

AN ABSTRACT OF THE THESIS OF

Thomas Lee De Keyser for the degree of Doctor of Philosophy  
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Title: THE EARLY MISSISSIPPIAN OF THE SACRAMENTO  
MOUNTAINS, NEW MEXICO - AN ECOFACIES MODEL  
FOR CARBONATE SHELF MARGIN DEPOSITION

Abstract approved:

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J. G. Johnson

This study involves a combined ecosystem-modeling approach to clarification of organism-substrate-environment relationships. The methodology developed - ecofacies analysis - combines three submodels (paleontological, sedimentological, stratal) into a single ecofacies model for the reef ecosystem, the links between the submodels being provided by analogy with the Holocene reef ecosystem.

Analysis of the Devonian and Mississippian depositional sequences in the Sacramento Mountains, New Mexico, necessitates a clarification and reinterpretation of the included stratigraphic units and requires several revisions in the stratigraphic nomenclature:

(1) the Middle Devonian Oñate Formation was deposited as a thin blanket throughout the Sacramento Mountains; it was draped over a pre-Oñate structural (?) high, separating a shallow, silled basin on the north from a deeper, offshore basin on the south; (2) the early Late Devonian Sly Gap and late Late Devonian Percha (?) formations,

the Early Mississippian Kinderhookian Caballero Formation, and the Early Mississippian Osagean Andrecito Member of the Lake Valley Formation filled the silled basin and prograded beyond the buried pre-Oñate high as several successive clastic shelf margins; (3) an abrupt reduction in the supply of terrigenous clastic sediment due to a postulated rise in sea level allowed colonization by the pioneer communities of the reef ecosystem. The reefs localized north of a buried Percha (?) paleoshoreline and south of the silled basin, above the pre-Oñate high and the Caballero and Andrecito shelf margins; (4) reefs north of the Percha (?) paleoshoreline coalesced to form a carbonate shelf; those south of the silled basin did not and are preserved as pinnacle reefs; (5) the previously described Alamogordo, Nunn, and Tierra Blanca members of the Lake Valley are facies of the reefs; they have no chronostratigraphic value and their use is discontinued; (6) the superjacent Arcente and Dona Ana members of the Lake Valley are separated from the remainder of the formation by an unconformity; they are removed from the Lake Valley and raised to formational rank; (7) the Arcente was deposited below the tops of the Lake Valley (restricted) reefs, further reducing the water depth around them; (8) with a return to clear-water conditions and reef growth, the shelf margin prograded to a position at or near the Lake Valley pinnacle reefs.

Community analysis of the Lake Valley (restricted) brachiopod

fauna does not permit identification of particular communities of stable composition. It does recognize an upward, intra-reef community succession, from a deep, below-wave-base community of diverse, small, thin-shelled brachiopods to a shallow, above-wave-base community of large, thick-shelled brachiopods, dominated by Spirifer spp., Imbrexia spp., Unispirifer spp., Marginatia sp. A, and Pseudosyrinx missouriensis. Description of the brachiopod fauna within this ecofacies framework allows clarification of many ecologic relationships between species and suggests that intraspecific variation is generally much greater than has been supposed.

Two new species are described: Coledium sugarloafensis and Cranaena longicrura. Serial sections are illustrated for most of the 47 species described and, in the case of two species of terebratulids (Cranaena longicrura and Beecheria sp. A), these are supplemented by isometric drawings of the loop and cardinalia. This is a new technique in brachiopod illustration.

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The Early Mississippian of the Sacramento Mountains,  
New Mexico - an Ecofacies Model for  
Carbonate Shelf Margin Deposition

by

Thomas Lee De Keyser

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Professor of Geology  
in charge of major

Redacted for privacy

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Head of Department of Geology

Redacted for privacy

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Dean of Graduate School

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Typed by Opal Grossnicklaus for Thomas Lee De Keyser



#### FRONTISPIECE

Photo of a large block of weathered reef core, Little Sugarloaf Mound, showing complex depositional texture and apparently encrusting growth forms

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but is the author of the first and still the most accurate geologic map of the Sacramento Mountains escarpment.

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THE EARLY MISSISSIPPIAN OF THE SACRAMENTO  
MOUNTAINS, NEW MEXICO - AN ECOFACIES  
MODEL FOR CARBONATE SHELF  
MARGIN DEPOSITION

INTRODUCTION

The concept of communities of organisms is not new to geology or to paleontology. In the introduction to the first of his "Kinderhook faunal studies," Stuart Weller (1899, p. 9) stated that:

In order to work out the relationships existing between the various local assemblages or local societies of organisms which were living during Kinderhook time in the present Mississippi Valley, it is our purpose to make a careful study of as many separate ones of these fossil societies as can be secured. In each one of these studies the fossils from a single horizon at a single locality will be discussed, that is, those organisms which we know actually lived together and formed a social community.

In spite of this early awareness of the uniqueness and importance of paleocommunities, development of the concept lagged. Had it not been for the study by Elias (1937), who applied the concept to the Permian of Kansas, one might almost say it had been entirely forgotten.

In the mid-1960's, however, the community concept was revived in geology, it having become evident that, whatever the problems of recognizing and interpreting life assemblages (biocoenoses), death assemblages (thanatocoenoses), and mixed assemblages, the concept still worked when applied to real problems.

Whether communities were identified on the basis of intuitive

means (Ziegler, 1965) or by statistical methods (West, 1972), two rather different opinions on what was the principal control on community distribution became evident: depth and substrate.

In an earlier paper (De Keyser, 1977), I took the position that the principal control on community distribution was depth. That conclusion was based largely on the work of Petersen (1913, 1915), Ziegler (1965), and Ziegler, Cocks, and Bambach (1968). There was little or no evidence in the study itself which supported that conclusion except that in changing from one community to another, up-section, there did not appear to be any significant change in the character of the enclosing sediments.

The present study was conceived as a test of the relative importance of substrate and depth as controls on community distribution; the Early Mississippian of the Sacramento Mountains (Figure one) was chosen for several reasons: (1) influence of other workers - I had direct knowledge of the stratigraphy of the Mississippian and considerable field experience in it from association with Drs. L. R. Laudon, L. C. Pray, and H. R. Lane. These three persons had, respectively, published the first detailed studies of the Mississippian stratigraphy of both the Sacramento Mountains and of southwestern New Mexico (Laudon and Bowsler, 1941, 1949); mapped, in detail, the geology of the Sacramento Mountains (Pray, 1961) and published the most detailed study of the core facies of the bioherms/reefs first described

by Laudon and Bowsher in their 1941 study (Pray, 1958); and published the most detailed conodont biostratigraphic scheme for the Mississippian of the Sacramento Mountains (Lane, 1974). It was Lane who actually recommended the Sacramento Mountains as a study area; (2) presence of known depositional relief of approximately 100 m. - the large bioherms in the Lake Valley Formation, first identified by Laudon and Bowsher (1941), had been shown to have up to 100 m. of depositional relief within distances of as little as 0.5 km. Thus, the possibility existed that a semi-quantitative depth framework for the community distribution could be constructed; (3) complex facies relationships - It was also known that there were complex facies relationships associated with the Lake Valley reefs; these seemed to be related to the abrupt changes in the thickness of the stratigraphic units, themselves. Therefore, the possibility also existed to test for a relationship between substrate and community distribution; (4) existence of a detailed conodont biostratigraphic framework - the sequence of conodont Faunal Units of Lane (1974) provided vital control for the relative synchronicity of identified brachiopods, necessary in determining their lateral distribution at a given time.

Because it was, from its conception, searching for relationships and interrelationships, this study has been as much concerned with synthesis of descriptive data as with description itself. This

has required the development of a conceptual framework of relatively great complexity, that is, a model. In the sections which follow, both the desired model, incorporating depth, substrate, and community distribution, herein named an ecofacies model, and the methodology by which it was derived, herein termed ecofacies analysis, are described.

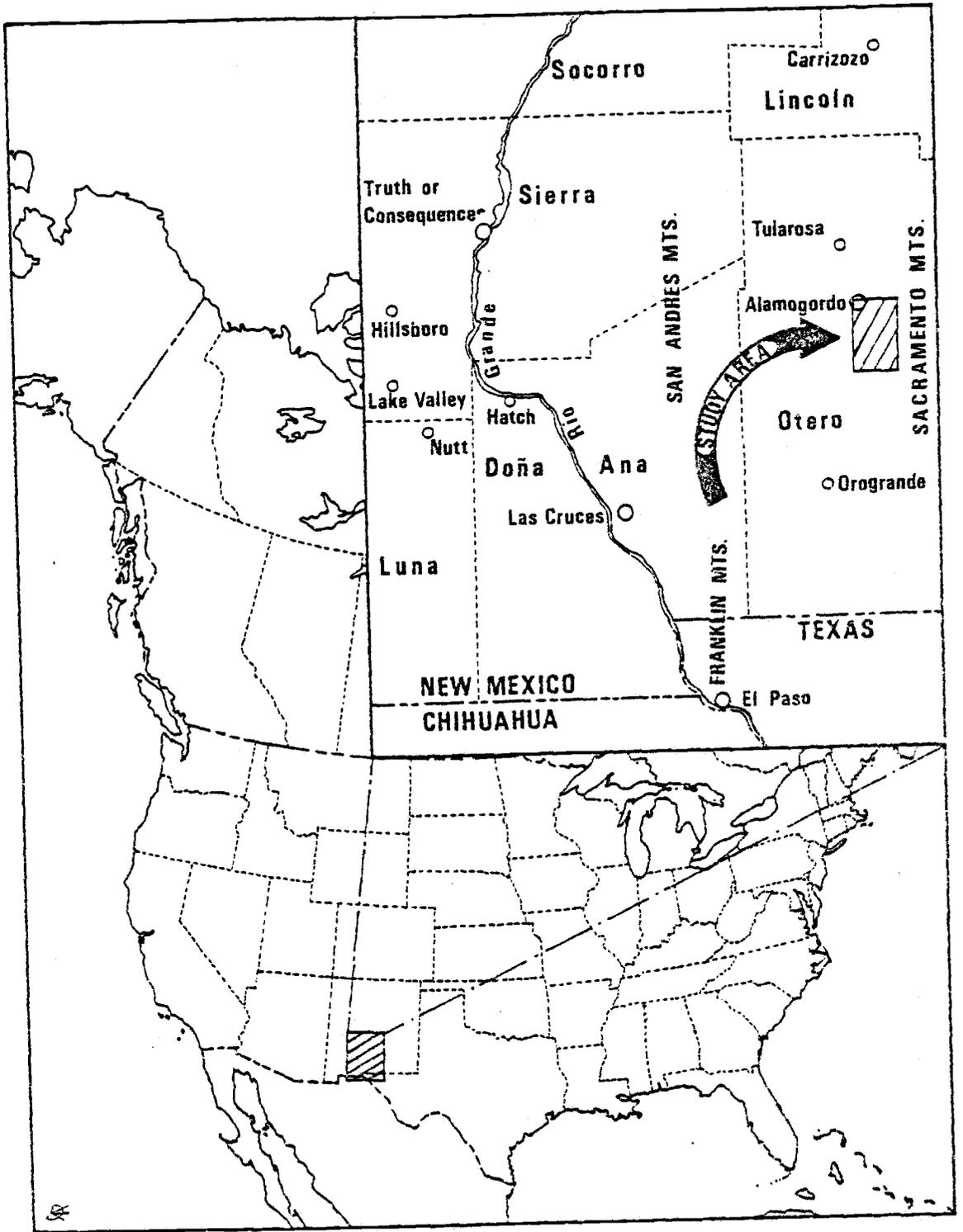


Figure 1. Map of south-central New Mexico showing principal areas referred to in text and (inset) location of study area.

## METHODOLOGY

Because of the setting of the Mississippian outcrop belt, in the west-facing escarpment of the fault block forming the Sacramento Mountains, it was convenient to select a series of sections along the escarpment and in the canyons cut into it (Figure 2). These sections were measured with a Jacob staff and abney level and, where more detail was necessary, with a steel tape. The section was recorded diagrammatically, to scale, in the field and the final sections drawn from field notes (Appendix C). Sampling for megafossils, conodonts, and lithology were extensive; virtually every fossiliferous horizon was sampled and conodont samples were taken above and below contacts, changes in lithology, and possible unconformities.

The data obtained from these sections, plus supplementary data from Laudon and Bowsher (1941) and Lane (1974) where necessary, were compiled as a transect from north to south, across what has been termed a carbonate shelf margin (Pray, 1975) (Figure 3).

With the exception of Miller (1881), Wachsmuth and Springer (1897), Muir-Wood and Cooper (1960), and Armstrong (1962), almost none of the megafauna of the Lake Valley and Caballero formations has been illustrated and described. Thus, description and illustration of the brachiopod fauna became an integral part of this study (Appendices A, D). For many taxa, it was difficult to place the New Mexico

species into one or another of the species described from the type Mississippian of the midcontinent. This may, in part, be due to the detailed nature of the sampling and the great ecological changes occurring in short distances. Further study will be required to resolve many of the taxonomic problems.

## LOCALITIES

Explanation - The locality numbers used in this report are keyed to the locality referencing system used by Amoco Production Co., Research Center, Tulsa, Oklahoma.

1. Locality 7719 - Alamo Canyon, Deadman Canyon Branch, East side, first tributary south of type section, W 1/2, SE 1/4, Section 3, T. 17 S., R. 10 E., Otero County, New Mexico.

2. Locality 7720 - Tepee Mound section; north side of first small canyon along front of escarpment north of mouth of Alamo Canyon, NE 1/4, SW 1/4, Section 34, T. 16 S., R. 10 E., Otero County, New Mexico.

3. Locality 7721 - Muleshoe North section; first tributary along front of escarpment, north of Muleshoe Mound, which cuts the escarpment formed by the Mississippian formations; NE 1/4, NW 1/4, Section 28, T. 17 S., R. 10 E., Otero County, New Mexico.

4. Locality 7722 - Muleshoe South section; first small tributary along front of escarpment, south of Muleshoe Canyon; NW 1/4, NE 1/4, Section 33, T. 17 S., R. 10 E., Otero County, New Mexico.

5. Locality 8242 - Lower Little Sugarloaf Mound section; N 1/2, NW 1/4, NW 1/4, Section 9, T. 18 S., R. 10 E., Otero County, New Mexico.

6. Locality 8243 - Upper Little Sugarloaf Mound section; NW 1/4,

NW 1/4, Section 9, T. 18 S., R. 10 E., Otero County, New Mexico.

7. Locality 8244 - South Little Sugarloaf Mound section; SW 1/4, NW 1/4, Section 10, T. 18 S., R. 10 E., Otero County, New Mexico.

8. Locality 8245 - San Andres Canyon section; E 1/2, NE 1/4, Section 33, T. 17 S., R. 10 E., Otero County, New Mexico. This section was measured approximately 100 m. west of Phantom Mound.

9. Locality 8246 - Dog Canyon North section; center of E 1/2, Section 10, T. 18 S., R. 10 E., Otero County, New Mexico.

10. Locality 8248 - Marble Canyon section, center of N. 1/2, Section 26, T. 16 S., R. 10 E., Otero County, New Mexico.

11. Locality 8249 - East Alamo Canyon section; NW 1/4, Section 7, T. 17 S., R. 11 E., Otero County, New Mexico.

12. Locality 9130 - Lead Canyon Section, SW 1/4, NW 1/4, Section 21, T. 17 S., R. 10 E., Otero County, New Mexico.

13. Locality 9131 - San Andres Mound section, N 1/2, Section 35, T. 17 S., R. 10 E., Otero County, New Mexico.

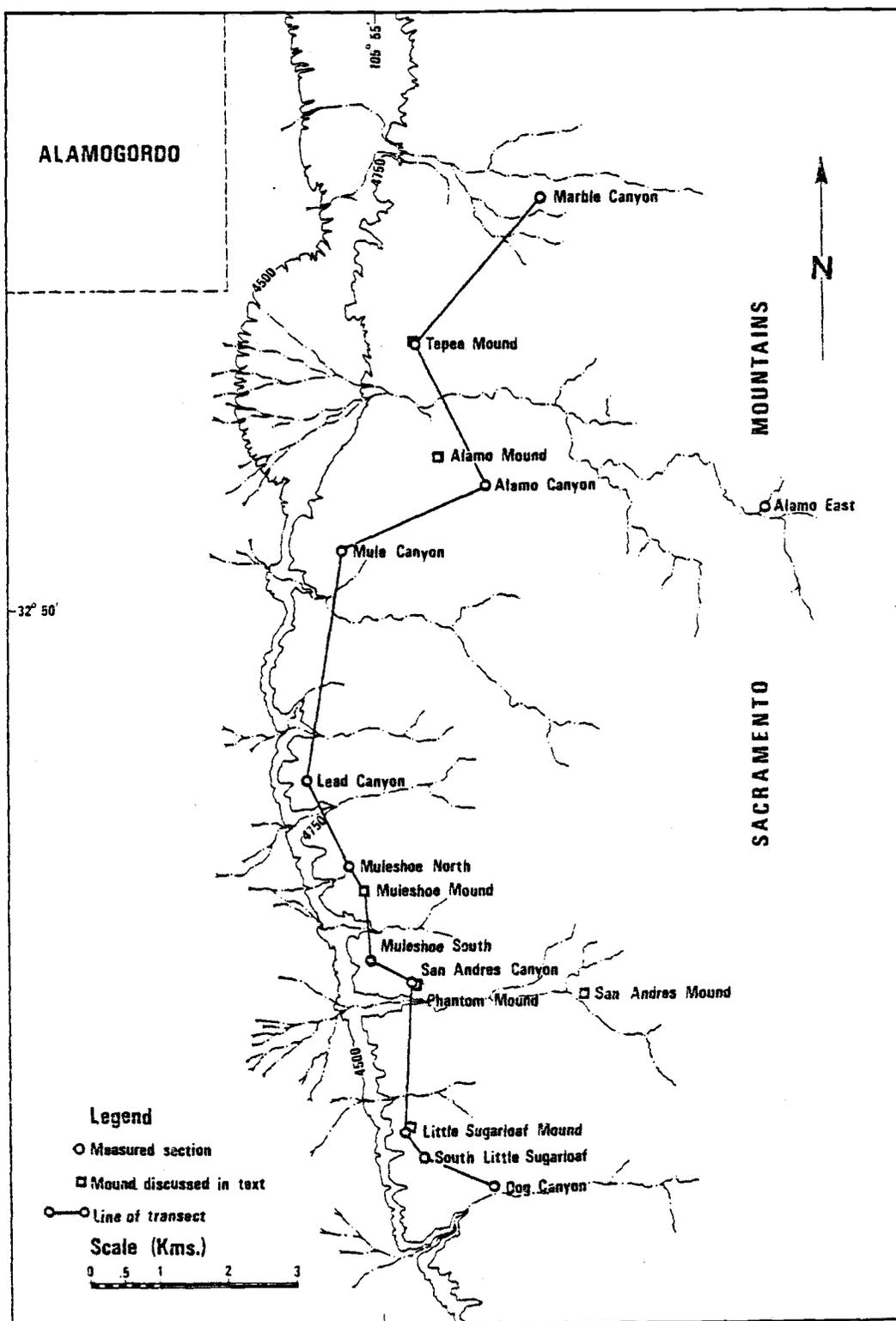


Figure 2. Simplified map of Sacramento Mountains escarpment showing location of sections used in construction of shelf-basin transect and of reefs referred to in text.

## RESTORED CROSS-SECTION OF SHELF-BASIN TRANSECT

An essential part of this study was the reconstruction of the paleobathymetry along the transect from the carbonate shelf, through the large basinal mounds, and into the starved basin. It seemed desirable to accomplish this largely on the basis of thickness and distribution of the stratigraphic units involved, i. e., the Mississippian Caballero, Lake Valley, Arcente, and Doña Ana formations and the subjacent, Devonian, Oñate, Sly Gap, and Percha (?) formations. Nearly all the data for such a cross-section were available from the present study but, where necessary, were supplemented with published information of Laudon and Bowsler (1941) and Lane (1974).

Assumptions used in the construction of the section are as follows: (1) The upper surface of the carbonate shelf was originally approximately horizontal. Thus, the top of the Lake Valley between Marble Canyon and Tepee Mound is represented as a horizontal line. (2) Inherited depositional topography of the base of the Lake Valley Formation is a composite of the thickness relationships and distribution of the preceding, non-biohermal formations. Thus, the Caballero Formation should provide the best basis for an approximation of paleobathymetry. Two principles were employed under this assumption: (a) where the Caballero is found to be thickening seaward, the top of the formation was made horizontal; (b) where the Caballero

was found to thin seaward, the base was drawn as a horizontal line. Thus, the overall stratal configuration and the paleobathymetry of the Lake Valley are not considered in the construction of the transect.

Several observations can be made from the resulting cross-section (Figure 3). Among the Devonian formations, only the Oñate is present along the entire transect. The overlying Sly Gap is present only to the north of the pre-Oñate "high" between Lead Canyon and San Adres Canyon. The Percha (?), absent at Tepee Mound, is present as a channel filling at the Marble Canyon section. South from Tepee Mound, it thickens, reaching a maximum of eight m. at Lead Canyon, then thins gradually and is absent at San Andres Canyon. The assumptions of depositional gradient applied to the Caballero result in an almost uniformly sloping depositional surface for the top of the unit as far as San Andres Canyon where there is a fairly abrupt break in slope. It is tempting to interpret this as a shelf margin for that depositional unit. The Andrecito Member of the Lake Valley Formation is the last essentially non-biohermal unit prior to the inception of mound growth. It is of nearly uniform thickness throughout the northern Sacramentos but thickens abruptly between San Andres Canyon and Little Sugarloaf Mound, beyond which it, too, thins.

With the inception of mound growth, the entire pattern of sediment thickness and distribution is profoundly altered. In the remainder of the Lake Valley, thickness increases toward the mounds and

depositional dips are quaquaversal away from them. Both of these characteristics began as slight tendencies and became increasingly dominant as the mounds continued to develop. Significantly, in the restored shelf basin transect (Figure 3), the tops of the carbonate shelf, Muleshoe Mound, and Little Sugarloaf Mound are all at virtually identical levels; a line drawn so as to connect their tops would make an essentially straight, horizontal line.

The Arcente Formation marks a return to a sedimentation pattern which reduces depositional relief; it was deposited in the basin, seaward of the shelf margin, and abuts against both the shelf margin and the large mounds. The Doña Ana, on the basis of thickness and distribution, also seems to have reduced the depositional relief by filling in between the mounds and along the seaward edge of the Lake Valley shelf. Based on other evidence, however, the Doña Ana can be shown to have been biohermal also. It exhibits many of the same facies and thickness relationships as can be seen in the Lake Valley.

It is evident, then, from the study of the overall configuration and thickness distribution of depositional units, that two fundamentally different types of deposition can be recognized in this transect. The Onate, Sly Gap, Percha (?) and Caballero formations; the Andrecito Member of the Lake Valley Formation; and the Arcente Formation, behave as passively-deposited sediment blankets which tend to

eliminate or reduce relief on the inherited depositional surface. The sediment source is predominantly extrabasinal. In the post-Andrecito Lake Valley Formation, a growth differential was established, with bioherms becoming point sources for sediment origin. The result is differentiation of the depositional surface and accentuation of inherited bottom topography, ultimately resulting in a flat, carbonate shelf area at or near sea level, separated from a sediment-starved basin by an abrupt shelf margin and steep slope.

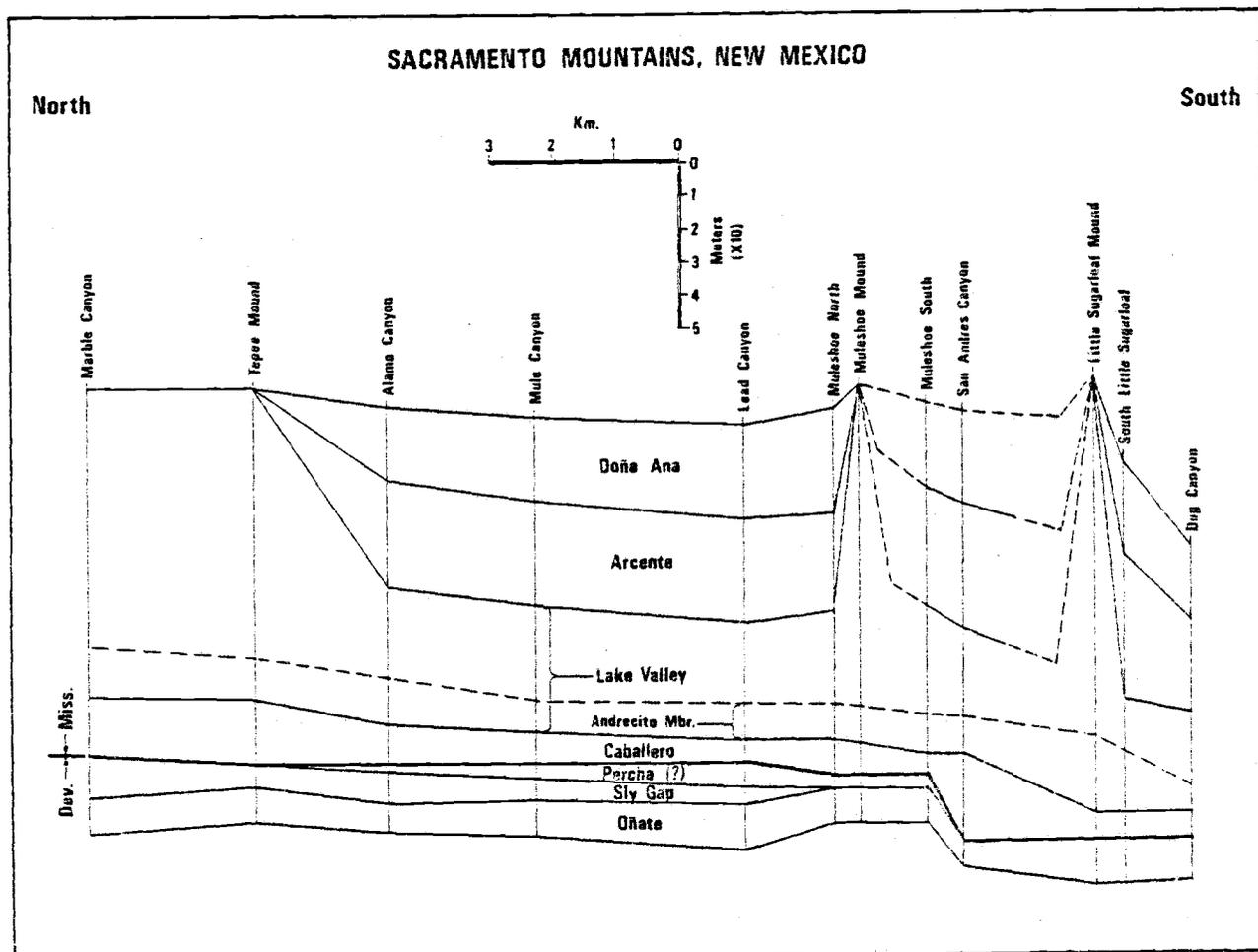


Figure 3. Restored shelf-basin transect along north-south fault escarpment of Sacramento Mountains, showing distribution and thickness of stratigraphic units referred to in text.

## STRATIGRAPHY OF DEVONIAN FORMATIONS

## Oñate Formation

The Oñate Formation (Stevenson, 1945) is the oldest Devonian formation present in the Sacramento Mountains. The type section is located on the north side of San Andres Canyon, San Andres Mountains, in Section 18, T. 18 S., R. 4 E., Dōna Ana County, New Mexico (Stevenson, 1945, p. 222). Because of military activities in the area, however, the type section is no longer accessible to the general public.

The Oñate is also the only Devonian formation continuous throughout the study area in the Sacramento Mountains. It disconformably overlies the Silurian Fusselman Formation. Exposures of the contact are uncommon but, where seen, the Oñate generally consists of approximately 0.5 m. of dark, silty shale overlying the weathered and eroded Fusselman. In eastern Alamo Canyon (Locality 8249), the base of the Oñate is conglomeratic, containing numerous clasts of dolomite and small chert pebbles eroded from the Fusselman. In San Andres Canyon, there appears to be several meters of relief on the Fusselman erosional surface. This is difficult to establish because of the imperfect nature of these streambed exposures.

The Oñate is lithologically variable. Along the north-south transect of Figure 3, these variations suggest a systematic change

toward more open marine, higher energy conditions southward. In the north, the formation is a silty, siliceous dolomite approximately 12 m. thick, containing numerous burrows and a small fauna consisting largely of chonetacean brachiopods and the ribbon-like bryozoan, Sulcoretopora anomalotruncata. Farther south, at Little Sugarloaf Mound, where the formation is 18 m. thick, it is more quartzose and has a larger, more diverse fauna containing rhynchonellids, Atrypa sp., and Schizophoria sp., suggestive of the Gypidula-Atrypa-Schizophoria Biofacies of Johnson (1974) or the atrypid-Schizophoria community of De Keyser (1977). In Dog Canyon, the southernmost area in which the Oñate Formation was examined in detail, the upper part of the formation has several thick (0.3-0.8 m.) sandstone beds containing numerous silicified brachiopods, most notably Atrypa sp. and Schizophoria sp. These beds were formerly included in the Sly Gap by Stevenson (1945, p. 234) and Laudon and Bowsher (1949) and in the Percha by Laudon and Bowsher (1941) but were correctly assigned to the Oñate by Pray (1961) and Bowsher (1967).

The Oñate Formation is unconformably overlain by the Sly Gap and Percha (?) formations in the northern and central parts of the Sacramento Mountains. In the southern part of the range (San Andres Canyon and south), the Oñate is overlain by a thin (0.2-0.4 m.), fissile, black shale also assigned to the Percha (?) Formation. Locally, as in Dog Canyon, this black shale may be absent and the

Oñate, then, is directly overlain by the Mississippian Caballero Formation. South of the study area, between Dog and Grapevine canyons, Pray (1961, p. 53) reported 2.4 to 4.6 m. of "light gray-brown, silty dolomite. . . overlain by dark-gray, noncalcareous fissile shale." He considered the lower, dolomitic strata to be Oñate and the overlying shales to be Percha in age.

Stevenson (1945) considered the Oñate to be late Middle Devonian or early Late Devonian in age. Cooper and Dutro (in prep.) based on conodonts and brachiopods, assign the Oñate a late Middle Devonian (Givetian) age. The Oñate was deposited during the Taghanic onlap of Johnson (1970).

#### Sly Gap Formation

Disconformably overlying the Oñate in the northern Sacramento Mountains is a six to 20 m. thick section of interbedded gray and black shales and silty, somewhat nodular limestones referred to the Sly Gap Formation by Stevenson (1945). Both brachiopods and conodonts place the age of these strata in the early Late Devonian (Frasnian) (Cooper, 1942; Johnson, 1976, oral comm.; Lane, 1978, written comm.). Previous authors have differed in their identification of these strata and which, if any, are of post-Sly Gap, Devonian age. The present definition and correlation of these strata differ from each of the previous classifications in one or more ways, hence,

some discussion is necessary.

Stainbrook (1935) was the first to study the Devonian strata in the Sacramento Mountains in any detail. He collected and described the fauna at a locality in the east end of Alamo Canyon (locality 8249), dated them as Late Devonian and correlated them with the Percha Formation, then the only Devonian formation known in New Mexico. This age assignment is imprecise; the Sly Gap is early Late Devonian (Frasnian) and the Percha is late Late Devonian (Famennian).

Laudon and Bowsher (1941) assigned all Devonian strata in the Sacramento Mountains to the Percha, perhaps following Stainbrook (1935). They were also undoubtedly influenced by Stevenson who, in a personal communication, informed them that his field studies in the area revealed three distinct units in the "so-called" Percha Formation, the upper one being separated from the others by a distinct angular unconformity (Laudon and Bowsher, 1941, p. 2111). In their stratigraphic sections: (1) "lower Percha" is approximately equal to the Oñate Formation; (2) "upper Percha" is approximately equivalent to the Sly Gap Formation; (3) the reference to a third member, unconformably overlying the other two, is a reference to a post-Sly Gap, pre-Caballero channel filling in Marble Canyon (locality 8248). This channel filling is assigned to the Percha (?) Formation and will be discussed under that heading. In the southern part of the range, San Andres Canyon and south, Laudon and Bowsher show only an

undifferentiated Percha (Laudon and Bowsher, 1941, Figures 22, 25-27); this is essentially equivalent to the Oñate Formation as recognized in this report.

Stevenson (1945) named the Oñate and Sly Gap formations for exposures in the San Andres Mountains, thereby providing names for the informal Percha units used by Laudon and Bowsher (1941) as previously discussed. He also discussed, but did not identify, the black shale channel filling in Marble Canyon (Stevenson, 1945).

In their second major study of the Mississippian strata of southwestern New Mexico, Laudon and Bowsher (1949) reclassified the Devonian strata in the Sacramento Mountains, recognizing both the Oñate and Sly Gap formations. They considered the Sly Gap to be overlain unconformably by the Mississippian Caballero Formation except at the Marble Canyon channel filling which they erroneously cite Stevenson (1945) as having assigned to the Contadero Formation (see discussion below under Percha (?) Formation). The undifferentiated Percha of Laudon and Bowsher (1941) was correlated with the Sly Gap and the Oñate was interpreted to be absent in the southern Sacramento Mountains. Stevenson (1945) and all subsequent workers (Pray, 1961; Bowsher, 1967; De Keyser, this report) have assumed essentially the opposite; namely, that the Sly Gap is absent in the southern part of the range. The Percha was not thought to be present in the Sacramento Mountains by Laudon and Bowsher (1949).

Pray (1961) also differed from earlier workers. He assigned the black channel filling in Marble Canyon to the Percha. The Devonian section in Dog Canyon, considered to be Sly Gap by Stevenson (1945, p. 234) and to be Oñate and Sly Gap by Laudon and Bowsher (1949, Figure 11), he assigned to the Oñate. He also assigned to the Oñate the Devonian strata in Escondido Canyon. These rocks had been correlated with the Sly Gap by Laudon and Bowsher (1949, Figure 11).

At a number of localities in the Sacramento Mountains, there is a thin (0.2-0.4 m.) section of black shale at the top of the Devonian section which is lithologically similar to the lower, Ready Pay Member of the Percha Formation. These black shales are shown at the top of the Devonian in each of the measured sections of Laudon and Bowsher (1941, Figures 16, 18, 21, 22, 25-27). Stevenson (1945, p. 243) mentions these black shales briefly, stating that:

The Ready Pay member [of the Percha] is believed to occur throughout southern New Mexico and probably in the Franklin Mountains of Texas. Black, fissile nonfossiliferous shale has been found above the Sly Gap and below the Mississippian formations in the Sacramento and San Andres Mountains.

Part of the problem, Pray (1961, p. 54) recognized, was that, at a number of localities in the Sacramento Mountains, such black shale occurs down in the Sly Gap where it may be overlain by nodular limestones of the Sly Gap. Where this happens, Pray concluded, the shales had been considered erroneously as Percha or Caballero and

the nodular limestones included in the Caballero (1961, p. 54). A second problem Pray encountered in correlating the Sly Gap southward in the Sacramento Mountains was that there are atypical strata at the top of the Sly Gap. He stated (1961, p. 55) that:

... In the vicinity of San Andres Canyon, a local section correlated as upper Sly Gap contains about 10 feet of thin- to medium-bedded, dark, argillaceous limestone and some 1- to 3-foot pods of replacement dolomite. Perhaps this part of the section is equivalent to the Contadero formation or even younger strata of pre-Percha, Upper Devonian age in the San Andres Mountains.

Thus, lithologic variation at the top of the Devonian section in the Sacramento Mountains was thought to be due to facies changes.

Where such strata are thickest, in the central part of the range, they were all assigned by Pray (1961) to the Sly Gap. In this report, these strata are assigned to the Percha (?) Formation, as is the black shale channel filling in Marble Canyon. The thin, black shale shown in an equivalent stratigraphic position by Laudon and Bowsher (1941, 1949), in sections in the southern part of the Sacramento Mountains, may also be of the same age, but was not studied in detail for this report.

#### Percha (?) Formation

The presence of the Percha Formation in the Sacramento Mountains has been suggested by several investigators (Laudon and Bowsher, 1941; Stevenson, 1945; Pray, 1961), but has never been proven. In the type area, along Percha Creek near Hillsboro,

New Mexico, the Percha has been divided (Stevenson, 1945) into a lower, black shale member, the Ready Pay Member, and an upper, gray, calcareous shale and silty, nodular limestone member, the Box Member. Because of the black shales present at or near the top of the Devonian section at many localities in the Sacramento Mountains, it is generally the Ready Pay Member which is considered to be present.

In this report, three groups of strata are identified as occurring in a stratigraphic position above the Sly Gap or Oñate formations and below the Mississippian Caballero Formation: (1) a black shale channel filling in Marble Canyon (locality 8248); (2) a thin lens of sedimentary strata (black shales; dark gray calcareous shales; dark, argillaceous limestones; thin, silty dolomites) at the localities between Alamo Canyon and San Andres Canyon; (3) a thin, black shale immediately below the base of the Caballero Formation in the southern part of the Sacramento Mountains (San Andres Canyon and south).

The Marble Canyon locality was known to Laudon and Bowsher (1941, 1949), Stevenson (1945) and Pray (1961). The exposure was discussed in detail by Stevenson and by Pray, hence, their interpretations are of interest.

Laudon and Bowsher (1941, p. 2111) considered the <sup>C</sup> Caballero, in the Sacramento Mountains, to be everywhere underlain by one of three members of the Percha Formation, the uppermost being



Figure 4. Photo of Marble Canyon section (Locality 8248), showing stratigraphic relationships at north end of erosional channel; A = Sly Gap Formation, B = Caballero Formation, C = Percha (?) Formation; person to right of letter "A" for scale (view is to west).

separated from the other two by an angular unconformity. This opinion was credited to personal communication of unpublished work of Stevenson (Laudon and Bowsher, 1941, p. 2111). However, Stevenson (1945, p. 236) stated that Bowsher had shared in the discovery of the Marble Canyon channel filling in the summer of 1939 and that, on later visits, he was accompanied by both Laudon and Bowsher, as well as by J. H. Bretz.

