advisable to test plastic caps in advance, to avoid undesirable surface contours or loss of materials. Mold release is not necessary when using plastic caps.

Developments in the Oklahoma Portion
of the Arkoma Basin, 1960-1965

John F. Roberts

The first natural-gas production in the Arkoma basin in eastern Oklahoma was near Poteau in Le Flore County in 1910. In the next few years several fields were discovered and developed as far west as Quinton in Pittsburg County. Production was from Hartshorne and upper Atoka sandstones at depths of less than 3,000 feet. All the gas was used locally, supplying small towns, smelters, and glass factories.

The first deep natural-gas production was discovered by the Red Bank Oil Company 1 Fee, sec. 23, T. 9 N., R. 24 E., in the basal Atoka sand in 1930. This deeper reservoir was not further developed until during World War II.

In the early 1950's, as the price of gas began to rise, several companies renewed activities in this large gas area and began acquiring blocks of acreage on known structures. In the late 1950's, deeper production was found in the old Kinta field and on the Milton anticline, both in Haskell County, just west of the Cartersville field.

Since Branan and Jordan in 1960 reviewed the early exploration in the Oklahoma portion of the Arkoma basin, development drilling there has increased yearly, whereas exploratory efforts have remained essentially constant.

During 1960 the Midwest Oil Corporation 1 Orr, C SW¼ sec. 8, T. 6 N., R. 22 E., in the old Norris field (Hartshorne gas production)
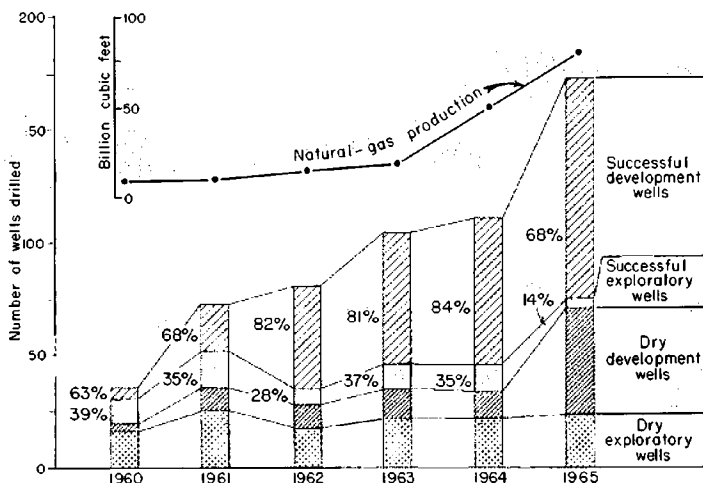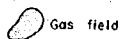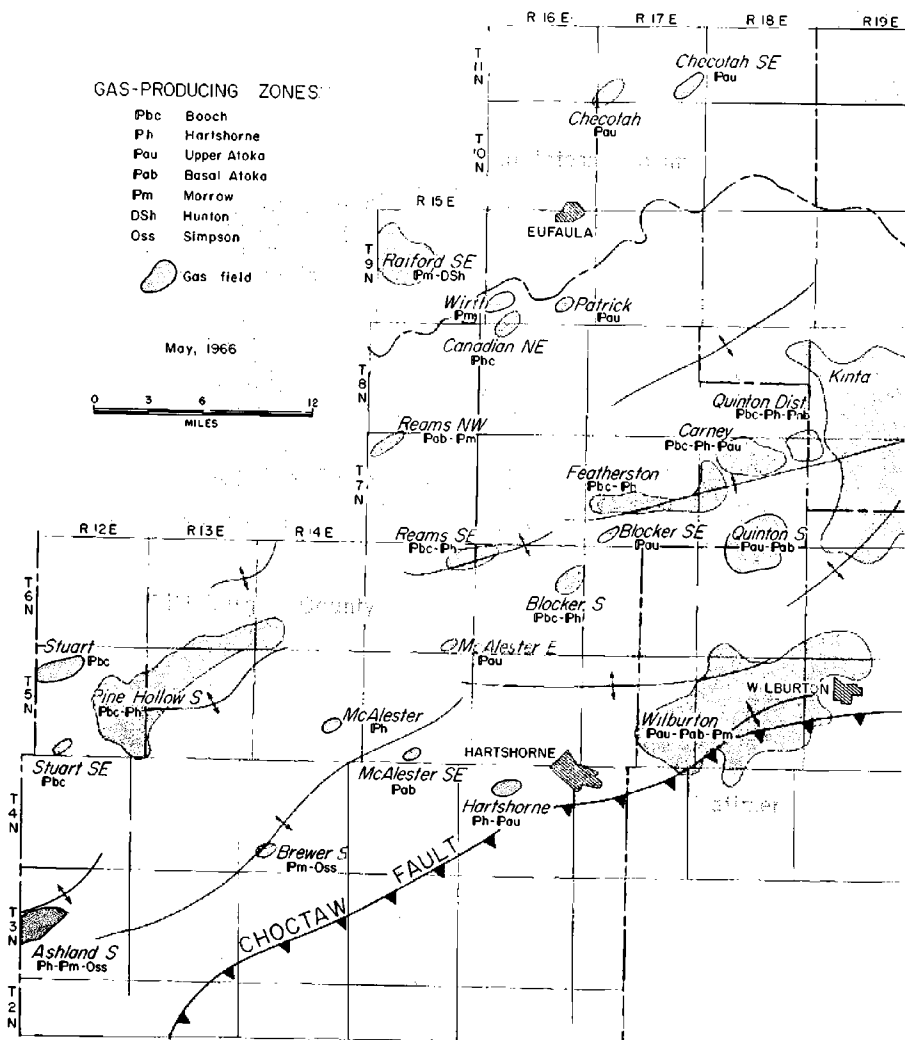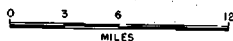

Figure 1. Annual natural-gas production, number of wells drilled, and success ratios in the Oklahoma portion of the Arkoma basin, 1960-1965.

