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Stratigraphy, Lithology, and Depositional Environment of the Black Prince Formation Southeastern Arizona and Southwestern New Mexico

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MASTER'S THESIS

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STRATIGRAPHY, LITHOLOGY, AND DEPOSITIONAL ENVIRONMENT
OF THE BLACK PRINCE FORMATION
SOUTHEASTERN ARIZONA AND
SOUTHWESTERN NEW MEXICO

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

by
Patrick K. Spencer
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Master of Science

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Dean of Graduate School

Advisory Committee

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Chairman

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ABSTRACT

The Black Prince Formation (new manuscript name) of southeastern Arizona and southwestern New Mexico is subdivided into four lithologic facies representing four environments of deposition. The first lithofacies consists of the basal member of the type section of the Black Prince Limestone and is a result of erosion and reworking of the underlying Escabrosa Limestone. The three limestone lithofacies suggest deposition on a shallow shelf under supratidal, intertidal and subtidal conditions. Cyclic fluctuations in sea level are seen in the rock record in the vertical alternation of lithofacies. Six unconformities are recognized and these are traceable throughout the region.

The microfauna of the Black Prince Formation is correlative with faunas described elsewhere in North America and indicates that the Black Prince Formation was deposited during late Chesterian (Mississippian) and Morrowan (Pennsylvanian) time. The end of Black Prince deposition is marked by the abrupt appearance of advanced species of Profusulinella suggesting that a major hiatus is present between the Black Prince Formation and overlying rocks.

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ACKNOWLEDGEMENTS

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INTRODUCTION

Statement of Problem

The stratigraphy, lithology, and fauna of the Black Prince Formation, of supposed early Pennsylvanian (Morrowan) age, have not been studied adequately. The lithologic and chronostratigraphic equivalents of the Black Prince, which are here referred to as the Black Prince Formation, have typically been included in the underlying or overlying formations and have not been studied in detail. Recent work by Ross (1973) indicates that the lithologic and stratigraphic relationships in the "Black Prince interval" are complex. In order to better understand these complex relationships a detailed study of the lithology and fauna is necessary.

Location of Project

The area studied for the present project includes about 70,000 km^2 in southeastern Arizona and southwestern New Mexico (Figure 1). Near the center of this area are the type section of the Black Prince Limestone described by Gilluly, Cooper, and Williams (1954), and the reference section, described by Nations (1963) which he considered to be more representative (sections 6,7;

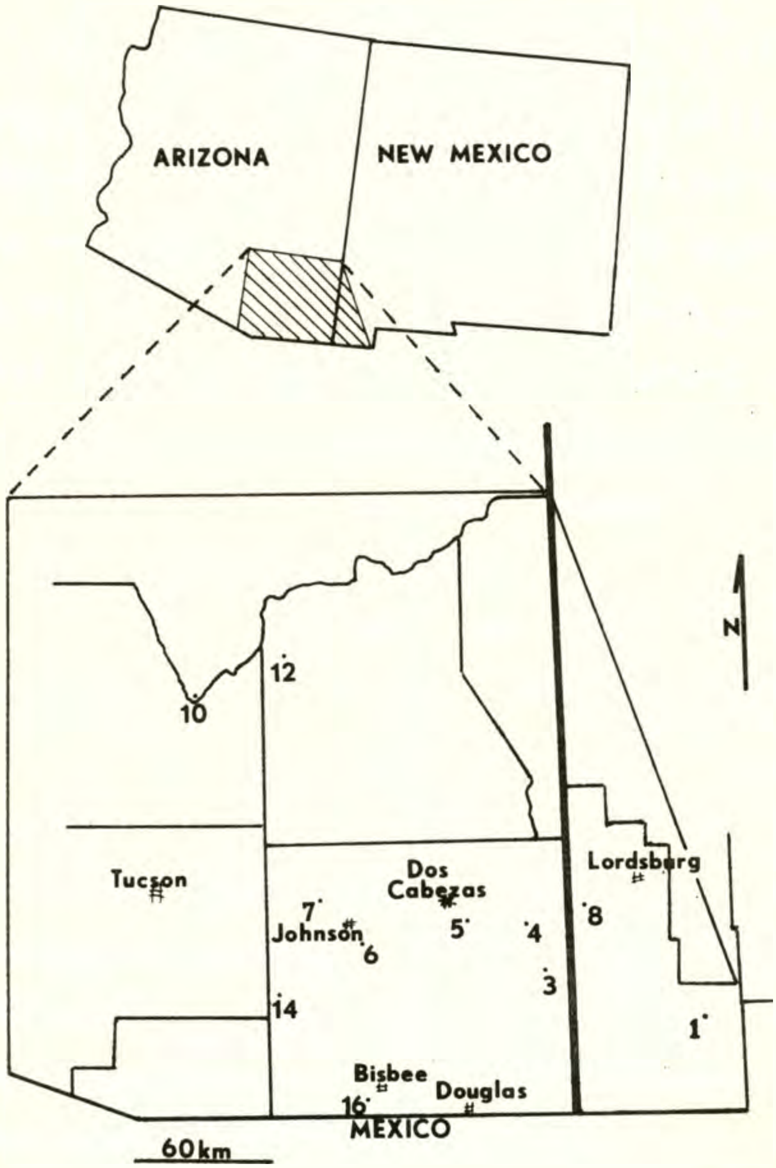

Figure 1. Index map showing approximate locations of measured stratigraphic sections.

Figure 1).

The Black Prince Formation

The Black Prince Limestone was named by Gilluly, Cooper and Williams (1954) for a sequence of limestone, shale, siltstone, and sandstone strata exposed near the Black Prince mine in the Johnson mining district of Arizona. Because these rocks are partially metamorphosed at that locality, a type section was described and measured 7.2 km southeast of the mine on the west slope of Gunnison Peak (section 6, Figure 1).

The Black Prince Limestone has a basal red to maroon shale member that separates it from the underlying Escabrosa Limestone in three measured sections located in the Gunnison Hills, Johnny Lyon Hills, and Little Dragoon Mountains of Central Cochise County, Arizona (Gilluly, Cooper, and Williams, 1954). In these three sections, the basal red shale member is overlain by a medium to coarse grained limestone member. The basal member ranges in thickness from three to ten meters. The total thickness of the formation ranges from thirty-five to fifty-two meters. In these sections, the Black Prince Limestone is overlain by a red clastic unit which, based on its inferred mode of origin, was included as the basal beds of the Horquilla Limestone.

Age: The occurrence of the silicified tetracoral Lithostrotionella in the basal member of the Black Prince lead Gilluly, Cooper, and Williams, (1954) to assign the Black Prince a late Mississippian age. Nations (1963) determined that the presence of Lithostrotionella was the result of erosion and reworking of the fossil from the underlying Escabrosa Limestone during late Mississippian time. Based on the occurrence of the primitive Fusulinacean genus Millerella in the limestone member of the Black Prince, Nations (1963) assigned an Early Pennsylvanian (Morrowan) age to the formation.

Distribution: As originally described, the Black Prince Limestone was restricted in geographic distribution to exposures in the central and northeastern portions of Cochise County in southeastern Arizona. Elsewhere in the region the basal shale member is thin or absent and Black Prince correlatives were mapped either as the upper part of the Escabrosa Limestone or were included in the overlying Horquilla Limestone. In southeasternmost Arizona and southwestern New Mexico Black Prince Limestone correlatives are separated from the Escabrosa Limestone

