STATE OF ARKANSAS

ARKANSAS GEOLOGICAL COMMISSION

Norman F. Williams, State Geologist

CONTRIBUTIONS TO THE GEOLOGY OF THE ARKANSAS OZARKS

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT.) PAGE

LIST OF ILLUSTRATIONS (CONT.) PAGE

HISTORY OF INVESTIGATIONS ON THE POST-ST. PETER ORDOVICIAN OF NORTHERN ARKANSAS: THE ART OF LAYER-CAKE GEOLOGY

William W. Craig 1/

ABSTRACT

The post-St. Peter Ordovician of northern Arkansas consists of, in ascending order, the Joachim, Plattin, Kimmswick, and Fernvale Limestones, and the Cason Shale. Subdivision of this dominantly carbonate sequence into its present rock-stratigraphic units was not apparent to the first geologists who worked in the area, and they erected formations that encompassed sizable portions of the stratigraphic section. The refinement that produced the present sequence of units came primarly through the paleontologic studies of H. S. Williams and E. O. Ulrich. These studies indicated that individual units erected by earlier geologists contained between their boundaries more than one distinct fauna. The indication that the original units were subdivisible on faunal grounds led to the discovery of the more subtle lithic changes that bounded each fauna.

Ulrich was especially influential in the development of the present stratigraphic nomenclature of these post-St. Peter strata. Ulrich's method of stratigraphic synthesis, which was undergirded by his belief in diastrophic periodicity, dictated that each formation was the product of a separate inundation of a sea that was characterized by rather uniform sedimentation and fauna. The time that elapsed between inundations produced changes that allowed successive faunas to be recognized. Thus, local stratigraphic sequences such as the Arkansas post-St. Peter strata, were comprised of unconformity-bounded, lithically homogeneous units, each of which possessed a faunal assemblage that was distinct from that above and below.

Recently discovered physical evidence supports Ulrich's layer-cake interpretation of the stratigraphic history of the post-St. Peter of northern Arkansas. However, a contrary opinion, which in essence states that this sequence of strata resulted from the superposition of the lithotopes of a single depositional system during one transgression is appealing and should be retained as a working hypothesis.

Recent investigations show that the Cason Shale, like the carbonate units erected by the early geologists in northern Arkansas, can also be subdivided into unconformity-bounded units, each of which represents a separate episode of earth history.

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New Orleans, Louisiana

INTRODUCTION

Can you bake a layer-cake, Charlie Bell, Charlie Bell
Can you bake a layer-cake, quite enticing
Or does it end up as a feast
Of gradational flour and yeast
Interfingering conformably with icing.

A word is in order about the subtitle. I considered others, such as "Confessions of a Layer-Cake Geologist", or, my favorite, "What you Always Wanted to Know about Layer-Cake Geology, but were Afraid to Ask". My colleagues, in their infinite wisdom, persuaded me against these.

Layer-cake geology is practiced primarily by paleontologists, and the accusation that it is art rather than science is an indictment by physical stratigraphers who do not appreciate the ways of paleontologists. I myself am not quite sure whether it is art or science, which is a sad confession for someone who is primarily a paleontologist. I am sustained in my work, however, by the optimistic hope that it is truly a science, but one in which the material is so esoteric and the chain of reasoning is so long and involved that the product produced only appears to be art.

It is true irony for me to find myself in the layer-cake camp, for years ago I devoted some time in attempting to demonstrate a facies relationship between some upper Ordovician and Middle Silurian strata. It is doubly ironical when I recall my student days at the University of Texas, where a healthy, open and nearly continuous debate concerning the philosophy of stratigraphic synthesis left most of us with a strong suspicion of the methods and products of "layer-caking". The chief antagonist of the layer-cake was W. Charles Bell, who was not necessarily against the proposition, but who did demand, and rightly so, that the lines of reasoning be several, clear and uncontradictory. Of course, careful examination into reputed layer-cake situations seldom found these conditions satisfied. The ditty at the beginning of this introduction, sung to the tune of "Billy Boy" at one of the year-end student productions, reflects the kind of good-humored ribbing Charlie received for his standards. To give credit where credit is due, the song was the creation of master lyricist Murray Felsher, who has long since abandoned ancient depositional systems for employment with the EPA where he worries over more relevant environments.

These Ordovician formations truly qualify as layer-cake geology. They were originally recognized on the basis of their contained faunas as distinct, unconformity-bounded units, each supposedly the product of a separate inundation of a Paleozoic sea that received rather uniform sedimentation. Recently gathered physical evidence suggests that the original paleontologic decisions, admittedly mystic, were correct. There is, however, a contrary opinion, which in essence states that this sequence of strata resulted from the superposition of the lithotopes of a single depositional system during one major transgression. I am of the opinion that the preponderence of our present information supports the layer-cake interpretation. However, I must admit that our knowledge of these units leaves much to be desired and that a re-examination of the rocks promises to aid greatly in the decision as to which of these prejudices is true.

A sequence of named formations constitutes a classification. Any classification presents in summary form the conceptions that those doing the classifying have of the way in which the objects being classified relate to one another. The development of the stratigraphic nomenclature of a sequence of rocks, then, traces the development of the ideas that geologists have had about the history of the rocks. My primary objective is to trace the development of thought on these strata by outlining the changes and refinements in their stratigraphic nomenclature from the first efforts to classify them to their present layer-cake status (see table 1). I have of necessity limited myself to those investigations that are in some way aligned with this objective. It is my hope that an understanding of how the present classification developed will provide a valuable framework within which to conduct future researches. An index map showing the general area of outcrop of the post-St. Peter units in northern Arkansas can be found in another article by me in this volume.

THE ARKANSAS SURVEY VS. H. S. WILLIAMS: THE FIGHT FOR THE FIRST LAYERS

In the summer of 1889, R. A. F. Penrose, Jr. began field investigations on the manganese deposits of Arkansas for the Arkansas Geological Survey, which at that time was under the able direction of J. C. Branner. Penrose's work in the northern part of the state was centered in the Batesville manganese district. The only prior investigation the Paleozoic rocks of northern Arkansas had received was in connection with a reconnaissance conducted by the first Arkansas Geological Survey under the direction of David Dale Owen (1858). Owen had included the strata from the top of the St. Peter Sandstone (his saccharoidal sandstone) through the present Boone Chert in a single unit, the Subcarboniferous or Cavernous Limestone, which he combined with stratigraphically higher units into the Subcarboniferous Limestone Period. The volume produced by Penrose (1891) is remarkable enough in that the field work and resultant 608 page text were completed from start to finish in a year and a half, but even more remarkable when you read in Branner's preface to the volume that in order to better evaluate the importance of the Arkansas manganese Penrose personally visited and examined every known manganese region in North America! This took him to eleven states, as widely separated as Georgia, Oregon, Utah and Vermont, as well as to Canada; only time prevented him from visiting Cuba and Chile. All this he did at his own expense, which, of course, he could well afford.

TABLE I. DEVELOPMENT OF STRATIGRAPHIC NOMENCLATURE

<table>
<tr><th colspan="2">PENROSE, 1891</th><th colspan="2">WILLIAMS, 1894</th><th colspan="2">WILLIAMS, 1900</th><th colspan="2">ULRICH, 1911</th><th colspan="2">MISER, 1922</th><th colspan="3">PRESENT</th></tr>
<tr><td rowspan="9">SILURIAN</td><td rowspan="7">ST. CLAIR LIMESTONE</td><td rowspan="5">SILURIAN</td><td rowspan="3">CASON LIMESTONE</td><td rowspan="5">SILURIAN</td><td rowspan="3">ST. CLAIR LIMESTONE</td><td rowspan="6">SILURIAN</td><td rowspan="3">ST. CLAIR LIMESTONE</td><td rowspan="3">SILURIAN</td><td>ST. CLAIR LIMESTONE</td><td rowspan="4">SILURIAN</td><td colspan="2">ST. CLAIR LIMESTONE</td></tr>
<tr><td rowspan="2">BRASSFIELD LIMESTONE</td><td rowspan="4">"CASON"</td><td>"button" shale</td></tr>
<tr><td rowspan="2">Brassfield Limestone</td></tr>
<tr><td rowspan="2">CASON SHALE</td><td rowspan="2">CASON SHALE</td><td rowspan="2">CASON SHALE</td><td rowspan="6">ORDOVICIAN</td><td rowspan="2">CASON SHALE</td></tr>
<tr><td rowspan="5">ORDOVICIAN</td><td>phosphatic beds & oolite</td></tr>
<tr><td rowspan="4">ORDOVICIAN</td><td rowspan="2">ST. CLAIR LIMESTONE</td><td rowspan="4">ORDOVICIAN</td><td rowspan="2">POLK BAYOU LIMESTONE</td><td>FERNVALE LIMESTONE</td><td>FERNVALE LIMESTONE</td><td colspan="2">FERNVALE LIMESTONE</td></tr>
<tr><td rowspan="3">ORDOVICIAN</td><td>KIMMSWICK LIMESTONE</td><td>KIMMSWICK LIMESTONE</td><td colspan="2">KIMMSWICK LIMESTONE</td></tr>
<tr><td rowspan="2">IZARD LIMESTONE</td><td rowspan="2">IZARD LIMESTONE</td><td rowspan="2">IZARD LIMESTONE</td><td>LOWVILLE LIMESTONE</td><td>PLATTIN LIMESTONE</td><td colspan="2">PLATTIN LIMESTONE</td></tr>
<tr><td>JOACHIM LIMESTONE</td><td>JOACHIM LIMESTONE</td><td colspan="2">JOACHIM LIMESTONE</td></tr>
<tr><td colspan="13">SACCHAROIDAL or ST. PETER SANDSTONE</td></tr>
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Penrose divided the Subcarboniferous Limestone of Owen into three formations. To a lower unit of "massive, blue or grayish-blue" limestone, in part lithographic, he gave the name Izard Limestone, a designation which was apparently already being used for these strata by Branner. To an upper series of "interbedded strata of chert and limestone" he applied the name Boone Chert, also apparently at the suggestion of Branner. Between the Izard and the Boone Penrose recognized a "crystalline limestone of light-gray, pink, chocolate-brown or purplish-black color" that he was unable to subdivide lithically. This was the unit with which the manganese ores of the Batesville region were associated.

During the course of his field investigations Penrose made several paleontologic collections from different stratigraphic levels of the Subcarboniferous Limestone of Owen. The collections were sent by Branner to H. S. Williams, who was at that time working under the auspices of the U. S. Geological Survey on the paleontology of the Mississippi Valley. Williams confirmed that the Boone Chert fossils were Lower Carboniferous in age. The fossils collected by Penrose from the Izard were imperfect calcite casts that were too poorly preserved to be assigned an age. The collections from the middle unit of crystalline limestone were puzzling in that Williams recognized in them assemblages of two distinct ages. One collection from along Folk Bayou four miles north of Batesville contained elements of Late Ordovician Cincinnati Age whereas other collections from St. Clair Spring, 1.5 mile north of Batesville, and localities to the west indicated a Silurian (Niagara) Age. The faunas were distinct enough to cause Williams to suspect that they came from two different limestone units, an opinion that he communicated to Branner early in 1890. It was Penrose's belief, however, that the two different faunas came from a single limestone unit that was continuous across the area, and he included all the coarse-grained limestone and associated rocks of the manganese interval in a single formation, which he named the St. Clair Limestone from the exposure at St. Clair Spring.

Because of the apparent conflict between the interpretation of the stratigraphy suggested by Williams and that made by Penrose and other geologists of the Arkansas Survey, Williams visited the Batesville region in the fall of 1890 and went over the ground with Branner. During this visit Williams was so impressed with the close physical similarity between the coarse-grained limestones of Ordovician, Silurian, and Mississippian ages that he became convinced that only by careful evaluation of the paleontologic evidence could grave mistakes be avoided in the interpretation of the historical geology of the region. He concluded that two different limestones, separated by the manganese horizon, were confused under the name St. Clair.

The following year Williams sent Stuart Weller, who at that time was a student of his engaged in paleontologic studies, to northern Arkansas to gather more collections and further interpret the historical geology of the region. In addition to this, Branner directed T. C. Hopkins, who was familiar with the stratigraphy in question through his work on the "marbles" of Arkansas, to collect additional samples from Penrose's St.Clair, carefully noting the position of each in relation to the manganese horizon. These collections were also sent to Williams, who examined them immediately and reported to Branner that, in relation to the manganese horizon, all collections from the limestone below were of Ordovician age and all from that above were of Silurian age. Hopkins (1893) referred to this determination in his report on the Arkansas "marbles", but he retained the single name St. Clair Limestone.

In 1894, Williams published a preliminary report on his studies of the St. Clair fauna. In this paper he underscored his belief that the St. Clair included two distinct limestones by restricting the name St. Clair to the rock containing the Ordovician fauna, and applying to the Silurian age member the name Cason Limestone, from the exposure at the Cason Mine. He also gave the name Cason Shale to ten feet of sandy, manganiferous shale between the two limestones at the Cason Mine. Williams concluded that fossils collected by Hopkins from this shale at the Cason Mine marked the beginning of the fauna of the limestone above, and thus the shale was Silurian in age. Furthermore, he believed that an interval of erosion separated the Cason Shale from the underlying Ordovician limestone.

In the succeeding years, Williams, Weller, and another Williams student, Gilbert Van Ingen, made exhaustive studies of the northern Arkansas faunas. In 1896, Van Ingen (see Williams, 1900, p. 282) pointed out to Williams that the only limestone exposed at St. Clair Spring contained the Silurian fauna and thus the name St. Clair was not appropriate for the Ordovician unit. In 1900, Williams published an article in which he corrected his mistake of 1894. He restricted the name St. Clair to the Silurian limestone and proposed the name Polk Bayou Limestone for the Upper Ordovician unit he had formerly called St. Clair. He also included in this report complete faunal lists that served as a basis for age assignments, and presented with even stronger conviction than before his belief that the Cason Shale was Silurian in age and represented an initial detrital phase of the sea in which the St. Clair was later deposited.

Williams' work settled once and for all the question of whether or not the coarse-grained limestone between the Izard and Carboniferous could be resolved into more than one unit, and most geologists accepted his subdivision of the St. Clair.

Branner was one who did not, and ever his later works (Branner,1896; Branner and Newson,1902) involving the units of northern Arkansas retain the single name St. Clair for the coarse-grained limestone in this part of the column. Although Branner and the more physically oriented geologists of the Arkansas Survey were willing to accept the paleontologist's determination that the St. Clair, as constituted by Penrose, encompassed a sizable portion of geologic time, they were unwilling to consider the paleontologist's decision that the unit involved two limestones separated by an unconformity.

Williams' studies illustrate an important character of these Paleozoic rocks, and that is that the simplicity of their lithic succession fails to reflect their somewhat more complicated history. This philosophy is a basic tenet in layer-cake geology. It is probably not strictly correct to identify Williams as a layer-cake geologist because he embraced many non-layer-cake attitudes in his approach to stratigraphic synthesis. Also the faunas he used to recognize major episodes of sedimentation in the stratigraphic succession of northern Arkansas were distinctly different from one another and, for what its worth, belonged to different geologic systems. Much finer distinctions are the hallmark of true layer-cake geology. However, the approach he used differs from that of the hard-core practitioners of the art only in terms of scale; the principle is the same.

THE STRATIGRAPHY OF MR. ULRICH: MASTER OF THE LAYER-CAKE

The most important individual influence in the development of the present stratigraphic nomenclature of the post-St. Peter Ordovician of northern Arkansas was that wielded by E. O. Ulrich. Ulrich, like Williams, was a long-time student of Paleozoic rocks and faunas. In the sense of ideas generated, the two of them were probably the most productive paleontologists of their time. However, their basic approach to stratigraphic synthesis differed on a number of points, a situation which from time to time placed them in opposition. Williams believed that lithotopes and biotopes shifted through time and space on a scale that was important geologically, and that consideration of this had to be taken into account in stratigraphic synthesis. As will be shown later, Ulrich's approach was quite different. Ulrich seems to be best remembered by later generations of paleontologists and stratigraphers as an autocratic paleontologist who traveled across the country interpreting stratigraphic history on the presence or absence of faunas. Such judgment is not entirely fair. Although paleontology did play an important role in Ulrich's decision making, the basic philosophy that undergirded his methodology led to a system of stratigraphic synthesis that was much more complex than the mere tracing of faunal units.

Ulrich's approach to stratigraphy was rooted firmly in diastrophic periodicity, a conviction which led him to believe that there existed a natural basis for the division of geologic time. He was firmly convinced that Early Paleozoic lands and seas were so different from modern ones that it was futile to look for modern analogs to ancient sediments. His conception of the Paleozoic craton was that of a nearly featureless plain composed of broad, shallow basins separated by low-lying land masses. The craton was bordered on its different sides by deep oceanic basins that were mostly mutually exclusive. Over this featureless landscape the Paleozoic seas oscillated frequently and rapidly. Periodic diastropic movements tilted the craton first in one direction, then in another, and in doing so allowed seas from different oceanic basins to invade portions of the craton at different times. Each sea was somewhat limited in extent, and in general the sea from only one oceanic basin at a time invaded the craton. The remainder of the craton was subaerially exposed, but it was not vigorously eroded because of its low relief. The variety of sedimentation that took place in any of these Paleozoic seas was considerably less than that occurring in modern seas because the featureless Paleozoic craton did not provide a variety of source areas or depositional sites. As a result, each incursion of the sea was a near-synchronous event throughout its extent and was characterized by more or less homogeneous sedimentation and fauna. The end product of the approach was a stratigraphy that almost categorically denied horizontal change in contemporaneous rocks and fossil faunas; thus to Ulrich no two units that differed lithically or faunally, whether in the same or different sedimentary basis, were of the same age.

Ulrich believed that he was able to demonstrate the relative ages of units deposited in different sedimentary basins by examining the superposition that occurred where their distal transgressive edges overlapped one another across the inter-basins highs. Seas transgressing in response to a tilt of the craton in one direction lapped over into adjacent basins and their sediments became intercalated with sediments deposited in seas that transgressed from another direction in response to another direction of tilt. Ulrich was convinced that he was able to demonstrate the correct sequence, origin, and distribution of Paleozoic marine invasions through determining the order in which the products of these invasions, the formations, were intercalated in the Paleozoic outcrops across the United States.

A conclusion that can be drawn from Ulrich's synthesis is that no one region contains anywhere near a complete stratigraphic record for even a minor increment of geologic time. For this reason he believed that the type section should play a very minor role in establishing the positions of units in the time scale. Ulrich felt that a composite standard section, worked out over the whole of the craton in the manner described, was the only practical approach to the standardization of time-stratigraphic terminology.

Ulrich's concept of a formation was not that of an objective unit based on its lithic or even its faunal attributes. Quite simply, a formation was a genetic unit. It was the only product of a particular epicontinental sea that existed only once in time. This was the unique attribute of each formation; this was the thing that distinguished one formation from every other formation; and this was his only real definition of a formation. If he could have confidently traced unconformities between widely-spaced outcrops he would have needed nothing else to vouch for a formation's identity. But alas, diastrophism as the ultimate basis of correlation, although serving him nicely as a theoretical organizer, failed him miserably as a practical tool. His diastropic thesis, however, possessed a potent factor. Because the sediments and faunas of each sea were rather uniform and, like the sea itself, unique in time, the lithology, fossils, and stratigraphic position of a sequence of strata could be used to identify to which one out of the many Paleozoic seas it belonged. However, these criteria did not in themselves define a formation; they simply facilitated recognition of that feature which ultimately defined each formation, which was its natural position in the scheme of things.

Ulrich's synthesis dictated that stratigraphic sequences in local regions be comprised of unconformity-bounded units, each the product of its own transgression. Unconformities separating the formation were obscure because erosion that took place between transgressions was slight. However, the problem of physically identifying the plane of erosion was of little consequence because each formation was the product of a different sea and thus contained its own distinctive fauna. No two juxtaposed faunas were exactly alike because the epicontinental seas responsible for them either transgressed from different oceanic basins, or, if the transgressions with which they were associated were from the same oceanic basin, enough time had elapsed between transgressions for the appearance of detectable changes in certain individual species or in the percentages of the faunal components. The following quote (1911, p. 373-74) illustrates the trust he eventually came to place in the ability of the faunal component as an identifier of each transgression:

> "Geologic literature is full of statements implying continuous deposition in sections that have since been shown on incontrovertible evidence to include greater or smaller hiatuses. Convincing physical evidence of subaerial decay and corrosion is often difficult to find in such obscurely marked instances of interrupted sedimentation; but in my own experience, the break indicated by the fossils seldom failed to be substantiated by the discovery of unconformable stratigraphic relations and as a rule of evidence pointing to land conditions."

This is, in rather abbreviated form, the kind of stratigraphic philosophy that Ulrich applied to the post-St. Peter Ordovician of northern Arkansas. In this sequence of strata Ulrich (1911) recognized the products (formations) of five separate epicontinental seas. The lower two were contained within the Izard Limestone, which he divided into the Joachim and Lowville Limestones; and the third and fourth were contained within the Polk Bayou Limestone, which he divided into Kimmswick and Fernvale Limestones. The upper one was the Cason Shale. He considered all contacts in this succession except that of the St. Peter-Joachim to be unconformable. Stratigrapher s who inherited Ulrich's scheme have devoted some time in attempting to determine just what it was to Ulrich's mind that distinguished these formations or just why it was that he considered them unconformable. Unfortunately, most of this time has been expended in northern Arkansas, and of course much of Ulrich's decision making was based on his detailed knowledge of other regions and his general overall conception of Paleozoic history. The units were not distinct and unconformable because they contrasted sharply with one another lithically and faunally because for the most part this is not the case. They were distinct and unconformable because they were deposited in different epicontinental seas. What was missing at these contacts, to Ulrich's mind, was the product of epicontinental seas that did not reach northern Arkansas. And the evidence for this, and thus for the unconformities, was in a series of Ordovician sections that extended from the Rocky Mountains to the Atlantic Seaboard.

H. D. MISER: THE COMPLETE FIELD GEOLOGIST

Ulrich would have been content to extend a formation name as far geographically as he could identify the distribution of the sea in which it was deposited. Thus he had no qualms about introducing into northern Arkansas stratigraphic terminology the Missouri names Joachim and Kimmswick, the Tennessee name Fernvale, and the New York name Lowville. In his 1911 volume Ulrich extended formation names into other areas; for the most part these were not accepted or have since been replaced. Such might also have been true for the northern Arkansas post-St. Peter units had it not been that in 1922 the Ulrich names were perpetuated and given credulence by publication of the finest geologic study ever done on these rocks. This was H. D. Miser's outstanding work on the geology of the Batesville manganese ores. Miser made many detailed observations on the units under discussion and established a lithic basis for each. Miser possessed that kind of astute professionalism that caused him to record most, if not all, of his observations, even those he did not fully comprehend; thus we inherit from him not merely a summary of opinion but a compendium of data. As a result his article still serves as the best and most lucid guide to the stratigraphy of this area.

In Miser's report the name Lowville was dropped in favor of the name Plattin. Ulrich had been quite impressed with the widespread nature of the Lowville type lithology, which is a "birdseye" lithographic limestone. In terms of lithic constancy over wide areas, he considered it the most notable of all Paleozoic formations. He considered the unit, of course, to be the product of an exceptionally widespread epicontinental sea that was coextensive with the present distribution of the lithic type. The use of a New York name in Arkansas apparently was too much for Miser.

Being the kind of geologist he was, Miser was careful to point out that the Joachim-Plattin, Plattin-Kimmswick, and Kimmswick-Fernvale contacts were "even" bedding plane contacts. However, he reported them as unconformable on Ulrich's sayso. Contacts like these qualify as paraconformities. Paraconformity is a much maligned concept that has become almost exclusively associated with the activities of paleontologists. The term means literally "not really a conformity" or "not the same as a conformity." It is a contact that exhibits none of the classical evidence of erosion, but which in a geologist's opinion none the less represents an erosional surface because something he "knows" should be there is missing. It is in essence an experienced-based interpretation. This missing something could be an assemblage of taxa, but doesn't necessarily have to be; certainly Ulrich's paraconformities were nothing quite this simple. Paraconformities, of course, are the most subjective of unconformities, and the term was proposed (Dunbar and Rogers, 1957, p. 119) to identify those erosional surfaces interpreted on this degree of subjectivity.

SAMPLING THE PRODUCT

Recent investigations into the geologic history of the post-St. Peter sequence of northern Arkansas have centered around the interpretation of the contacts between its different units. This is of course a proper emphasis, because the most important thing a stratigrapher does is to decide the historical significance of the change from one lithic type to another. These decisions provide the major framework within which the history is interpreted. A package of rocks bounded by unconformities should comprise a series of units related to one another in some logical pattern of lithotopes shifting in space and time; units across unconformities do not necessarily fit into a related depositional pattern. The exasperating feature of the post-St. Peter sequence of northern Arkansas is that whereas the units appear to fit a pattern to be expected of in part contemporaneous lithotopes superposed in a transgressing sea, as has been recently suggested by Young, Fiddler, and Jones (1972a b), there is also evidence to support Ulrich's inference that each unit is unconformity bounded. The latter evidence relates to the so-called "petrographic" unconformities reported by Freeman (1966a). These are welded contacts exhibiting micro-irregularity and post-lithification truncation of features in the subjacent unit. In view of this discovery, Ulrich's previous quote, which constituted a rather general prediction that unconformities would eventually be found to accompany the units he recognized on faunas, seems almost ominous. However, it is clearly evident that Ulrich had observed such contacts nearly three-quarters of a century ago.

The following quote (1911, p. 526) is his most lucid statement on the subject, but similar references appear throughout his work:

> "Very important stratigraphic boundaries, perhaps marking great hiatuses, are often included in an apparent lithologic unit. Indeed, the contact plane may be so tightly cemented that the rock above and beneath it forms a single layer. The latter is a common occurrence when a fine-grained limestone, like the Lowville or Stones River, is on either side of the line. In the Mohawk Valley of New York the top surface of the Lowville is often smoothly planed, either parallel with or slightly across the bedding planes, and riddled with vertical worm bores an inch or two in length. Generally not a vestige of detrital matter separates this surface from the overlying darker limestone (of some later Black River or early Trenton age), which fills the burrows and forms so close a joint that hand specimens showing the contact are easily procured."

This description remarkably parallels the appearance of the Plattin-Kimmswick contact. However, there is no indication that Ulrich had seen the Arkansas welded unconformities. His description of them from similar stratigraphic situations, and his general prediction of where they might eventually be found in the post-St. Peter sequence, carry the hint that he operated less on intuition than might be suspected. At any rate, the discovery of these contacts would appear to constitute belated vindication of his stratigraphic conclusions in northern Arkansas, and, if you excuse the expression, to serve as frosting on the cake he was so instrumental in making.

It is unnecessary here to further characterize or discuss the historical significance of these contacts; all this has been done ably, and from contrasting points of view, by Freeman (1966a, b; 1972) and Young, et.al. (1972a,b). I will, however, reserve the privilege of making a summary comment about them.

THE CASON SHALE: THE THIN-LAYERED CAKE

The uppermost Ordovician rock in northern Arkansas is contained in the Cason Shale, a name traditionally applied to the stratigraphic interval between the Fernvale and St. Clair Limestones. Until recently the Cason has been thought to be an unconformity-bounded unit composed dominantly of phosphatic sandstone and shale that presumably accumulated during one episode of deposition. Recent investigations show that in its type area around Batesville this unit, although seldom exceeding a few feet in thickness, consists of several rock types, contains at least two unconformities, and ranges in age from Late Ordovician to Middle Silurian. In ascending order, the Cason consists of phosphatic sandstone and shale, oolitic limestone, pelmatozoan limestone, and sandy, calcareous shale containing flattened algal "buttons". Although there is a natural tendency to assume that the lithic types of so thin a unit should be related to one another within some common pattern of deposition, it seems almost certain now that such is not the case. To find that a unit as thin as the Cason could be divided into mutually exclusive episodes of history has been a layer-cakers dream, and one to which paleontology has made a significant contribution. In fact, it is hard to imagine a comprehensible analysis of the interval without the information provided by its fossil taxa. The broad framework of the interval has been established (Craig,1969), at least to my satisfaction, and nothing beyond briefly outlining the development of thought concerning the stratigraphic position of its different parts needs to be considered here.

It is obvious that early workers (Penrose,1891; Williams, 1894, 1900; Branner, 1896; and Branner and Newsom, 1902) confused the lower phosphatic sands and shales with the Devonian Saverton Shale, at least at those places where the Cason is directly overlain by the Boone Chert. Miser observed every rock type in the Cason, but inasmuch as the occurrence of the individual units is sporadic he did not see them all together at any one locality. Because of this, and also because he was completely mislead by Ulrich's interpretation of meager paleontologic data, Miser was unable to order the units in their proper historical sequence. He reported the Cason as a heterogeneous, unconformity-bounded unit of Ordovician age between the Fernvale and St. Clair.

The Ordovician age for the Cason came from the algal "buttons", which Ulrich identified as Girvenella richmondensis, a guide to the Richmond of the Cincinnati region. These buttons occur only in the upper-shale unit, which forms the type Cason at the Cason Mine north of Batesville. Conodonts from the "button" shale at the Cason Mine and other localities are identical to those in the Lower St. Clair, and there is little doubt now that Williams' conclusion at the time he named the Cason, namely that both faunally and lithically the shale represents a basal detrital phase of the St. Clair, was correct. Interestingly enough, Ulrich was aware that algal "buttons" of exactly the same structure also occurred in the basal few feet of the St. Clair, which he considered to be of Middle Silurian age. He called these Girvenella, but tactfully omitted the trivial name. In retrospect, it seems likely that Ulrich assigned the Cason to the Ordovician primarily on lithology. The Ordovician in the Mississippi Valley ends with a shale, and a similar termination in Arkansas fit his stratigraphic concepts.

Miser (1922) hinted that the "button" shale was conformable with the St. Clair. However, during the course of his investigation a circumstance developed that made it impossible to report the two units as conformable. This circumstance was the discovery near Batesville, in a soil horizon on top of the Cason, of manganese oxide-replaced fossils that Ulrich identified as species common in the Brassfield of Madison County, Kentucky. Ulrich knew of Brassfield outcrops to the west of the Batesville district, and the inference was that the Brassfield had once been present above the Cason at Batesville but had been removed by erosion prior to the deposition of the St. Clair. Conodonts from the pelmatozoan limestone of the Cason agree well with those of the Brassfield of Tennessee, and it is fairly certain that this unit is the phantom Brassfield of the Batesville district. Miser did not consider that he had ever seen the Brassfield in the Batesville district but chances are that he did and failed to recognize it. In 1941 he reported the occurrence of a manganiferous carbonate rock up to 36 inches thick sandwiched between shale in the Cason interval. This would have to be the Brassfield resting on the lower phosphatic shale and overlain by the "button" shale. The fact that it occurred within the "Ordovician" Cason Shale, however, circumvented the chance of him recognizing it for what it was.

The lower phosphatic beds and oolitic limestone are discussed in another article in this volume. It seems almost certain that they are the only Ordovician part of the Cason; the rest belongs to the Silurian.

