Cyclic sedimentation of the Upper Fayetteville Formation

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CYCLIC SEDIMENTATION OF THE UPPER FAYETTEVILLE FORMATION

BY

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A

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I. ACKNOWLEDGMENT

This problem was suggested to the writer by Dr. Alfred C. Spreng, Associate Professor in the Department of Geology, Missouri School of Mines and Metallurgy. The study of the Fayetteville Formation was made possible by School transportation to the field areas by Dr. A. C. Spreng.

The writer gratefully acknowledges his cooperation in introducing him to the stratigraphy of northern Arkansas and east central Oklahoma, and especially in critically reading the manuscript.

II. INTRODUCTION

In the past decade considerable interest has developed in the geology of the Boston Mountain area of northern Arkansas. This has been due to exploration for oil and gas in the area and the related desire to know more about the structure and stratigraphy of the region. Principal work has been done by the University of Arkansas, the United States Geological Survey, and oil companies. This study involves only one of the formations making up the geologic column in the Boston Mountains, the Upper Mississippian (Chesterian Series) Fayetteville Formation.

Portions of the upper part of the Fayetteville Formation of northwestern Arkansas and northeastern Oklahoma consist of interbedded calcareous and argillaceous beds which form a rhythmic or cyclic pattern. Such patterns are ordinarily not seen in the Mississippian rocks around the Ozark Plateau, except perhaps in a crude fashion in the Chesterian rocks on the east flank of the Ozark Plateau. The lithologic units in the Chester cycles there are much thicker and less sharply defined. Rhythmic sedimentation has been described (Bokman, 1953) in the Meramecian series and Stanley Formations which are deposited nearer the axis of the Ouachita geosyncline in the Fayetteville area. Rhythms of various types have also been observed by the writer in the rocks of the underlying Moorefield and overlying Pitkin and Atoka Formations in the area of the study. They are, however, not as distinct as those of the Fayetteville and involve clastic rocks except for the Pitkin Formation.

III. PURPOSE OF STUDY

The purposes of this thesis are:

1. To study the lithology of the Fayetteville Formation.
2. To measure in detail the exposures of the cyclical deposits in the Fayetteville and some examples in the Pitkin Formation, in order to give a detailed description of the nature of these deposits.
3. To try to determine the nature of the environment of deposition for these cyclic beds, and
4. To determine whether these cyclic beds may be of any value in making detailed correlations between exposures of the Fayetteville showing this peculiar type of deposition.

IV. LOCATION AND AREAL EXTENT

The outcrop band of the Fayetteville Formation occupies a considerable area in the western portion of the Boston Mountains, in northwestern Arkansas, and northeastern Oklahoma. The Boston Mountains form the dissected southern edge of the Ozark Plateau and attain a height of 800 feet. Most of the crests in the Mountains stand between 1,000 and 1,500 feet above sea level (Croneis, 1930, p. 9). Steep cliffs and narrow valleys are numerous throughout the province.

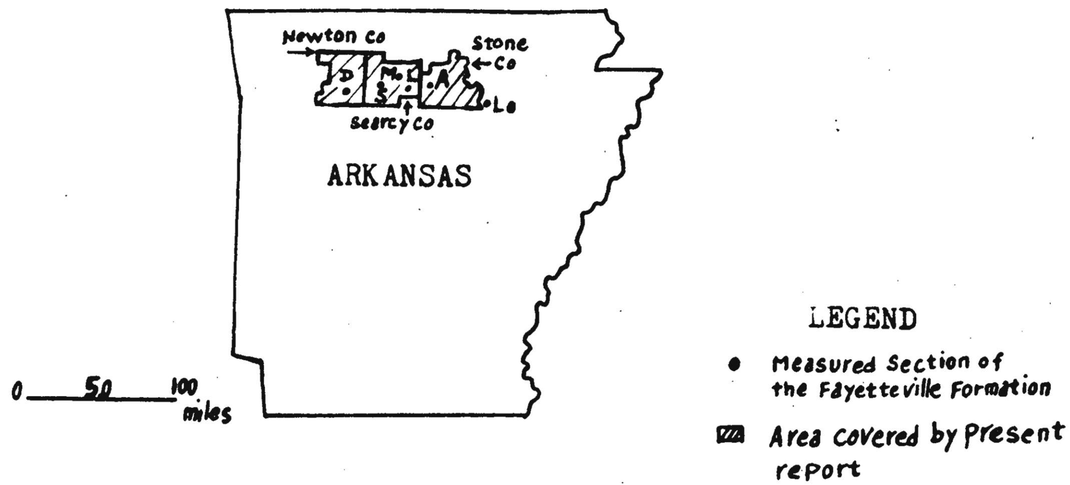
The sections measured for the present study are located in Newton, Searcy, and Stone Counties in north central and northwestern Arkansas and in Muskogee County in east central Oklahoma.

The type area was not studied since the section in that area is reported (Croneis, 1930) to consist only of shale. Sections have been studied and described at Locust Grove, Alco, Leslie, Marshall, Snowball, and Deer in Arkansas, and Fort Gibson Dam and Braggs Mountain in Oklahoma (Figs. 4, 6, 8, 11, and 13). These sections (abbreviated L, A, Le, M, S, D, F, and B respectively) are diagrammatically plotted in Figure 3 to a scale of one inch equal to 3-1/3 feet which scale permits the details of the cyclic repetition to be shown.

Location and descriptions of the sections are given in Figure 3. Small circles to the left and adjacent to the columns show the stratigraphic horizons at which samples were taken in the field.Red circles indicate where sample were taken for thin section study;black circles indicate where samples were taken for lithologic and laboratory study.

Sections described in this report can be reached from Arkansas State Highways 66, 65, and 7 and also by means of some graveled county roads which traverse the area, and from Oklahoma State Highways 10 and 80. (Figs. 1 and 2)

Road cuts and steep-sided stream valleys provide the clear and continuous exposures necessary for this study; although the total thickness of the formation did not exceed 218 feet, it was not completely exposed in any one locality.



INDEX MAP OF ARKANSAS

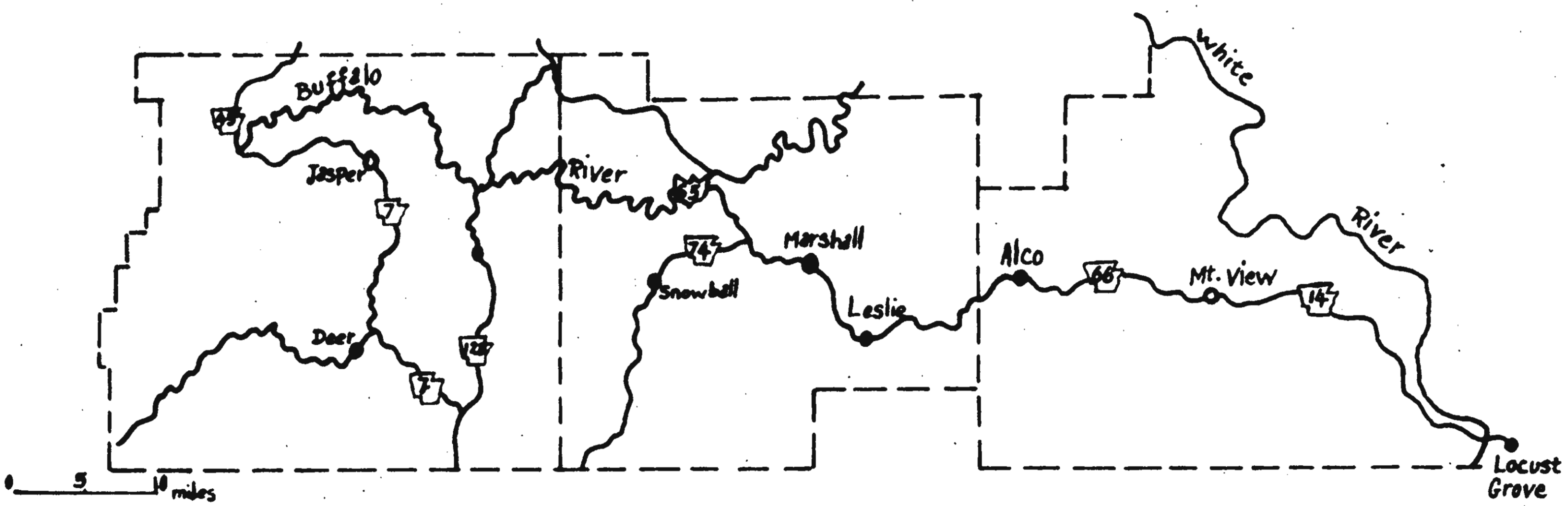
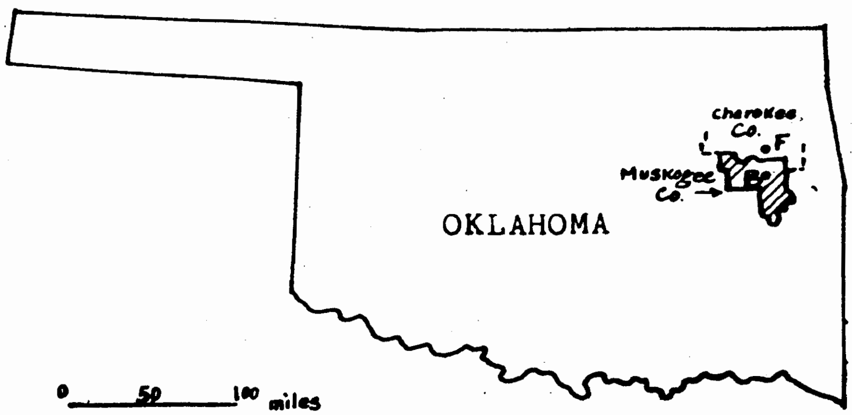


Fig.I Map showing location of measured sections of the Fayetteville Formation, Arkansas.