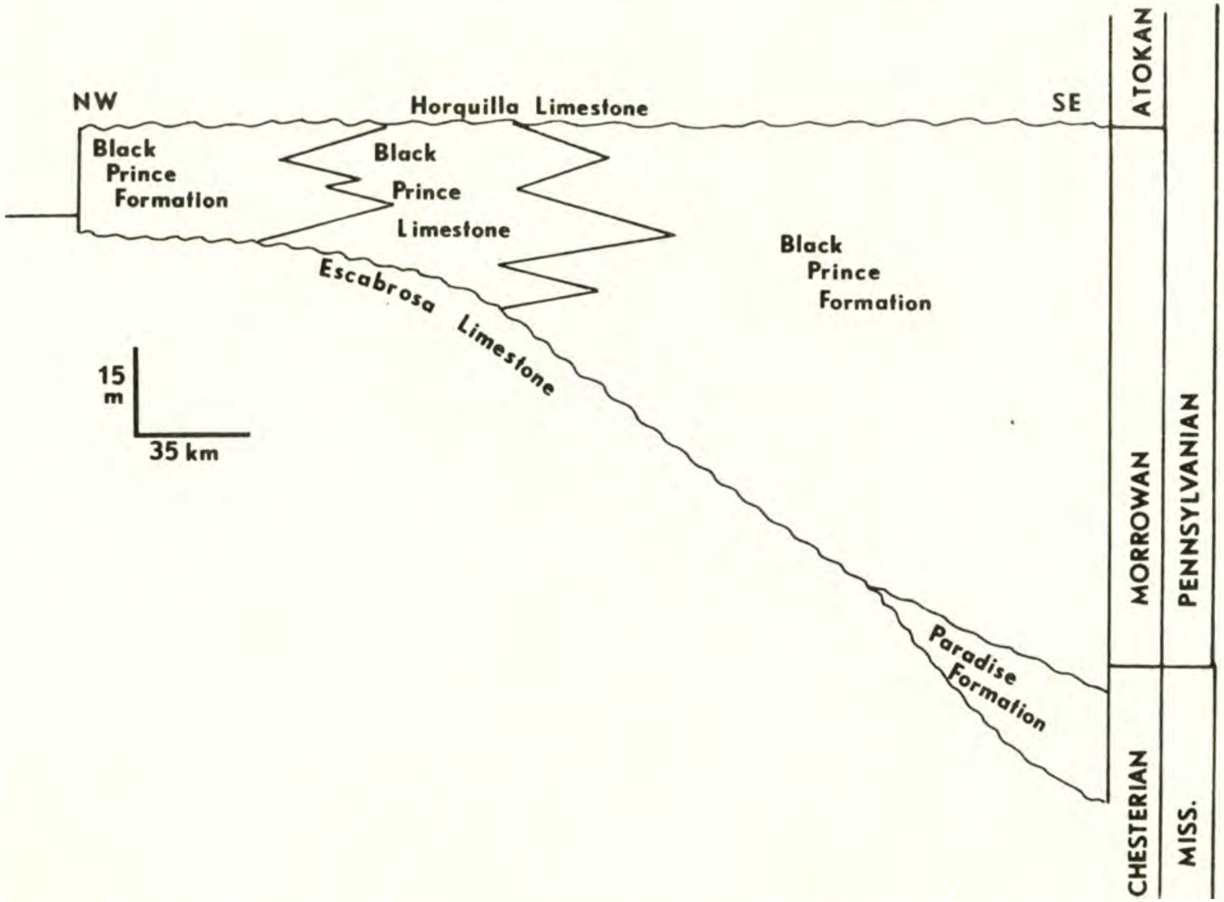

Figure 2. Generalized Upper Mississippian- Lower Pennsylvanian stratigraphic relationships, southeastern Arizona, southwestern New Mexico.

by the Lower Chesterian Paradise Formation consisting of thin to thick bedded limestone, sandstone, and shale. In these areas Black Prince correlative strata were mapped as the lower part of the Horquilla Limestone. Figure 2 shows these generalized Upper Mississippian and Lower Pennsylvanian stratigraphic relationships.

For the purpose of this study, Black Prince Limestone correlative strata outside the type area will be referred to as the Black Prince Formation because of the variations of the lithologies. Exposures outside the type area lack the lower clastic unit or the clastic unit at the base of the Horquilla and are not readily distinguished from overlying or underlying rocks. The Black Prince Formation does, however, possess a lithology and fauna which serves to separate it from associated rocks.

Previous Work

Detailed studies of Black Prince Formation in southeastern Arizona and southwestern New Mexico include a few papers dealing with the Black Prince Limestone in Cochise County (Gilluly, Cooper, and Williams, 1954; Nations, 1963). Most workers have made passing reference to the Black Prince Formation as part of other types of studies (Ross and Tyrrell, 1965; Ross and Sabins, 1965; Sabins, 1957a). Ross (1973) recognized the Black Prince depositional interval in this region as being distinctly different from pre- and post-Black Prince intervals and recognized regional unconformities separating Black Prince Formation from underlying and overlying rocks. Ross (1973) indicated that there were probably several fluctuations of sea level during the Black Prince depositional interval. These fluctuations of sea level have been documented in the Ozark shelf region (Saunders, Ramsbottom, and Manger, 1979).

Studies of the Black Prince fauna in the region have been limited to a few fossil age determinations which were sufficient only to bracket a particular exposure to the Black Prince interval. In general, the details of the stratigraphy and deposition patterns in this region during the Black Prince interval have not been studied.

Scope of Study

The present study examines the details of Black Prince deposition through a study of lithologic variations, both vertically and laterally, in measured stratigraphic sections. The microfauna of these rocks has not been studied or described adequately and the present study looks in detail at the Foraminifera. Comparison of this diverse microfauna with microfaunas described elsewhere in North America aids in establishing stratigraphic relationships in the Black Prince Formation.

LITHOLOGY

The Black Prince Formation in southeastern Arizona and southwestern New Mexico is subdivided into four lithologic facies representing four environments of deposition. They are: 1) basal clastic lithofacies; 2) micritic limestone lithofacies; 3) skeletal limestone lithofacies; 4) oolitic limestone lithofacies. The basal clastic lithofacies comprises the lower member and the three limestone lithofacies the upper member of the Black Prince Limestone of Gilluly, Cooper, and Williams (1954). The limestone classification follows Folk (1959).

Basal Clastic Lithofacies: These rocks are composed of red to maroon siltstone, shale, sandstone and limestone pebble conglomerate with some thin gray limestone beds (figure 3).

Gilluly, Cooper, and Williams (1954) attributed this clastic lithofacies to the accumulation of an insoluble residue resulting from erosion and reworking of the underlying Escabrosa Limestone. The basal clastic lithofacies is present as a thin (3 to 10 m) unit at the base of sections 6, 7, 14, and 16 (Figure 1). In other sections, the basal lithofacies is present as a conglomeratic or calcarenitic bed that is traceable throughout the study area.

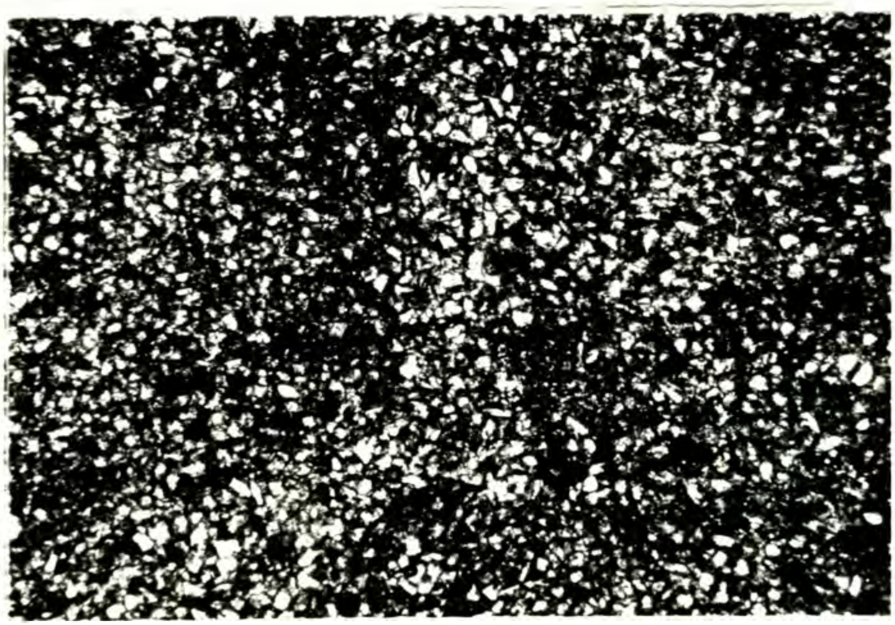

Figure 3. Basal siltstone of the Black Prince Formation. x100

Micritic Limestone Lithofacies: These rocks are composed of fine grained lime mud with zero to ten percent of fossil allochems and are micrite or fossiliferous biomicrite.

The micritic limestone lithofacies was desposited under the shallowest conditions, with deposition occurring in a protected area or an intertidal mud flat. Flood tides transported some of the micrite to this environment from areas seaward. The fine grained mud then settled out and was left in place as the tide receded. Some of the micrite in this environment probably formed as a result of micritization of skeletal allochems. Portions of this environment were probably exposed except during the highest tides.

Rocks of this lithofacies were deposited shoreward from the other two limestone lithofacies. The micritic limestone lithofacies is widely distributed both vertically and laterally in the central and northwestern portions of the study area. Rocks of this lithofacies are not common in the southeastern areas.

Skeletal Limestone Lithofacies: Rocks of this lithofacies are composed of fragmented and whole fossils of pelecypods, gastropods, brachipods, crinoids, echinoids, bryozoans, and Foraminifera. These rocks have a matrix of micrite and occasionally a sparry calcite cement. Fossil allochems range from 10 to 85 percent and the rocks range from sparce to packed biomicrite. Allochems range in size from large (several mm) to small indistinct grains (.1 mm or less). Textures seen in some of the grains suggest that some of the micrite matrix was formed in place by micritization of larger fragments. According to Bathurst (1966, in Bathurst, 1976), micritization is a result of endolithic algae which envelop an allochem and gradually break it down. Micrite envelopes formed in this manner were noted on allochems in some of the samples studied (Figure 4).