GAS-PRODUCING ZONES

Pbc	Booch
Ph	Hartshorne
Pau	Upper Atoka
Pab	Basal Atoka
Pm	Morrow
DSh	Hunton
Oss	Simpson

Gas field

May, 1966

0   3   6   12
MILES

Checotah SE
Pau

Checotah
Pau

EUFAULA

Raiford SE
Pm-DSh

Wirth
Pm

Patrick
Pau

Canadian NE
Pbc

Kinta

Quinton Dist
Pbc-Ph-Pab

Reams NW
Pab-Pm

Carney
Pbc-Ph-Pau

Featherston
Pbc-Ph

Reams SE
Pbc-Ph

Blocker SE
Pau

Quinton S
Pau-Pab

Blocker, S
Pbc-Ph

Stuart
Pbc

McAlester E
Pau

Pine Hollow S
Pbc-Ph

W LBURTON

McAlester
Ph

Wilburton
Pau-Pab-Pm

Stuart SE
Pbc

HARTSHORNE

McAlester SE
Pab

Brewer S
Pm-Oss

Hartshorne
Ph-Pau

CHOCTAW   FAULT

Ashland S
Ph-Pm-Oss

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Figure 2. Map of the Oklahoma portion of the Arkoma basin, showing natural-gas fields, their producing zones, and positions of major anticlinal axes.

was a dual completion in the Red Oak sand at depths from 7,180 to 7,335 feet and basal Atoka sand at depths from 11,510 to 11,570 feet. Bottom-hole shut-in pressure was 4,775 psi in the deeper zone. About the same time the Ambassador Oil Corporation 1 Williams Unit, C NW¼ sec. 23, T. 5 N., R. 18 E., in the old Wilburton field (upper Atoka production) was completed in basal Atoka sand between 8,811 and 8,831 feet. Bottom-hole shut-in pressure was 4,629 psi. These two wells, completed at greater depths than previous discoveries, and with higher pressures and thicker sands, indicated that much greater gas reserves should be present in the basin than had been believed.

In 1961 twice as many wells (73) were drilled as in the previous year. This was due to the fact that realization of greater reserves per acre inspired rapid development of acreage under lease before expiration dates. By this time lease bonus prices had increased many times regardless of relation to known surface structures. The increased drilling activity resulted in many discoveries in both deeper and shallower zones in proved areas and in the successful completion of numerous step-out wells, 2 or 3 miles from production.

Total drilling again increased in 1962, with discoveries in new zones, outposts, and new fields. Most significant was the discovery of dry natural gas in the Simpson and in the Arbuckle. The Carter-Gragg Oil Company 1 Mullins, C SE¼ SW¼ sec. 29, T. 4 N., R. 14 E., was a dual completion in Morrow at depths of 10,231 to 10,346 feet and in Simpson at depths of 11,664 to 11,900 feet. The Pan American Petroleum Corporation 1 Williams Unit, C E½ SE¼ NW¼ sec. 36, T. 8 N., R. 22 E., after crossing a fault from Atoka into Simpson beds, was drilled to a total depth of 9,800 feet in basement rocks, and casing was set through the Arbuckle. Tests through perforations in the Arbuckle gauged gas as much as 5 million cubic feet per day, but formation water was associated. Attempts to isolate the salt-water zones and maintain commercial gas production were unsuccessful, and the well was plugged.

In 1963 and 1964 total drilling activity continued to increase and additional pay zones were discovered in proved areas. Extensions were completed and new fields were discovered in all parts of the basin. An interesting completion, the Humble Oil & Refining Company 1 Bledsoe in sec. 9, T. 8 N., R. 23 E., described by Jordan (1964), found significant dry natural gas in the Hunton and Simpson. The nearest Hunton production had been 40 to 50 miles to the east and west; east in the Bonanza field in Sebastian County, Arkansas, and west in the Southeast Raiford field in McIntosh County. The only other Simpson production was 40 miles to the southwest in southwestern Pittsburg County.

Development-drilling activity in 1965 jumped to a high of 173 well completions. This increase was due to completion of a major gas pipeline reaching from the Arkansas border into Coal County. This pipeline assured early connections for newly completed wells, avoiding the delays previously endured before the development of a market. Exploratory efforts declined and fewer discoveries and extensions were

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made than in many of the previous years. The most significant discovery of the year appears to have been the Gose 1 White Fuel, C SW¼ NE¼ sec. 34, T. 7 N., R. 18 E., a dual completion in upper and basal Atoka and the initial well in the South Quinton field, which now has several producers and extends southward into T. 6 N., R. 18 E. Of interest are the completions in the Wilburton field of Latimer County, south of the surface trace of the Choctaw fault zone. Those wells in T. 5 N., R. 18 E., south of the fault, reached reservoirs similar to their north offsets which reached the basal Atoka sand in the 10,000-foot to 11,000-foot range. However, the Shell 1-4 Williams-Mabry, sec. 4, T. 4 N., R. 18 E., seemed to cut several thrust-plates in drilling to a total depth of 9,541 feet. The well was plugged back for completion in the first penetration of basal Atoka sand at 2,947 feet to 3,042 feet. It was offset east, west, and south by dry holes.

Drilling in 1966 has continued the pace attained in 1965. Additional gas-sales contracts have been signed, bringing the leased acreage committed to sales contracts to approximately 90 percent. This fact should lead to rapid orderly evaluation of all undeveloped or unexplored acreage.

Several discoveries have been made so far in 1966. Notable is the Peno field in T. 10 N., R. 27 E., in northeasternmost Le Flore County. Four wells have been completed in three zones, Alma, basal Atoka, and Cromwell.

Figure 1 shows annual natural-gas production and the total drilling in the Arkoma basin from 1960 through 1965. It is noted that 1961 and 1965, the years showing the greatest increase in the total number of wells over the previous year, have lower success ratios than have the more similar years of 1962, 1963, and 1964. Perhaps these three years reflect more consideration in the selection of drilling locations. The graph is based upon information from the Oklahoma Corporation Commission, from the *Oil and Gas Journal,* and from publications of the American Association of Petroleum Geologists and the International Oil Scouts Association.

Figure 2 shows the present fields in the basin, their productive zones, and relationships to major surface anticlinal axes. The rapid increase in areal extent of various fields resulted in confusion as to the boundaries of neighboring fields. Kinta has engulfed such familiar old fields as Cartersville, Redlands, Lequire, McCurtain, Milton, and Bokoshe.

A selected bibliography of symposium-type publications, each of which contains numerous papers containing both general and specific information pertinent to the Arkoma basin, is appended. Most of these papers contain comprehensive bibliographies of earlier works concerning the area.