Stevenson (1945, p. 234-237) discussed the Marble Canyon channel filling at length, evidently attaching considerable significance to the stratigraphic relationships which it implied. As interpreted by Stevenson, a normal succession of Fusselman, Oñate, and Sly Gap formations is in angular contact with a section of black shales and thin sandstones; these formations are truncated by pre-Mississippian erosion and overlain by the Lake Valley Formation, the Caballero Formation being absent. The contact at the base of the black shales was thought to be a high angle, normal fault plane.

Careful study of this exposure, including measurement of three short sections through the affected interval, reveals that the interpretation of Stevenson is seriously in error. The black shales are not in fault contact with the Oñate and Sly Gap. Rather, they occur as a channel filling in a large erosional channel which cuts through the entire Sly Gap Formation and slightly into the underlying Oñate. The black shales reverse their dip when traced southward and, less than

100 m. away from the northern end of the exposure, can be seen to be rising again. Moreover, the Caballero Formation, thought to be absent by Stevenson (1945, p. 234), is 17 m. thick, excellently exposed and highly fossiliferous at this locality. In Figure 11 of Stevenson (1945, p. 235) (Figure 4), it corresponds to those strata marked "B" and identified as the Lake Valley Formation. The more thickly-bedded strata, visible at the top of the exposure, are the basal, Andrecito Member of the Lake Valley Formation. The beds marked "A" in the figure are the Sly Gap Formation; the black shales themselves, marked "C," were not assigned by Stevenson to any definite formation.

Later, Laudon and Bowsher (1949, p. 22-24) stated that:

... The basal Mississippian rocks rest on the Sly Gap formation with the exception of one local exposure in Marble Canyon where they rest on the Contadero Formation (Stevenson, 1945, p. 235).

This reference to Stevenson is incorrect; the only statement made by Stevenson as to the age of these black shales in Marble Canyon is that they are "post-Sly Gap and pre-Lake Valley" (Stevenson, 1945, p. 235).

Pray (1961) also studied the outcrop in detail and was the first to correctly interpret it as an erosional channel. He assigned these black shales in the Marble Canyon section to the Percha shale but considered all other black shales occurring in an equivalent stratigraphic position in the northern Sacramento Mountains to be part of

the Sly Gap Formation (Pray, 1961, p. 56).

The second occurrence of strata occupying this position in the section is represented by five measured sections at localities between Alamo Canyon and San Andres Canyon. The dark, argillaceous limestone and silty dolomite in the San Andres Canyon area, correlated as upper Sly Gap by Pray (1961, p. 55), are a part of this unit. Several factors point to their being the same depositional unit and not a facies of the underlying Sly Gap, in addition to their position in the section. Lithologically, they show a greater similarity in adjacent sections than they do to either the underlying Sly Gap Formation or the overlying Caballero. Their distribution also differs from both of these formations, being less widely distributed than the Caballero and occurring farther south than the Sly Gap. Thus, south of Lead Canyon, the Percha (?) Formation is directly in contact with the Oñate Formation.

Attempts to paleontologically correlate these black shales and argillaceous limestones with the Percha Shale in its type area have been unsuccessful. At the Marble Canyon section, only rare inarticulate brachiopods were found. In the sections between Alamo and San Andres canyons, a thin (0-.3 m.), brown shale at the base of the Percha (?) section yielded small strophomenid brachiopods but these do not seem to be forms representative of the Percha. Gastropods found in the fine-grained limestones have proven to be similarly

nondiagnostic. Finally, several large conodont samples failed to provide datable specimens. Until such time as these strata can be paleontologically dated, their assignment to the Percha Formation must be regarded as tentative.

The thin, black shales occurring in the southern part of the Sacramento Mountains may also be of the same age. They are apparently discontinuous, however, because, at Dog Canyon, the only locality where this third black shale occurrence was studied, the shale is present abutting the eroded end of an Oñate, silty dolomite stratum.

In summary, it seems probable that these three packages of strata (the black shale channel filling, the lens of black shale and argillaceous limestone, and the thin black shale) are part of a single depositional sequence. Based on the restored depositional transect (Figure 3), the channel filling (not shown on the transect) occurs landward of the paleoshoreline running approximately through Tepee Mound section (locality 7720). The lens appears to fill a shallow, "silled" basin north of a buried, possibly structural, pre-Oñate high and to have prograded slightly beyond it as a clastic shelf margin. The thin black shales in the southern part of the range (not shown on the transect, Figure 3) probably represent a thin, basinal equivalent deposited beyond the clastic shelf margin. The dark, argillaceous limestones occur at the seaward margin of the silled basin, where

energy levels would be higher, and beyond reach of most of the terrigenous clastics.

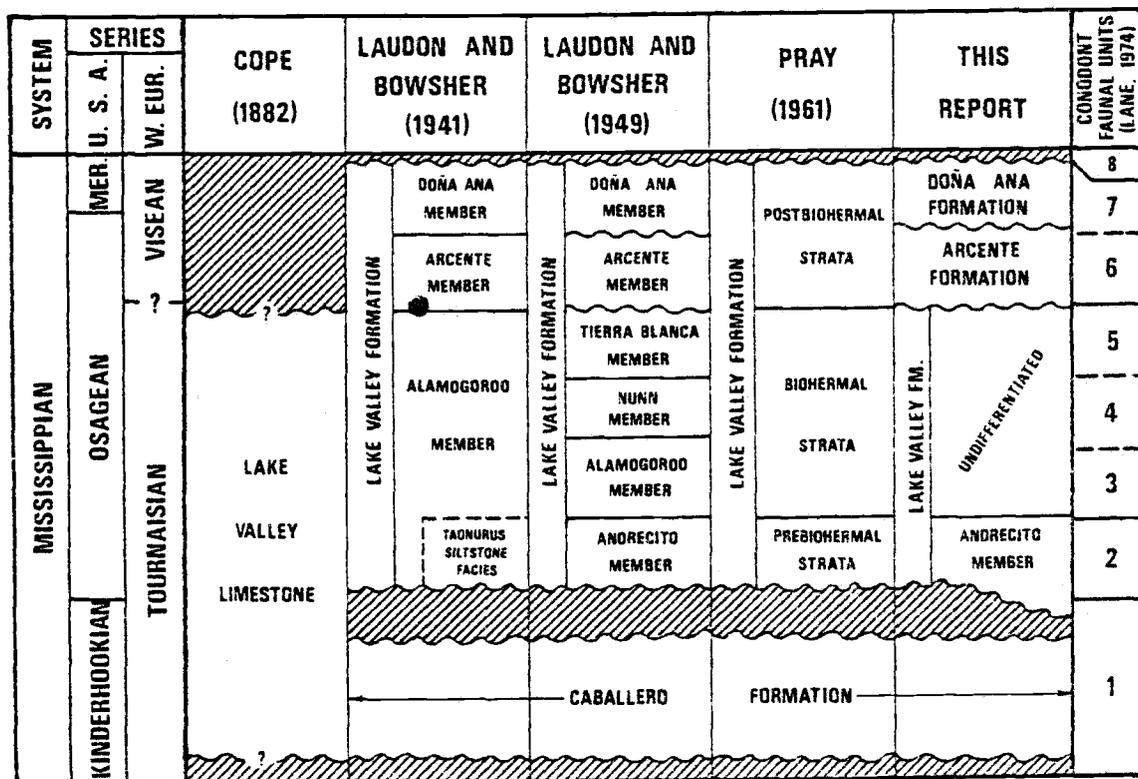


Figure 5. Correlation chart for Early Mississippian formations in Sacramento Mountains, showing changes in terminology.

## STRATIGRAPHY OF MISSISSIPPIAN FORMATIONS

## Caballero Formation

The Caballero Formation was named by Laudon and Bowsher (1941, p. 2114) to distinguish the "basal gray, nodular, shaly limestone beds," separated by a disconformity from the overlying Lake Valley Formation. These beds were originally included in the Lake Valley Formation (Cope, 1882; Figure 5) although this seems to have been as much the result of subsequent usage as by original designation. As early as 1894, Clark referred to a nodular limestone 48 feet (14.6 m.) thick at the base of the Mississippian section at Lake Valley, New Mexico. Not only is this thickness identical to that measured by Laudon and Bowsher (1949, p. 58), but the description of the unit given by Ellis (1894, p. 140), "nodules of limestone up to 2 or 3 inches in diameter, surrounded by a weak limestone cement," also closely agrees with that of Laudon and Bowsher. Nowhere, however, does Clark employ any term for these strata other than as Mississippian or by such terms as "nodular limestones." Somewhat later, Gordon (1907) published a section from the same locality as Clark, listing Clark's "nodular limestone" as the basal unit of the Lake Valley Formation. All subsequent authors until Laudon and Bowsher (1941) seem to have followed this usage.

The type section for the Caballero Formation is given by Laudon

and Bowsher (1941, p. 2114) as "the upper end of Deadman Canyon in the south center of Section 3, T. 17 S., R. 10 E., Otero County, New Mexico." This is actually a reference to Deadman Canyon Branch of Alamo Canyon, in the Sacramento Mountains, and is the same section as Locality 1 of Lane (1974). Locality 7719 of this report is located in the first narrow canyon south of the type section (approximately 100 m.).

Although described as a nodular, argillaceous limestone with interbedded, thin calcareous shales, there are significant facies changes that occur in the formation. At the northern localities (Figure three), the Caballero attains its thickest (17-20 m.), most characteristic development (only the San Andres Canyon section, Locality 8245, is thicker). This northern area corresponds approximately in distribution to the later, Lake Valley carbonate shelf. Southward along the transect, in the Mule Canyon and Lead Canyon areas, it thins markedly, seemingly losing most of the limestone beds, and is only 7.5 m. thick at Lead Canyon (Locality 9130). It thickens somewhat and becomes more fossiliferous in the vicinity of Muleshoe Mound, then abruptly thickens to 27 m. in the San Andres Canyon section. In the southern part of the transect, Little Sugarloaf Mound section and south, the Caballero again has abruptly thinned. It is approximately nine m. thick at Little Sugarloaf Mound and gradually thins to less than five m. in the southernmost exposures in the

Sacramento Mountains (Pray, 1961). Moreover, a short distance south of San Andres Canyon, the formation loses its nodular appearance, becoming more shaly and less fossiliferous.

Both the lower contact, with the Percha (?), Sly Gap and Oñate formations, and the upper contact, with the Andrecito Member of the Lake Valley Formation, are disconformable (Figures three, four). The Caballero rests on Percha (?) and Sly Gap at Marble Canyon (Locality 8248); on the Sly Gap at Tepee Mound (Locality 7720) and Alamo East (Locality 8249); on the Percha (?) at Alamo Canyon (Locality 7719), Mule Canyon, Lead Canyon (Locality 9130), Muleshoe North (Locality 7721) and Muleshoe South (Locality 7722); and on the Oñate from San Andres Canyon (Locality 8245) southward. Only at Marble Canyon can an angular unconformity be seen. The Caballero is overlain by the Andrecito everywhere in the Sacramento Mountains. Locally, as at the Alamo Canyon locality, the contact is an angular unconformity with several feet of relief.

Laudon and Bowsher (1941, p. 2123), based on invertebrate fossils, dated the Caballero as Kinderhookian in age and correlated it with the Chouteau Limestone of Missouri. Based on conodonts, the Caballero is middle to late Kinderhookian in age, equal to Faunal Unit 1 of Lane (1974, Figures 2, 4, p. 277). As defined by Lane, Faunal Unit (F. U.) 1 includes the Siphonodella sandbergi-Siphonodella duplicata Zone (Sandberg and Klapper, 1967, p. B47) through

the lower part of the Siphonodella cooperi hassi Subzone (Thompson and Fellows, 1970, p. 56). Perhaps because of this, there are some places where the Andrecito Member of the superjacent Lake Valley Formation is as old as F. U. 1. The Caballero itself becomes as young as the Gnathodus delicatus--Siphonodella cooperi cooperi Zone of Thompson and Fellows (1970, p. 55; Lane, 1974, p. 277, Figure 2). If this interpretation is correct, the Caballero can be correlated with the upper part of the Hannibal and all of the Chouteau in the type area.

#### Lake Valley Formation

The term Lake Valley has undergone considerable modification in both usage and content (Figure 5). In its initial usage (Cope, 1882), it referred in a very general way to the entire Mississippian limestone section above the Percha at the type section on Apache Hill, immediately north of Lake Valley, New Mexico. This usage became general with publication of Gordon's (1907) section and remained unchanged until the investigations of Laudon and Bowsher (1941, 1949).

Recognizing that the lower, "nodular limestone" of the Lake Valley (Clark, 1894) was of Kinderhookian age and separated from the remainder of the Lake Valley by an unconformity, Laudon and Bowsher (1941, p. 2114) named these beds the Caballero Formation and removed them from the Lake Valley. The second major change made by Laudon and Bowsher (1941) was the inclusion of additional

strata, the Arcente and Doña Ana, within the Lake Valley. These units are exposed in the Sacramento and San Andres Mountains, but are not present at the type section.

Because of the markedly different areal distribution, the abrupt change in lithology, and the unconformable nature of the contact between the Arcente and the underlying parts of the Lake Valley, it is proposed to remove the Arcente and Doña Ana members from the Lake Valley and to raise them to formational rank, viz., the Arcente Formation and the Doña Ana Formation. This has the added advantage of allowing each of the resulting formations to be discussed as a depositional sequence within which the facies identifiable are in genetic relation to each other (Figures three and five).

As restricted here, the Lake Valley Formation consists of the sequence of calcareous shales, silty limestones, biohermal limestones, and crinoidal packstones and grainstones lying above the Caballero Formation and below the Arcente and Doña Ana formations in the Sacramento and San Andres Mountains. At the type section at Apache Hill, Lake Valley, New Mexico, this would correspond to the same strata included in the original definition of the formation after removal of the Caballero. This also corresponds to the Alamogordo Member of Laudon and Bowsher (1941) and to the later-defined members: Andrecito, Alamogordo (restricted), Nunn and Tierra Blanca (Laudon and Bowsher, 1949, p. 11, 12).

The latter names were given to the vertical succession of lithologies observable at the (Laudon and Bowsher, 1941) type section in Deadman Canyon Branch of Alamo Canyon, in the south center of Section 3, T. 17 S., R. 10 E., and at the (Laudon and Bowsher, 1949) type section at Apache Hill. These sections were chosen by Laudon and Bowsher because they thought this was a representative stratigraphic section for the entire area. Yet, they also recognized that, in the vicinity of bioherms, this "normal succession" could not be recognized; there, the biohermal lithology represents the entire thickness of the formation above the Andrecito Member. There, also, the lithologic types representing the Nunn and Tierra Blanca members can be found as lateral correlatives of the bioherms, i. e., in facies relationship. Moreover, conodont biostratigraphy has demonstrated that the bioherms are equivalent in age to the Alamogordo, Nunn, and Tierra Blanca members combined. Thus, the member names of Laudon and Bowsher (1949) cannot be used in a time-stratigraphic sense.

Pray (1961, p. 59), in mapping the geology of the Sacramento Mountains escarpment, chose not to use the member names of Laudon and Bowsher. Instead, he found it convenient to subdivide the Lake Valley into prebiohermal, biohermal, and postbiohermal strata. This practice allows a more integrated discussion of the facies relationships associated with the bioherms. As employed by Pray, these terms

were equated to the member names of Laudon and Bowsher (1949) approximately as follows: prebiohermal = Andrecito; biohermal = Alamogordo, Nunn and Tierra Blanca, combined; postbiohermal = Arcente and Doña Ana. In the present paper, the Lake Valley (restricted) will be discussed in terms of only two subdivisions: a pre-biohermal, clastic unit corresponding to the Andrecito Member of Laudon and Bowsher (1949) and the remaining, undifferentiated part of the Lake Valley (restricted) which is characterized by the development of many bioherms and which can be differentiated into shelf, slope, and basin environments (Figures 2 and 3). The Arcente and the Doña Ana will be discussed separately in later sections of this paper.

Another prominent feature of the Early Mississippian strata in the Sacramento Mountains is the presence of great lateral variations in thickness. Specifically, the Caballero and Lake Valley (unrestricted) formations and the overlying, Late Mississippian Rancheria and Helms formations have been said to "form mutually compensating wedges that taper out toward the southeast and northwest respectively" (Pray, 1961, p. 59). This relationship was noted by Laudon (1948) and by Laudon and Bowsher (1949), but was attributed to uplift and erosional truncation of the Early Mississippian strata in the southern area followed by subsidence and deposition of the Late Mississippian strata (Laudon, 1948, Figure 6, p. 295), the two wedges of sediment being

separated by a widespread unconformity. The southward thinning was considered by Pray to be "caused both by variation of depositional thickness and by subsequent erosion along unconformities either during or subsequent to Mississippian-time" (Pray, 1961, p. 59). A third interpretation, that the Lake Valley (unrestricted) and Rancheria are in facies relationship, was presented by Armstrong (1962, p. 20).

Publication of the conodont biostratigraphy of the Sacramento Mountains (Lane, 1974) has confirmed the view of Pray (1961) and, in part, of Laudon (1948) and of Laudon and Bowsher (1949). The Lake Valley (unrestricted) and the Rancheria are not in facies relationship; they are separated by a distinct unconformity in most of the Sacramento Mountains area. Furthermore, the southward thinning of the Lake Valley (unrestricted) is largely the result of depositional thinning and intraformational unconformities, as suggested by Pray (1961).

Restriction of the Lake Valley Formation by removal of the Arcente and Doña Ana does not greatly alter this "wedge-on-wedge" interpretation. In fact, it further clarifies the thickness relationships, since the resulting stratigraphic units may be regarded as genetic increments in the basinal progradation of a carbonate shelf margin.

A third major feature of the Lake Valley Formation (restricted) is the presence of large carbonate mounds or bioherms, mentioned above in relation to the complex facies changes observable both laterally and vertically within the Lake Valley. Laudon and Bowsher were

the first to describe these carbonate buildups in the Sacramento Mountains where they are both numerous and excellently exposed. They were interpreted by Laudon and Bowsher (1941, p. 2126-2132) as biohermal in nature. It was recognized that they were formed, at least in part, contemporaneously with the surrounding sediments; that they rose considerably above the adjacent seafloor, resulting in high depositional dips; and that they were largely responsible for the complex facies relationships adjacent to the mounds. Nevertheless, they described the core of the bioherms as "distinctly and markedly unfossiliferous" (Laudon and Bowsher, 1941, p. 2129) and emphasized the abundance of crinoidal debris and the lack of corals as characteristics distinguishing them from "Silurian coral bioherms" (1941, p. 2127).

The presence of corals is not, in itself, a valid criterion for the existence of the reef ecosystem. The absence of corals from the reef ecosystem, the result of a late Frasnian extinction event, merely made that niche available to another group of organisms: the camerate crinoids. Neither is the core facies of the bioherms unfossiliferous. By systematically examining the surface of the exposed core, pockets containing abundant fossils (gastropods, bivalves, brachiopods, corals, bryozoans, and rare trilobites) can be found. Conodonts, rare or absent in the rest of the bioherm, are also present in significant numbers in these pockets. Such local

accumulations of invertebrate fossils probably represent depressions in the original growth surface of the reef where these invertebrates either grew or collected after death.

Perhaps influenced by Laudon and Bowsher's statement that the bioherms were unfossiliferous and by the apparent lack of a framebuilder, other, later workers have suggested other hypotheses for their formation. Pray (1958, 1961), influenced by Elias (1948, 1949; Elias and Condra (1957) and Parkinson (1957), suggested that fenestrate bryozoa may have served as current baffles, trapping lime mud and allowing contemporaneous, submarine cementation to stabilize the whole. The resulting mass, Pray felt, did not result in a wave-resistant framework although possibly capable of upward growth into somewhat turbulent water. He also recognized that, in other bioherms, bryozoa are not sufficiently numerous to have served such a function and that another mechanism is required. His conclusion was that (Pray, 1961, p. 65):

The bioherms are interpreted to have grown below the zone of appreciable wave abrasion. Many probably formed initially in relatively deep waters, and appear to have been capable of growth into somewhat turbulent waters.

Petrologic study of buildups of approximately the same age in Ireland has led to still another suggested mode of origin, this time largely inorganic (Schwartzacher, 1961; Lees, 1961). Although both authors emphasize inorganic aspects of the reefs, Lees discusses the presence of bioclastic material and the fossiliferous pockets (1961,

p. 104, 105). Rejecting the structural importance of fenestrate bryozoa in the development of the buildups, Lees (1961, p. 101) concludes that:

...the banks are accretionary structures formed in situ by accumulation of carbonate mud and bioclastic sand trapped and retained by organisms, probably plants, which are not preserved. Bryozoa acted as auxiliary supporting structures in some cases but do not form a framework.

Wilson (1975), in a summary of "the Lower Carboniferous Waulsortian facies," seems to favor a hypothesis combining current-shaping of hydrologic accumulations and sediment-entrapment by bryozoans and crinoids (Wilson, 1975, p. 166, 167):

Perhaps thickets of stalked crinoids, which supported masses of fenestrate bryozoans intertwined with them, offered effective baffles to gentle currents which commenced to heap up fine mud in lee areas in roughly conical piles. Once started, the perimeter of such piles was progressively colonized by crinoids and fenestrates which thrived as relative sea level rose. Their colonies gradually formed a wall-like thicket which surrounded and grew atop an increasing mound of mud. The quiet water within the growing ring of organic thickets accumulated mud and coarser bioclastic debris drifted down the flanks. Exposed to gentle currents on the slope and around the outside of the mounds, this flank material was winnowed clean of lime mud. A steadily rising sea level is envisaged, the top of the mound never reaching very close to wave base and remaining below the photic zone.

Wilson recognized the frequent association of such buildups with the shelf margin but considered them to be mostly a basal feature, accumulating below the level of the shelf, citing, "as a partial analog," the lithoherms described at 700 m. depth in the Straits of Florida

(Neumann, Keller, and Kofoed, 1972; Neumann, Kofoed, and Keller, 1977). There seems to be little if any basis for this suggestion (De Keyser, 1978).

In this paper, the buildups in the Lake Valley Formation are considered to be in-place accumulations of predominantly biological debris and to represent a constructional, organic substrate and accompanying, upward-shallowing, depth-related community succession, culminating in a shallow-water reef facies which is a direct analog of the modern tropical reef ecosystem. Integration of stratigraphic, lithologic, and paleontologic data allows the construction of a single, ecofacies model (new term) for the development of the reefs, the accompanying carbonate shelf, and the adjacent, offshore, starved basin.

The pronounced thickness variations in the Lake Valley (restricted) are directly related to the presence of the reefs (Figure 2). In the northern Sacramento Mountains, where the reefs are smaller and closer together, a carbonate shelf has developed; there, the Lake Valley is approximately 95 m. thick. South of this shelf, the formation thins abruptly to about 48 m. In this area, no reefs are developed. Still farther south, near Muleshoe and San Andres Canyons, several very large reefs cause local thickenings of the formation to 110-130 m. South of these large reefs, the Lake Valley again thins abruptly, to approximately 30 m. in Dog Canyon, and is apparently absent at

Grapevine Canyon at the southern end of the range (Pray, 1961).

A conodont sample from these southernmost exposures in Grapevine Canyon contained a mixed fauna, with Faunal Units 3 and 8 present in the same bed (Lane, 1978, in press). Whether this represents continuous sedimentation during this entire period or reworking of sediments and conodonts representing F. U. 3 into the basal beds of the overlying Rancheria Formation cannot be determined without additional field study.

The age of the Lake Valley was given as Osagean by Laudon and Bowsher (1941, 1949), based on brachiopods and crinoids. This agrees with the conodont biostratigraphy of Lane (1974) in which the Lake Valley, as restricted herein, corresponds to Faunal Units 2 through 5 (Lane, 1974, p. 273). This correlates closely with the age of the Burlington Shelf (Lane, 1978, in press).

#### Arcente Formation

Laudon and Bowsher (1941, p. 2116) proposed the name Arcente Member for the approximately 33 m. of thin- to thick-bedded, medium to dark gray, silty lime mudstones and thin, interbedded calcareous shales overlying the Alamogordo Member of the Lake Valley (= Andre-cito, Alamogordo, Nunn and Tierra Blanca members of Laudon and Bowsher, 1949; = Lake Valley Formation as redefined herein) and overlain by the crinoidal wackestones, packstones and grainstones

and reef progradations of the Doña Ana Member of the Lake Valley Formation (= Doña Ana Formation as redefined herein). As discussed above, it is proposed herein to remove the Arcente from the Lake Valley Formation and raise it to formational rank. The Arcente Formation represents a single depositional sequence; its lithology, distribution and thickness all differ markedly from the underlying Lake Valley. It lies unconformably on the Lake Valley and, although it does exhibit some facies changes, these are, generally, unlike those in the Lake Valley and, together, constitute a set of genetically-related, laterally-correlative environments. These limestones were mistakenly referred to by Laudon and Bowsher as siltstones. The type section, designated by Laudon and Bowsher (1941, p. 2116), is located in the south center of Section 3, T. 17 S., R. 10 E., Otero County, New Mexico, in Deadman Canyon Branch of Alamo Canyon.

The distribution and thickness of the Arcente Formation is closely related to the depositional topography resulting from reef development in the underlying Lake Valley Formation. As the Lake Valley abruptly thins to the southeast along a northeast-southwest line, the Arcente thickens in a compensatory manner. It again thins and pinches out against the sides of the large reefs which developed basinward from the Lake Valley shelf edge. Its effect, therefore, is to diminish the depositional relief caused by Lake Valley reef growth. South of the large reefs, the Arcente again thins rapidly and is absent

in the southern part of the range. The overall external form of the Arcente, in a shelf-basin transect, can be described as a lens in a slope front fill position (Mitchum, Vail, and Sangree, 1977).

In general, the Arcente seems to have been inhospitable to growth of the large populations of crinoids which characterize the Lake Valley reef and shelf sediments. There is little evidence that there was any significant reef growth in the area during deposition of the Arcente. However, conodonts indicative of Faunal Unit 6 (Lane, 1977, written comm.) were recovered from the top of San Andres Mound, near the east end of San Andres Canyon (Figure 2). This is one of the large, basinal reefs which rise abruptly through the Arcente, Doña Ana, Rancheria and Helms formations and even up into the Pennsylvanian Gobbler Formation. Hence it is likely that reef growth could have continued or been reestablished on such a prominent topographic feature rising abruptly from the adjacent deep waters where argillaceous sediments were being deposited. Due to lack of adequate exposures and apparent structural complications, it was not possible to confirm the stratigraphic relationships in and adjacent to the San Andres Mound.

The base of the Arcente is interpreted to be unconformable on the underlying Lake Valley, corresponding approximately to the boundary between Faunal Units 5 and 6 of Lane (1974). Physical evidence for this interpretation is of several types. Perhaps most significant

is the markedly different areal distribution of the Arcente with respect to the underlying Lake Valley. The Arcente is exposed only in the San Andres and Sacramento mountains, to the south and east (basinward) of the Lake Valley shelf margin. The variations in thickness of the Arcente, as discussed above, also indicate the presence of such an unconformity. Whereas relief on the Lake Valley depositional surface increased with time, the opposite is true of the Arcente. With its onlapping stratal terminations and divergent internal stratal configuration, the Arcente reduced the inherited depositional topography with time.

Laudon and Bowsher initially concluded that, in spite of the unconformity suggested by these stratigraphic relations, there was little or no time break between the Lake Valley and the Arcente (1941, p. 2133-2135). Later, this opinion was revised when they stated that (1949, p. 29):

The Arcente... was thought to rest conformably on the underlying [Lake Valley] (Laudon and Bowsher, 1941, p. 2135) but the rapid changes in thickness suggest marked unconformity. Recent studies of the contact indicate that the Arcente... rests unconformably on the underlying beds.

Although covered at many localities by slumping of the lower, argillaceous beds of the Arcente, the contact, where exposed, is only represented as a sharp lithologic break, accompanied by a "persistent thin silty sandy zone at the base and local thin red oxidized streaks along the contact" (Laudon and Bowsher, 1941, p. 2135). In other

areas, however, angular relations can be seen. On the south side of Little Sugarloaf Mound, the basal beds of the Arcente, dated as Faunal Unit 6 of Lane (1974; 1977, written comm.) can be seen to lie with abrupt, angular unconformity against the side of the Lake Valley part of the reef. The Arcente thickens rapidly away from the mound, primarily by addition of beds within the formation. At the same outcrop, the Doña Ana can be seen resting unconformably on the Arcente.

In Ash Canyon, in the San Andres Mountains, Laudon and Bowsher (1949, p. 45) noted that:

In a few local areas along the north wall of the canyon thin deposits of both Arcente and Doña Ana... are exposed in erosional valleys cut in the [Lake Valley] surface.

They noted a similar relationship in San Andres Canyon, San Andres Mountains (Laudon and Bowsher, 1949, p. 47):

The Arcente..., 14 feet [4.3 m.] thick, rests unconformably on the [Lake Valley], with a sharply defined boundary. Considerable relief and evidence of solution are apparent on the [Lake Valley] surface. Marked changes in thickness are also discernible within short distances. Rounded, abraded, apparently reworked fossils occur in the basal few inches of the Arcente....

Thus, the conclusion reached in the present investigation, that the Arcente Formation unconformably overlies the Lake Valley Formation, is in agreement with that of Laudon and Bowsher (1949).

Based on invertebrate fossils, Laudon and Bowsher (1941) assigned the Arcente to the early Osagean, noting that, of the 21 species collected by them, seven were known from the Kinderhookian

and all were known from the Osage. In the Faunal Unit scheme of Lane (1974), the Arcente apparently represents all of F. U. 6 and, possibly, part of F. U. 7. It must be noted, however, that this relationship is not consistent in all of Lane's sections. In Alamo Canyon, at the type section, the top of the Arcente is F. U. 7 in age (Lane, 1974, Figure 3); at Dog Canyon, the contact between the Arcente and Doña Ana is shown to correspond with the break between F. U. 6 and F. U. 7 (Lane, 1974, Figure 5); at Agua Chiquita Canyon, the Arcente is shown as F. U. 7 (?) in age (Lane, 1974, Figure 6). This apparent discrepancy in the age of the Arcente may be a result of the criteria used in identifying the Arcente-Doña Ana contact. As noted by Laudon and Bowsher (1941, p. 2136):

The Arcente [Formation]... grades upward into the Doña Ana [Formation] with no signs of disconformity. It is generally difficult to place the contact between the [formations]. The basal portion of the Doña Ana is in many places interbedded with silts very similar to those of the Arcente.

In the present study, the Arcente-Doña Ana contact is considered to be an unconformity. On the south side of Little Sugarloaf Mound, where the Arcente strata terminate against the side of the Lake Valley reef in an onlapping relationship, the Arcente is overlain unconformably by a Doña Ana age reef progradation. A conodont sample collected from the Arcente immediately below the contact was dated as F. U. 6 (Lane, written comm., 1977). In other sections, identification of the Arcente-Doña Ana contact is more difficult. If

selection is based on lithologic criteria alone, i. e., the first appearance of cherty, crinoidal limestone, the contact may be placed many feet higher than its position when chosen on stratal criteria also.

By careful attention to stratal configuration, it is possible to identify a single, unconformable contact. Specifically, identification of such a contact is based on the relationship of the strata above and below the contact to the contact itself (Mitchum, Vail, Sangree and Thompson, 1977). The internal stratal configurations of the Arcente and Doña Ana are markedly different, representing separate and distinct depositional sequences. The Arcente, as mentioned above, has a parallel to divergent stratal configuration with good lateral continuity to individual beds; the Doña Ana displays a complex, lenticular or prograding clinoform stratal configuration (Mitchum, Vail, Sangree and Thompson, 1977), reflecting sediment origin and deposition prograding outward from centers of reef growth. This interpretation remains subject to confirmation by additional conodont dating.

#### Doña Ana Formation

The name Doña Ana Formation is proposed for strata designated Doña Ana Member of the Lake Valley Formation by Laudon and Bowsher (1941, p. 2116). The type section is retained in the south center of Section 3, T. 17 S., R. 10 E., Deadman Canyon Branch of Alamo Canyon, Otero County, New Mexico.

Like the Arcente Formation, the Doña Ana has a markedly different distribution than the Lake Valley, being confined to the San Andres and Sacramento Mountains outcrop belts, generally south and east of the Lake Valley carbonate shelf margin. Its thickness, too, varies in a manner similar to that of the Arcente. It thickens basinward from the Lake Valley shelf margin and away from the large reefs, reaching its maximum thickness immediately south of these reefs and then abruptly thinning.

In the Sacramento Mountains, the Doña Ana is absent north of Alamo Canyon and thickens abruptly to approximately 28 m. at Lead Canyon (7.8 km. distant). It reaches a maximum of nearly 35 m. adjacent to Little Sugarloaf Mound, then thins southward (Figure 3). It is again absent in the southern end of the Sacramento Mountains, in Grapevine Canyon. Overall, its external geometry is that of a lens, occupying a slope front fill position much like the subjacent Arcente Formation.

Lithologically, however, the Doña Ana is markedly different from the underlying Arcente. Reef development, absent from the Arcente, is again present in the Doña Ana, resulting in discernible facies changes. The only well-exposed reef is on the south flank of Little Sugarloaf Mound. It appears not to have grown above the earlier Lake Valley reef, but to have colonized the side of that structure and prograded away from it, as can be seen by the

steeply-dipping crinoidal flank beds. In sections near such centers of reef growth, the transition from lime mudstone or wackestone to crinoidal packstone and grainstone is abrupt. In sections farther away from centers of reef growth, this transition is more gradual, the change to crinoidal limestone occurring over a vertical distance of up to 15 m. Thus, there is a broad similarity in depositional pattern between the Doña Ana and the late stages of Lake Valley deposition, with deposition controlled by and prograding outward from centers of reef growth, ultimately coalescing to form a shallow water carbonate shelf. This Doña Ana shelf represents a basinward progradation of the earlier Lake Valley shelf margin to a position at or just basinward from the large, isolated, Lake Valley reefs.

As was discussed above under the Arcente Formation, this pattern of deposition makes the Arcente-Doña Ana contact appear gradational in many sections. Repeated examination of this contact in different sections, however, using stratal configuration as well as lithologic criteria, allows recognition of a single, distinct break above which the variable transition to crinoidal packstone and grainstone takes place. It is this break which is chosen as the Arcente-Doña Ana contact. If the contact is chosen on purely lithologic grounds, i. e., the appearance of crinoidal packstone and grainstone, the contact will appear to become younger away from centers of reef growth. This fact may help to explain the apparent inconsistency in placement of the

Arcente-Doña Ana boundary in the Faunal Unit scheme of Lane (1974).

In their initial studies of the Mississippian of the Sacramento Mountains, Laudon and Bowsher (1941, p. 2137) considered the Arcente-Doña Ana contact to be conformable and gradational. In the San Andres Mountains, however (1941, p. 2156), they noted evidence of local unconformity between the Arcente and Doña Ana:

"Local hills appear to be left on the Arcente surface and the Doña Ana... overlaps them." Later, they described this relationship, observed in San Andres Canyon in the San Andres Mountains, in greater detail (1949, p. 47):

Along parts of the north canyon wall, the boundary between the Arcente and Doña Ana appears to be unconformable, and at one place the Arcente appears to have been overlapped by the Doña Ana.

Additional evidence for an unconformable contact may be found in the exposures on the south side of Little Sugarloaf Mound. At that location, as mentioned earlier, the eroded surface of the Lake Valley reef can be seen in contact with both the Arcente and the Doña Ana.

The latter rests abruptly on top of an irregular Arcente surface. The Arcente beds abut the base of the Doña Ana reef progradation. Thus, the basal contact of the Doña Ana is considered to be an unconformity.

The upper contact of the Doña Ana, with the Rancheria Formation and with the Pennsylvanian, is an unconformity (Laudon and Bowsher, 1941, 1949; Pray, 1961). Conodont biostratigraphy (Lane,

1974) indicates that the time represented by this hiatus decreases southward, suggesting northward onlap by the Late Mississippian Rancheria Formation.

EARLY MISSISSIPPIAN ("WAULSORTIAN") REEFS IN THE  
SACRAMENTO MOUNTAINS: STRATIGRAPHIC  
RELATIONSHIPS AND CONFIGURATION

The presence of organic carbonate buildups in Early Carboniferous (Mississippian) rocks was first reported by Tiddeman (1889) in England. Application of the term "Waulsortian" to these reefs has been a common practice, based on the abundance of crinoids and bryozoans in the massive core of both the Mississippian examples and of the Devonian (Frasnian) reefs to which the term was originally applied (Lecompte, 1936, 1937). There have been numerous reports of similar reefs in North America, including: Tennessee (Fort Payne Chert) (Marcher, 1963); the southern Ozarks (St. Joe Limestone in northeast Oklahoma; = Compton, Northview and Pierson formations in northwest Arkansas and southwest Missouri) (Purdue and Mizer, 1916; Laudon, 1939; Clark, 1941; Harbaugh, 1957; Troell, 1962; Thompson and Fellows, 1970); Montana (Paine Member of Lodgepole Formation) (Merriam, 1958, in Cotter, 1965; Stone, 1972; Smith, 1977); northern Alberta (Pekisko Formation) (Morgan and Jackson, 1970).

In New Mexico, such reefs are well known in the Lake Valley Formation in the Sacramento and San Andres Mountains. The first mention of these reefs is by Laudon (1939), although Laudon and Bowsher (1941) are usually given credit for the discovery since field

work for the latter paper was started in 1936 (Laudon and Bowsher, 1941, p. 2107).

The following discussion is intended to provide an empirical basis for the conceptual model of reef growth and carbonate shelf development which will be presented later. Of particular importance are details of reef substrate, size, overall geometry, stratal configuration and relationships, chronostratigraphic relationships, community succession and nature and distribution of associated, reef-derived, facies. Each reef examined will be discussed individually, beginning in the shelf area and proceeding to the larger, basinal reefs.

Many of these reefs have been recognized principally by their present, mound-like, topographic shape without regard for their mode of origin. Thus, they have been informally called knoll reefs in Great Britain (Tiddeman..., 1889) and mounds in New Mexico (Pray, 1958).

#### Tepee Mound

This mound, so named because of the distinctive shape of its massive core, with steep, evenly-sloping sides and narrow top, can be seen from the road leading southeast from Alamogordo to the mouth of Alamo Canyon. It is exposed in the south-facing cliff on the north side of the first small canyon north of the mouth of

Alamo Canyon, in SW 1/4, Section 34, T. 16 S., R. 10 E., Otero County, New Mexico (Locality 7720) (Figures 2, 6).