The skeletal limestone lithofacies was deposited under high energy conditions relative to the micrite lithofacies as suggested by the fragmental nature of allochems. Dissipation of wave and tidal energy across a broad shallow shelf provided the energy necessary to fragment the hard parts of organisms that lived in this environment. Solid state micritization by endolithic algae and constant abrasion due to wave and tidal action produced the micrite both here and in environments shoreward. Periodic storms provided energy sufficient to transport some of the coarser skeletal allochems shoreward to the intertidal-supratidal boundary. The skeletal lithofacies was deposited seaward from the micritic lithofacies under

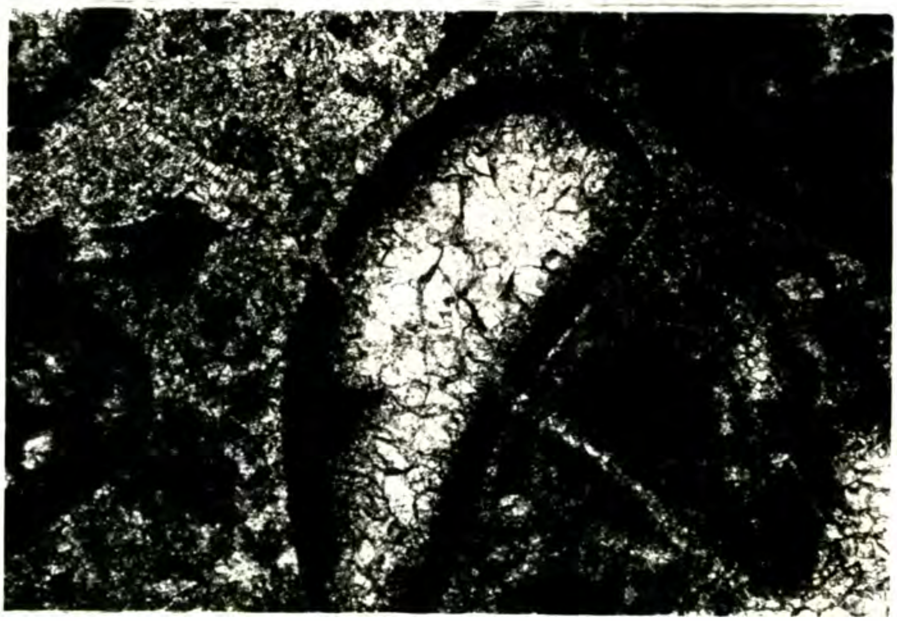

Figure 4. Micrite envelope on skeletal fragment. x100

intertidal to shallow subtidal conditions.

The skeletal limestone lithofacies is common in all measured sections studied. In the central part of the study area (sections 15, 7, 14, 16), these rocks comprise the major portion of the section.

Oolitic Limestone Lithofacies: Rocks of this lithofacies are composed of ooids enclosed in a matrix of sparry calcite (Figure 5). In some samples ooids are associated with skeletal debris (Figure 6). Ooid nuclei consist of virtually anything that was available, generally indistinct carbonate grains, which are probably the remains of the shells of molluscs and also include crinoid fragments and Foraminifera (Figure 7).

The oolitic limestone lithofacies was deposited under the highest energy conditions in tidal passes at the edge of shallow shelf areas. In modern environments such as the Great Bahama Bank, ooids form at the seaward edges of shallow shelf areas (Bathurst, 1976).

In these areas, waves and tidal currents undergo frictional drag on the bottom. These waves and currents provide energy sufficient to keep grains in constant motion. Caueux (1935) and Donahue (1965) in Bathurst (1976), list agitation of grains as a necessary requirement

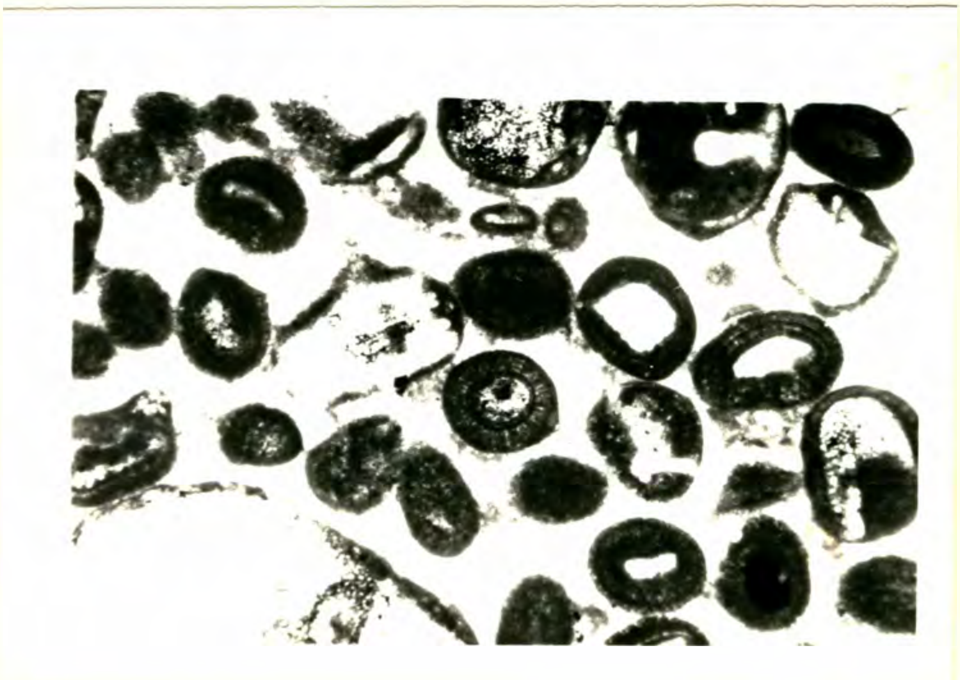

Figure 5. Packed Oosparite; tidal channel-shelf edge deposit. x 25

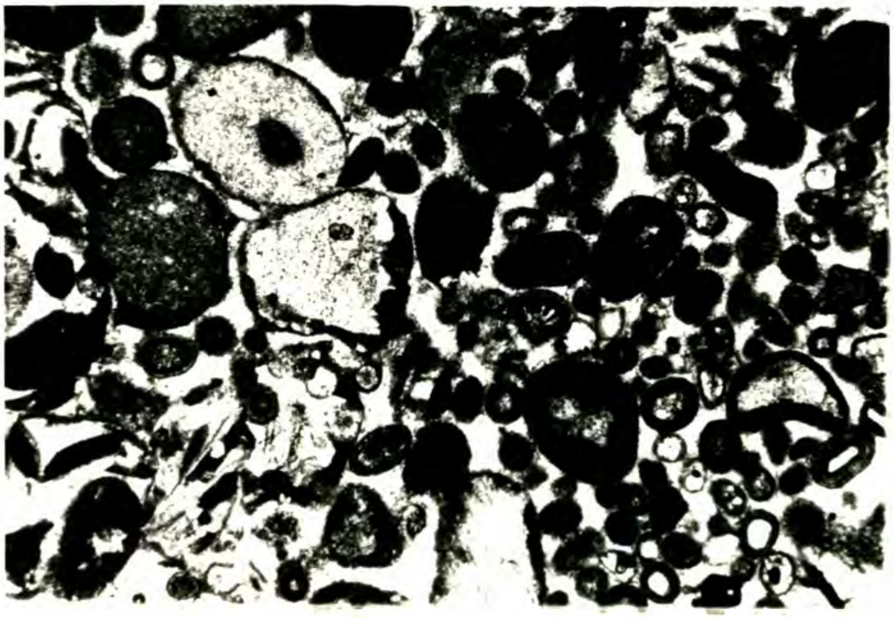

Figure 6. Ooids associated with skeletal debris. x 25

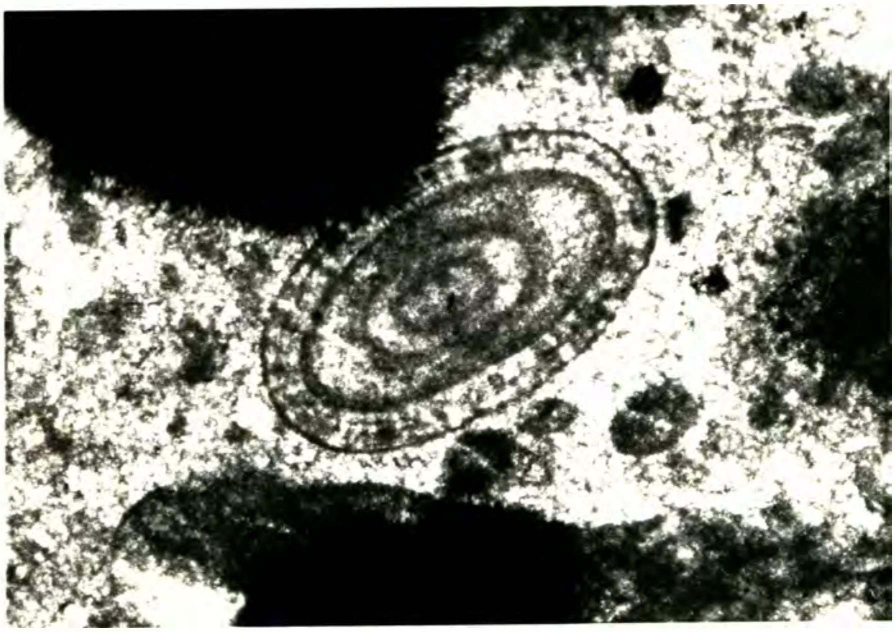

Figure 7. Ooid nuclei consisting of Foraminifera (Eostaffella). x100

for ooid formation.

The oolitic limestone lithofacies is common in sections in the southeastern areas and less common elsewhere. In the northwestern part of the study area rocks of this lithofacies occur only near the base of section 12. Lithofacies and environment are shown diagrammatically in Figure 8.