Considering the heterogeneous group of units now known to belong to the Cason Shale, and further considering the existence within the Cason of the Brassfield, itself a mappable unit, it seems apparent that the stratigraphic nomenclature of the interval needs revision.

RETROSPECT AND PROSPECT

Looking back over this century-plus history of investigations, the major impression received is that paleontology has been far more influential than lithology in the division of the post-St. Peter Ordovician strata into rock-stratigraphic units. Changes in fossil faunas at different stratigraphic levels has simply been more evident than changes in lithology within this dominantly carbonate succession. Lithic distinctions have been searched for only after faunal distinctions suggested that subdivision was possible. Paleontology, through Ulrich's diastrophic concepts, also has played the dominant role in interpreting the major framework of the stratigraphic history recorded by the strata; and later, physical evidence has been found to support the paleontologic interpretations. Not until recently has anyone worried much about the detail of the lithic attributes of these units, and these studies seem to have been overly influenced by the desire to support one or another of the theories pertaining to the historical relationship between the units. In short, lithology, rather than making a contribution independent of the interpretation based on the fossils, has served as a handmaiden to paleontology.

In prospect, each of these units deserves a detailed study of its own. Only with the knowledge such a study provides can we hope to fully understand the history of each unit and the historical relation of one unit to another. We know in general their structural, lithic, and faunal attributes, but we know very little about the vertical or horizontal distribution of these properties. Finally, these studies need to be made on strata, and not formations. As we examine the rocks, which are the only real things with which we deal, we must to a certain extent put out of our mind the classification we have erected for them. The mesmerizing effect of a stratigraphic classification is that it draws our attention all too strongly to the boundaries we think important, and consequently we concern ourselves disproportionantly with the nature of the property changes across formation contacts as compared with these same changes within the body of a formation. For example, if welded unconformities like those that bound the post-St. Peter units exist at lithic boundaries within the units, then our interpretation of these rocks might be somewhat altered.

The welded contacts, which have such an important impact on the interpretation of the stratigraphic history, need a more detailed examination over a much greater area. The preponderance of our present knowledge suggests that they represent significant interruptions in the depositional history of the sequence of strata. They are not confined to this part of the column; I have observed them between the "button" shale and the Brassfield, the St. Clair and the Brassfield, and at other formational contacts in the Mid-Continent region. There are enough of them to suggest that either they carry temporal significance or that geologic time is more or less faithfully represented by the strata preserved for our study. In spite of this conclusion I must confess that there is a certain amount of appeal, emanating from the sequence of lithic types, in the suggestion that these strata were deposited during what in overall essence was a single transgression. It would be premature at this point to cast aside this possibility.

In closing, permit me a few words about Mr. Ulrich. His conclusions about the geologic history of these post-St. Peter rocks were based on the recognition in northern Arkansas of lithic and faunal patterns familiar to him from his work over broad areas of the North American craton. The sum total of his experience and prejudice, the latter which to a certain extent is rooted in experience, led him to a layer-cake interpretation of these strata. Experience-based decisions are disconcerting to those of us without experience, and you may take it as fact that nobody before or after Ulrich has ever matched his overall knowledge of Paleozoic rocks and faunas. We would like to see in support of conclusions about the geologic history of a sequence of strata incontrovertible evidence in the rock itself. Instead, we find the interpretations of a man who has seen more rocks and fossils than we have seen. The evidence we now have concerning the history of these rocks would seem to support the three-quarters of a century old analysis made by Ulrich. The most logical interpretation of this sequence of strata is the layer-cake one. Before you conclude that my support of Ulrich's decisions in northern Arkansas constitutes an endorsement of his overall approach to stratigraphic synthesis, let me hasten to add that I am not so naive as to believe that such a transfer can be made. After all, it is possible to be right for all the wrong reasons. The interpretations he made in several other local areas, particularly in the geosynclinal regions, using the same craton-integrated approach have since been flatly refuted. If anything, we would expect that with a system so integrated as his the failure of any part would mean a collapse of the whole. There is one other factor, and this is concerned with Ulrich himself, that causes us to be inclined against his philosophy of stratigraphic synthesis. He presumably first examined the rocks and faunas and later concluded that their distribution supported the theory of a Paleozoic craton influenced by periodic diastrophism. However, it seems apparent that the first inklings of this generalization came to him rather early in life as a precocious young lad growing up among the fossiliferous hills of Cincinnati (for instance, see his 1911 paper, p. 501). Thus his theories might have matured more rapidly than his experience. With an overall pattern in mind, the lumping and splitting options available to any taxonomist make it a rather simple procedure to find agreement between data and theory. In short, it is possible that his mind made the tightest circle that can be made by the mind of any natural scientist -- he accepted as fact the very proposition he set out to prove. I might interject that this is a failing of men and not of theories. Those who would set out to examine a theory different from that of Ulrich's are also subject to the influence of the "tight circle". But there is something about Ulrich that gnaws at the back of the mind. This is the image of a man who possessed keen powers of observation, paid strict attention to detail, and was so intensely curious about his subject that he acquired a phenomenally broad experience in it. Some of his conclusions seem correct, and it just might be that somewhere in his system there resides a bit of truth. After having spent some time in his footsteps, I am inclined to find a little comfort in his admonition that in the study of Early Paleozoic depositional systems the present is not much of a key to the past.

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INSOLUBLE-RESIDUE STUDIES OF UPPER CANADIAN ROCKS IN NORTHEASTERN ARKANSAS AND SOUTHEASTERN MISSOURI

Mary H. McCracken 1/

ABSTRACT

Study of insoluble residues prepared from 24 American Zinc Company drill holes in Sharp and Lawrence Counties, Arkansas was made between the autumn of 1965 and the spring of 1967. A number of marker zones were identified in the carbonate section. It was found that the insoluble-residue markers extend across the dolomite-limestone boundary in several formations. When these markers were traced to the outcrop they were found in rocks of the Everton, Black Rock, Smithville, and Powell formations. These same markers have been successfully used in correlating well samples from the Missouri and Arkansas embayment areas.

Some of the best insoluble-residue types are: cherts, silt, sand grains, accessory minerals and silicified oolites.

On the basis of these studies, a map and two cross sections have been prepared for this paper.

ACKNOWLEDGMENTS

The preliminary sample examination of drill hole material from the American Zinc Company was done while the author was employed by the Missouri Geological Survey in 1967. The author wishes to thank the Missouri Geological Survey* and Dr. Wallace B. Howe, Missouri State Geologist, for sponsoring the work on this paper. Dr. Howe has made valuable suggestions as have James A. Martin and Jack S. Wells of the Survey staff. Slides and figures were prepared by the Graphics Section, and photographs were prepared by Arthur W. Hebrank of the Missouri Geological Survey staff. The American Zinc Co. (now the AZCON Corp.) through Dan R. Stewart, made available the drilling data. William J. Newby, formerly of the American Zinc Co., and Dan R. Stewart were helpful in identifying some of the residue material in outcrops. The Arkansas Geological Commission has cooperated in making the paper possible.

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INTRODUCTION

In 1966 and 1967 the American Zinc Company drilled a number of diamond-drill holes on their zinc properties in Sharp and Lawrence Counties, northeastern Arkansas. The area had been mapped as dolomite of upper Canadian and Everton age, but many of the cores and a few outcrops were found to be a dense, lithographic limestone varying in color from light tan to black. The Missouri Geological Survey's insoluble-residue method was used to help in establishing a correlation between these drill holes and the surface. Samples from 23 drill holes and one measured outcrop section were studied (Table I). The cuttings and cores were correlated with the surface and across the dolomite-limestone boundaries.

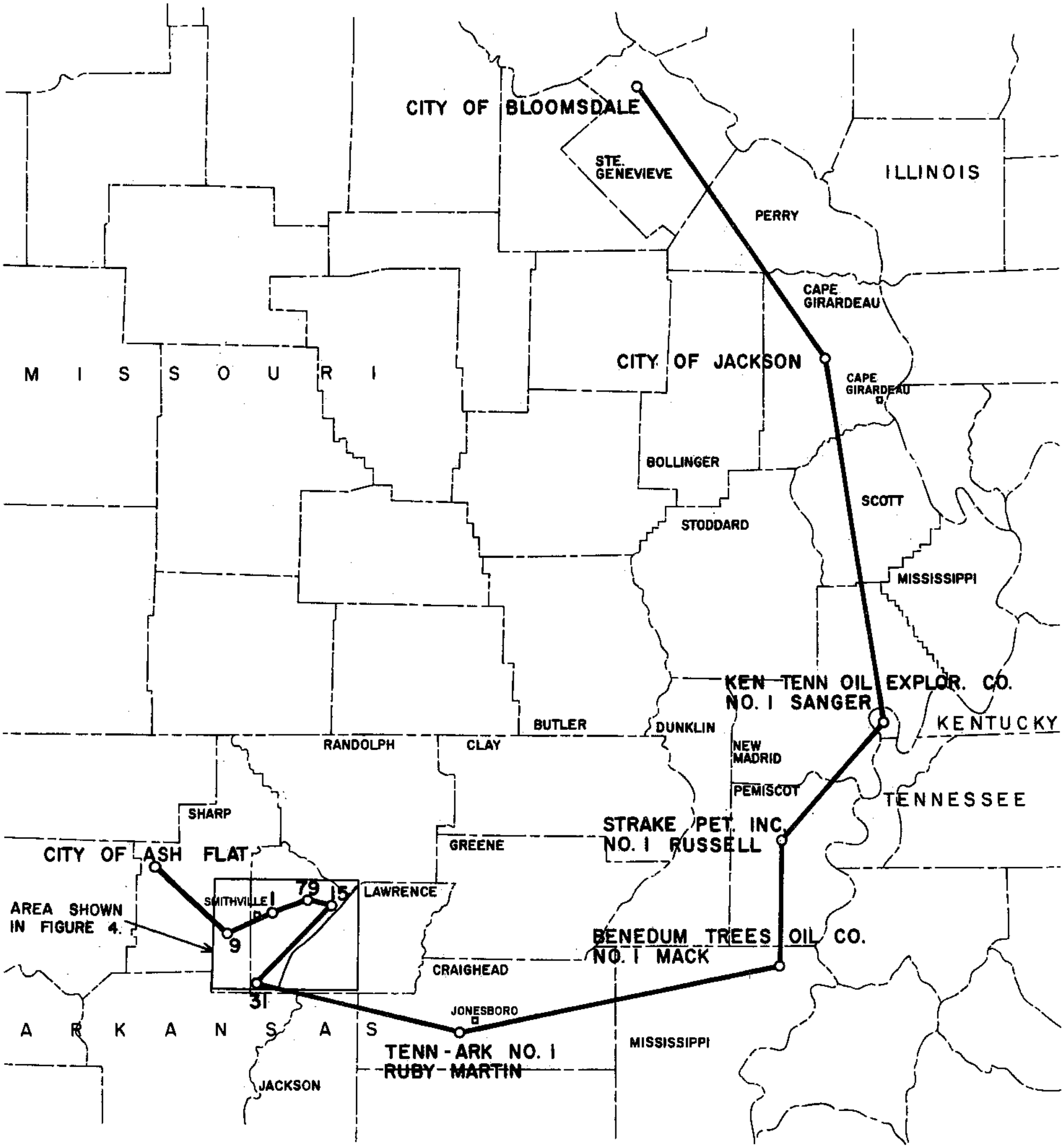
STUDY AREA

The 23 drill holes studied lie in eight townships, T. 15, 16, and 17 N., and R. 1, 2, 3, and 4 W., in Lawrence and Sharp Counties, Arkansas (Figure I). Early Ordovician rocks of this area have been difficult to classify down through the years. Some of the factors causing this lack of detailed classification are: topography; forest cover: proximity to older rocks of similar types to the west, with which they were usually considered to be equivalent; and difficulty in mapping because of lack of key beds in an essentially carbonate terrane of some thickness in which limestone and dolomite beds are interfingered. McKnight (1935) points out that the area has a more subdued topography than the general northern Arkansas Ozark region. Relief is on the order of 50 to 100 feet with a few areas of maximum relief along the main streams of up to 200 feet. The country is gently rolling, with considerable forest cover of second-growth oak, cedar, and some pine. Outcrops are in general not conspicuous. The Northeast Arkansas zinc district lies in the area covered by this drilling, and most of the holes studied are on or near the sites of abandoned mining properties worked principally during the Civil War and World War I.

The main drainage is to the Strawberry River, which crosses the area from northwest to southeast before entering the Black River. One of the tributaries of the Strawberry River is Big Creek, along which hole NEA 9 is located, near the site of the Arbuckle mine. Another tributary of the Strawberry passes through Smithville. Most of the better outcrops are along such streams.

Patches of Cretaceous and Tertiary clays and gravels show that parts of this area have only recently been exhumed from under similar sediments preserved immediately to the east in the Mississippi embayment.

Thus, the subdued topography is in part inherited from the Cretaceous peneplain.


CITY OF BLOOMSDALE
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PERRY
CAPE GIRARDEAU
CITY OF JACKSON
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M I S S O U R I
BOLLINGER
SCOTT
STODDARD
MISSISSIPPI
KEN TENN OIL EXPLOR. CO.
NO. I SANGER
KENTUCKY
BUTLER
DUNKLIN
RANDOLPH
CLAY
NEW MADRID
PEMISCOT
TENNESSEE
SHARP
STRAKE PET. INC.
NO. I RUSSELL
GREENE
CITY OF ASH FLAT
SMITHVILLE
1
79
15
LAWRENCE
AREA SHOWN IN FIGURE 4.
9
BENEDUM TREES OIL CO.
NO. I MACK
CRAIGHEAD
31
JONESBORO
A R K A N S A S
TENN-ARK NO. I
RUBY MARTIN
MISSISSIPPI
JACKSON

Figure 1

PREVIOUS STRATIGRAPHIC WORK

Dr. E. O. Ulrich was the first person to discover an unusual series of rocks in the Sharp and Lawrence County area. He collected a rich gastropod fauna from the Lincoln mine area near Smithville, Arkansas and then another fauna, with sponges, from a quarry near Black Rock, Arkansas. He sent the samples of fossil material to Washington and wrote a short note incorporated in his "Revision of the Paleozoic System" (1911,p.668), describing these rock units as part of his Yellville Formation. He thought the Black Rock was about 40 feet thick. Later he subdivided the Yellville Formation to place the Black Rock and Smithville above the Powell Formation. Thus they became his youngest Canadian formations in the Middle West.

Following Ulrich's work, little was done in the area until quite recently. McKnight (1935) did not make a decision as to the age of the Smithville or Black Rock, believing further study was needed. He considered the rocks to be of either Canadian or Everton age. McKnight quotes an unpublished report by Ulrich giving thicknesses of 55 feet for the Black Rock and 65 feet for the Smithville. McKnight also points out that the geologic map of Arkansas gives thicknesses of 200 feet for each of these formations. Few people gave much thought to the age of these rocks, preferring to lump them with the Powell and Cotter, or Everton, and it was thought by most people that the sequence was entirely dolomitized.

In the late 1930's and early 1940's, the Missouri Geological Survey became interested in the northern portion of the embayment due to some deep drilling. It soon became apparent that southeastern Missouri has a much thicker sequence of early Paleozoic rocks than is present in the Ozark area and northern Missouri. Also, it was found that these rocks are not all dolomites, but often contain lithographic limestones which are frequently dark-gray to black in color. Several Paleozoic sections were drilled in 1938 in the vicinity of Reelfoot Lake, Tennessee. Samples from these wells were sent to the Missouri Geological Survey by the Tennessee Geological Survey for an insoluble-residue study to try to tie them in with the Ozark section. These samples, by both residue studies and fossil identification, proved to be of the Bonneterre Formation (Late Cambrian). Following this, three deep wells -- two in Arkansas and one in Missouri -- helped to complete information about the stratigraphic section in the basinal area southeast of the Ozark uplift. These three wells were: (1) Tenn-Ark Corp. #1 Ruby Martin et al., sec. 35, T. 14N., R. 3 E., Craighead County, Arkansas; (2) Benedum Trees Oil Co. #1 Mack, in sec. 3, T. 15N., R. 12 E., Mississippi County, Arkansas; and (3) Strake Petroleum Co. #1 Russell, in sec. 24, T. 19N., R. 11E., Pemiscot County, Missouri. These gave the control needed to outline the Pascola arch and gave a yardstick to measure other wells in the area of this northeastern Arkansas basin (Grohskopf, 1955).

The only one of these wells which can be used in the study of the Sharp and Lawrence County holes is the Tenn-Ark #1 Ruby Martin. The other wells, because of the pre-Cretaceous erosion over the Pascola arch, enter the Paleozoic lower in the section than the Canadian beds which crop out in Sharp and Lawrence Counties. However, the wells showed a much thicker, blacker, and more calcareous section in the Cambrian and Lower Ordovician rocks than anyone had previous expected.

In 1950, Earl McCracken wrote a paper (unpublished) for the Arkansas Geological Survey, in which he correlated the Tenn-Ark #1 Ruby Martin well. He used the names Black Rock and Smithville for units which he thought would be equivalent to Ulrich's Black Rock and Smithville Formations in northeastern Arkansas. He also used the term "Post-Black Rock" for additional beds of dark limestone lying between sponge-bearing Black Rock below and Everton-St. Peter rocks above.

Caplan (1954, p. 53) stated that while the Smithville and Black Rock had been considered to be either a facies of the Everton or post-Powell; pre-Everton in age, he felt that they were equivalent to the Everton and that they were of Chazy age. His thicknesses were identical with those of McKnight (1935). (Editor's Note) Currently Caplan regards the Smithville and Black Rock as post-Powell, pre-Everton in age (oral communication).

Latest unpublished work by Wise and Yochelson (1971) places the Smithville and Black Rock in the Lower Ordovician (Canadian Series), but they feel that the Black Rock is a member within the Smithville Formation and not entitled to formational rank.

INSOLUBLE-RESIDUE UNITS

The standard insoluble-residue method used by the Missouri Geological Suvey was used in studying these samples. It was initiated in the early 1920's by H. S. McQueen (1931) and refined and expanded by Grohskopf and E. McCracken (1949). It is still used in the same manner in the study of cuttings and cores submitted to the Missouri Geological Survey. To date, some 27,000 sets of cuttings have been studied by this method.

Insoluble-residue material seems to be a function of the sedimentary environment in which the carbonate rocks were deposited. Therefore, residue studies are very effective in zoning thick sequences of carbonate rocks which would otherwise show little variation.

In the American Zinc Company drilling, five major, distinctive residue types (Plate 00) were used in correlation. A description of these follows, beginning with the youngest rock unit and proceeding to the oldest, as in drilling:

FIVE DISTINCTIVE RESIDUE TYPES

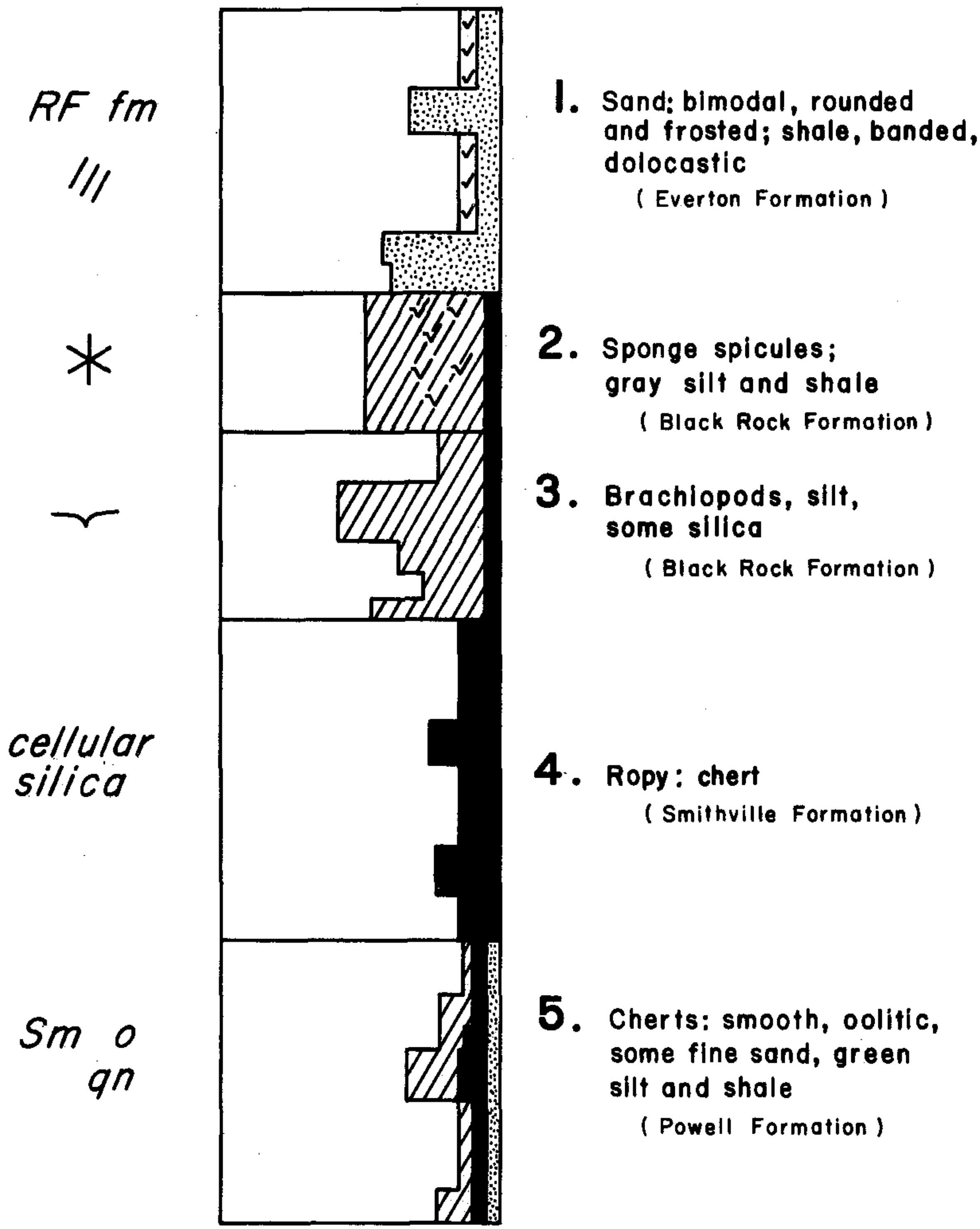
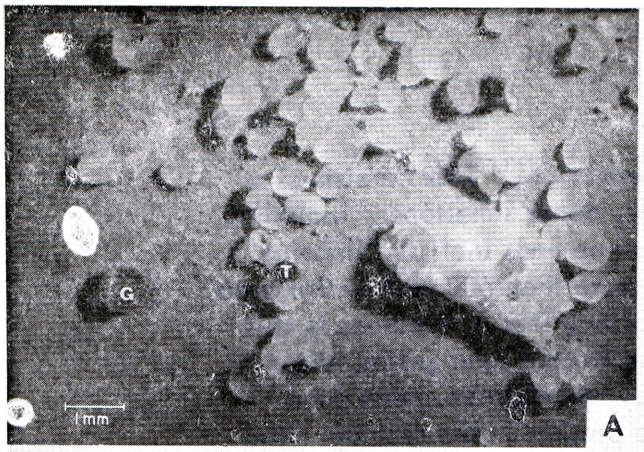
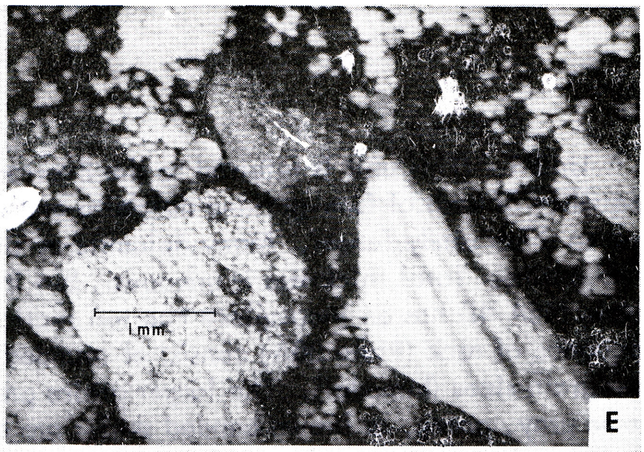
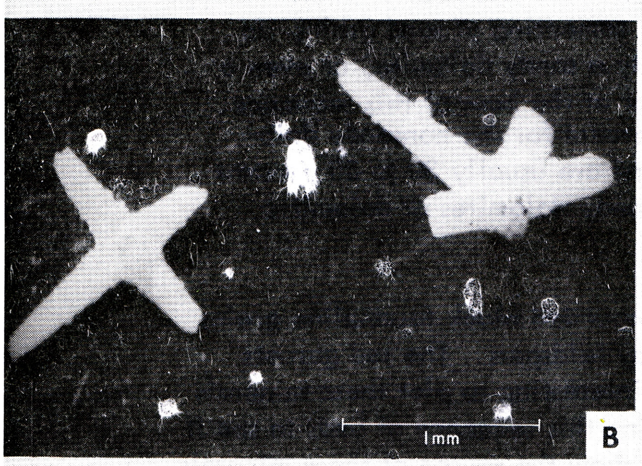
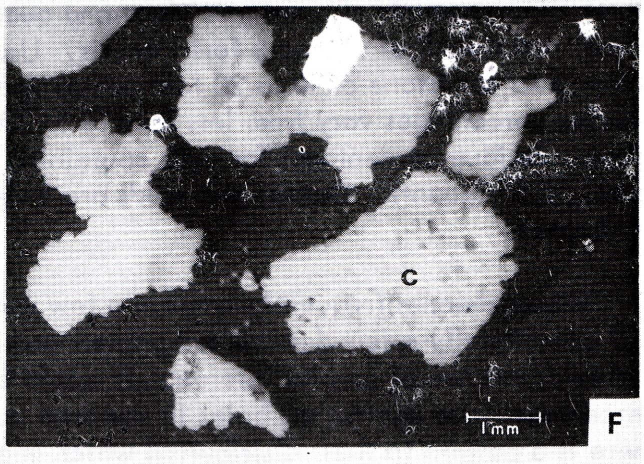


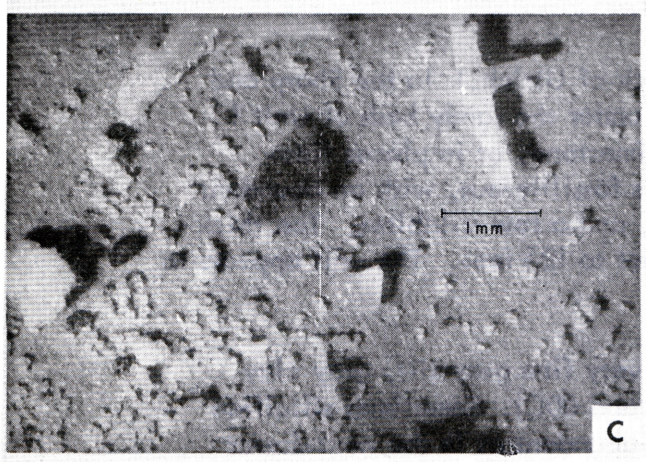
Figure 2

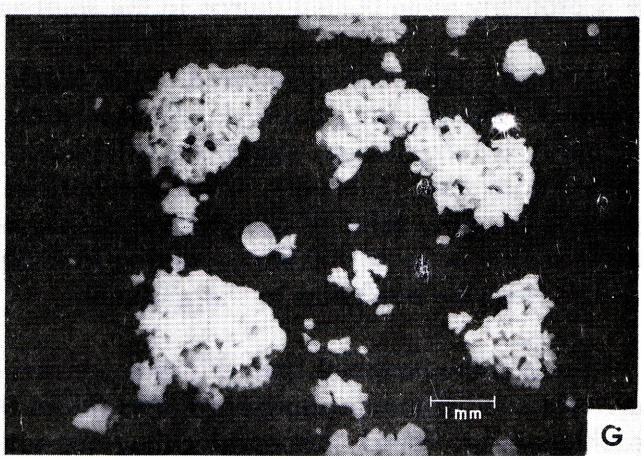












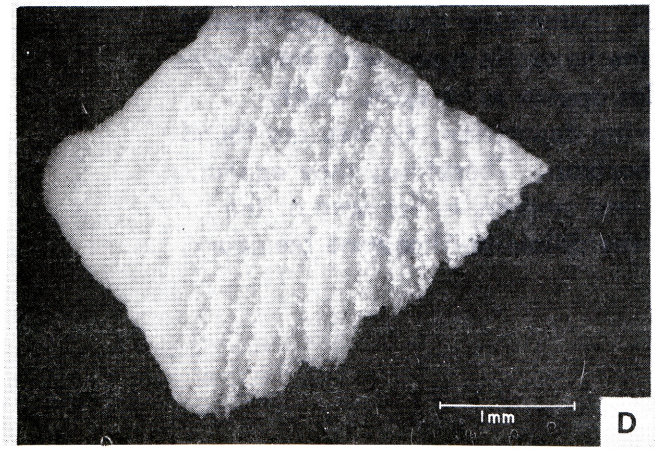


Plate 00.--Characteristic insoluble residues from upper Canadian and basal Champlainian rocks of northeastern Arkansas and neighboring areas: (A) rounded and frosted sand grains with garnet grain, G, and tourmaline grain, T, of Unit 1 (Everton); (B) sponge spicules and (C) silt with sponge spicules of Unit 2 (upper Black Rock); (D) silicified brachiopod fragment and (E) silt with silicified brachiopod fragments of Unit 3 (lower Black Rock); (F) ropy chert with cellular silica, C, of Unit 4 (Smithville); (G) green, dolomoldic shale of Unit 5 (Powell).

Unit 1. (This unit is referred to the Everton Formation.) This consists of a sequence of beds of fine-grained dolomite and dark, dense limestones, including one to three sandy lenses. Many dolomite or limestone beds include "floating" sand grains. Total thickness is unknown, but it is more than 600 feet in this area. (Hole NEA 41) has an incomplete Everton section of 605 feet.) Residues in this sequence of rock (Plate 00A) consist of rounded and frosted sand grains, often of two grain sizes (bimodal). The larger grains greatly resemble St. Peter sand. Some gray, green, or brown banded shales are also present in the residue. The shale bands are often separated by gray silt grains. There is a lack of chert (some minor amounts of quartzose chert and quartz cementing of sand grains do occur) and a lack of siliceous fossil debris. Usually a sandy dolomite, or even a rather pure sandstone of 10 to 20 feet occurs near or at the base of this sequence. Residue percentages vary from less than 10 to 20 percent for the nonsandy dolomites. Residue percentages for beds containing sand are usually 30 to 80 percent (rarely 100 percent). Usually the sands are truly sandy dolomites or dolomitic sandstones.

The sandstones frequently contain a few well-rounded black tourmaline grains and occasionally a few detrital red garnets and gray feldspars. The red garnets and feldspars are of special interest. It would be interesting to plot these minerals percentage-wise against all holes in the area cutting this sequence of beds to see if there is a pattern to their distribution which might show the source of these minerals (it is probably some buried source to the southeast).