Tepee Mound is the best example of the two-part division of these reefs to be seen in the Sacramento Mountains, although it is largely inaccessible for sampling. The base of the mound can be seen resting on grain-supported encrinites which are somewhat depressed by the weight of the reef. The contact is abrupt, with no sign of gradation or interbedding. Along the eastern edge of the exposure, it is possible to climb up the flank of the core nearly to its top. Here, again, the integrity of the contact between the massive core and the enclosing sediments is unbroken by gradation or interbedding; it is everywhere "knife-sharp." The enclosing beds of crinoidal marls and encrinites appear to thin and terminate against the massive core in an onlapping relationship. The entire massive, tepee-shaped core of the reef is approximately 20 m. high.

Overlying the steep-sided lower core without obvious disconformity is a second stage of mound development. This upper, later stage of mound growth could not be directly examined. However, visual examination from directly below and by telephoto lens from several angles consistently gives the impression of a massive, crinoid-rich, unbedded, hard substrate which grew upward an additional approximately 20 m. and prograded outward over the flank beds shed from it (Figure 6).



Figure 6. Photo of Tepee Mound (Locality 7720), showing massive, unbedded lower reef core and progradations of upper reef core over flank beds (view is to northeast).

Where exposures are suitable, i. e., more or less through the center of the reef mass, this two-part subdivision of the mounds is always present. In the succeeding discussion, the lower, steep-sided, massive core, lacking flank beds, will be referred to as the lower reef core; the upper, prograding, crinoid-rich, unbedded core will be referred to as the upper reef core.

#### Alamo Mound

Exposed in the west wall of Deadman Canyon Branch of Alamo Canyon, in the W. 1/2 of Section 3, T. 17 S., R. 10 E., is another, somewhat larger mound here referred to as Alamo Mound (= bioherm number 27 of Bowsher, 1948). It is located almost directly west of Laudon and Bowsher's (1941) type section of the Lake Valley Formation (= Locality one of Lane, 1974).

Although the section through the reef is essentially at a right angle to the section through Tepee Mound, the same essential features are distinguishable. Again, there is a lower, massive, steep-sided core similar in appearance to that exposed in Tepee Mound. It also is surmounted by a more crinoidal-rich, upper reef core which, upon attaining a maximum upward extent, began prograding out over bedded, crinoidal packstone and grainstone flank beds shed from the advancing upper reef core. Alamo Mound was apparently situated at or slightly beyond the margin of the carbonate shelf which can be seen exposed

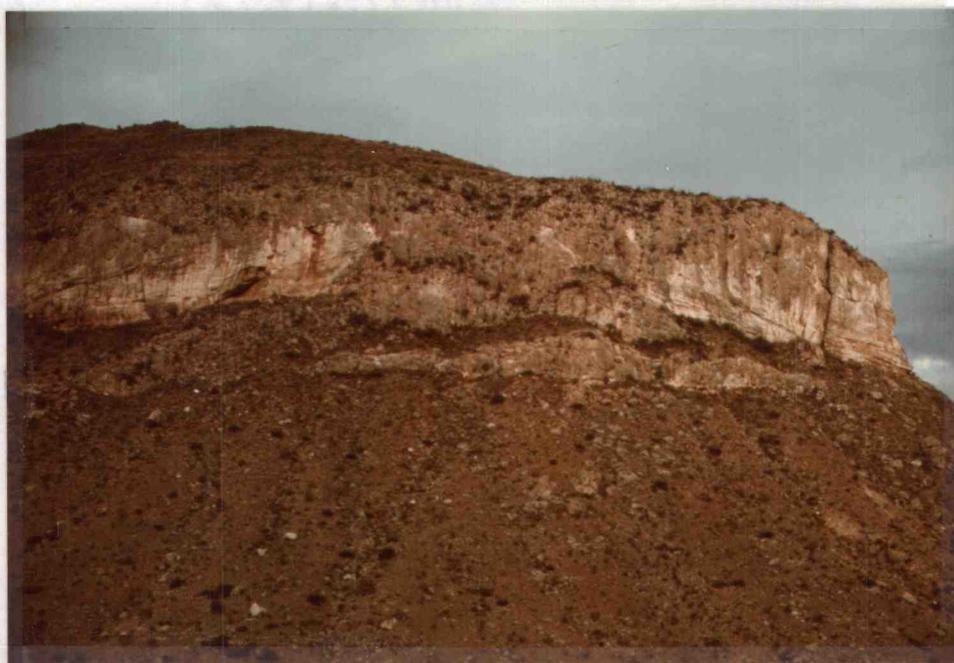


Figure 7. Photo of Alamo Mound, showing massive lower reef core (dark) and upper reef core (light) (view is to west).

in the north wall of Alamo Canyon, to the northeast. Again, the steepness of the cliff face prevented measurement of the height of the mound. However, from available topographic maps and inference from measurements obtained at Locality 7719, immediately to the east across the canyon, it is estimated to be approximately 50 m. high, perhaps 30 m. of this representing the lower core (Figure 7).

#### Muleshoe Mound

Located on the north side of the mouth of Muleshoe Canyon, in the SE 1/4, NW 1/4, Section 28, T. 17 S., R. 10 E., Muleshoe Mound is the farthest north and most accessible of the large reefs in the Sacramento Mountains (Figure 8). Between it and the reefs exposed in Deadman Canyon Branch of Alamo Canyon is a distance of approximately six km. in which no reefs are known. Also in that distance, the shelf encrinites referable to the Nunn and Tierra Blanca members of Laudon and Bowsher (1949) completely lose their identity.

Because of its prominence and relative ease of accessibility, Muleshoe Mound was examined in detail by both Laudon and Bowsher (1941) and by Pray (1958, 1961). The size and stratigraphic relationships of the reef are clearly observable (Figure 8). From the lowest exposed reef core to the top, it measures about 110 m. vertically. It has been largely exhumed by erosion so that its overall

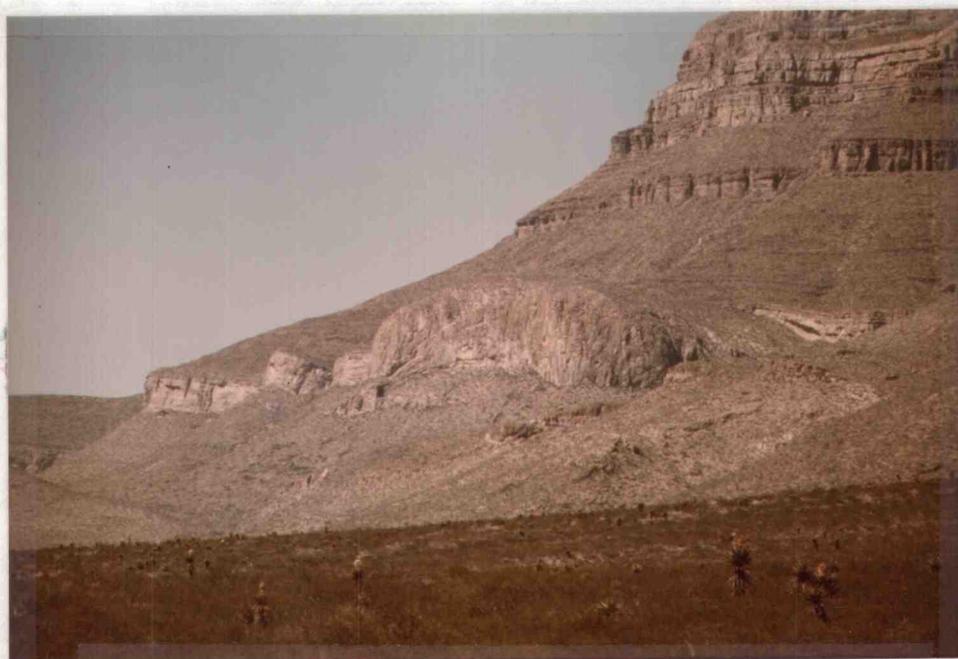


Figure 8. Photo of Muleshoe Mound, showing massive, unbedded appearance and hemispherical shape; lower reef core barely discernible in lower center of mound (arrow) (view is to northeast).

shape can be confirmed as rounded, almost hemispherical. No significant differences have been noted in these exposures, hence, no current direction or preferred orientation seems to be indicated.

The reef itself, although largely uncovered by erosion, is still almost entirely intact. Nonetheless, it can be seen that Muleshoe Mound, too, began as a high, narrow, lower reef core. From this initial core, the upper reef core extends upward slightly higher in addition to prograding outward from it. Flank beds, dominantly of crinoidal packstone and grainstone, containing occasional clasts of mound core, can be traced outward visually from the reef into the equivalent basinal strata. Initially, these may dip as steeply as 40 degrees but they flatten out in short distances away from the mound. Some larger blocks of reef core can also be found in these flank beds; on the southeast corner of the mound, such an allochthonous block more than 10 m. across, is prominently exposed.

Depositional relief on Muleshoe Mound is significant. The entire Arcente, Doña Ana and Rancheria formations abut the flanks of the upper reef core and the Pennsylvanian Gobbler Formation dips quaquaversally away from the top of the mound as well, although at angles of only a few degrees. Thus, it is probable that a significant part of the original reef was removed by erosion prior to final burial during the early Pennsylvanian.

### Phantom Mound

So named because it has largely been removed by erosion, there are, nevertheless, evidences that Phantom Mound was comparable in size to the other large reefs located basinally from the main carbonate shelf. It is located on the north wall of San Andres Canyon, about 0.5 km. east of the mouth of the canyon, in E 1/2, NE 1/4, Section 33, T. 17 S., R. 10 E.

From a distance, there is little to suggest the original size of Phantom Mound except, perhaps, that the slope below is nearly covered with boulders of reef core ranging from small pieces to huge blocks more than five m. across (Figure 2). The base of the remaining part of the mound can be seen in several places and consistently shows dips of about 10-15 degrees downward toward a point out in the canyon and southeast of the mound remnant.

Upon close examination, the mound remnant consists of at least three identifiable units, each a breccia of slumped mound core. Individual blocks range in size from a few cm. to more than one m. across; all are enclosed in a matrix of crinoidal and other fine bioclastic debris with little or no lime mud. No contact was found with an undisturbed reef core; larger and larger blocks occur toward the center of the reef. In the opposite direction, within 100 m., the breccia has essentially become a crinoidal packstone. Of even greater



Figure 9. Photo of Phantom Mound (just east of Locality 8245), showing rubble strewn slope below mound and allochthonous debris flow at its base and to left; mound originally extended to right and out of page into present canyon.

interest, when the blocks of reef core in the breccia are examined more closely, they can be seen to be blocks of an earlier breccia (a breccia within a breccia). Similar fabrics have been observed within the English Lower Carboniferous reef knolls by Parkinson (1957). That these blocks were well-cemented and solid can be seen by the nature of the contact of the breccia flows with the underlying crinoidal packstones and grainstones; the blocks of mound core penetrate the underlying, uncemented, flank beds up to 0.5 m., deforming them plastically. The same general relationships are true of each successive allochthonous flow.

The top of the mound is also exposed. Strikes and dips of the onlapping crinoidal beds of the Lake Valley and of the lime wackestones of the overlying Arcente Formation are approximately 30 degrees away from a point out in the canyon, beyond the preserved part of the mound and significantly above it. At a level even with the base of the mound, the strata on either side dip away gently, suggesting initiation of mound growth on a pre-existing, local topographic high. The presence of dips pointing inward immediately under the mound is attributed to compression of the underlying strata by the weight of the growing reef.

#### Little Sugarloaf Mound

Located in NW 1/4, NW 1/4, Section 9, T. 17 S., R. 10 E.,

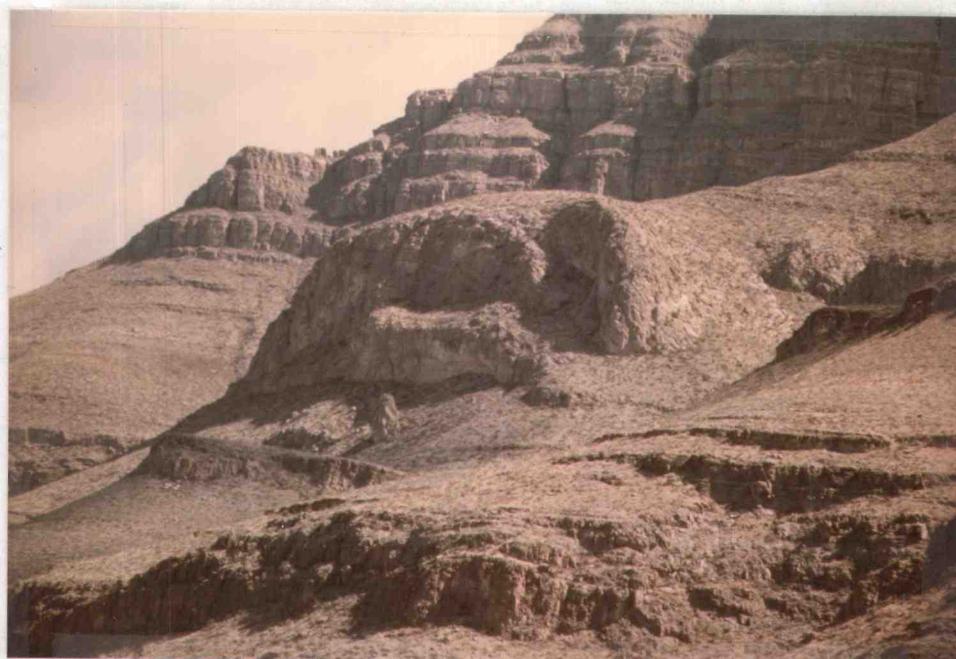


Figure 10. Photo of Little Sugarloaf Mound (Localities, 8242, 8243), showing lower and upper reef cores, hemispherical shape, and Doña Ana-age progradation from right rear of mound.

Little Sugarloaf Mound is the farthest south of the large basinal reefs (Figures 2, 3). Although somewhat difficult of access, two sections (Localities 8242 and 8243) were measured and collected. From base to top, the mound measures over 110 m. and, being situated right on the west-facing fault escarpment halfway between the mouth of San Andres and Dog Canyons, is easily visible from the Alamogordo-El Paso highway.

Erosion has almost completely exhumed the mound; only the east side is still sediment-covered, revealing its relationship to the enclosing strata (Figure 10). The reef core is exposed as a nearly vertical cliff in which the contacts between several successive progradations of the upper reef core can be seen. Only a small part of the lower reef core is exposed. From the southwest corner, it is possible to climb up this face and onto the top near the center of the mound.

The base of the mound can also be approached from the west, directly below the cliff face. Here, there is an additional, earlier period of reef development exposed, probably representing the lower reef core (Figure 11). It is succeeded by bedded crinoidal packstone and grainstone and then by the main body of the upper reef core. This stratigraphic succession can be explained by visualizing the line of section represented by the cliff face. If the line of the section were placed through an idealized reef similar in configuration to Tepee

Mound such that the section cut tangentially (i. e., vertically, but off center) through the mound, it would expose the flank of the lower reef core, a series of flank beds shed from the upper reef core, and the upper reef core itself. Such an interpretation is consistent with all the field data from Little Sugarloaf Mound. Most convincing is the dip of the bedded crinoidal packstones and grainstones which overlie the lower reef core; they dip away from the center of the mound at approximately 30 degrees (Figure 11).

From the top of the mound, several significant observations can be made. Perhaps most striking is the direct visual confirmation of original depositional relief approaching 100 m. To the south, the Lake Valley Formation off-reef equivalents dip into the basin at angles in excess of 30 degrees, thinning to approximately 20 m. at Locality 8244 which is clearly visible about 0.5 km. away.

On the south flank of the mound, the Arcente Formation abuts the mound and its unconformable relationship with the mound is clearly visible. Tracing the Arcente southward to Locality 8244, it thickens in a short distance to approximately 42 m.

Even more spectacularly, the Dona Ana Formation, where it onlaps the Lake Valley part of Little Sugarloaf Mound, has an upper reef core configuration. From its unconformable contact with the Lake Valley mound and still below its top, this Dona Ana reef prograded southward, shedding beds of crinoidal debris and then

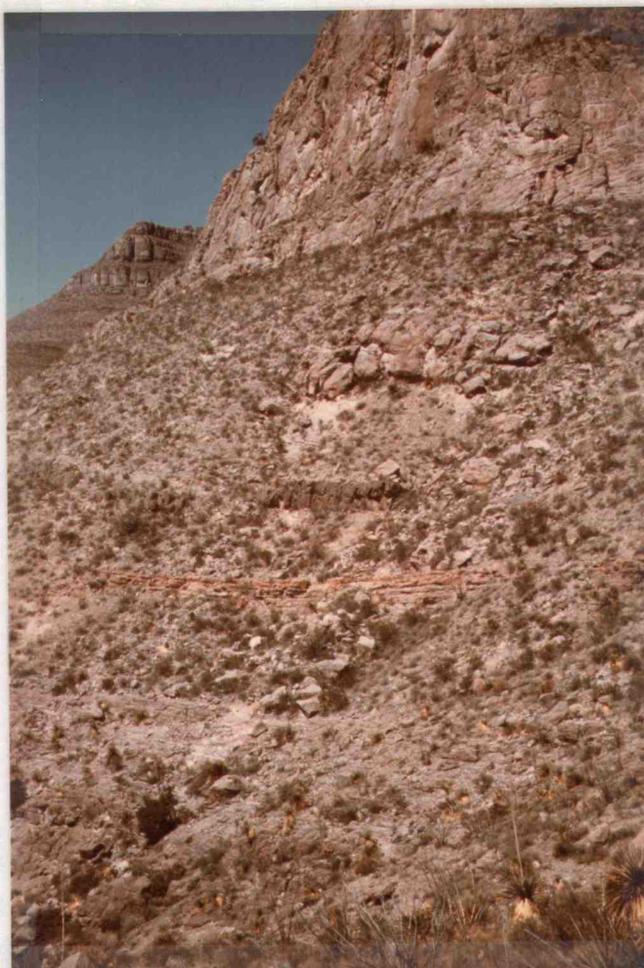


Figure 11. Photo of front (west) face of Little Sugarloaf Mound (Locality 8242), showing Oñate Formation (brown), Caballero Formation (below black diabase sill). Andrecito Member of Lake Valley Formation (above sill), lower reef core (midway between sill and base of cliff face), prograding flank beds, and upper reef core (cliff face).

overgrowing them (Figure 18). Several increments of Doña Ana mound growth can be distinguished visually. The base of the Doña Ana adjacent to the mound is also unconformable on the Arcente Formation. The Rancheria Formation, unconformably overlying the Doña Ana, also abuts it. Finally, the Pennsylvanian Gobbler Formation overlaps both the Doña Ana mound and Little Sugarloaf Mound itself. Where the Gobbler is exposed near the top of the mound, it still exhibits low angle quaquaversal dips away from it.

Here, as in the case of Muleshoe Mound, considerable erosion of the top of the reef seems probable. Thus, original depositional relief in the immediate vicinity of the mound may have considerably exceeded 100 m. In addition, preservation of the shallowest-water communities seems unlikely except as debris broken loose and washed down the sides of the mound. Only one possible example of preservation of such shallow water communities as allochthonous blocks was discovered in this study.

Discovery of the above allochthonous block of a probable shallow-water reef community was a fortuitous occurrence made during examination of the Doña Ana reef progradation. A prominent irregularity was observed on top of the Doña Ana mound at the point where the Rancheria Formation overlapped it (Figure 12). Although exposed in the cliff face, it was possible to examine and sample this block. The block itself clearly



Figure 12. Photo of Dona-Aña age reef progradation on southeast corner of Little Sugarloaf Mound.

overlies the Doña Ana and is separated from it by a layer of crinoid- and bryozoan-rich, largely chertified sediment apparently trapped there at the time of emplacement of the large block. The sample was obtained from the lower part of the main allochthonous block. It yielded conodonts representing F. U. 3-5 of Lane (1974; Lane, written comm., 1977). The acid residues from the block, almost completely silicified, are a dense network of fenestrate bryozoans and very small brachiopods representing a community unlike any other seen anywhere in the area, either in the reefs or in non-reef strata. Although its position in the mound cannot be accurately reconstructed, its age and its allochthonous position on top of the Doña Ana, significantly below the top of the Lake Valley part of Little Sugarloaf Mound, clearly indicate an upslope origin for it. This is consistent with the age of the top of the mound, dated as F. U. 4 of Lane (1977, written comm.).

#### San Andres Mound

San Andres Mound (Figure 13) is the least accessible of the basinal reefs and, based on field study, possibly also the largest. It is situated 3 km. east of the mouth of San Andres Canyon, at the point where the canyon divides into north and south branches, in W 1/2, NE 1/4, Section 35, T. 17 S , R. 10 E. The height of the exposed mound core was measured as 91 m. immediately north of the small stream which has cut a depression into the top and front of the mound.

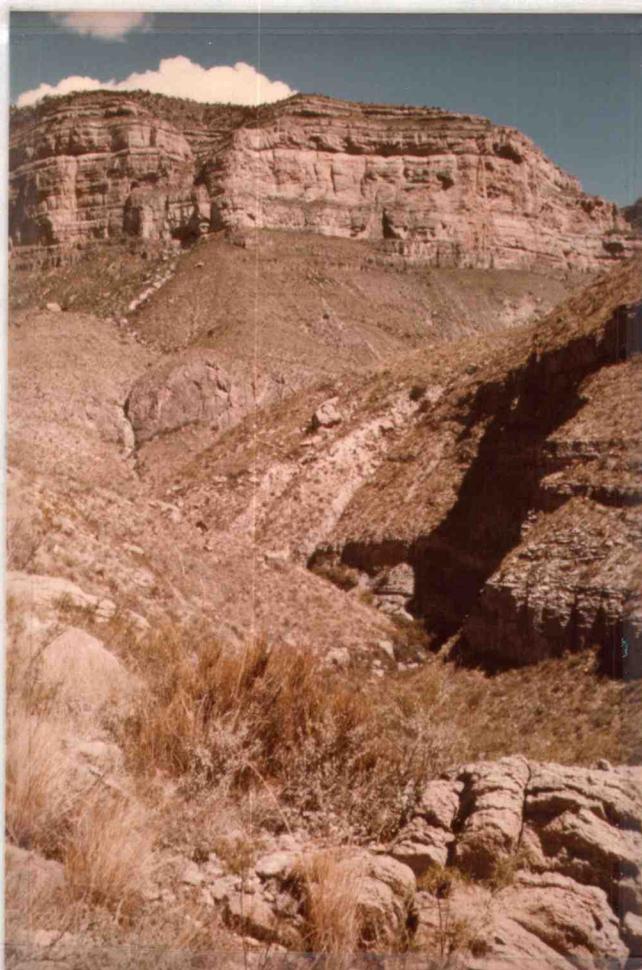


Figure 13. Photo of San Andres Mound (Locality 9131) from top of Phantom Mound (dark, massive rocks at left center).

The top of the mound south of this intermittent stream channel is somewhat higher but could not be measured accurately. Neither is the base of the mound exposed; strata at the front of the mound dip more than 50 degrees away (west) from the base of the mound. Farther down the slope below the base of the mound, in a small intermittent stream channel, an exposure of cherty lime wackestone yielded conodonts no older than F. U. 8 and possibly F. U. 10 or younger, almost certainly derived from the Late Mississippian Rancheria or Helms Formation (Lane, 1977, written comm.), suggesting structural complications.

At the top of the mound, in the small stream channel mentioned above as bisecting the mound into northern and southern parts, the contact with the overlying Pennsylvanian Gobbler Formation is exposed. Thick-bedded limestones near the base of the Gobbler dip away from the reef at approximately 25 degrees. In the basal shales of the Gobbler, a large clast of reef core 20 cm. in length was found (Figure 14), indicating the considerable erosion of the top of reef before overlap by the Pennsylvanian. Conodonts obtained from immediately below the top of the mound, in the stream channel, were dated as F. U. 6 (Lane, written comm., 1977). This is the only evidence of Arcente-age reef growth in the Sacramento Mountains. Since San Andres Mound was located in deep water, well out in the

basin, it seems likely that reef growth continued here, isolated from the influx of terrigenous clastics.

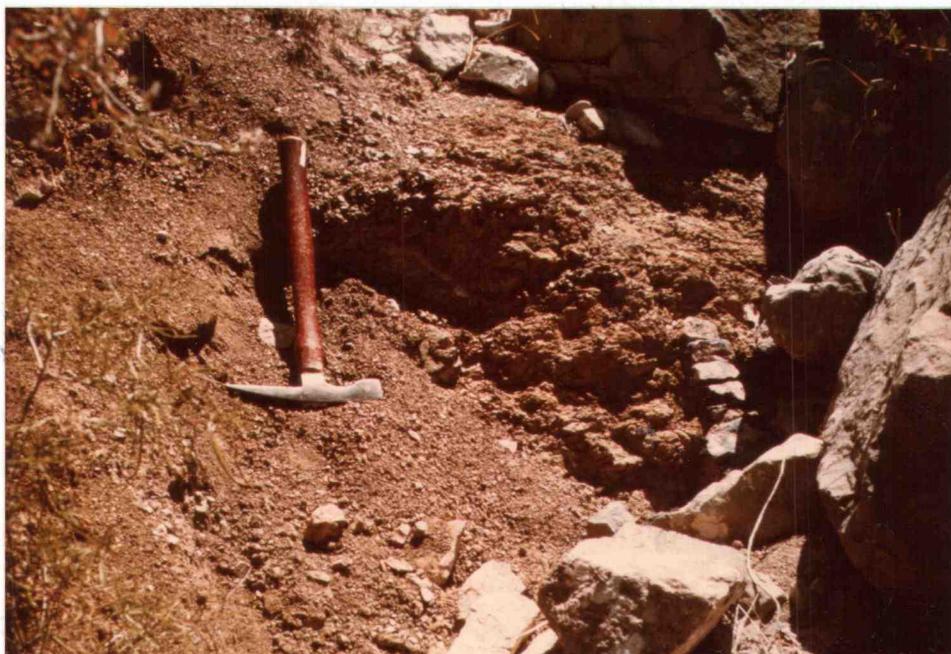


Figure 14. Photo of clast of San Andres Mound reef core (arrow) enclosed in shales of Pennsylvanian Goble Formation, top of San Andres Mound (Locality 9131).

## REEF GROWTH AND SHELF DEVELOPMENT IN THE LAKE VALLEY FORMATION--AN ECOFACIES MODEL

### Introduction

In recent years, a number of models for clear water sedimentation have been presented (Shaw, 1964; Irwin, 1965; Anderson, 1971; Wilson, 1974, 1975). Many of the basic features of these models can be traced to Rich (1951); Adams, Frenzel, Rhodes and Johnson (1951); and Van Siclen (1958). All have been influential in formulation of the present, ecofacies model.

The ecofacies model differs most from these earlier models in that they are descriptive; they describe a set of biofacies or lithofacies at a moment in time or as a recurrent phenomenon. The ecofacies model is dynamic, describing the change in these patterns as a function of time. It, therefore, is integrative, and, at different times during its development, resembles other, non-dynamic, facies models. Because of this, the ecofacies model has value as a predictive tool in research and exploration.

The central, unifying concept of the ecofacies model is the ecosystem, consisting of a succession of communities, the physical environment which they inhabit, and the physical processes acting in that environment. The goal of ecofacies modeling and analysis is to reconstruct the ecosystem in detail and to record the changes occurring in it through time.

Appropriately, the reef ecofacies model began as an analysis of community distribution in and adjacent to the reefs in the Lake Valley Formation; the goal was to determine the importance of depth as a control on community distribution. It was hoped that, by reconstructing the paleotopography during deposition and then estimating water depth at one or more points, a model of paleobathymetry could be constructed. A second problem in community analysis is the role of substrate. While some authors have emphasized the importance of depth, others have relied predominantly on substrate as the principal control on community distribution. Thus, it was necessary, in reconstructing the environment of the communities, to be able to correlate this with substrate as well as with position along the paleobathymetric profile. Since both substrate and community composition vary in response to physical processes acting in the environment, it was also necessary to take into consideration indicators of energy distribution (wind, waves, light). Thus, in addition to being a conceptual framework, the ecofacies model is also a methodology suited to statistical testing and quantitative manipulation.

Three kinds of geological information are employed in the construction of the ecofacies model: (1) stratigraphic, (2) sedimentologic and (3) paleontologic. These three bodies of data constitute submodels in the ecofacies model. The environmental processes are the links between the submodels.

### Stratigraphic Submodel

The stratigraphic submodel employed bears strong resemblances to the model utilized in seismic stratigraphic interpretation (Vail and others, 1977). Recognizing that stratal surfaces are depositional surfaces and may be considered as time lines, an analysis of stratal configuration provided a measure of the change of depositional topography through time and of facies equivalence at a given moment in time. The basic unit for stratal analysis is the depositional sequence, defined by Mitchum, Vail and Thompson (1977, p. 53) as

a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities.

This concept is based on the larger scale sequences of Sloss (1963) but is also similar to the depophase of Johnson (1971) and the synthem of Chang (1975).

Stratal analysis consists of the following steps: (1) identification of the depositional sequences, (2) reconstruction of depositional topography at the onset of deposition of the sequence being analyzed, (3) description of overall geometry of the depositional sequences and (4) analysis of the internal stratal configuration within each depositional sequence. Where necessary, paleontologic or sedimentologic data were used to supplement or confirm observed relationships.

The principal limit on the detail and accuracy of stratal analysis is

the amount and continuity of exposure. In the Sacramento Mountains, both are excellent.

#### Sedimentological Submodel

The second, sedimentological submodel includes such data as composition, particle size, sorting, grading, color, and mode of deposition (e. g., sedimentation, secretion or encroachment). In addition, fundamental difference exists between carbonate and terrigenous clastic depositional systems. Although both end members are normally present, one is generally dominant. Terrigenous clastics are extrabasinal in origin, whereas carbonates are intrabasinal in origin, and are predominantly the result of biological activity, either by direct precipitation or as a byproduct of normal, physiological activity.

The reef ecofacies model, because it is an essentially pure carbonate system, can be somewhat simplified. There are relatively few compositional end members: calcium carbonate, chert, and terrigenous silt and clay. Dolomite is present in significant amounts only in the Oñate Formation. Because of the characteristically bimodal size distribution of carbonates (mud and grains) and the classification used (Dunham, 1962), particle size is easily treated. Sorting and grading may be complex but, because only a small number of distinctive depositional units can be recognized, these

characteristics can be observed in the field. Color, in carbonate rocks, is largely a function of particle size; dark color may be generally correlated with small particle size. Finally, because carbonates are predominantly organic in origin, the most useful data derivable from them is their identity, i. e., the faunal composition of the rock. Thus, there is a close link between the sedimentological and paleontological submodels. Each community of organisms forms a distinct lithology. In the case of flank beds, the faunal composition of the rock is the key to its origin.

#### Paleontological Submodel

The paleontological submodel is split into two separate bodies of data. First, conodonts were collected at critical points in the sections and used for biostratigraphic control. These can be related to the scheme of faunal units developed by Lane (1974) and provide good chronostratigraphic control where discontinuous exposures and abrupt facies changes were encountered. Second, the invertebrate macrofauna, especially brachiopods, was used to identify recurrent communities which were the basis for paleoecological reconstructions.

By combining data from all three submodels into a dynamic model of the reef ecosystem, several important observations can be made. (1) The stratal configuration clearly shows that, with the inception of reef growth, the overwhelming bulk of the sediments in

the depositional sequence is of reef origin. (2) The sedimentological submodel reveals that the sediments are dominantly organic in origin; each distinct lithofacies is also a distinct biofacies. Where the sediments are allochthonous, their faunal composition is the key to their origin. (3) Within the reef core facies (i. e., the unstratified, solid rock mass representing continuous colonization of a hard, organic substrate), there is a vertical brachiopod community succession which documents the vertical growth of the reef core into shallow water and its subsequent progradation.

From these observations, it is concluded that the Lake Valley carbonate shelf is a complex of reef and reef-derived sediments, virtually all organically precipitated. The process of growth and development is continuous from beginning to end in a stable environment. Where interrupted by epeirogenic or eustatic perturbations, development of the reef ecofacies complex may resume essentially where it left off and continue to the same climax configuration which is approximately equivalent to the stratigraphic reef of Dunham (1970). The main stages in this process and the principal controls acting on it are as described in the following sections.

### Inception of Reef Growth

#### Colonization

Inception of reef growth-colonization of the substrate by

encrusting organisms - is the first step in the development of the reef ecofacies complex. This can occur on any area of the seafloor which is relatively free of fine-grained clastic sediment and above the base of the euphotic zone. Such areas may be local topographic highs; they may be swept by locally stronger currents; or they may be located seaward of structural or topographic depressions which serve as traps for land- or shore-derived clastic sediment.

In the Sacramento Mountains, inception of reef growth within the Lake Valley Formation (restricted) may be attributed to a set of events, beginning in Devonian time. Referring, again, to Figure three, note that the Oñate Formation formed a local topographic high which trapped the sediments of the superjacent Sly Gap Formation in a shallow, "silled" basin shoreward of it. The Sly Gap is not found south of this high. The next younger formation, the Percha (?), filled this basin and prograded somewhat beyond it as a clastic shelf margin. The shoreline during Percha (?) time corresponded approximately with the Tepee Mound section because south of that point it is present as a thin, discontinuous blanket of strata. North of the Tepee Mound paleoshoreline, it is known only as a channel filling in the Marble Canyon section. The position of the Lake Valley carbonate shelf margin corresponds closely to the position of the probable Percha (?) paleoshoreline.

The Caballero Formation, best developed beneath the Lake Valley

shelf, thins gradually seaward from the Percha (?) paleoshoreline to a position immediately seaward of the buried Oñate high (San Andres Canyon section). It reaches its maximum thickness at this point, then thins abruptly, forming a clastic shelf margin.

Localization of the large reefs, beyond the shelf margin, can also be explained in relation to buried depositional topography. Muleshoe Mound is situated directly above the buried Oñate high. Little Sugarloaf Mound is located directly above an anomalously thick section of the Andrecito Member of the Lake Valley Formation which probably represents an additional seaward progradation of the clastic shelf margin. That such buried depositional features should exert an influence on sedimentation patterns is not unreasonable. For comparison, one might cite the presence of quaquaversal dips in the Pennsylvanian Gobbler Formation above buried Lake Valley reefs.

The depositional topography at inception of Lake Valley reef growth may be summarized as a gently seaward-sloping clastic shelf margin with local topographic highs corresponding to a buried shoreline; a buried, possibly structural, high (Oñate); and a succession of progradations of a clastic shelf margin.

Two factors may have interacted in the actual inception of reef growth. First, each successive progradation of the clastic shelf margin increased the width of the shelf and decreased the slope on the shelf. This may have reduced the amount of clastic sediment being

transported across the shelf. A second factor which may have aided in the inception of reef growth in the Lake Valley is a rise in sea level (Figure 15). This would have caused a sudden reduction in the supply of clastic sediments to the entire shelf area by (1) causing a retreat of the shoreline, (2) submergence of the source area for the clastic sediments or (3) establishment of a new, lower depositional gradient across a wider shelf.

The first factor, gradual increase in shelf width and correspondingly decreased depositional gradient, is unlikely to have resulted in the essentially simultaneous inception of reef growth over an extensive area, which occurred in Lake Valley time. A rise in sea level, with the several effects listed above, is a far more likely explanation for the nature and timing of this stage of reef development. Such a rise of sea level has been suggested during deposition of the Paine Member of the Lodgepole Formation by Gutschick, Mc Lane and Rodriguez (1976), Rose (1976) and Smith (1977) and may have been eustatic. The magnitude of this rise in sea level may have been sufficient to submerge large areas of the continental backbone (= transcontinental arch), thereby explaining the great extent of carbonate deposition at this time (Johnson, 1974).

Although there appears to be a maximum depth below which colonization does not take place, this does not imply depth control in the strict sense. Rather, the interactions of several factors are

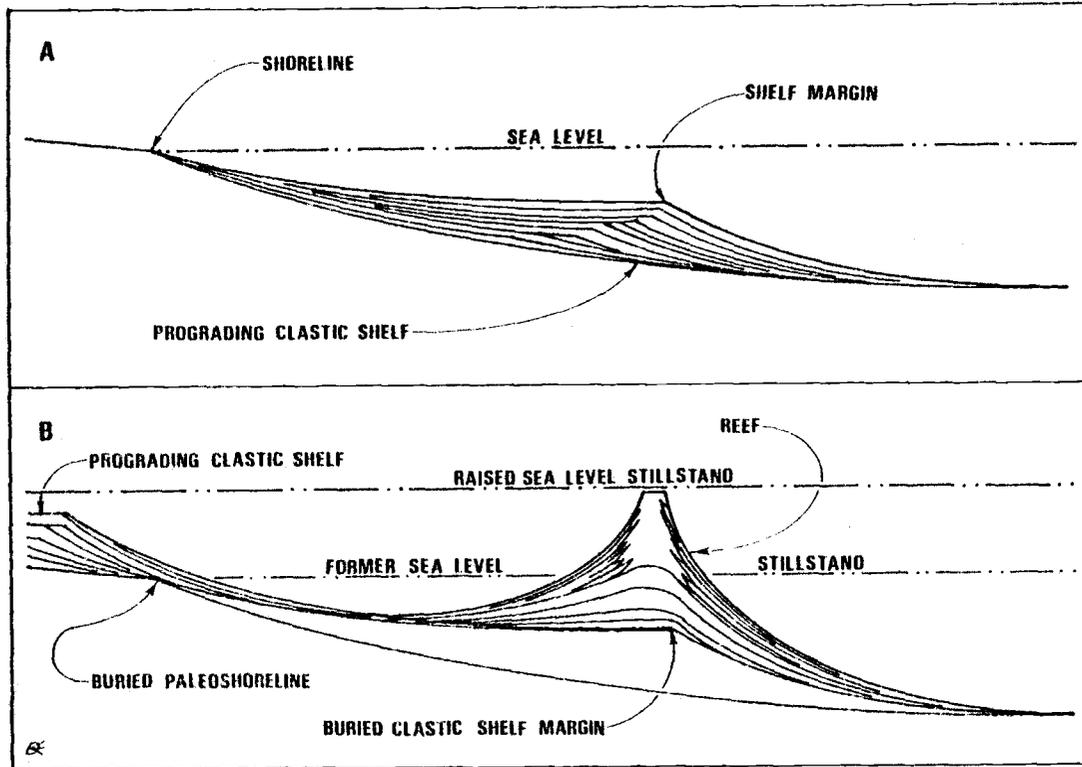


Figure 15. Diagram showing inferred relationship of a rise in sea level to inception of reef growth.

probably involved, among them being light intensity and distribution (daily and seasonal), water clarity (related to clastic sedimentation rate), and water temperature. This maximum depth is the level at which the rate of upward growth of the newly established organic substrate (= pioneer community of reef ecosystem), equals or exceeds the ongoing rate of clastic sedimentation, thereby maintaining its relative topographic elevation.