INDEX MAP OF OKLAHOMA

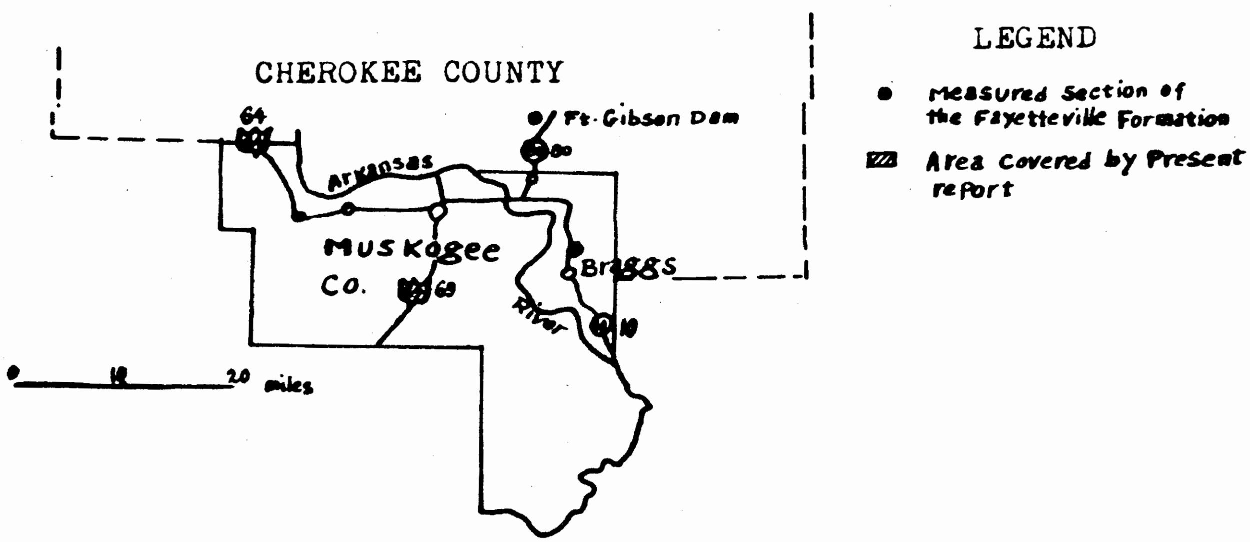


Fig.2 Map showing location of measured section of the Fayetteville Formation, Oklahoma.

V. GEOLOGIC SETTING

The formations that crop out in northwestern Arkansas are nearly all of Carboniferous age and both Pennsylvanian and Mississippian systems are represented. The Mississippian rocks consist predominantly of limestones, cherty limestones and shales. The Boone Formation, the Batesville Sandstone, and the Fayetteville Shale comprise the greater portion of the rocks of Mississippian age (see Table 1).

The Fayetteville consists of a black shale and locally alternating beds of shale and limestone which represent the cyclical deposition which was studied. The formation was named by F. W. Simonds (1891) as the Fayetteville Formation from exposures near Fayetteville, Washington County, Arkansas, in the valley of West Fork of White River. Clark (1941) reported it in Missouri. Its distribution in Barry County, Missouri, is in northern outliers of the Boston Mountains, Reed Mountain, Lennox Mountain, and Oakleigh Mountain (Branson, 1944, p. 267).

The Boston Mountains represent the dissected southern portion of the Ozark Plateau. The dominant structural control is a series of northeast-trending normal faults that separate the area into a series of prominent fault blocks with steep escarpments and gentle dip slopes capped by the resistant sandstone of the Atoka Formation (Huffman, 1953, pp. 5-25).

The beds of the Morrowan and Chesterian Series crop out below the Atoka Sandstone; the Pitkin Limestone which overlies the Fayetteville Formation is the youngest formation of the

Mississippian System (and Chesterian Series) in northern Arkansas and the northeastern part of Oklahoma. The currently accepted rock column for the Boston Mountains is given in Table I.

TABLE I

System	Series	Formations and Members
Pennsylvanian	Atokan	Atoka Formation
	Morrowan	Bloyd Formation Kessler Limestone Member Brentwood Limestone Member
		Hale Formation
Mississippian	Chesterian	Pitkin Formation
		Fayetteville Formation Wedington Sandstone Member Batesville Sandstone Hindsville Limestone Member
	Meramecian	Moorefield Shale
	Osagian Kinderhookian	Boone Formation St. Joe Limestone Member

Stratigraphic Classification of Rocks in the Boston Mountains of Northwestern Arkansas

VI. FIELD WORK

The field studies were conducted under the direction of Dr. A. C. Spreng. The work was started in October 1959 and continued intermittently until July 1960. Sections were found where the outcrops were well exposed: in road cuts, in the sides of hills and in valleys where the streams have exposed bed rock. All sections were measured by means of a hand level and/or steel tape, the sequence of beds and character of each individual bed were noted and described. Laminations in the beds were counted and mineralogy and spatial features were studied.

Fossiliferous horizons were collected, though not extensively.

Three of the sections which were studied have previously been recorded by others: one section (Snowball, Arkansas, Location S) was described by W. A. Chisholm in an open file report of the U. S. Geological Survey and two locations were selected from Oklahoma Geological Survey Guide Book I, on pre-Atoka Rocks by G. G. Huffman (April, 1953).

VII. SAMPLING

Eight sections containing the Fayetteville Formation and Lower Pitkin Formation were examined. Samples were collected to give an extensive distribution throughout the Fayetteville Formation and to represent the widest geographic distribution.

For laboratory and petrographic work most samples were taken by chiseling or breaking out fresh parts of the bed in the face of the exposed rocks. Some samples were selected on both sides of and adjacent to the contact of shale and limestone. Other samples were chosen from the same bed, at the greatest possible distance from each other in an exposure. Samples were taken at every change in lithology. The thickness of a bed represented by one sample varied from two inches to a maximum of 14 feet.

VIII. STRATIGRAPHY

1. PREVIOUS WORK

No detailed work has previously been done on cyclic sedimentation in northern Arkansas. However, its general nature has been described by early workers in the area such as Croneis (1930) and Purdue and Miser (1916) in the Harrison Quadrangle. More recently, Bokman (1953) has described rhythmic bedding in the Stanley and Jackfork formations in the Ouachita Mountains. Huffman (1953) gives additional measured sections of the Fayetteville in northeastern Oklahoma, but the rhythmic nature of these latter beds was not brought out.

The following causes have been suggested for the cyclic development or rhythmic sedimentation as found in various geologic systems (Lombard, 1956, p. 447):

(a) Frequent tectonic movement

(b) Climatic pulsation (Gignoux, 1950)

(c) Shifting and variations of sea currents (Bersier, 1951 in Lombard, 1956)

Other cyclic phenomena considered as a general cause for sedimentary cycles are: astronomic, solar, climatic, and physicochemical factors (Richter, Bernburg, 1950 in Lombard, 1956). Solar factors are external phenomena and their development would be a matter of question. Barrell (1917) considered that natural rhythms or cycles which he termed "orbital rhythms" depend upon motions in the solar system. The notion of cyclic repetitions caused by turbidity currents (Daly, 1936; Kuenen, 1937), is very important. Locally this same phenomenon may originate by normal currents rather than turbidity currents (Lombard, 1951). Kuenen (1950) proposed that turbidity currents of high density are a possible mechanism by which graded deposits are formed.

It is not uncommon that a series of cyclic deposits may be developed due to the periodicity of physicochemical processes in the sea (Sverdrup, 1942; Allee, et al, 1950). Environmental periodicities are explained by Allee (1950, pp. 85-87). Physicochemical aspects of deposition include such phenomena as diffusion, hydrogen ion concentration (acidity and alkalinity), chemical buffering of the environment, and absorption.

The orderly repetition of sequence of late Paleozoic strata probably represents the best and most widespread illustration of the effects of recurrent conditions of sedimentation (Wanless and Shepard, 1936). Working in central Illinois, Udden (1912) first recognized that Pennsylvanian strata could be subdivided into four series of beds each composed of a similar series of beds arranged in the same order; this sequence consists of sandstone, shale, coal and limestone. This consideration was a clear exposition of cyclic sedimentation but his work had received no particular attention from geologists at that time.

Stout (1923) found likewise, that in Ohio, certain types of strata, notably underclays, coals, and limestones, occur in a cyclic sequence.

Weller (1930) suggested that these subdivisions should be considered formations and, in 1932 he coined the term "cyclothem" for such repetition. Weller (1931) prefers a diastrophic cycle of alternating submergence and uplift to explain these Pennsylvanian repetitions.

It would be expected that the mode of occurrence of cycles varies with respect to their distance from the source area and the location and configuration of the shore line.

Wanless and Shepard (1936) therefore classified their Pennsylvanian cycles as consisting of the following types:

(1) Piedmont facies

(2) Delta facies, and

(3) Neritic facies

The Piedmont facies is composed of a thick section of coarse continental clastics and is located close to the source.

The Delta facies is composed of marine and non-marine sediments. Located further from the source, it is generally thinner and its clastics are finer and not arkosic.

Still farther from the source, the Neritic facies consists chiefly of marine sediments.

Weller, Willman, and Payne (1942) have described such (facies) in Illinois; Roger and Stout (1931), working in West Virginia and Ohio, also have described cycles similar to the Delta facies.

Such an arrangement of facies has not been observed or reported for the Fayetteville Formation.

Dott (1958) says that alternations of agitated and quiet bottom conditions produced the cyclic appearance in mechanically deposited Pennsylvanian of northeastern Nevada.