Unit 2. (This unit is referred to the Black Rock of Ulrich.) In the Sharp and Lawrence County area, the rock unit immediately under the sandy beds of Unit 1 is usually a dark, dense, sometimes lithographic limestone, or in places fine-grained dolomite. This unit, if not dolomitized, is fossiliferous, with an abundant fauna of sponges, crinoids or cystids, brachiopods, and a few trilobites. The thickness is on the order of 100 feet, varying from 50 feet to 125 feet. The unit appears to thicken from the northwest to the southeast.

The residue material from this unit consists of very fine gray silt, gray clay particles, and siliceous sponge spicules (Plate 00B and 00C). Sometimes silicified brachiopods are found, but usually they are not as abundant as in the next-lower unit. The percentages of residue are in general higher than in the dolomites of the overlying unit (usually 20 to 50 percent), and the St. Peter-type rounded and frosted sand is lacking. The siliceous sponge spicules are the hexactin type, with three axes joined at right angles. These siliceous fossil spicules appear to be quite easily preserved and must have been widely distributed during deposition, as they are found over a considerable area at this same stratigraphic horizon. Therefore, they appear to be a good marker. Certainly they are one of the best markers in the area of the northeast Arkansas zinc district. They carry across the dolomite-limestone boundary, as do the other residue types described here.

Unit 3. (This unit is also referred to the Black Rock of Ulrich.) Beneath the sequence of beds carrying sponge spicules is another sequence of beds which can be either dolomite or dark limestone. These are similar to the sponge beds, except that they carry an abundant brachiopod fauna accompanied by large gastropods (Plate 00D and E). This sequence of beds has little or no chert, the silicified brachiopods being made up of white quartz.

Residue percentages of this unit consist of from 20 to 60 percent silt, gray clay-shale with silicified brachiopods, and sometimes fragments of silicified gastropods. Sponge spicules are absent, but brachiopod debris is abundant. Thickness of this unit is on the order of 125 feet. It varies from 85 feet to 165 feet and seems to thicken to the southeast. The total thickness of the sponge and brachiopod units, where complete, is about 225 feet. These units have much in common residue-wise. They seem to form a sedimentary unit. The chief component in both units is a gray silt, approaching clay size in the upper portion.

Unit 4. (Gastropod-ropy-chert zone; this unit is referred to the Smithville Formation of Ulrich.) Beneath the zone of abundant brachiopod fragments (Unit 3), are rocks with one of the best residue types ever found in the Ozark area. The sequence consists of at least 300 feet of strata which are either fine-grained dolomite or dense, dark limestone. In the Northeast Arkansas zinc district this unit is frequently dolomitized, especially in mineralized areas.

Residues from this unit contain a greater percentage of chert than any of the overlying units. This chert is unusual (Plate 00F). It has been described by Yochelson and Wise (1972) as "a meshwork of irregular flattened structures." Frequently the centers of these branching-chert or ropy-chert forms are a honeycomb of clear quartz, and some could be described as cellular silica. Gastropods or gastropod fragments are sometimes present in the residue material. In addition to the peculiar chert, residues contain green waxy shale and some silt; a gray to green shale (which may be metabentonite) is found toward the base of these beds. The lower parts of holes NEA 11, 32, 33, 35, 36, 72, 79 and 82 appear to have reached Unit 5 (Powell Formation) under the ropy chert.

Thickness of the ropy-chert unit varies from 260 feet to 350 feet, averaging about 325 feet. To the south, the holes were not deep enough to reach this unit, usually stopping in the sponge beds (Unit 2). Some of the drill holes started in this unit, and two holes (NEA 9 and 68) started beneath this unit. Unit 4 is found at the surface in the Smithville area, along Highway 63 near Imboden, and at the type Smithville locality (the Lincoln mine site). The weathered surface contains the same peculiar chert as the residues and is present in the area described by Yochelson and Wise (1972) as the locality where they discovered the association of the operculum and shell of the Smithville type fossil, Ceratopea unguis. Residue percentages are on the order of 15 to 30 percent by volume, generally about 15 percent. Mineralization with zinc sulfide seems to be most intense in the ropy-chert section. This is probably due to its porosity.

Unit 5. (Green shale, silt, transluscent chert zone; this unit is referred to the Powell Formation.) Two of the American Zinc Company drill holes, NEA 9 and 68, started in a silty, cherty dolomite and continued in this section to total depths of 564 feet and 600 feet, respectively. The residues from this section match the upper part of the water well at Ash Flat, Arkansas, and the author believes the section to be Powell. Surface work shows these two holes to be in a fault block which is described under the section on structure.

Residues from these two holes consist of from 10 to 40 percent by volume (usually 10 to 20 percent) of fine sand; silt; greenish to gray dolomoldic shale, (Plate 00G) and cherts. The cherts are frequently dolocastic, sometimes smooth, transluscent, sparingly oolitic, and occasionally contain a few silicified small gastropods or cystid plates. A few thin, plate-like quartz structures occur. In general, there is a greenish cast to the fresh rock and residues.

The sequence of the beds drilled below Unit 1, if present in its entirety, is always the same (Figure 2) : sponge beds, above brachiopod beds, above ropy-chert beds, above Powell-type residue material. Unit 1 (sandy beds) overlaps both the sponge and brachiopod beds and rests upon ropy-chert beds in one instance in the American Zinc drilling (Figure 3).

STRATIGRAPHIC NOMENCLATURE

An attempt has been made to stress the use of beds which have distinctive insoluble-residue characteristics, rather than to stress formational names, either old or new. The author believes the following points are valid, however: it now seems that a basin of early-Paleozoic age, as outlined by Earl McCracken (1950), does exist in northeastern Arkansas and adjacent areas of southeastern Missouri, western Kentucky, and western Tennessee. The Ordovician beds certainly thicken in this area. Also, many of the formational boundaries of the Ozarks section seem to become blurred, and the individual formations often lose their identities. The erosional unconformity at the base of the Everton-St. Peter-Joachim (Buffalo River group of Ulrich) rests on older and older beds as one leaves the basin and approaches the Ozark area. Thus, Unit 1 (the sandy basal beds in the area of this report, which are most likely Everton) rest on the sponge beds (Unit 2) in the hole NEA 15, on the brachiopod beds (Unit 3) in NEA 79, and on the gastropod-ropy-chert beds (Unit 4) in NEA 1 (Figures 3 and 4). To the west, it has been found to rest on Powell and Cotter (McKnight, 1935). To the north, in Missouri, it can be found on the gastropod-ropy-chert beds in the City of Jackson well on the Powell in Ste. Genevieve County (Weller and St. Clair, 1928), and on uppermost Cotter in Jefferson County (Figure 1).

The roughly 200 feet of rock comprising the sponge and brachiopod residue zones (Units 2 and 3) could certainly be called the Black Rock of Ulrich, and certainly the gastropod-ropy chert beds do form the Smithville of Ulrich, since they are traced directly to the type locality of that formation. Drilling such as these American Zinc tests certainly gives a much more accurate measure of thickness than any previous surface work. The Tenn-Ark well has additional silty beds between the lower, sandy Everton and the top of the sponge-spicule beds, as has been described by Earl McCracken (1950).

If overlapping of beds is one good criterion for unconformity, then this points to a good one at the base of the Buffalo River group (Everton). This certainly would be the best place to put the Chazy-Beekmantown break, in my opinion, and would put the beds beneath into the Canadian Series. The area studied, when taken together with the available drilling data in southeastern Missouri, points to a typical offlap-onlap series between the Canadian and Champlainian Series as the northeast Arkansas basin is approached.

CORRELATION WITH WELLS IN NORTHEASTERN ARKANSAS AND SOUTHEASTERN MISSOURI

Some 30 miles southeast of the area of the American Zinc Company drilling, the Tenn-Ark #1 Ruby Martin well, sec. 35, T. 14N., R. 3E, Craighead County, Arkansas, drilled a Paleozoic section correlated by Earl McCracken as follows:*

*Note: In the original log, Earl McCracken correlated the upper part of the Tenn-Ark #1 Ruby Martin well as follows: 571 feet post-Black Rock from 1672 to 2243; this includes what he later broke down into 201 feet St. Peter-Everton and 370 feet post-Black Rock. I believe he would now consider all the rock above 1873 feet to be Everton; at the time he studied the samples the extremely thick Everton section present in northeastern Arkansas was unknown.

Thickness		From	To
1672	Tertiary and Cretaceous (undifferentiated)	0'	1672'
201	St. Peter and Everton (Buffalo River Group)	1672	1873
370	post-Black Rock	1873	2243
425	Black Rock	2243	2668
601	Smithville	2668	3269
1131	Powell-Cotter (undifferentiated)	3269	4400
422	Jefferson City	4400	4822
270	Roubidoux	4822	5092

In this well the "Black Rock" section residues contain the sponge spicules, gray silty material, and brachiopod fragments present in Units 2 and 3 of the American Zinc holes, and the "Smithville" contains the ropy-chert section. This well has always been very difficult to fit into the normal stratigraphic sequence, because much of the section is black limestone; at various times the Paleozoic section was considered to be middle Ordovician (possibly Plattin), then thought to be a facies variation of middle Ordovician rocks ranging in age from Plattin through Everton, then all Canadian or older. However, if one takes into consideration the thickening of beds into the Northeast Arkansas basinal area, it is really not out of line to use the above correlation. The 201 feet of Everton is similar to Unit 1 of the American Zinc drilling. Of course it is not a complete Everton section; Suhm (1972 has shown that this section thickens and becomes more of a carbonate sequence to the east.

Below Unit 1 and above Unit 2 (sponge beds), the Tenn-Ark well has 370 feet of section resembling the gray, silty limestone and dolomite of the "Black Rock" (Units 2 and 3), except that it lacks the fossil debris of these units. This thickness is not out of line when one notes that between holes NEA 79 and 15 the Black Rock unit (Units 2 and 3) is thickening on the order of 15 feet per mile; an additional 33 miles would account for both the thickening of the Black Rock unit (Units 2 and 3) and the addition of the post-Black Rock unit of the Tenn-Ark well, which does not appear in the Sharp and Lawrence County area, but which has a similar type of gray silt residue.

In comparing thicknesses of the Powell-Cotter, Jefferson City, and Roubidoux formations in the Tenn-Ark #1 Ruby Martin against the City of Ash Flat well)the closest section for comparison) the following thicknesses are present:

	Ash Flat	Tenn-Ark #1 Ruby Martin
Powell-Cotter	555	1131
Jefferson City	200	422
Roubidoux	160	270

Thickening of all Canadian units seems to be on about the same scale and in the same direction.

Northeastward from the area of the American Zinc drilling into Missouri one passes across the Pascola arch, over which pre-Upper Cretaceous erosion has stripped all the upper Canadian and higher beds from the Paleozoic section. North of this structural feature, wells and outcrop sections in Bollinger and Cape Girardeau Counties in Missouri show a typical Smithville section, with the fauna of large gastropods present at the surface in the Marble Hill area. This is shown in wells at the City of Jackson in Cape Girardeau County and City of Chaffee in Scott County as the typical ropy-chert residue. In a well in Fulton County, Kentucky, the Ken-Tenn #1 Sanger, the section contains not only the ropy-chert unit, but also above it, the brachiopod and sponge units (Figures 1 and 3).

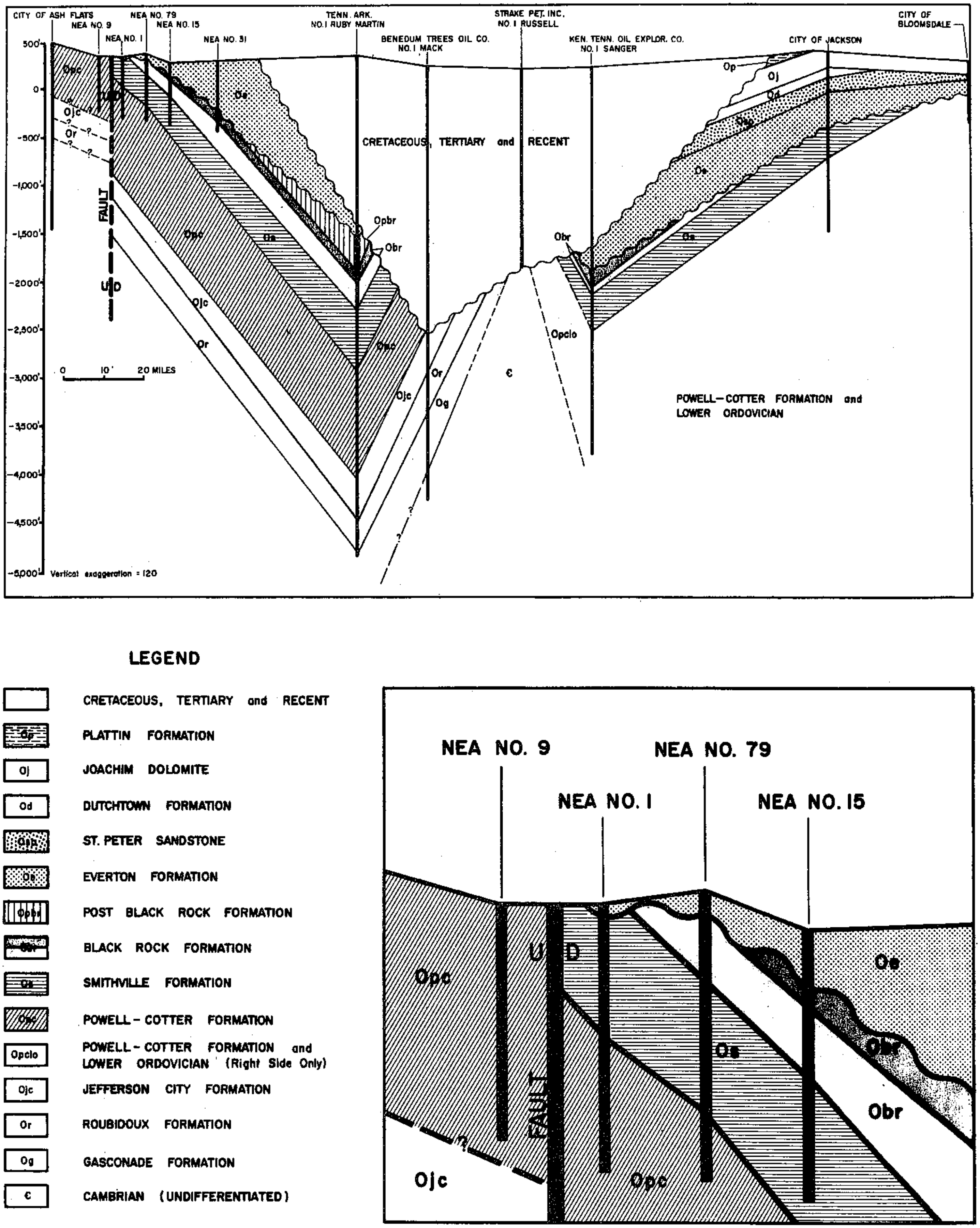
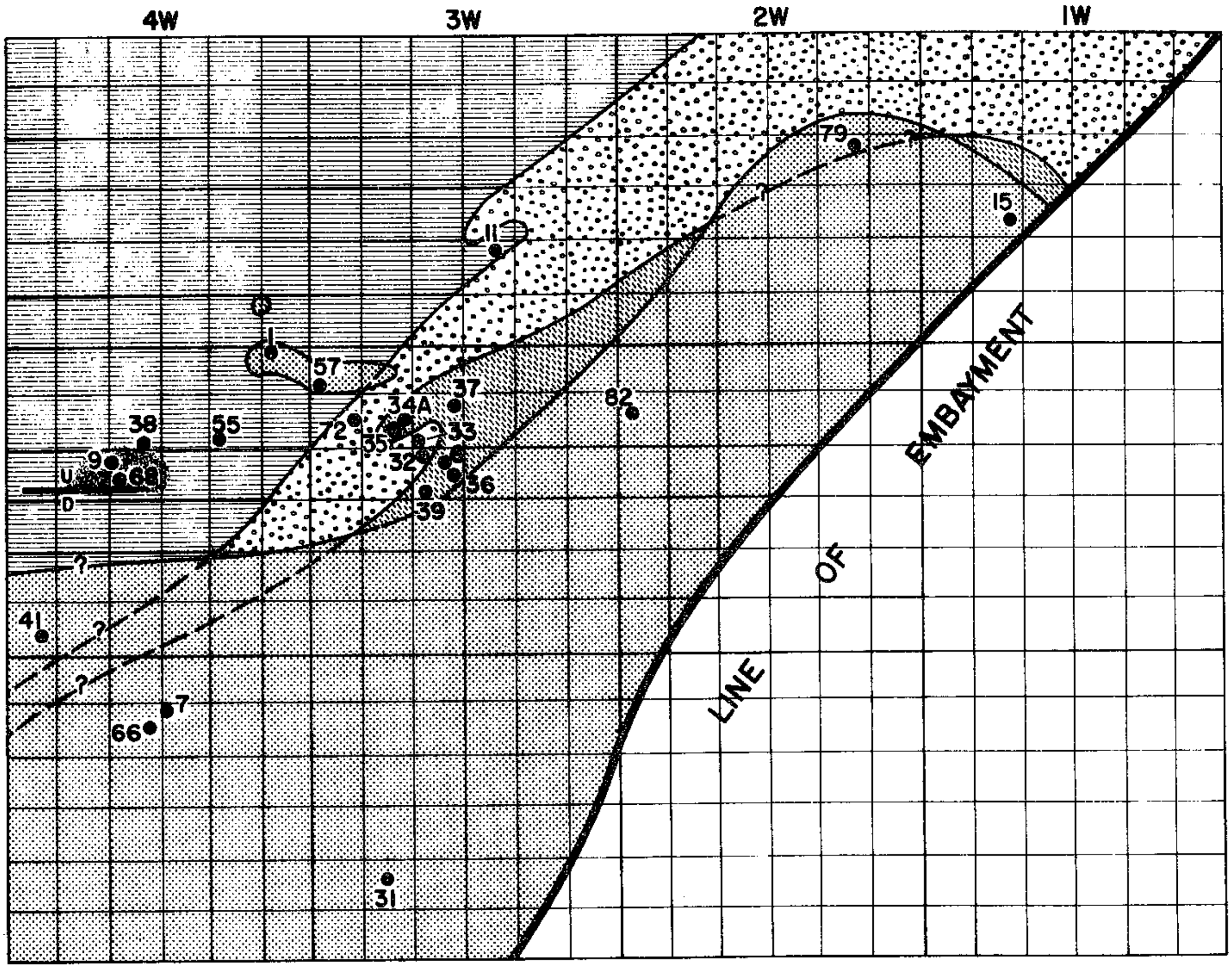

CITY OF ASH FLATS
NEA NO. 9
NEA NO. 1
NEA NO. 79
NEA NO. 15
NEA NO. 31
TENN. ARK. NO. 1 RUBY MARTIN
BENEDUM TREES OIL CO. NO. 1 MACK
STRAKE PET. INC. NO. 1 RUSSELL
KEN. TENN. OIL EXPLOR. CO. NO. 1 SANGER
CITY OF JACKSON
CITY OF BLOOMSDALE
500'
0
-500'
-1,000'
-1,500'
-2000'
-2,500'
-3,000'
-3,500'
-4,000'
-4,500'
-5,000'
Vertical exaggeration = 120
0 10' 20 MILES
FAULT
U D
CRETACEOUS, TERTIARY and RECENT
POWELL-COTTER FORMATION and LOWER ORDOVICIAN
Opc
Ojc
Or
Os
Oe
Opbr
Obr
Og
Opclo
Op
Oj
Od
Osp
C
LEGEND
CRETACEOUS, TERTIARY and RECENT
PLATTIN FORMATION
JOACHIM DOLOMITE
DUTCHTOWN FORMATION
ST. PETER SANDSTONE
EVERTON FORMATION
POST BLACK ROCK FORMATION
BLACK ROCK FORMATION
SMITHVILLE FORMATION
POWELL - COTTER FORMATION
POWELL - COTTER FORMATION and LOWER ORDOVICIAN (Right Side Only)
JEFFERSON CITY FORMATION
ROUBIDOUX FORMATION
GASCONADE FORMATION
CAMBRIAN (UNDIFFERENTIATED)
NEA NO. 9
NEA NO. 79
NEA NO. 1
NEA NO. 15
Opc
U D
FAULT
Os
Oe
Obr
Ojc
Opc

Figure 3

STRUCTURE

The map (Figure 4) prepared from the drill hole data shows a rather unusual pattern. This is in part due to the topography, with older formations showing up in the valleys. However, several areas of faulting are undoubtedly present. One of these shows up near the boundary of secs. 17 and 18, T. 16N., R. 4W., as one climbs out of the valley of Big Creek. Here Smithville (gastropod-ropy-chert zone) is faulted against Powell (green-gray siltstone residue). The throw of the fault is unknown, but must be on the order of several hundred feet. This can be demonstrated since the hill separating Big Creek and Fool Creek has a relief of 200 feet. The base of the hill is in Smithville Formation (gastropod-ropy-chert zone; Unit 4) and the top of the hill is in Unit 5, which is referred to the Powell Formation. Thus, a throw of at least 200 feet is in order, most probably more, as the top of the hill seems to be well within the Powell Formation and not the top; neither is the base of the hill in lowermost Smithville. Hole NEA 9, at the Arbuckle mine, was one of the first studied and it appeared to have a Powell section. This was out of line with other holes studied -- all the rest were in what was considered to be Smithville or younger. When the location of that hole was visited the surrounding rock was badly sheared and the surface rock looked like Powell. Leaving the area, a distinct shear zone was crossed to the south of the old Arbuckle mine as the trail climbed the hill out of the valley of Big Creek. In an attempt to find out more about this anomalous hole, a study of the Poughkeepsie topographic sheet was made. A ridge separating Big Creek and Fool Creek in sec. 17 and 18, T. 16 N., R. 4 W., showed a topographic variation of just over 200 feet. It was thought that the problem might be solved by observing this long section of rock. When that area was examined the fault of Powell against Smithville was located. This block of Powell contains the anomalous hole NEA 9 and the later-drilled hole NEA 68 in sec. 16, T. 16N., R. 4W., and the fault must cross the trail up the hill from the drill holes in the same section. It is possible that this fault extends farther to the east and could account for some of the peculiar pattern of the distribution of the rock units depicted on the map, notably along Cooper Creek, in secs. 8 and 9 and T. 16N., R. 3 W. Faulting may also account for the outlier of Unit 2 in secs. 35 and 36, T. 17 N., R. 4 W. Faulting and brecciation is seen also in the quarry at Imboden and in some of the mining areas-notably the Jeffries and Fugate areas. It would seem that faulting and brecciation or shearing of the rock units could have had a bearing on the ore deposition.

A study of several drill holes in secs. 8, 9, and 16, T. 16 N., R. 3 W., gave a picture of the general strike and dip of the beds. By plotting the elevation of the base of the brachiopod zone and then contouring, it was found that the dip was in general to the south, with a slight easterly component. Then, the elevation of the top of the sponge beds could be calculated, and where this elevation was at the surface, as shown on the topographic map, the outcrop of the sponge beds was located. This was the first time these sponges had been located in outcrop by the American Zinc Company people. In much the same way, the brachiopod beds were found northwest of the Lincoln mine area (hole NEA 11).



EVERTON
Rounded and frosted Sand beds

BLACK ROCK
Sponge beds

Brachiopod beds

SMITHVILLE
Ropy chert beds

POWELL
Chert and green silt beds

Figure 4

CONCLUSIONS

An insoluble-residue study of cuttings from 23 drill holes in Sharp and Lawrence Counties, Arkansas has produced the following results:

1. The rocks drilled were divided into five major units, each with a distinctive type of residue.

2. The true thicknesses of the rock units present in the area were found for the first time, when an entire unit was drilled.

3. Dip to the southeast and strike to the northeast of these beds was calculated from closely spaced holes.

4. A major fault was located along Big Creek, near one of the holes with an anomalous section, drilled at the Arbuckle mine site.

5. Insoluble-residue markers carry across the limestone-dolomite boundary and are thus of great value in carrying rock units from the dolomitic platform to the limestone basinal areas.

6. It appears that the chief mineralization, as shown by ZnS in residue material in the northeastern Arkansas area is in the Smithville rock; this is in agreement with Bridge's idea as quoted by McKnight.

7. Additional faulting is probably present in the area, as shown by erratic patches of rock types on the map, as in sec. 35, T. 17 N., R. 4 W.; this may have a bearing on mineralization.

8. The most likely break between the Canadian and Champlainian Series seems to be between the sandy basal beds of Unit 1 and the sponge-bearing beds of Unit 2 (Figure 3).

9. In thick sections of carbonate rocks, insoluble-residue studies can be used to correlate key beds or intervals successfully.

TABLE 1. - AMERICAN ZINC DRILLING IN NORTHEASTERN ARKANSAS

Number, Name Location of Holes	Surface Elev.	Thickness Sandy Everton	Elev. Top of Sponge Beds	Thickness of Sponge Beds	Elev. Top of Brachiopod Beds	Thickness of Brachiopod Beds	Elev. Top of Ropy Chert Bed	Thickness of Ropy Chert Bed	Powell Formation	Elev. Top of Powell	Remarks
NEA #1 Jeffery mine NW¼, sec. 1. T. 16N., R. 4 W.	300	60	--	--	--	--	240	340+?	?	?	T. D. 520' Lower 70' may be Powell
NEA #6 Winters Property NE¼, sec. 16, T. 16 N., R. 3 W.	260	25	235	100	135	75	60	200+	--	--	T. D. 405' Limestone Section
NEA #7 Townsley property NW¼, sec. 10, T. 15 N. R. 4 W.	363	545	-182	105	-287	--	--	--	--	--	T. D. 635'
NEA #9 Arbuckle Mine NW¼, sec. 16, T. 16 N., R. 4 W.	350	--	--	--	--	--	--	--	564+	350?	All of section in the Powell Formation T. D. 564'
NEA #55 SW¼, SW¼, sec. 11, T. 16 N. R. 4 W.	400	?	?	?	?	?	?	?	?	?	T. D. 375' Hard to correlate - probably breccia section.
NEA #57 SW¼, SW¼, sec. 6, T. 16N. R. 3 W.	370	40	--	--	--	--	330	260	283	70	T. D. 583' Some limestone
NEA #66 Pearce Mine SE¼, SE¼, sec. 9, T. 15 N., R. 4 W.	355	600	-245	15+	--	--	--	--	--	--	T. D. 615' Small amount limestone
NEA #68 Arbuckle Mine NE¼, SW¼, sec. 16, T. 16N., R. 4 W.	330	--	--	--	--	--	--	--	600	330?	All of section dolomite in Powell Fm. T. D. 600'
NEA #72 Perkins SW¼, NW¼, sec. 8, T. 16 N., R. 3 W.	265	--	--	--	at surface	85	180	315	225+	-135	Dolomite section T. D. 625'
NEA #79 Phillips NE¼, NE¼, sec. 15, T. 17 N., R. 2 W.	383	75	308	50	258	110	148	290	180+	-142	Dolomite section T. D. 704'
NEA #11 Lincoln Minesite NE¼, sec. 27, T. 17 N., R. 3 W.	354	--	--	--	--	--	at surface	350	295+	304	T. D. 645' Very little limestone
NEA #15 near Campbell Mine SE¼, Sec. 20, T. 17 N., R. 1 W.	290	75	215	125	90	100	110	300+	--	--	T.D. 650' Dolomite section

Number, Name Location of Holes	Surface Elev.	Thickness Sandy Everton	Elev. Top of Sponge Beds	Thickness of Sponge Beds	Elev. Top of Brachiopod Beds	Thickness of Brachiopod Beds	Elev. Top of Ropy Chert Bed	Thickness of Ropy Chert Bed	Powell Formation	Elev. Top of Powell	Remarks
NEA #31 Doyle property Sec. 29, T. 15 N., R. 3 W.	320±	510	-190	120	-310	125+	--	--	--	--	T. D. 755' Dolomite section
NEA #32 NE¼, NW¼, sec. 16, T. 16 N., R. 3 W.	275	--	--	--	275	150	125	350	100+	-225	Brachiopod beds at surface T.D. 600'
NEA #33 SW¼, SW¼, sec. 9, T. 16 N., R. 3 W.	270	--	--	--	at surface	100+	170	350	155+	-180	T. D. 605' Limestone section
NEA #34 A. NE¼, SE¼, sec. 8, T. 16 N., R. 3 W.	270	--	270	115 possibly more as there is 35' of soils	120	50*	70	60+	--	--	T. D. 261' Some limestone, probable fault at 200' shortens brachiopod section
NEA #35 Durham property SW¼, SE¼, sec. 8, T. 16 N., R. 3 W.	300	80	220	70	150	75*	75	325	25+?	-25	T. D. 625' * Brachiopod section unusually thin
NEA #36 Sec. 16, T. 16 N., R. 3 W.	275?	--	at surface	50	225	165	105	335	105+?	-275	T. D.655' Some limestone.
NEA #37 SE¼, NE¼, sec. 9, T. 16 N., R. 3 W.	300	--	at surface	75	225	125	100	65+	--	--	T. D. 315' Limestone section
NEA #38 Fugate Mine Sec. 9, T. 16 N., R. 4W.	339	--	--	?	?	?	?	?	?	?	Hard to correlate - probably drilled in brecciated material T. D. 605'
NEA #39 SE¼, SW¼, sec. 16, T. 16 N., R. 3 W.,	310	--	at surface	125?-	185	125	60	265+	--	--	T. D. 515' Samples start at 40' to sponge zone - Limestone section
NEA #41 Golconda Mine NE¼, SE¼, sec. 31, T. 16 N., R. 4 W.	525	605+	at surface	--	--	--	--	--	--	--	T. D. 605' Entire section seems to be in Everton
NEA #82 L. Penn SE¼, NW¼, sec. 7, T. 16 N., R. 2 W.	320	115	205	70	135	155	-20	260	35+	-280	Much limestone T. D. 635'
Peebles Bluff Section Sec. 23, T. 17 N., R. 4 W.	594	--	--	--	--	--	--	Incomplete section of 261'	--	--	Outcrop section all in Smithville Incomplete section 261'

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LOWER ORDOVICIAN STRATIGRAPHIC RELATIONSHIPS AT SMITHVILLE, ARKANSAS AND ADJACENT AREAS

O. A. Wise, Jr.[1], E. L. Yochelson[2] and B. F. Clardy[1]

ABSTRACT

At Smithville, Arkansas, limestone of the Black Rock Formation is interpreted as a lateral equivalent of the Smithville Formation; previously, the Black Rock had been considered to be an overlying unit of youngest Early Ordovician age. The fauna of the Smithville is predominantly one of free-living mollusks, whereas that of the Black Rock is primarily one of sedentary organisms. In spite of these biotic differences, forms are intermixed enough to support the conclusion of contemporaneity which is based on physical stratigraphy.

Faunal lists are provided for the Smithville and Black Rock at Smithville, Ark., and other nearby localities. One species of gastropod, Ceratopea unguis, is particularly common in the Smithville Formation, and at Smithville, it occurs above characteristic Black Rock lithology. Recognition of the Black Rock as a lateral facies removes the "time" of Black Rock deposition as a consideration in regional correlation; the Black Rock is reduced in rank to a member of the Smithville Formation.