### Localization

Initially, relief on the organic substrate may be very subtle. Nevertheless, from the beginning, there is a tendency for the substrate to differentiate into areas of sediment production and areas of sediment accumulation. Throughout the development of the reef ecofacies depositional system, sediment "drainage" is critical. Gradually, bioclastic sediment and whatever small amount of terrigenous silt and clay is present will tend to concentrate in low areas, burying the organic substrate and causing a localization of carbonate production into centers of reef growth (Figure 16). This marks the beginning of the second stage of reef development.

### Upward Growth to Wave Base

In a broad sense, reef development, subsequent to its inception, is a deterministic process. Following colonization of the initial

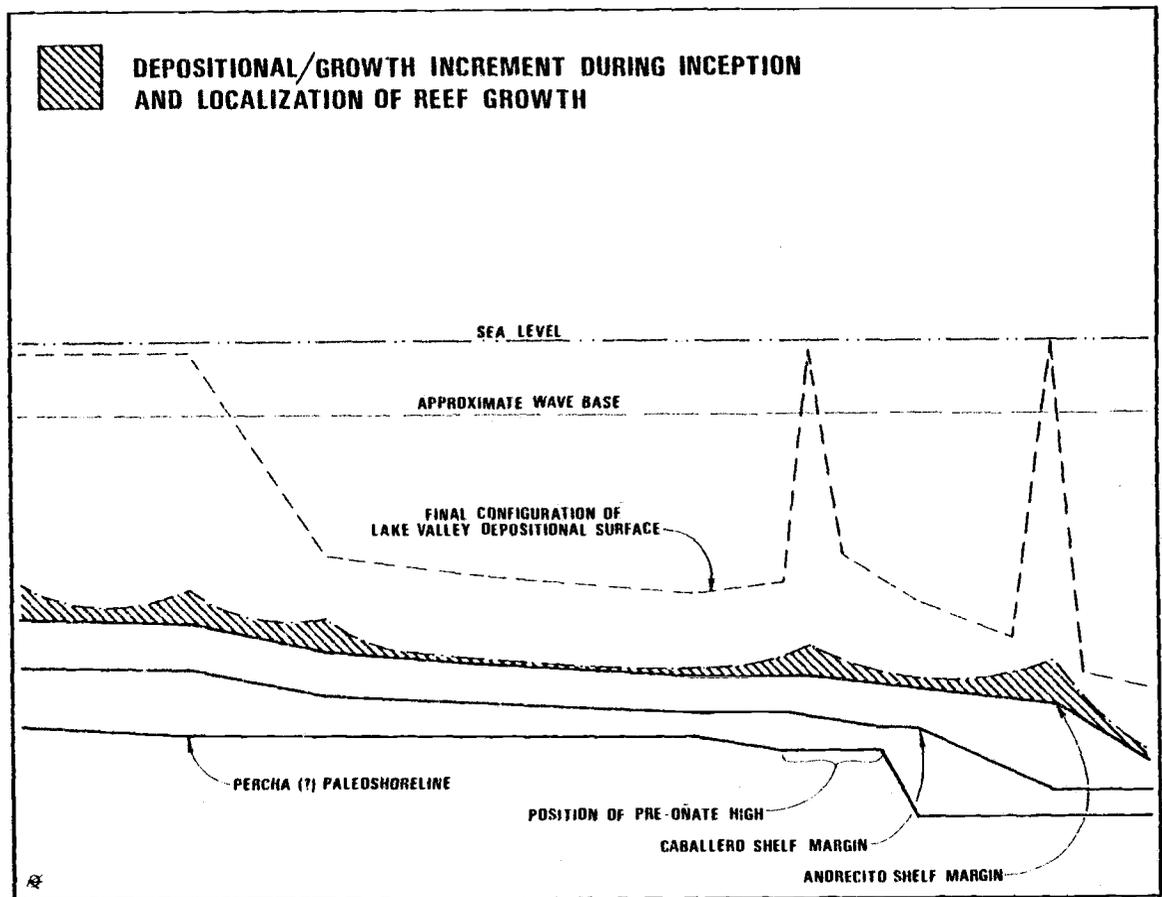


Figure 16. Diagram showing depositional/growth increment and approximate depositional topography along shelf-basin transect during inception and localization of centers of reef growth.

depositional surface and localization as centers of reef growth, upward growth to wave base results in a distinctive, steep-sided reef core (Figure 17).

During this stage of development, it is not possible to characterize the reef by most of the usual criteria. The initial expression of the reef may be as a gentle upward mounding of the sediment surface with a divergent internal stratal configuration, passing abruptly into an unstratified, massive, tepee- or cone-shaped core. The beds immediately below this core may contain locally greater amounts of skeletal debris, representing a higher-energy benthic community than in the surrounding strata. Several of the Sacramento Mountains reefs rest on beds containing large amounts of crinoidal debris. In fact, as far down as the Caballero Formation, the strata beneath the carbonate platform and beneath the large reefs seaward of the platform margin contain a more diverse, higher energy community than in other areas.

The brachiopod community in the basal part of the massive reef core, initially, is similar to that in time-equivalent strata. There is a gradual, non-evolutionary, upward change in species composition and dominance within this community. When wave base is reached, however, there is a relatively sudden change in community composition. Thus, it is meaningful to speak of only two communities, one at or above and one below wave base. The community found above

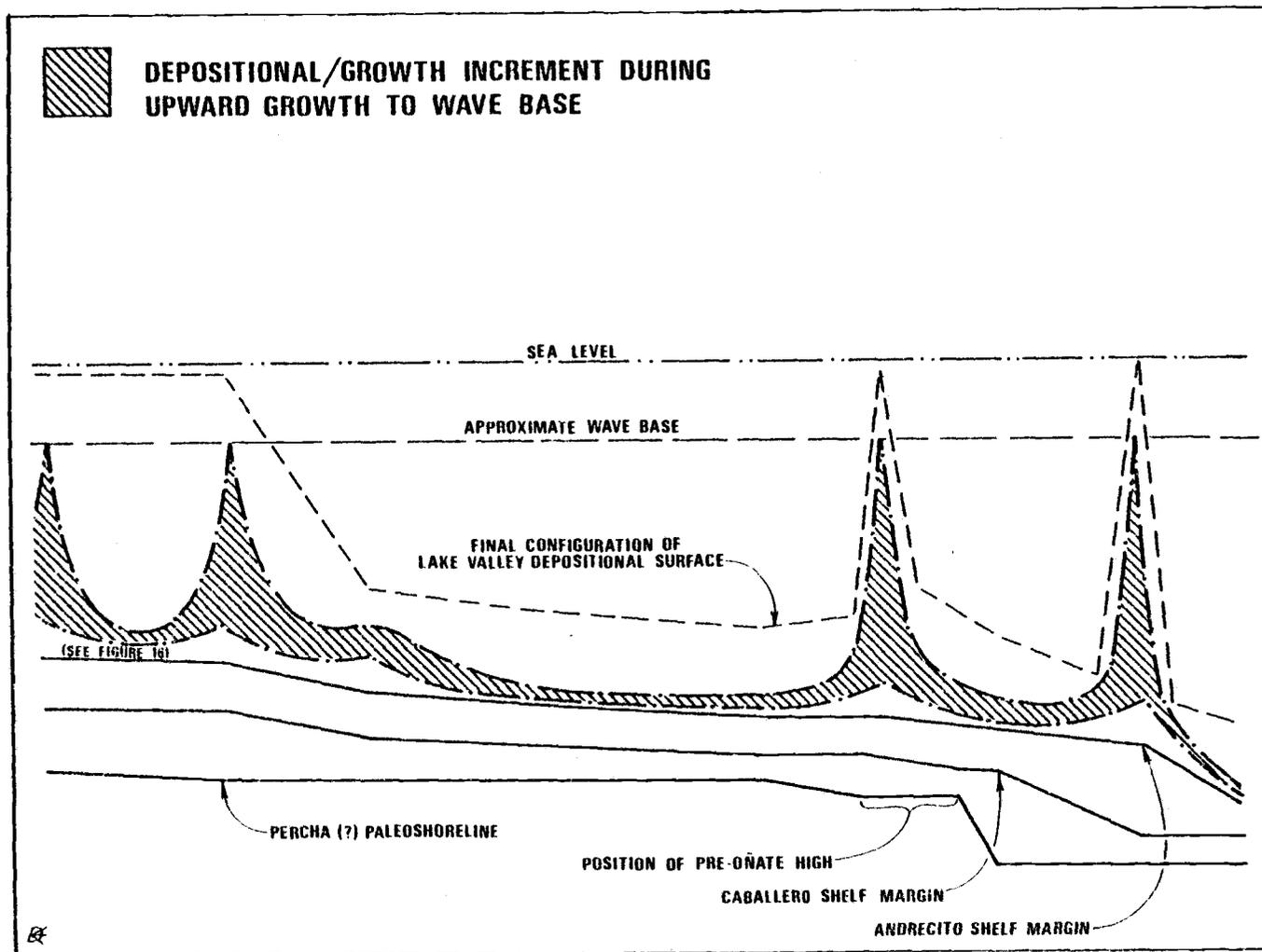


Figure 17. Diagram showing depositional/growth increment and approximate depositional topography along shelf-basin transect during upward growth to wave base of centers of reef growth.

wave base has been commonly referred to as the "reef" fauna.

The greatest change in the ecofacies pattern and in reef configuration also occurs upon attainment of wave base. During this stage of predominantly upward growth below wave base, there are no flank beds; sediment drainage from these reefs while below wave base is by gravity, not by water movement. It is this fact which explains the extremely high depositional slopes (above the angle of repose for loose clastic sediments) in the massive, lower reef core. Absence of flank beds seems likely to be one of the principal reasons why some authors have considered these reefs to be entirely of deep-water origin.

Another important aspect of upward growth of the reef into shallow water is that there is an upward, non-linear, increase in the rate of carbonate sediment production (Wilson, 1975, Figure I-2). The upward growth rate increases as depth decreases, and may be ten to 100 times greater at the surface than at 100 m. depth. This change in rate of calcium carbonate production with depth is comparable to the decrease in light intensity with depth. This reduction takes place in two ways (Figure 18): (1) a screening out of much of the spectrum of solar radiation in the first 10 m. water depth; (2) a gradual attenuation of the remaining blue-green portion of the solar energy spectrum with increase in depth below 10 m. (Sverdrup, 1942). The overall change in solar radiation with depth is shown in Figure 19.

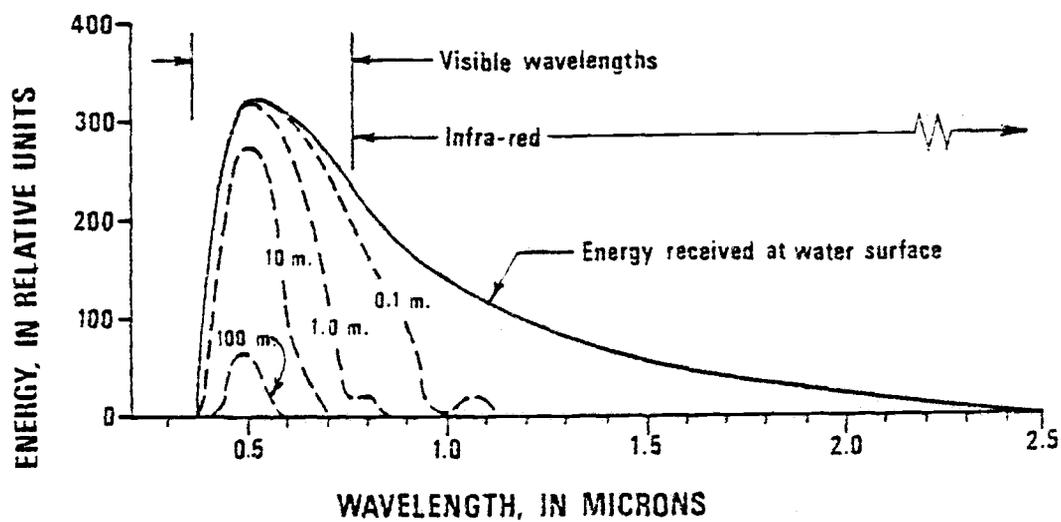


Figure 18. Diagram showing decrease in light intensity with increasing depth, by wavelength (after Strahler and Strahler, 1973).

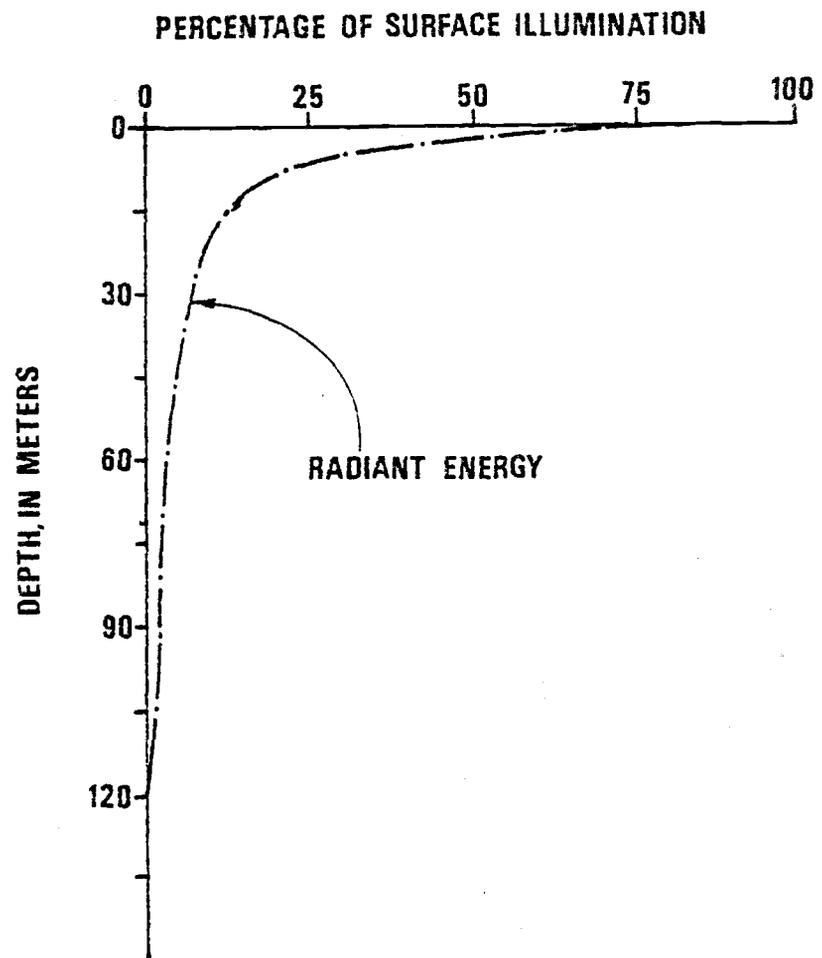


Figure 19. Diagram showing overall decrease in light intensity with increasing depth (after Stoddart, 1969).

## Attainment of Wave Base - Inception of Flank Bed Deposition

### Wave Base

In spite of the numerous references to wave base in geological literature, there does not appear to be any general concensus or understanding of what wave base really is or of how it affects sedimentation. Upon being asked for a definition of wave base, the most frequent response from a geologist would be: one-half the wavelength ( $L/2$ ). This is the view most frequently expressed in textbooks. It is based on the decrease in diameter, with increasing depth, of the circle described by a particle suspended in the water column, in a plane normal to the wave front. This dimension, the orbital diameter, decreases rapidly with depth until reaching a depth of  $L/2$ . Below  $L/2$ , the orbital diameter decreases very slowly (Figure 20). Since the orbital diameter is only 0.04 of its surface value at  $L/2$ , the effects of wave motion can probably be ignored at greater depths.

This definition of the term wave base is misleading, however, in that it fails to explain the sharpness of the break in stratal configuration attributed to wave base. What is most usefully defined is the maximum depth at which sand-size grains can be moved by wave motion in the water column. In the Sacramento Mountains, this depth may be clearly indicated as the interface between the massive,

unstratified, upper reef core and the subjacent, reef-derived, flank beds. It marks the boundary between hard, encrusting, organic substrate above and loose, depositional, clastic substrate below; as such it represents the maximum depth to which wave action is capable of transporting loose sediment off of the organic substrate. This is the physical boundary in the marine environment which it is desired to define.

As an initial step, it is necessary to examine the variation of orbital diameter in wind-generated waves as a function of period, height and wavelength as well as of depth (Table 1 and Figure 20). From the graph, it can be seen that the values for  $L/2$  lie on a line which connects equivalent relative points on successive wave fronts rather than any particular depth.

A second problem in determining the value of wave base is that, although larger waves are characterized by relatively large orbital diameters at greater depths, these waves also have a longer period. By calculating orbital velocities for the same waves in Table 1 (Table 2) and plotting these values (Figure 21), it is seen that orbital velocities vary in a manner similar to orbital diameter.

Two problems remain: (1) what orbital velocity should be selected as marking the threshold of sediment motion and (2) at what depth will this minimum value orbital velocity be found? Komar and Miller (1974) have studied this problem; their results are reproduced

Table 1. Variation of orbital diameter with depth for selected waves (T=2 seconds to T=14 seconds after Sverdrup, Johnson, and Fleming (1942); T=16 seconds after Verhoogen and others (1970)).

| Physical dimensions for selected waves: |                        |                          | Orbital diameter, D, in m. at selected depths, d: |                  |                  |                  |                 |
|---|------------------------|--------------------------|---|------------------|------------------|------------------|-----------------|
| period, T,<br>in secs.                  | wavelength<br>L, in m. | wave height,<br>H, in m. | d=L/16;<br>D=.68L                                 | d=L/8;<br>D=.46L | d=L/4;<br>D=.21L | d=L/2;<br>D=.04L | d=L;<br>D=.002L |
| 2                                       | 6.2                    | .25                      | .17   | .115             | .05              | .01              | .0005           |
| 4                                       | 25                     | 1.00                     | .68   | .46              | .21              | .04              | .002            |
| 6                                       | 56                     | 2.00                     | 1.36  | .92              | .42              | .08              | .004            |
| 8                                       | 100                    | 5.00                     | 3.40  | 2.30             | 1.05             | .20              | .010            |
| 10                                      | 156                    | 7.00                     | 4.76  | 3.22             | 1.47             | .28              | .014            |
| 12                                      | 225                    | 10.00                    | 6.80  | 4.60             | 2.10             | .40              | .020            |
| 14                                      | 306                    | 12.00                    | 8.16  | 5.52             | 2.52             | .48              | .024            |
| 16                                      | 376                    | 14.70                    | 9.52  | 6.76             | 3.09             | .59              | .029            |

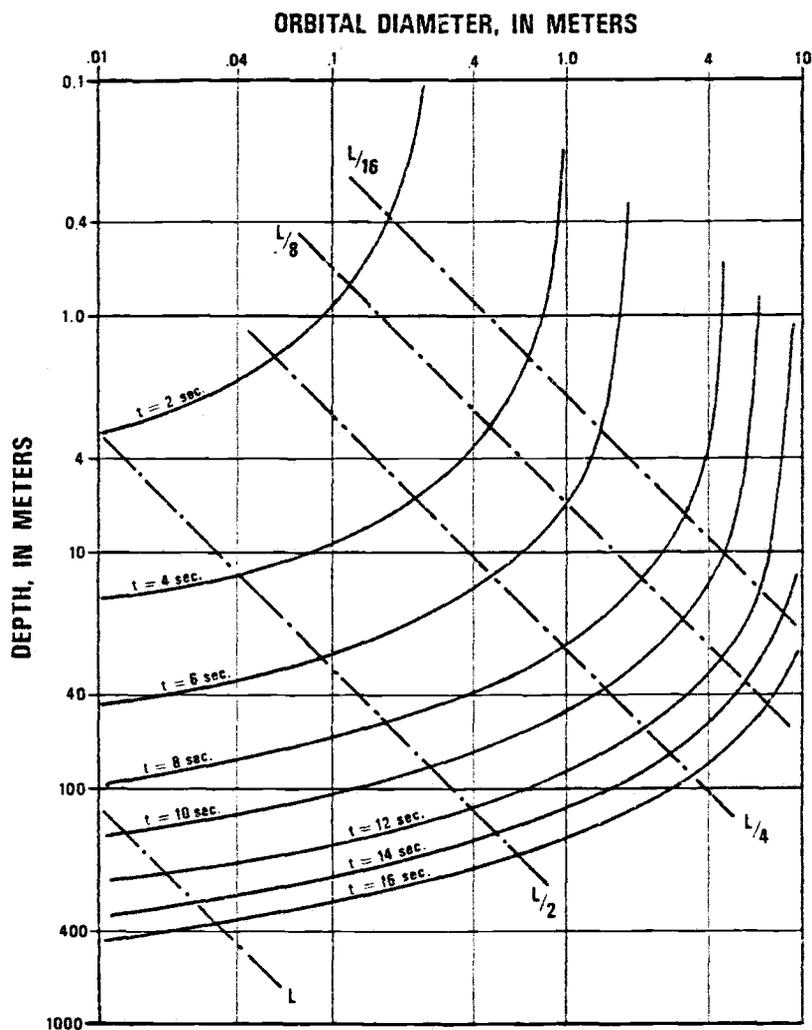


Figure 20. Diagram showing relationship between orbital diameter and depth for selected waves (data from Table 1).

Table 2. Variation of orbital velocity with depth, for selected waves (data after Sverdrup, Johnson, and Fleming (1942)).

| <u>Physical dimensions for selected waves:</u> |                         |                          | <u>Orbital velocities, V, in m/sec., at selected depths, d:</u> |       |       |       |        |
|--|-------------------------|--------------------------|---|-------|-------|-------|--------|
| period, T,<br>in secs.                         | wavelength,<br>L, in m. | wave height,<br>H, in m. | $(V = \frac{\pi D}{T})$   |       |       |       |        |
|  |                         |                          | d=L/16  | d=L/8 | d=L/4 | d=L/2 | d=L    |
| 2  | 6.2                     | .25                      | .267  | .181  | .033  | .0016 | .00008 |
| 4  | 25                      | 1.00                     | .534  | .361  | .165  | .0314 | .0016  |
| 6  | 56                      | 2.00                     | .712  | .482  | .220  | .0419 | .0021  |
| 8  | 100                     | 5.00                     | 1.335   | .903  | .412  | .0785 | .0039  |
| 10   | 156                     | 7.00                     | 1.495   | 1.011 | .462  | .088  | .0044  |
| 12   | 225                     | 10.00                    | 1.780   | 1.204 | .550  | .105  | .0052  |
| 14   | 306                     | 12.00                    | 1.831   | 1.239 | .565  | .107  | .0054  |

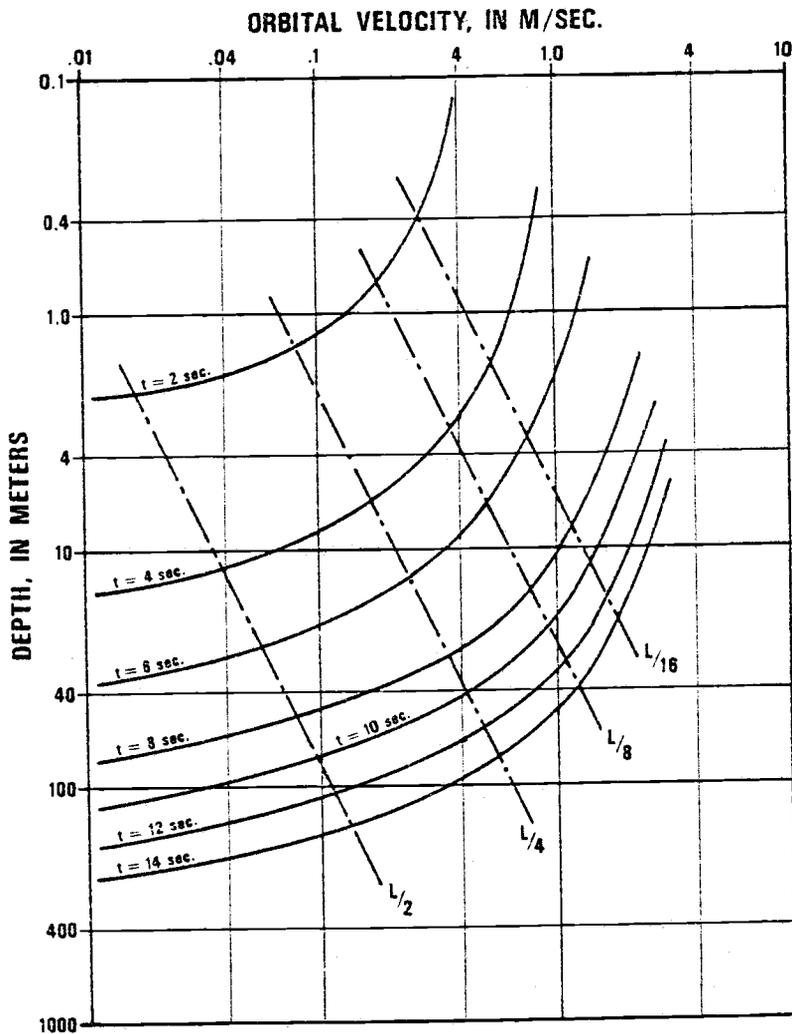


Figure 21. Diagram showing relationship between orbital velocity and depth for selected waves (data from Table 2).

in Figure 22. In this diagram, the curve is a composite of two sets of values; an empirical relationship for orbital velocities capable of inducing only laminar motion at the sediment-water interface and a theoretical relationship for orbital velocities resulting in turbulent motion at the sediment-water interface. This approximately defines the threshold of motion for particles 0.5 mm. in diameter. For carbonate sediments which have a distinctly bimodal size distribution (recognizable in the distinction between mud and grains), the value 0.5 mm. is also a meaningful dividing line. For the range of variation in period of commonly observed waves, 1-15 seconds, this corresponds to orbital velocities of from 10 to 25 cm./sec., which is the desired range of values.

The second problem is to determine the depth at which the necessary orbital velocity will be attained in a given locality. Since this depth varies with wave size, it will not be determinable except as a statistical entity. That is, it is related to the wave-size frequency distribution. As an example, consider the record of successive waves reproduced as Figure 23. The dominant average wave height is from 1.5 to 2.0 m. On the graph of orbital velocity (Figure 21), these values are enclosed in the field defined by waves "T = 4 sec." and "T = 6 sec." and orbital velocities of 10 cm./sec. and 25 cm./sec. This defines an overall range in depth to wave base of from 5 m. to 22 m. As the period of time over which the wave size frequency distribution

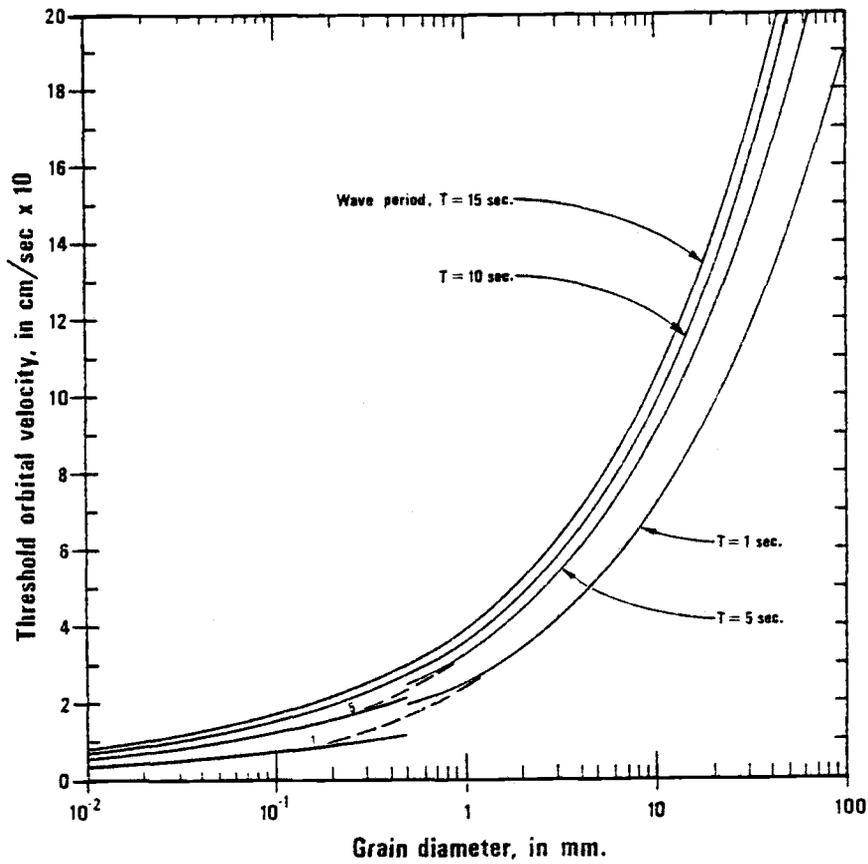


Figure 22. Diagram showing relationship between grain diameter and threshold orbital velocity, for selected wave periods (after Komar and Miller, 1974).

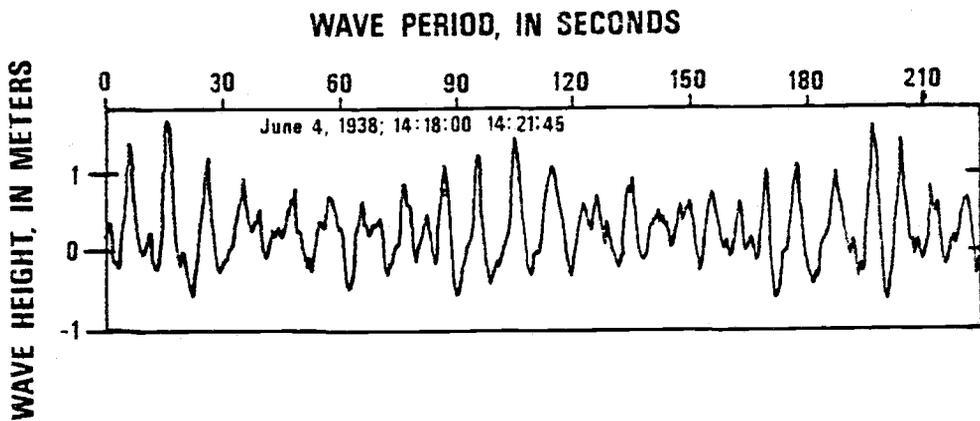


Figure 23. Record of successive waves passing the end of Scripps Institution pier (after Sverdrup, Johnson, and Fleming, 1942).

is averaged increases, the values for depth to wave base will converge on a single, mean value. This value can be meaningfully referred to as wave base.

### Ecofacies Distribution

Because of the pronounced break in stratal configuration and facies which accompanies attainment of wave base, most workers have failed to recognize the continuity in time and space of the hard, organic substrate which is basic to the reef ecosystem. This organic substrate, the continuous succession of benthic communities which inhabit it, and the accompanying modification of the environment are basic features of the ecofacies model. Instead, most definitions and descriptions of reefs, both fossil and Recent, conform primarily to the stratal configuration and facies pattern produced by the reef ecosystem after it has reached wave base.

In the ecofacies model, the changes coincident with upward growth above wave base may be summarized as follows: (1) inception of flank bed deposition and (2) replacement of the lower reef core fauna by the upper reef core fauna.

The record of flank bed deposition is clearly preserved in the stratal configuration. The lower reef core, below wave base, has no flank beds. Because the lower core is steeper than the angle of repose for unconsolidated clastic sediment, the first flank beds onlap

against its sides until reaching upward to wave base. Having reached this stage, the reef complex can be differentiated into areas of sediment production and areas of sediment deposition. The intertonguing of massive reef core and reef-derived flank beds is the record, to time, of the changing position of this interface.

The second change, replacement of the lower reef core brachiopod community by the upper reef core brachiopod community, is equally abrupt. In the lower reef core, there is a diverse community of small, thin-shelled brachiopods. This is replaced, in the upper reef core, by a less diverse community of large, thick-shelled brachiopods dominated by Spirifer spp., Imbrexia spp., Unispirifer spp., Marginatia sp. A, and Pseudosyrinx missourensis. This community succession is supported by the fact that, in the reef-derived flank beds and debris flows, the contained brachiopods are invariably representative of the upper reef core community.

#### Progradation and Coalescence of Centers of Reef Growth

Once they have grown upward into shallow water, at or near sea level, the centers of reef growth are experiencing optimum conditions for growth (Figure 24). They are in warm, shallow, strongly illuminated waters with good circulation. Carbonate production is at a maximum, hence production of flank beds and progradation of the hard, organic

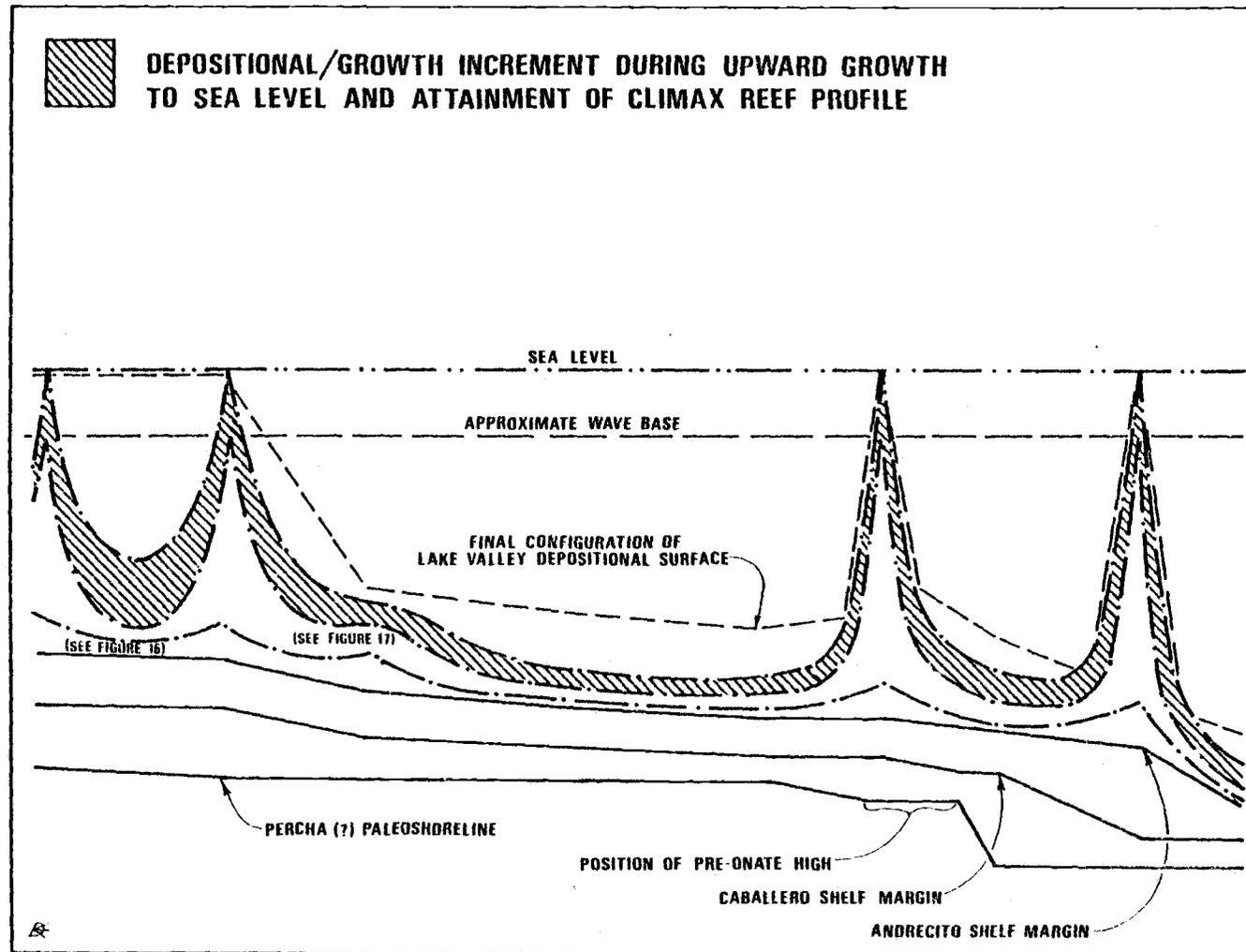


Figure 24. Diagram showing depositional/growth increment and approximate depositional topography along shelf-basin transect during upward growth to sea level of centers of reef growth and attainment of climax reef profile.

substrate over them can be rapid (largely dependent on water depth).

In the shallower, northern area, where the reefs were closer together, the clastic fans of reef detritus from adjacent reefs overlapped, quickly filling in the interreef areas (Figure 25). Finally, the flank beds filled in the depositional topography between the reefs. At this point, drainage of bioclastic sediment from the reefs was no longer possible; the hard, organic substrate was buried by its own sediment; and reef growth was terminated except at the seaward edge of the resultant carbonate shelf.

In the area of the deeper-water, basinal reefs, the rate of progradation was much slower; the depositional relief was much greater; and the reef-derived sediments were spread over a much greater area. Hence, there was little or no progradation of the upper reef core. The resultant reef, its overall geometry, its stratal configuration and its depositional setting are precisely that of a pinnacle reef (Hugh, Briggs, and Gill, 1973) (Figure 26).

#### Progradation of the Carbonate Shelf Margin

The position and shape of the shelf margin immediately after coalescence of the centers of reef growth was highly irregular, dependent upon the initial topography colonized by the reef ecosystem. The Lake Valley shelf margin seems to have had an irregular margin aligned approximately northeast-southwest. The large

reefs in the San Andres Canyon area were isolated from the main shelf area and did not contribute to its development. This was the position and shape of the reef ecosystem and carbonate shelf when deposition of the reef ecofacies complex was interrupted at the end of Lake Valley time.