Foraminiferal Facies: In supratidal and shallow subtidal environments (the micrite lithofacies) Foraminifera are rare. Those that do occur are primarily benthonic types (Monotaxinoides). Most of these are fragmented. This fact combined with the environmental interpretation (alternately submerged and exposed) suggests that Foraminifera found in this lithofacies probably did not live here but were transported from the seaward environments. In the intertidal to shallow subtidal environment (the skeletal lithofacies), Foraminifera are abundant (Millerella, Paleotextularia, Globivalvulina, Calcivertella). These are both benthonic and encrusting types and most specimens are whole. It is unlikely that a fauna this diverse, with relatively few fragmented specimens, was transported to this environment from elsewhere. This fauna probably lived in this environment. In the tidal

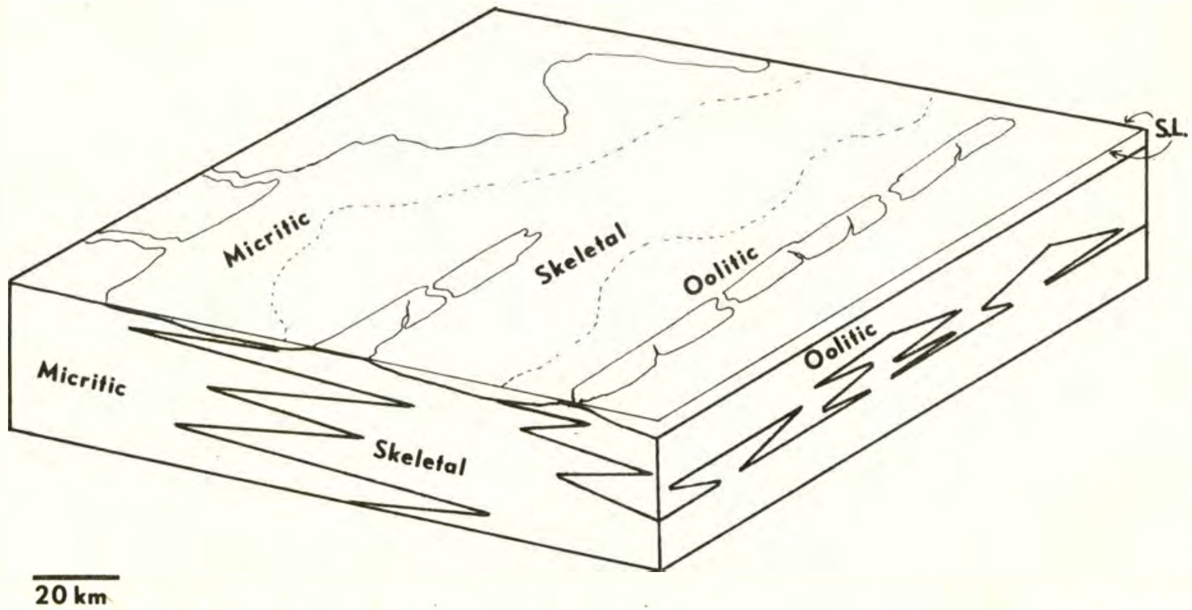

Figure 8. Idealized lithofacies-environment relationships. No vertical scale intended.

channel-shelf edge environment (the oolitic lithofacies), Foraminifera are abundant and are benthnoic types (Millerella, Eostaffella). They are found primarily as ooid nuclei (Figure 7). In the oolitic lithofacies there is little evidence for a resident fauna.

The lithologic and faunal evidence suggests that deposition occurred on a broad shallow shelf in warm waters. The lateral and vertical continuity of rock types associated with a particular overall environment, in this case a warm shallow shelf environment, indicates that these rocks were deposited in an epicontinental sea. Using the terminology of Irwin (1965), the rocks represent the Y and Z zones (barrier and shoreward). The X zone (open sea) is not represented in the rocks except as will be discussed subsequently, near the base of section 3. Similar distribution of rock types can be observed in the upper Paleozoic Williston Basin of North America (Irwin, 1965).

Facies Variation and Cyclic Deposition

Vertical and lateral facies variations in the Black Prince Formation are abrupt, abundant, and apparently cyclical, probably reflecting rapid fluctuations in sea level. The lithofacies appear to migrate laterally in response to changing sea level.

The Blue Mountain section (section 4, Figure 1) is one of the thickest and most complete sections measured in the Black Prince Formation. It shows typical examples of vertical facies changes. At Blue Mountain the Black Prince Formation overlies unconformably rocks of the Paradise Formation of lower Chesterian age. Black Prince deposition begins with a bed of calcarenite overlain by a skeletal limestone bed, indicating intertidal to shallow subtidal conditions. Directly above this is a bed of micritic limestone representing high intertidal or protected conditions. The next several samples show a progression upward from skeletal limestone to slightly oolitic skeletal limestone to oolitic limestone and indicates transgression. The oolitic limestone was deposited at the edge of the shelf in a tidal channel and represents the transgressive maxima for this cycle. The next several samples consist of skeletal elements and algal-coated ooids which indicates that the area of ooid formation was farther offshore. The next sample consists of algal-coated grains with clastic material and indicates proximity to the shoreline. The cycle then begins again with sekletal limestones. The cycle is shown diagrammatically in Figure 9. Beds of limestone pebble

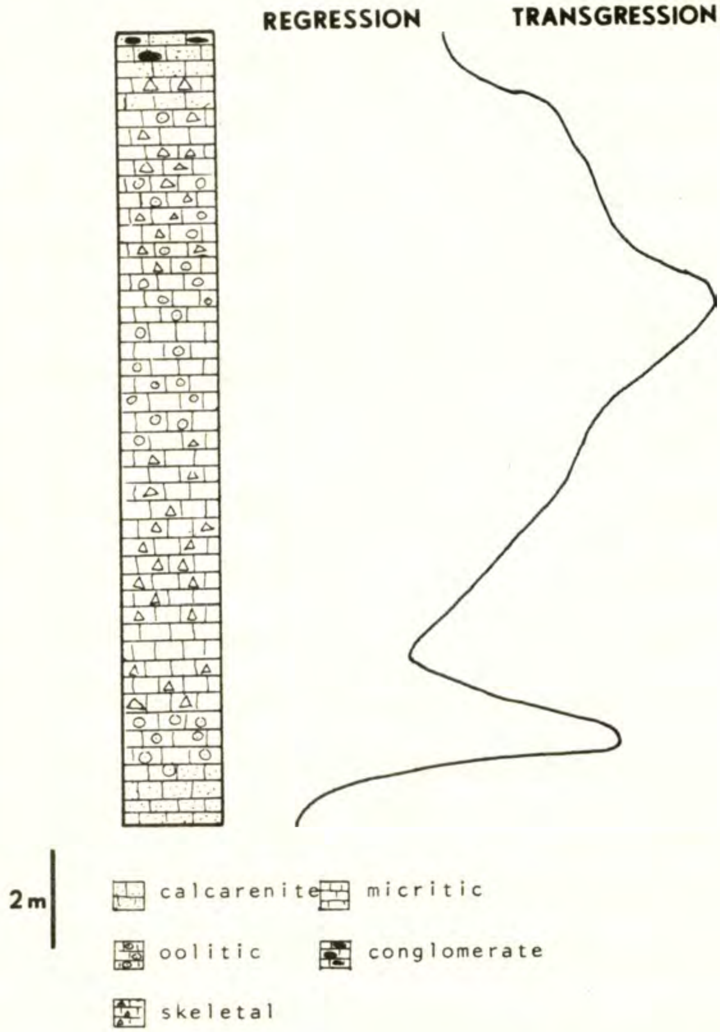

Figure 9. Cyclic deposition in the lower portion of the Blue Mountain section

conglomerate are scarce at Blue Mountain indicating that there were no extensive erosional periods. The section is nearly complete.

To the northwest, the Dos Cabezas section (section 5) demonstrates a similar pattern of cyclic deposition. In this section, however, the micritic limestone lithofacies is more common indicating that periodically the area was subjected to intertidal-supratidal conditions due to a lowering of sea level. The presence of limestone intraclasts in some samples suggests that areas to the northwest were emergent and subjected to erosion. The most common lithofacies at the Dos Cabezas section is skeletal limestone. During most of the Black Prince interval this part of the depositional basin was subjected to shallow subtidal and intertidal conditions.

Other measured sections in this part of the depositional basin (sections 7, 14, 16) show lithologies similar to the Dos Cabezas section. Skeletal and micritic limestone are the most common lithofacies present. These sections contain breaks in the depositional cycle which are marked by the presence of limestone conglomerates and intraclasts.

About 80 km north of Tucson two sections were measured; about 3 km north of the town of Winkleman (section 10) and on the south side of the San Carlos Reservoir on the San Carlos Indian Reservation (section 12). Both of these sections are thin (18 m and 17 m respectively); dominant lithofacies are the skeletal and micritic limestones indicating supratidal to intertidal conditions. Oolitic limestones are absent except near the base of section 12. The presence of limestone conglomerates and intraclasts, and the alternation of skeletal and micritic limestones suggest submergence, emergence and unconformity. Figure 10 shows nine representative sections and supposed unconformities.