INTRODUCTION

The Smithville Formation, originally designated a limestone, and the Black Rock Formation, also originally designated as a limestone, were formally introduced into geologic literature by G. C. Branner (1929) in the explanation of rock units on the 1929 edition of the Geologic Map of Arkansas. Smithville and Black Rock are named for small towns in northeastern Arkansas. The Smithville was considered to overlie the Powell Limestone unconformably and the Black Rock, to overlie the Smithville unconformably; they are so shown on the Ordovician correlation chart (Twenhofel and others, 1954) and in other scattered references. Both the Smithville and the Black Rock were considered to be Early Ordovician in age, the Black Rock being unconformably overlain by the Middle Ordovician Everton Formation (J. Bridge, in Wilmarth, 1938, p. 711). Essentially no new geologic investigations were done in the Sharp and Lawrence County region for three decades after publication of the State Map. Renewed interest in mineral deposits of the region has led to additional surface examination and considerable drilling (Caplan, 1960).

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Colleagues in Federal, State, academic, and commercial organizations have aided this work, particularly with regard to identification of fossils. Although the bulk of fossil collections are not cited here, assistance was rendered as follows: sponges, R. M. Finks (Queens College, City University of New York); brachiopods, G. A. Cooper (U. S. National Museum) and R. B. Neuman (U. S. Geological Survey); pelecypods, John Pojeta, Jr. (U.S.G.S.); cephalopods, R. H. Flower (New Mexico Bureau of Mines, Socorro, N. Mexico); conodonts, J. W. Huddle (U.S.G.S.); graptolites, W. B. N. Berry (University of California, Berkeley); ostracodes, J. M. Berdan (U.S.G.S.); trilobites, H. B. Whittington (Cambridge University, Cambridge, England).

Special thanks go to D. F. Toomey, who first pointed out Early Ordovician sponges to O. A. Wise, and to the late W. E. Ham, who advised on initial fieldwork. Enigmatic colonial forms from the Black Rock were examined by R. M. Finks, R. S. Boardman, O. L. Karklins, W. A. Oliver, Matthew Nitecki, T. J. M. Schopf, and finally Willard Hartman, who suggested that they might be sclero-sponges, an obscure group only recently identified in the modern seas.

Fieldwork was sponsored by the Arkansas Geological Commission under the direction of N. F. Williams. The illustrations were drafted by L. P. Kelone of the Arkansas Geological Commission.

Fig. 1-Index map of Arkansas showing the general area of this report.

REGIONAL SETTING

Lower Ordovician rocks crop out in northern Arkansas on the southern flank of the Ozark uplift. Regionally, this is a structural plateau tilted slightly to the south. That area discussed herein is principally in Sharp and Lawrence Counties, but also extends into Randolph, Independence, Fulton, and Izard Counties (fig. 1).

Outcrops are scattered, and the country roads and highways afford most of the better exposures. Individual exposures are relatively limited; in part on the basis of subsurface data, the combined thickness of the Smithville and Black Rock in the vicinity of Smithville, Arkansas is estimated at 500 feet. Karst is widespread through the section, and lithologic complications arise from the filling of sinks and caves by anomalous rock types.

The rocks are relatively flat lying; regional dip is 25 to 30 feet per mile southward. Gentle warping has resulted in many reversals of dip locally, and the topography reflects the structure.

A continuous section of about 250 feet of Smithville-Black Rock is exposed in the NE$\frac{1}{4}$ sec. 22, T. 17 N., R. 4 W. However, because the Black Rock although present, is not well defined in this section, the exposure is not considered desirable as a type section.

Little information is available on how the Arkansas geological map of 1929 was compiled. Apparently it became evident to Ulrich that a sequence of rocks younger than Powell and older than Everton was present in the northeastern Paleozoic area. To accommodate this sequence, the names Smithville Limestone and Black Rock Limestone were introduced nominally by Branner, the Smithville being the older unit (fig. 2). Each was assigned a thickness reaching a maximum of 200 feet. It would appear that these concepts were based by Ulrich primarily on faunal assemblages (McKnight, 1935, p. 26). McKnight went on to remark: "The boundaries and character of the formations were never satisfactorily defined in print."

Just east of the town of Black Rock, Lower Ordovician rocks are covered by younger sediments of the Mississippi embayment. To the south, they are covered by the Everton (Middle Ordovician). The Everton outcrop swings north through Sharp and Fulton Counties (Branner, 1929) almost to the Missouri line, and effectively separates the Lower Ordovician exposures of the eastern area, discussed here (fig. 2), from the more westerly exposures. Along with this geographic separation there appears to be a noticeable change in lithologic character; the western area is more argillaceous. There is a noticeable increase in eastward thickening of the Cotter through Everton interval.

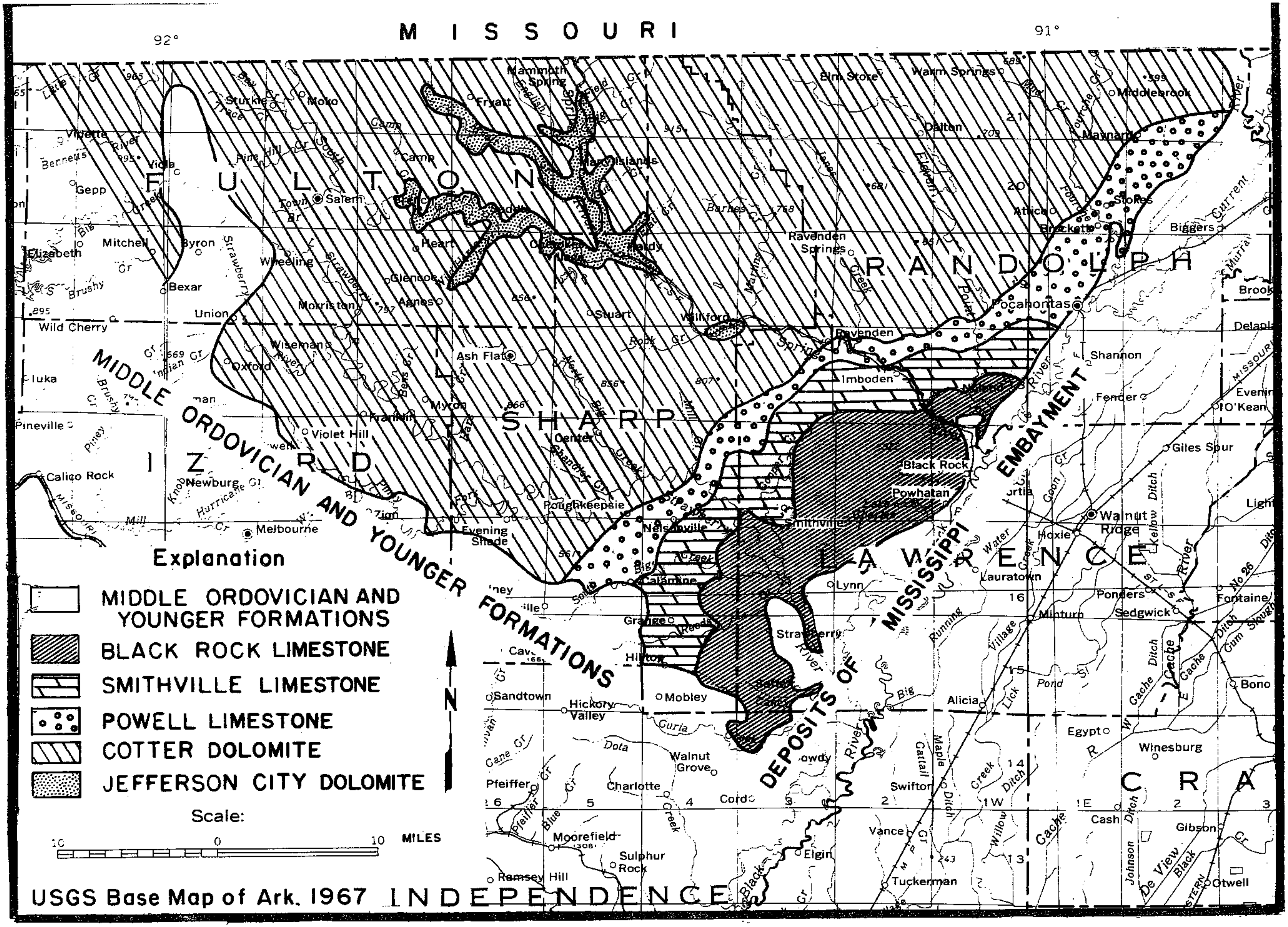


Fig.2

LOWER ORDOVICIAN SURFACE GEOLOGY OF NORTHEASTERN ARKANSAS, MODIFIED FROM THE GEOLOGIC MAP OF ARKANSAS (BRANNER, 1929)

Fig. 3 HISTORICAL DEVELOPMENT OF LOWER ORDOVICIAN NOMENCLATURE, NORTHERN ARKANSAS

SYSTEM	SERIES	BRANNER ARK. GEOL. SURVEY CIRCA 1890-1900	ADAMS USGS PROF PAPER 24 1904	PURDUE & MISER USGS ATLAS FOLIO 202 1916	BRANNER ARK. GEOLOGIC MAP 1929	Mc KNIGHT USGS BULL. 853 1935	THIS REPORT 1970
ORDOVICIAN	LOWER				BLACK ROCK LIMESTONE		SMITHVILLE FORMATION (BLACK ROCK MBR)
					SMITHVILLE LIMESTONE		
				POWELL LIMESTONE	POWELL LIMESTONE	POWELL DOLOMITE	POWELL DOLOMITE
		MAGNESIAN LIMESTONE	YELLVILLE LIMESTONE	COTTER DOLOMITE	COTTER DOLOMITE	COTTER DOLOMITE	COTTER DOLOMITE
					JEFFERSON CITY DOLOMITE	JEFFERSON CITY DOLOMITE	

PREVIOUS WORK

Although several comprehensive studies have dealt with the western parts of Ordovician outcrop in northern Arkansas, relatively little primary geologic mapping or stratigraphic investigation was ever done in the eastern area under discussion. This area was covered by a regional map in Branner (1900), which showed all Ordovician rocks as a single unit. This single-unit designation was used in the classic Yellville area to the west by Adams (1904) in his work on lead and zinc deposits of northern Arkansas. The historical development of stratigraphic classification is shown in figure 3.

The first separation of the several Ordovician formations in northern Arkansas was made on the State Geologic Map (Branner, 1929; see fig. 2). The names Powell and Cotter were introduced from the Eureka Springs-Harrison quadrangles where they were described and mapped by Purdue and Miser (1916); subsequently, these names were used in the Yellville quadrangle, when mapped by McKnight (1935). The name Jefferson City had been given to a series of rocks in central Missouri by Winslow (1894). In 1912, this name was applied to the lower part of the Yellville Limestone of north Arkansas by E. O. Ulrich during his investigations; the upper part was called Cotter (McKnight, 1935).

Figure 2 shows that the outcrop belts of the Black Rock, Smithville, and Powell Formations trend northeast, more or less paralleling the edge of the Mississippi Embayment, rather than trending generally east as do the other Paleozoic rocks of northeastern Arkansas. Map-unit contacts in this part of the State are generalized and do not follow the topography, in contrast to topographically related digitations shown for other formation boundaries in the Ozark Plateau area. "This generalization was necessary to facilitate publication of the geologic map on schedule, for time did not permit detailed mapping of the northeastern outcrops" (H. D. Miser, oral communication, 1967).

A regional reconnaissance during the late 1960's showed that the outcrop patterns for the Lower Ordovician formations on the geologic map of Arkansas (Branner, 1929) were incorrect. Rather than roughly paralleling the northeast trend of the Mississippi Embayment, the alignment of outcrops appears to be generally east, more or less along the same trend as the Middle Ordovician formations (fig. 4).

This orientation was determined primarily by tracing a fossiliferous calcilutitic limestone from Black Rock to just north of Poughkeepsie. The same unit is thought to extend to U. S. Highway 167 just north of the Strawberry River, where the rock is so silicified and dolomitized that its identification might be questioned.

The calcilutitic limestone is in the upper 100 feet of the Smithville Formation and is the most distinctive lithology in the Lower Ordovician of northeastern Arkansas. Other scattered limestone beds in the Lower Ordovician are neither as widespread nor as continuous as the Black Rock Limestone Member of the Smithville.

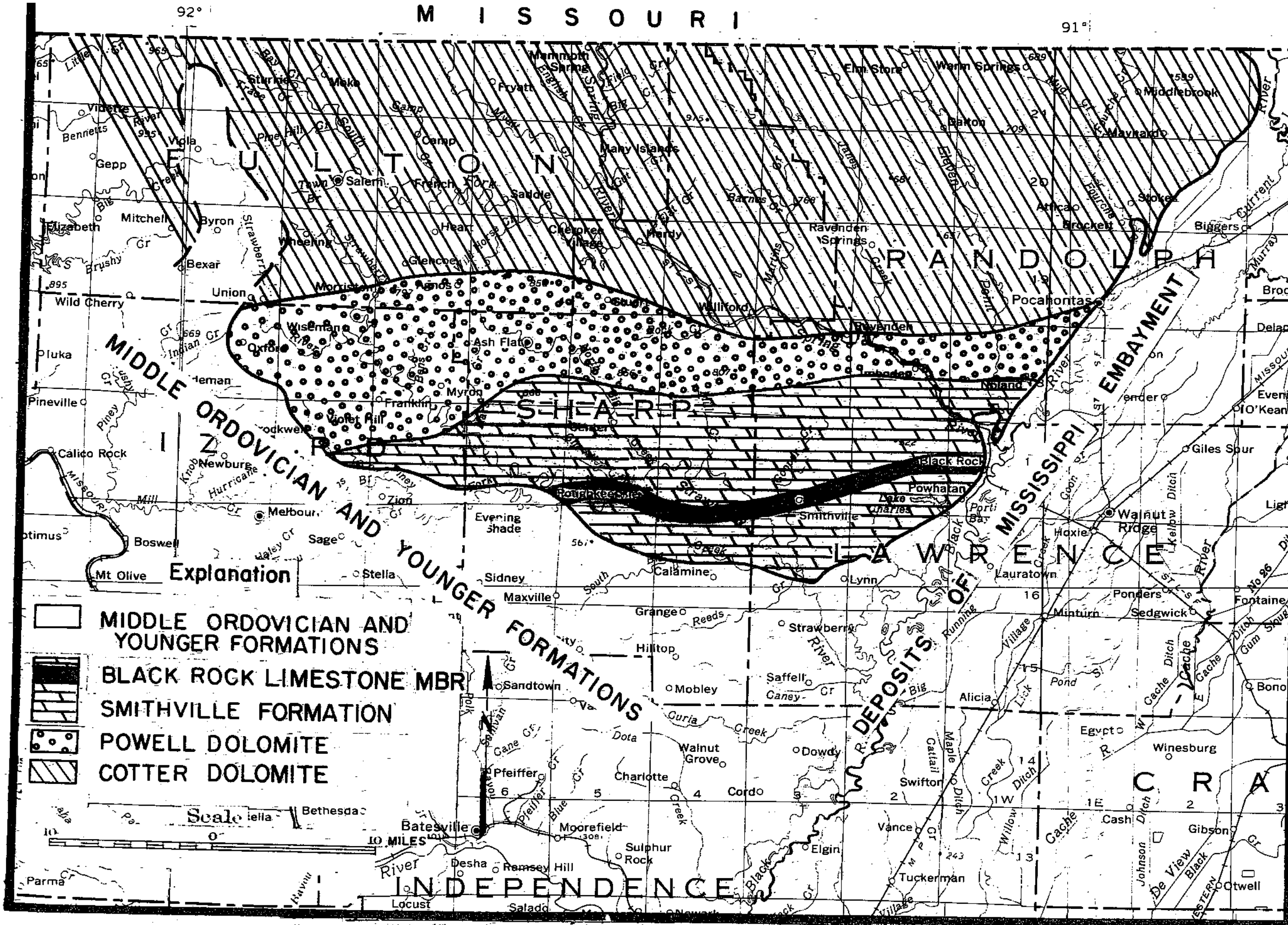


Fig. 4 DISTRIBUTION OF ROCK UNITS IN LOWER ORDOVICIAN OF NORTHEASTERN ARKANSAS

Geology compiled by O. A. Wise and B. F. Clardy

Data from a regional reconnaissance indicate that the Black Rock is a limestone in the upper Smithville dolomite and better fits the stratigraphic section as a lateral equivalent of part of the Smithville Formation. The aim of the remainder of this paper is to document and support that conclusion.

LITHOLOGY

Lower Ordovician rocks exposed in northeastern Arkansas are predominantly dolomite. Sandstone, limestone, chert, and shale do not exceed 10 percent of the section. The thick chert beds, prominent in surface exposures, are not found in the subsurface. Chert beds or nodules found in coring are usually only an inch or two thick. Limestone, for the most part, is limited to the upper 100 feet of the Smithville Formation and constitutes the Black Rock Limestone Member of this report.

Although individual hand specimens might be quite similar, dolomites of the Smithville, Powell, Cotter, and Jefferson City Formations are different if compared on a gross interval basis. The Smithville is a light tan to white, nearly aphanitic to very fine grained dolomite and is separated from the underlying Powell by a green shale interval. Whereas rocks of this interval may extend over several feet of section, individual shale beds are, for the most part, less than 6 inches thick. The green shale interval is considered to be the top of the Powell.

The Powell is a light-tan to brown dolomite, very fine to medium fine grained. There are thin chert partings or nodules in the Powell in the subsurface; the surface exposures have some chert debris, whereas the Smithville shows very little. The Cotter Dolomite is tan to brown, fine to medium coarse grained and is sometimes separated from the Powell by a chert bed approximately 1 foot thick.

Rocks generally become lighter and the grain size smaller from the base to the top of the Cotter-Powell-Smithville section. We have not been able to recognize or separate the Jefferson City Dolomite from the Cotter; however, little work has been done in the part of northern Arkansas where the Jefferson City might be expected to crop out.

The exposed Lower Ordovician rocks of northern Arkansas do not have sharp, well-defined formation boundaries. The one distinctive lithologic unit that can be followed across the area is the limestone of the Black Rock Limestone Member of the Smithville. Exposures of this distinctive lithology occur from the town of Black Rock on the east to just west of Poughkeepsie (fig. 4). The unit is 100 feet thick, no more than 20 feet being exposed at any single outcrop. The limestone is a gray-blue calcilutite, very fossiliferous in part, containing predominantly sponges, brachiopods, algae, ?sclerosponges?, and a few cephalopods, trilobites, and graptolites.

Although our work is confined to northeast Arkansas, additional studies are currently in progress near Lutesville, Missouri by Michael Fix, Washington University. Even though this area is more than 90 miles east-northeast of Smithville, Arkansas, Fix has found the typical mollusk fauna of the Smithville. It occurs mainly in residual soils, but the few outcrops are lithically similar to the Smithville Formation. Possible sclero-sponges have been recovered at one outcrop.

THE SMITHVILLE FORMATION AND ITS BIOTA

The Smithville Formation is primarily a finely crystalline tan to buff dolomite estimated to be about 500 feet thick. The upper 100 feet of the formation contains a 20 to 30 foot limestone interval which has a rather varied biota of mainly algae, sponges, and for want of a more certain identification ?sclerosponges?, but including brachiopods, some gastropods, rare cephalopods, and rare trilobites. This limestone interval is considered here to be the Black Rock Limestone Member of the Smithville Formation. From place to place, a sandstone also occurs in this upper hundred feet of section and presents some confusion and difficulty in field separation of the Smithville from the lower part of the Everton Formation.

Subtle differences in surface outcrops of carbonate rocks are less easy to distinguish in the subsurface. Core drilling has not encountered the thick bedded cherts found on the surface. Intense silicification observed from place to place on the outcrop appears to be a weathering phenomenon.

The limestone contains a few silicified fossils. Etching in hydrochloric acid produced (USGS 6758-CO):

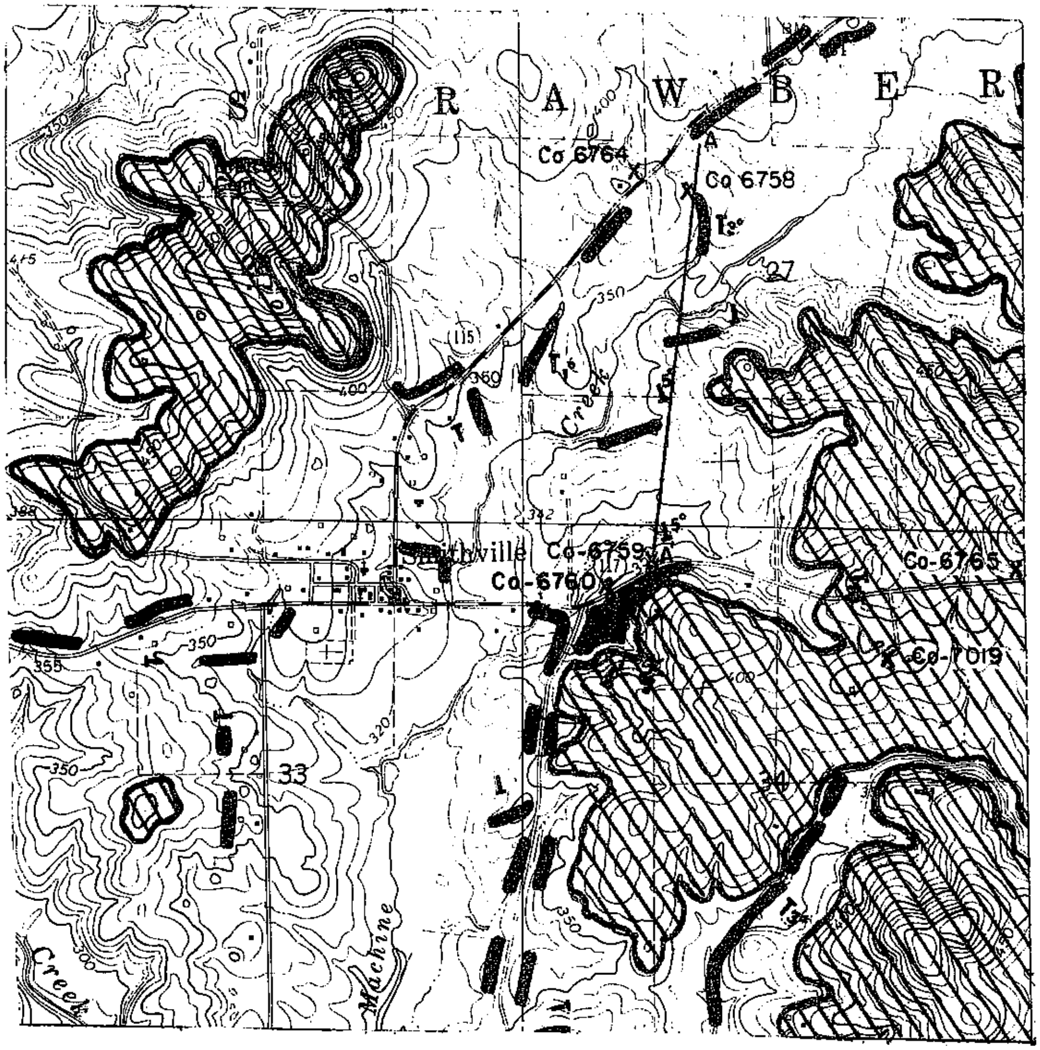
- Ceratopea unguis Yochelson and Bridge
- Aff. Loxoplocus (Lophospira) sp.
- Pleurotomaricean gastropods (two genera undetermined)
- "Holopea" sp.
- Murchisonia? sp. indet.
- High-spired gastropod indet.
- Cephalopods undet.
- Eoleperditia? sp. indet.

Etching s sample in acetic acid freed four conodont specimens representing three species:

- Drepanodus subarcuatus Furnish
- Scandodus sp.
- Scolopodus quadriplicatus Branson and Mehl.

Another test of a 3-kg. sample yielded only five specimens: three specimens of Scolopodus quadriplicatus and one each of Acodus tripterolobus Mound and Paltodus vaxiabilis? Furnish.

Fig.5- GEOLOGIC MAP OF SMITHVILLE ARKANSAS AND VICINITY



Base from U.S. Geological Survey
Smithville 7 ½ minute quadrangle, 1965

Geology mapped by O.A. Wise
1970

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

Explanation

N

Outcrop of Black Rock Limestone Member

Sandstone and chert and sandstone residuum

Dolomite and dolomite and shale residuum

T Dip symbol

X Co-6760 Collecting locality

A —— A' Crossection location of fig. 6

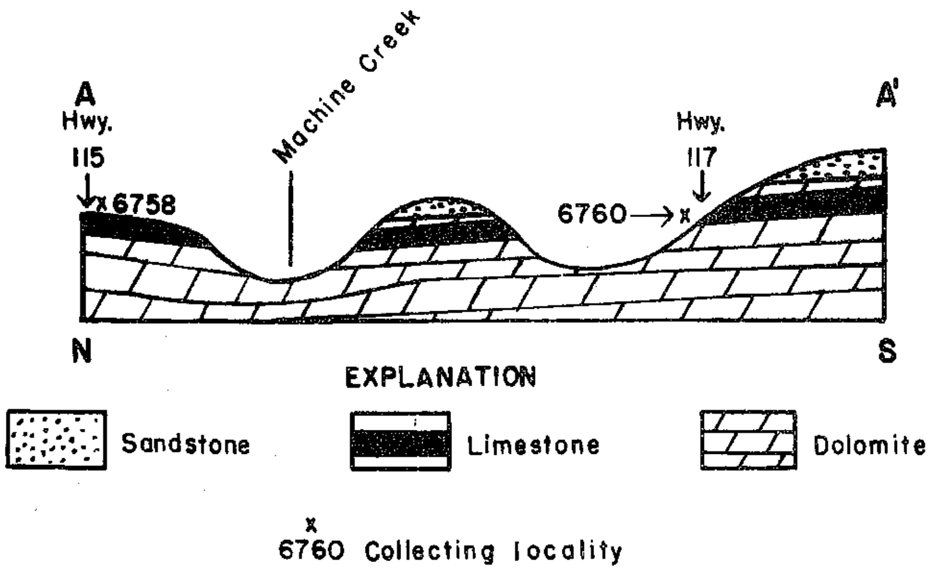


Fig. 6

Diagrammatic cross section 1/2 mile east of Smithville, Arkansas.
(See figure 5 for location)

Originally, considerably more limestone probably was present in the section than is present today. In the roadside park, sec. 13, T. 17 N., R. 2 W. (3 miles northwest of Black Rock), an abrupt lateral change from limestone to dolomite can be observed in the Black Rock Limestone Member. Throughout the area, silicified fossils weather from dolomite. It is undetermined why the limestone has been selectively dolomitized.

No type section for the Smithville Formation has ever been designated. An excellent exposure that contains the limestone may be seen in an unnamed draw trending north from Machine Creek, about ¼ mile east of the west edge of sec. 27, T. 17 N., R. 3 W. (see USGS 6758-CO, figs. 5, 6). Here about 7 feet of light-gray limestone crops out. The base is exposed at about 325 feet in altitude. Above this exposure, the slopes are covered with grass pasture and surficial material. This is the best exposure of the Smithville in the vicinity and presumably constitutes the section from which Ulrich collected the Smithville fauna and which was responsible for the formation name. However, this fauna, although diverse and well preserved, has never been described, so that many identifications of gastropods are of new species and new genera.

Etching in hydrochloric acid shows one striking feature that is not obvious on the outcrops. There is a large insoluble residue of elongate siliceous tubular fragments, which are rare and found only in short lengths on surface exposures. Their abundance and general orientation at steep angles to bedding suggest at first glance that this might represent an "algal meadow" which acted as a sediment trap. However, their irregularity makes it much more likely that these may be feeding burrows of soft-bodied animals. Similar structures are present in sediments off the Bahama Banks where gastropods browse upon, and effectively destroy, algal mats (Peter Garrett, Univ. Wales, oral commun., 1969; R. Ginsburg, Univ. Miami, oral commun., 1972).

Less than 1/10 mile northwest of the Machine Creek exposure, in a shallow roadcut along State Highway 115, 1 mile northeast of Smithville, a clay residuum occurs at an altitude of about 360 feet. This noteworthy locality in the NW¼ sec. 27, T. 17 N., R 3 W. (USGS 6764-CO; fig. 5) yielded a prolific fauna from the red and yellow residuum. The residuum is only 25 feet topographically (and about 20 ft. stratigraphically) above USGS 6758-CO; all the intervening grass-covered section is limestone apparently similar to that exposed in the draw. Not only are fossils remarkably abundant, but this assemblage demonstrates that the residuum may contain a far more varied fauna than that normally extracted by acid in the laboratory. This outcrop has produced, among other fossils, a unique life association of shell and operculum of the gastropod <u>Ceratopea unguis</u> Yochelson and Bridge (Yochelson and Wise, 1972). Almost certainly, E. O. Ulrich used elements of this fauna to identify the Smithville Formation. The fauna consists of:

Possible sclerosponges
Eopteria sp. undet.
"<u>Scenella</u>" new sp.

New monoplacophoran genus
Tropidodiscus macek (Billing)
New genus? cf. Tropidodiscus
Ceratopea unguis Yochelson and Bridge (opercula and shells)
Loxoplocus (Lophospira) n. sp. one
Loxoplocus (Lophospira) n. sp. two
Eotomaria n sp.
"Helicotoma" sp.
Pleurotomariacean undet. n. sp. one
Pleurotomariacean undet. n. sp. two
"Holopea" n. sp. sp.
Plethospira n. sp. sp.
Murchisonia (Hormotoma) sp.
High-spired gastropod indet., not Murchisonia
Eoleperditia? sp.
Cephalopods undet.

About 20 miles to the west, at the southern limit of the Smithville Formation as we interpret it, in a roadcut along U. S. Highway 163, near Evening Shade, Arkansas, in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 22, T. 17 N., R. 6 W. (USGS 6755-CO), the Smithville fauna consists of:

Ceratopea unguis Yochelson and Bridge (opercula)
Fragments of shell, probably Ceratopea
Pleurotomariacean undet. n. sp. one
Pleurotomariacean undet. n. sp. two
Fragments cf. Teiichispira
Fragments cf. Helicotoma
Murchisonia (Hormotoma) sp. indet.
New genus, possibly a subulitid
Cephalopods undet.

To the east-northeast, near the nortnern limit of Smithville outcrop, about 1 3/4 miles southwest of Imboden, Arkansas, roadcuts in the NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 29, T. 18 N., R. 2 W. (USGS 6776-CO) produced the following:

?sclerosponges?
Polytoechia sp. indet.
Hypseloconus n. sp.
Proplina sp.
cf. Teiichispira sp.
Macluritacean gastropod
Fragment, questionably an operculum
Ceratopea unguis Yochelson and Bridge (opercula and shells)

New genus of gastropod
Pleurotomariacean undet. n. sp. one
Pleurotomariacean undet. n. sp. two
Pleurotomariacean undet. n. sp. three
"*Holopea*" n. sp.
Helicotoma n. sp.
"*Helicotoma*" sp.
Clisospira n. sp.
Murchisonia (*Hormotoma*) sp. indet.
Murchisonia (?*Hormotoma*) n. sp.
Cephalopods
Bathyurid trilobite pygidium indet.