After emergence of the Lake Valley shelf, followed by deposition of the silty, slope-front fill Arcente, there was a return to clear water conditions, renewed reef growth and progradation of the shelf margin to a position at or slightly beyond the most seaward of the pinnacle reefs, Little Sugarloaf Mound. Thus, the renewed reef progradation outward from the coalesced centers of growth smoothed out irregularities in the outline of the shelf margin, resulting in a straight or gently curving, arcuate reef tract. This increase in regularity of the reef profile was accompanied by a decrease in the amount of control exercised by the depositional topography originally colonized by the reef ecosystem.

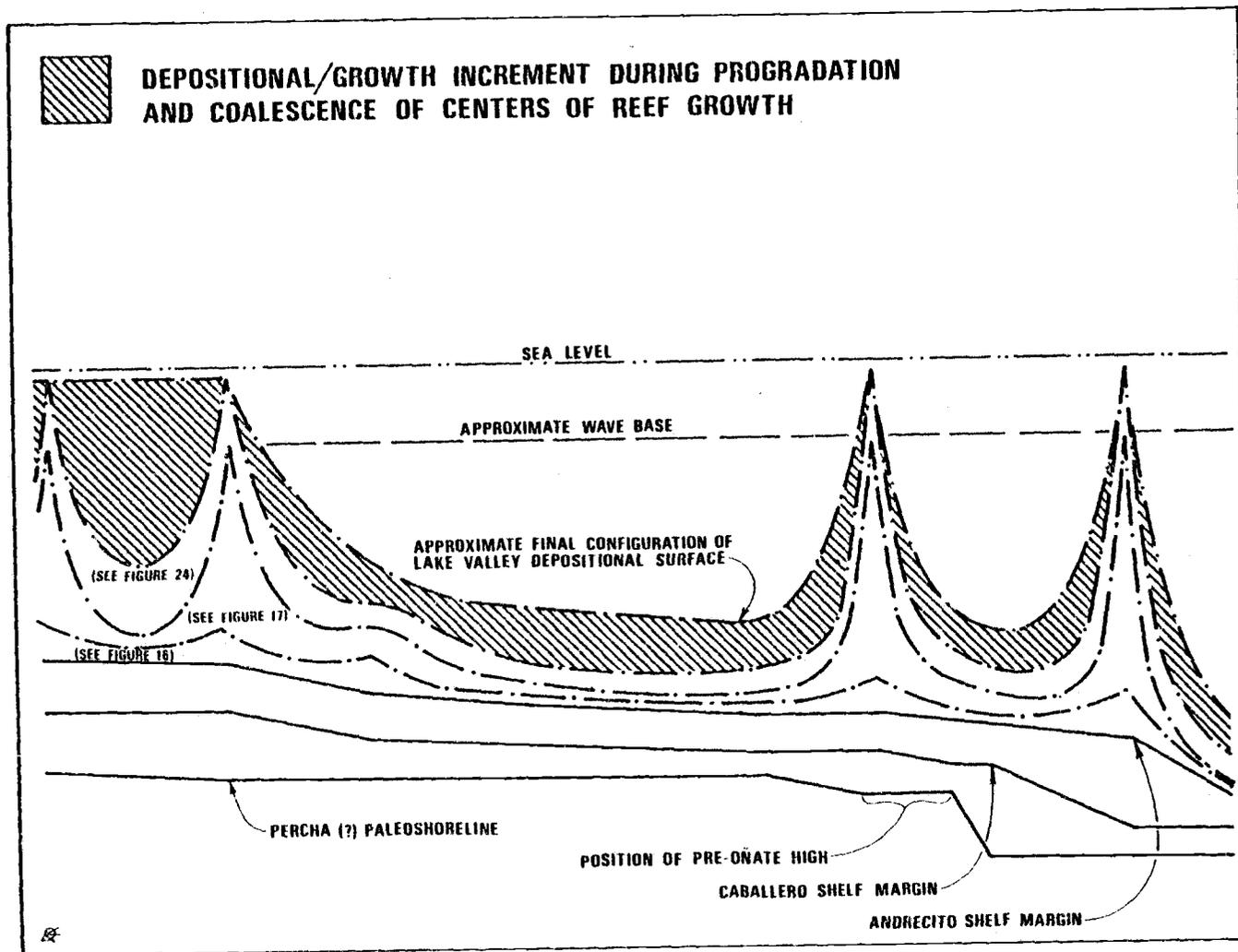


Figure 25. Diagram showing depositional/growth increment and approximate depositional topography along shelf-basin transect during progradation and coalescence of centers of reef growth to form a shallow, nearly horizontal carbonate shelf and offshore "pinnacle" (non-coalesced) reefs.

## IDEALIZED STRATAL CONFIGURATION FOR A "PINNACLE" REEF

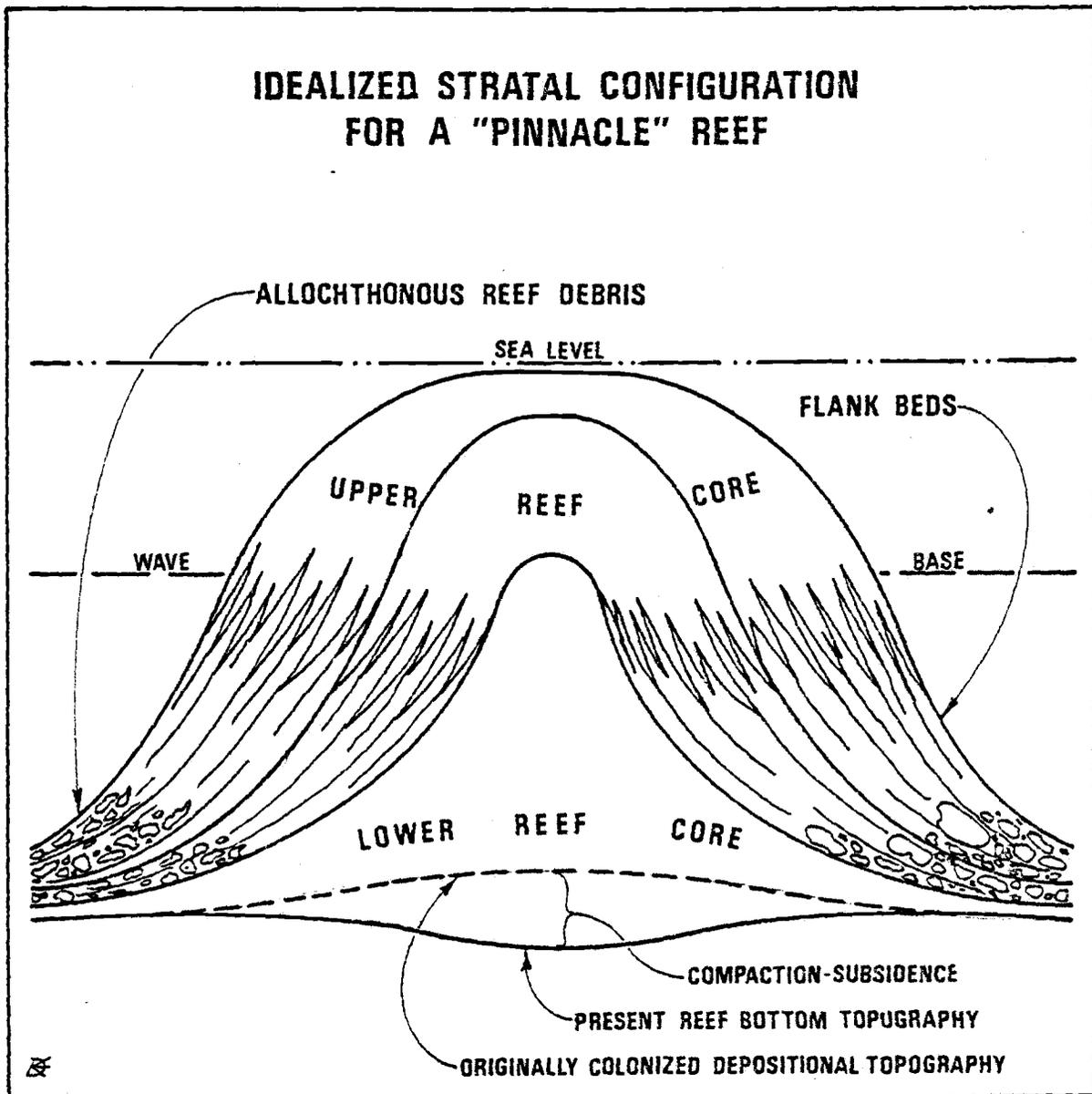


Figure 26. Diagram showing inferred shape and configuration of a "pinnacle" (non-coalesced) reef of the type represented by Little Sugarloaf, Muleshoe, Phantom, and San Andres mounds.

## SUMMARY AND CONCLUSIONS

By constructing paleontologic, sedimentologic, and stratal submodels and linking these by analogy with the Holocene reef ecosystem, a process termed ecofacies modeling, a dynamic model has been outlined for the Early Mississippian of the Sacramento Mountains, New Mexico. This model is termed the reef ecofacies model.

Basic to the ecofacies modeling methodology is the construction of an ecofacies transect based on closely-spaced measured sections. The transect is subdivided into several depositional sequences which are unconformity- or disconformity-bounded and in which the facies are in genetic relationship. The external geometry and internal stratal configuration of these units are then analyzed and reconstructed. This information is redrawn along the transect according to thickness distribution rather than to present topography or to some stratigraphic horizon (usually drawn as a straight line). So plotted, the depositional sequences assume characteristic shapes and positions. The paleontologic and sedimentologic data, when examined in the context of such a transect, conform remarkably well to the position of such features as paleoshorelines, clastic shelf margins, and carbonate shelf margins (reefs).

A principal unifying feature in each case is the depth to wave base, defined statistically as the time-averaged depth to the threshold

of sediment movement due to wave action. So defined, wave base is easily and closely related to ecofacies distribution. Relative fluctuations in sea level, probably eustatic, also bear a predictable relationship to depositional sequence boundaries and to ecofacies distribution within the sequences. During post-Andrecito Lake Valley time, the tops of the carbonate shelf and the non-coalesced, offshore reefs are almost precisely accordant, their tops at or near sea level. The bases of the reefs, although not accordant, define a maximum depth at which colonization by the pioneer community of the reef ecosystem could occur, identifiable as the base of the euphotic zone.

The completed model provides an excellent basis for reconstruction of the Early Mississippian carbonate shelf margin. The position and general stratigraphic relationships of this shelf margin are already known for much of the western margin of North America (Rose, 1976; Gutschick, Mc Lane, and Rodriguez, 1976) and for parts of the eastern interior basin (Thompson and Fellows, 1970; Lane, 1978, in press). The advantage of the ecofacies model, however, is that, by integrating several bodies of data into a single conceptual framework, greater precision may be achieved in the prediction of selected features, such as reef trends, shelf margins (carbonate and clastic), shorelines, and shelf-edge and basin sands. Although similar in some respects to the methodology of seismic stratigraphic interpretation, the present modeling strategy was developed by use of surface

outcrop data alone; the two methodologies are, therefore, complementary and mutually confirmative.

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**APPENDICES**

APPENDIX A

SYSTEMATIC PALEONTOLOGY

Phylum BRACHIOPODA

Class ARTICULATA

Order ORTHIDA

Suborder DALMANELLIDINA

Superfamily ENTELETACEA Waagen, 1884

Family SCHIZOPHORIIDAE Schuchert and Le Vene, 1929

Subfamily SCHIZOPHORIINAE Schuchert and Le Vene, 1929

Genus Schizophoria King, 1850Schizophoria cf. chouteauensis Weller, 1914

(Plate 1, figures 8 to 15; Figure 27)

MATERIAL: Locality 7719, sample 10; locality 7720, sample 8; locality 7721, samples 12, 15, 16; locality 7722, samples 11, 14; locality 8243, samples 2-4, 6-9, 11, 15; locality 8244, samples 2-5, 10; locality 8245, samples 9-12, 16, 17, 18 (float), Caballero (float); locality 8246, samples 4-6; locality 8248, samples 9, 11 (float), 12, 31, 35; locality 8249, sample 8; 38 articulated specimens (1 serially sectioned), 59 pedicle valves, 21 brachial valves.

OCCURRENCE: Caballero and Lake Valley Formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian); conodont Faunal Units 1-4, 5?, of Lane (1974; 1978, written comm.).

EXTERIOR: Shell of small to large size, subequally biconvex, slightly wider than long, greatest width near midlength, outline sub-elliptical; lateral profile lenticular, with greatest convexity in posterior; cardinal extremities rounded, hinge line about 0.5 or less of width; ventral interarea low, triangular, apsacline; delthyrium open, triangular; dorsal interarea very low, triangular, orthocline; fold and sulcus lacking, anterior commissure smoothly-rounded, recti-marginate; ornament consisting of fine radial costellae which increase by intercalation, about 4/mm. at anterior margin of a specimen 12 mm. wide; surface also marked by variably-spaced concentric

growth lines; shell substance punctate; dimensions of a large and a small specimen, respectively: length, 26.1 mm., 10.7 mm.; width, 26.7 mm., 12.4 mm.; thickness, 14.9 mm., 6.50 mm.

INTERIOR: (Based on calcined and scraped specimens and on transverse serial sections, Figure 27). Ventral valve with deeply-impressed, cordate muscle field, divided by prominent myophragm which increases in height anteriorly, length about 1/3 length of shell; dorsal valve with thick brachiophore bases which diverge anteriorly at nearly 90 degrees; muscle field about 1/3 length of shell, divided by low myophragm and bounded by low ridges laterally and anteriorly; cardinal process fimbriate, with prominent median lobe and 1 or 2 lateral lobes on either side.

DISCUSSION AND COMPARISONS: Externally, the New Mexico specimens closely match S. chouteauensis Weller, 1914. Weller, however, provided neither a discussion nor illustrations of the internal characters of S. chouteauensis. Hence, a definite assignment to that species must await study of Weller's type specimens. He did, however, state that S. chouteauensis may be distinguished from S. swallowi in being smaller, in lacking any flattening of the brachial valve, and in being more nearly equally biconvex (Weller, 1914, p. 164). It may be distinguished from S. sedaliensis by its smaller size, lack of flattening in the ventral valve, and in lacking any anterior emargination of the ventral muscle scar.

Superfamily DALMANELLACEA Schuchert, 1913

Family RHIPIDOMELLIDAE Schuchert, 1913

Genus Rhipidomella Oehlert, 1890

Rhipidomella tenuicostata Weller, 1914

(Pl. 1, figs. 1 to 7; Fig. 28)

Rhipidomella tenuicostata Weller, 1914, p. 158, pl. 20, figs. 27-29.

Rhipidomella tenuicostata: Branson, 1938, p. 43, pl. 5, figs. 23, 24.

MATERIAL: Locality 7720, samples 5, 9, 10; locality 7721, sample 12; locality 7722, sample 7; locality 8244, sample 9; locality 8245, samples 9 (float), 15 (float), Caballero (float); locality 8248, samples 11 (float), 12, 30, 35; 23 articulated specimens (1 serially sectioned), 5 pedicle valves, 1 brachial valve.

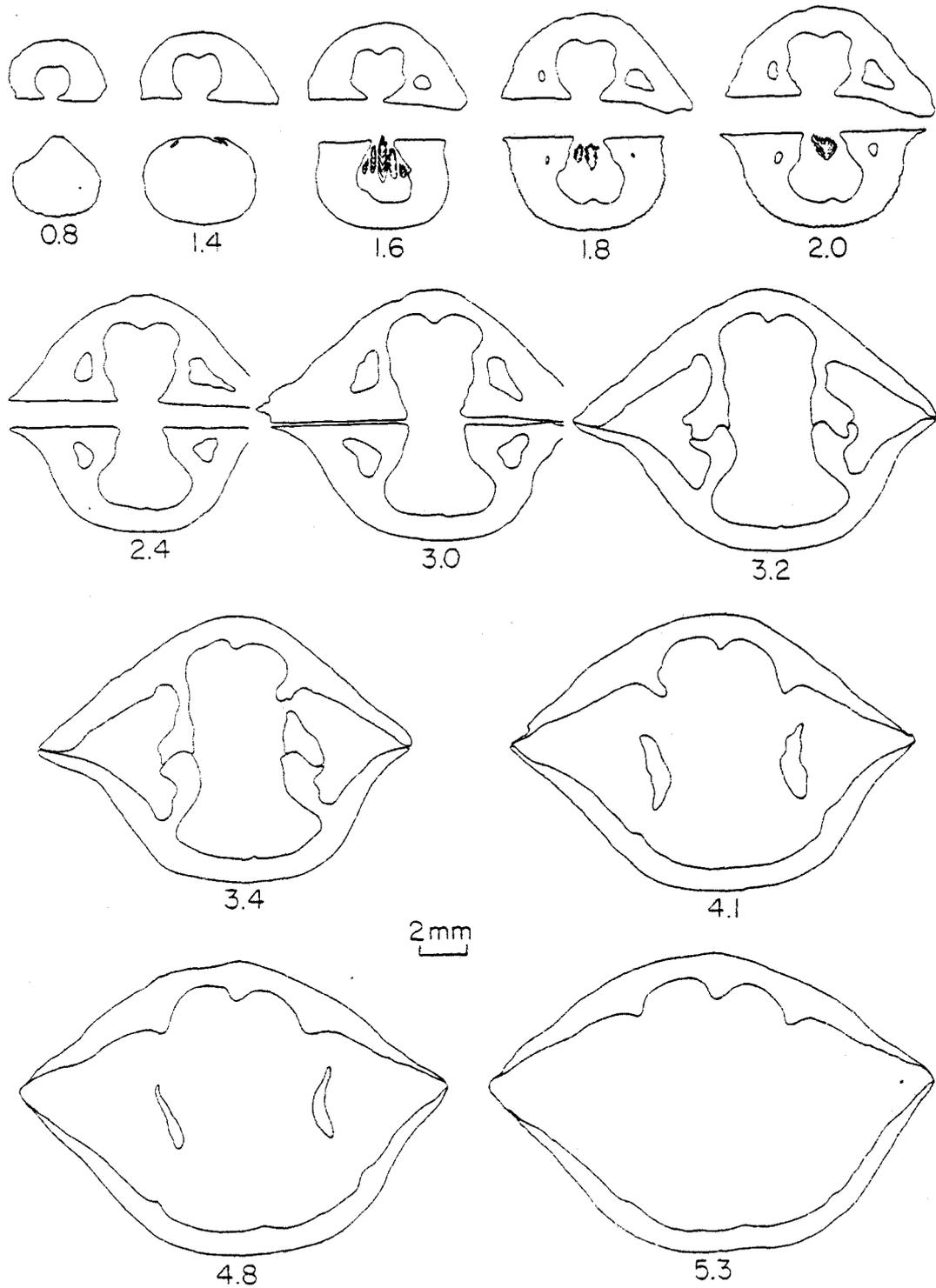


Figure 27. Transverse serial sections of *Schizophoria* cf. *chouteauensis*: specimen from sample 8248-11 (distances in mm. from ventral beak).

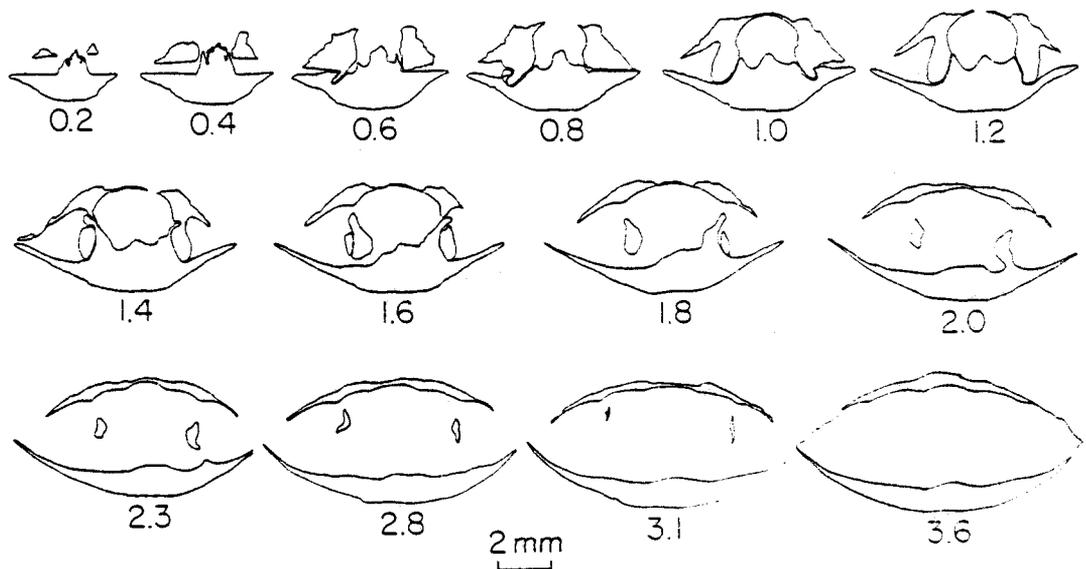


Figure 28. Transverse serial sections of Rhipidomella tenuicostata; specimen from sample 8248-11 (distances in mm. from ventral beak).

OCCURRENCE: Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian); conodont Faunal Units 1-4, 5?, of Lane 1974.

EXTERIOR: Shell of medium size, slightly dorsibiconvex, wider than long, outline suboval to subcircular; lateral profile lenticular; beaks small, low; cardinal area low, hinge about 0.35 of greatest shell width, notothyrium closed by chilidium; commissure rectimarginate, with very slight dorsal sinus in large specimens; ornament consisting of fine, radiating costellae (about 4/mm.) and irregularly-spaced concentric growth lines; dimensions of two nearly perfect specimens: length, 17.8 mm., 12.0 mm.; width, 18.2 mm., 12.1 mm.; thickness, 8.3 mm., 5.3 mm.

INTERIOR: (Based on transverse serial sections, Figure 28) Ventral valve with strong dental lamellae; dorsal valve with large, erect cardinal process of complexly digitate cross section, flanked by strong brachiophore bases which diverge anteriorly; shaft of cardinal process continuing forward as high, thick myophragm; brachiophores oval, becoming platelike anteriorly.

DISCUSSION AND COMPARISONS: In external form, these specimens from the Caballero and Lake Valley formations are essentially identical to R. tenuicostata of Weller (1914) (Figure 28). Internally, the species is characterized by its prominent cardinal process and stout myophragm; it is this feature which serves to distinguish R. tenuicostata from other species of Rhipidomella (Weller, 1914, p. 160).

#### Order STROPHOMENIDA

#### Suborder STROPHOMENIDINA

#### Superfamily STROPHOMENACEA King, 1846

#### Family LEPTAENIDAE Hall and Clarke, 1894

#### Genus Leptagonia McCoy, 1844

#### Leptagonia cf. analoga (Phillips), 1836

(Plate 1, figures 16 to 19; Plate 2, figures 1 to 6)

MATERIAL: Locality 7719, sample 10; locality 7720, sample 8; locality 7721, sample 16; locality 7722, sample 14; locality 8243,

samples 1, 6-9, 13; locality 8245, samples 9-11, 12 (float), 18 (float); locality 8246, samples 4, 5; locality 8248, samples 11 (float), 12, 25, 31, 35; locality 8249, sample 10; 19 articulated specimens, 18 pedicle valves, 17 brachial valves, 6 fragments.

**OCCURRENCE:** Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian); conodont Faunal Units 1 to 4, 5?, of Lane (1974; 1978, written comm.).

**EXTERIOR:** Shell of small to medium size; both valves initially slightly convex, at anterior margin both valves sharply geniculated dorsally; anterior margin with slight to prominent sinus; geniculate anterior part of shell frequently over 1/2 length of shell; wider than long, greatest width anterior to midlength, outline subtrapezoidal; cardinal area long, both interareas very low, triangular; cardinal process covered by chilidium, delthyrium closed by pseudodeltidium, pedicle foramen in ventral umbo, obscure in mature specimens; ornament consisting of: (1) prominent rugae on both valves, (2) fine radiating capillae, (3) very fine concentric growth lines; dimensions of a small and large specimen, respectively: length, 9.58 mm., 19.8 mm.; width, 14.4 mm., 27.0 mm.; length of geniculate anterior margin, 6.98 mm., 15.6 mm.; thickness, 5.89 mm., 13.6 mm.

**INTERIOR:** (Based on spalled and/or broken specimens; imperfectly known) Ventral valve with crenulated teeth, muscle scar subelliptical, with median ridge and bounded by prominent ridge along anterior and lateral margins; dorsal valve with bilobed cardinal process; dorsal muscle scars not observed.

**DISCUSSION AND COMPARISONS:** Weller (1914) recognized L. analoga in North American faunas on the basis of the original description and figure of Phillips (1836). Because of this and the imperfect knowledge of the New Mexico species and its range of variation, no definite specific assignment has been made.

## Suborder PRODUCTIDINA

## Superfamily PRODUCTACEA Gray, 1840

## Family LEIOPRODUCTIDAE Muir-Wood and Cooper, 1960

Genus Productina Sutton, 1938Productina sampsoni (Weller), 1909

(Plate 2, figures 7 to 18)

Productus sampsoni Weller, 1909, p. 300, pl. 12, figs. 18-22.Productus sampsoni: Weller, 1914, p. 129, 130, pl. 13, figs. 30-35.Productus sampsoni: Moore, 1928, p. 265.Productus sampsoni: Branson, 1938, p. 33, pl. 2, figs. 26-30.Productina sampsoni: Sutton, 1938, p. 552, pl. 63, figs. 1-4.Productina sampsoni: Muir-Wood and Cooper, 1960, p. 181, 182, pl. 123, figs. 1-10.Productina sampsoni: Muir-Wood, 1965, p. H471, fig. 338, no. 2a-d.Productina sampsoni: Carter, 1967, p. 289, 290, pl. 19, figs. 1a-2d.

MATERIAL: Locality 7719, samples 10, 11; locality 7720, sample 9; locality 7721, sample 13; locality 8242, sample 19; locality 8243, samples 1, 3, 5?, 8, 9, 11; locality 8245, samples 7, 9-11, 12 (float); locality 8246, samples 5, 7; locality 8248, samples 11 (float), 12, 25, 27, 35; 132 articulated specimens, 31 pedicle valves, 12 brachial valves.

OCCURRENCE: Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian); reef core ecofacies and higher energy regions of clastic shelf and shelf margin ecofacies; conodont Faunal Units 1 to 4 of Lane (1974; 1978, in press; 1978, written comm.).

DESCRIPTION: As described by Muir-Wood and Cooper, 1960, p. 181, 182, pl. 123, figs. 1-10.

DISCUSSION AND COMPARISONS: This small species has been frequently identified in Early Mississippian collections from the Mississippi Valley area, the southwestern Ozarks, and southern New Mexico. It, or a closely similar species, is also present in Early Mississippian strata of the Brooks Range, Alaska. Its occurrence in the Caballero and Lake Valley formations in the Sacramento

Mountains seems to be very strongly environmentally controlled. It is present in the higher energy, dominantly carbonate, parts of the Caballero Formation, generally at sites of later reef inception, and in the reef core ecofacies where it was found in large numbers in a pocket or depression in the reef surface (sample 8243-11). The reef-dwelling specimens reveal no morphological difference from the shelf-dwelling specimens other than a generally larger size.

Family OVERTONIIDAE Muir-Wood and Cooper, 1960

Subfamily OVERTONIINAE Muir-Wood and Cooper, 1960

Genus Geniculifera Muir-Wood and Cooper, 1960

Geniculifera boonensis (E. H. Branson), 1938

(Plate 2, figures 19 to 23)

Avonia boonensis Branson, 1938, p. 40, pl. 2, figs. 20, 31-33, pl. 3, fig. 22.

Geniculifera boonensis: Muir-Wood and Cooper, 1960, p. 187, 188, pl. 47, figs. 11-15.

Geniculifera boonensis: Muir-Wood, 1965, p. H472, fig. 340, no. 1a-d.

MATERIAL: Locality 8248, sample 12 (float); 5 articulated specimens.

OCCURRENCE: Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

DESCRIPTION: As described by Muir-Wood and Cooper, 1960, p. 187, 188, pl. 47, figs. 11-15.

Genus Rhytiophora Muir-Wood and Cooper, 1960

Rhytiophora cf. blairi (Miller), 1891

(Plate 2, figures 24 to 28)

MATERIAL: Locality 8243, samples 3, 6-8; locality 8244, sample 4; locality 8245, samples 9 (float), 16; 8 pedicle valves, 9 brachial valves.

OCCURRENCE: Caballero (?) and Lake Valley formations, Early

Mississippian, Kinderhookian (?) and Osagean (Tournaisian); conodont Faunal Units 1 (?), 3 of Lane (1974).

**EXTERIOR:** Shell medium to large for genus, subcircular to subquadrate; pedicle valve convex, lateral profile subsemicircular; ears small but prominent, greatest width along anterior margin, trail short, curving; brachial valve slightly concave on visceral disc, somewhat geniculate along anterior and lateral margins of visceral disc. Ornament consisting of branching, discontinuous rugae on visceral disc of both valves, only weakly-developed on flanks and trail; spines numerous and well-developed on most of shell, situated at anterior ends of radial ridges, especially where these intersect rugae; entire surface of both valves marked by minute growth lamellae. Dimension of a complete pedicle valve: length, 22 mm.; width, 25 mm.; thickness, 12 mm.

**INTERIOR:** Not observed.

Rhytiophora cf. calhouensis (Moore), 1928

(Plate 3, figures 1 to 7, 11 to 15)

**MATERIAL:** Locality 7722, sample 8; locality 8244, sample 9; locality 8245, samples 11 (float), 12 (float), 16 (float), Caballero (float); locality 9130, sample 8; 2 articulated specimens, 8 pedicle valves, 4 brachial valves.

**OCCURRENCE:** Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian).

**EXTERIOR:** Shell of medium to large size for genus; outline subelliptical to subcircular; lateral profile subsemicircular. Pedicle valve convex, greatest width slightly anterior to hinge line; ears medium to large, prominent. Brachial valve only slightly concave, moderately geniculate along anterior and lateral margins. Ornament consisting of numerous, regular, subparallel rugae on visceral disc of both valves, weak or absent on flanks and trail; spines sparsely distributed on ears, flanks, trail; entire surface of both valves marked by minute concentric growth lamellae. Dimensions of a complete pedicle valve: length, 26 mm.; width, 33 mm.; thickness, 19 mm.

**INTERIOR:** Not observed in detail.

Rhytiophora sp. A

(Plate 3, figures 8 to 10, 16 to 24)

**MATERIAL:** Locality 8248, samples 9, 11, 25; 4 articulated specimens, 5 pedicle valves.

**OCCURRENCE:** Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

**EXTERIOR:** Shell of small to medium size for genus, outline subcircular; pedicle valve convex, trail short, venter somewhat flattened; slightly geniculate at anterior end of venter; ears prominent, flanks steep or nearly vertical, greatest width along anterior margin; umbo rounded, slightly incurved beyond hinge line. Brachial valve slightly concave on visceral disc, moderately geniculate along anterior margin; trail short, curving. Ornament consisting of numerous prominent concentric rugae on visceral disc of both valves, rugae frequently discontinuous, branching, only weakly developed on flanks and trail; spines on radial costae which become more prominent anteriorly, usually occurring where these intersect rugae, most numerous on ears, flanks, trail; entire surface of both valves apparently marked by numerous minute, concentric growth lamellae; dimensions of an average specimen: length, 19.3 mm.; width, 20.3 mm.

**INTERIOR:** Not observed.

Rhytiophora sp. B

(Plate 4, figures 15 to 24)

**MATERIAL:** Locality 8243, samples 6, 9, 14; 2 articulated specimens, 2 pedicle valves, 2 brachial valves.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Units 3B, 4 of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell small for genus, outline subcircular; pedicle valve convex, evenly curving from umbo to anterior margin, trail short; ears prominent, flanks fairly steep; greatest width at anterior margin, umbo small, extending only slightly beyond hinge line. Brachial valve weakly concave on visceral disc, moderately geniculate

along anterior and lateral margins, trail short, gently curving. Ornament consisting of concentric rugae on visceral disc of both valves, rugae frequently discontinuous or branching, only weakly developed on flanks and trail; spines on radial costae, becoming more prominent anteriorly, usually occurring where intersecting rugae; most numerous on ears, flanks, trail; surface of both valves marked by numerous, minute growth lamellae. Dimensions of a nearly complete specimen: length, 10.0 mm.; width, 12.1 mm.; thickness, 4.6 mm. (approximate).

INTERIOR: Not observed.

Genus Stegacanthia Muir-Wood and Cooper, 1960

Stegacanthia bowsheri Muir-Wood and Cooper, 1960

(Plate 4, figures 1, 2)

MATERIAL: Locality 7720, sample 11; locality 8245, sample Caballero (float); locality 8248, sample 12; 1 articulated specimen, 3 pedicle valves, 1 brachial valve.

OCCURRENCE: Caballero Formation and Andrecito Member of Lake Valley Formation, Early Mississippian, Kinderhookian and Osagean (Tournaisian); conodont Faunal Units 1, 2 of Lane (1974).

DESCRIPTION: As described by Muir-Wood and Cooper, 1960, p. 199, 200; pl. 52, figures 1-6; pl. 66, figures 3-5.

Family BUXTONIIDAE Muir-Wood and Cooper, 1960

Subfamily BUXTONIINAE Muir-Wood and Cooper, 1960

Genus Marginatia Muir-Wood and Cooper, 1960

Marginatia sp. A

(Plate 4, figures 3 to 8)

MATERIAL: Locality 7721, sample 16; locality 7722, samples 10, 14; locality 8242, sample 19; locality 8243, samples 1-3, 5-9, 11, 14, 15; locality 8245, samples 10, 12 (float), 18 (float); locality 8246, sample 16; locality 8248, sample 17; locality 8249, sample 15; 33 articulated specimens, 34 pedicle valves, 17 brachial valves.

**OCCURRENCE:** Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian).

**EXTERIOR:** Shell of medium to large size for genus, outline subcircular to subquadrate. Ventral valve strongly convex, trail long; sulcus weak or absent, beginning as flattening or slight concavity on venter and continuing anteriorly onto trail; ears prominent but not sharply set off; flanks steep, greatest width along anterior margin; lateral profile subsemicircular, beak incurved beyond hinge line. Dorsal valve gently concave on visceral disc, rather sharply curving along anterior and lateral margins to conform with trail of ventral valve. Ornament consisting of concentric rugae and radial costae which intersect to form a prominent reticulate pattern, especially on visceral disc of both valves; spines few in number, erect, larger on trail. Dimensions of a complete specimen: length, 35 mm.; width, 31 mm.; thickness through visceral disc, 13 mm.

**INTERIOR:** Not observable in detail, due to fragmentary nature of most specimens and sparry calcite infilling.

#### Order RHYNCHONELLIDA

Superfamily RHYNCHONELLACEA Gray, 1848

Family TRIGONIRHYNCHONIIDAE Schmidt, 1965

Genus Ptychomaletoechia Sartenaer, 1961

Ptychomaletoechia (?) sp. A

(Plate 5, figures 16 to 21; Figure 29)

**MATERIAL:** Locality 8248, samples 11 (float), 35; 3 articulated specimens (1 serially sectioned).

**OCCURRENCE:** Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

**EXTERIOR:** Shell small, biconvex, subglobose, somewhat wider than long, outline subpentagonal, ventral beak acute, suberect, curving slightly over dorsal beak, beak ridges weakly developed; lateral profile subtriangular, commissure strongly uniplicate, 5 simple costae on fold, 4 on sulcus, 5 or 6 on each flank; ornament consisting of minute, closely-spaced growth lines; dimensions of 2 complete specimens:

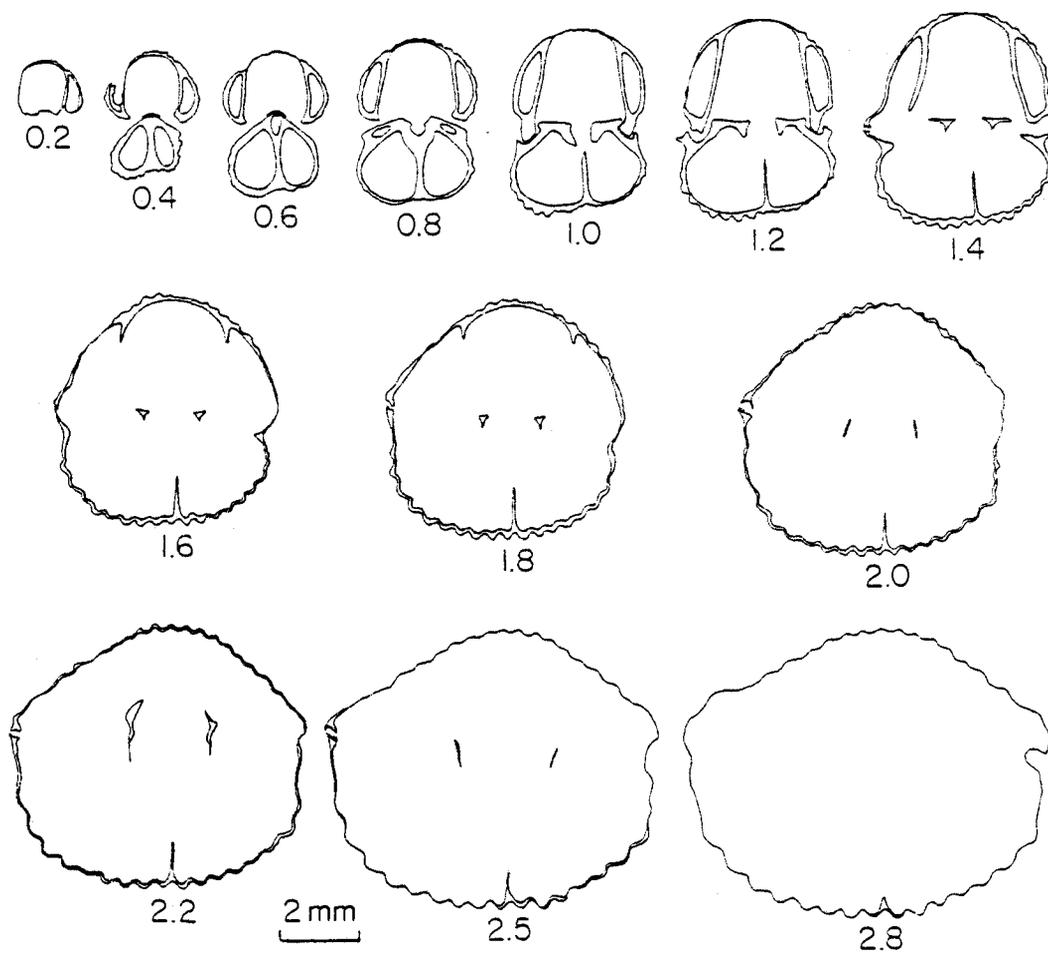


Figure 29. Transverse serial sections of Ptychomaletoechia (?) sp. A; specimen from sample 8248-11 (distances in mm. from ventral beak).

length, 9.93 mm., 9.19 mm.; width, 12.4 mm., 9.98 mm.; thickness, 8.18 mm., 6.58 mm.