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GEOLOGICAL HIGHWAY MAP SERIES

CARL C. BRANSON

The first of a proposed series of eleven geological highway maps of the United States was issued by the American Association of Petroleum Geologists during its fiftieth convention at St. Louis in April. The map was prepared by the Geological Highway Map Committee, Phillip Oetking (chm.), Dan E. Feray, and H. B. Renfro. The first map covers Missouri, Arkansas, Kansas, and Oklahoma. The scale is one inch to 30 miles and the color printing is well done in 39 colors.

The map serves its purpose well: to provide a guide to geologic units for informed laymen and earth-science teachers and students. The map is obtainable from A. A. P. G. headquarters, Box 979, Tulsa, Oklahoma, 74101. It is available folded for $1.00, or rolled for $1.25.

This first map was compiled without consultation with any of the four state geological surveys concerned. Had such advice been solicited, some errors would have been eliminated. For instance, in Oklahoma, Jackfork is Meramecian, Paluxy is Antlers, the spelling is Collings Ranch, Springer is Chesterian, Mayes in the Arbuckle Mountains area is but a subsurface facies.

Nonetheless, the map is a good beginning, and the committee should be admired for its efforts and service.

Type Section of the Oologah Limestone

P. A. Chenoweth*

INTRODUCTION

The purpose of this note is to present and describe a type section of the Oologah Limestone (Desmoinesian). Meager exposures in the area of the type locality have necessitated the use of a drilled core for the type section. A precedent for such usage is clearly established (Cohee, 1956, p. 2012).

The Oologah Limestone of northeastern Oklahoma and southeastern Kansas is a widely recognized and useful stratigraphic unit. It is often used as a subsurface mapping datum in much of northern Oklahoma. The formation is formed by the coalescing of two ledges of limestone, the Pawnee and Altamont, which farther north are separated by the Bandera Shale (Gould, 1925, p. 69). From the vicinity of Talala, Rogers County, southward to Broken Arrow, Tulsa County, the Oologah is exposed in conspicuous bluffs and a narrowing belt of rolling limestone hills. At Broken Arrow the unit changes abruptly to shale and cannot be recognized south of this locality. The equivalent strata occupy a position near the base of the Wewoka Formation.

The Oologah was named and first described by Drake (1897) from exposures along Fourmile Creek at the west edge of the town of Oologah, Rogers County, Oklahoma. Drake's original description, quoted below, is rather brief and generalized and does not contain a detailed type section. Oakes (1952), Peterson (1951), Travis (1942), Alcock (1942), and Sparks (1955) all included partial measured sections of the formation in the general vicinity of the type locality.

Workers in northern Oklahoma, notably Ohern (1910), applied the terms Pawnee, Bandera, and Altamont (as defined in Kansas by Swallow [1866], Adams, Girty, and White [1903], and Adams [1896]) to equivalent units in Oklahoma, regarding them as formations which merge southward to form the Oologah. Oakes (1952) revised the nomenclature and extended the name Oologah to the Kansas-Oklahoma line to include, in ascending order, the Pawnee Limestone, Bandera Shale, and Altamont Limestone as members. Since the limestones form prominent escarpments and the intervening shale thins rapidly and irregularly both southward along the outcrop and westward in the subsurface, it seems desirable to retain Oakes' usage in Oklahoma. Furthermore, owing to the value of the Oologah as a subsurface mapping datum in all of northern Oklahoma (it is most frequently referred to as the "big lime" in the subsurface [Jordan, 1957, p. 17]), the establishment of a type section would be most useful. Reasons for such a section are clearly set forth by Dunbar and Rodgers (1957, p. 269):

> . . . we hold that a formation is primarily based on a concept in the mind of its describer, and that the type

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* Sinclair Oil & Gas Company, Tulsa, Oklahoma.

section is a device for obtaining at least one objective tie-point for the concept. Whoever thereafter uses that for-mation name implies that he has tried to determine as well as he may what was the original concept of the for-mation and that he either accepts that concept or is modifying it within reasonable limits, which should be explicitly stated, and in any case that he still includes within the formation those beds at the type locality that the original describer considered typical.

Exposures of the Oologah in the type locality are incomplete. Erosion has produced a steep escarpment in the gorge of the Verdigris River east of the town, and the lower portion of the formation is admirably exposed in cliffs at the east end of Oologah dam (fig. 1). A better and fresher exposure is that in the quarry near the camp ground at the west end of the dam. Filling of the reservoir will, how-ever, partly obscure both of these outcrops. Only the upper few feet of the formation crop out along Fourmile Creek about two miles west of the river. Between these two main areas of outcrop an unknown thickness of the formation is buried beneath a veneer of soil and alluvium. Regional dip is very low to the west, on the order of 40 to 50 feet per mile; consqeuently a complete well-exposed section is not available for study.

Although the Oologah is abundantly fossiliferous in the vicinity of the type locality and elsewhere, the only published systematic
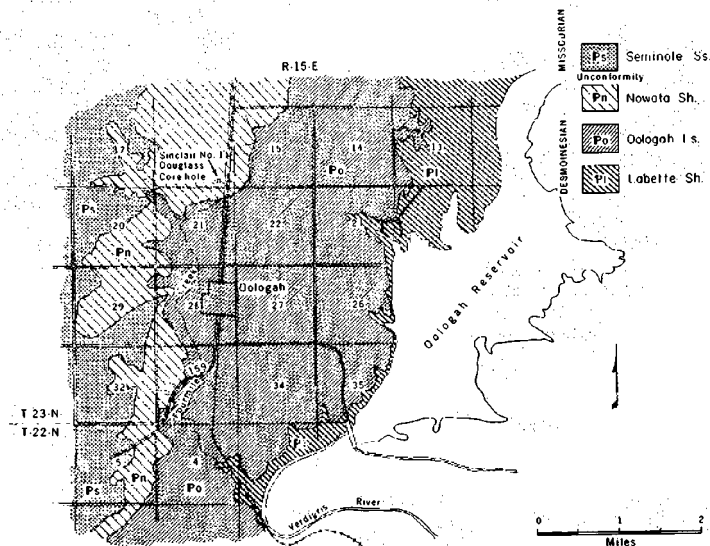

Figure 1. Geologic map of the vicinity of the type section of the Oologah Limestone, near Oologah, Rogers County, Oklahoma.

faunal list is too brief to be of value (Decker, in Gould, 1925). The more comprehensive listing of Peterson (1951) is neither readily available nor are the illustrations of good quality.