THE BLACK ROCK LIMESTONE MEMBER AND ITS BIOTA

As with the Smithville, study of the Black Rock Limestone Member (Lower Ordovician) is hampered in that no type section has ever been designated. The upper part of the unit may be seen in an abandoned quarry just north of Black Rock, Ark. This quarry exposes about 30 feet of limestone and dolomite; other limited exposures of a sponge-bearing limestone are to be found 2-3 miles north of the town of Black Rock.

Most of the limestone in the quarry is stromatolitic and similar to that exposed near Smithville. The rock is massive with beds about 4 feet thick, and it breaks with a subconchoidal fracture. Beds at the top of the Black Rock quarry (USGS 6769-CO) in NW$\frac{1}{4}$ sec. 16, T. 17 N., R. 1 W., yielded many ?sclerosponges?, some specimens of *Diparelasma magnum* Ulrich and Cooper, rare *Tritoechia*? species, and very rare cephalopods.

The following faunal list was compiled from three small collections (USGS 6427-CO, 6696-CO, and 6768-CO) made at different times from beds estimated to be 15-10 feet below the top of the quarry:

Sponges undet.
Possible sclerosponges undet.
Diparelasma typicum Ulrich and Cooper
D. magnum Ulrich and Cooper
Hesperonomiella costatula Ulrich and Cooper
Tritoechia? sp.
New genus? cf. *Tropidodiscus*
Euomphaloid gastropod indet.
Teiichispira sp. indet. (shell only)
Macluritid gastropod genus indet. (platelike operculum)
Trochonema? sp. indet.
Gastropod indet.

Murchisonia (Hormotoma) sp.
Kyminoceras sp. indet.
Endoceroid cephalopod undet.
Cephalopod indet.

The sponge- and ?sclerosponge?-bearing limestone is well exposed along a country road running north from Black Rock and also along U. S. Highway 63 north of Black Rock. At the Verkler quarry on the west side of Highway 63, 4 miles northeast of Black Rock, beds at the top of the exposure (USGS 6770-CO) contain essentially the same fauna as that at the top of the abandoned quarry. They yielded abundant ?sclerosponges?, a few specimens of Diparelasma magnum Ulrich and Cooper, rare Syntrophia torynifera Ulrich and Cooper, and very rare cephalopods.

The light-colored aphanitic limestone, crowded with algal mats, sponges, and ?sclerosponges? was found in closely spaced outcrops as far west as Poughkeepsie, Ark. (fig. 4). Limited limestone outcrops that are considered to be this same stratigraphic interval have been found even further west, extending almost to Highway 167. Throughout this region, the fossil ?sclerosponge? characteristically is silicified, and specimens are particularly common in residuum at many localities. In contrast, specimens of undoubted sponges seldom weather out from the limestone, and they are almost never found silicified, although locally they occur in profusion in the matrix.

Three miles north of Black Rock, residual soils and chert are found through a vertical distance of about 50 feet along the slope of a small valley on the east side of U. S. Highway 63 in the NE¼ sec. 11, T. 17 N., R. 2 W. The upper part of the residual soil contains many silicified ?sclerosponges?, as in the abandoned Black Rock quarry and the Verkler quarry. The lower part of this slope has yielded a small collection (USGS 6774-CO) of fossils similar to those found lower in the unit at Black Rock:

Lithistid demosponges
Possible sclerosponges
Polytoechia alabamenis Ulrich and Cooper
?Euchasma sp. indet.
Eopteria sp. indet.
?Teiichispira sp. indet. (shell only)
Macluritid gastropod genus undet. (platelike operculum)
"Helicotoma" sp. indet.
Ceratopea sp. indet. (shells only)
aff. Plethospira sp. indet.
Pleurotomarian gastropods indet.
Gastropod indet.

GEOLOGY AT SMITHVILLE, ARKANSAS

The relationship of the Smithville Formation to the Black Rock is best determined in the immediate vicinity of Smithville, Arkansas, where limestone bearing both typical Smithville and characteristic Black Rock faunas is exposed (fig. 5). At Smithville, the local topographic relief is gentle, and several feet of alluvium masks much of the bedrock. Shallow roadcuts on Arkansas Highways 115 and 117 provide some of the better exposures.

Along Arkansas Highway 115, northeast of Smithville, the Smithville fauna can be collected from the residuum. It is predominantly a molluscan fauna, opercula of Ceratopea unguis being the most common fossil. A number of roadcuts from Smithville northward to the prominent scarp southwest of Imboden, Arkansas (fig. 4) have been examined, and all have produced characteristic Smithville fossils. Below the mantle of residuum, typical Smithville lithology is present along this road. The composition of the various faunules obtained varies slightly, possibly because of vagaries of local silicification or collecting from slightly different levels within the Smithville, but within the area of Smithville outcrop, the residuum consistently produces a characteristic fauna. However, a few silicified ?sclerosponges? also have been obtained intermixed with the silicified residue of Smithville mollusk fauna.

A roadcut along Arkansas Highway 117, about ½ mile east of Smithville, exposes about 8 to 10 feet of Black Rock lithology (USGS 6759-CO); some 20 feet of overlying and underlying beds crop out on adjacent slopes. The rock is a light-gray aphanitic limestone. Digitate cryptozoan structures are present, showing a relief of several inches; they are most obvious on a wet or weathered surface. Sponges and ?sclerosponges? are also present in abundance. The cryptozoans appear to be segregated in different bands, but sponges are scattered throughout the beds. The massive limestone has no distinct bedding. Several Ceratopea opercula were found in the soil residuum immediately above this outcrop and on the hilltops to the south and east.

Immediately above the aphanitic limestone exposed on Arkansas Highway 117, and a few yards southwest of the shallow roadcut, a shale interval less than 6 inches thick has yielded graptolites of latest Early Ordovician age (USGS 6760-CO). Graptolites were known for many years from dolomite in the Graceland mine (a zinc prospect abandoned half a century ago) about 3 miles northwest of Smithville. These occur in the dump debris which reportedly was excavated from the mine shaft. Their exact stratigraphic position cannot be determined, as the mine shaft, which was in the bed of a creek, has since filled with gravel. However, they probably occur very near or at the same horizon as the roadcut outcrop. The graptolite fauna from both localities was reported by Berry (1970).

The base of the outcrop on Highway 117 is at an altitude of 340 feet; it is 3/5 ths mile almost due south of the draw that runs into Machine Creek where the Ceratopea-bearing limestone of the Smithville Formation occurs at an altitude of 335 feet. An extremely slight northern dip can be seen here and at intervening exposures, whereas the gentle dip of strata north of Machine Creek is to the south. There is no evidence of faulting or other structural complications, and the dip is so slight that strata appear to be flat-lying between these two outcrops. Surface alluvium covers much of the bedrock between the two outcrops, but the physical evidence indicates that Black Rock (sponge-bearing) beds exposed here are laterally equivalent to Smithville (*Ceratopea*-bearing) limestone on the Machine Creek tributary.

Fifteen hundred feet east and topographically above the Black Rock limestone outcrop on Highway 117, $1\frac{1}{4}$ miles east of Smithville in NE$\frac{1}{4}$ sec. 34, T. 17 N., R. 3 W., is a shallow roadcut at an altitude of 410 feet (USGS 6765-CO). About 15 feet of sandstone, stratigraphically above the Black Rock outcrop, is exposed in the roadcut.

Opercula of *Ceratopea* were collected in the sand and clay residuum at the top of the hill, precluding transport from other areas. Some of the opercula are more slender than those recovered from the Smithville Formation along Highway 115 about 1-1/10 miles to the northwest (6764-CO) but still seem to be within the limits of variability of *C. unguis*. This locality has thus yielded the first Early Ordovician fossils from beds overlying the Black Rock. The limited faunule (USGS 6765-CO) recovered here includes:

Ceratopea unguis Yochelson and Bridge
Loxoplocus (*Lophospira*) sp. indet.
Pleurotomariacean indet.
Low-spired gastropod cf. *Helicotoma*
Plethospira sp. indet.
Cephalopods undet.

INTERPRETATION

We conclude that the local geology at Smithville, Arkansas, demonstrates that the limestones of the Black Rock and the Smithville are lateral facies of one another. In spite of the occurrence of alluvium, the proximity of typical Smithville along Highway 115 to typical Black Rock along Highway 117 is significant. The outcrops are separated by no more than $\frac{1}{4}$ mile laterally and no more than 10 feet topographically, the dips indicating that these are the limbs of an extremely gentle synclinal structure (fig. 6). Molluscan fossils characteristic of the Smithville overlie the sponge-bearing beds of the Black Rock on the southern limb of this structure. Accordingly, we suggest that the status of the Black Rock be reduced from that of a formation to that of a member of the Smithville Formation.

The fossils of the Smithville and Black Rock facies are different, which is one of the reasons the units were considered to be of significantly different ages. This difference in fauna is thought to be a facies variation, although there is some slight admixture of the fauna in this area. Where ?sclerosponges?, one of the most characteristic fauna of the

Black Rock, occur with Smithville fossils, both are in residuum and appear to have been weathered from a common "host" rock. It is futile to speculate how great a thickness of rock produced the fossils found in a residual accumulation.

A particularly significant piece of evidence is the discovery of Ceratopea unguis opercula stratigraphically above the Black Rock along Highway 117. A supplemental piece of faunal evidence is the molluscan fauna within the Black Rock. Although this fauna has little in common directly with the characteristic Smithville assemblage, a few forms occur in both; certainly it is not as different as the cryptozoan, ?sclerosponge?, and sponge association is from the Smithville fauna. The few brachiopods found in the Smithville are genera that occur in the Black Rock.

Therefore, we interpret the geology at Smithville, Arkansas, as being within a local zone of interfingering of two different facies. The Black Rock appears to be reefal; the facies shows some of the characteristics of a reef-flat environment, in an area quiet enough to encourage chemical as well as biologic precipitation of calcium carbonate by the predominantly sedentary biota. In marked contrast, the Smithville facies seems to be a lime mud that supported a large biota of crawling and swimming organisms. In a broad sense, this might be interpreted as a lagoon deposit behind the shallow reef-flat.

In a stratigraphic sense, the new interpretation has significance far beyond northeastern Arkansas. Traditionally, the Black Rock has been considered a formation overlying the Smithville. The Smithville is readily correlated with units in other areas, Ceratopea unguis being an important fossil in this regard. Thus, to name only two areas, the Smithville is equivalent to the upper part of the El Paso Limestone in Texas, and the upper part of the West Spring Creek Formation in Oklahoma.

Correlation of units from other areas with the Black Rock has been more difficult (Sando, 1958, p. 844) and has resulted in the Black Rock being considered either Early or Middle Ordovician (Ross, 1951, p. 31; Ross, 1968, H-3).

The limited fauna of the Black Rock is extremely specialized and atypical of other Early Ordovician assemblages in the profusion of ?sclerosponges?. Further, we believe that it lived contemporaneously with the Smithville fauna and therefore has no stratigraphic value in its own right; other than that it is found in the upper part of the Smithville.

AGE OF THE SMITHVILLE-BLACK ROCK FAUNAS

Although there is little question in the literature as to the Early Ordovician age of the Smithville Formation, and even the Black Rock Limestone Member, the evidence for such an age assignment has never been presented in full. There is always some hazard in accepting as evidence faunal lists undocumented with illustrations and descriptions, but all involved are in essential agreement as to the Early Ordovician age of the Smithville and at least some taxa of the Black Rock fauna. Even though substantial collections have been assembled and some forms have been described for a number of years, it may be some time before the fauna is documented in its entirety. Under these circumstances, a summary of statements bearing on the age seems appropriate.

The algal structures are unstudied, but are unlikely to contribute any meaningful data on age relationships. Generally similar stromatolites occur in the appropriate environment throughout the lower Paleozoic. The problematic microorganism Nuia has been reported from the Black Rock (Toomey, 1967), but it is known from both older and younger rocks.

The sponges from the Black Rock also contribute little unequivocal data. Prof. Robert Finks has noted (oral communication) that lithistid sponges of the Ordovician are poorly known. The available material collected during this study is more typical of that found elsewhere in younger Ordovician rocks. The ?sclerosponges?, if that assignment is correct, were only recently recognized as being of a high-level taxonomic importance in the present-day seas. Their importance in the fossil record and the stratigraphic significance of genera and species remains to be determined. Still, they constitute a most interesting biological discovery, for apparently this markedly extends the range of the group. Although the external shape of colonies varies somewhat, much of this may be the result of crowding, clight differences in the hardness of the bottom, and other factors not of taxonomic importance. Prof. Willard Hartman has suggested that at most, only a few forms are present, and perhaps all representatives collected may be the same species.

Brachiopods from the Black Rock have been known for some decades, thanks to the monographic work by Ulrich and Cooper (1938). The newly collected specimens are comparable with genera and species described earlier. These are considered by G. A. Cooper to be of late Early Ordovician age because of their stage of evolutionary development, not simply because of their occurrence in the Black Rock.

The graptolites in the Black Rock are those that typically occur near the Lower Middle Ordovician boundary (Berry, 1970). A fauna similar to that from the Graceland mine was described by Decker some years ago from the upper part of the West Spring Creek Formation in Oklahoma.

The ostracodes from the Smithville identified by J. M. Berdan as Eoleperdita? probably represent a new genus. Probably only one species has been found. Berdan has indicated that the ostracodes are not similar to those from the early Middle Ordovician Whiterock Stage in Nevada or younger Ordovician occurrences that she has examined.

Three of the five conodonts identified to species have long ranges. Acodus tripterolobus occurs in the West Spring Creek and Joins Formations of Oklahoma.

The conodonts collectively probably represent a zone close to the Lower-Middle Ordovician boundary; correlation of the Smithville to the West Spring Creek is reasonable.

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STRATIGRAPHY AND CONODONT FAUNAS OF THE CASON SHALE AND THE KIMMSWICK AND FERNVALE LIMESTONES OF NORTHERN ARKANSAS

William W. Craig 1/

ABSTRACT

The Kimmswick and Fernvale Limestones are similar in many respects. Both represent deposits of interrupted transgressions that moved over a carbonate terrain that had been exposed and subjected to subaerial erosion. As a result, the basal deposit of each unit is medium- to coarse-grained calcarenite. The presence of finer-grained textures at the top of each unit, and in the case of the Fernvale the abundance of shell material in the uppermost layers, is interpreted as representing an increasing water depth that accompanied transgression. Above this level in each unit knowledge of deposition is cut short by the occurrence of the overlying transgressive deposit. Epeirogenic uplift preceding each transgression was apparently greater in the west than in the east of the outcrop belt as evidenced by the thinning and eventual disappearance of formations in this direction.

The Fernvale and Kimmswick differ primarily in that Fernvale deposition was marked by conditions of wave energy that were more persistent through time and of broader geographic impress. Also, faunal diversity over most of the Fernvale seafloor was considerably less than over the Kimmswick seafloor. As a result, the Fernvale is a better-sorted limestone in which skeletal parts of attached echinoderms comprise the greater percentage of the grains. At times during the deposition of the Kimmswick, wave action persisted long enough in certain places to produce sediment types that mimic the Fernvale lithology. For the most part, however, the Kimmswick is a lower energy deposit composed of a heterogeneous mixtrue of poorly-sorted fossil debris.

Only the basal portion of the Cason Shale in the Batesville district is Ordovician in age. The initial deposits are phosphatic conglomeratic sandstone channels occurring in a larger body of the phosphatic shale. The phosphate grains are skeletal parts and limestone fragments that have been replaced by phosphate. Inarticulate

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brachiopod shells are also common. All grains are polished and rounded, and it seems likely that they were reworked from the underlying Fernvale, which contains phosphate grains similar to those of the Cason except that they are not polished or rounded. The texture and geometry of the rock suggests a fluvial origin for this unit. Phosphatic sediments are also the initial deposit of the Cason in Gilbert region. Unlike the Batesville district, however, most of the Cason in the west of the outcrop belt is shale, and reworking of grains from the underlying Fernvale appears not to have been as common as in the Batesville district.

The phosphatic beds of the Cason were more or less directly followed, but not intermixed with, deposits of the oolitic limestone, dismicrite, and intrasparite in the Batesville district, and silty, dolomitic shale in the Gilbert area. The historical relationship of these different lithic types of the Cason is not completely understood.

Six superposed conodont faunas are recognized in the units under discussion. The distinction between the faunas is mainly in the relative abundances of their elements and not so much in the possession by any fauna of elements unique to it. The lowest fauna is the fauna of the Kimmswick Limestone; the next three are in the lower, upper, and uppermost portions of the Fernvale Limestone respectfully; fauna five occurs in the phosphatic shale of the Gilbert area; and fauna six occurs in the Cason oolitic limestone of the Batesville district and the dolomitic shale of the Gilbert area. Faunas three and four of the upper and uppermost Fernvale disappear to the west where they apparently have been removed by pre-Cason erosion. This conslusion is strengthened by the occurrence in the phosphatic beds of the Batesville Cason of reworked elements of fauna four.

INTRODUCTION

The three units considered in this report are the uppermost Ordovician deposits of northern Arkansas. Only the basal phosphatic sandstone and shale beds of the Cason are Ordovician in age. The remainder of the stratigraphic interval traditionally considered as Cason is now definitely known to be Early and Middle Silurian in age. The type Cason at the old Cason manganese mine just north of Batesville does not contain these basal phosphatic beds or oolitic limestone. It is comprised entirely of a stratigraphically higher shale that is slightly phosphatic and contains flattened algal "buttons". This latter shale, which is Middle Silurian in age and represents a basal detrital phase in the deposition of the overlying St. Clair Limestone, is the uppermost unit in the Cason; it rests unconformably on all lower Cason strata. The basal phosphatic beds of Ordovician age are the most widespread geographically of all the Cason units, and it is with them, unfortunately, that the name Cason is most commonly associated. Although it is

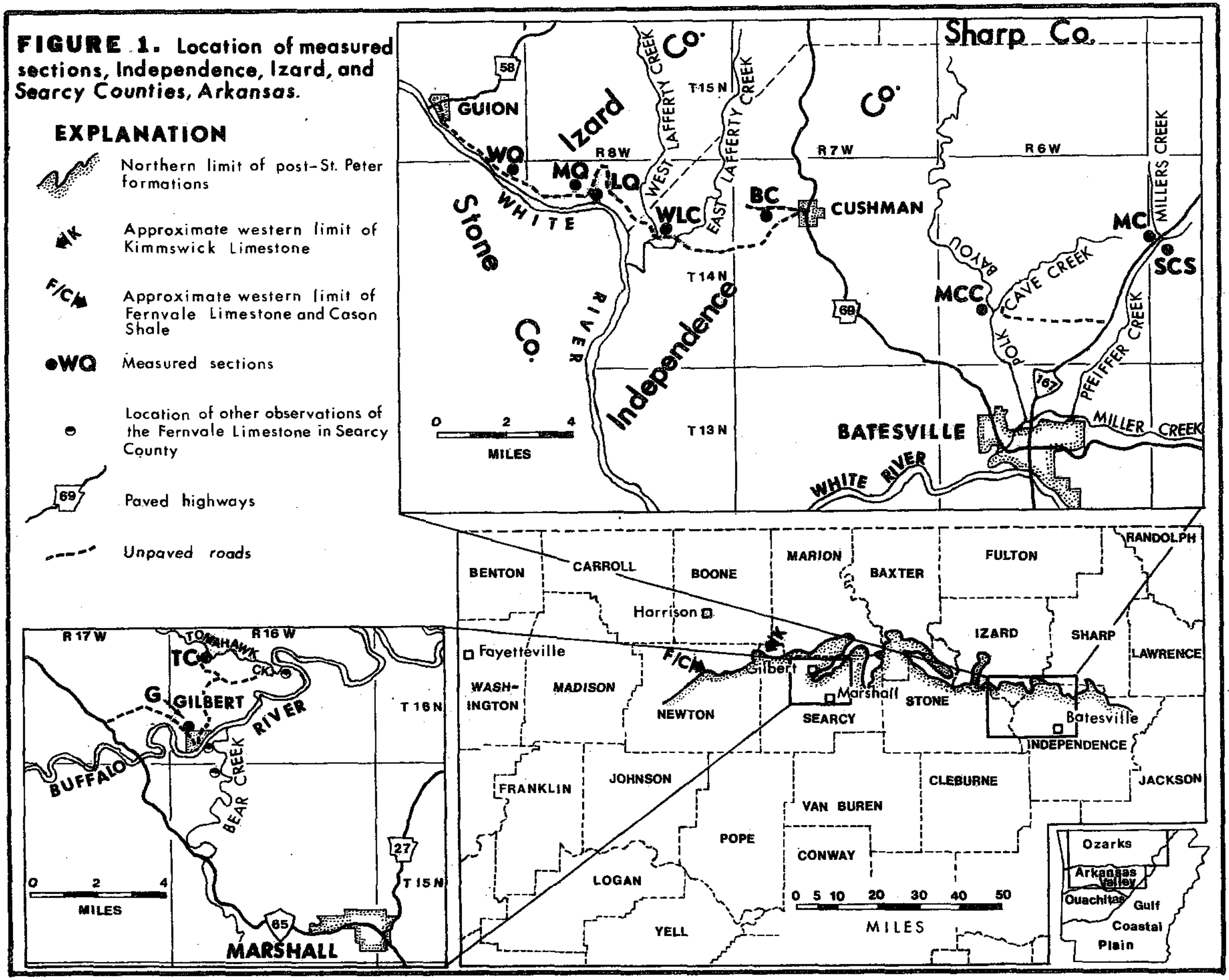

FIGURE 1. Location of measured sections, Independence, Izard, and Searcy Counties, Arkansas.

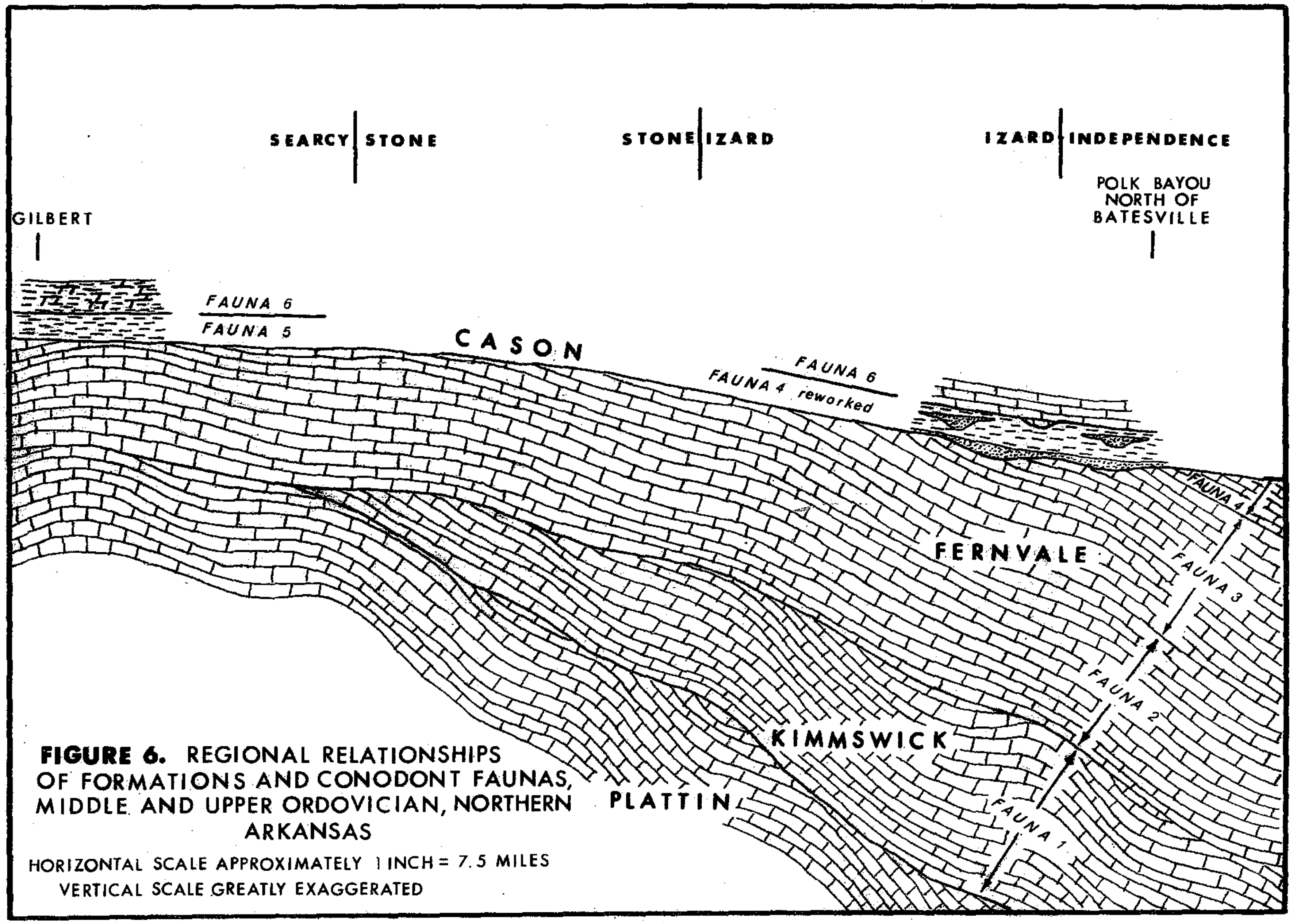

FIGURE 6. REGIONAL RELATIONSHIPS OF FORMATIONS AND CONODONT FAUNAS, MIDDLE AND UPPER ORDOVICIAN, NORTHERN ARKANSAS

HORIZONTAL SCALE APPROXIMATELY 1 INCH = 7.5 MILES
VERTICAL SCALE GREATLY EXAGGERATED

apparent now that the name Cason is not really appropriate for this Ordovician phosphatic sandstone and shale and associated oolitic limestone, the name is retained here because it is presently the only one available for these strata. All references to the Cason Shale in this paper will specifically mean these lowermost strata of Ordovician age. Information concerning the Silurian portion of the Cason can be found in Craig (1969).

The Ordovician units under consideration form a narrow and irregular east-west outcrop belt across northern Arkansas (fig. 1). A few miles east of Batesville this belt is covered by the Mesozoic and Cenozoic rocks of the Mississippian Embayment. All three units have their thickest and most persistent development in the Batesville manganese district of Independence and Izard Counties. The Fernvale and Cason extend westward into Newton County (Purdue and Miser, 1916). The Cason of these western outcrops, however, is of sporadic occurrence and somewhat different from the Batesville Cason in its lithic development. Except for McKnight's (1935) report of a Kimmswick outcrop in western Searcy County, the unit appears to be absent west of Stone County.

My examination of these units has been confined primarily to two areas of their outcrop belt: The Batesville district on the east and the Gilbert area on the west (fig. 1). This examination has been carried on in association with an investigation of the conodont faunas in this part of the column. Because a knowledge of these faunas has added greatly to my understanding of the stratigraphic history of these uppermost Ordovician strata, it is proper and necessary that they be referred to in this report. Six faunas are recognized in the formations under discussion. The distinction between the faunas is mainly in the relative abundances of their elements and not in the possession by any individual fauna of elements unique to it. Inasmuch as the names of the taxa in no way enhance the stratigraphic discussion, and in many respects would detract from it, I shall avoid their use in the body of the text. The faunas occur in superposition, and I shall refer to them by number. For those familiar with the taxonomy of Ordovician conodonts and interested in knowing the composition of the six faunas, I have added at the end of the paper a short description that illustrates the salient features of each one. Figure 6 shows the stratigraphic and geographic distribution of the six faunas.

The history of investigations on these strata and the changes in their stratigraphic nomenclature are outlined in another article in this volume. I also mention in this other article opinions on the interpretation of the Plattin-Kimmswick contact and the Kimmswick-Fernvale contact, both of which I consider unconformable. I shall let that discussion also serve this paper, and it is not my intent to further remark on these two formational contacts except where such remarks serve the purpose of clarity.

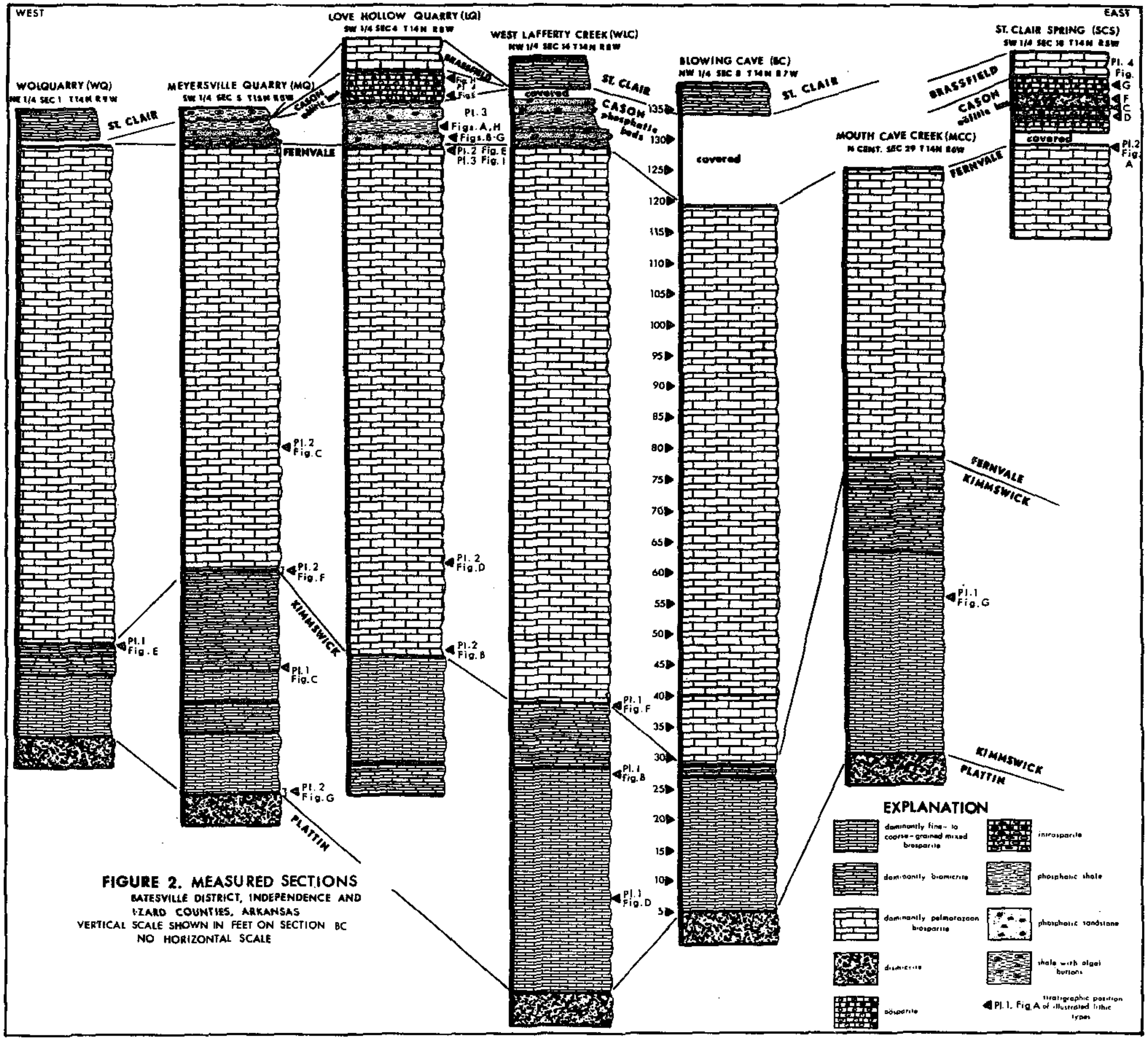

FIGURE 2. MEASURED SECTIONS
BATESVILLE DISTRICT, INDEPENDENCE AND IZARD COUNTIES, ARKANSAS
VERTICAL SCALE SHOWN IN FEET ON SECTION BC
NO HORIZONTAL SCALE

KIMMSWICK AND FERNVALE LIMESTONES

BATESVILLE DISTRICT

Stratigraphy - Although the Kimmswick and Fernvale appear to be separated by an unconformity representing a portion of Middle and Late Ordovician time, they have a similarity in lithic character by virtue of the common possession of coarse-grained calcarenite that requires they be considered together in a discussion of their stratigraphy. This coarse-grained calcarenite, whereas distinctive in itself, is remarkably similar in aspect at different stratigraphic levels. It is much more characteristic of the Fernvale, of which it comprises the bulk, than it is of the Kimmswick; however, some sections of Kimmswick include enough of it to cause this unit to appear grossly similar to the Fernvale.