Anderson and Kirklander (1960) point out in their paper on the cycles of Jurassic Todilto Formation New Mexico, that cyclic deposition has generally been divided into two genetic types:
(a) Climatic cycles, and (b) Cycles related to the rise and fall of sea level.

The writer believes, then, that from a comparison of the Fayetteville with other formations described in the literature (see previous work), Fayetteville deposition occurred in a relatively shallow water environment, which was subjected to climatic cycles which might have had a considerable effect on the water temperature and at least to periodic current action. Hence it would appear that some of the explanations given by several of the authors above should be considered in explaining the origin of the Fayetteville cycles.

2. DISTRIBUTION AND THICKNESS

The easternmost occurrence of the Fayetteville Formation is a few miles southeast of Batesville, Arkansas, and the formation occurs as far north and west as Fairland and Gore, Oklahoma. Its exposures from north to south are confined to a belt along the lower slopes of the northern edge of the Boston Mountains (Croneis, 1930, p. 66).

The Fayetteville is of variable thickness; its thickest exposure is 400 feet to the east of Carrollton, Arkansas. It becomes thinner to the north and west, or in some parts of northeastern Oklahoma it is only 10 feet thick. (Croneis, 1930, p. 66).

In the Arkansas area the cyclic portion of the Fayetteville Formation which is exposed and could be measured in detail varies from 22 feet (section L) to 123 feet (section M) (see Figure 3). Neither of these figures represent the total thickness of the formation. In the area studied the Fayetteville Formation is generally uniform in character. Its shale beds locally become more calcareous where the cyclic phase is well developed at the top of the sections.

The exposures of the Fayetteville are usually forested and concealed by soil. Its outcrops are limited to steep hillsides, valleys, and particularly, roadcuts.

3. LITHOLOGY

The Fayetteville Formation consists chiefly of greyish black, carbonaceous shale, but it includes near its top a member known as the Wedington Sandstone. This member is prominent throughout the northwestern parts of Arkansas and probably not present in Newton, Searcy, and Stone Counties, the areas studied. Locally, also, in the upper part of the formation occur the interbedded

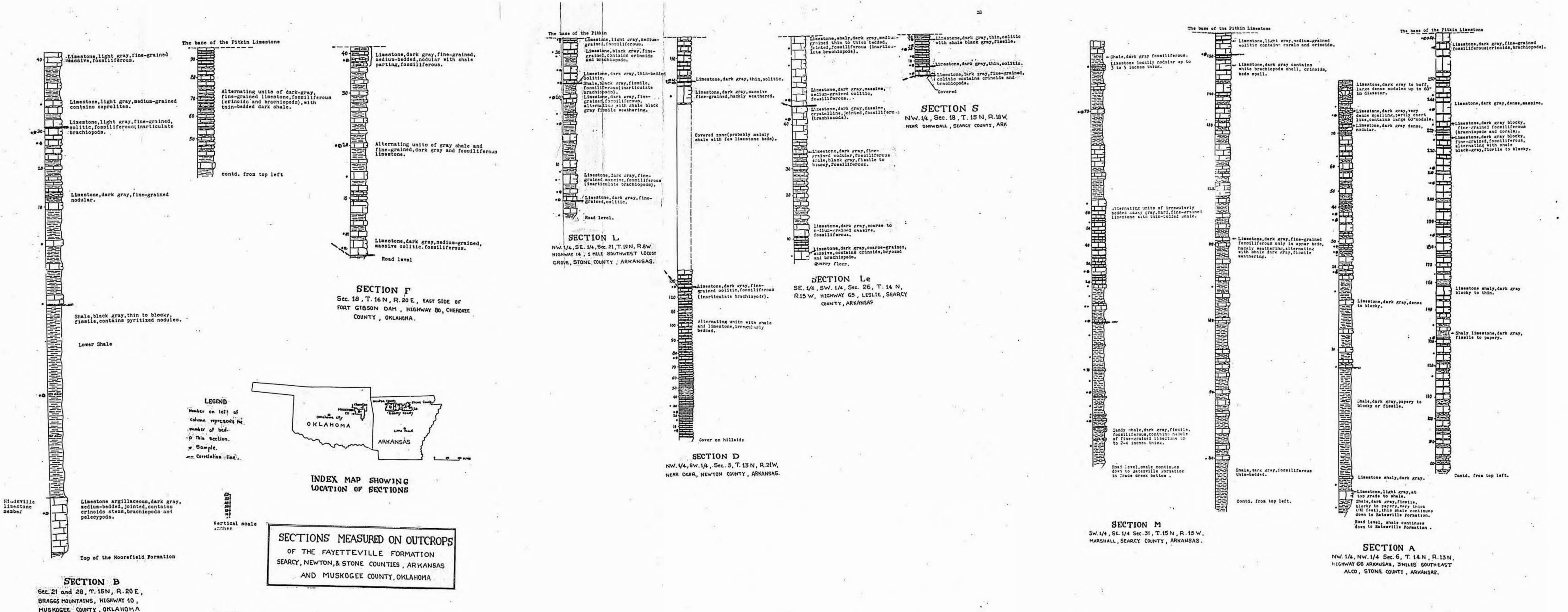

SECTIONS MEASURED ON OUTCROPS
OF THE FAYETTEVILLE FORMATION
SEARCY, NEWTON, & STONE COUNTIES, ARKANSAS
AND MUSKOGEE COUNTY, OKLAHOMA
INDEX MAP SHOWING
LOCATION OF SECTIONS
OKLAHOMA
ARKANSAS
LEGEND
Number on left of column represents the number of bed.
Thin section.
Sample.
Correlation line.
Vertical scale
The base of the Pitkin Limestone
Limestone, light gray, fine-grained massive, fossiliferous.
Limestone, light gray, medium-grained contains coprolites.
Limestone, light gray, fine-grained, oolitic, fossiliferous (inarticulate brachiopods.
Limestone, dark gray, fine-grained nodular.
Shale, black gray, thin to blocky, fissile, contains pyritized nodules.
Lower Shale
Hindsville limestone member
Limestone argillaceous, dark gray, medium-bedded, jointed, contains crinoids stems, brachiopods and pelecypods.
Top of the Moorefield Formation
SECTION B
Sec. 21 and 28, T. 15N, R. 20E, BRAGGS MOUNTAINS, HIGHWAY 10, MUSKOGEE COUNTY, OKLAHOMA
Alternating units of dark-gray, fine-grained limestone, fossiliferous (crinoids and brachiopods), with thin-bedded dark shale.
contd. from top left
Limestone, dark gray, fine-grained, medium-bedded, nodular with shale parting, fossiliferous.
Alternating units of gray shale and fine-grained, dark gray and fossiliferous limestone.
Limestone, dark gray, medium-grained, massive oolitic, fossiliferous.
Road level
SECTION F
Sec. 18, T. 16N, R. 20E, EAST SIDE OF FORT GIBSON DAM, HIGHWAY 80, CHEROKEE COUNTY, OKLAHOMA.
SECTION L
NW. 1/4, SE. 1/4, Sec. 21, T. 12N, R. 8W HIGHWAY 14, 1 MILE SOUTHWEST LOCUST GROVE, STONE COUNTY, ARKANSAS.
Road level.
Limestone, dark gray, thin, oolitic.
Limestone, dark gray, massive fine-grained, hackly weathered.
Covered zone (probably mainly shale with few limestone beds).
Limestone, dark gray, fine-grained oolitic, fossiliferous (inarticulate brachiopods).
Alternating units with shale and limestone, irregularly bedded.
Cover on hillside
SECTION D
NW. 1/4, SW. 1/4, Sec. 5, T. 13N, R. 21W, NEAR DEER, NEWTON COUNTY, ARKANSAS.
SECTION Le
SE. 1/4, SW. 1/4, Sec. 26, T. 14 N, R. 15 W, HIGHWAY 65, LESLIE, SEARCY COUNTY, ARKANSAS
Quarry floor.
Covered
SECTION S
NW. 1/4, Sec. 18, T. 15 N, R. 18W, NEAR SNOWBALL, SEARCY COUNTY, ARK
Shale, dark gray fossiliferous.
Alternating units of irregularly bedded shaly gray, hard, fine-grained limestone with thin-bedded shale.
Sandy shale, dark gray, fissile, fossiliferous.
Road level, shale continues down to Batesville Formation in Trace Creek bottom.
SECTION M
SW. 1/4, SE. 1/4 Sec. 31, T. 15 N, R. 15 W, MARSHALL, SEARCY COUNTY, ARKANSAS.
Shale, dark gray, fossiliferous thin-bedded.
Contd. from top left.
Limestone, dark gray, dense, massive.
Shale, dark gray, papery to blocky or fissile.
Limestone shaly, dark gray.
Road level, shale continues down to Batesville Formation.
Contd. from top left.
SECTION A
NW. 1/4, NW. 1/4 Sec. 6, T. 14 N, R. 13 N, HIGHWAY 66 ARKANSAS, 3 MILES SOUTHEAST ALCO, STONE COUNTY, ARKANSAS.

Fig 3

calcareous beds - the cyclic phase - which permits the formation to be divided informally into two parts - the lower shale and the upper cyclic phase. Divided in this manner, the formation is described below:

A. The Lower Shale

This unit consists of a thick, black, fissile, carboneceous shale which weathers to yellow-brown or yellow clay. Near its base it contains numerous concretions of clay ironstone, or sideritic concretions, most of which are cut by veins of calcite and show a septarian structure (Croneis, 1930, p. 67) (see Figure 9). These concretions are in places so numerous that they make up almost continuous septarian layers..

This unit forms by far the thickest part of the Fayetteville Formation. It is generally underlain by the Batesville Sandstone.