Drake (1897, p. 377) established the Oologah as a formation. His original description is as follows:

> At and in the vicinity of Oologah this limestone is massive, hard, gray, rather unevenly textured, and in places contains gray chert nodules. On weathering, the limestone breaks into irregular pieces. This bed forms an east-facing escarpment fifty to one hundred feet high along the west side of Verdigris River valley east of Oologah.

The name was established in a footnote on page 377:

> This bed has been called the Oologah limestone because it is finely exposed in Oologah, along Four Mile Creek at the west edge of Oologah, and in an escarpment some three miles to the east of that place.

In the subsurface, the formation is recognized in much of northern Oklahoma. It is known from wells in the Oklahoma City area (Kurash, 1964) and is present above the Fort Scott (Oswego) Limestone in the Northeast Gage pool of Ellis County (Richardson, 1965, p. 99). Apparently the formation was laid down upon a shelf, the southern border of which had an arcuate trend, convex toward the south. First oil production in Tulsa County was from the Oologah (Dillé, in Oakes, 1952, p. 113), where the formation was erroneously equated by drillers with a thick limestone found at the same depth in the oil fields of Pennsylvania. The term "big lime" thus came to be applied to the Oologah. This usage has spread, and at present both geologists and drillers use the term more or less loosely (as in Richardson, 1965) for the Oologah, as well as for other limestones (Jordan, 1957, p. 17). It is partly in the hopes of establishing uniformity in the nomenclature of this unit that this paper is being presented.

The Oologah Formation and its equivalents in Kansas (Pawnee Limestone, Bandera Shale, Altamont Limestone) are assigned to the Marmaton Group of the upper part of the Des Moines Series (Moore, 1948; Oakes and Jewett, 1943). It rests upon the Labette Shale; at localities near Tulsa is some evidence for a slight disconformity at the contact. In the type locality, however, the contact appears to be sharp and even and shows no evidence of erosion. A 6-inch bed of calcarenite, replete with specimens of the large brachiopod *Echinaria semipunctata* (Shephard), is just above the contact in the bluff below the Will Rogers birthplace in SW cor. sec. 13, T. 23 N., R. 15 E., about 2.5 miles east of the type section. This bed cannot be identified in the core of the type section. At places are discontinuous beds and lenses of fossiliferous calcarenite and concretionary calcilutite in the upper part of the Labette, but at only one or two localities is it difficult to distinguish the contact.

The Oologah is overlain conformably by a dark-gray to coaly

black bed of carbonaceous to phosphatic shale here assigned to the Nowata Formation. The contact is uneven and sharp (fig. 2). Travis (1942) regarded this dark phosphatic shale as an equivalent of the Stone Lake Member of the Altamont Formation (Alcock, 1942, p. 66). An 18-inch bed of dense limestone above the shale was equated with the Tina Limestone Member of the Altamont. If these correlations as suggested by Travis are correct, then the 8-inch bed of fossil hash (unit 44 of type section) may be the southern equivalent of the Worland Limestone Member of Kansas (Jewett, 1941) and the gray calcareous shale beneath is the Lake Neosho Member of the Kansas section.

Owing to the relative thinness of these units, the absence of good continuous exposures between Oologah and the Kansas border, and the general similarity of these strata with others in the Desmoinesian of northeastern Oklahoma, such long-range correlations are extremely tenuous. This writer prefers to regard these beds as phases, probably local, of the lower part of the Nowata Formation. For the purpose of establishing a type section, the top of the Oologah is arbitrarily placed at the top of the uppermost thick limestone. Owing to slumping of the softer shales above and to generally deep soil cover, the contact of the Oologah and the Nowata is exposed at few places. An exception is the broad outcrop in the right bank of the Verdigris River, sec. 21, T. 28 N., R. 16 E., about 31 miles north of the type section. At that locality the basal bed of the Nowata is an earthy, smutty coal about 18 inches thick. The upper surface of the Oologah (Altamont Member) contains paper-thin seams of coal. Numerous carbonized wood fragments are imbedded in the limestone (Alcock, 1942, p. 81; Bloesch, 1928, p. 10). Such evidence suggests a gradual, though rapid, change in environment and does not imply exposure and erosion. An offshore marine environment evidently gave way to a coastal swamp as a result of the change of sea level.

TYPE SECTION

A core of the complete interval of the Oologah Formation in the type locality has been secured. Virtually perfect recovery of the core, 4 inches in diameter, was obtained, thus providing an excellent record of the formation. The core hole was located so as to drill the lower 30 feet of the Nowata Shale and carried deep enough to penetrate the upper 6 feet of the Labette Shale. Both contacts were recovered (figs. 2, 3). The core has been slabbed and one-half retained as a permanent record; it is stored at the Tulsa Research Center of Sinclair Oil & Gas Co., 5300 East Skelly Drive, Tulsa.

Oologah Limestone (Type Section)

Sinclair Core Hole No. 1 Douglass. Location: 1,100 feet west of the east line and 300 feet north of the south line, sec. 16, T. 23 N., R. 15 E., approximately 1 mile north of Oologah, Rogers County, Oklahoma, and 300 feet west of U. S. Highway 169. Contractor: Jim Winnek, Inc. Completed: November, 1965. T. D.: 118½ feet.

FROM TO
46. 0 -17′ 0″ Soil and alluvium, no recovery.

Nowata Shale

45. 17' 0"-25' 7" Shale, medium dark-gray, calcareous, soft. Smooth uneven fracture, very slightly hackly. At places fossil fragments on bedding planes. Below 23 feet core slabs show faint laminations of medium light-gray shaly calcisiltite.

44. 25' 7"-26' 3" Limestone; fossil hash composed mainly of crinoid and brachiopod fragments in shale matrix. Grades from calcilutite to coarse calcarenite. Glauconite fairly common. A ½-inch layer near base is a foraminiferal (**Endothyra**-like) sand. Bottom and top contacts sharp but uneven.

Possibly equivalent to Lake Worland Limestone Member of the Altamont Formation of Kansas (Jewett, 1941).