The overall pattern of deposition in southeastern Arizona and southwestern New Mexico during the Black Prince interval suggests cyclic advance and retreat of the sea beginning with transgression from southwest to northwest in Late Chesterian time. Lithologic evidence in the form of an oolitic limestone preserved near the base of section 12 suggests that one of the early Black Prince transgressions reached far enough up the basin axis so that shelf-margin conditions existed in this area. Faunal evidence, to be discussed subsequently, lends support to this suggestion.

The contrast in thickness between sections to the southeast (sections 4, 17; 94 and 79 m, respectively) and

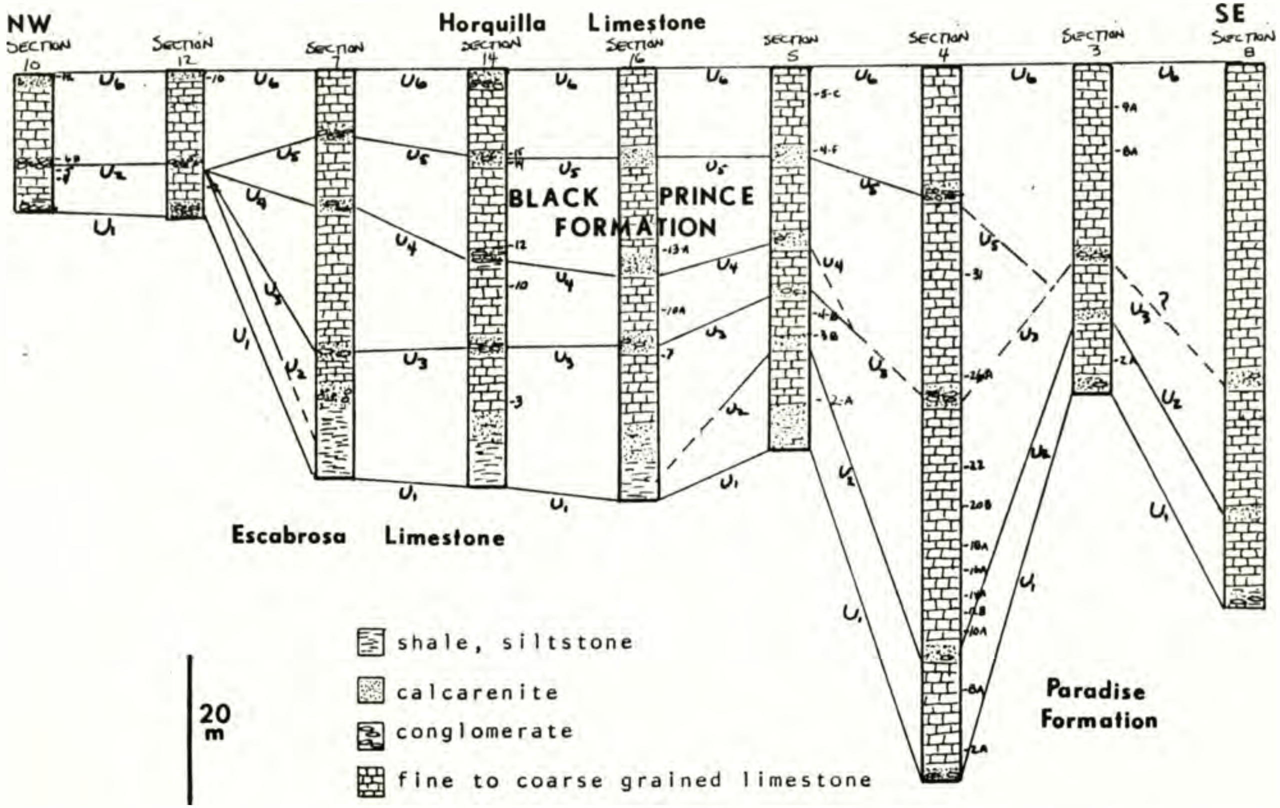

Figure 10. Representative measured stratigraphic sections showing recognized unconformities in the Black Prince Formation.

sections in the northwest (sections 10, 12; 18 m and 17 m, respectively) and the presence of unconformities marked by limestone conglomerates and calcarenites in sections in the central and northwestern parts of the study area suggest the following interpretation.

Although cyclic deposition in the southeastern sections is recorded in the vertical alternation of lithofacies, conglomerates are scarce, implying that once the initial Black Prince transgression began, the seas did not recede to the extent that these areas were emergent; the depositional record in the southeast is nearly complete. To the northwest the total thickness of Black Prince Formation is less and limestone conglomerates become more common, indicating that periodic regressions exposed these areas to erosion. In the northwestern-most part of the basin of deposition the thin Black Prince sections suggest that more of the Black Prince interval is represented by hiati than is preserved in the rock record.

At the Portal section (section 3) the Black Prince Formation totals about 40 m in thickness whereas in nearby sections (4 and 17) the total thickness is on the order of 70 to 90 m. Also, near the base of the Black Prince Formation in the Portal section a laminated calcareous black shale (Zone X) suggests deposition in the open ocean. This rock unit was not observed in other sections. Sabins (1957b) and Drewes (1978) suggested that late Paleozoic sections in southeastern Arizona and southwestern New Mexico were thrust faulted into their present positions and that several thrust sheets are present in the region. The anomalous thickness and stratigraphy of the Black Prince Formation of the Portal section might be explained if the original position of section 3 was beyond the shelf-basin margin, perhaps southeast of its present position. Initial Black Prince transgression deposited typical shallow water carbonate sediments. During maximum transgression, open ocean conditions existed in the area of the Portal section so that a laminated shaly lime mud was deposited. This environment corresponds to the X Zone of Irwin (1965). The presence of a thin Black Prince section probably resulted from one or both of the following: 1) The position of the section at the time of deposition was periodically beyond the influence of major sedimentation and the sediments were not available for deposition. An analogous situation is seen on the present Gulf Coast where Holocene sediments are thickest nearer to shore and thin offshore as a result of a reduced rate of deposition (C.A. Ross, personal comm.). 2) Currents originating in the open ocean swept the area of the Portal section clear of sediments. A similar situation is seen in the present Straits of Florida where Pleistocene limestones are found free of Holocene sediment cover.

Six unconformities have been recognized in the Black Prince Formation of southeastern Arizona and southwestern New Mexico, and these can be related to cyclic advance and retreat of late Chesterian and Morrowan seas in the region. Unconformities are marked in the rock record by the presence of limestone conglomerate and/or calcarenitic beds, or the abrupt appearnce of a distinctly more advanced fauna. The unconformities are traceable throughout most of the region studied. Figure 10 shows nine representative measured sections and the recognized unconformities.

The first unconformity (U_1, Figure 10) separates the Black Prince Formation from the underlying Escabrosa Limestone in the central and northwestern areas and from the Paradise Formation in the southeast. In the type area of the Black Prince Limestone of Gilluly, Cooper and Williams (1954), and northwestward, the hiatus of U_1

represents most or all of Chesterian time. In the southeast (sections 3, 4, and 8) the hiatus is considerably shorter, perhaps representing only middle Chesterian time.

Based on fossil evidence, to be discussed subsequently, the initial Black Prince transgression began in the late Chesterian. This transgression covered the major portion of the depositional basin, with the exception of sections 7, 14, and 16. These areas were apparently emergent and did not receive typical shallow marine sediments. In these areas, the basal clastic member of the Black Prince Limestone is present. Unconformity 2 (U_2, Figure 10) marks the end of this first transgressive episode and also marks the Chesterian-Morrowan boundary in the region. U_2 is marked by conglomeratic or calcarenitic beds and is traceable throughout the study area. As shown by the dashed line of Figure 10, U_2 may occur within the basal member of the Black Prince Limestone in the type area. At sections 10 and 12, the hiatus of U_2 spans most of Morrowan time.

After U_2, there were three cycles of transgression and regression. The regressive phases are marked by U_3, U_4, and U_5 on Figure 10. During this period, which includes early and middle Morrowan time, oscillation of sea level was confined to the central part of the depositional basin. In the northwest (sections 10, 12) unconformities 3, 4, and 5 are coincident with U_2; the three transgressive pulses did not reach this area. To the southeast (sections 3, 4, and 8), the unconformities are not apparent, suggesting that these areas received sediment continuously during this period of time.

The final Black Prince transgression deposited shallow marine carbonates typical of the Black Prince Formation in all portions of the depositional basin studied. Contained within these sediments is a fauna that is typical of foraminiferal Zone V of this report.

Unconformity 6 marks the top of the Black Prince Formation and may represent the Morrowan-Atokan boundary in the region. The unconformity in the field is marked by the abrupt appearance of a distinctly more advanced Fusulinacean fauna dominated by advanced species of the genus Profusulinella. Elsewhere in North America, this fauna is typical of Atokan time. The duration of the hiatus at U_6 has not been determined.

FAUNA

Macrofossils are rare in the Black Prince Formation. They consist primarily of brachiopods, a few ammonoids, and the colonial coral Chaetetes. Macrofossils are of limited value in working out stratigraphic relationships because of their scarcity and also because of difficulties in extracting complete, identifiable specimens. The majority of the macrofossils are fragmented components of the skeletal limestone lithofacies and are unidentifiable beyond the taxonomic level of class.