B. The Cyclic Beds

The Marshall area exhibits an excellent exposure of these cyclic beds (see section M, Fig. 8). Two complete sections are found along Arkansas Highway 65 roadcuts on both sides of an anticlinal hill at the southeast edge of town. The cyclic beds total 123 feet in thickness on this hill. These cyclic beds rest upon the Lower Shale member (as defined herein) of the Fayetteville Formation. These strata are overlain by the Pitkin Limestone. Cyclic beds form benches or small cliffs above the gentle slopes of the Lower Shale which are easily removed by erosion.

The cycles in all the sections show a similar pattern of sequence. Some variations in pattern, however, were observed. For example, in section A, a zone of large limestone nodules occurs as a layer (see Fig. 5 and sketch, p. 53). This resulted in a minor deformation of the over- and under-lying beds. However, in sections D and S (see Fig. 3) cyclic beds are very similar in thickness of beds and their character. In other sections (M, Le, and F) the limestone beds near the top of the cycles are thicker and more fossiliferous than the intervening shale beds.

In the sections examined, layers are generally thin- to thick-bedded but at some intervals beds are relatively massive. The limestone phase of the cyclic unit is nearly always a single entity or bed, that is, it represents continuous deposition.

In Fig. 10, thickness and number of limestone beds for sections A, D, F, L, Le, M, and S are plotted to show comparatively the pattern of thickness in the various areas. The curves are asymmetrical and where all or most beds could be measured and plotted the curve is skewed to the right. The modal classes fall in the classes bounded by 2 and 5 inches.

Had additional beds at the base of the Pitkin Limestone been included the curves would have become skewed to the right still more (Fig. 10).

Lithologic characteristics of the cyclic beds are as follows:

1. The argillaceous phase consists of blocky to thin or platy-bedded, hard to moderately hard, fissile shales, dark gray on a freshly broken surface and light gray on a weathered, dry, surface. Organic material gives the shale its dark gray color. Ordinarily the beds are nearly barren of fossils, although crushed shells of pelecypods and brachiopods were found. These are similar to those in the lower shale except that productid brachiopods occur only in the cyclic beds. A study of the faunal lists given by Croneis (1930, p. 69) shows that at least 250 species of fossils appear in the Fayetteville Formation. The most common species noted in the section studied in the field are: "Productus" inflatus, Linoproductus, Orthotetes subglobosus, and Caneyella nasuta. Chitinous brachiopods are also numerous.

Occasionally, remains of indirect evidence of life in the limestone beds were found. Easton (1960, p. 21) explains that animals such as worms, probably, may ingest large qantities of sediment and then expel the material in contorted string, or tubes, called casting. In like fashion fecal matter called coprolites may occur as tubes or of disassociated organic debris on otherwise unfossiliferous bedding planes (see Fig. 12).

The shale is somewhat calcareous and locally, small, flat, nodules of limestone are present. The well-weathered outcrops of shale and limestone are sharply set off from each other. Weathered contacts between the limestone and the shale are sharp. Where the shale is more calcareous it weathers light gray and breaks into subcuboidal fragments.

2. The carbonate phase of the Fayetteville cycles consists of thin to thick-bedded, fine-grained, dark gray, angular weathering fragments of limestone layers separated by shale beds. The limestone layers range from 1 to 35 inches in thickness. It is also significant that many individual layers, some of which are only a few inches thick, are remarkably persistent. Occasionally the limestone will be represented as a nodular bed or a thin bed will laterally become a nodular bed. The limestone layers become more abundant and prominent upward near the base of the Pitkin Limestone (Fig. 6). In more calcareous parts of the sections the alternating shale and limestone beds may be represented by thin-bedded limestone separated by very thin shale partings. The contact between the two units is readily recognized only when weathering has emphasized the bedding plane between them. The limestone layers are in some places transitional above and below into the shale. The detailed lithologic description of the measured sections is given in Fig. 3.

C. PITKIN FORMATION

The Pitkin limestone which overlies the Fayetteville Formation outcrops from Batesville in northeastern Arkansas to Muskogee in northeastern Oklahoma, and is also cyclic. The Pitkin consists of massive layers of compact to porous blue-gray to grayish white limestone. At the Leslie exposure (section Le) the basal Pitkin is represented by thin layers of limestone, somewhat shaly. A sharp boundary between it and the Fayetteville does not exist. This appears to be the case in the Oklahoma section also where its basal portion is more shaly (see sections B and F) than in other sections studied.

In the area studied the Pitkin limestone is quite variable in thickness. It ranges from 20 to 100 feet in thickness. The Pitkin stands out on weathering as a steep cliff above the subjacent Fayetteville Formation. The Pitkin is very fossiliferous, the screw-like bryozoan, *Archimedes*, being very common, as are also corals, brachiopods, and crinoids. A list of the fauna is given by Girty (1911).

4. CORRELATION

The study of the cycles of the Fayetteville Formation in the measured sections was made in part to determine if there are features in the cyclic phases which would be of correlative value. However, it was found that the cycle types and character and sequence of the beds as a whole remain remarkably uniform over wide areas and give

Fig. 4 - Outcrop of cyclic beds, Section A, along Arkansas Highway 66 near Alco, Stone County, Arkansas

Fig. 5 - Closeup of Fig. 4, showing large "nodular" bed in lower part of limestone-shale sequence, Section A, Arkansas Highway 66

Fig. 6 - Cliff and quarry in the upper portion of the Fayetteville Formation. Cyclic beds showing transitional zone. Top is the massive Pitkin limestone. Arkansas Highway 65, Leslie, Arkansas

Fig. 7 - Closeup, Section M, showing development of ledge forming unit (in upper third of photograph) consisting of limestone beds with only thin shale partings. Arkansas Highway 65, Marshall, Arkansas

Fig. 8 - Typical cyclic beds of shale-limestone in the Fayetteville Formation as exposed in roadcut along Arkansas Highway 65 southeast of Marshall, Arkansas

Fig. 9 - Septarian zone in the lower shale of the Fayetteville Formation as exposed in Trace Creek east of Arkansas Highway 65, 1-1/2 miles southeast of Marshall, Arkansas

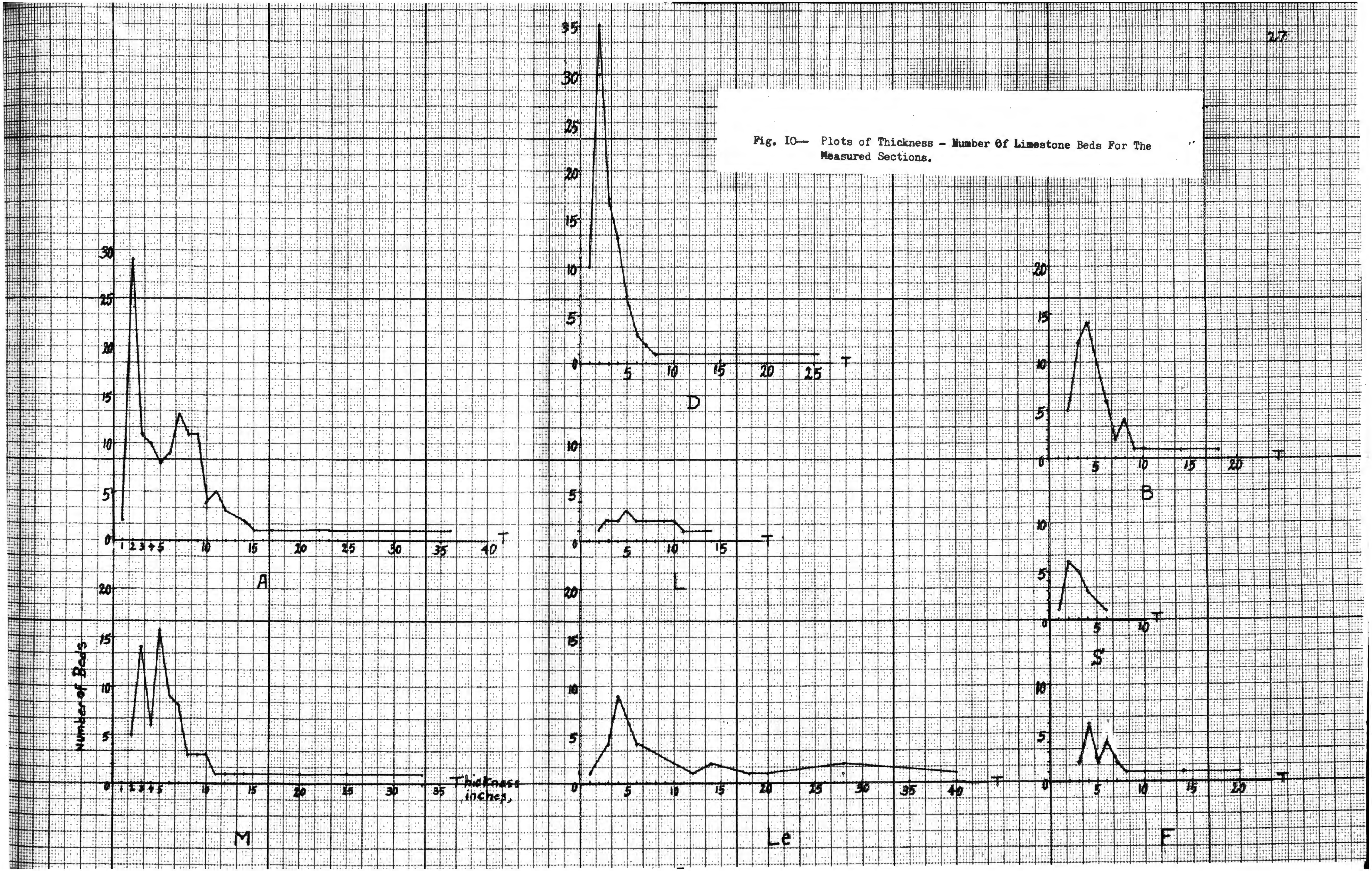


Fig. IO— Plots of Thickness - Number Of Limestone Beds For The Measured Sections.

no indication that there are corresponding correlative sequences or features.