43. 26' 3"-27' 11" Shale, medium dark-gray to dark-gray, calcareous, unevenly fractured, slightly hackly. Minute foraminifers abundant throughout; at places larger fossil fragments.

May be equivalent to the Lake Neosho Shale Member of the Altamont Formation of Kansas (Jewett, 1941).

42. 27' 11"-29' 5" Calcilutite, dense, hard, medium light-gray. Abundant fossils throughout; in top 6 inches crinoid stems common, below this they are rare. Algal flakes and blades, small foraminifers common throughout. In upper 3 to 4 inches are some algal-shale layers. Few scattered reworked angular dark-gray shale fragments. Base sharp, but lower part contains detached fragments of underlying shale and somewhat coarser shell and crinoid fragments.

Possibly corresponds to the Tina Limestone Member of the Altamont Formation (Travis, 1942, p. 65).

41. 29' 5"-33' 7" Shale, noncalcareous, dark-gray to grayish-black; slight olive cast in places. Uneven smooth blocky fracture. A few scattered phosphate nodules up to 1 inch in diameter. Basal contact sharp, uneven.

Possibly corresponds to the Stone Lake Shale Member (Travis, 1942, p. 65).

Oologah Limestone

Altamont Member

40. 33' 7"-33' 9" "Algal shale" in 2-inch irregular bed at an angle to the core. Mostly light to medium olive-gray calcilutite, probably argillaceous, with parallel patches and streaks of medium dark-gray shale. Fossil fragments, probably crinoids, algae, and brachiopods scattered throughout. Dark shale streaks and patches extend down about 1 to 2 inches into bed beneath.

39. 33' 9"-40' 3" Limestone, light-gray to medium light-gray; consisting of irregular layers, blebs, lenses, and patches of algal calcilutite and fine calcarenite or calcisiltite,
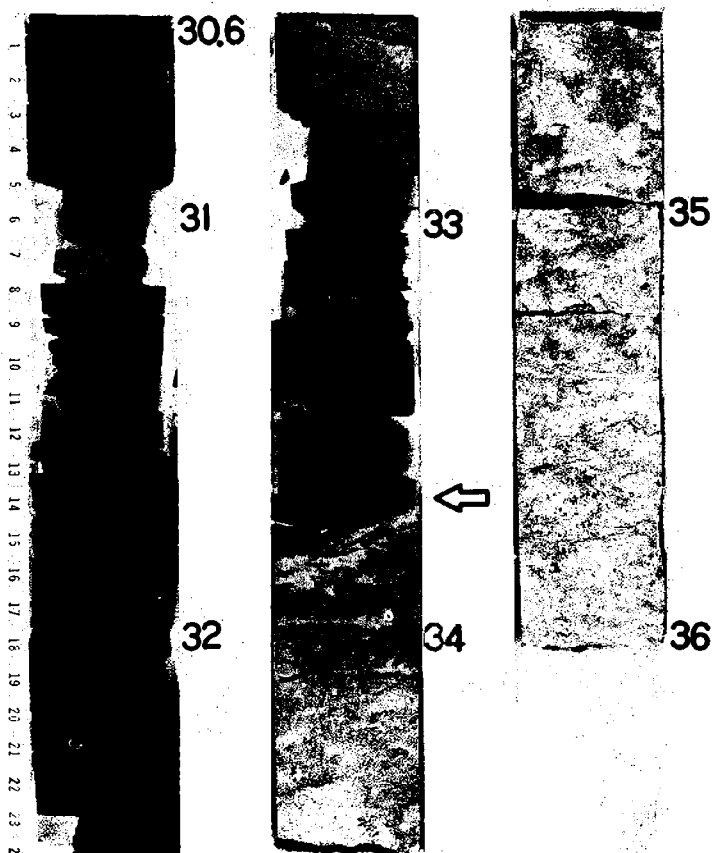
Figure 2. Contact of the Nowata Shale and the Oologah Limestone (Alta-
mont Member). Plane of contact appears (arrow at 33 feet 8 inches) at
the base of a dark-gray to coaly black shale. Lowermost 4 inches of Nowata
shale have been softened by meteoric waters and core recovery was in-
complete. Upper beds of Oologah are composed of irregular blebs and
lenses of algal calcilutite with some patches of fine calcarenite. Algal blades
are replaced by brown sparry calcite. Thin wavy partings at 35 feet 6 inches
are stylolites and algal shale laminae.
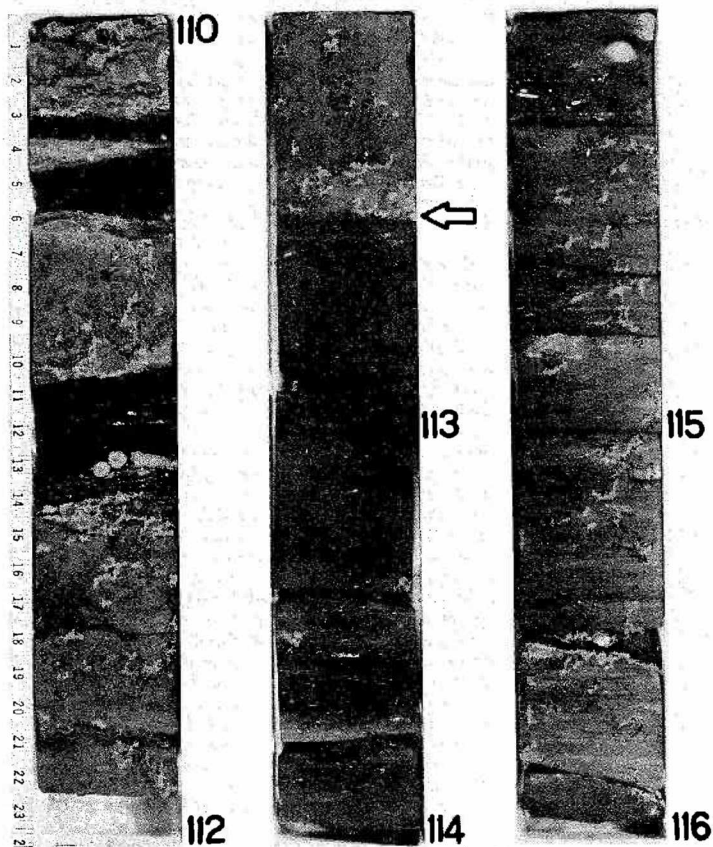
Figure 3. Base of the Oologah Limestone. Contact of the Labette Shale and the Pawnee Member of the Oologah Limestone. Arrow at 112 feet 6 inches marks the plane of contact at a change from dense uniform medium light-gray calcilutite in the Pawnee, to silty calcareous medium dark-gray hard shale in the Labette. Calcareous concretions as at 114 feet 1 inch are characteristic of the upper Labette; the fossiliferous shale bed between 113 feet 6 inches and 114 feet 3 inches has been noted in many outcrops of the Labette.