INTERIOR: (Based on transverse serial sections, Figure 29) Ventral interior with well-developed, slightly divergent dental lamellae; floor of valve evenly curving, forming domed chamber with dental lamellae; dorsal valve with shallow, narrow septalium, supported on high median septum which extends anteriorly beyond ends of crura; septalium covered only posteriorly, no indication of apical foramen; cardinal process small, comb-like, as in uncinulids, situated at posterior extremity of hinge plate.

DISCUSSION AND COMPARISONS: Ptychomaletoechia (?) sp. A rather closely resembles Rhynchopora spp. It may be distinguished, externally, by its nonpunctate shell; internally, it has a smaller septalium which extends farther anteriorly than the flat hinge plate, and lacks an apical foramen, unlike Rhynchopora spp. Furthermore, no cardinal process was observed in any of the specimens of Rhynchopora spp. sectioned.

Family PUGNACIDAE Rzhonsnitskaya, 1956

Genus Shumardella Weller, 1910

Shumardella obsolescens Weller, 1910

(Plate 5, figures 11 to 15; Figure 30)

Shumardella obsolescens Weller, 1910, p. 513, fig. 15.

Shumardella obsolens (Hall): Weller, 1914, p. 224, pl. 26, figs. 1-9.

Shumardella obsolens Weller: Branson, 1938, p. 51, pl. 5, figs. 11-13.

Shumardella obsolescens Weller: Carter, 1967, p. 301, pl. 22, figs. 1a-8e, text fig. 3.

MATERIAL: Locality 7721, sample 2; locality 8246, sample 26; locality 8248, samples 9, 11, 12, 25, Float; 14 articulated specimens (1 serially sectioned).

OCCURRENCE: Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

EXTERIOR: Shell small, subglobose, nearly smooth, greatest width slightly anterior of midline; ventral beak small, pointed,

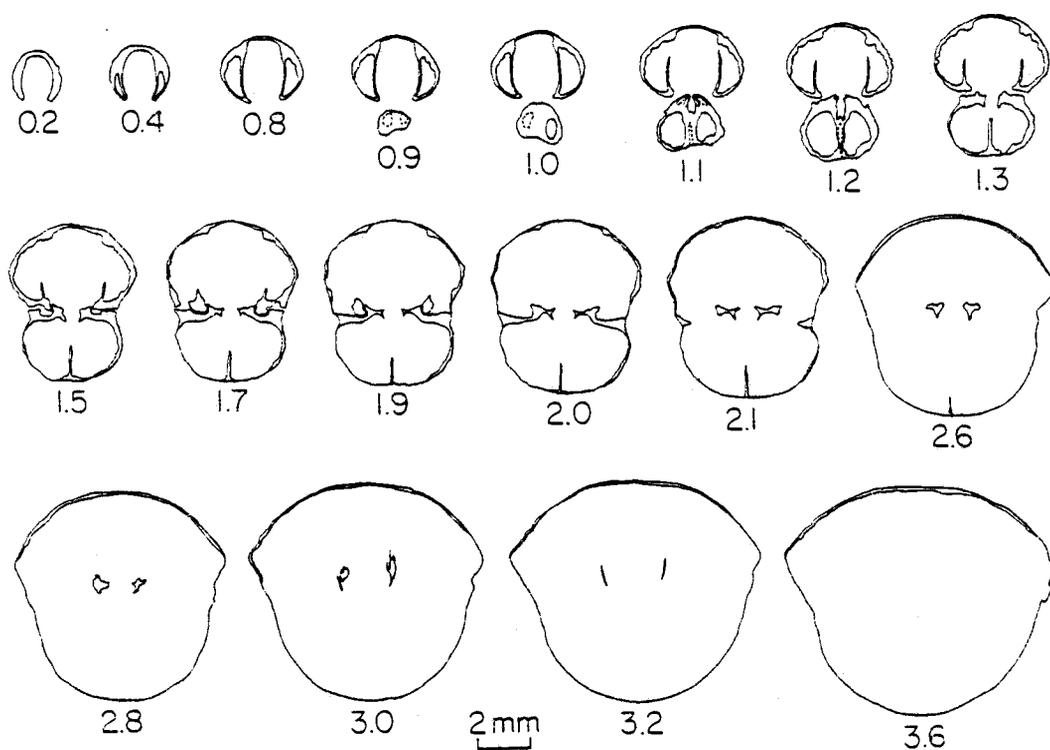


Figure 30. Transverse serial sections of *Shumardella obsolescens* Weller, 1910; specimen from sample 8248-25 (distances in mm. from ventral beak).

incurved slightly, apical angle approximately 120 degrees; fold and sulcus well-developed, beginning near mid-length, deepening to broad, rounded outline at anterior margin; ornament faint or obsolete, hence species name, consisting of faint, closely-spaced concentric growth lines and weak plications, commonly 3 in number, on fold and sulcus; dimensions of a complete specimen: length, 9.75 mm.; width, 9.65 mm.; thickness, 6.98 mm.

INTERIOR: (Based on transverse serial sections, Figure 30) Ventral valve with short dental plates, barely extending far enough anteriorly to provide support for well-developed teeth; dorsal valve with cardinal plate divided posteriorly into outer hinge plates and crural bases of triangular cross-section, the latter fusing with the high dorsal median septum to form a narrow septalium; crural processes extending forward beyond median septum, becoming thin, bladeliike anteriorly; cardinal process lacking.

Family YUNNANELLIDAE Rzhonsnitskaya, 1959

Genus Paraphorhynchus Weller, 1905

Paraphorhynchus sp. A

(Plate 4, figures 9 to 14; Figure 31)

MATERIAL: Locality 7719, sample 10; locality 7720, sample 9; locality 8245, sample 6; locality 8248, samples 11, 25; 8 articulated specimens (1 serially sectioned).

OCCURRENCE: Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

EXTERIOR: Shell of medium size, biconvex to subglobose, outline subtriangular to broadly ovate; ventral beak small, suberect, beak ridges prominent in both valves, apical angle approximately 100 degrees; fold and sulcus well-developed, deep, broadly-rounded to subangular, beginning posterior to midlength of shell; commissural suture with 2 or 3 plications on fold and sulcus, generally 2 on lateral slopes, plications sharp near anterior margin, low and rounded over most of shell, faint or obsolete near beaks; entire surface of shell faintly capillate (best seen on spalled interiors and near anterior margins); concentric ornament consisting of fine, closely-spaced growth lines; dimensions of an average size, slightly crushed specimen: length, 17.1 mm.; width, 14.3 mm.; thickness, 5.8 mm.

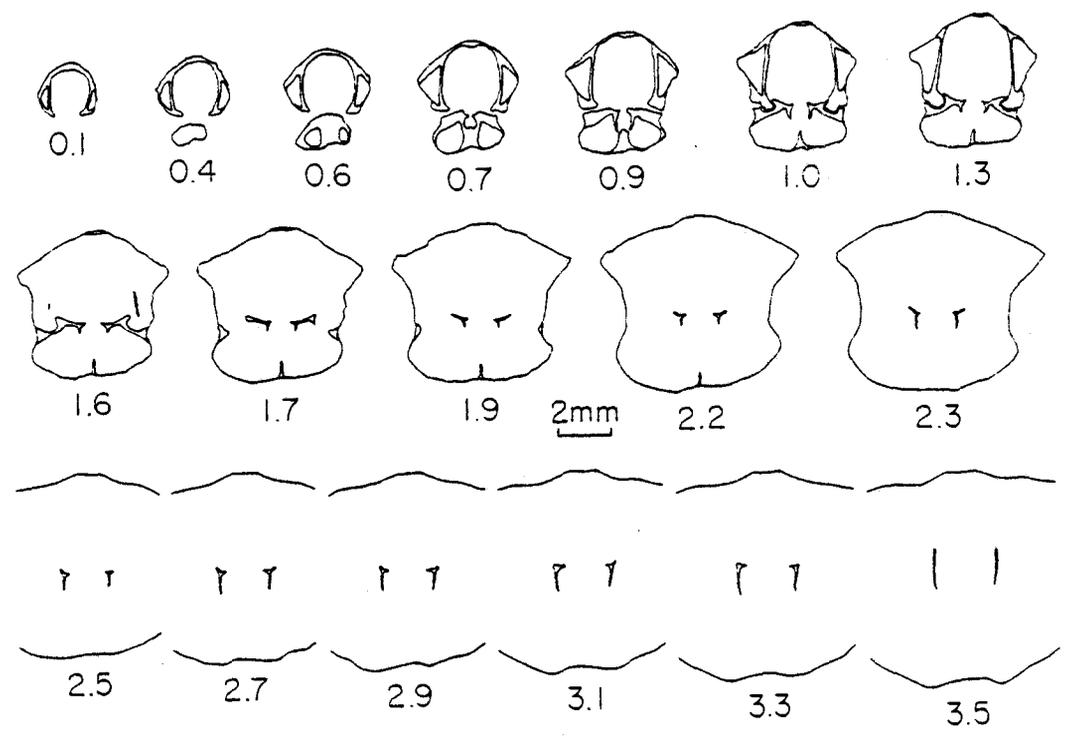


Figure 31. Transverse serial sections of Paraphorhynchus sp. A; specimen from sample 8248-25 (distances in mm. from ventral beak).

INTERIOR: (Based on transverse serial sections, Figure 31). Cardinal process lacking; ventral valve with strong dental plates extending forward to immediately anterior to strong, well-developed teeth; dorsal valve with septalium composed of outer hinge plates and crural bases of triangular cross-section; crura extending dorsally approximately 1/2 distance to floor of valve and fuse with dorsal median septum; median septum extending only short distance anterior of septalium before ending abruptly; immediately anterior to median septum, crural processes expand dorsally to form high, thin plates, then end abruptly.

DISCUSSION AND COMPARISONS: Based on the limited amount of material available for study, including no specimen which is neither crushed nor partially broken, it appears that Paraphorhynchus sp. A is distinct from all other species assigned to the genus. Generally, it seems to be somewhat smaller and less strongly plicate than P. bushbergense Branson, 1938; P. elongatum Weller, 1905; P. striatocostatum (Meek and Worthen), 1868; or P. transversum Weller, 1905. The variability within the genus, however, as described by Branson (1938), appears to be great, so that there may be overlap in many or all morphological features and among all these species.

Superfamily STENOSCISMATACEA Oehlert, 1887 (1883)

Family ATRIBONIIDAE Grant, 1965

Subfamily ATRIBONIINAE Grant, 1965

Genus Atribonium Grant, 1965

Atribonium (?) sp. A

(Plate 5, figures 1 to 10, Figure 32)

MATERIAL: Locality 8243, sample 11; 3 articulated specimens (1 serially sectioned).

OCCURRENCE: Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Unit 4 of Lane (1974; 1978, in press; 1978, written comm.).

EXTERIOR: Shell small for genus, slightly ventribiconvex; slightly longer than wide, greatest width at or near midlength, outline subcircular; thickness approximately 0.6 to 0.7 of length or width, lateral profile lenticular, convexity of both valves increasing

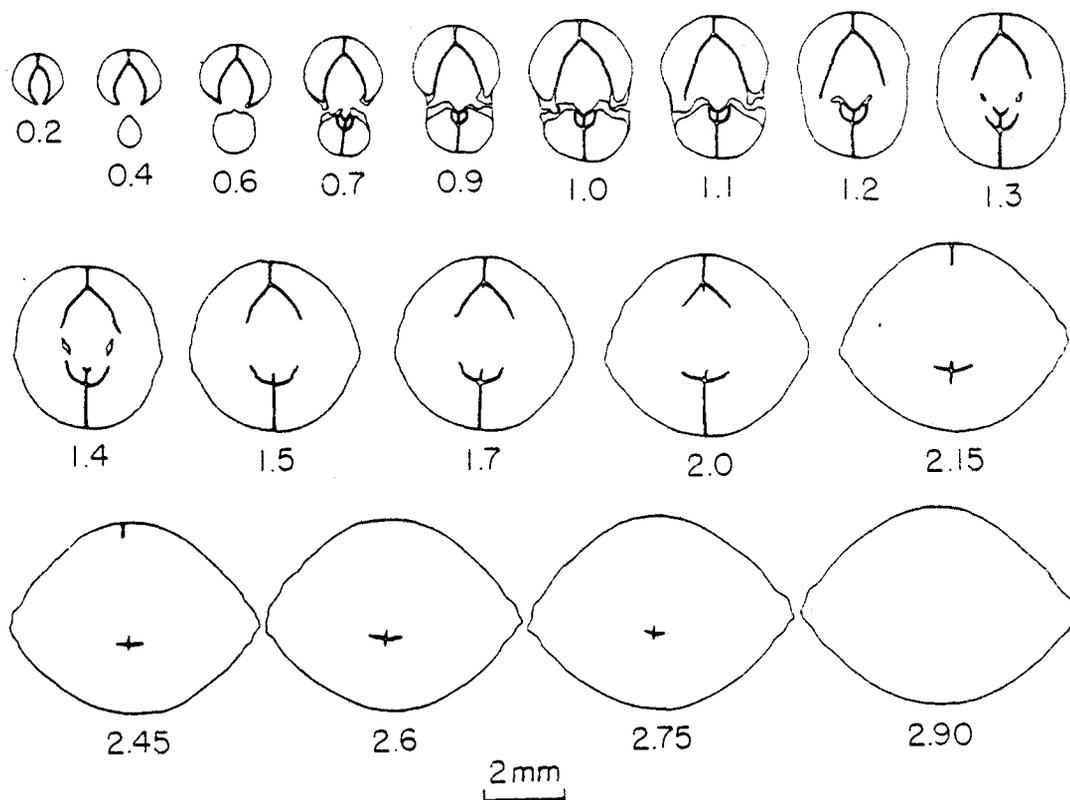


Figure 32. Transverse serial sections of *Atribonium* (?) sp. A; specimen from sample 8243-11 (distances in mm. from ventral beak).

posteriorly, beaks sharply incurved; pedicle foramen not observable; anterior commissure nearly rectimarginate, with only slight suggestion of dorsal fold and ventral sulcus; radial ornament lacking; concentric ornament consisting of a few irregularly-spaced growth lines; dimensions of two articulated specimens: length, 7.80 mm., 5.69 mm.; width, 7.72 mm., 5.31 mm.; thickness, 4.70 mm., 3.81 mm.

INTERIOR: (Based on transverse serial sections, Figure 32.) Ventral valve with well-developed dental lamellae which converge and fuse along midline of valve to form deep spondylium supported by median septum duplex, the latter extending only slightly anterior of the spondylium. Dorsal valve lacking cardinal process; hinge plate divisible into thick, lateral parts and thin, medial segment between ends of camarophorium; camarophorium narrow, supported by high median septum; intercamarophorial plate present, continuing anterior of hinge plate to anterior end of camarophorium as low septum; median septum joined to floor of valve to point opposite termination of spondylium, then continuing as low ridge on dorsal surface of camarophorium, giving distinctive t-shaped cross-section to anterior end of camarophorium; crural bases originating at junction of ends of camarophorium and ends of thin, medial segment of hinge plate, crura extending only slightly anteroventrally from hinge plate (do not appear to be broken).

DISCUSSION AND COMPARISONS: Assignment of this species to the genus Atribonium, although based on limited data, seems justified. The external shape, weak ornament, and weak or absent plications might occur jointly in small specimens or small species of Coledium and Stenosisma also. The details of internal configuration, however, seem more clearly related to Atribonium. Two details, in particular, stand out in the description of Atribonium by Grant (1965, p. 38): (1) "intercamarophorial plate thinning and declining anterior to hinge plate, disappearing about 2 mm. anterior to beak...;" (2) "camarophorium capping median septum anterior to termination of intercamarophorial plate...." In Coledium and Stenosisma, the intercamarophorial plates extend only slightly beyond the hinge plate and the median septum extends nearly or entirely the length of the median septum, increasing in length anteriorly. Thus, the peculiar, straight, transversely +-shaped extension of the camarophorium, intercamarophorial plate, and median septum seems most consistent with the definition of Atribonium.

Family STENOSCISMATIDAE Oehlert, 1887 (1883)

Subfamily STENOSCISMATINAE Oehlert, 1887 (1883)

Genus Coledium Grant, 1965

Coledium sugarloafensis, n. sp.

(Plate 5, figures 22 to 31; Figure 33)

**MATERIAL:** Locality 8243, samples 1, 3, 6, 7; locality 8248, samples 11, 12, 26; 48 articulated specimens (1 serially sectioned), 5 brachial valves, 1 pedicle valve.

**OCCURRENCE:** Caballero (?) and Lake Valley formations; Early Mississippian, Kinderhookian (?) and Osagean (Tournaisian); conodont Faunal Units 1 (?), 3 of Lane (1974).

**EXTERIOR:** Shell of average size for genus, subelliptical, wider than long; average dimensions for 13 complete specimens from asmples 8243-6 (Figure 34): length, 9.1 mm.; width, 10.2 mm.; thickness, 5.6 mm.; immature specimens moderately dorsibiconvex, small specimens being of nearly equal convexity. Uniplicate, the deflection of the line of commissure beginning about 6 to 7 mm. anterior to ventral beak, small specimens, thus, being nearly rectimarginate. Costae absent or faintly visible near anterior margin (2 shallow costae visible near the anterior margin of the fold on one specimen); concentric ornamentation consisting of weakly-developed growth lines. Stolidium not observed on any specimen.

**INTERIOR:** (Based on transverse serial sections, Figure 33) Ventral valve with spondylium formed by convergent dental plates, supported on a very low median septum duplex which continues anterior to the spondylium for nearly 1 mm. Dorsal interior with short hinge plate from which the intercamarophorial plate extends to the midpoint of the camarophorium; camarophorium high, narrow, deep, becoming slightly higher anteriorly, extending about 1 mm. anterior to base of median septum duplex and ends of crura; crura extending about 0.5 mm. anteriorly from hinge plate before curving abruptly ventrally and terminating; cardinal process not seen.

**DISCUSSION AND COMPARISONS:** Coledium sugarloafensis, n. sp., most closely resembles C. evexum Grant, 1965, from the Chappel Limestone of Texas. It differs from that species in having

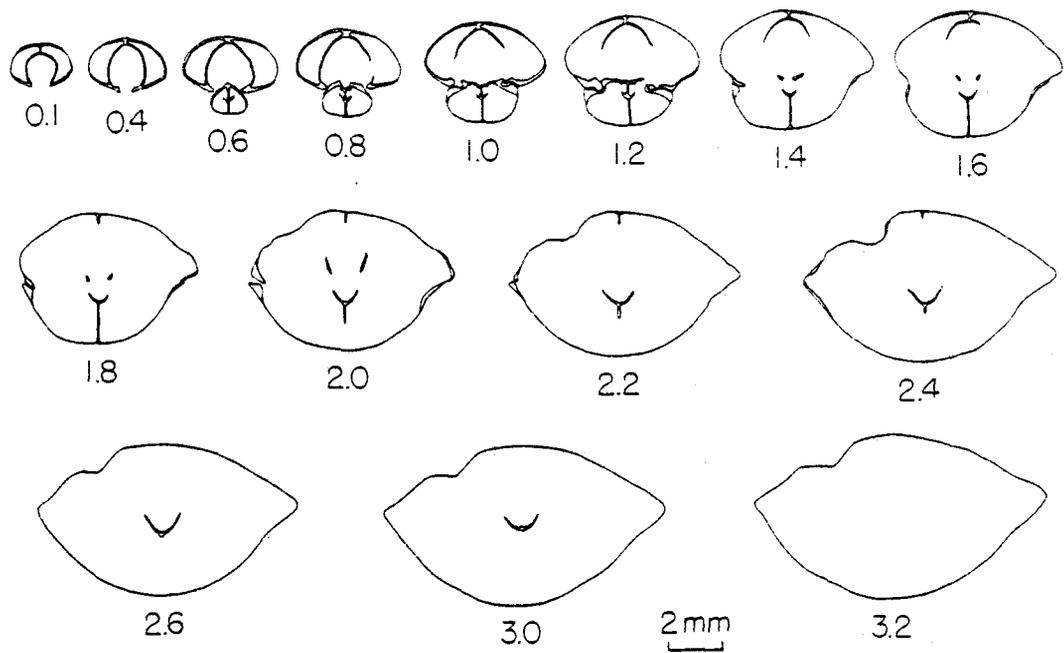


Figure 33. Transverse serial sections of Coledium sugarloafensis n. sp.; specimen from sample 8243-6 (distances in mm. from ventral beak).

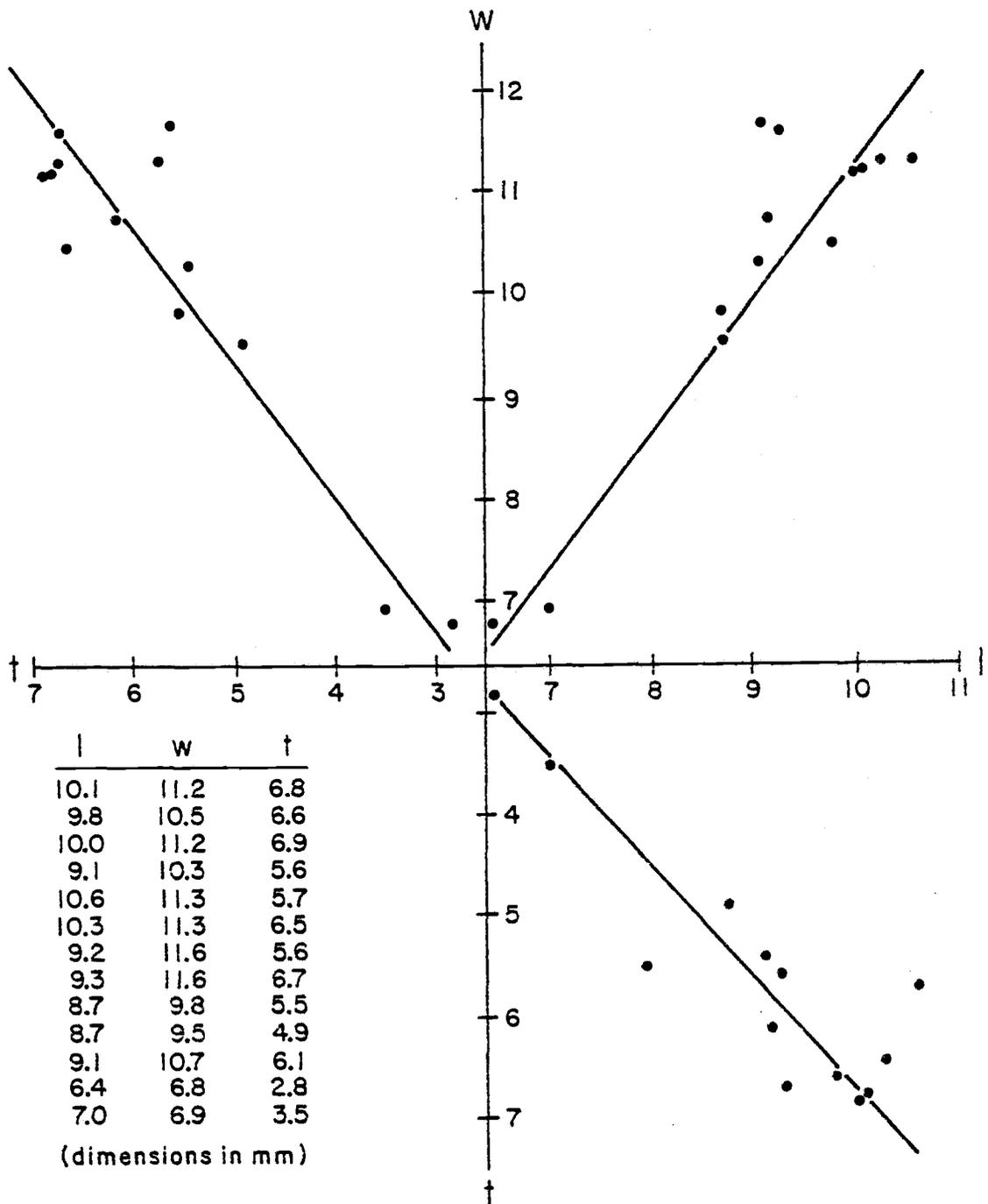


Figure 34. Comparison of principal dimensions (length, width, thickness) of 13 specimens of Coledium sugarloafensis n. sp.; specimens from sample 8243-6.

a lower, broader, more nearly rectangular fold and sulcus as seen in an anterior view. Internally, the median septum duplex supporting the spondylium is shorter in C. sugarloafensis, the spondylium being nearly sensile.

The occurrence of C. sugarloafensis in the Caballero Formation is somewhat uncertain as none of the specimens occurring there was sectioned. With the exception of those few specimens, all of the remaining material was obtained from the reef core ecofacies in Little Sugarloaf Mound, locality 8243.

Superfamily RHYNCHOPORACEA Muir-Wood, 1955

Family RHYNCHOPORIDAE Muir-Wood, 1955

Genus Rhynchopora King, 1865

Rhynchopora sp. A

(Plate 6, figures 1, 2; Figure 35)

MATERIAL: Locality 9130, sample 11; 1 articulated specimen (serially sectioned).

OCCURRENCE: Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

EXTERIOR: Shell of medium size for genus, biconvex, outline subpentagonal; lateral profile subtriangular, commissure strongly uniplicate, 8 simple costae on fold, 7 on sulcus, and 6 or 7 on each flank; shell substance minutely punctate; dimensions of specimen: length, 13.9 mm.; width, 19.5 mm.; thickness, 12.4 mm.

INTERIOR: (Based on transverse serial sections, Figure 35) Ventral valve with strong dental lamellae which end rather abruptly anterior of teeth; dorsal valve with undivided hinge plate and triangular septalium supported by median septum, median septum continuing well forward of ends of crura; cardinal process lacking; crura initially hook-shaped before descending ventrally as thin plates.

Rhynchopora sp. B

(Plate 6, figures 3 to 9; Figures 36, 37)

MATERIAL: Locality 8243, samples 1, 2, 4, 6, 7; 40 articulated

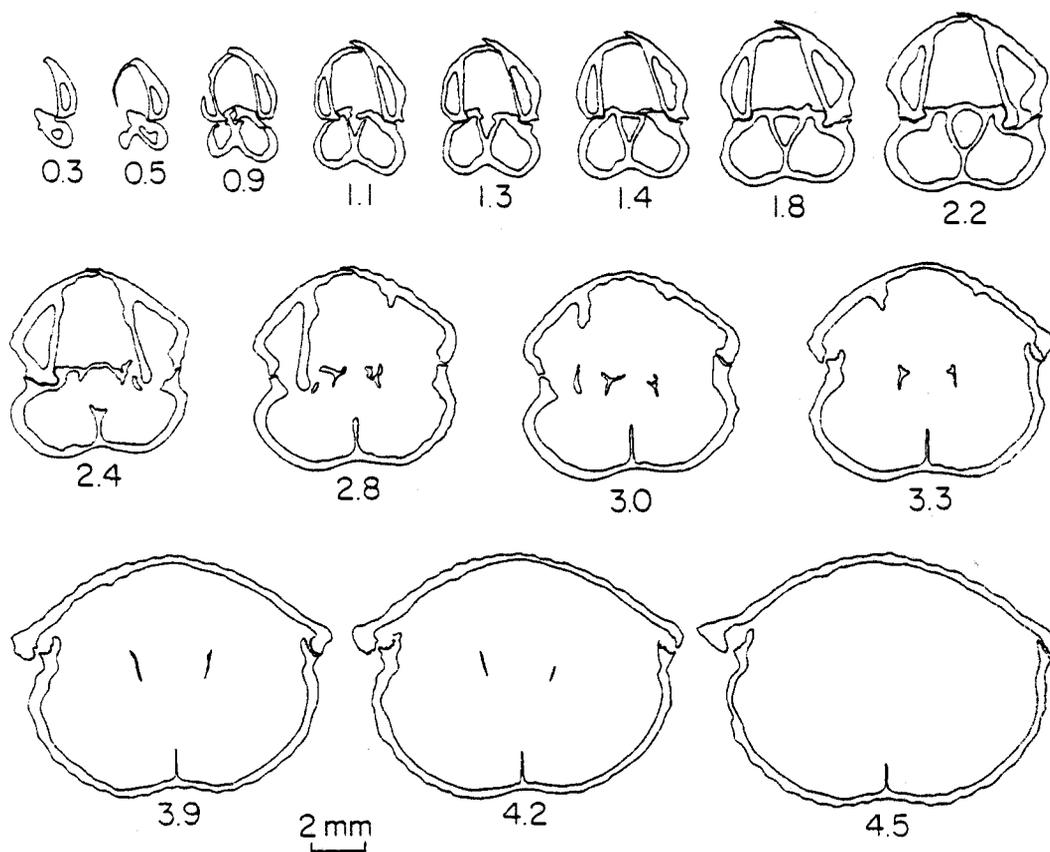


Figure 35. Transverse serial sections of *Rhynchopora* sp. A; specimen from sample 9130-11 (distances in mm. from ventral beak).

specimens (5 serially sectioned), 2 pedicle valves, 2 brachial valves.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Unit 3B of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell subglobose, of medium to large size for genus, wider than long, length and thickness subequal, biconvex, outline subpentagonal; lateral profile subtriangular; ventral beak small, obtuse, suberect, beak ridges lacking; commissure strongly uniplicate, fold with 5 to 9 coarse, rounded plications, flanks with 5 to 10 simple, rounded plications which decrease in size laterally; ornament consisting of minute, closely-spaced growth lines; dimensions of two nearly complete specimens: length, 20.2 mm., 19.1 mm.; width, 23.7 mm., 23.9 mm.; thickness, 16.6 mm., 15.4 mm.

**INTERIOR:** (Based on transverse serial sections, Figures 36, 37) Ventral valve with dental lamellae and small teeth; dorsal valve with narrow septalium supported on high, thin median septum; crura sigmoid or arcuate in cross section with descending, platelike extensions; cardinal process lacking.

Rhynchopora sp. C

(Plate 6, figures 10 to 14; Figure 38)

**MATERIAL:** Locality 8243, samples 3, 5; 5 articulated specimens (2 serially sectioned).

**OCCURRENCE:** Lake Valley Formation; Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Unit 3B of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell of medium size for genus; biconvex, wider than long, longer than thick, outline subelliptical; lateral profile subtriangular; anterior commissure strongly uniplicate, fold high, subrectangular, 6 to 8 simple, rounded plications on fold, 6 to 8 on each flank, decreasing in size laterally; ornament consisting of minute, closely-spaced growth lines; shell substance minutely punctate; dimensions of a complete specimen: length, 15.4 mm.; width, 18.0 mm.; thickness, 14.6 mm.

**INTERIOR:** (Based on transverse serial sections, Figure 38) Ventral valve with strong dental lamellae and teeth; dorsal valve with wide, deep septalium, sides of septalium turning in against ends of

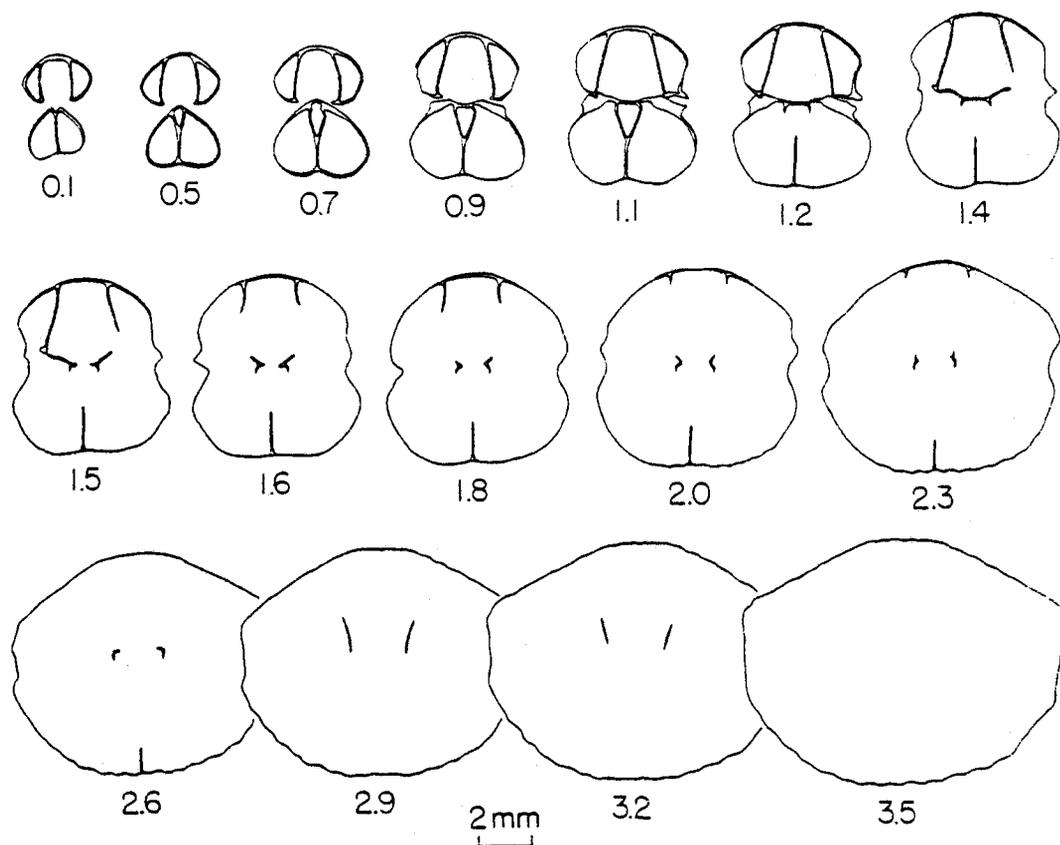


Figure 36. Transverse serial sections of *Rhynchopora* sp. B; specimen from sample 8243-2 (distances in mm. from ventral beak).

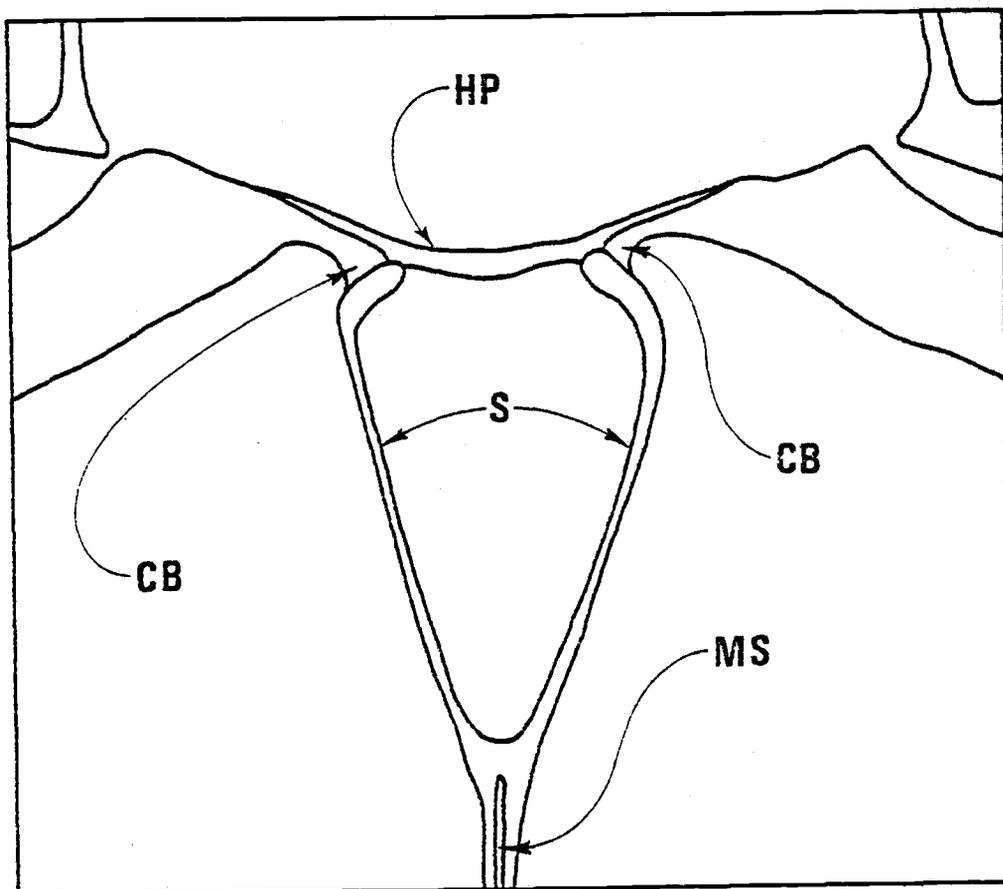


Figure 37. Details of hinge plate (HP), septalium (S), crural bases (CB), and median septum (MS) of Rhynchopora sp. B; specimen from sample 8243-2; based on transverse serial section 1.0 mm. anterior to ventral beak.