Correlation based on the following criteria was attempted: a) physical features such as exceptional thickness or thickness pattern in the beds or lithologic features such as texture, insoluble residues, and other features that might be noted in thin sections; b) paleontologic, an attempt to relate those beds in the upper part of the cycle beds which contained megafossil material. No detailed collection of the fauna was made, however.

Three lithologic features were most helpful in recognizing and correlating parts of the whole formation:

(a) the Batesville sandstone at the base of the section,

(b) the beginning of the oolitic beds at or near the top of the cyclic beds of the Fayetteville Formation. These oolites are recognized more easily in thin section than in hand specimen. They indicate the beginning of the environment which gave rise to the Pitkin oolitic limestone. Whether the oolitic formation began at the same time in all areas is doubtful.

(c) the base of the Pitkin as marked by the beginning of the massive or thick-bedded, oolitic, crinoidal limestone.

The two lithologic changes marking the top and base of the formations are the most reliable markers noted in the field, i. e. the Batesville Sandstone at the base and the massive Pitkin Limestone at the top.

The cyclic beds as a whole are in all probability equivalent and occur in the upper Fayetteville, although in Oklahoma some cyclic limestone-shale units occur near the base also. Within themselves the cyclic beds could not be correlated from area to area as already indicated.

The correlative horizons which have just been discussed are shown by red dashed lines in Figure 3.

Fig. 11 - Section M, closeup of Fig. 8 showing the upper cyclic beds southeast of Marshall, Arkansas. Fayetteville-Pitkin contact in the underbrush at top of photo.

Fig. 12 - Coprolites in a fallen block rock from limestone (bed 35), Section B, Braggs Mountain, Highway 10, Muskogee County, Oklahoma. Dashed line in Fig. 13 shows the stratigraphic position of this bed.

Fig. 13 - Lower part of Section B, along Highway 10, about 10 miles north of town of Braggs, Muskogee County, Oklahoma.

IX. LABORATORY WORK

1. ACID INSOLUBLE RESIDUES

Nearly all of the carbonate phases of the cyclic beds contain a large fraction of noncarbonate materials. These were removed from the carbonate matrix and studied by making insoluble residues. The procedure for the preparation of the samples and recovering residues was as follows:

The samples were ground in an iron mortar and sieved through a 45-mesh screen; ten grams of sieved material was weighed on a beam balance (with an accuracy of 0.01 grams), and then placed in an 100 ml. beaker. The sample was covered with 10 cc. of 1:1 HCl and the acid was allowed to digest the carbonate. The maximum time required was two hours. Only a small amount of acid was used to prevent foaming caused by rapid effervescence of powder and fine material. After an hour additional acid was added, if necessary, but one application was frequently sufficient. After digestion was completed the solution was decanted and rinsed with distilled water. The residue was dried and weighed. Since the original sample was 10 grams the weight of the residue times 10 is the percentage of acid insoluble residue in the sample (Table II). This table shows average residue content (including organic matter) for the Fayetteville Formation is about 85 percent and is composed of fine, brown and tan, argillaceous material with somewhat fluffy or dark brown organic matter remaining.

The microscopic study of the residues indicates that they are dominantly fine clay minerals.

Thus, for the samples of limestones and calcareous shales that were analyzed, the residues ranged from 96 to 64 percent in the shales and from 56 to 26 percent in the limestones. This indicates a considerable variation in the composition of the beds in the cycles. The only observable pattern in the residues is the obvious increase in the argillaceous part and decrease in the limestone portion. No studies were made to determine variation in content of residues within parts of individual layers, for example, the top and bottom of beds compared with the middle. For eighteen beds sampled in the Marshall section (Table II, p. 35) there was no trend toward systematic increase or decrease in residue content in the limestone or calcareous shale beds. Neither were any patterns of the latter type observed in the field in any of the sections.

Since the character of the residue is essentially the same in both the limestone and shale part of the cycle it would seem that fluctuation in the precipitation of calcium carbonate was the chief factor which caused the beds to be cyclic in development.

2. DETERMINATION OF ORGANIC MATTER

Quantitative analysis of the samples was made to determine variation in the organic matter of various portions of the Fayetteville cycles. The method which was used for approximate determination of the organic content, is the hydrogen peroxide method (Twenhofel and Tyler, 1941), as follows:

One half gram of the sample of raw shale (dried and sieved) was weighed and treated with 10 cc. of fresh hydrogen peroxide (30%) in a beaker until the organic matter was decomposed (about 2 hours). Many complex reactions occur between materials and the hydrogen peroxide; precipitates frequently coat and stain the residues. The solution was filtered, the residue was ignited for two hours at about 200 C. and weighed. It is not uncommon to have a residue show a color change, because the effect of heating the sample at relatively high temperatures causes a change of the state of iron oxide. The difference of the second weight from the original weight gives the amount of the organic matter.

A general conclusion can be drawn that light-colored limestone beds have a low organic content; and dark-colored beds a high organic content; also it should be pointed out that the organic content of the sediments varies, relatively with the grain size.

Table II presents the results of the analyses. The table indicates that the organic matter reaches a maximum value of 24 percent and a minimum value of 4 percent in the sections; the average organic content is about 12 percent.

TABLE II

Percent analyses of organic matter and insoluble residue in the Fayetteville Formation, Arkansas. (Refer to Figures 1 and 2 for location of the sections, thickness of the bed sampled, and lithologic description.) Values are for shale beds except where number is underlined, in which case it represents a limestone analysis.

Section	Sample (bed number)	Percent Organic Matter	Percent Insoluble Residue
M	MS_{1}	4	96
	MS_{3}	13	88
	MS_{4}	--	<u>38</u>
	MS_{5}	10	96
	MS_{7}	24	--
	MS_{9}	6	82
	MS_{10}	--	<u>56</u>
	MS_{11}	12	94
	MS_{13}	15	96
	MS_{17}	18	86
	MS_{18}	--	<u>34</u>
	MS_{29}	--	92
	MS_{53}	10	--
	MS_{80}	8	--
	MS_{105}	10	--
A	AS_{1}	12	--
	AS_{3}	24	78
	AS_{6}	--	<u>26</u>

Section	Sample (bed number)	Percent Organic Matter	Percent Insoluble Residue
	AS 15	—	64
	AS 19	16	88
	AS 23	—	82
	AS 63	8	80
	AS 125	8	90
	AS 165	—	78
	AS 225	—	88
	AS 260	16	—
L	LS 1	12	92
	LS 9	10	88
	LS 19	8	94
	LS 28	—	36
*Average for section M		11.8	81.4
*Average for section A		14.00	81.8
*Average for section L		10.00	91.3
*Average for sections M, A, and L		11.9	84.8

*Excluding the limestone beds.

--Indicates no analyses.

3. DETERMINATION OF HYDROCARBONS

At almost all the exposures of the Fayetteville Formation the odor of petroleum was given off by fresh broken or powdered rock. There are various procedures that are suggested for the determination of hydrocarbons in the samples (Twenhofel and Tyler, 1941).

In this report a qualitative test has been employed so that the results are approximate; the method is as follows:

A small quantity, about one gram of sample, was ground to 45-mesh size, air dried, and placed in a test tube with a small quantity of chloroform (about 2 cc.), and was shaken for a minute. The contents were then filtered and the light amber to yellowish-brown filtrate was held against an ultraviolet light lamp. The milkiness of the sample color depends on the quantity of oil in the sample. In this test all the samples indicated no oil.

It might be possible that the petroliferous odor was derived from organic decomposition products, which would not give a test for petroleum by the above method.

X. PETROGRAPHIC WORK

Of the various samples collected from the Fayetteville Formation, those selected for thin sections were considered representative of the lithologic facies. Thin sections were cut from the oriented hand specimens collected in the field.

Approximately 65 individual thin sections from different limestone layers in the upper Fayetteville Formation were examined microscopically. Locations of horizons of the prepared thin sections are indicated by red circles in Figure 3.

Thin sections were studied by low and medium power objective (10 mm., 100X) and the sections were observed both by transmitted and reflected light in order to identify opaque minerals. The description which follows presents briefly details which were observed under the petrographic microscope.

At the onset it may be stated that the specimens taken from the cyclic units which were studied under the petrographic microscope imply a two phases genesis:

1. A fine-grained calcareous sediment, usually uniform, microcrystalline, calcite ooze, was deposited in a calm environment probably at moderate depths.
2. A relatively rapid change, such as caused by either depositional change or bottom currents, ultimately permitted the deposition of fine-grained clastics-clays and organic matter in this environment.

1. THE LIMESTONE

Thin sections of individual beds of a given outcrop are quite uniform in lithology. Limestone, for instance, rarely grades laterally or vertically into shale. In general there is little or no variation in internal structure of beds and contacts between continuous beds are sharp and featureless. All that can be said is that the limestone and shale are separated by a definite plane of continuity and that this separation is probably affected by a slight difference in grain size on either side of the contact.

Rarely can a limestone thin section be seen which grades upward into the overlying shale, and even less commonly downward into the underlying shale bed.

The overall rock appearance in a thin section is characterized by the presence of a clear cementing mosaic (Fig. 17) of calcite and a dark brown carbonaceous and argillaceous clay.