The Kimmswick ranges in thickness from 0 to 55 feet in northern Arkansas. It rests unconformably on the underlying Plattin Limestone, and at one locality, West Lafferty Creek (section WLC, figs. 1 and 2), an angular relationship exists between the two units (Freeman, 1972). The contact between the two formations is an unmistakable change from lithographic limestone to medium- to coarse-grained calcarenite (pl. 2, fig. G).

The Kimmswick is dominantly a light- to pinkish-gray, poorly-washed and poorly-sorted mixed biosparite that is intimately associated with biomicrite (limestone names after Folk, 1959). Much of the matrix of the biomicrite is larger than true micrite size (less than 4 microns), but too small to be identified as to origin. The texture of the rock is that of identifiable fossil skeletons scattered through a rather equigranular matrix of 10 to 20 microns. This is the kind of texture that Miser referred to as fine grained. He reserved the term dense for true micritic limestone. The matrix of the Kimmswick micrites is either recrystallized from chemically precipitated lime mud or the product of the attrition of larger skeletal parts by the activity of burrowing organisms, or both. Regardless of the interpretation of the origin of the matrix of the Kimmswick micrite, the rock is no doubt the product of a low-energy environment. Grains are a heterogeneous combination of corals, bryozoans, brachiopods, trilobites, pelmatozoans, and molluscs (spar replaced) that range in size from fine to very coarse. Shell material is partially fragmented and randomly oriented, and the sediment in some areas obviously churned, imparting to the rock a burrowed appearance. Patches of micrite which could represent burrows strengthen this impression.

Some of the Kimmswick, indeed a significant amount of it in some sections, is more thoroughly washed and better sorted, and the rock approaches in type the pelmatozoan biosparite so characteristic of the Fernvale. All gradations exist between biomicrite and well-sorted biosparite, and there appears to be no pattern in the occurrence of rock types except the general tendency for biomicrite and poorly-washed biosparite to dominate the upper layers of Kimmswick. Representative Kimmswick rock types are illustrated on plate 1.

The Fernvale ranges in thickness from 0 to over 100 feet in northern Arkansas. It rests unconformably on the Kimmswick and is overlain unconformably by the phosphatic beds of the Cason Shale, which in the Batesville district fill small channels in the top of the Fernvale.

The Fernvale has a more constant lithic character than the Kimmswick. It is composed almost entirely of coarse- to very coarse-grained pelmatozoan biosparite. In the western part of the Batesville district in the vicinity of Penter's Bluff and north along the White River the basal two to three feet contains coral colonies, some of which appear to be attached on the upper surface of the Kimmswick. Skeletal material of brachiopods, trilobites, bryozoans, ostracodes, and corals occurs throughout the Fernvale but tends to increase in the upper portion of the thickest sections to produce a poorly-sorted, fine- to coarse-grained mixed biosparite. Pelmatozoans are not the dominant constituent of this upper shelly portion of the Fernvale. Whole fossil specimens are mostly restricted to these upper layers and to the lower few feet of the unit. Detrital clay, stained with iron and manganese oxide, is also a prominent constituent of the upper layers of thicker sections. As a result, the usual light- to pinkish-gray color of the unit acquires a dark-red to dark-brown cast toward the top. All considered, the energy conditions prevailing during the accumulation of the upper layers of Fernvale would appear to be less than those prevailing earlier in the unit's deposition. Representative Fernvale rock types are illustrated on plate 2.

The coarse-grained pelmatozoan biosparite of the Kimmswick is quite similar both in lithic character and outcrop expression to that of the Fernvale. It is rather devoid of skeletal material other than pelmatozoan parts. In general, the pelmatozoan biosparite of the Fernvale tends to be more consistently coarser than that of the Kimmswick, but this distinction is not exceedingly clear-cut and does not provide much satisfaction to the geologist intent on separating the two units in the field. Hand specimens of this lithic type from the two formations cannot be objectively assigned to either unit. In natural outcrop the biosparite of both units is thick-bedded, may be distinctly cross-bedded, and weathers to a loosely indurated pelmatozoan sand. A feature of the lithic distribution that aids in an objective separation of the two units is the tendency for coarse-grained limestone to be confined to the lower and middle parts of the Kimmswick. The upper part of the Kimmswick is generally exceedingly fine-grained, a condition that led Miser (1922) to remark on its similarity to the lithographic Plattin Limestone underlying the Kimmswick. The contrast between the upper fine-grained Kimmswick and the overlying consistently coarse-grained Fernvale provides an easily identifiable and objective boundary for separating the two formations in the field. It is at this boundary between fine-grained and coarse-grained limestone that there occurs the faunal change which Ulrich used to originally separate the two formations. This is also the boundary that exhibits the "petrographic" unconformity (see pl. 2, fig. F) illustrated in cross-section by Freeman (1966a). Although Freeman's discussion was restricted to only one locality, Meyersville Quarry (section MQ, figs. 1 and 2) the top bedding plane of the Kimmswick in natural exposures exhibits a patchwork of Fernvale that suggests deposition of the latter formation on a slightly irregular upper surface of the former. This is exactly what one would expect the "petrographic" unconformity to look like in plan view, and it is assumed that this contact relationship exists throughout the outcrop area of the Kimmswick and Fernvale.

The association of distinct lithic change, recognizable faunal difference, and evidence of truncation at what is essentially an ordinary bedding plane contact throughout the outcrop area of the two limestones appears to me to be ample evidence that the Kimmswick and Fernvale are separated by a surface of erosion. It would seem that any one of these three criteria could be used to identify the plane of historical significance that separates the two formations. There are sections, however, where the lithic and faunal criteria for separation either do not unequivocally coincide, or their coincidence results from the fortuitous occurrence of a foot or so of fine-grained rock at the top of the Kimmswick. The latter situation is well-illustrated at Blowing Cave (section BC, figs. 1 and 2), a mile west of Cushman. At this locality the entire 24 feet of Kimmswick is dominated by light-gray, coarse-grained pelmatozoan biosparite except for the upper one foot, which is mixed biomicrite. The faunal change occurs, as usual, at the lithic boundary. The occurrence, however, of Kimmswick coarse-grained biosparite nearly up to the Fernvale contact serves as a warning that there could be sections where coarse-grained Kimmswick is in contact with coarse-grained Fernvale. In such examples, application of the lithic criterion for separation of the two units would be difficult, if not impossible. Love Hollow Quarry (section LQ, figs. 1 and 2) provides an example that approaches this situation. There is in the face of the lower level of the quarry a change from biomicrite to a pelmatozoan biosparite that ranges in grain size from medium to coarse; from this level up to the Cason no more fine-grained limestone occurs in the section. The tendency is to place the Kimmswick-Fernvale contact in this section at the distinct grain size change just described because this is the kind of change that most commonly occurs at their common boundary. The faunal change, however, is 17.5 feet higher in the section at a more subtle lithic change from the medium- and coarse-grained pelmatozoan biosparite to a pelmatozoan biosparite that ranges in grain size from coarse to very coarse. The latter lithic change, although sharp, can be interpreted simply as a slight increase in energy conditions, which is not the kind of phenomenon to which much historical significance is generally attached. The third criterion of "petrographic" unconformity is inapplicable here because both the upper and lower grain size changes are stylolitic. I place the contact between the Kimmswick and Fernvale in this section at the faunal change without hesitation because it seems to be the best choice to insure that its position agrees stratigraphically with the position of the contact in other sections. Although careful examination at Blowing Cave and Love Hollow Quarry leads to the discovery of the lithic boundary between the two formations, the two sections illustrate that mimicry of the Fernvale lithic type by the Kimmswick can cause difficulty in identifying their contact in the field.

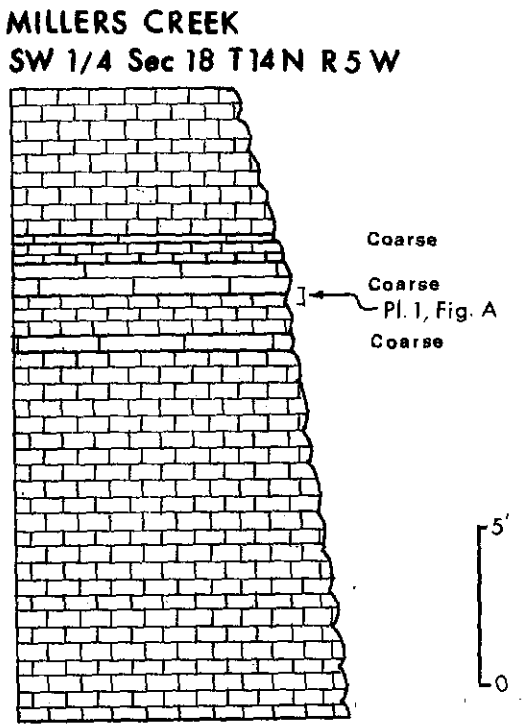

Figure 3. Kimmswick Limestone at Millers Creek north of Batesville, Arkansas. Outcrop consists of dominantly fine-grained pelmatozoan biosparite with a few coarse stringers interbedded with three thin layers of very coarse-grained pelmatozoan biosparite. Contacts between the fine biosparite and very coarse biosparite are sharp and stylolitic. The position of the coarse layers is marked on the diagram.

The existence of a welded contact exhibiting the features of an unconformity at the Kimmswick-Fernvale boundary raises the question of the nature of the transition between beds of different grain size within the Kimmswick Limestone. I have attempted to examine these transitions as carefully as exposures allow and have yet to find one that qualifies as a "petrographic" unconformity as illustrated by Freeman. Certainly some of these changes are gradational; such is true for the contacts between the biomicrite and the underlying coarser-grained Kimmswick at both West Lafferty Creek and the mouth of Cave Creek (section MCC, figs. I and 2). In some sections of the Kimmswick distinctly different grain sizes are in sharp contact, but in every example of this phenomenon thus far examined the boundary separating the rock is stylolitic. This is true for the previously mentioned contact between the biomicrite and the medium- to coarse-grained pelmatozoan biosparite in Love Hollow Quarry, and similarly for the change from biomicrite to medium- to coarse-grained mixed biosparite approximately 14 feet above the base of the Kimmswick in the Meyersville Quarry. An extremely interesting Kimmswick outcrop in this respect is Millers Creek (section MC, figs. I and 3). At this locality in a vertical distance of 3 1/2 feet of rock there occurs no less than three changes from fine-grained pelmatozoan biosparite to coarse- to very coarse-grained pelmatozoan biosparite and back again (fig. 3, and pl. I, fig. A). All contacts are sharp and stylolitic. Unfortunately, stylolitic contacts give no direct evidence on the original nature of the transition between two rock types unless proof exists that very little rock was removed by solution along the stylolite. Conodont faunas do not appreciably change across the contacts and are obviously of the Kimmswick type. The contact between the Kimmswick and Fernvale at Meyersville Quarry, the locality where the "petrographic" unconformity between the two units was first recognized and illustrated by Freeman (1966a), is also in part stylolitic. In places along the quarry wall, however, the contact is stylolite free, and where this is true it retains the sharp change in grain size and exhibits truncation features associated with the "petrographic" unconformity. Whether this same relationship exists for the sharp grain size changes within the Kimmswick seen at Millers Creek and other outcrops is not known. If it does, our understanding of the history of these rocks might be considerably altered.

Conodonts - The distinction between the conodont faunas of the Kimmswick and Fernvale is mainly in the relative abundances of their elements and not so much in the possession by either fauna of elements unique to it. It is true that small differences do exist between certain types; however, the use of these differences as a basis for assignment to different species does not meet with widespread approval among students of Ordovician conodonts. In spite of this similarity, there is no real problem in distinguishing between the faunas of the two limestones because in general species that are rare in the Kimmswick characterize the Fernvale, and vice versa. A cursory glance at a collection is enough to determine from which of the two units it comes.

The traditional age assignments of the Kimmswick and the Fernvale have been Middle (Trenton) and Late (Richmond) Ordovician respectively. If these assignments are accepted it would seem that the unconformity separating the two formations represents at least a portion of Late Ordovician time. The conodont elements that characterize the Kimmswick fauna, which is the first of the six faunas mentioned earlier, are reasonably widespread, and seem almost certainly to be of Middle Ordovician (Barneveld) age. However, one of the unfortunate features of Ordovician faunal provincialism is that the characteristic Fernvale elements are more restricted in their distribution. They are most common in what presumably are the Fernvale equivalents of the Mississippi Valley. The Fernvale fauna is not in very close agrements with Middle Ordovician faunas and the most characteristic of its elements have not been reported from the Cincinnati region, which is the standard reference section for the North American Upper Ordovician. Thus the traditional method of age determination by comparison with a standard fails altogether with the Fernvale. The difference between the Kimmswick and Fernvale conodont faunas, being a difference of percentages of elements rather than kinds of elements, neither supports nor militates against the interpretation of a disconformity between the two units. The faunas are easily distinguished, but it is not clear that any important taxa are missing at their common boundary.

The Richmond age for the Fernvale derives from the studies of E. O. Ulrich, whose philosophy of stratigraphic synthesis is outlined in my other article in this volume. Ulrich (1911, p. 423-424) noted that the Fernvale and the Cincinnati Richmond faunas possess very few species in common, but he ascribed to the former a Richmond age because north of Gallatin, Tennessee, he observed it intercalated between the Arnheim and Waynesville Formations, both of which are part of the Richmond deposits of the Cincinnati region. By the dint of Ulrich's authority, the Fernvale fauna, which is limited in distribution to the east of the Mississippi but is widespread to the west, became the index of what was known in Ulrich's day as the "western Richmond". Since that time the Richmond age of these Fernvale species has become so ingrained in the minds (and correlation charts) of biostratigraphers that few have questioned how it is that this fauna, which compares so inadequately with that of the Richmond in its type area, has come to be the identifier of that very stage throughout a large area of the United States. Some geologists who have doubted that the "western Richmond" was really Richmond in age have attempted other correlations for it, but most of these attempts have been variations of the standard method of comparing species, a procedure that Ulrich early recognized as futile. To my knowledge the observation that led Ulrich to his assignment of the Fernvale has not been refuted, and 75 years later it remains as the strongest piece of evidence bearing on the question.

Most of those conodont species that characterize the Kimmswick (fauna I) by their inevitable presence and abundance are either exceedingly rare or absent altogether in collections from the Fernvale. Furthermore, their distribution in the Fernvale is restricted to the lower half of the unit. The upper half of the Fernvale contains only characteristic Fernvale elements without the background of species common to the Kimmswick. These two faunas found in the lower and upper Fernvale constitute faunas two and three respectively of the sequence of six faunas. The upper and lower Fernvale can usually be discriminated on this basis. The above distribution is true except for the uppermost shelly Fernvale at

St. Clair Spring. The fauna from these rocks, besides having the usual complement of the Fernvale forms, contains a strong recurrence of species characteristic of the Kimmswick. This combination of forms constitutes fauna 4. I will come back to this feature in the discussion of the Cason Shale.

GILBERT AREA

I have not examined the Fernvale in detail in the western part of the outcrop belt. Judging from the reports published on this area (Purdue and Miser, 1916; McKnight, 1935; Maher and Lantz, 1952; Maher and Lantz, 1953; Glick and Frezon, 1965; Freeman, 1966b; Young, et al, 1972a) and from my rather limited observations in Searcy County, the character of the Fernvale is much the same as in the Batesville district, except it appears to be thinner and does not exhibit an increase of shell material in its upper layers. Conodonts from the Fernvale of the Gilbert area are indicative of those from the lower half of the formation in the Batesville district. It would thus seem that if the Fernvale were once as thick to the west as to the east, its present reduced thickness in Searcy County has resulted from the removal of beds from the top by erosion rather than the loss of basal beds by onlap to the west.

CASON SHALE

PHOSPHATIC BEDS

Stratigraphy – The phosphatic sandstone and shale unit of the Cason is widespread in the Batesville district west of Polk Bayou. It seldom exceeds ten feet in thickness and is generally considerably less than this. It forms poor outcrops except where sandstone dominates, and consequently little detail is known about the rock. It is an interesting and varied unit that deserves a comprehensive study of its own. Love Hollow Quarry contains the best available exposure and has provided me with most of my understanding of the unit. The Cason in the quarry is covered at places by rubble so that the interval is not continuously exposed. At some places along the quarry face the unit is composed entirely of sandstone, at others of intercalated sandstone and shale, and at still others entirely of shale. The distribution of sandstone and shale along the face of the quarry changes almost day by day as the Cason and St. Clair are stripped-off the underlying Kimmswick and Fernvale Limestones from which the quarry produces. The character of the unit in the quarry, as well as its appearance in natural exposures, which consist of sandstone ledges that do not persist far along the outcrop, suggest that these basal Cason phosphatic beds are composed of sandstone channels coursing through a larger body of shale.

Thin sections of the phosphatic, conglomeratic sandstones (pl. 3, figs. B-G) show that the grains are composed almost entirely of calcium carbonate material that has been replaced by phosphate. Particularly abundant among the grains are pelmatozoan parts, but clams, snails, trilobite and articulate brachiopod shells, and fragments of fine-grained limestone are also present. Also present in considerable abundance are glauconite grains and fragments of phosphatic brachiopods. Quartz comprises less than five percent of the grains. The rock is very poorly sorted; the smallest grains are quartz which average about 1 mm in diameter, and the largest are phosphatized fragments of fine-grained limestone which in long dimension measure up to 20 mm. The grains are cemented by calcite and quartz, and by stringers of clay. The shale has much the same aspect as the conglomeratic sandstone except that clay matrix is the predominant constituent of the rocks. Grains include a large percentage quartz silt and considerable amounts of phosphate grains similar to those in the conglomeratic sandstone, but of smaller size. Grains in the shale occur in the matrix as disseminated grains, as stringers, and as elliptical patches that apparently represent the accumulation of coarse material in small topographic lows on the clay depositional surface (pl. 3, fig. A).

Residues from the phosphatic shale processed for conodonts by boiling and heavy liquid separation contain an abundance of phosphatic grains of the same types that are observed in thin section. The most striking feature of these grains is their high degree of rounding and polish (pl. 3, fig. H). The same is true for fragments of phosphatic brachiopods and grains of glauconite. There is little doubt that these grains underwent transportation prior to their deposition in the layers that now form the lower phosphatic unit of the Cason Shale. It is likewise certain that the phosphate replacement took place prior to transportation and deposition, otherwise the phosphate grains would not possess the high luster they now have. The most likely source for these grains is the underlying Fernvale limestone; and indeed, inspection of thin sections from the upper shelly Fernvale reveals incipient phosphatization of grains and larger areas of the rock (pl. 2, Figure A). Furthermore, heavy liquid separations of acetic acid residues of Fernvale contain phosphatized grains similar to those in the overlying Cason except for their lack of polish and rounding (pl. 3, fig. I). These cursory observations suggest that phosphatization of the grains that now comprise the basal phosphatic beds of the Cason in the Batesville district took place in the Fernvale either during the deposition of the limestone or when it was later exposed to weathering. The phosphatic grains in the upper beds of the Fernvale were later reqorked and deposited in the layers that now comprise the basal Cason. Whether this reworking took place in a marine or nonmarine environment is at present an unsettled question. I have not seen any fossils in the Cason phosphatic beds that could be considered indigenous; all appear reworked. The basic geometry of the sedimentary body, that of channels coursing through a main body of shale, seems to be more indicative of a fluvial deposit than of a transgressive marine unit. However, a much more comprehensive investigation of the unit will be necessary before firm conclusions can be drawn concerning its environment of deposition.

Conodonts - Conodonts from the phosphatic shale at Love Hollow Quarry support the reworking hypothesis for the grains of the Cason deposit. Most of them are abraded and polished, some to the extent that only a person with a working knowledge of conodonts in this part of the column could identify them to species. The fauna compares closely with that from the upper part of the Fernvale exposed at St. Clair Spring (fauna 4); that is, it contains a mixture of characteristic Fernvale and Kimmswick species. In this respect it is unlike the fauna in the Fernvale directly underlying the Cason at Love Hollow Quarry. The upper forty feet of the Fernvale at this locality contains that fauna produced by the upper Fernvale throughout most of the district: Characteristic Fernvale species without the addition of characteristic Kimmswick species (fauna 3). If the conodonts from the phosphatic beds of the Cason at Love Hollow Quarry are reworked from below, a conclusion I feel is warranted on the objective bases of their preservation and the presence of the reworked phosphate and glauconite grains, then it appears likely that the "zone" of mixed Fernvale and Kimmswick species (fauna 4) present in the upper part of the Fernvale at St. Clair Spring once extended across the Batesville district. It would follow, then, that this "zone" has been removed from the top of the Fernvale in those sections that I have examined west of St. Clair Spring by post-Fernvale erosion and redeposited, along with other resistant Fernvale grains, in the basal phosphatic beds of the Cason.

OOLITIC LIMESTONE

Stratigraphy - I have observed the oolitic limestone of the Cason in the Batesville district at St. Clair Spring and Love Hollow Quarry. To my knowledge it has not been reported from outcrops west of the district. Maher and Lantz (1952) recorded in the Marshall, Arkansas, water well four feet of oolitic limestone which they included in the base of the St. Clair. These same authors (1953) noted that a similar bed occurs in the St. Clair at St. Clair Spring. It is now known, however, that the oolitic limestone at St. Clair Spring occurs several feet below the base of the St. Clair and is separated from the St. Clair by the Brassfield Limestone. If the oolitic limestone in the Marshall water well and the one at St. Clair Spring are the same, the Marshall occurrence is the only report of this unit to the west.

At St. Clair Spring the oolitic limestone is a light-gray, coarse-grained, fossiliferous (whole macrofossils) pelmatozoan biosparite that grades upward into an oosparite, intrasparite and dismicrite (pl. 4, figs. L, D, F, G). It rests without apparent irregularity on the underlying fine-grained, shelly Fernvale; however, the contact is partially covered and does not persist for any appreciable distance along the outcrop. Association of the oosparite with the above mentioned limestone types indicates that this poorly preserved and little known unit was once more lithically varied within the district.

The Cason at Love Hollow Quarry is difficult to study because it contains a high concentration of iron and manganese oxides that has partially obliterated textures and created exotic color boundaries that are discordant with lithic boundaries. As is true of the underlying phosphatic beds, the oolitic limestone at this locality changes both its form and position along the quarry face as the Cason interval is cut back. It can be as thick as five feet or entirely absent at any one position in the quarry, and as quarrying operations continue it can disappear from where it has been previously observed and appear in a position where its occurrence was not formerly noted. When and where present, it is always between the phosphatic beds below and either the Brassfield Limestone or the "button" shale above. I have visited the quarry several times and have measured a number of Cason sections, each of which are invariably unique in their detail. My knowledge of the interval, therefore, is a composite, as is the graphical representation of the unit accompanying this report (fig. 2). Although I have previously reported (Craig, 1969) briefly on the oolitic limestone at Love Hollow Quarry, a reiteration and expansion of the facts as they are now known is necessary here. The oosparite in the quarry most commonly occurs as a one- to two-foot layer. On one occasion I observed a five-foot layer of the limestone that contained at its base a pelmatozoan biosparite like that at St. Clair Spring. A series of thin sections from this layer shows that the rock begins at its base with a pelmatozoan biosparite in which the fossil fragments have superficial oolitic coatings (pl. 4, fig. E), and grades upward into an oosparite entirely comprised of ooliths with typical oolitic structure and little or no indication of nuclei (pl. 4, fig. H). The gradation appears to be a continuous one in which nuclei become smaller and oolitic coatings become larger.

Occasionally quarrying will expose a section of the Cason where the normal one- to two-foot layer of oosparite undergoes a remarkable thickening over a short distance. Although in cross-section these thickenings appear to be channel fills, the three-dimensional geometry of the bodies is quite unlike what would be expected if this were their true origin. These thickenings were first brought to my attention by the quarry superintendent, who showed me an oosparite with extremely large ooliths (1/8 inch diameter) that he had collected from one of them. On a later occasion I was fortunate in being at the quarry when one of the bodies was exposed in the quarry face (pl. 4, fig. A). It was about five feet across at the top and about five feet thick at its thickest portion. The base of the body descended rapidly so that maximum thickness was obtained about a foot in from the edges of the thickening. Because quarrying was in progress I did not have the opportunity to examine the body in detail. Both oosparite and oomicrite were present, but their relationship was not determined. A layer of oosparite about eight inches thick came into both sides of the body and thickened into the shape just described. The upper margin of the body was parallel to the overlying "button" shale. As the quarry wall was stripped back, the thickened body disappeared, leaving only a thin layer of oosparite in its place (pl. 4, fig. B). These observations suggest that the three dimensional shape of the thickening was more or less hemispherical, and that the body resulted from the filling of a bowl-shaped depression. It is possible, of course, that the body is actually a channel fill, and that its apparent shape resulted from the appearance of a meander in the plane of the quarry face. However, both the shovel operator and quarry superintendent stated that such bodies are exposed periodically in the quarry and that they always disappear after a few shovelfuls of stone. If they are channel fills it seems remarkably fortuitous, if not downright impossible, that their orientation is such that only meanders and never straighter stretches of channel show up in the plane of the quarry face.

I previously reported (Craig, 1969) that the oolitic limestone rests conformably on the underlying phosphatic beds. This opinion was based primarily on the observation that the bedding in the underlying phosphatic shale appeared to conform to the base of the thickened oolitic limestone body just described. However, considering that my observation of the body was extremely limited, essentially between shovelfuls, and further considering the possibility that loading on top of the thickened oolitic body might have caused post-lithification deformation in the underlying shale, I am presently not so strongly inclined toward this conclusion. The main element of my present doubt stems from the nature of the oolitic limestone; it is extremely pure. Examination of several thin sections and acid residues of this rock has failed to disclose a single phosphatic or detrital grain. It is beyond my comprehension that these two units could be in part contemporaneous and yet not include some mixing. There are some spherical phosphate and iron-oxide grains about the size of ooliths in the phosphatic beds, but their internal structure is not typically oolitic. The discovery and study of these two units at new localities, which I believe must certainly exist in the Ordovician of northern Arkansas, will no doubt yield significant information relating to their historical relationship.

Conodonts - The oolitic limestone has produced conodonts from both St. Clair Spring and Love Hollow Quarry. It is a distinctive fauna characterized by low diversity and the small size of its individuals. Most of its members are present in the uppermost Fernvale fauna (fauna 4), which is found at St. Clair Spring and which has been reworked into the phosphatic beds at Love Hollow Quarry; however, it differs markedly from this subjacent assemblage in the absence of that group of species most characteristic of the Fernvale and in the addition of a very few new elements. There is little known about the conodont faunas in this part of the stratigraphic column, but from the information that is available it would seem that the oolitic limestone is approximately the same age as the Girardeau Limestone and Noix Oolite on the northeastern flank of the Ozark Dome. These units have been continuously involved in a boundary dispute, with some workers placing them in the Ordovician System and some in the Silurian. Ulrich considered their macrofauna to be the uppermost Richmond fauna in the United States. The major change in the Ordovician-Silurian conodont succession in northern Arkansas is between the oolitic limestone of the Cason and the overlying Brassfield Limestone. Therefore the oolitic limestone is here considered the youngest Ordovician rock in northern Arkansas. Inasmuch as these ancient faunas really were not knowledgeable of Ordovician and Silurian time, this conclusion is purely a matter of convenience on my part; and whether the oolitic limestone be considered Ordovician or whether it be considered Silurian does not change, of course, the stratigraphic details, which speak for themselves.

GILBERT AREA

I have observed the Cason Shale of the Gilbert area at only two localities; consequently my knowledge of the unit in this part of the outcrop belt is not at all comprehensive. The phosphatic shale designated as Cason in this area most certainly belongs to the basal phosphatic beds and not to the "button" shale, which also possesses a small percentage of phosphatic grains and nodules. My observations of the unit agree with those of Maher and Lantz (1953), who report an average thickness of about fifteen feet for the Cason in this area. The two sections I have examined contain three different kinds of shale. The Gilbert section (fig. 4) has at its base a few feet of black, fissile, silty shale containing large, dense, black phosphate nodules. The microresidue obtained by boiling this shale contains a very small amount of polished, well-rounded phosphatic grains. The section changes abruptly across a thin siltstone bed into a greenish-gray silty shale that is very dolomitic. Phosphate, if it occurs at all in this rock, is not noticeable, and microresidues are devoid of polished grains. The few feet of Cason at the Tomahawk Creek section (fig. 5) is a nearly homogeneous soft, dark-green to maroon, silty shale with large phosphate nodules like those in the Gilbert section. Polished phosphatic grains occur in greater numbers in the Tomahawk Creek Cason than in the fissile shale at Gilbert, but their abundance falls far short of that in the phosphatic beds of the Batesville district.

The Gilbert Cason differs from that in the Batesville district in that it contains very little phosphatic sandstone. The only report of phosphatic sandstone from the western part of the outcrop belt is by Purdue and Miser (1916), who described a section of Cason approximately twenty feet thick from just north of Jasper, Arkansas, which is about twenty-five miles west of Gilbert. The section contained one foot of fossiliferous, phosphatic, conglomeratic sandstone at its base. The fossils were fragmentary and some apparently were imbedded in the phosphatic pebbles of the conglomerate. Above this basal conglomerate was about twenty feet of calcareous shale or argillaceous limestone. The possibility seems strong that the conglomeratic sandstone at Jasper has the same origin as the conglomeratic sandstone in the Batesville district, and that the fossils it contains, all judged to be Ordovician forms by Purdue and Miser, are reworked from below. The upper shale in the Purdue and Miser section, as well as the dolomitic shale reported by Glick and Frezon (1965) from the Snowball area to the west of Gilbert, is similar in description to the shale in the upper part of the Gilbert section.