the whole having a bouldery appearance. Contacts between lithologies in some places are gradational, in others marked by a parting plane of "algal shale" or stylolites. Some calcilutite has birdseyelike inclusions of sparry calcite (algal?). In places are light bluish-gray calcite inclusions. Interval from 35 to 38 feet has light-yellowish oil stain but little visible porosity. Lower 2 feet is similar to rest except coarse parts are mainly calcisiltite; thin shale partings or stylolites somewhat more common. Large crystal-filled vugs in basal few inches.

38. 40' 3"-40' 7" Calcilutite; similar to bed 39 except all fine-grained, with a mixture of light bluish-gray and medium yellowish-gray patches; the latter being very slightly coarser. Algal blades, replaced by brown sparry calcite, common throughout. Base is a ¼- to ½-inch bed of medium-gray algal shale.

37. 40' 7"-41' 5" Calcisiltite, medium light-gray, argillaceous; with abundant large (5-10 mm) fossil fragments, algae, crinoids, brachiopods, and finely laminated algal shales, in thin irregular streaks in upper half, increasing downward.

36. 41' 5"-42' 8" Shale, calcareous, fossiliferous, medium-gray to medium dark-gray; the fossils producing contrasting white streaks and layers and curving shards; these are mostly brachiopods and algae (?). Near base are three large (1 to 2 inches) and several small irregular inclusions of tan to buff-gray calcisiltite. Possibly pebbles, but showing no rounding.

35. 42' 8"-54' 8" Calcilutite/calcisiltite similar to bed 39 except "fragments" are not so large and appear to be more nearly bedded. Abundant algal blades throughout, replaced by sparry calcite. Most of this unit is typical algal ls., but in places (47 to 48 feet) algal blades are less common. Mostly light gray to medium light gray. At 48 feet 4 inches is a 1-inch bed of crinoidal (?) calcarenite, which occurs in patches in a finer matrix with some thin algal shale laminations. Scattered large crinoid stems between 50 feet and 50 feet 6 inches. Top 3 feet has small vugs, light-yellowish oil stain. "Algal shale" stylolites are almost absent but occur mostly from 51 feet 4 inches to 52 feet and again between 54 feet and 54 feet 8 inches.

34. 54' 8"-55' 8" Calcilutite/siltite. Essentially the same as unit 35 but with a large (2" x 3") irregular fossiliferous yellowish-gray chert inclusion and several smaller ones.

33. 55' 8"-62' 3" Calcilutite, dense, hard, light-gray to medium light-gray; with areas and layers of skeletal calcarenite and calcisiltite, abundant flakes and blades of algae, and some beds of sparse "algal shale," notably from 56 feet to 57 feet, from 55 feet 5 inches to 55 feet 10 inches, and from 61 feet 6 inches to 61 feet 8 inches. Sparse coarse fossil debris. Yellowish-gray fossiliferous very irregular, chert blebs at 61 feet 3 inches.

32. 62' 3"-62' 5" 2-inch bed composed of wavy beds of dense calcisiltite, medium yellowish-gray; with thin "algal-shale" laminae and pods of coarse (algal?) fossils.

31. 62' 5"-63' 7" Calcarenite/siltite, light-gray to medium yellowish-gray; in irregular lumps and blebs of all size grades down to lutite. Some coarse fossils (algal blades, coral). 1½-inch yellowish-gray chert lump at top, irregular 3- to 4-inch zone of similar chert from 63 feet to 63 feet 4 inches. Bottom 3 inches is fine skeletal calcarenite with vertical calcite-filled fracture.

30. 63' 7"-64' 0" Calcilutite, medium yellowish-gray; with fine wavy laminae of algal shale rarely as much as 1 mm thick. Central portion is about 2½ inches of fine calcarenite or calcisiltite.

29. 64' 0"-67' 9" Calcilutite/siltite, light to medium light-gray; in lumpy irregular beds and blebs with abundant algal blades and plates and some thin zones of crinoidal debris. Much white to creamy-white chert replacing algae (?) in irregular slabby shapes up to ¼ inch thick, mostly oriented parallel to bedding, but some irregularly disposed. Basal 3 inches entirely chert, bluish gray and yellowish gray intermixed in flakes and lumps. Whole unit gives appearance of reworking.

28. 67' 9"-69' 3" Zone of alternating beds of limestone and "algal shale." Limestone is dominantly dense uniform calcisiltite, medium light gray, in part very finely layered in wavy bands. Algal shale is typical medium dark gray with faint olive tinge in beds up to 3 inches thick, the thicker ones containing lumps of calcilutite/siltite up to ½ inch by 1 inch. This zone has a ½-inch shale at top, a 3-inch limestone, a 1½-inch shale, and a 1-inch limestone, then a 3-inch shale bed. The lower 4 to 5 inches of the thick limestone contains wavy shale laminae and a 2-inch lump of fine calcarenite.

27. 69' 3"-69' 10" Limestone, composed of light- to medium light-gray calcilutite with abundant flakes, blades, and shreds of algae replaced by brown sparry calcite. Some foraminifers.

26. 69' 10"-73' 3" Calcisiltite, laminated, medium yellowish-gray. Laminations produced by thin streaks of algal shale or algal siltite. At 72 feet 7 inches is a 1-inch irregular bed of "algal shale." From 71 feet 3 inches to 71 feet 8 inches is a large slightly finer grained inclusion of lighter gray lutite with a few streaks of algal shale. This resembles a large burrow or boulder (?) and is separated from the rest of the core by a fine sheath of medium-gray algal shale or a stylolite or an argillaceous layer. Smaller lumps occur at 72 feet also. Lower 6 inches is dense uniform calcisiltite not laminated as above.