The calcite matrix in some specimens show a surprising uniformity of shape and sizes (Fig. 17) ranging between 20 to 60 microns (0.02-0.06 mm). These grains of calcite are usually irregularly shaped, colorless, and microcrystalline.

Carbonaceous matter and argillaceous materials are loosely packed in a microcrystalline calcite matrix (Fig. 16). The argillaceous material is aggregated to about the same size as the matrix calcite.

The limestone usually shows very fine lamination and sometimes delicate cross-bedding. Every thin section examined contained cark brown, very homogeneous, carbonaceous clay; any organic structures that may have been present were evidently destroyed by bacterial and chemical action. Concurrent accumulation of organic and mineral (clay) constituents on a still sea bottom prevented the sorting of these materials (Fig. 15). It is suggested these as plants or extremely minute organisms. These constituents occur repeatedly.

Structureless organic material is characteristic in all the samples studied. The reason why the ratio of calcite to argillaceous material in the environment changes (i. e. why a change from limestone shale takes place) does not bcome evident from a study of the thin sections themselves.

The appearance of the limestone in thin section suggests deposition as a gentle "rain" of particles of calcite (or perhaps aragonite) and clay material on a calm bottom environment, only occasionally disturbed by gentle currents.

A. Oolites

Oolites were observed in some thin sections which belong to the upper portion of the Fayetteville Formation. Most of the oolites have a radial, or concentric structure or both. Oolites appear to have grown outward from a center. In some oolites the growth has taken place around a nucleus such as calcite grain or pellet-like of clay inclusions. The nuclei are of various sizes and shapes but as successive layers enclose them, more and more spherical forms develop. The concentric laminae are of unequal thicknesses and are distinguishable from each other because of slight differences of color, opacity, and crystal structure (Fig. 14). Some of the thicker layers may consist of radially directed calcite fibers.

The oolites are composed of microcrystalline calcite; they range in size from 60 to 300 microns, are well-rounded, spherical to ellipsoidal, and scattered throughout the limestone bed. The oolites are sometimes partly and/or wholly coated by a dark, filmy, argillaceous material which forms a dark ring around the oolite in the section (Fig. 14). The oolitic beds are obviously the products of bottom currents and their most common mode of origin was by settling through comparatively slight bottom currents which rolled the calcite grains allowing clay to accumulate on the calcite.

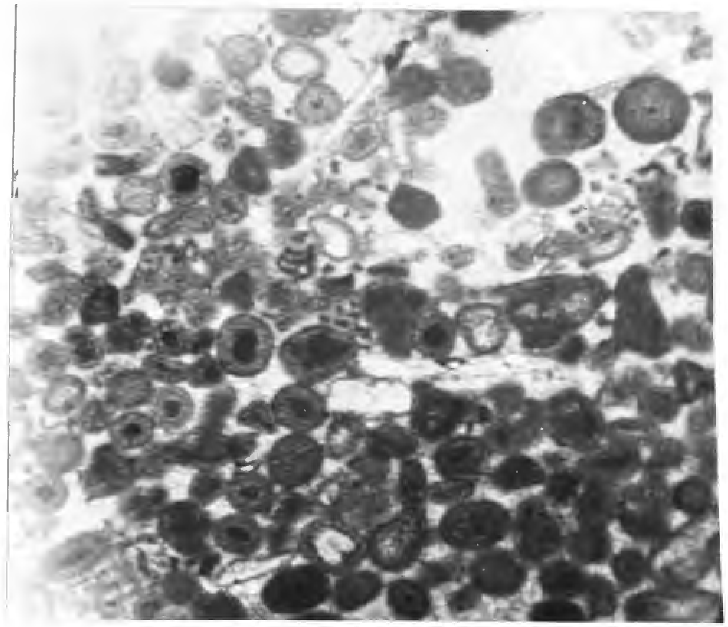


Fig.14 -- pohtomicrograph of oolitic limestone (bed 41), section L, Leslie, Arkansas. Note well-rounded and radiating oolites with nuclei of clayey material pellets or calcite. Dark spots are aggregated carbonaceous clay material (X 10).

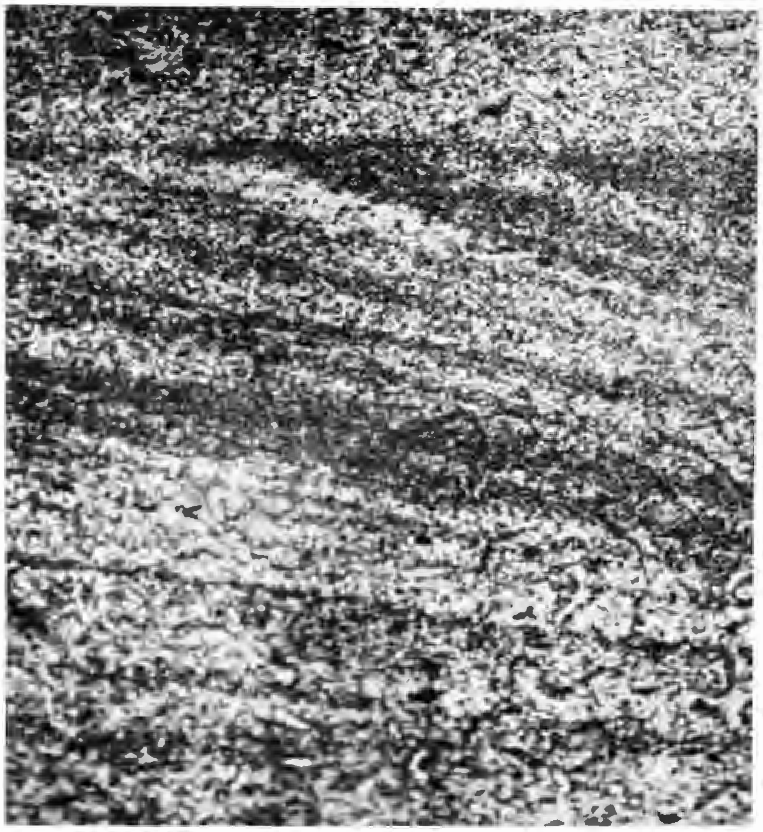


Fig. 15 - Photomicrograph of limestone (bed 214) Section A, along Arkansas Highway 66, near Alco, Stone County, Arkansas. Cross-bedded laminae including small grains of limestone (white) and aggregated carbonaceous clay. (x8)

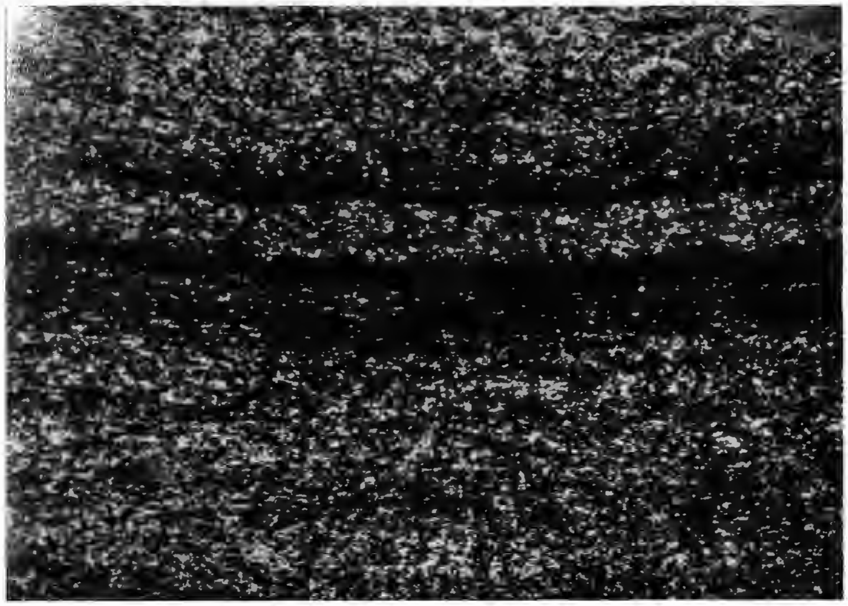


Fig. 16 - Photomicrograph of limestone bed (No. 260) in the Fayetteville Formation, showing the curved laminations, Section A, Arkansas (x8).

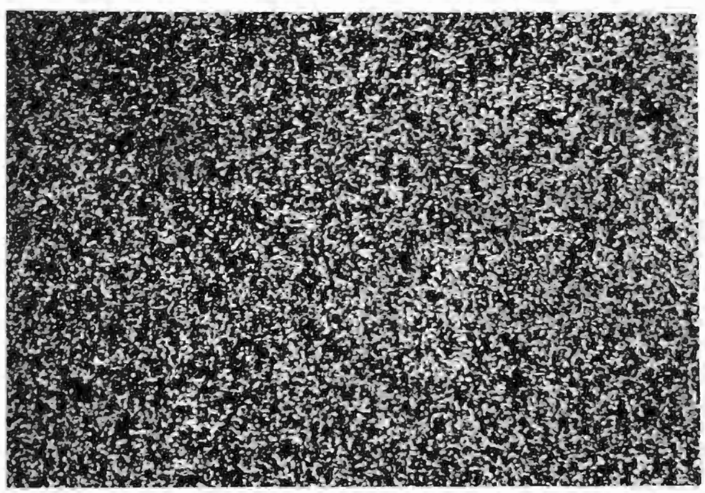


Fig. 17 - Photomicrograph of limestone bed (No. 20) showing uniform arrangement of microcrystalline limestone (white) with flakes of aggregated carbonaceous shale from Section A, Arkansas Highway 66, Stone County, Arkansas (x8).