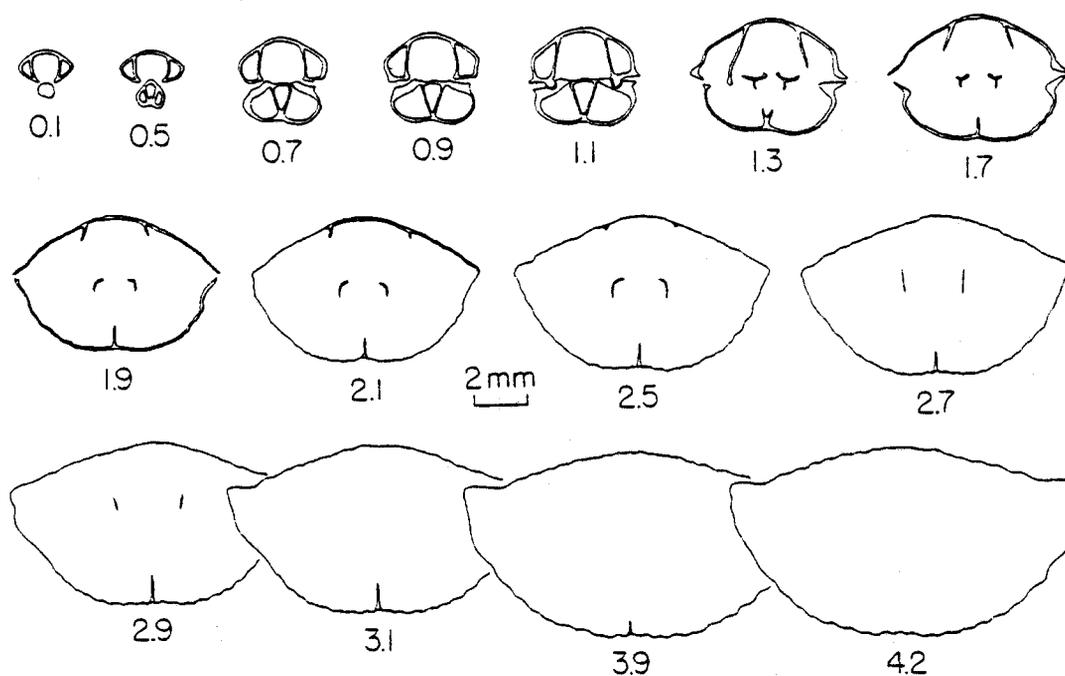


Figure 38. Transverse serial sections of Rhynchopora sp. C; specimen from sample 8243-5 (distances in mm. from ventral beak).

crural bases, base of septalium slightly elevated above floor of valve on low median septum which may increase in height anterior of septalium; crura arcuate in cross section with descending, platelike extensions; cardinal process lacking.

Rhynchopora sp. D

(Plate 6, figures 15 to 18; Figure 39)

**MATERIAL:** Locality 8243, samples 8, 11, 15; 7 articulated specimens (3 serially sectioned).

**OCCURRENCE:** Lake Valley Formation; Early Mississippian; Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Units 3B, 4 of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell of small to medium size for genus, biconvex, width greater than length, length greater than thickness, outline sub-pentagonal; lateral profile subtriangular; beak small, suberect, apical angle approximately 90 degrees; commissure strongly uniplicate; fold with 6 to 8 low, simple, rounded costae, each flank with 6 to 9 simple costae which decrease in size laterally; surface marked by minute, closely-spaced growth lines, shell substance minutely punctate; dimensions of a complete specimen: length, 10.3 mm.; width, 12.8 mm.; thickness, 8.46 mm.

**INTERIOR:** (Based on transverse serial sections, Figure 39) Ventral valve with thin dental lamellae and small teeth; dorsal valve with wide, subequilateral, triangular septalium supported by median septum of subequal height, sides of septalium generally turned inward against ends or crural bases; crura arcuate in cross section, with descending, platelike anterior extensions; cardinal process lacking.

Order SPIRIFERIDA

Suborder RETZIIDINA

Superfamily RETZIACEA Waagen, 1883

Family RETZIIDAE Waagen, 1883

Genus Hustedia Hall and Clarke, 1893

Hustedia (?) sexplicata White and Whitfield, 1862, p. 294.

(Plate 6, figures 19 to 23)

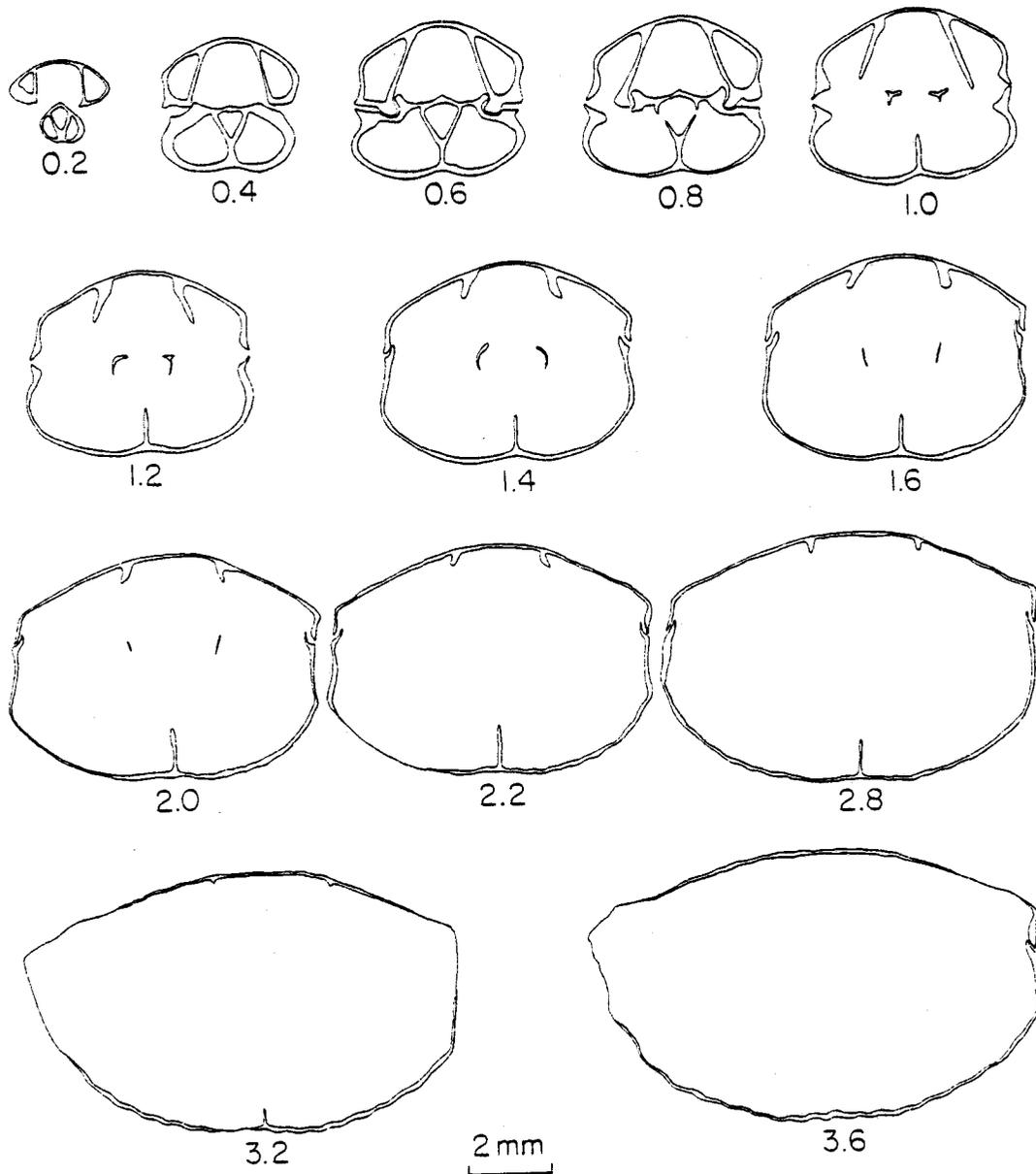


Figure 39. Transverse serial sections of *Rhynchopora* sp. D; specimen from sample 8243-11 (distances in mm. from ventral beak).

Retzia sexplicata White and Whitfield, 1862, p. 294.

Ptychospira sexplicata: Weller, 1914, p. 435, 436; pl. 76, figs. 35-46.

Ptychospira sexplicata: Branson, 1938, p. 70, 71, 176, pl. 9, fig. 4; pl. 19, figs. 37, 43, 44.

MATERIAL: Locality 7722, samples 8, 13; 1 articulated specimen, 1 pedicle valve.

OCCURRENCE: Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

EXTERIOR: Shell small; shell substance densely punctate; slightly wider than long, outline subcircular; biconvex, lateral profile lenticular; sharply plicate, with 6 angular plications, each extending from beak to commissure; beak small, apsacline, sharply incurved over small, triangular interarea; dimensions of only complete specimen available: length, 8.61 mm. width, 9.35 mm.; thickness, 5.38 mm.

INTERIOR: Not observed; specimen partially silicified, hence, not suitable for serial sectioning.

DISCUSSION AND COMPARISONS: This small, distinctive brachiopod occurs widely in Early Mississippian rocks of the United States, being reported from the Chouteau, Fern Glen, Bushberg, New Providence, and Burlington formations (Carter and Carter, 1970). H. (?) sexplicata was originally described as Retzia sexplicata by White and Whitfield (1862). Hall and Clarke (1894, p. 112, 113) later assigned R. sexplicata, R. longirostris, and Terebratula ferita to their new genus, Ptychospira, with T. ferita as type species. The name Ptychospira, however, had been preemptively assigned to a gastropod (Slavik, 1869) and Cooper (1942, p. 288) established the genus Plectospira with T. ferita as type. Because of the lack of suitable material for serial sectioning, the interior of the present species is not known. A similar species, Hustedia ? problematica Girty, 1926, from the Chappel Limestone, Texas, was figured by Carter (1967, Text - fig. 12); Carter assigns this species to Plectospira, comparing it with R. sexplicata. Carter's serial sections, however, reveal a distinct cardinal process and, therefore, are more correctly assignable to Hustedia. For this reason and because of the overlapping morphological variation of it and R. sexplicata (H. problematica may have as many as six plications, while R. sexplicata may have from 6 to 12) (see plate 28,

figures 9a-e, of Carter, 1967), the latter species is questionably assigned to Hustedia, subject to clarification of the internal morphology of R. sexplicata.

Suborder ATHYRIDIDINA

Superfamily ATHYRIDACEA McCoy, 1844

Family ATHYRIDIDAE McCoy, 1844

Subfamily ATHYRIDINAE McCoy, 1844

Genus Athyris Buckman, 1906

Athyris cf. lamellosa (Leveille), 1835

(Plate 7, figures 1 to 8; Plate 14, figures 17, 18; Figures 40 to 42)

**MATERIAL:** Locality 7719, sample 11; locality 7720, sample 9; locality 7721, samples 10, 16; locality 7722, samples 7-9; locality 8244, samples 8, 10; locality 8245, samples 9, 15, 17 (float), Caballero (float); locality 8246, samples 5, 7; locality 9130, sample 8; 41 articulated specimens (5 serially sectioned), 3 brachial valves, 4 fragments, 1 internal mold.

**OCCURRENCE:** Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian); conodont Faunal Units 1 to 4, 5 (?) of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell size variable, small to large, biconvex, length: width ratio about 0.8, outline suboval; lateral profile lenticular; beaks small, nearly straight; hingeline straight, about 0.8 of width of shell; fold and sulcus low, broad, very weakly-developed in small specimens, strongly-developed in large specimens, beginning slightly posterior to midlength of shell; ornament consisting of numerous concentric growth lamellae extended as wide frills which may be more than half length of shell; dimensions of two specimens; length, 21.0 mm., 30.0 mm.; width, 25.0 mm., 42.0 mm.; thickness, 13.3 mm., 19.0 mm.

**INTERIOR:** (Based on transverse serial sections, Figures 40, 41) Two distinct morphological varieties can be recognized, based on variations in internal features. Because these variations are not externally detectable and because the two varieties occur in different

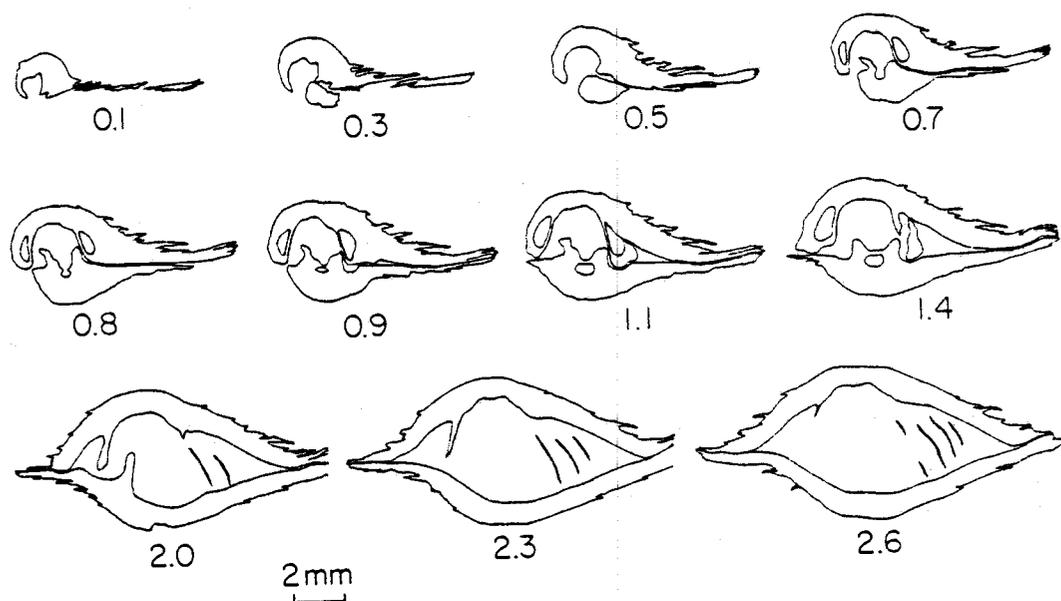


Figure 40. Transverse serial sections of *Athyris* cf. *lamellosa*, ecofacies morphotype A (non-reef); specimen from sample 7722-8 (distances in mm. from ventral beak).

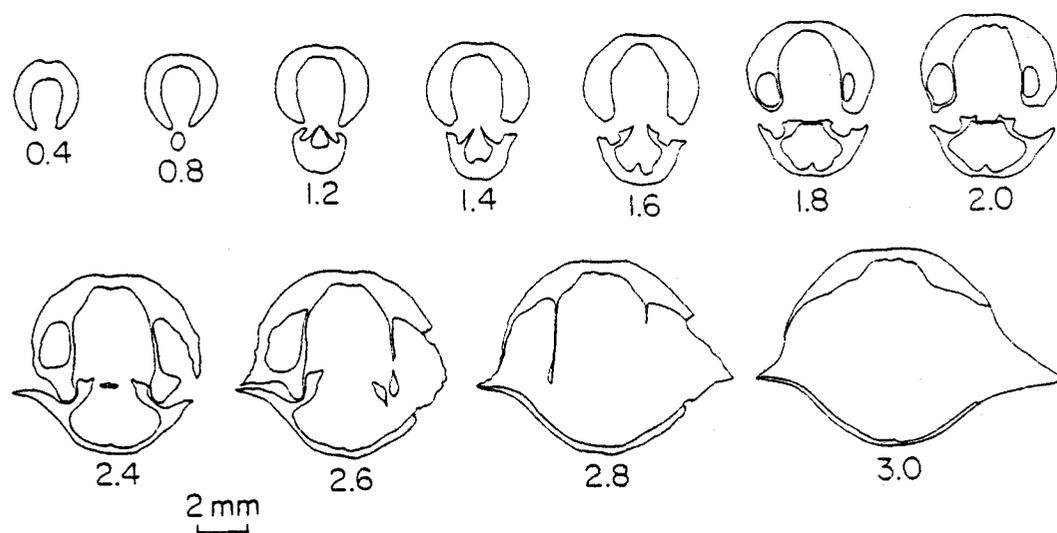


Figure 41. Transverse serial sections of Athyris cf. lamellosa,  
ecofacies morphotype B (reef); specimen from sample  
8243-11 (distances in mm. from ventral beak).



ecofacies, their internal features are described separately below as ecofacies morphotypes. That is, they are considered to represent varied environmental responses within a single species.

Ecofacies morphotype A (non-reef) (Based on transverse serial sections, Figure 40) Ventral valve with dental lamellae; dorsal valve with thin, deeply-depressed, apically-pierced cardinal plate; crura broken, not observed.

Ecofacies morphotype B (reef) - (Based on transverse serial sections, Figure 41) Ventral valve with dental lamellae; dorsal valve with thin, high, apically-pierced cardinal plate and median ridge; crura not observed; secondarily thickened.

DISCUSSION AND COMPARISONS: Because there is inadequate material at hand to determine the range of variation of the internal features or to correlate them with external variation, no attempt has been made to recognize the two ecofacies morphotypes as distinct species.

Genus Cleiothyridina Buckman, 1906

Cleiothyridina cf. glenparkensis Weller, 1914

(Plate 7, figures 9 to 13; Figure 43, 44)

MATERIAL: Locality 7720, sample 9; locality 7722, sample 8; locality 8245, samples 11, 15, Caballero (float); locality 8246, sample 5; locality 8248, samples 11, 30, 35; locality 9130, sample 11; 46 articulated specimens (1 serially sectioned), 1 pedicle valve, 1 brachial valve.

OCCURRENCE: Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian); uncommon in reef core ecofacies.

EXTERIOR: Shell of small to medium size, biconvex, sub-circular to transversely elliptical outline; beaks small, sharply incurved; lateral profile lenticular; ornamentation consisting of numerous, closely-spaced growth lamellae which extend beyond the shell surface as small, flattened spines.

INTERIOR: (Based on transverse serial sections, Figure 43) Ventral valve with strong, ventrally-converging dental lamellae;

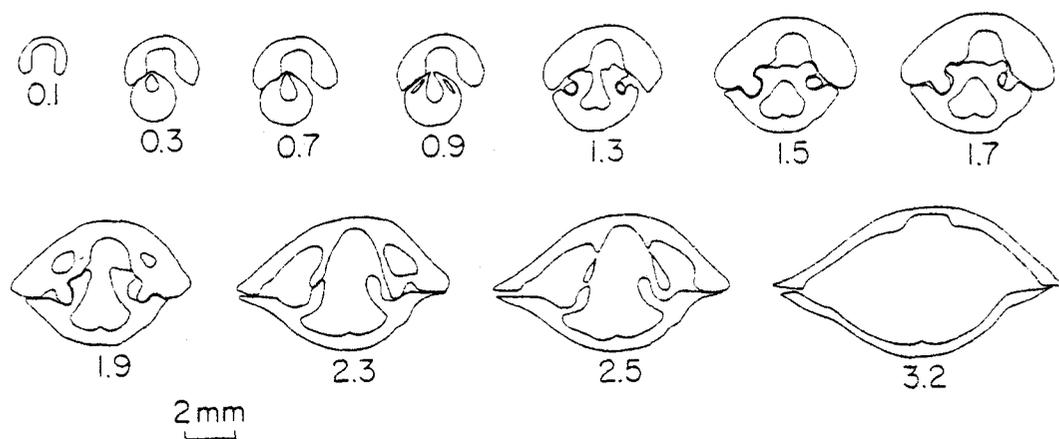


Figure 43. Transverse serial sections of Cleiothyridina cf. glenparkensis; specimen from sample 7722-8 (distances in mm. from ventral beak).

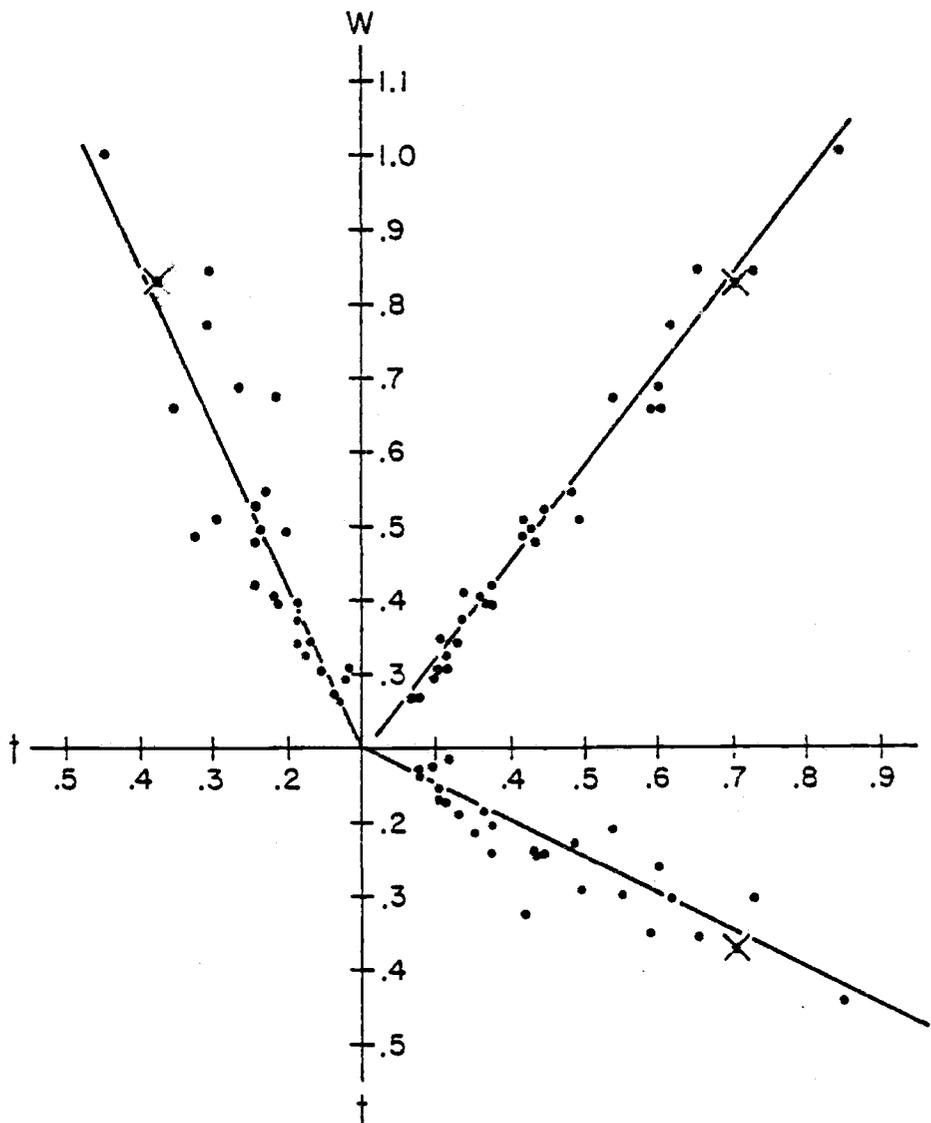
*Cleiothyridina cf. glenparkensis*

Figure 44. Comparison of principal dimensions (length, width, thickness) of complete specimens of Cleiothyridina cf. glenparkensis.

dorsal valve with small, apically-pierced cardinal plate, very low median ridge; crura and jugum not observed.

DISCUSSION AND COMPARISONS: Although Weller (1914) did not illustrate serial sections of any species of Cleiothyridina, the morphological details of its interior are reasonably well known and generally conservative. Externally, C. cf. glenparkensis is nearly identical to C. glenparkensis Weller, 1909, and may be conspecific with it (Figure 44).

Cleiothyridina prouti (Swallow), 1860

(Plate 7, figures 14 to 18; Figure 45)

Spirifera proutii Swallow, 1860, p. 649

Spirifera temeraria: Miller, 1881, p. 314; pl. 7, figs. 9-9b.

Cleiothyris prouti: Weller, 1909, p. 313, pl. 14, figs. 12-15.

Cleiothyridina prouti: Weller, 1914, p. 474, 475; pl. 79, figs. 13-16.

Cleiothyridina aff. C. prouti: Carter, 1967, p. 347-349; pl. 32, figs. 1a-4e; text-fig. 22.

MATERIAL: Locality 7721, sample 14; locality 8242, sample 19; locality 8243, sample 1; locality 9130, sample 10; 5 articulated specimens (1 specimen serially sectioned).

OCCURRENCE: Caballero and Lake Valley formations, Early Mississippian, Linderhookian and Osagean (Tournaisian).

EXTERIOR: Shell of small to medium size, strongly biconvex; wider than long, greatest width slightly posterior to midlength, cardinal extremities broadly rounded, outline subelliptical; ventral interarea small, apsacline, beaks sharply incurved, almost in contact; lateral profile subelliptical; fold and sulcus deep, sharply-defined, smoothly rounded; surface ornament consisting of numerous closely-spaced growth lamellae extended into thin, flattened spines, the spines of successive lamellae being so aligned as to lie in distinct rows, thereby simulating a finely reticulate pattern, spacing between rows about 1.5-2.0 width of spines; dimensions of sectioned specimen: length, 15.2 mm.; width, 20.8 mm.; thickness, 11.8 mm.

INTERIOR: (Based on transverse serial sections, Figure 45) Shell thickened posteriorly; ventral valve with dental lamellae and low median ridge; dorsal valve with thick, medially-created, posteriorly perforated cardinal plate and median ridge, the latter thickened

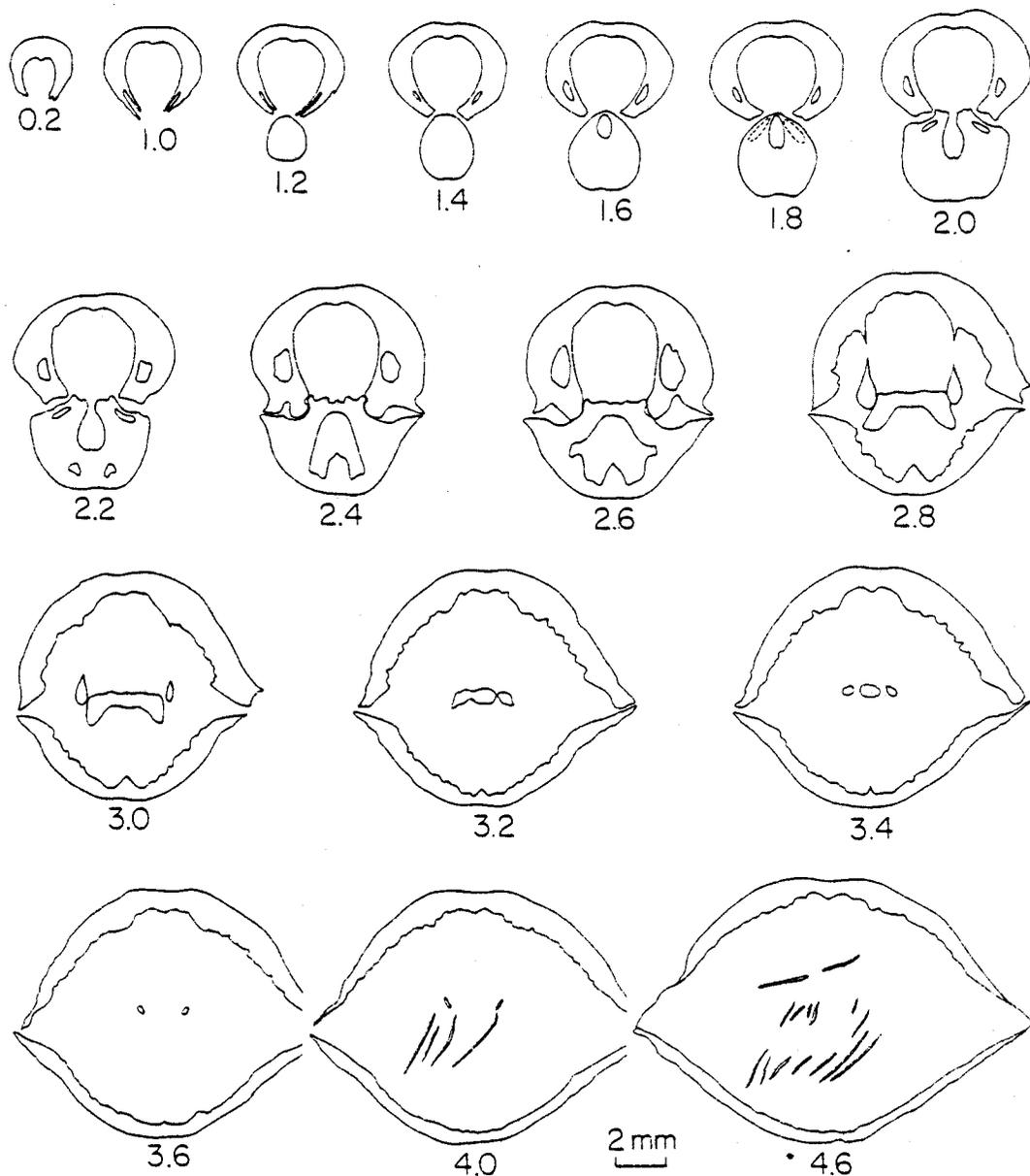


Figure 45. Transverse serial sections of Cleiothyridina prouti (Swallow), 1860; specimen from sample 7721-14 (distances in mm. from ventral beak).

posteriorly to form high, wide mhophragm; crura round, becoming bandlike in cross section anteriorly.

DISCUSSION AND COMPARISONS: The Caballero and Lake Valley specimens are considered to be identical both to C. prouti s. s. and to C. aff. C. prouti, described from the Chappel Limestone by Carter (1967). Although the Chappel specimens are smaller than typical C. prouti and smaller than the New Mexico specimens, this difference seems minor. Miller (1881) described a single specimen of this species as Spirifera temeraria; that name is a junior synonym of C. prouti.

Genus Composita Buckman, 1906

Composita cf. globosa Weller, 1914

(Plate 7, figures 19 to 28; Figures 46, 47)

MATERIAL: Locality 7719, sample 9; locality 7720, sample 4; locality 8248, samples 9, 11, 35; 6 articulated specimens (3 serially sectioned), 1 internal mold.

OCCURRENCE: Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974; 1978, written comm.).

EXTERIOR: Shell small, biconvex, outline subcircular to pyriform, usually slightly longer than wide; lateral profile lenticular; fold weakly-developed in small specimens, moderately-developed in large specimens; commissure weakly to moderately uniplicate; ventral beak erect; ornament consisting of numerous closely-spaced growth lines, not developed into frills or spines, and fine radial striations; dimensions of a typical mature specimen: length, 11.4 mm.; width, 11.1 mm.; thickness, 7.37 mm. (Figure 47).

INTERIOR: (Based on transverse serial sections, Figure 46) Ventral valve with short dental lamellae; dorsal valve with triangular, apically-pierced cardinal plate; low median ridge; crural bases oval to subtriangular, arising at lateral margins of cardinal plate; crura round, apparently broken off just anterior to cardinal plate; shell outline at anterior end of cardinal plate subcircular. Two additional specimens, from samples 7719-9 and 8248-9, were sectioned; both had closely similar internal features.

DISCUSSION AND COMPARISONS: Composita cf. globosa is identical externally, to C. globosa. Weller (1914), however, neither

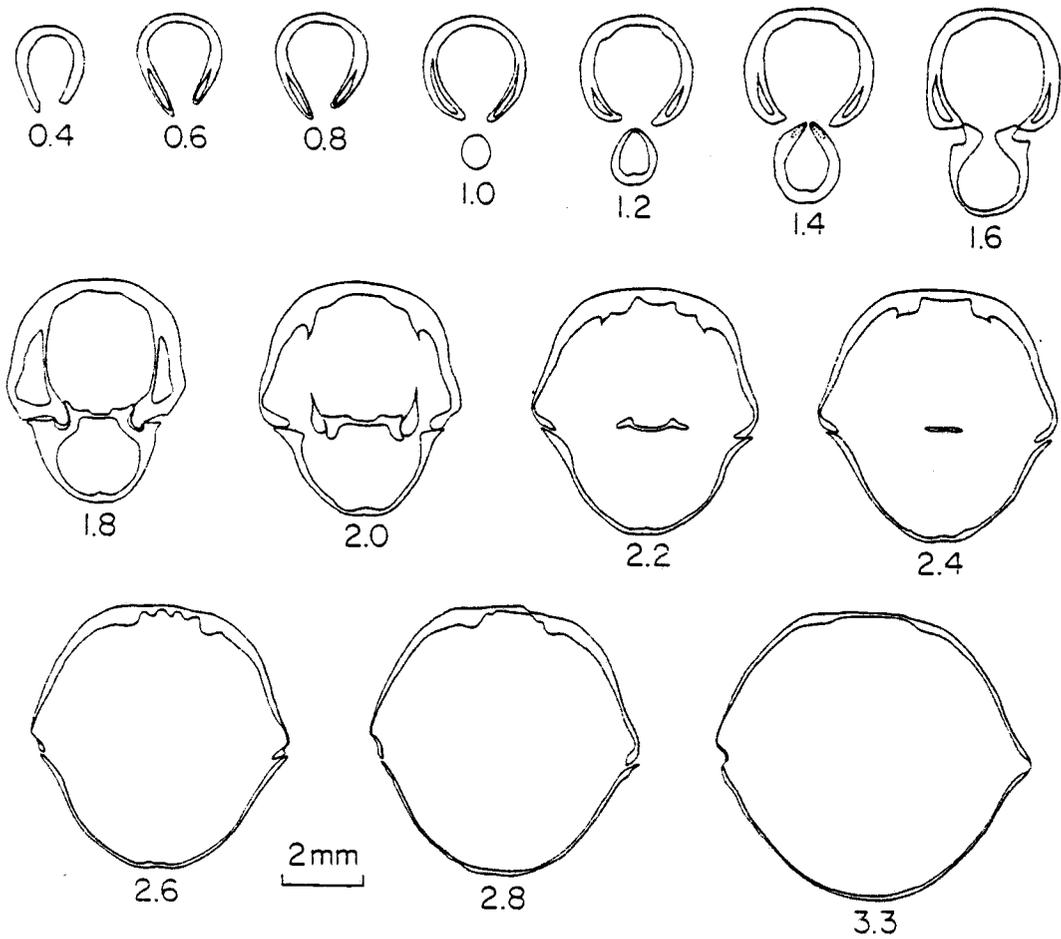


Figure 46. Transverse serial sections of *Composita* cf. *globosa* Weller, 1914; specimen from sample 7720-4 (distances in mm. from ventral beak).

*Composita cf. globosa* Weller, 1914

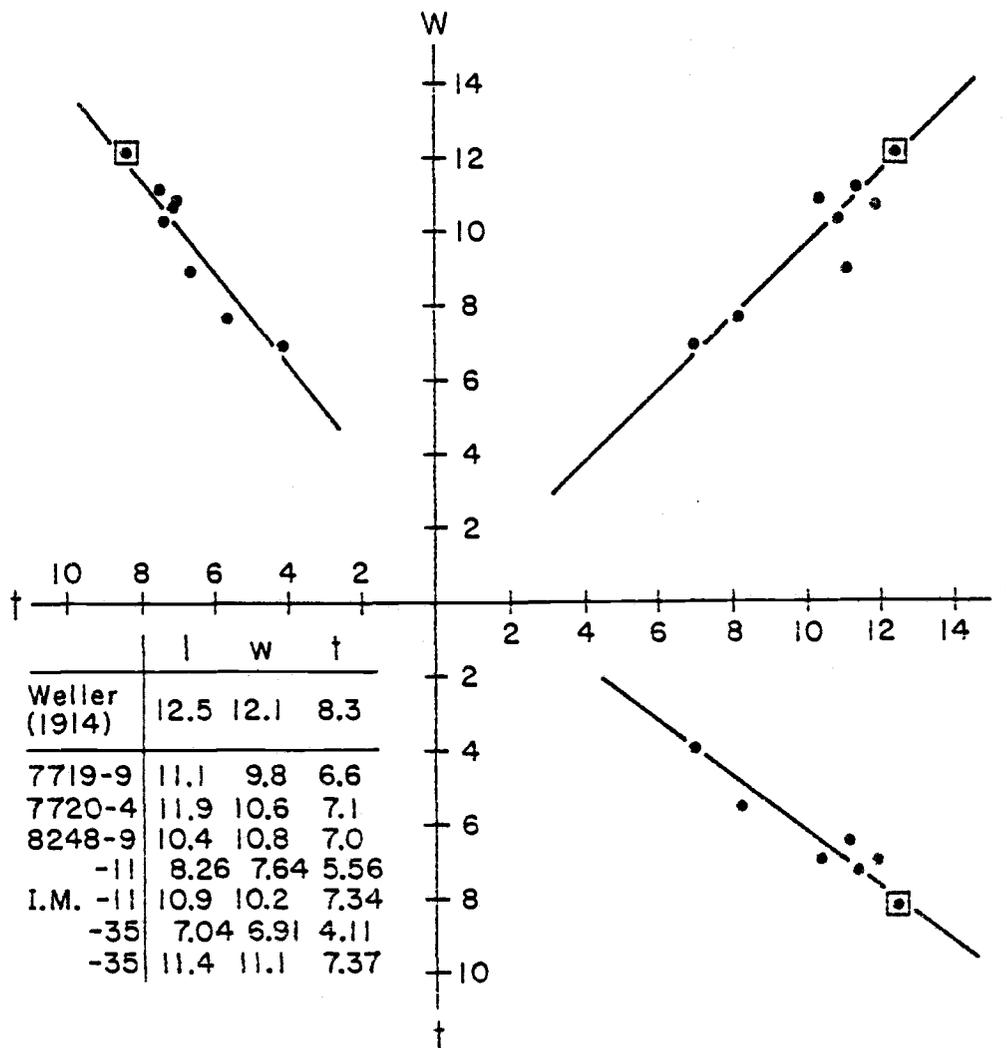


Figure 47. Comparison of principal dimensions (length, width, thickness) of Composita cf. globosa.

figured nor discussed the interior of C. globosa. Armstrong (1962) reports C. globosa from the Keating Formation of New Mexico and Arizona. His figures of the interior of C. globosa, however, are not adequate for specific comparison. Actinoconchus ? sp. of Carter (1967) externally resembles C. cf. globosa and might be confused with it on that basis. Internally, however, Actinoconchus ? sp. completely lacks a cardinal plate (Carter, 1967, Text-figure 20) and, on that basis alone, cannot be an Actinoconchus. Until the interior of C. globosa of Weller is studied in detail, the Caballero specimens cannot definitely be assigned to that species.

### Suborder SPIRIFERIDINA

#### Superfamily DELTHYRIDACEA Phillips, 1841

#### Family AMBOCOELIIDAE George, 1931

#### Genus Crurithyris George, 1931

#### Crurithyris parva (Weller), 1899

(Plate 8, Figures 25 to 34; Figure 48)

Ambocoelia parva Weller, 1899, p. 20; pl. 4, figs. 1-4

Ambocoelia parva: Weller, 1914, p. 424, 425; pl. 77, figs. 32-35.

Ambocoelia parva: Branson, 1938, p. 25, 26; pl. 22, figs. 27-30.

Crurithyris parva: Carter, 1967, p. 350-354; pl. 33, figs. 1a-8e; text-figs. 23, 24.