The presence of polished phosphate grains in the phosphatic shales of the Gilbert Cason suggests the possibility that its conodonts might also be reworked. However, their preservation does not give the appearance of reworking, and as far as now known they do not include the characteristic species of the subjacent Fernvale. In light of this knowledge I consider a reworking hypothesis for this fauna as untenable. The fauna is in essence a modified St. Clair Spring Fernvale fauna (fauna 4), the modification resulting primarily from the absence of species that characterize the greater thickness of the Fernvale.

GILBERT
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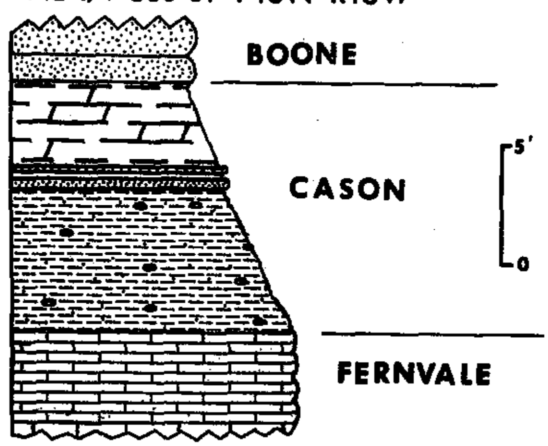


Figure 4. Cason Shale at Gilbert, Arkansas. Outcrop consists of black, fissile phosphatic shale below and greenish-gray dolomitic shale above. Conodont fauna 5 occurs in the lower shale and fauna 6 in the upper one.

The conodont fauna of the dolomitic shale in the upper part of the Gilbert section is comprised of extremely small individuals and is of low diversity. There is little doubt in my mind that the fauna is indigenous. Its composition agrees rather well with that of the oolitic limestone fauna of the Batesville district.

The conodonts from the phosphatic shale of the Gilbert area and those from the Gilbert dolomitic shale and the oolitic limestone of the Batesville district constitute faunas five and six, respectively, of the conodont succession. The phosphatic beds of each region no doubt are nearly correlative, although how they might fit into a regional facies pattern is not clear to me. The same can also be said of the relation between the dolomitic shale and the oolitic limestone.

HISTORICAL SUMMARY

Figure 6 presents the following summary in diagramatic form. The Kimmswick and Fernvale Limestones represent interrupted transgressions that moved over surfaces that had been subaerially exposed and subjected to weathering and erosion. The duration of the lacuna separating the Plattin and Kimmswick was for a portion of Middle Ordovician time and that separating the Kimmswick and Fernvale was for the early portion of Late Ordovician time. Regression preceding each transgression was accompanied by, and possibly to some extent the result of, epeirogenic uplift of the Ozark Dome region. The uplift preceding the deposition of each unit appears to have been greater in the west than in the east of the present outcrop belt as evidenced by the thinning and eventual disappearance in this direction of the units (Plattin and Kimmswick) below each unconformity. The sparse amount of detrital material in each limestone suggests that each transgression took place over a dominantly carbonate terrain. As a result, the initial deposits of each transgression are represented by calcarenites. The conclusion by Young, et al (1972a) that the post- St. Peter sequence of strata in northern Arkansas represents the superposition of in part contemporaneous lithotopes during a single transgression of the sea is indeed provocative. It is possible of course that these strata are the result of one overall transgression. However, in the sections I have examined the details of the Plattin, Kimmswick, and Fernvale do not support the contention that this was an uninterrupted transgression. These units are not gradational in either a continuous or an intercalated sense, and the distinctiveness of their faunas and the features of their contacts seem to defy interpretation within the context of lithotopes following one another directly in time. If the model of an overall but periodically interrupted transgression is valid, the supporting evidence must be sought in the subsurface to the south of the outcrop belt.

The initial deposit of the Kimmswick transgression was a poorly-sorted and poorly washed biosparite in which the range in grain size is directly related to the range in

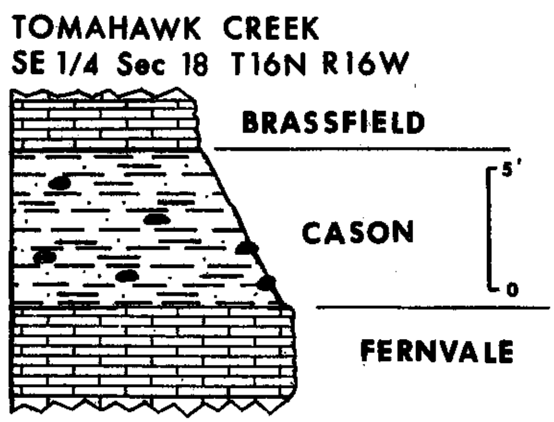


Figure 5. Cason Shale along tributary to Tomahawk Creek north of Gilbert, Arkansas. Outcrop consists entirely of soft, dark-green to maroon mottled shale with large phosphate nodules. The shale contains conodont fauna 5.

size of the skeletal material which comprises it. Randomly oriented skeletal material and irregularly distributed areas of micrite indicate that wave action operating in the environment of deposition was ineffective in overcoming the plowing and burrowing activities of organisms. Layers of better-washed and better-sorted pelmatozoan biosparite similar to that in the overlying Fernvale occur in a haphazard fashion from section to section. They are probably related to conditions of higher wave energy that were restricted in time and space, and possibly also bear some relationship to the attached echinoderm communities that provided the major portion of their grains. The change upward of the Kimmswick into a thoroughly-burrowed biomicrite and poorly-washed biosparite is the only distinct lithic trend in the Kimmswick; this trend is interpreted as representing an increasing water depth that accompanied the transgression. Above this, knowledge of Kimmswick deposition is cut short by the occurrence of the transgressive deposit represented by the Fernvale Limestone.

Fernvale deposition differs from that of the Kimmswick primarily in being marked by conditions of wave energy that were more persistent through time and of broader geographic impress. Also, faunal diversity over most of the Fernvale seafloor was considerably less than that over the Kimmswick seafloor. As a result of these differences, the Fernvale is a better-sorted limestone in which skeletal parts of attached echinoderms comprise the greater percentage of the grains. The Kimmswick possesses grains as large as the Fernvale, and at certain times in certain places wave energy persisted long enough to produce sediment types that mimic the Fernvale lithology. For the most part, however, coarse Kimmswick grains are included in a heterogeneous mixture of fossil "trash" that has been mixed and fragmented by biologic activity. On the other hand, the bulk of the Fernvale appears to have been deposited under conditions somewhat inhospitable to benthonic animals that require a stable substrate or that live off organic-rich muds.

Very few animals were plowing through Fernvale sediment looking for sustenance. The initial deposits of the Fernvale do include some whole skeletons of stable substrate animals such as corals and brachiopods. The presence of these animals is probably related to the solid footing provided by the underlying Kimmswick and to lower near-shore energy conditions as compared to those just off-shore during Fernvale deposition. The greater portion of the Fernvale appears to have been deposited as a shallow-water pelmatozoan sand that migrated across the shelf region in the form of subaqueous dunes. The upward decrease in textural maturity and grain size and increase in shell material in the Fernvale represents increasing water depth that accompanied continued transgression. As with the Kimmswick, further knowledge of Fernvale sedimentation is cut short by the unconformity bounding its upper surface.

The distinctive conodont fauna (fauna 1) that inhabited the sea during the deposition of the Kimmswick did not return in full strength with the Fernvale transgression. Instead, a quite differently constituted fauna (fauna 2), which contains only a token amount of characteristic Kimmswick species, is found in the lower half of the Fernvale. The reason for this is unknown. The difference in the faunas does not seem to stem from a difference in a depositional environment of the two formations; certainly the two units are not significantly unlike in this respect. Nor is it because members of the Kimmswick fauna are near extinction and in the process of being replaced because they recur with all their former vigor higher in the Fernvale. Possibly Ulrich's (1911) opinion that the Kimmswick and Fernvale faunas (he was talking about macrofossils) originated from different ocean basins is true. This would suggest the following sequence of events for the Fernvale conodont succession: The Fernvale transgression brought in a fauna whose geographic origin was different from that of the Kimmswick. The few individuals of characteristic Kimmswick species in this fauna (Fauna 2) persisted through part of the deposition of the Fernvale and then became extinct in the area leaving only the characteristic Fernvale forms (Fauna 3). As transgression continued connection was made with the geographic area that was "home" for the characteristic Kimmswick species, which then migrated into the region that is now northern Arkansas and mixed with characteristic Fernvale species to form the uppermost Fernvale fauna (Fauna 4). Bergstrom and Sweet (1966) have suggested a somewhat different model for conodont distributions that is similar to this one in that it involves the concept of geographic regions characterized by particular assemblages of species which periodically migrate outward to invade other areas.

Sometime after the invasion into the area of the characteristic Kimmswick species regression once again exposed the region to subaerial erosion. Either during this time or just before it some of the carbonate material in the Fernvale was replaced by phosphate. Subsequent transgression deposited the Cason Shale, which includes in it reworked phosphate grains from the Fernvale below. During the time of regression several species that characterized the bulk of the Fernvale fauna disappeared from the northern Arkansas region and thus did not accompany the Cason transgression. In the Batesville district these forms are found in the phosphatic sandstone and shale of the Cason, but their preservation and the associated features of their occurrence indicate that they are reworked from the uppermost Fernvale (Fauna 4). In the Gilbert region, large scale reworking of grains from below into the Cason is not indicated, and the phosphatic shale of this western area is judged to carry the conodont fauna indigenous to the Cason transgression (Fauna 5).

The phosphatic beds of the Cason were more or less directly followed, but apparently not intermixed with, deposits of oolitic limestone, dismicrite, and intrasparite in the east of the present outcrop belt and silty, dolomitic shale in the west. These beds contain the uppermost Ordovician fauna in northern Arkansas (Fauna 6).

The temporal and paleogeographic relationships of the different rock types belonging to the Ordovician portion of the Cason Shale are not completely understood. Although much of the unit has been removed by pre-Silurian erosion, there is, no doubt, enough preserved to provide a greater understanding than we now possess of the details of the geologic history of its deposition.

THE CONODONT FAUNAS

The following presents the major composition of each of the conodont faunas discussed in the text. All names are those of disjunct taxonomy.

FAUNA 1 - Kimmswick Limestone: A typical Midcontinent fauna of which ninety percent belongs to the following species listed in their order of decreasing abundance: Phragmodus undatus, Oistodus abundans, Panderodus gracilis, Drepanodus homocurvatus, Cordylodus delicatus, Dichognathus brevis, D. typica, Distacodus falcatus, Panderodus feulneri, P. cf. P. panderi, Ozarkodina concinna, Cordylodus flexuosus, Aphelognathus polita (and A. abrupta), Oistodus inclinatus, and Zygognathus mira.

FAUNA 2 - Lower Fernvale: Dominantly a Mississippi Valley fauna with similarities to the faunas of the Cape Limestone and Maquoketa Shale. Ninety percent belongs to the following species listed in their order of decreasing abundance: Ozarkodina inclinata, a new species of Panderodus with deep lateral sulci, P. gracilis, Drepanodus homocurvatus, Panderodus panderi senso stricto, Panderodus simplex, Belodina inclinata, Belodina ornata, Cordylodus flexuosus, C. delicatus, Prioniodina furcata, Belodina produnda, Ambalodus triangularis, and fragments of Amorphognathus ordovicica. Also present are rare specimens of species that are characteristic of the Kimmswick. These are Phragmodus undatus, Oistodus abundans, Dichognathus typica, D. brevis, Distacodus falcatus, and Panderodus cf. P. panderi, which comprise fifty percent of the Kimmswick fauna, but only two percent of the Fernvale fauna.

FAUNA 3 - Upper Fernvale: A modified lower Fernvale fauna dominated almost entirely by the species of Belodina and Panderodus found in fauna 2. Also present are Ambalodus triangularis, Amorphognathus ordovicica, Drepanodus homocurvatus, D. suberectus, and Oistodus inclinatus. All others listed for the fauna 2 are absent.

FAUNA 4 - Uppermost Fernvale (found in the Fernvale at St. Clair Spring and reworked into the phosphatic beds of the Cason): This fauna is basically an upper Fernvale fauna (fauna 3) mixed with, and for the most part overshadowed by, species that have their greatest abundances in the Kimmswick and/or the lower Fernvale fauna. Those Kimmswick and lower Fernvale recurring species figuring strongly in this fauna are Phragmodus undatus, Zygognathus mira, Dichognathus typica, D. brevis, Ozarkodina concinna, Cordylodus delicatus, C. flexuosus, Oistodus abundans, Prioniodina furcata, the Keislognathus group, and certain species of Trichonodella, the most notable being T. tenuis. Also important to this fauna are two species that occur rarely in lower faunas, Acodus unicostatus and and Scolopodus insculptus. The latter has the development of the posterior oral cusp that caused Branson and Mehl to originally place it in Phragmodus. Three other species in this fauna apparently occur in the northern Arkansas succession for the first time. These are a species of Carniodus (Carniodus sp. of Walliser's Bereich I), Acodus similaris (probably a Panderodus), and a species of Oistodus whose cusp and base are nearly parallel and of equal length. These forms are notable in that they are important constituents of higher faunas.

FAUNA 5 - Phosphatic shale of the Cason in the Gilbert area: This fauna is basically a modified fauna 4 that has lost the characteristic Fernvale species of Belodina and Panderodus. Characteristic species are Scolopodus insculptus, Walliser's Carniodus sp., the "parallel" Oistodus, Ambalodus triangularis, Acodus homocurvatus, Amorphognathus ordovicica, members of the Keislognathus group, Ozarkodina concinna, Trichonodella tenuis, Cordylodus delicatus, C. flexuosus, Prioniodina furcata, Drepanodus homocurvatus, Phragmodus undatus, Zygognathus mira, and some unnamed forms. In many respects this fauna is close to that of the British Keisley Limestone.

FAUNA 6 - The Cason dolomitic shale of the Gilbert area and the oolitic limestone of the Batesville district: At present this low diversity fauna is poorly known. Its individuals are extremely small and difficult to work with. It differs from fauna 5 by the apparent absence of some species plus the addition of a few others. Notable among the additions are Keislognathus group species with widely spaced denticles, and a form closely related to Ambalodus triangularis (Prioniodina girardeauensis). Carrying over from below are Carniodus sp., the "parallel" Oistodus, Cordylodus delicatus, C. flexuosus, Ozarkodina concinna, Drepanodus homocurvatus, Amorphognathus ordovicica, Zygognathus mira, and Trichonodella tenuis.

EXPLANATION OF PLATE 1

(All figures are negative prints of acetate peels of the Kimmswick Limestone)

Figure A. Section MC, X7.2. Stylolitic contact between fine-grained pelmatozoan biosparite (below) and coarse-grained pelmatozoan biosparite. Stylolite marked by arrows.

Figure B. Section WLC, X5. Poorly-washed, poorly-sorted, fine- to coarse-grained mixed biosparite containing skeletal material of pelmatozoans, brachiopods, trilobites, corals, and bryozoans. This rock type is with biomicrite of Figures C, E, and F.

Figure C. Section MQ, X5. Mixed biomicrite with random orientation of skeletal grains and "churned" appearance that indicates activity of burrowing organisms. Matrix grains are larger than true micrite (4 microns or less), but too small to be identified as to origin. They are either recrystallized from chemically precipitated lime mud or the product of the attrition of larger skeletal parts by biologic activity, or both. This rock type is found throughout the Kimmswick but is most characteristic of the upper layers. This is the rock most commonly found directly beneath the Fernvale.

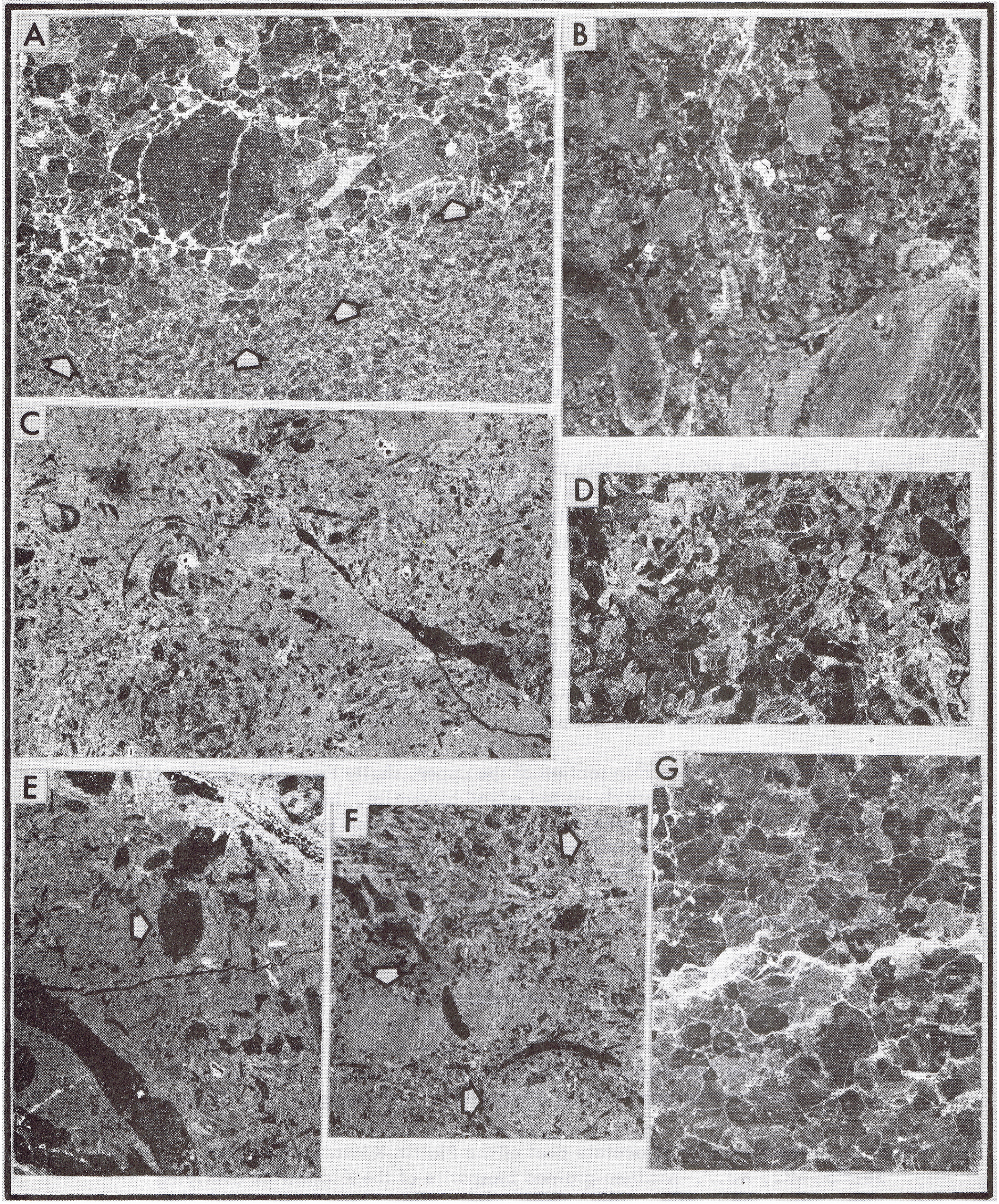
Figure D. Section WLC, X5. Coarse-grained pelmatozoan biosparite with accessory skeletal fragments of other animals. This reasonably well-sorted rock type, along with that illustrated in Figure G, are closely comparable to the Fernvale in composition and texture. Compare with the Fernvale illustrated on Plate 2, Figure C. All gradations occur between this rock type and the poorly-sorted mixed biosparite of Figure B. Most Kimmswick well-sorted biosparites are confined to the lower and middle portions of the unit.

Figure E. Section WQ, X5. Mixed biomicrite. Arrow points to dark patch that apparently represents a burrow filled with sparry calcite.

Figure F. Section WLC, X5. Mixed biomicrite. Random grain orientation and poor sorting indicates burrowing. Micrite patches devoid of skeletal fragments (arrows) were probably made by burrowing animals.

Figure G. Section MCC, X5. Well-sorted pelmatozoan biosparite devoid of accessory skeletal material. See Figure D for comparison.

PLATE 1



EXPLANATION OF PLATE 2

Figure A. Photomicrograph of the Fernvale, Section SCS, X12.5. Fine-grained mixed biosparite. Large dark area is a portion of limestone that has been phosphatized. These phosphatized grains and larger areas of the Fernvale were later reworked into the phosphatic sandstone and shale of the overlying Cason. Note the high percentage of shell material and the comparatively small (for the Fernvale) grain size, both of which are features characteristic of the uppermost layers of the unit in the Batesville district.

Figure B. Negative print of acetate peel of the Fernvale, Section LQ, X5. Pelmatozoan biosparite with a high percentage of coral characteristic of the lower layers of Fernvale at some localities in the western portion of the Batesville district.

Figure C. Negative print of acetate peel of the Fernvale, Section MQ, X5. Pelmatozoan biosparite with some shell material. Sorting and alignment of shell material indicates accumulation under influence of persistent wave action. This is near minimum grain size for the pelmatozoan biosparite of the Fernvale.

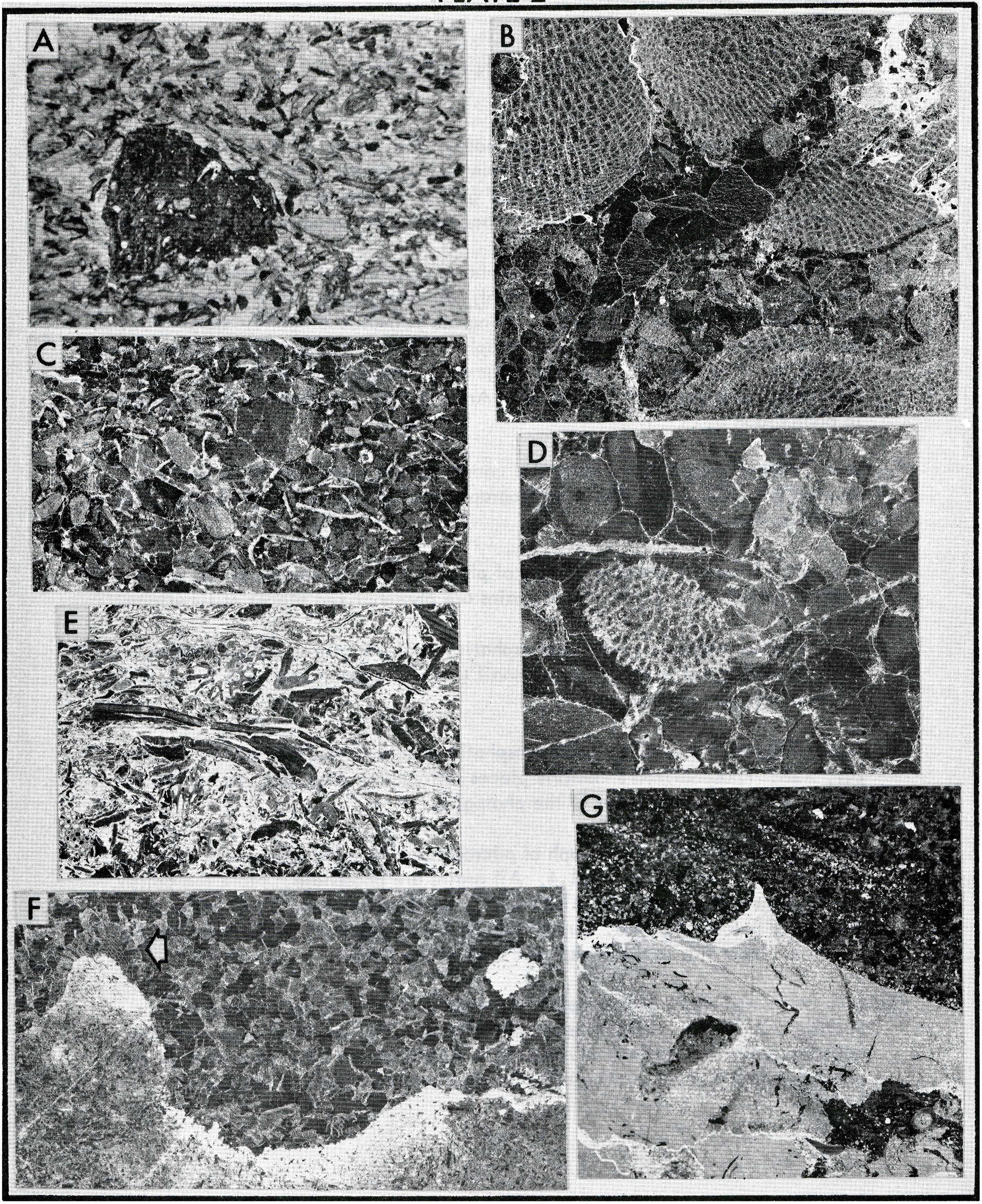
Figure D. Negative print of acetate peel of the Fernvale, Section LQ, X5. Very coarse-grained pelmatozoan biosparite. This is about maximum grain size for the Fernvale. Layers of this very coarse-grained biosparite occur throughout the lower and middle Fernvale. They contain very little skeletal material other than pelmatozoan parts. Compare with Figure C.

Figure E. Negative print of thin section of the upper, shelly Fernvale, Section LQ, X4.8. Poorly-washed, poorly-sorted mixed biosparite. Note the high percentage of shell material and fine-grained matrix (which is light colored on this negative print). Acid residues indicate that most of the fine-grained material is detrital mud, although lime mud is probably present also. Rock in which shell material dominates over pelmatozoan parts is characteristic of the upper portion of the Fernvale in the Batesville district.

Figure F. Negative print of acetate peel of the Kimmswick-Fernvale contact, Section MQ, X5. Coarse-grained pelmatozoan biosparite of the Fernvale overlying mixed biomicrite of the Kimmswick. Note the coral (arrow) encrusting a "micro-pinnacle" of the irregular upper surface of the Kimmswick. This and Figure G are the "petrographic" unconformities of Freeman. For a discussion of their interpretation see Freeman (1966a, 1972) and Young, *et al.* (1972a, b).

Figure G. Negative print of acetate peel of the Plattin-Kimmswick contact, Section MQ, X3.7. Medium-grained biosparite of the Kimmswick overlying dismicrite of the Plattin. Dark patches within Plattin are of Kimmswick lithic type. White-rimmed grains in the Kimmswick are quartz sand, which is common in the base of the Kimmswick at this locality and section WLC. For further discussion see Figure F.

PLATE 2



EXPLANATION OF PLATE 3

Figure A. Photomicrograph of phosphatic shale of the Cason, Section LQ, X11.8. Grains are quartz, phosphate replacement of carbonate, glauconite, and phosphatic brachiopods. Elliptical patch of grains that apparently accumulated in a low spot on the mud depositional surface occurs in the center of the photograph.

Figures B and C. Photomicrographs of phosphatic conglomeratic sandstone of the Cason, Section LQ, X28. B) unpolarized light; lath-like grains are phosphatic brachiopods and grains of rounded outline are pelmatozoan parts. Large grain truncated by the bottom of the photograph is a phosphatized piece of fine-grained limestone. Arrow points to a large fragment of phosphatic brachiopod. C) polarized light; dark grains are phosphate. Arrow points to phosphatic brachiopod shell in photograph B.

Figure D. Photomicrograph of phosphatic conglomeratic sandstone of the Cason, Section LQ, X28. Left side of photograph shows a large piece of phosphatized limestone with clam.

Figure E. Negative print of thin section of phosphatic conglomerate sandstone of the Cason, Section LQ, X1.7. Large grains are phosphatized pieces of limestone.

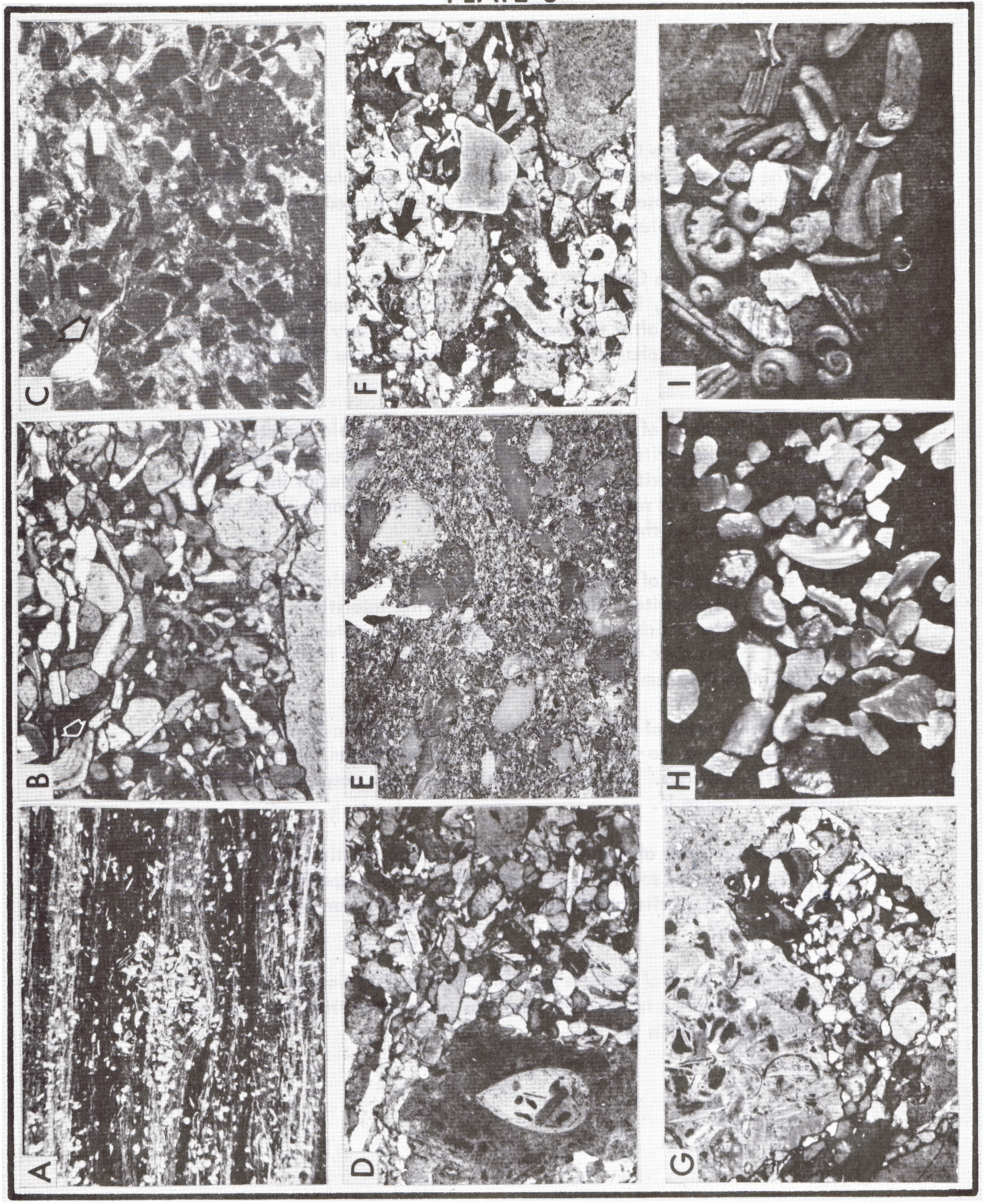
Figure F. Photomicrograph of Cason phosphatic conglomeratic sandstone, Section LQ, X28. Arrows point to phosphatized snail (lower), pelmatozoan part (center) and oolitoid objects (upper).