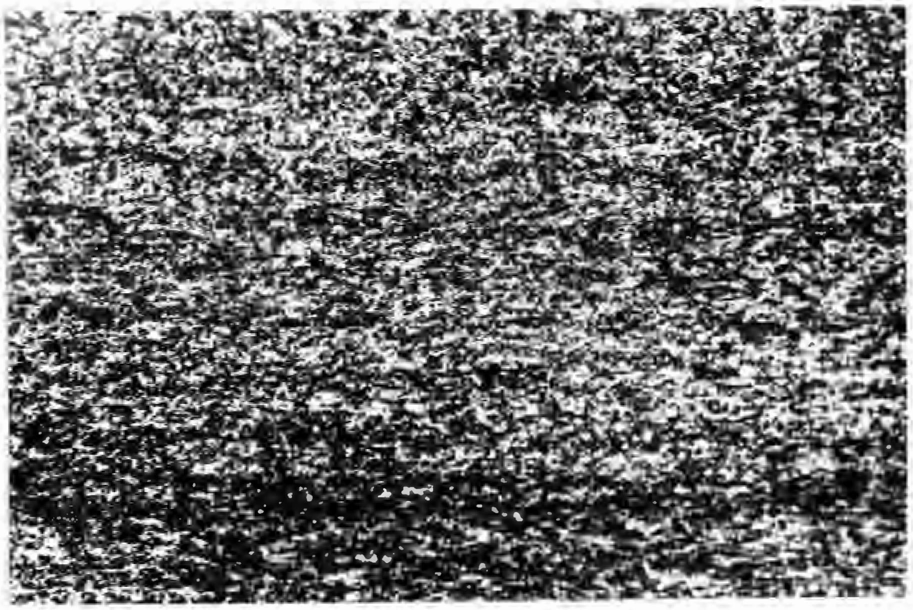


Fig. 18 - Photomicrograph of limestone, Section A, (bed 36), near Alco, Arkansas. Note gray microcrystalline layer-like calcite and dark organic shale flakes.

Fig. 19 - Photomicrograph of limestone (bed 140) showing dark organic clay pellets, shell outline and microfossil fragments. Section D, Newton County, Arkansas (x8).

B. Fossils

Brachiopod and pelecypod fragments can be recognized in thin section from the upper limestone beds in the Fayetteville Formation by their shape, and crystalline structure. Large fragments or whole shells are readily identified by their shape, but for smaller broken detrital fragments the shape was not diagnostic and this detritus could not readily be identified.

Some fragments of bryozoan were recognized by fine cellular pattern of their zooids.

C. Pellets

Another constituent of the limestone beds are pellets which are found in some of the beds in the measured sections. The pellets consist of aggregation of clay material devoid of internal structure; they range in size from 20 to 60 microns. In shape, they are irregularly rounded to spherical (Fig. 19).

They are seldom layered, generally being scattered through calcitic ooze or fossiliferous calcitic ooze. The pellets have been observed to occur in "micro" cross-beds (Fig. 15), and are often interlaminated with clay indicating they were current-deposited.

The mode of origin of these pellets is believed to be current movements of aggregated clayey materials, and through additional current action these masses are rounded (Folk, 1959, pp. 25-26). Their accumulation at a particular locality is due to a brief slackening of current velocity.

2. THE SHALES

The shale seems to be clays consisting almost entirely of translucent (or brown-coated) and hackly grains. Aggregates appear as sugary grains with resinous luster. Weathered shales have a brick-red color in thin section.

As the material is extremely fine-grained under the petrographic microscope the argillaceous materials did not reveal the characteristic minerals in these mixtures of particles of varying sizes.

Thin sections of these dark and fine-grained shales were difficult to make.

Grim (1942, p. 228) says that; "clays and shales are composed essentially of extremely minute crystalline particles of one or more members of a small group of minerals known as the clay minerals." These particles would certainly conform to this definition. The color of shales generally results from a pigmentation of some kind. The darker the shale, the higher the content of organic matter.

Near the top or bottom of beds, especially at the transition which lithology changes from limestone to shale, variation in grain size was not apparent.

Noteworthy features in the shales are pyrites, laminations, and fossils. They are discussed below.

A. Pyrites

Samples of different horizons from the Upper Cyclic portion were macro- and microscopically examined, some thin sections contained very little pyrite particles. A large amount of pyrite was observed in a thin section of nodular limestone from the Lower Shale bed. The pyrite particles in this limestone were disseminated, dark-yellowish with a low reflectivity under the microscope; its brown tarnish may be caused by weathering.

These pyritic nodules suggest an origin in an euxinic environment. Such euxenic facies usully show a development of green or black shale rich in decomposable organic matter. Pettijohn (1957, p. 150) says that pyrite commonly is associated with organic matter. The organic matter evidently furnished the sulfur to the environment which maintained the iron in the ferrous state (Pettijohn, 1957, p. 452).

3. THE LAMINATIONS

Laminations were observed in only a few of the thin sections from the samples of rocks in the Fayetteville Formation. Thin sections show alternations of two definite laminae: a light brown microcrystalline limestone (calcite mosaic) and dark brown to black organic matter which alternates with layers of clay or argillaceous shale (see Figures 15 and 16).

The contacts between the two parts of the lâmination and between the successive laminae are transitional. Although they appear sharp by megascopic examination some of the laminae show somewhat of a gradation in grain size from coarse at the bottom to fine at the top (Figures 15 and 16). The upper, fine-grained part of these laminae is richer in organic matter whereas the lower part is richer in mineral matter.

The average thickness of 60 of these laminae in one thin section (bed 214, section A) is 0.3 mm.; but the range in thickness is rather variable - from 0.1 to 0.7 mm. (Figure 15). In other thin sections, such as the bed 260, (section A) the average thickness of 16 laminae is 1.6 mm. (Figure 16), and in the bed 36 (Section A) the average thickness of 14 laminae is 0.9 mm.

In the organic laminae, flakes of the organic matter composed of clay with some grains of crystalline carbonate are predominant, and organic matter is a minor constituent; whereas in the mineral laminae carbonate grains and some clays are more abundant. Crystalline grains, in laminae, have sometimes been partially cut off by bottom currents and rapidly redeposited.

The organic matter in laminae are composed of extremely minute particles so that it is not possible to identify its character.

In no thin section of these laminations were fragments of fossils observed.

It is possible that the organic matter was deposited during active vegetation growth and warmer weather in the milder seasons.

Occurrence of the laminations involving calcareous materials is dependent, basically, upon the periodicities in climatic changes. Other physical factors which are effective are concentration and depositional changes of the materials in basin. The lamination would seem to require an environment of gentle currents probably in water of moderate or greater depths. A gentle underwater current may arrange and size the grains, all during the very slow rain and continuous fall of the deposited materials.

XI. ENVIRONMENT OF DEPOSITION

1. MECHANISM OF CYCLIC DEPOSITION

For no part of the stratigraphic column where cyclic distribution of sediments occur has it been possible to state with finality the environment of deposition. The environment of deposition of the Fayetteville likewise poses many debatable problems.

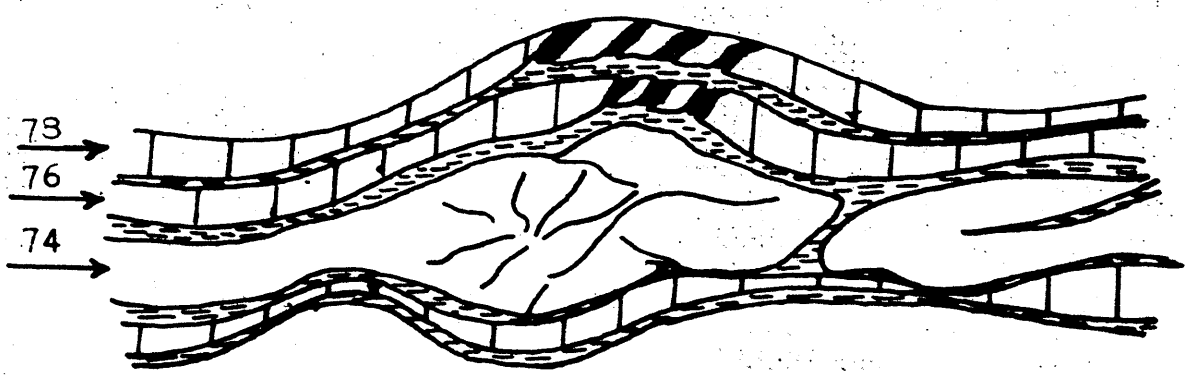
Sedimentation in the Fayetteville seas was dependent on the size, shape, and bottom configuration of the hydrographic basin and shoreline; the streams that fed the basin, and the number of streams would be significant; also it was likely that favorable climatic conditions had to be available for the repeated deposition of both carbonaceous shale and chemical limestone.

The bottom was uniform enough so that the clastic material was distributed rather uniformly over a large area of the northern part of the Fayetteville sea. The inflow of detrital material, may have been higher in certain areas than others but were uniformly distributed by the slight currents available.

During late Fayetteville times, chemically precipitated calcium carbonate began accumulating along with the clastic clays. The deposited carbonate was controlled by several factors; for example, temperature and evaporation which are closely related to climate and seasons, the rate of growth and production of minute aquatic organisms, and the seasonal inflow of water into the depositional basin from the surrounding drainage area. The cyclic character, that is, the alternate precipitation and non-precipitation of the carbonate was due to a change in one of the above environmental factors. Whether the low clastic content of the calcareous phase of the cycle is due just to increase in carbonate precipitation with decrease in clastic input, is debatable; however, it would be less difficult to explain if only one of the variables- the carbonate- need be explained, unless, of course, the explanation for the presence of the carbonate also affected a change in the amount of clastic clays being supplied.