Microfossils are abundant in the Black Prince Formation and consist mainly of Foraminifera. Present are 3 superfamilies, 10 families, and 17 genera (Table 1; Plates 1 through 4).

Foraminiferal Zonation

Five Late Mississippian and Early Pennsylvanian foraminiferal assemblage zones are recognized in the Black Prince Formation of southeastern Arizona and southwestern New Mexico. Their stratigraphic distribution with respect to representative measured sections is shown in Figure 11. Zones established for this study are referred to by Roman numerals and each is characterized by a distinctive

TABLE I: LISTING OF FORAMINIFERAL GENERA

SUPERFAMILY	FAMILY	GENUS	
FUSULINACEA von Moller, 1878	Ozawainellidae Thompson & Foster, 1937	Millerella	Thompson 1942
		Eostaffella	(Thompson) 1951 Rauzer-Chernousova, 1958
	Fusulinidae von Moller, 1878	Profusulinella	Rauzer-Chernousova, 1936
		Pseudostaffella	Thompson, 1942
ENDOTHYRACEA Brady, 1884	Paleotextulariidae Galloway, 1933	Paleotextularia	Schubert, 1921
		Climacammina	Brady, 1883
		Paleobigenerina	Galloway, 1933
	Tetrataxidae Galloway, 1933	Valvulinella	Schubert, 1907
	Biseriaminidae Cherneysheva, 1941	Globivalvulina	Schubert, 1921
	Tournayellidae Dain, 1953	Tournayella	Dain, 1953
	Endothyridae Brady, 1884	Endothyra?	
		Chernyshivella	Lipina, 1955
		Bradyina	von Moller, 1878
	Archaediscidae Cushman, 1925	Archaediscus	Brady, 1873
		Brunsia	Mikhaylov, 1939
	Lasiodiscidae Reyetlinger, 1939	Monotaxinoides	Braznikova & Yartseva, 1956
MILIOLACEA Ehrenberg, 1939	Fischerinidae Millett, 1898	Calcivertella	Loeblich & Tappan, 1964

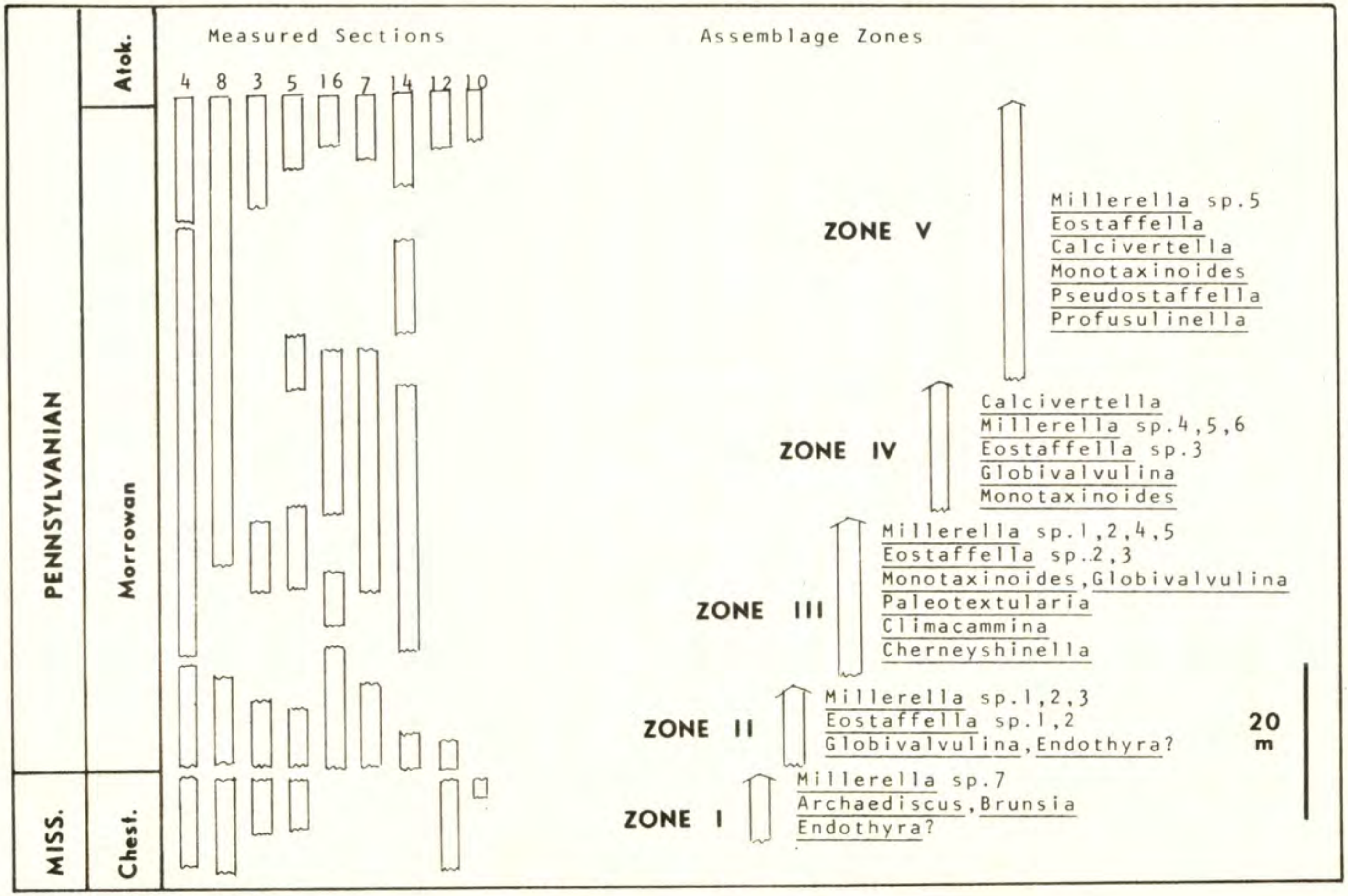

Figure 11. Foraminiferal zonation of the Black Prince Formation.

assemblange of Foraminifera. The Formainifera are not necessarily continuous throughout a zone and some range through several zones. Portions of several measured sections were assigned to a particular zone on the basis of associated Foraminifera rather than the most distinctive species or genus.

Zones were established initially based on the occurrence of Foraminifera in the Blue Mountain section (section 4). This is one of the thickest and most complete sections studied and foraminiferal occurrences here are relatively well defined. Other measured sections are interrupted by unconformities and significant portions of the time spanned by these sections is represented by hiati (figure 11).

Zone I: At Blue Mountain, Zone I of the Black Prince Formation includes about 12 m of Upper Mississippian (Chesterian) strata that overlie the Paradise Formation. The top of this zone appears to mark the Chesterian-Morrowan boundary. Zone I is also recognized at Dos Cabezas (section 5), where the lower 10 m of strata are included; Portal (section 3), lower 8 m; and San Carlos (section 12), lower 10 m. Characteristic Foraminifera occurring in Zone I are a small species of Millerella

(M. sp. 7, Plate 1, Figures 1, 2). These are similar to individuals assigned to M. tortula by Zeller (1953). Associated with Millerella in Zone I are numerous species of the family Endothyridae and a few specimens from the family Archaediscidae (Archaediscus, Brunsia; Plate 4, Figures 1-4).

Zone II: Zone II includes about 12 m of strata at Blue Mountain, which include earliest Morrowan time. This zone is recognized at the base of all measured sections with the exception of section 10 at the northwestern limit of the study area. The zone is characterized primarily by the occurrence of species of the genus Millerella (M. sp. 1; Plate 1, Figures 3-5) which are similar to specimens referred to M. marblensis by other authors (Zeller, 1977; Thompson, 1944). Associated with Millerella sp. 1 in Zone II are two other species of Millerella (M. sp. 2, M. sp. 3; Plate 1, Figures 6-10) which may represent varieties of M. marblensis. Other Foraminifera occurring in Zone II are two species of the genus Eostaffella (E. sp. 1, E. sp. 2; Plate 2, Figures 1-4), Globivalvulina cf G. moderata (Plate 3, Figures 8, 9) and specimens from the family Endothyridae (Plate 4, Figure 1).

Zone III: At Blue Mountain Zone III includes about 23 m of strata. Portions of Zone III can be recognized in sections 3, 5, 7, 8, 10, 14, and 16, although the complete zone is not recognized at any section other than Blue Mountain. Characteristic Foraminifera occurring in the zone are two species of Eostaffella, which are referrable to E. pinguis, and may be varieties of this species (E. sp. 2, E. sp. 3; Plate 2, Figures 3-7). Also occurring within the zone are four species of Millerella (M. sp. 1, M. sp. 2, M. sp. 4, and M. sp. 5; Plate 1, Figures 3-8, 11-16), Monotaxinoides (Plage 3, Figures 5, 6), Globivalvulina (Plate 3, Figures 7-9), Paleotextularia, Climacammina (Plate 4, Figures 2-6), and Cherneyshinella (Plate 4, Figure 8).

Zone IV: Zone IV includes about 17 m of strata at Blue Mountain. Portions of the zone are recognizable also in sections 7, 8, 14, and 16. At sections 3, 10, and 12, Zone IV is apparently missing and is lost in an hiatus. Foraminifera characteristic of this zone are three species referrable to the genus Millerella (M. sp. 4, M. sp. 5, M. sp. 6; Plate 1, Figures 11-17), Eostaffella (E. sp. 3; Plate 2, Figures 5-7), Globivalvulina, Monotaxinoides, and Calcivertella (Plate 4, Figures 9-11).