25. 73' 3"-73' 6" 3-inch bed of "algal shale" and calcisiltite. Limestone is an egg-shaped lump, up to 3 inches wide, enclosed in medium dark-gray shale in wavy thin laminae.

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24. 73′ 6″-75′ 4″   Calcisiltite/calcilutite, light to medium light-gray; in irregular lumps and patches similar to unit 39, with many algal blades and flakes and a few skeletal arenite patches.

23. 75′ 4″-75′ 11″   One inch of "algal shale"-calcisiltite underlain by chert, bluish-gray, light yellowish-gray, and medium-gray, fossiliferous. Appears to have replaced 1-inch bed of algal shale and a 4- to 5-inch bed of calcilutite or calcisiltite similar to unit 24.

22. 75′ 11″-78′ 11″   Limestone, similar to unit 38; light to medium light-gray, blotchy; calcisiltite and calcilutite in thin irregular patches; in places having sharp contacts, elsewhere gradational. A few streaks of slightly porous very-fine calcarenite with yellowish oil stain. Lower 1 foot has algal limestone-type lithology with algal blades and plates in blotchy calcilutite/calcisiltite. ½-inch streak of algal shale 3 inches above base.

21. 78′ 11″-79′ 1″   Shale, possibly "algal shale," medium dark to dark gray, with much wavy-layered medium light-gray calcisiltite beds and a ½-inch layer containing triangular fossil fragments (**Prismopora**?). Bed thins across core. Basal contact sharp, inclined.

20. 79′ 1″-81′ 2″   Limestone, similar to unit 22; calcisiltite and calcilutite in patchy mixture. Top 2 to 3 inches is uniform well-sorted medium light-gray calcisiltite with a well-developed horizontal stylolite. Thin algal shale bands at 79 feet 6 inches, 80 feet, and 80 feet 9 inches. From 80 feet 3 inches to 80 feet 9 inches bed is coarse algal limestone with large algal blades in calcilutite/calcisiltite.

19. 81′ 2″-81′ 7″   Chert zone. Composed of an irregular 1- to 2-inch layer of bluish-gray and brown fossiliferous chert sandwiched between equal layers of "algal shale" with lumpy calcisiltite. Few large fossils (crinoid, **Prismopora**?).

18. 81′ 7″-82′ 1″   Limestone, calcilutite/calcisiltite similar to unit 20. Algal limestone type, with plates and blades of algae. Whole is light- to medium-light gray.

17. 82′ 1″-82′ 5″   Chert, mottled bluish-gray, medium-gray, and medium yellowish-gray, fossiliferous.

16. 82′ 5″-83′ 0″   Calcilutite, medium light-gray; with considerable algal blades, crinoid stems, and other fossil fragments. Dense, hard. A few thin streaks of medium-gray "algal shale."

15. 83′ 0″-83′ 11″   Calcilutite, dense, algal; as in unit 16 but with mottling of bluish gray and light gray, mostly bluish.

Bandera Member

14. 83′ 11″-84′ 3″   Shale, medium dark- to dark-gray, calcareous, fossiliferous. Grading downward to medium-gray shaly calcilutite in lower half. 1-inch phosphate nodule in upper shaly half. Fossil fragments—algae, bryozoans, brachiopods (?), mostly in shale portion.

13.   84′ 3″-84′ 11″   Shale, grayish-black to black; with bedding parallel
to thin lenses of slightly lighter gray shale. Noncal-
careous, but split surface of core effloresces a thin
calcite (?) crust. Phosphate nodules in upper 3
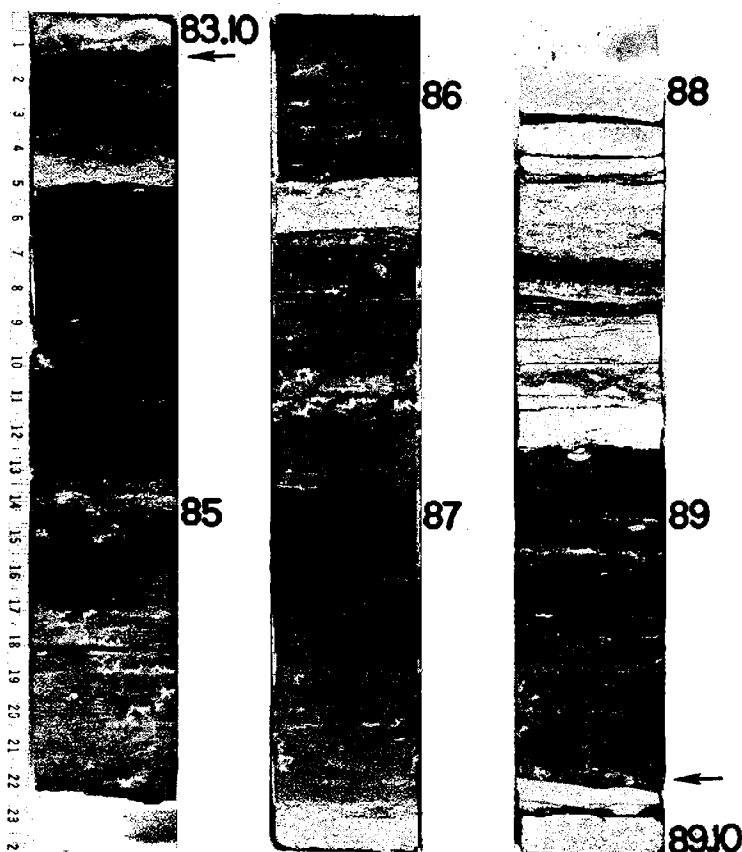inches. Pyrite common throughout. Shale has a
smooth uneven fracture.

Figure 4. Bandera Shale Member, Oologah Limestone. Arrows mark top
and bottom contacts of the member, here 5 feet 10 inches thick. Upper 1
foot is mainly a grayish-black to black clay shale with phosphatic nodules
up to 1 inch in diameter. Section from approximately 85 feet to 87 feet 11
inches is alternating thin laminae of dark shale and medium-gray calcareous
siltstone containing much pyrite and traces of glauconite. From 87 feet 11
inches to 89 feet is a bed of medium-coarse skeletal calcarenite. Basal 1
foot is medium dark-gray calcareous shale with thin streaks of calcisiltite.