Figure G. Photomicrograph of Cason phosphatic conglomeratic sandstone, Section LQ, X28. Phosphatized limestone pieces surrounding sand-size grains. Note the snail in the lower center of the photograph.

Figure H. Reflected-light photograph of microresidue from the phosphatic shale of the Cason, Section LQ, X31.4. All grains are phosphate. Note the polish and roundness of the grains. Also note the abraded appearance of the large conodont, Belodina ornata, center right in the photograph. This is the typical aspect of the grains in the phosphatic beds of the Cason.

Figure I. Reflected-light photograph of microresidue from the uppermost Fernvale, Section LQ, X12.5. All grains are phosphate. Compare polish and roundness with the grains in Figure H. Grains like these apparently became rounded and polished when they were reworked into the phosphatic beds of the Cason.

PLATE 3



EXPLANATION OF PLATE 4

Figure A. Oosparite of the Cason at Love Hollow Quarry. The white rock in front of the shovel is the bowl-shaped thickening described in the text. Arrows indicate the base of the oosparite as it is followed toward the shovel from the right of the picture.

Figure B. Oosparite of the Cason at Love Hollow Quarry. Light-colored layer (about one foot thick), indicated by arrow, is all that remained of the thickening (Figure A) after the shovel had cut the quarry face back. Dark rock below is the phosphatic shale and rock above is the Silurian "button" shale.

Figure C. Negative print of acetate peel of the Cason oolitic limestone, Section SCS, X6.6. Intrasparite overlain by dismicrite. Dismicrite is probably of algal origin. Intrasparite might represent algal mat material that has been torn up, rounded, and redeposited. Dismicrite, intrasparite, and oosparite are all gradational at the SCS Section.

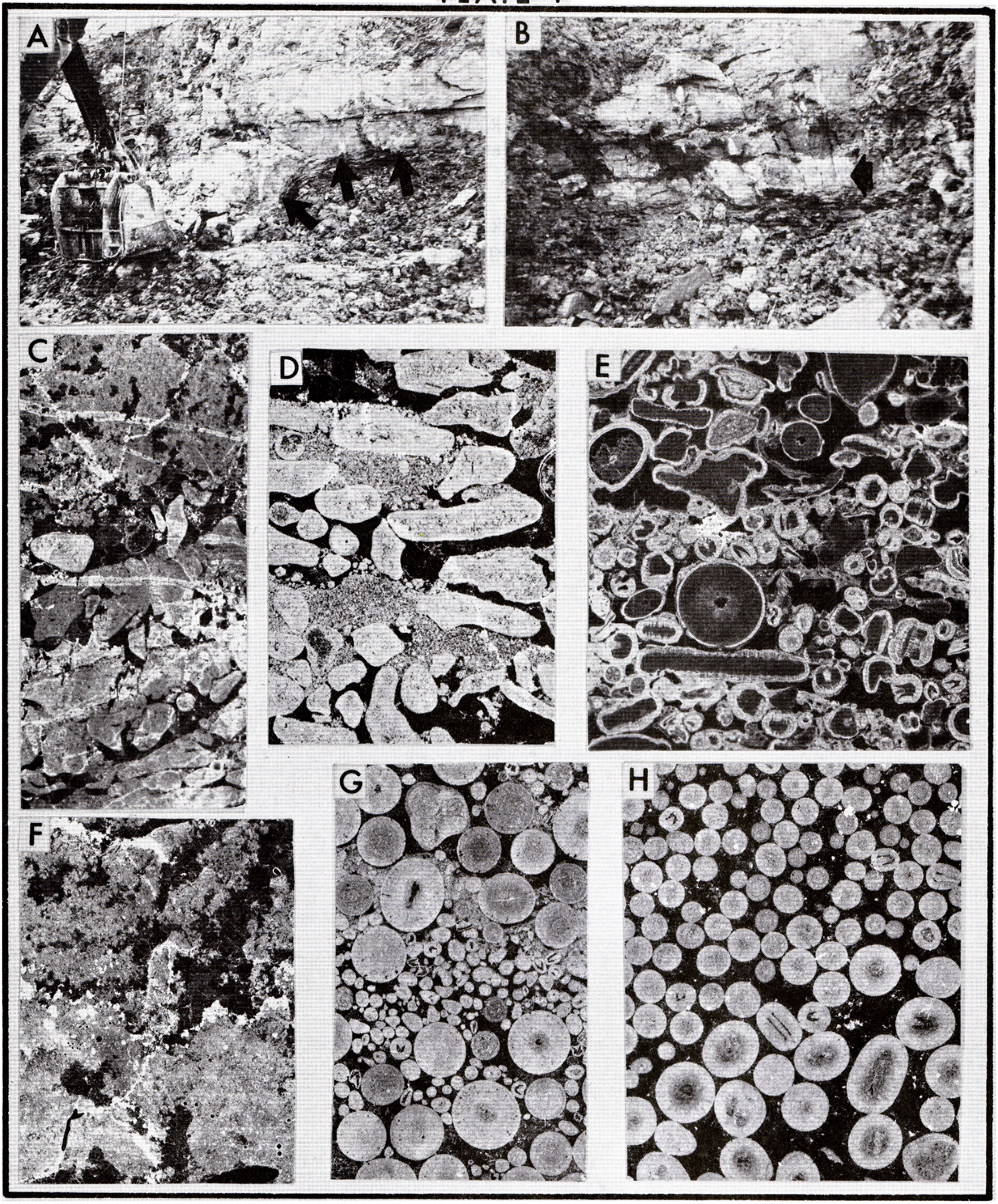
Figure D. Negative print of acetate peel of the Cason oolitic limestone, Section SCS, X6.6. Intrasparite. Finer material flooring interstices probably filtered down from overlying algal mat deposit (dismicrite). A few ooliths are present in this rock type. Texture of the intraclasts is similar to that of the sediment of the dismicrite.

Figure E. Negative print of thin section of the Cason oolitic limestone, Section LQ, X6.6. Coarse- to very coarse-grained pelmatozoan biosparite with superficial oolitic coatings. This rock grades upward into oosparite like that illustrated in Figure H.

Figure G. Negative print of acetate peel of the Cason oolitic limestone, Section SCS, X6.6. Bimodal sorting is characteristic of the oosparite at this locality. The base of the oosparite at this locality is a pelmatozoan biosparite just as at Section LQ.

Figure H. Negative print of acetate peel of Cason oolitic limestone, Section LQ, X6.6. Specimen from which peel was made came from the bowl-shaped thickening described in the text.

PLATE 4



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STRATIGRAPHIC RELATIONSHIPS BETWEEN THE BLOYD AND ATOKA FORMATIONS (PENNSYLVANIAN) OF NORTHERN ARKANSAS

Doy L. Zachry 1/
Boyd R. Haley 2/

ABSTRACT

Recent geologic mapping indicates that the Bloyd-Atoka boundary to the east of Washington County is not correctly located on the Geologic Map of Arkansas published in 1929. In Madison County and to the east the boundary as shown on the 1929 map was placed at the base of a quartz pebble-bearing sandstone unit -- a unit that is within the Bloyd Formation and below the Bloyd-Atoka boundary, as defined and mapped by Purdue in 1907, in the Winslow quadrangle of Washington County.

INTRODUCTION

The contact of the Bloyd Formation and the overlying Atoka Formation is a useful and significant mapping horizon within the Pennsylvanian strata of northern Arkansas. It is exposed on the northern flank of the Boston Mountains and can be traced eastward from the Oklahoma-Arkansas border to the Mississippi Embayment. Mapping by many workers along the outcropping contact served as a basis for the Bloyd-Atoka boundary shown on the Geologic Map of Arkansas published in 1929.

In preparing a new geologic map of Arkansas the Bloyd-Atoka contact was examined in previously unmapped areas. This investigation provided conclusive evidence that the Bloyd-Atoka boundary depicted on the 1929 State Geologic Map and used by many workers subsequent to 1929 east of Washington County is stratigraphically well below the boundary designated at the type locality of the Bloyd in the Washington County area.

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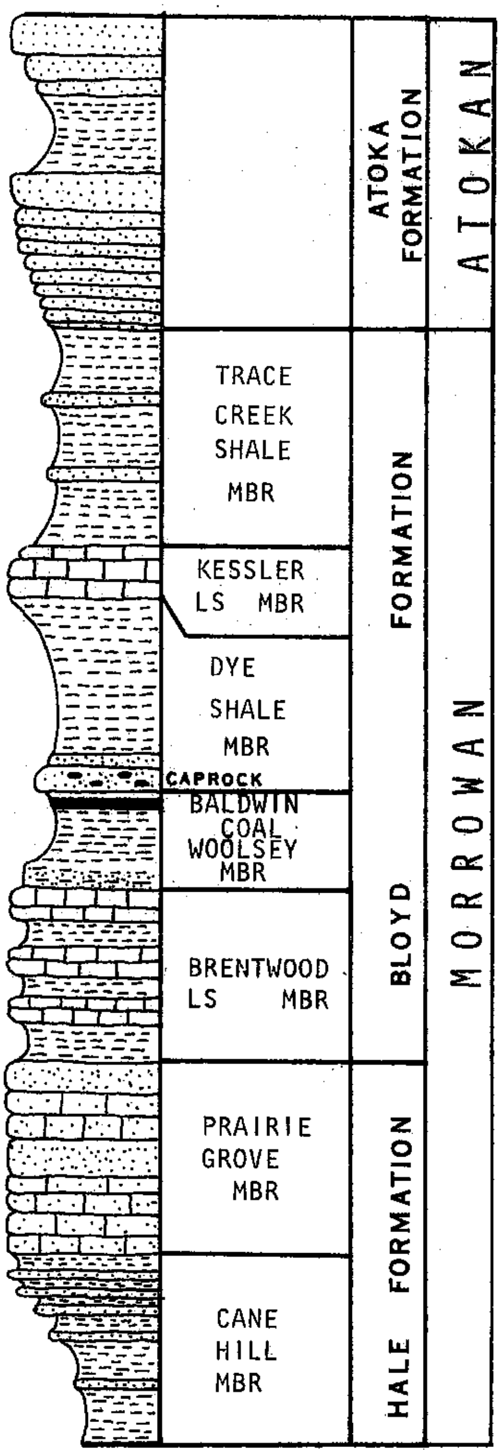
Figure 1.--Generalized stratigraphic succession of Pennsylvanian formations and members in Washington County, Arkansas.



Pennsylvanian strata in northern Arkansas are assigned to, from older to younger, the Hale, Bloyd, and Atoka Formations (fig. 1). This sedimentary sequence is composed of numerous and repetitive units of sandstone, siltstone, shale and limestone. Members within the sequence display lateral variations in lithic properties and are not easily identified and mapped on a regional scale.

MORROWAN SERIES

The Hale and Bloyd Formations (fig. 2) belong to the Morrowan Series; the type localities of the Hale, Bloyd, and Morrowan area in Washington County, Arkansas. Strata of the Hale and Bloyd crop out in an east-trending belt on the northern flank of the Boston Mountains. They are also locally exposed in deep, south-draining stream valleys on the southern flank of the mountains (Arkansas Geological Survey, 1929).

Henbest (1953, 1962a) divided the Hale Formation into the Cane Hill and the overlying Prairie Grove Members (fig. 1). The Cane Hill Member is composed dominantly of shale and silty shale. It contains many beds of very fine to fine-grained sandstone. The Prairie Grove Member is composed of more massive beds of sandstone, calcareous sandstone, and limestone.

In Washington County the Bloyd Formation has been divided into five members (Simonds, 1891; Henbest, 1962a). The vertical succession of these members (fig. 1) is important to the Bloyd-Atoka boundary as a mapping horizon, and to the problem about it east of Washington County. Two shale members, the Dye and Trace Creek, were not named until 1962 (Henbest, 1962b).

The Brentwood Limestone Member of the Bloyd Formation is a sequence of limestone and shale units resting on the Hale Formation. It is overlain throughout much of Washington County by a thin unit of primarily siltstone and shale named the Woolsey Member. The Woolsey commonly includes, near the top of the member, a thin coal seam called the Baldwin coal.

Unconformably overlying the Woolsey Member is the Dye Shale Member, which is composed dominantly of black to gray shale. The basal unit of the Dye is a thin conglomeratic sandstone or sandy limestone called caprock that commonly overlies the

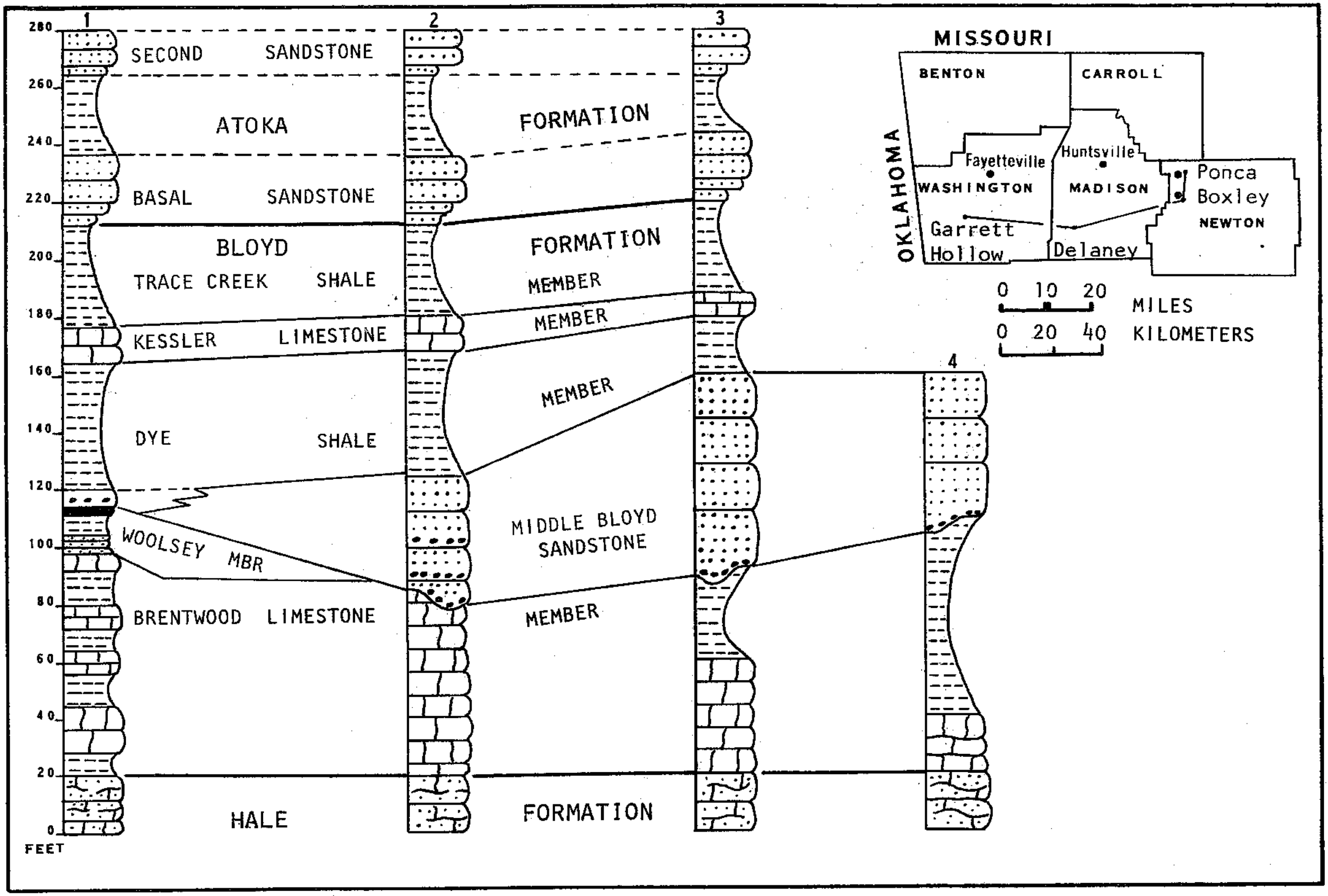


Figure 2.--Generalized stratigraphic sections depicting the major lithic units within the Bloyd and Atoka Formations in Washington, Madison, and Newton Counties, Arkansas.

Baldwin coal. This unit is not present everywhere in Washington County and at some localities is separated from the coal by several feet of shale. This basal unit of the Dye is of particular importance to the recognition of Bloyd-Atoka boundary problem.

The Dye Shale Member is overlain by the Kessler Limestone Member, a thin, fairly persistent carbonate unit in northwestern Arkansas (fig. 1). Overlying the Kessler and underlying the Atoka Formation is the Trace Creek Shale Member of the Bloyd Formation. It is composed primarily of shale with thin beds of siltstone and very fine-grained sandstone. The sandstone beds are thicker and more abundant near the top of the member.

ATOKA FORMATION

The Atoka Formation is a succession of sandstone, siltstone and shale units that overlie the Bloyd Formation. Its base is generally described as the base of the lowest continuous sandstone unit above the Kessler Limestone Member (fig. 1). Strata of the Atoka Formation form the surface rocks in most of the Boston Mountains region and in part of the Arkansas Valley region to the south. The formation is overlain in the Arkansas Valley by the Hartshorne Sandstone.

DEFINITION OF THE BLOYD-ATOKA BOUNDARY WINSLOW QUADRANGLE, WASHINGTON COUNTY

The name Atoka Formation was introduced by Taff and Adams (1900) in a report concerning the Eastern Choctaw coal field of southeastern Oklahoma. They applied the name to a thick succession of sandstone and shale units that underlies the Hartshorne Sandstone.

In northwestern Arkansas, the sedimentary rocks above the Bloyd Formation were first investigated by Owen (1858). He referred to these strata as the Millstone grit. Simonds (1891), in a later description of the geology of Washington County, accepted Owen's terminology and applied the name Millstone grit to a similar sequence. The name Winslow Formation, derived from a town in Washington County, was introduced by Adams (1904) to replace the name Millstone grit of Owen and Simonds. In 1907, Purdue further described the Winslow Formation and the Bloyd-Winslow boundary by detailed mapping in the Winslow quadrangle of southern Washington and northern Crawford Counties.

In 1930, Croneis equated the Atoka Formation of Taff and Adams (1900) with the later-named Winslow Formation of Adams (1904) and Purdue (1907), and suggested that the older name Atoka should be applied in northern Arkansas to the sedimentary rocks overlying the Bloyd Formation. This suggestion was accepted by most of the geologists that were concerned with these strata. The name Winslow has been abandoned. It is the original definition of the Bloyd-Atoka boundary (formerly Bloyd-Winslow boundary) as established by Purdue (1907) in southern Washington County that should be adhered to when mapping Pennsylvanian strata in parts of the State east of Washington County.

REVISION OF THE BLOYD-ATOKA BOUNDARY EAST OF WASHINGTON COUNTY

In Washington County and within the Winslow quadrangle (fig. 2) the first continuous sandstone unit above the Hale Formation rests on the Trace Creek Shale Member of the Bloyd Formation and is the basal unit of the Atoka. In this part of western Arkansas, the Bloyd is approximately 200 feet thick. In Madison County, adjacent to Washington County, the first continuous sandstone unit above the Hale rests unconformably on the Brentwood Member of the Bloyd. It ranges from 30 to 100 feet in thickness and contains abundant quartz pebbles. This sandstone unit thickens to the east and extends eastward to the Mississippi Embayment. Purdue and Miser (1916), when investigating the strata in Madison County, assumed that this unit was the basal sandstone of the Atoka Formation. The lateral change in the lithology of the Bloyd from the sequence of Washington County (Henbest, 1926b) to the pebble-bearing sandstone of Madison and Newton Counties can be examined in southern Madison County. This area was not mapped in detail prior to 1970, and thus no direct physical link was recognized between the strata of Washington County and those farther east that comprise three-quarters of the Bloyd-Atoka outcrop belt. Detailed mapping of this intermediate area during the summer and fall of 1970 and 1971 demonstrated that the quartz pebble-bearing sandstone unit assigned to the Atoka by Purdue and Miser (1916) lies beneath a limestone that resembles the Kessler Limestone Member of Washington County (fig. 2). The mapping also demonstrated that the basal sandstone unit of the Atoka of the Winslow quadrangle is stratigraphically above this limestone and above the quartz pebble-bearing sandstone.

The thick quartz-pebble-bearing sandstone unit of Madison County is not correlative with the basal sandstone of the Atoka Formation to the west, but represents extensive sandstone development in the middle and lower part of the Bloyd Formation throughout the eastern three-quarters of the outcrop belt. The middle sandstone thins abruptly to the west and can be correlated with the thin, discontinuous caprock of the Dye Shale Member in Washington County (fig. 2). Its continuity with the caprock has not been confirmed, because the Woolsey Member and the associated Baldwin coal are absent where the sandstone is well developed. The basal sandstone unit of the Atoka Formation can be mapped eastward from Washington County and its base is the Bloyd-Atoka boundary in northern Arkansas.

The stratigraphic correlations established during the 1970-71 mapping were in part recognized in 1888. Gilbert Harris, in a short contribution to the Arkansas Geological Survey Annual Report of 1888, (p. 149-154) investigated the area between Fayetteville, in Washington County, and Huntsville, in Madison County. He recognized a false Millstone grit (basal Atoka of this report) and a Millstone grit proper (middle Bloyd sandstone of this report). He noted that the sandstone overlying the Baldwin coal (caprock of Henbest) in the Fayetteville area was the representative of the Millstone grit proper in the Huntsville area (fig. 3). His observations and conclusions were not recognized for 86 years inasmuch as his false Millstone grit at Fayetteville became the Atoka of the western part of the outcrop belt, and his Millstone grit proper became the Atoka of the eastern part of the outcrop belt.

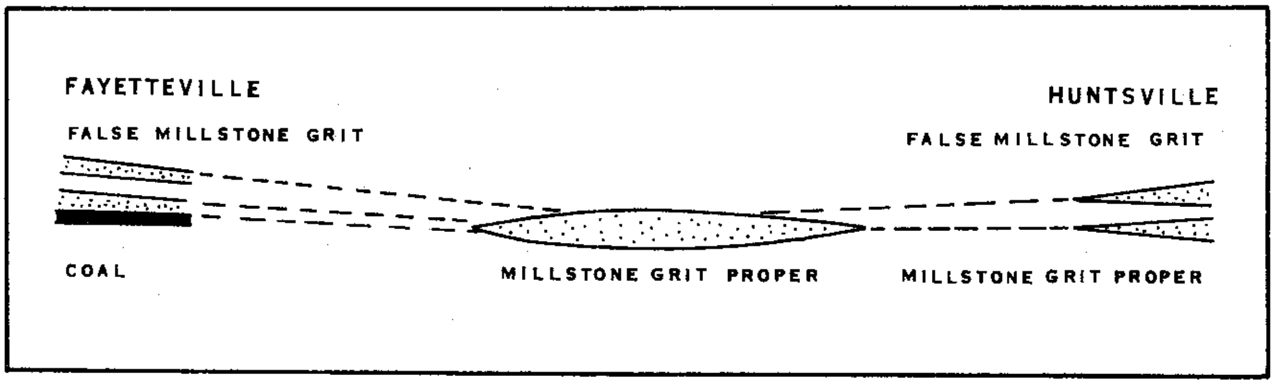


Figure 3.--Stratigraphic relationships among sandstone units now referred to the Bloyd and Atoka Formations between Fayetteville and Huntsville, Arkansas (Harris, 1891, p. 153).

The lower contacts of the middle sandstone of the Bloyd and the basal sandstone of the Atoka are different. The middle sandstone of the Bloyd has not been recognized in Washington County but may be represented by the sandy and conglomeratic caprock of the Baldwin coal. In western Madison County (fig. 2), the middle sandstone overlies a limestone unit of the Brentwood Member. Its lower contact is a conspicuous unconformity manifested by the channeled and irregular upper surface of the underlying limestone. Locally, blocks of the limestone are incorporated within the overlying sandstone unit. Farther east near Boxley in Newton County (fig. 2), the middle sandstone of the Bloyd rests on shale of the Brentwood Member. At this locality the middle sandstone is more than 100 feet thick. The unit is also thick near Ponca, in Newton County, and rests unconformably on shale of the Bloyd (fig. 2).

In contrast, the basal sandstone of the Atoka grades into the underlying Trace Creek Member of the Bloyd Formation. The Trace Creek locally contains many thin beds of sandstone intercalated with shale. The sandstone beds are thicker and more abundant near the top of the member and are succeeded by more massive but similar beds in the Atoka. No evidence of an unconformity was observed.

In petrographic characteristics and sedimentary structures the middle sandstone of the Bloyd and the basal sandstone of the Atoka are substantially different. The middle sandstone of the Bloyd has a sharp lower boundary at its base and thick beds directly above the boundary. It is composed of medium-grained sandstone and contains abundant, well-rounded pebbles of vein quartz. Large-scale, tabular, cross-stratified sets comprise approximately 60 percent of the unit. The sets range from 1 to 4 feet in thickness. They are commonly underlain by thin beds of quartz-pebble conglomerate and overlain by a thin unit of ripple-laminated sandstone. The cross-stratified sets may be partially truncated by channel fills of coarse sandstone and conglomerate. No grain-size trend was noted in vertical sections through the unit. Paleocurrent measurements throughout Madison County indicate that the sand and gravel was emplaced by competent, unidirectional currents that flowed in a southerly direction.

The basal sandstone of the Atoka Formation is characterized by upward coarsening grain size. Thin beds at the base of the Atoka and within the upper part of the underlying Trace Creek Member are composed of siltstone and very fine sandstone. They contain many ripple laminations and burrows. These thin beds grade upward into thick beds of fine-grained sandstone that contain horizontal laminations or appear structureless. Either one or several cycles of coarsening may be present within the basal Atoka unit. Large-scale cross-stratification, quartz pebbles, and medium to coarse sand that characterize the middle sandstone of the Bloyd occur only rarely in the basal sandstone of the Atoka Formation.

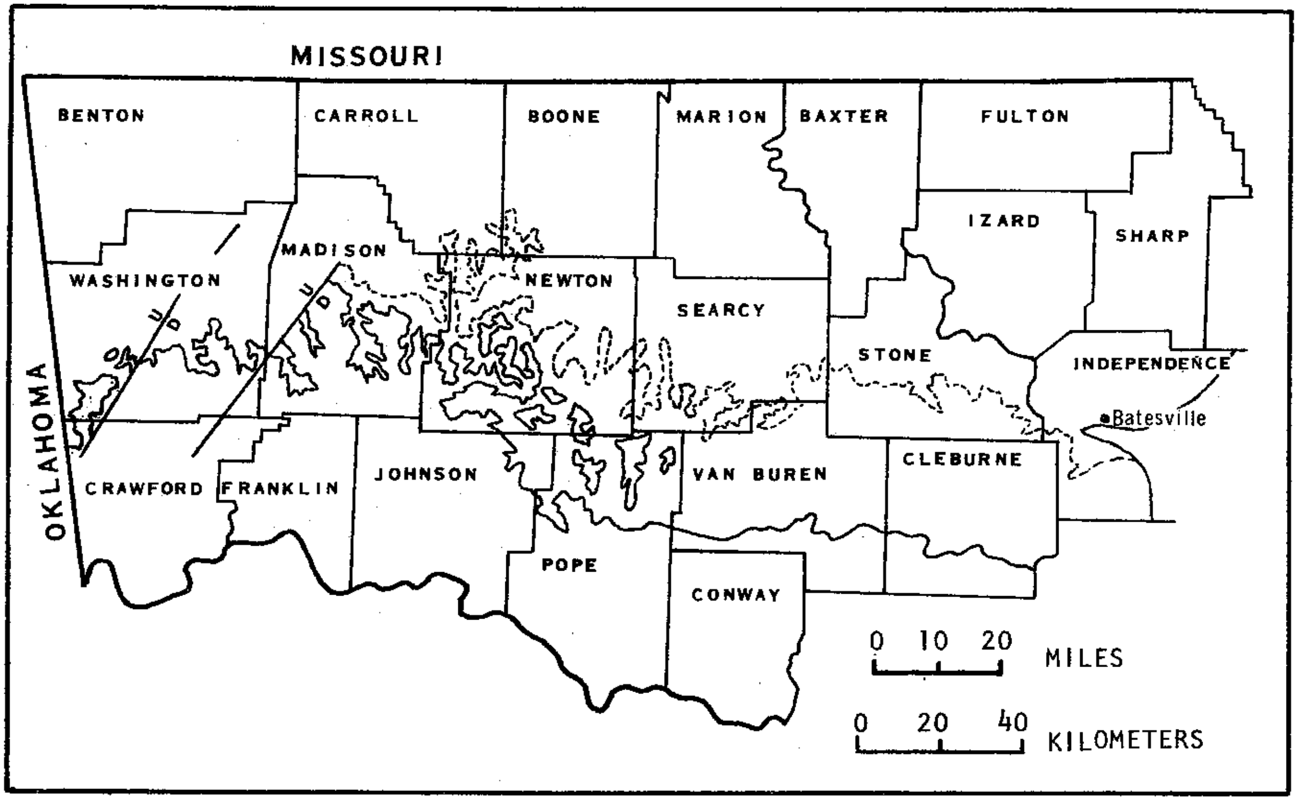


Figure 4.--Approximate location of the Bloyd-Atoka boundary as depicted on the Geologic Map of Arkansas (1929) (broken line) and as determined by recent geologic mapping (solid line).

The basal sandstone unit of the Atoka (fig. 2) forms a single ledge and the next higher sandstone forms a characteristic "double ledge" that is readily visible on aerial photographs. This combination of weathering characteristics provides a basis for identificationand is a valuable tool in regional mapping of the Bloyd-Atoka boundary. Both sandstone units have been mapped eastward from Washington County for more than 120 miles.

CONCLUSIONS

An investigation of the Bloyd-Atoka boundary at outcrops in northwestern Arkansas has resulted in a substantial modification of the position of this boundary as depicted on the Geologic Map of Arkansas published in 1929. In Washington County only minor changes in the location of the boundary are necessary because the boundary had been correctly mapped in that area. East of Washington County across the State the Bloyd-Atoka boundary of the 1929 map is north of the position determined by recent mapping (fig. 4). At the latitude of Batesville in Independence County, near the eastern margin of the outcrop belt, the Bloyd-Atoka boundary of this report is approximately 30 miles south of the boundary as depicted on the 1929 map. The revised boundary was mapped by Zachry in Washington and Madison Counties, Arkansas. From Madison County eastward the boundary was mapped by Haley of the United States Geological Survey.

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