Zone V: Zone V occupies the upper 39 m of strata at Blue Mountain and portions of the zone are recognized in all sections shown in Figure 11. Characterizing this zone are specimens referrable to Millerella (M. sp. 5; Plate 1, Figures 13-16). M. sp. 5 occurs first at Blue Mountain about the middle of Zone III and is present throughout the remainder of the section. At the top of Zone IV, however, M. sp. 5 becomes the only representative of the genus Millerella and it was on this basis that the zone was distinguished. Other Foraminifera occurring in Zone V are Globivalvulina, Monotaxinoides, Eostaffella, Calcivertella, a primitive species of Pseudostaffella (Plate 2, Figure 11), Eostaffellina (Plate 2, Figure 12), and a small, globular species of Profusulinella.

Directly above Zone V in all sections of the Black Prince Formation studied is a bed containing abundant, large species of Profusulinella. Although the genus Profusulinella first occurs in the upper part of the Portal section (section 3) at a position within Zone V, this occurrence is a primitive, sub-fusiform species. These strata lie within the Black Prince interval. The abrupt appearance of this distinctly more advanced species of

Profusulinella marks the first appearance of Atokan faunas and indicates an unconformity and hiatus representing the lower part of the Zone of Profusulinella and separating these strata from the underlying Black Prince Formation.

STRATIGRAPHY

The distribution of Foraminifera, particularly those belonging to the Family Fusulinacea, in the Black Prince Formation corresponds with foraminiferal occurrences in strata of equivalent age in other parts of North America.

Zone I of the Black Prince Formation contains a fusulinacean fauna consisting of species of Millerella (M. sp. 7) which resemble specimens referred to M. tortula by Zeller (1953). She recognized M. tortula in the middle Chesterian Glen Dean Limestone of Illinois. Associated with M. tortula in the Glen Dean are species of the family Endothyridae. A similar association was found at Blue Mountain. Also present in Zone I of this report are members of the family Archaediscidae (Archaediscus and Brunsia = Hemiarchaediscus). Mamet (1968) described these genera as occurring in his Zone 19 which is late-early Namurian (middle to late Chesterian) and is younger than the Glen Dean Limestone. Brenckle (1977) also recognized Hemiarchaediscus in the middle Chesterian Pitkin Limestone of Arkansas. Zone I at Blue Mountain is apparently middle or late Chesterian in age.

Zone II is characterized by the appearance of Millerella sp. 1 (cf. M. marblensis) and the base of this zone marks the Chesterian-Morrowan boundary. Zeller (1977) studied thin sections of rocks of Chesterian and Morrowan age and noted specimens referrable to M. marblensis in the Braggs Member of the Sausbee Formation (lowest Morrowan) of Oklahoma and also in the Prairie Grove Member of the Hale Formation of Arkansas, of equivalent age. The highest occurrence of M. marblensis noted by Zeller (1977) is in the Brentwood Limestone Member of the Bloyd Shale which is approximately middle Morrowan age.

Zones III and IV of the Black Prince Formation contain Millerella referrable to M. pressa along with species of Eostaffella referrable to E. pinguis and E. advena. Zeller (1977) noted specimens of M. pressa in lower Morrowan strata of Arkansas and Oklahoma. The species ranges upward to the Shale "A" Member of the McCully Formation.

Thompson (1945) found Millerella pressa in the Belden Formation of Colorado, but was uncertain as to the position of the Belden within the Morrowan. Thompson (1944, 1945) also noted occurrences of Millerella pinguis and M. advena (= Eostaffella pinguis, E. advena) in the

Kearney Formation and in the Brentwood Limestone Member of the Bloyd Shale, both of which are middle-upper Morrowan age. These occurrences correspond in general with the distribution of these species at Blue Mountain.

Zone V contains strata of late Morrowan age and is distinguished on the basis of the presence of *Millerella* sp. 5 as the only representative of the genus *Millerella*. Zeller (1977) found similar relationships in the upper Morrowan Shale "A" Member of the McCully Formation. Other units of late Morrowan age examined by Zeller (1977) are either non-fossiliferous or contain indeterminant species of *Millerella*.

CONCLUSIONS

The Black Prince Limestone of Gilluly, Cooper, and Williams (1954) and correlative strata in southeastern Arizona and southwestern New Mexico are subdivided into four distinct lithofacies, each representing a different environment of deposition. They are: basal clastic lithofacies, resulting from erosion and reworking of the underlying Escarbrosa Limestone; micritic limestone lithofacies, deposited on supratidal and intertidal mudflats or in protected areas; skeletal limestone lithofacies, deposited in intertidal and shallow subtidal environments; and the oolitic limestone lithofacies, deposited at the shelf edge in tidal channels. The limestone lithofacies represent conditions of increasing energy from the micritic lithofacies to the oolitic lithofacies. Depositional patterns during the Black Prince interval suggest that the overall environment was that of a shallow epicontinental sea.

Deposition during the Black Prince interval was cyclic and these cycles are seen in the vertical alternation of lithofacies in measured stratigraphic sections. Cycles of deposition are bounded by unconformities marked in the rock record by limestone conglomerates and calc arenite beds. Six unconformities are recognized defining five episodes of transgression and regression. The first transgression covered the entire region studied. Subsequent oscillations of sea level were confined to the central part of the study area. Deposition was essentially constant in the southeastern areas during the Black Prince interval. The final Black Prince transgression occupied the entire basin of deposition.

Strata studied for this report are subdivided into five foraminiferal assemblage zones. The first of these zones contains a fauna that has been correlated with Chesterian faunas elsewhere in North America and indicates that initial Black Prince transgression began in the late Chesterian. The succeeding four faunal zones contain a microfauna that has been correlated with early, middle, and late Morrowan faunas in North America. The end of the Black Prince interval is marked by the abrupt appearance of an advanced Fusulinacean fauna which, elsewhere in North America, is typical of Atokan time.

Based on the distinctive lithologies and fauna observed in strata studied for this report it is here proposed that the Black Prince Limestone of Gilluly, Cooper, and Williams (1954) be redefined to include limestone and clastic strata in southeastern Arizona and southwestern New Mexico marked at the base by a prominent unconformity on top of the Escabrosa and Paradise Formations and at the top by the appearance of an advanced (post-Morrowan) Fusulinacean fauna. The name Black Prince Formation is proposed for these strata.

Explanation of Plate 1
All figures x100 unless noted

FAMILY OZAWAINELLIDAE

figure 1:	*Millerella* sp. 7;	section 5,	sample 5-2-A
figure 2:	*Millerella* sp. 7;	section 4,	sample 4-2-A
figure 3:	*Millerella* sp. 1;	section 4,	sample 4-12-B
figure 4:	*Millerella* sp. 1;	section 4,	sample 4-14-A
figure 5:	*Millerella* sp. 1;	section 5,	sample 5-2-A
figure 6:	*Millerella* sp. 2;	section 4,	sample 4-10-A
figure 7:	*Millerella* sp. 2;	section 14,	sample 14-10
figure 8:	*Millerella* sp. 2;	section 14,	sample 14-3
figure 9:	*Millerella* sp. 3;	section 5,	sample 5-4-B
figure 10:	*Millerella* sp. 3;	section 10,	sample 10-6-B
figure 11:	*Millerella* sp. 4;	section 4,	sample 4-26-A
figure 12:	*Millerella* sp. 4;	section 4,	sample 4-10-A
figure 13:	*Millerella* sp. 5;	section 14,	sample 14-10
figure 14:	*Millerella* sp. 5;	section 3,	sample 3-9-A
figure 15:	*Millerella* sp. 5;	section 3,	sample 3-9-A
figure 16:	*Millerella* sp. 5;	section 3,	sample 3-9-A
figure 17:	*Millerella* sp. 6;	section 4,	sample 4-20-B

Location of samples shown on Figure 10.


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Explanation of Plate 2
All figures x100 unless noted

FAMILY OZAWAINELLIDAE

figure 1: Eostaffella sp. 1; section 4, sample 4-18
figure 2: Eostaffella sp. 1; section 4, sample 4-31
figure 3: Eostaffella sp. 2; section 4, sample 4-10-A
figure 4: Eostaffella sp. 2; section 4, sample 4-10-A
figure 5: Eostaffella sp. 3; section 4, sample 4-8-A
figure 6: Eostaffella sp. 3; section 5, sample 5-5-C
figure 7: Eostaffella sp. 3; section 4, sample 4-16-A
figure 8: Eostaffella sp. 4; section 5, sample 5-4-F
figure 9: Eostaffella sp. 4; section 4, sample 4-22
figure 10: Eostaffella sp. 4; section 4, sample 4-16-A

FAMILY FUSULINIDAE

figure 11: Pseudostaffella sp. (x25); section 10; sample 10-12
figure 12: Pseudostaffella sp; section 14, sample 14-14
figure 13: Profusulinella sp; section 10, sample 10-12
figure 14: Profusulinella sp; section 12, sample 12-10

Location of samples shown on Figure 10.