12. 84' 11"-87' 11" Shale/siltstone, calcareous, medium-gray to medium dark-gray. Consists of thin irregular layers and laminae of shale and quartz siltstone, both calcareous, with much pyrite. Upper 1 inch has a few thin laminae of the black shale of unit 13 and much fossil (crinoids, algae [?]) debris, trace of glauconite. 1-inch zone at 86 feet 6 inches is mostly a coarse skeletal limestone of cream and light-brown crinoid (?) fragments. Unit grades downward into unit **11**.

11. 87' 11"-89' 0" Calcarenite, mottled medium-gray, grayish-brown, and cream; mostly coarse but with some thin beds of very-fine calcarenite and streaks of medium dark-gray shale. Appears to be mostly crinoid fragments, some foraminifers.

10. 89' 0"-89' 9" Shale, medium-gray to dark-gray, calcareous. A few thin streaks of fossil material and calcisiltite. Similar to unit 12 but less calcisiltite.

Pawnee Member

9. 89' 9"-90' 8" Calcarenite, fine to very-fine, medium light-gray to medium-gray. Mostly skeletal (crinoid) material with some foraminifers. Thin shale partings similar to unit **10**. In calcarenite are many small blebs of bluish-gray to medium-gray clay or calcilutite, possibly pellets.

8. 90' 8"-93' 0" Calcilutite, medium-gray to medium light-gray, dense, hard; at places patches of bluish gray. Algal blades and chips scattered throughout, with some large crinoid fragments. At 91 feet 10 inches and at 92 feet 8 inches are 1-inch beds of typical "algal shale," medium dark gray to olive gray; in thin wavy laminae enclosing scattered coarse fossils. Bottom 3 inches has coarse vermicular algae. A large (2") brachiopod is at 92 feet 6 inches, partly filled with platy calcite (?) crystals.

7. 93' 0"-93' 8" Chert, mottled, medium light-gray and tan. Replacing calcarenite—abundant small (fine to medium) skeletal grains. At places vugs filled with light-bluish nonfossiliferous chert.

6. 93' 8"-98' 0" Calcarenite, light olive-gray, mostly very-fine to fine-grained, uniform; but with scattered coarse grains, these most abundant in basal 3 inches. Sand is skeletal, foraminifers, pellets (?), and some possible oölitic-coated grains. At 96 feet is a large partly filled cavity lined with coarse calcite crystals, the central part being platy to micalike calcite. Near top are some burrows filled with slightly coarser calcarenite.

5. 98' 0"-103' 4" Calcirudite, uniform, medium light olive-gray. Composed of calcite sand similar to bed **6** but with an abundance of large crinoid joints and stems up to 10 mm in diameter. Many algal blades and plates in middle third, some streaks of "algal shale" but not common.
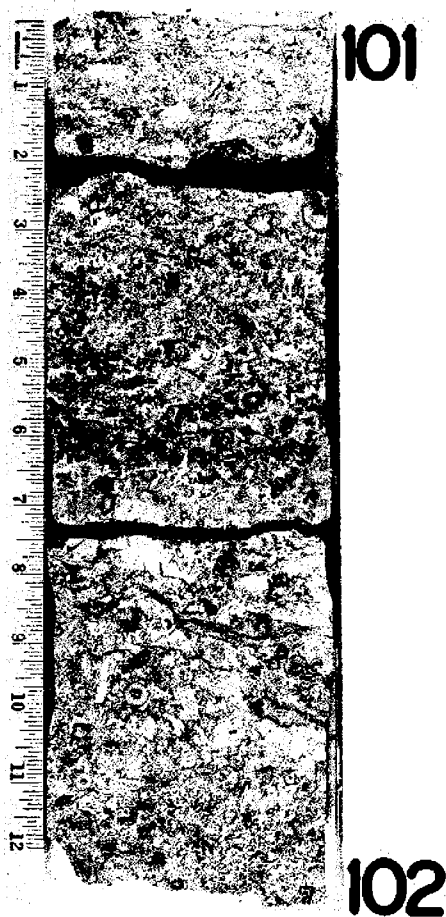
Figure 5 Crinoidal calcirudite. A typical bed in the coarse phase near the middle of the Pawnee Limestone Member. Rock is composed almost wholly of coarse skeletal sand with numerous large crinoid columnals and some thin wavy streaks of algal shale. Minute foraminifers are common. Beds similar to this occur in the quarry at the west end of Oologah dam.

Figure 6. Typical lithology in Altamont Limestone Member. Section of core shown consists of alternating beds of limestone and algal shale. Limestone is mainly dense uniform medium light-gray calcisiltite containing blades and flakes of algae replaced by brown sparry calcite. Algal shale is medium dark gray with a faint olive tinge. It occurs in fine wavy laminae containing pods and lenses of coarse crinoidal sand. At 69 feet is a 2-inch lump of fine calcarenite enclosed in algal shale.

Figure 7. Part of the lower Altamont Member with a well-developed dark-gray algal shale (at 79′). Triangular inclusions in algal shale are cross sections of branches of the common bryozoan Prismopora triangularis.

4. 103′ 4″-108′ 7″   Calcilutite, algal, mottled bluish-gray, medium light-gray, and tan; with patches and beds of coarse to very-coarse calcarenite/rudite, mostly crinoidal as in unit 5. Lower few inches is mostly dense medium light-gray calcilutite with some evidence of burrowing or reworking.

3. 108′ 7″-111′ 4″   Zone of alternating beds of "algal shale," shale, and calcilutite. The latter is medium to light olive gray, dense, with a few scattered algal blades and plates, in 3 beds up to 12 inches thick. Algal shale is medium dark gray in 4 beds up to 4 inches thick, irregular; in places enclosed lumps of calcilutite and coarse crinoid fragments. Basal shale is more nearly a true shale but appears to grade downward into algal shale.

2. 111′ 4″-112′ 6″   Calcilutite, dense, uniform, medium light-gray to medium-gray; some algal blades; a few scattered sand-sized fossil fragments.

Labette Shale

1. 112′ 6″-118′ 7″   Shale, silty, calcareous, medium-gray to medium dark-gray, fairly hard; breaking with an uneven hackly fracture. A few scattered fossils, mostly crinoid stems. Limestone concretions up to 2 inches thick in bottom 1 foot. Bottom of core.

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Pages 148 and 149: Figures 2 and 3 are transposed.

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