Temporary lowering of wave base caused local reworking of the materials deposited during the limestone phase of the cycle - the oolites, pellets, and the shell materials. The temporary lowering of wave base or submarine currents might have been responsible for the formation of the nodular beds. Sliding seems to have been possibly evident in this environment in the formation if the large nodules described for the Alco section are due to this cause (see sketch). The uniform argillaceous nature of nearly all of the limestone beds is probably due to the repeated stirring by waves or currents on the relatively shallow sea floor.

The shale phase of the cycle was deposited under quieter conditions than those of the limestone. Undisturbed conditions are indicated by the uniformity of shale



Sketch, showing an unusual nodular limestone bed(74) up to 5 feet thick, section A, Arkansas. Note the central scattered fractures due to stress, and open cracks in the overlying beds (76 and 78) filled with calcite. Laterally the bed becomes a uniform tabular limestone.

layers laterally, the development of laminations, and from the general environments proposed for the deposition of such dark shales. The chemical phase of this environment and for that of limestone is discussed below.

2. CHEMICAL ENVIRONMENT

In suggesting the chemical environment of deposition of the Fayetteville it would be appropriate to compare it with an analogue in modern seas. However, such a situation does not appear to exist. Nor does the mineral assemblage of the formation give more than a general clue as to the nature of the source area.

The calcite which begins appearing in the upper part of the section, may have been precipitated from sea water by several means: organically, by plants and animals or inorganically by disturbance of the chemical and physical stability of the environment of the sea water.

Probably the precipitation of lime from sea water is due to a consequence of bacteriological activity (Kuenen, 1950, pp. 217-221). Where plants are involved, the process usually involves an extraction of carbon dioxide from sea water, by which process the solubility of the lime is reduced. Where bacteria are involved, it is supposed that these organisms produce ammonia, with the result that the more alkaline water will cause the marine waters to become oversaturated with lime. Calcium carbonate may be deposited as aragonite, but it is doubtful whether aragonite will persist for any considerable time in geological formations, since it is a monotropic form and tends to change to calcite (Mason, 1958, p. 174).

Oxidation potentials and pH are the basic controls which determine the nature of many sedimentary products. Krumbein and Garrels (1952, in Mason, 1958, p. 166). and Emery (1960, p. 265) found that pH and oxidation potential (Eh) are of fundamental importance in formation of chemical sediments. The hydrogen ion concentration or pH of natural water is of great significance in chemical reactions accompanying sedimentary processes.

It has been noticed that the sea is slightly alkaline whereas most terrestrial waters are somewhat on the acid side (Mason, 1958). Sea water is a buffered solution ($CaCO_3$-CO_2-H_2O), that is, changes from acid to alkaline condition, or vice versa, are resisted (Sverdrup et al, 1942, p. 195, Allee, 1950, p. 173). This property is of vital importance to the marine organism.

Some striking correlations between pH and living community distribution have been reported (Allee et al, 1950, p. 174). The limits of pH toleration differ more or less for different species. One can but wonder about the role played by pH in controlling this factor. This might also, be a reason for scarcity of fossils in the measured sections.

Discussion of the concentration of carbon in sea water is complicated by the fact that it occurs not only in the form of carbonic acid and its salts but also in appreciable amounts as a constituent of organic material, either living or dead. The solubility of carbon dioxide depends upon the temperature and salinity of the water, and exchange of carbon dioxide with the atmosphere takes place at the surface.

Photosynthesis in the surface layers reduces the amount of carbon dioxide in the water, and respiration increases the concentration.

It is now considered that CO_2 can exist in the following forms in sea water and that under any given set of conditions these equilibria will prevail (Sverdrup et al, 1942, p. 192, Weller, 1960, p. 15): CO_2 (dissolved) $\rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3$ (bicarbonate) $\rightleftharpoons \overset{=}{C}O_3$ (carbonate).

If an alkaline substance such as calcium hydroxide is present in sea water (sea water is normally alkaline), the equilibrium will be shifted toward the carbonate, and the amount of carbonate will be increased.

The pH of sea water in contact with the air will vary between about 8.1 and 8.3, depending upon the temperature and salinity of the water and partial pressure of carbon dioxide in the atmosphere (Sverdrup et al, 1942, p. 209 and Emery, 1960, p. 265). Relatively large seasonal and annual fluctuations of variations in temperature and salinity might occur in the sea. The salinity may increase during the low rainfall on the land surrounding the sea or basin, and fresh-water drainage from the land after heavy rains could reduce (although slightly) the salinity in the sea. At subsurface levels, the pH will vary with the extent to which the CO_2 content of water is modified by biological activity. The factors that may modify the concentrations of the substances in sea water are rainfall, inflow of river water and biological activity.

The periodic inflow of water into the depositional basin from surrounding drainage basin may be considered as a factor contributing to the rate of precipitation of calcium carbonate.

The fine crystalline to amorphous groundmass of many limestones may be formed by the gradual rise in temperature of a saturated current which causes inorganic precipitation.

Another environmental factor which is probably of greater importance is the process of photosynthesis carried on by the phytoplankton in the summer. The plankton, probably algae, take carbon dioxide out of the system, reduced the acidity of the water and the solubility of calcium carbonate.

The organic matter which is presumably of marine origin, and possibly also contains terrestrial plants which were carried to the sea along with the clay particles, was deposited with the clay and limestone in the basin.

Trask (1932, p. 112) indicated phytoplankton as the source of the organic matter in modern marine sediments.

The organic matter was deposited chiefly during their peak of production, probably in the spring. These lowly organized plants, such as marine algae left no other trace other than the carbonaceous content of shale and limestone when they died.

It is believed that a layer of ooze constantly accumulated by the death and decay of the aquatic organisms, while other organisms continued to grow above. Under favorable climatic conditions, this was the predominate material that accumulated; later, due to a change in climate or seasons on land or the ability of marine plants to grow in the sea, only calcite accumulated. This formed the laminae. Whether this was an annual feature is difficult to determine.

The origin of argillaceous shale may be explained in a number of ways. For example, argillaceous material might be precipitated by the flocculating action of sea water.

The carbonaceous shale was deposited slowly in a reducing marine environment rich in organic matter. Sulfide irons were possibly present, produced by the reduction of sulphate. In a near calm basin stagnating water may be formed, while the surface layer is generally diluted by fresh water coming from the surrounding land. At depths the oxygen is gradually consumed and as soon as it is all used up, hydrogen sulfide begins to form. The hydrogen sulfide, in turn, sets upon iron salts and precipitates black amorphous iron sulfide, which crystallizes later to pyrite. The deposition of the thick Lower Shale is similar to the shales which occur in the cyclic beds, but represents conditions of relatively uninterrupted deposition for a longer period of time.

The fauna of the dark shale is marine. Most of the cyclic beds are very sparse in fossils. This might very likely have been controlled by the reducing condition present on this sea floor. Only the upper portions of limestone beds are represented by shells such as brachiopods and pelecypods where environmental conditions might have been more favorable for marine life.

3. CLIMATE OF FAYETTEVILLE TIME

Knowledge of the formation of cyclic beds is sparse, particularly for those formations of the Upper Mississippian. However, present interpretations which are based on detailed data available from field observations and petrographic studies, may contribute to the solution of the problem. Because of the difficulties of conception of the Fayetteville sea basin, surrounding physiography and prevailing regional climate, there is a great lack of data on the variables.

Judging from the types of sediments compared with present day types and environments, the following account must, therefore, appear most reasonable:

In temperate regions cyclic beds might result from the climatic cycles, and these affect the physicochemical state of the sea. Temperature changes might have played an important role in deposition. A climate such as one with relatively high humidity (temperature representing one extreme of conditions) conceivably might have been similar to that now found in subtropical areas. Considering the type of organism and sediments, it would seem that the prevailing climate was warm and relatively humid.

CONCLUSIONS

An examination of the limestone and shale rhythms of the upper Fayetteville Formation (upper Chesterian) shows that these repetitions are different from the well-known Pennsylvanian cycles (cyclothems) both in the character of the lithologies and the probable mode of origin. It differs in origin from the Pennsylvanian cyclothems in that, a) the Fayetteville accumulated along the narrow edge of a geosyncline (Ouachita) whereas the Pennsylvanian accumulated over a broad neritic shelf area, b) the lithologic units making up the Fayetteville suggest that these cycles were also of shorter duration, c) it would also appear unreasonable that cycles such as these could be controlled solely by subsidence, as suggested by most hypotheses for the origin of the Pennsylvanian cycles.

In regard to the latter it must be said that tectonism was significant in providing the setting for the late Meramecian and Chesterian beds by shifting depositional sites from the Ozark Dome region to its edges.

The predominant feature of the Fayetteville Formation is the deposition of clay materials. This material began accumulating when the sea floor was moderately smooth but with enough relief, so that circulation was often restricted and locally the section was incompletely developed because of irregularity of bottom topography.

In the late Fayetteville calcite (or aragonite) began accumulating along with the clay. The calcium carbonate was deposited for short intermittent periods but neither the calcium carbonate nor the clays were deposited exclusively from each other. This pattern continues into the Pitkin Formation with the clay becoming a minor constituent. The exact cause of precipitation of the carbonate from the sea water might be due to a number of variables.

It may be precipitated from sea water by increasing the temperature of the water; this reduces the solubility of carbon dioxide and/or calcium carbonate; it may be precipitated by activity of marine plants which subtract carbon dioxide from the sea water and thereby precipitate calcium carbonate.

During the development of the limestone the environment was considerably more hospitable to invertebrates with calcareous skeletal material - particularly productid brachiopods, pelecypods, and some crinoids. Even these are most abundant near the transitions into the Pitkin Formation whose limestone contains less detrital material. It is possible that it was just this material which made the waters too turbid during the time most of the cyclic beds were forming, which made the environment unhospitable for these organisms.

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