Explanation of Plate 3
All figures x100 unless noted

FAMILY ARCHAEDISCIDAE

figure 1: _Archaediscus_ sp; section 12, sample 12-2
figure 2: _Archaediscus_ sp; section 12, sample 12-2
figure 3: _Archaediscus_ sp; section 5, sample 5-3-B
figure 4: _Brunsia_ sp; section 3, sample 3-2-A

FAMILY LASIODISCIDAE

figure 5: _Monotaxinoides_ sp; section 5, sample 5-3-B
figure 6: _Monotaxinoides_ sp; section 10, sample 10-5

FAMILY BISERIAMINIDAE

figure 7: _Globivalvulina_ sp. cf. G. _bulloides_, section 4, sample 4-12-A
figure 8: _Globivalvulina_ sp. cf. G. _moderata_, section 14, sample 14-14
figure 9: _Globivalvulina_ sp. cf. G. _moderata_, section 14, sample 14-15

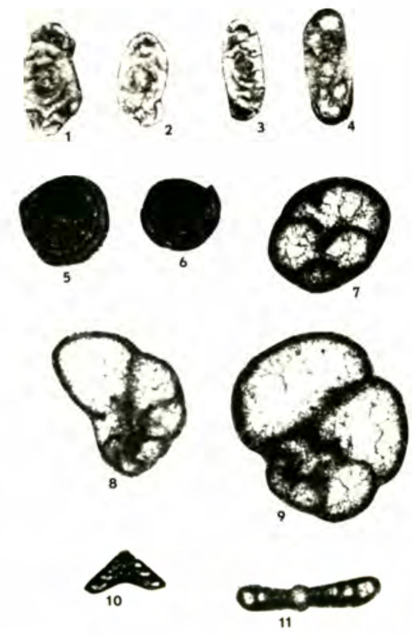
FAMILY TETRATAXIDAE

figure 10: _Valvulinella_ sp; section 10, sample 10-12

FAMILY TOURNAYELLIDAE

figure 11: _Tournayella_ sp; section 12, sample 12-2

Location of samples shown on Figure 10.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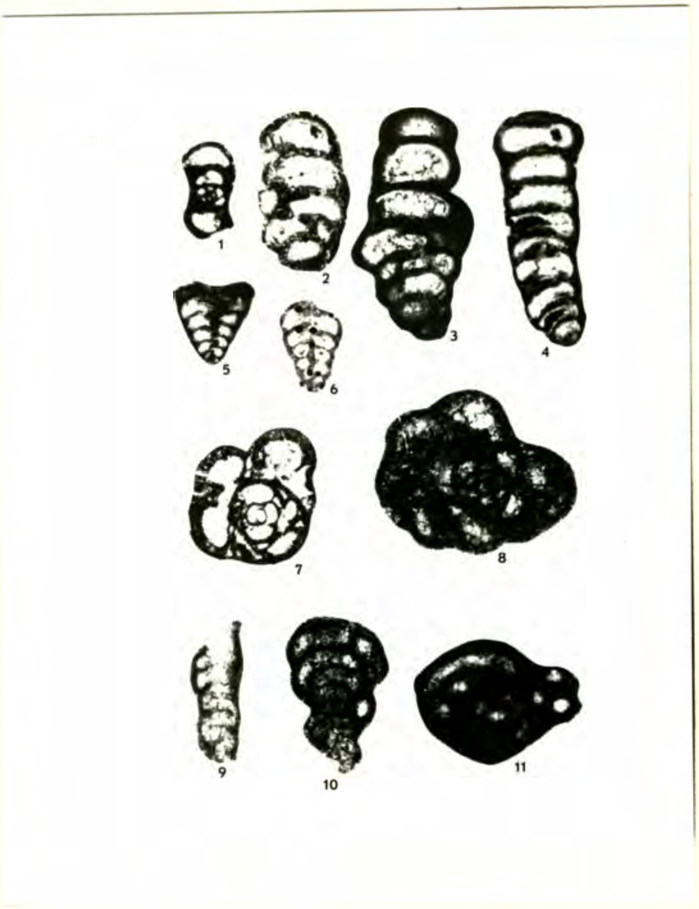
Explanation of Plate 4
All figures x100 unless noted

FAMILY ENDOTHYRIDAE
figure 1: Endothyra? sp; section 3, sample 3-2-A
figure 7: Bradyina sp; section 3, sample 3-9-A
figure 8: Cherneyshinella sp; section 16, sample 16-13-A

FAMILY PALEOTEXTULARIIDAE
figure 2: Climacammina sp; section 16, sample 16-7
figure 3: Climacammina sp; section 10, sample 10-12
figure 4: Paleobigenerina sp; section 16, sample 16-10-A
figure 5: Paleotextularia sp; section 3, sample 3-8-A
figure 6: Paleotextularia sp; section 14, sample 14-10

FAMILY FISHERINIDAE
figure 9: Calcivertella sp; section 10, sample 10-4
figure 10: Calcivertella sp; section 4, sample 4-10-A
figure 11: Calcivertella sp; section 4, sample 4-26-A

Location of samples shown on Figure 10.



REFERENCES CITED

Bathurst, R. G. C., 1966, Boring algae, micrite envelopes and lithification of molluscan biosparites, in Bathurst, R. G. C., Carbonate Sediments and Their Diagenesis: Amsterdam, Elsevier Scientific Publishing Company, p. 381.

__________________, 1976, Carbonate Sediments and Their Diagenesis: Amsterdam, Elsevier Scientific Publishing Company, 658 p.

Brenckle, P., 1977, Foraminifers and other calcareous microfossils from Late Chesterian (Mississippian) strata of northern Arkansas, in Sutherland, P. K., and Manger, W. L., eds., Upper Chesterian-Morrowan stratigraphy and the Mississippian-Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 73-87.

Cayeux, L., 1976, Les roches sedimentaires de Brance, in Bathurst, R. G. C., Carbonate Sediments and Their Diagenesis: Amsterdam, Elsevier Scientific Publishing Company, p. 301.

Donahue, J. D., 1976, Laboratory growth of pisolite grains, in Bathurst, R. G. C., Carbonate Sediments and Their Diagenesis: Amsterdam, Elsevier Scientific Publishing Company, p. 301.

Drewes, H., 1978, The Cordilleran orogenic belt between Nevada and Chihuahua: Geological Society of America Bulletin, v. 89, p. 641-657.

Folk, R. L., 1959, Practical petrographic classification of limestones: Bulletin American Association of Petroleum Geologists, v. 43, p. 1-38.

Gilluly, J., Cooper, J. R., and Williams, J. S., 1954, Late Paleozoic stratigraphy of central Cochise County, Arizona: U.S. Geological Survey Professional Paper 266, 49 p.

Irwin, M. L., 1965, General theory of epieric clear water sedimentation: Bulletin American Association of Petroleum Geologists, v. 49, p. 445-459.

Mamet, B. L., 1968, Foraminifera, Etherington Formation (Carboniferous), Alberta, Canada: Bulletin of Canadian Petroleum Geology, v. 16, no. 2, p. 167-179.

Nations, J. D., 1964, Evidence for a Morrowan age for the Black Prince Limestone of southeastern Arizona: Journal of Paleontology, v. 37, p. 1252-1264.

Ross, C. A., 1974, Pennsylvanian and early Permian depositional history, southeastern Arizona: Bulletin American Association of Petroleum Geologists, v. 57, no. 5, p. 887-912.

Ross, C. A., and Sabins, F. F., 1965, Early and Middle Pennsylvanian fusulinids from southeast Arizona: Journal of Paleontology, v. 39, no. 2, p. 173.

Ross, C. A., and Tyrrell, W. W., 1965, Pennsylvanian and Permian fusulinids from the Whetstone Mountains, southeast Arizona: Journal of Paleontology, v. 39, no. 4, p. 615.

Sabins, F. F., 1957a, Stratigraphic relations in the Chiricahua and Dos Cabezas Mountains, Arizona: Bulletin American Association of Petroleum Geologists, v. 41, p. 466-570.

______________, 1957b, Geology of the Cochise Head and western part of the Vanar quadrangles: Geological Society of America Bulletin, v. 68, p. 1315-1342.

Saunders, W. B., Ramsbottom, W. H. C., and Manger, W. L., 1979, Mesothemic cyclicity in the mid-Carboniferous Ozark shelf region?: Geology, v. 7, p. 293-296.

Thompson, M. L., 1944, Pennsylvanian Morrowan rocks and fusulinids of Kansas: Kansas Geological Survey Bulletin 52, p. 409-431.

______________, 1945, Pennsylvanian rocks and fusulinids of east Utah and northwest Colorado correlated with Kansas section: Kansas Geological Survey Bulletin 60, p. 17-84.

Zeller, D. E. N., 1953, Endothyrid Foraminifera and ancestral fusulinids from the type Chesterian (Upper Mississippian): Journal of Paleontology, v. 27, no. 2, p. 183-199.

______________, 1977, Microfauna from Chesterian (Mississippian) and Morrowan (Pennsylvanian) rocks in Washington County, Arkansas, and Adair and Muskogee Counties, Oklahoma, in Sutherland, P. K., and Manger, W. L., eds., Upper Chesterian-Morrowan stratigraphy and the Mississippian-Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, p. 89-99.