**MATERIAL:** Locality 7720, sample 9; locality 8244, samples 2, 3; locality 8245, sample 6; locality 8246, samples 3-5; locality 8248, samples 11 (float), 12, 26, 30 (float); 8 articulated specimens (1 serially sectioned), 13 pedicle valves, 4 brachial valves.

**OCCURRENCE:** Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian).

**EXTERIOR:** Shell small, strongly ventribiconvex, slightly wider than long, outline subelliptical; fold and sulcus very weakly-developed, commissure rectimarginate; ventral valve strongly convex, umbo prominent, directly above hinge line, beak strongly curved over interarea, ventral interarea triangular, apsacline, lateral margins marked by distinct line separating vertically-striated interarea and remainder of shell surface which is marked only by concentric growth lines; delthyrium open, triangular; cardinal

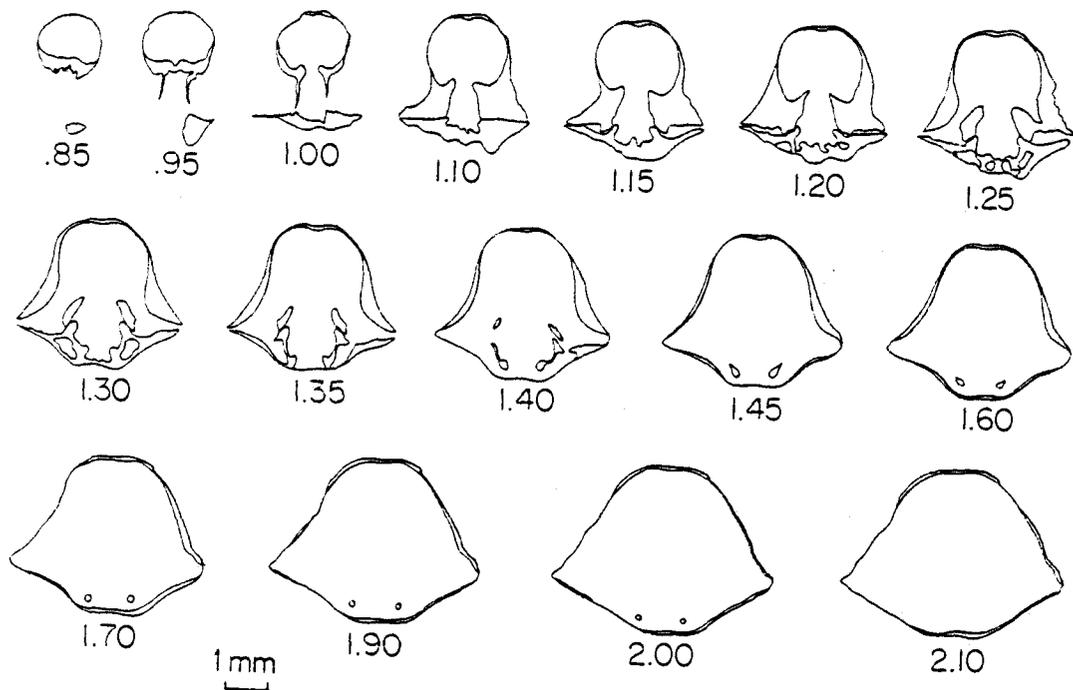


Figure 48. Transverse serial sections of Crurithyris parva (Weller), 1899; specimen from sample 8248-35 (distances in mm. from ventral beak).

extremities broadly rounded, hinge line about 0.5 of width; dorsal interarea very low, triangular, orthocline; dimensions of a nearly perfect specimen: length, 7.16 mm.; width, 7.98 mm.; thickness, 5.61 mm.; mean ( $\bar{x}$ ) and standard deviation (s) of dimensions for 7 specimens from sample 8248-11: length,  $\bar{x}$  = 6.10 mm., s = .678 mm.; width,  $\bar{x}$  = 6.70 mm., s = .832 mm.; thickness,  $\bar{x}$  = 4.43 mm., s = 1.00 mm.

INTERIOR: (Based on transverse serial sections, Figure 48) Ventral valve with teeth ridges, but without dental lamellae; dorsal valve with low, sessile, simple cardinal process, short crural plates supporting crural bases; crura near floor of valve, initially pyriform in cross section, becoming rodlike anteriorly.

DISCUSSION AND COMPARISONS: The New Mexico specimens closely resemble C. parva as described by Weller (1899, 1914) and are considered to be conspecific with it. The species is also known from the Chouteau Limestone of Missouri (Branson, 1938) and the Chappel Limestone of central Texas (Carter, 1967). A similar, possibly identical, species of Crurithyris occurs in the Arcente Formation in the Sacramento Mountains where, with chonetids, it represents the commonest recurrent brachiopod association.

Superfamily SPIRIFERACEA King, 1846

Family MUCROSPIRIFERIDAE Boucot, 1959

Genus Voiseyella Roberts, 1964

Voiseyella novamexicana (Miller), 1881

(Plate 8, figures 1 to 6)

- Spirifera novamexicana Miller, 1881, p. 314; pl. 7, figs. 10-10b.  
Delthyris novamexicana: Weller, 1914, p. 304, 305; pl. 36, figs. 18, 19, 22-24 (not 15-17, 20, 21).  
Delthyris novamexicana: Branson, 1938, p. 58; pl. 6, figs. 8-10.  
Tylothyris cf. novamexicana: Armstrong, 1962, p. 53; pl. 6, fig. 26.  
Amesopleura novamexicana: Carter, 1967, p. 366-371; pl. 33, figs. 9a-12e; text-fig. 29.

MATERIAL: Locality 8245, samples 12 (float), Caballero (float); 1 articulated specimen, 1 pedicle valve, 2 brachial valves.

**OCCURRENCE:** Caballero Formation ? (float samples only), Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 ? of Lane (1974).

**EXTERIOR:** Shell of medium size, biconvex, width approximately  $1/3$  greater than length of pedicle valve, outline of brachial valve semicircular; lateral profile subelliptical, greatest convexity of pedicle valve at hinge line, greatest convexity of brachial valve anterior to hinge line; ventral interarea trapezoidal, nearly orthocline, ventral beak sharply incurved over open, triangular delthyrium; fold and sulcus wide, smooth, gently-rounded, bounded by high ventral plications and deep dorsal furrows, flanks each with four or five plications which decrease in size toward cardinal extremities; ornament consisting of a few faint growth lines irregularly spaced over most of shell but densely crowded near anterior margin; dimensions of a nearly perfect specimen: length of pedicle valve, 13.0 mm.; length of brachial valve, 9.58 mm.; width, 17.3 mm.; thickness, 10.7 mm.

**INTERIOR:** Interior of ventral valve not observed; dorsal valve with low median ridge extending nearly  $2/3$  length of shell; crural plates lacking; cardinal process spiriferoid, composed of several thin plates and roughly developed into two larger, lateral lobes and a smaller median lobe, entire structure supported by thick deposit of shell material.

**DISCUSSION AND COMPARISONS:** Although the presence of dental lamellae in the ventral valve could not be confirmed, the specific identify of this species seems clear. It clearly displays the inflated anterior margin with densely crowded growth lamellae listed as distinguishing characteristics of the genus by Roberts (1964, p. 187). Mucronate extensions of the cardinal extremities were not observed; this feature is apparently greatly variable in its development, however, and is of doubtful generic or even specific value. Weller (1914, pl. 36, figs. 18, 19, 22-24) illustrates specimens in which both extremes can be seen; if his figures 15-17, 20, 21, prove also to be conspecific with V. novamexicana, then even greater variation in this characteristic may be assumed. V. novamexicana resembles V. ? mundula (Rowley), 1893, in its general form but may be distinguished from the latter species in having fewer lateral plications (7-10 in V. ? mundula).

Genus Tylothyris North, 1920Tylothyris sp. A

(Plate 8, figures 12 to 19; Figure 49)

**MATERIAL:** Locality 7722, sample 8; locality 8245, samples 9 (float), 10, 13, 16; locality 8246, sample 12; locality 8248, sample 35; 5 articulated specimens (1 serially sectioned), 7 pedicle valves, 1 brachial valve.

**OCCURRENCE:** Caballero Formation and Andrecito Member of Lake Valley Formation, Early Mississippian, Kinderhookian and Osagean (Touranisian); conodont Faunal Units 1, 2 of Lane (1974).

**EXTERIOR:** Shell of medium size, biconvex, width about 1.75 of length of pedicle valve, cardinal extremities acute, with slender mucronate extensions in juvenile specimens (interpreted from growth lines); lateral profile lenticular; interarea long, narrow, trapezoidal; ventral interarea apsacline, beak small, sharply incurved, delthyrium triangular, deltidial plates not observed, probably lacking; fold and sulcus well-developed, smooth, bounding plications/furrows prominent, flanks each with 4 to 6 plications which decrease in size laterally; surface of both valves with numerous, closely-spaced growth lines; shell substance impunctate; dimensions of a nearly complete specimen: length of pedicle valve, 9.14 mm.; length of brachial valve, 7.92 mm.; width, 18 mm. (estimated); thickness, 6.48 mm.

**INTERIOR:** (Based on a calcined and scraped specimen and on transverse serial sections, Figure 49) Ventral valve with strong dental lamellae; median ridge (?) present anterior of thickened ventral umbo; dorsal valve with cardinal process of comblike cross section; crural plates lacking.

**DISCUSSION AND COMPARISONS:** Dental lamellae and a median septum are listed as distinguishing characteristics of Tylothyris by Pitrat (1965, p. H687). T. sp. A, however, appears not to have a median septum but only a median ridge, visible anterior to the thick ventral umbo. Because of the partial silicification of the specimen sectioned, it could not be determined whether a median septum is indeed present but largely buried in the thickened shell material of the ventral umbo.

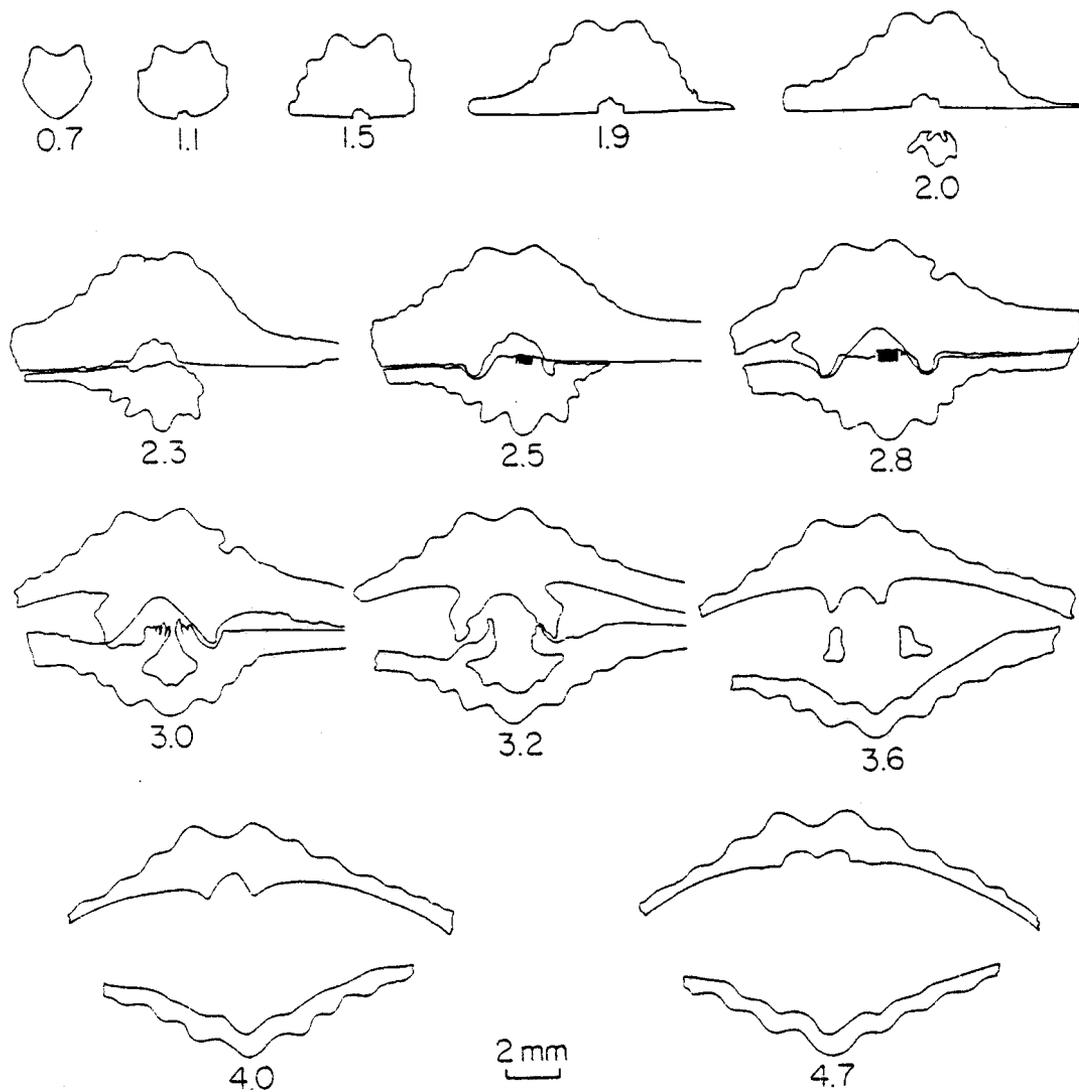


Figure 49. Transverse serial sections of *Tylothyris* sp. A; specimen from sample 7722-8 (distances in mm. from ventral beak).

Family SYRINGOTHYRIDIDAE Frederiks, 1926

Subfamily SYRINGOTHYRIDINAE Frederiks, 1926

Genus Pseudosyrinx Weller, 1914

Pseudosyrinx missouriensis Weller, 1914

(Plate 9, figures 1 to 5)

Pseudosyrinx missouriensis Weller, 1914, p. 406-408; pl. 65, figs. 5-9; pl. 66, figs. 11-13.

Pseudosyrinx missouriensis: Branson, 1938, p. 68, 69; pl. 8, figs. 12-15.

Pseudosyrinx missouriensis: Pitrat, 1965, p. H692; fig. 563: 4a, b.

**MATERIAL:** Locality 7721, sample 21; locality 8243, samples 4-8, 11, 13; locality 8244, samples 5-7, 10; locality 8245, samples 18, 20; 5 articulated specimens, 39 pedicle valves, 11 brachial valves.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies or in reef-derived allochthonous debris flows; conodont Faunal Units 3B, 4 of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell very large, robust; shell substance thick, densely punctate; much wider than long, cardinal extremities acute; ventral valve very high, interarea procline, high, triangular, surface marked by intersecting vertical and horizontal striations; delthyrium high, narrow, triangular; fold and sulcus deep, gently-rounded, smooth, flanked by from 16 to 25 gently-rounded plications on each lateral slope; dimensions of the largest, best-preserved specimen: length of pedicle valve, 48 mm.; length of brachial valve 38 mm.; width (estimated), 90 mm.; thickness, 50 mm.; height of interarea, 41 mm.; width of delthyrium at base, 15 mm.

**INTERIOR:** (Based on examination of calcined and scraped specimens) Ventral valve with dental lamellae extending about 1/2 length of valve; diductor muscle field confined to area between dental lamellae, corresponding approximately to border of fold, bisected by low median ridge; delthyrial plate slightly depressed below plane of interarea, less than half height of interarea, syrinx absent; dorsal valve not observed.

DISCUSSION AND COMPARISONS: The Lake Valley specimens of P. missouriensis closely resemble P. missouriensis of Weller (1914) in nearly every detail, both internally and externally, except in the number of lateral plications and in overall size. They have from 15 to as many as 25 plications on each lateral slope, whereas P. missouriensis has only 16-18, according to Weller (1914, p. 407). Nevertheless, since this variation can be seen within a single sample, it seems likely that these specimens are conspecific with P. missouriensis. The New Mexico specimens are more similar in size to P. gigas Weller; however, in the latter species, the procline inter-area slopes more steeply forward, making an angle of only about 40 degrees with the commissural plane. In P. missouriensis, this angle is from 55 to 60 degrees.

Genus Syringothyris Winchell, 1863

Syringothyris halli Winchell, 1863

(Plate 8, figures 20 to 24)

Syringothyris halli Winchell, 1863, p. 8.

Syringothyris halli: Weller, 1900, p. 79; text-fig. 2.

Syringothyris halli: Weller, 1901, p. 158-159; pl. 13, figs. 1-3.

Syringothyris halli: Weller, 1914, p. 390-391; pl. 72, figs. 13-23.

MATERIAL: Locality 7720, sample 8; locality 8248, samples 25, 26, 35; 3 articulated specimens, 2 pedicle valves.

OCCURRENCE: Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974).

EXTERIOR: Shell small for genus, dorsibiconvex, wider than long, greatest width at or immediately anterior of hingeline, outline subcircular; ventral valve subpyramidal, cardinal area and anterior surface descending to commissural plane in nearly straight lines, slope of anterior surface about 75 degrees, slope of cardinal area about 45 degrees; fold and sulcus low, smooth, with about 10 low plications on each flank; delthyrium open; syrinx long, straight, slender; shell substance punctate.

INTERIOR: Not observed.

## Family CYRTOSPIRIFERIDAE Termier and Termier, 1949

Genus Cyrtospirifer Nalivkin in Frederiks, 1919 (1924)Cyrtospirifer latior (Swallow), 1863

(Plate 9, figures 6 to 15; plate 10, figures 2 to 6; Figures 50, 51)

Spirifer latior Swallow, 1863, p. 86Spirifer latior: Weller, 1914, p. 316, 317; pl. 38, figs. 9-13.Spirifer latior: Branson, 1938, p. 60, 61; pl. 6, figs. 11, 12, 14-21, 23, 24, 44.Cyrtospirifer ? latior: Sanders in Easton, Sanders, Knight, and Miller, 1958, p. 55; pl. 5G, figs. 27-37.

MATERIAL: Locality 7719, samples 9, 10; locality 7720, sample 4; locality 7721, sample 2; locality 7722, sample 12; locality 8245, sample 11; locality 8248, samples 9, 11 (float), 12, 25; approximately 80 specimens (1 serially sectioned).

OCCURRENCE: Caballero Formation and Andrecito Member of Lake Valley Formation, Early Mississippian, Kinderhookian and Osagean (Tournaisian); conodont Faunal Units 1, 2 of Lane (1974).

EXTERIOR: Shell below average size for genus, moderately transverse, greatest width at or immediately anterior to hinge line; inflated, subsemicircular in outline; average dimensions, based on 21 specimens from samples 8248-11, 8248-12: length, 11.1 mm.; width, 13.6 mm.; thickness 7.87 mm. (Figure 51). Slightly ventri-biconvex, ventral beak moderately to strongly apsacline, surface with growth lines parallel to hinge line and striations normal to it; hinge line denticulate (Figure 50, 3.6 mm.) Ventral sulcus beginning as a distinct, flat-bottomed furrow between a pair of sulcus-bounding costae; anteriorly, each sulcus-bounding costa dividing medially to form one or two sulcal costae on either side of the median furrow, the median furrow continuing from the beak to the anterior margin. Dorsal fold low, weakly-defined, barely interrupting profile of shell near beak, becoming more distinct anteriorly; defined, throughout its length, by two bounding furrows; a single furrow near the beak dividing within the fold to form as many as 8, more commonly about 4, weakly-defined costae at anterior margin; lateral slopes each with 12 to 18 simple, rounded costae. Microornament consisting of numerous, closely-spaced, growth lamellae (about 12/mm.) and fine, closely-spaced, radial capillae (about 15/costa) intersecting growth lamellae to form a very fine reticulate pattern.

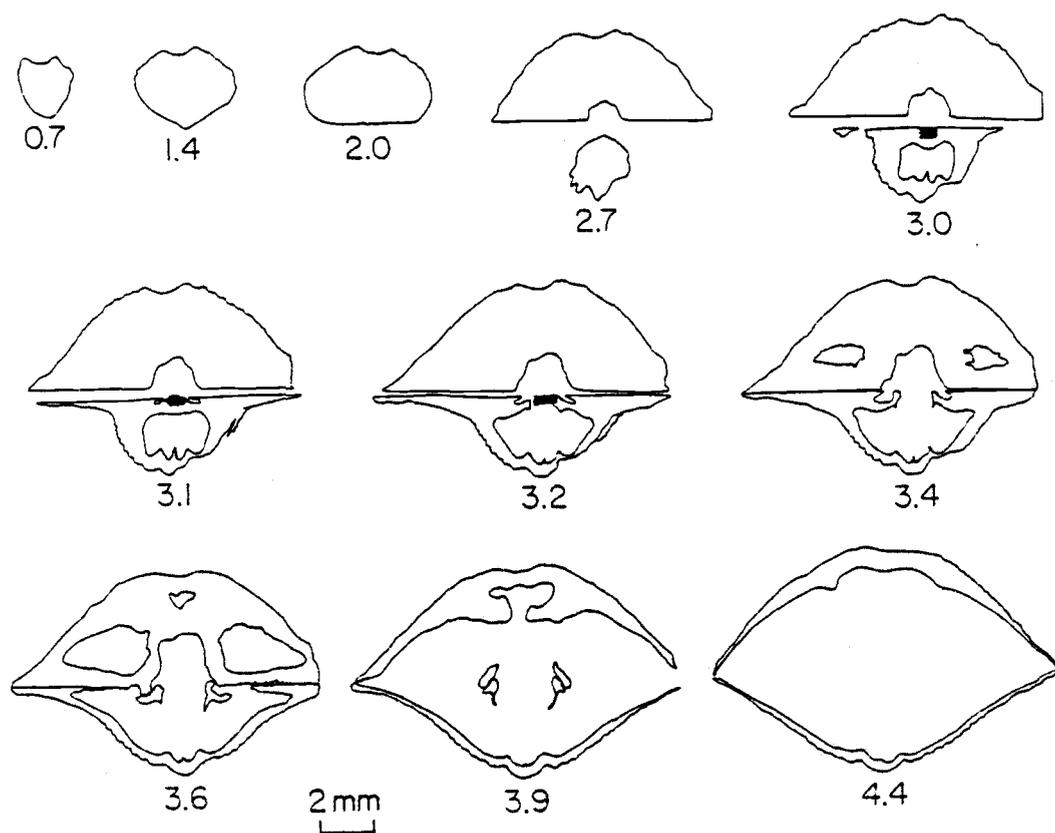


Figure 50. Transverse serial sections of *Cyrtospirifer latior* (Swallow), 1863; specimen from sample 8248-25 (distances in mm. from ventral beak).

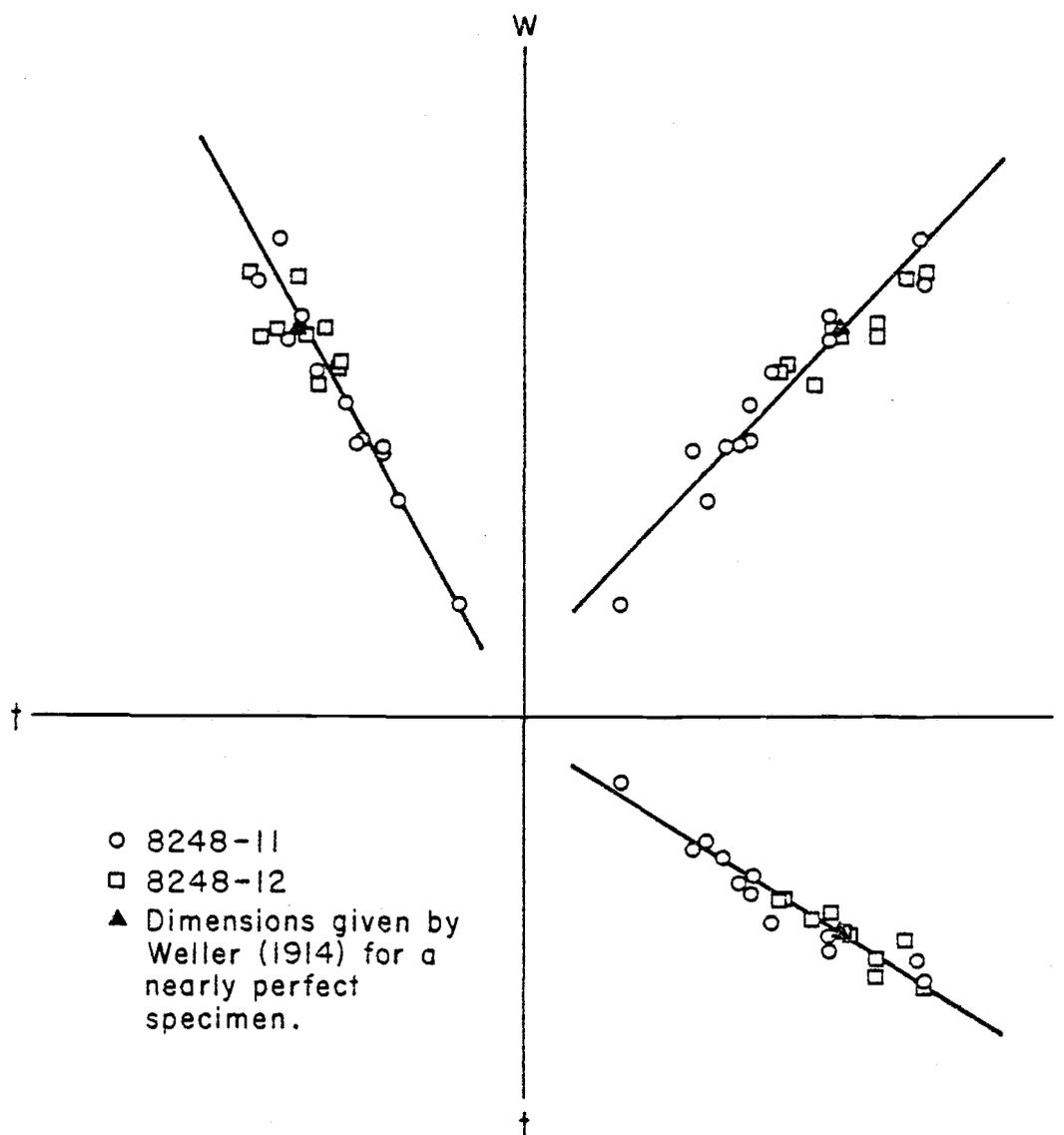


Figure 51. Comparison of principal dimensions (length, width, thickness) of complete specimens of *Cyrtospirifer lator* (Swallow), 1863, from samples 8248-11, 8248-12 with those given by Weller (1914, p. 316).

INTERIOR: (Based on transverse serial sections, Figure 50) Ventral valve with dental plates and subdelthyrial plate, lacking median septum; dental plates diverging anteriorly, intersecting shell lateral to sulcus-bounding costae and enclosing wide muscle field; dorsal valve with sharp, low median ridge and cardinal process of comblike cross section.

DISCUSSION AND COMPARISONS: As discussed by Weller (1914) and Sanders (in Easton, Sanders, Knight, and Miller; 1958), the species was not illustrated by Swallow (1863). Weller (1914, p. 316), however, regarded a specimen in the Greger Collection, labeled by Swallow, as representing the species. The New Mexico specimens closely conform to Weller's description and there is little doubt that the two forms are conspecific, in spite of the fact that Weller did not provide any details of the interior.

Species to which C. latior bears a strong resemblance include Parallelora marionensis (Shumard), Spirifer osagensis Swallow, and Spirifer louisianensis Rowley. P. marionensis may be distinguished by its nearly rectangular interarea, its large size, and the presence of bifurcating costae adjacent to the fold and sulcus. S. osagensis may be distinguished by its mucronate cardinal extremities and in having fewer costae on the lateral slopes. In S. louisianensis, there are still fewer costae on the flanks (10-13); otherwise, the species bears a marked resemblance to C. latior, even to size and details of microornament. The interiors of S. osagensis and S. louisianensis have not been illustrated.

Reference of Mississippian species of spiriferaceans to the genus Cyrtospirifer have been extremely limited in North American literature. Externally, C. latior, P. marionensis, S. osagensis, and S. louisianensis all bear a strong resemblance to Cyrtospirifer. Additionally, Spirifer platynotus Weller, 1914, was referred to Spirifer (Cyrtospirifer) platynotus by Nalivkin (1937). Details of internal structures, however, are known only for C. latior and P. marionensis; both are compatible with the definition of Cyrtospirifer. Interpretation of the generic relationships of the remaining species and clarification of the use of Cyrtospirifer for Mississippian spiriferaceans must await elucidation of the details of the internal structure of such species as S. osagensis, S. louisianensis, and S. platynotus.

Cyrtospirifer sp. A

(Plate 9, figure 16; Plate 10, figures 7 to 14; Figure 52)

**MATERIAL:** Locality 7720, sample 9; locality 7721, samples 12, 15; locality 7722, samples 8, 9, 12; locality 8245, Caballero (float); locality 8246, samples 5, 12; locality 8248, sample 12; locality 9130, sample 8; 9 articulated specimens, 48 pedicle valves.

**OCCURRENCE:** Caballero Formation and Andrecito Member of the Lake Valley Formation, Early Mississippian, Kinderhookian and Osagean (Tournaisian); conodont Faunal Units 1, 2 of Lane (1974).

**EXTERIOR:** Shell of small to medium-large size; slightly ventribiconvex, wider than long, greatest width anterior to hinge line approximately 1/3 length of shell; outline subelliptical; lateral profile lenticular; ventral interarea low, triangular apsacline, beak incurved over open, triangular delthyrium; dorsal interarea not developed; fold and sulcus present, sulcus shallow, broad, with 6-10 low, rounded plications which increase by bifurcation; fold very low, broad, barely elevated above surface of shell, marked by shallow bounding furrows, with 6-10 bifurcating plications; flanks each with 13 to 20 low, rounded, non-dividing plications; ornament consisting of numerous, closely-spaced growth lamellae and radial lirae, forming a minutely reticulate pattern; dimensions of the largest complete specimen: length of pedicle valve, 17.5 mm.; length of brachial valve, 15.3 mm.; width, 22.1 mm.; thickness, 11.8 mm.; width of largest intact pedicle valve, 57 mm.

**INTERIOR:** (Based on calcined and scraped specimens and on transverse serial sections, Figure 52) Ventral valve with short dental lamellae and subdelthyrial plate; muscle scar shallow, elongate-oval in outline, confined by dental lamellae to width of sulcus; dorsal valve with spiriferoid cardinal process of comb-like cross section; crural plates lacking.

**DISCUSSION AND COMPARISONS:** Small specimens of Cyrtospirifer sp. A may be distinguished from C. latior, with which it may cooccur, by its more transverse shape and shallower, wider, less distinct fold and sulcus which also has more numerous plications (4 to 8 in C. latior). Internally, C. latior and C. sp. A may be distinguished on the width of the ventral muscle field, contained by the dental lamellae, laterally; in C. latior, these are wider than the width of the sulcus, while, in C. sp. A they are approximately the same width as the sulcus.

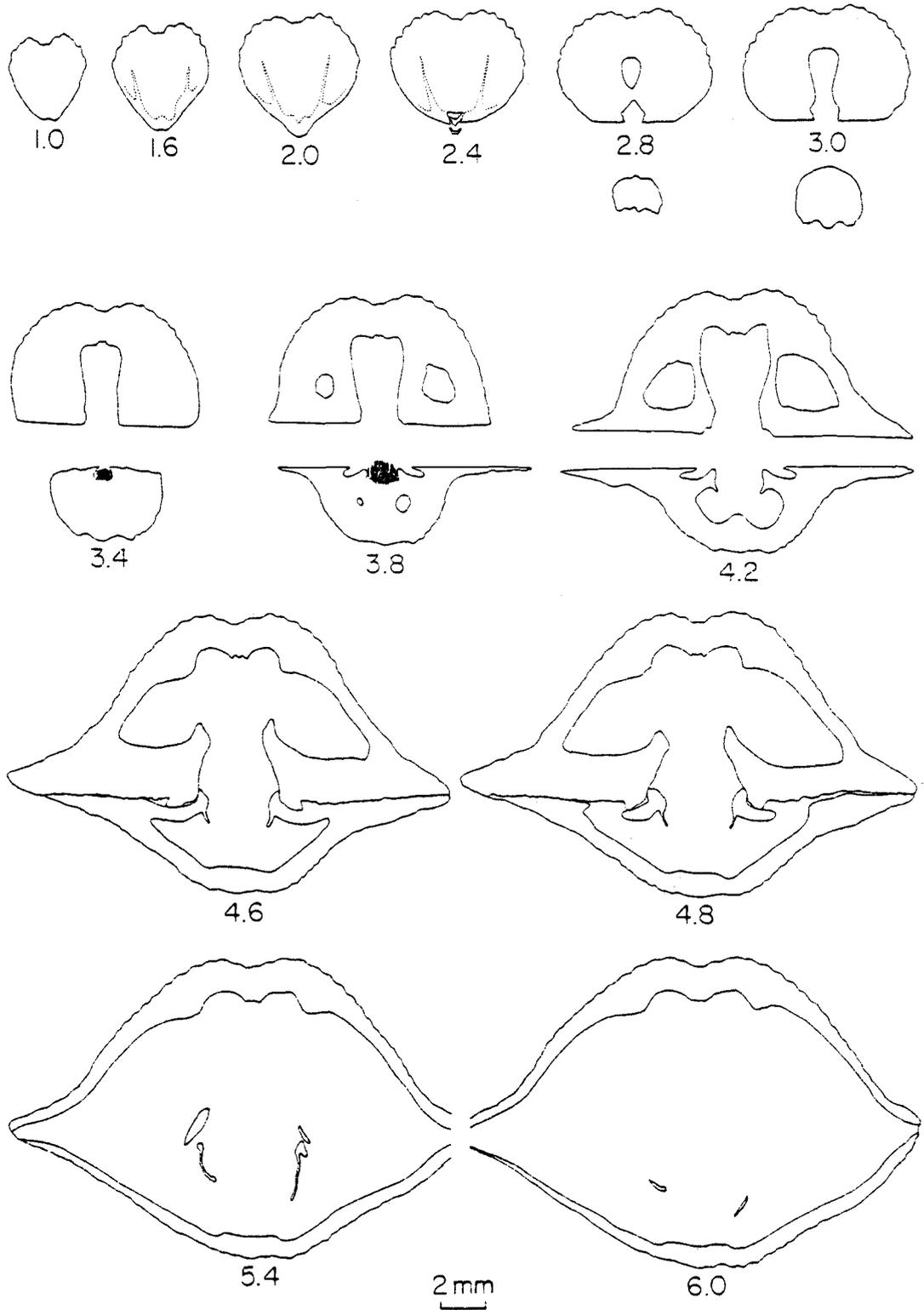


Figure 52. Transverse serial sections of *Cyrtospirifer* sp. A; specimen from sample 8246-12 (distances in mm. from ventral beak).

Family SPIRIFERIDAE King, 1846

Subfamily SPIRIFERINAE King, 1846

Genus Spirifer Sowerby, 1816

Spirifer cf. logani/grimesi Hall, 1858

(Plate 10, figure 1)

MATERIAL: Locality 8243, sample 7; locality 8244, samples 7, 8, 10; 13 pedicle valves.

OCCURRENCE: Lake Valley Formation, Early Mississippian, Osagean (=Tournaisian 3); reef core ecofacies or in reef-derived allochthonous debris flows.

EXTERIOR: Shell large, biconvex (?), outline subcircular; ventral interarea triangular, apsacline; delthyrium triangular, open, no delthyrial plates observed; greatest width anterior of hinge line; sulcus broad, shallow, with about 15 costae, flanks each with about 25 bifurcating costae; ornament consisting of fine radial lirae; dimensions of a large pedicle valve: length, approximately 70 mm.; width, 85 mm.; convexity, 20 mm.; brachial valve not observed.

INTERIOR: Ventral valve with dental lamellae, short sub-delthyrial plate, and muscle scar extending laterally beyond sulcus; dorsal valve not observed.

DISCUSSION AND COMPARISONS: Assignment of these specimens to Spirifer Sowerby is reasonably definite based on the lirae surface ornament, short hinge line, and wide ventral muscle scar. Spirifer cf. logani/grimesi may be distinguished from S. cf. gregeri by its wide muscle scar and generally larger size. The specific characters observable in the available collections are insufficient to allow distinction between S. grimesi and S. logani, both of Hall (1858).

Spirifer cf. gregeri Weller, 1914

(Plate 11, figures 6 to 9)

MATERIAL: Locality 7722, sample 14; locality 8243, sample 7; locality 8244, sample 7; 14 pedicle valves.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies and reef-derived allochthonous debris flows.

**EXTERIOR:** Shell medium-large to large, biconvex (?), wider than long, greatest width anterior to hinge line, outline subcircular; ventral interarea low, triangular, apsacline, beak large, incurved over open, triangular delthyrium; sulcus broad, fairly shallow, not differentiated from remainder of shell; costate, about 15 to 17 on sulcus, at least 25 on each flank, costae becoming very faint laterally from sulcus; ornament consisting of fine radial capillae; dimensions of a nearly complete pedicle valve: length, 61 mm.; width, 80 mm. (estimated); convexity, 18 mm.; brachial valve not observed.

**INTERIOR:** Ventral valve with dental lamellae, short subdelthyrial plate, and narrow muscle scar (confined to width of sulcus); dorsal valve not observed.

**DISCUSSION AND COMPARISONS:** Spirifer cf. gregeri may most reliably be distinguished from S. cf. logani/grimesi by its narrow muscle scar (flaring beyond the width of the sulcus in S. cf. logani/grimesi). The only reliable method of distinguishing it from Unispirifer is by the extended hingeline in the latter genus; although use of such a variable character in generic identification seems unwise, at present, no better criterion has been recognized.

Genus Imbrexia Nalivkin, 1937

Imbrexia sp. A

(Plate 11, figures 1 to 5)

**MATERIAL:** Locality 8242, sample 19; locality 8243, samples 1-3, 5, 6, 8, 9; locality 8245, samples 15, 20; 4 articulated specimens, 20 pedicle valves, 3 brachial valves.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies and reef-derived allochthonous debris flows; conodont Faunal Unit 3B of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell of medium to medium-large size, biconvex, strongly transverse to mucronate; outline subelliptical to subquadrate; lateral profile lenticular; ventral interarea long, narrow, subtrapezoidal, apsacline; delthyrium triangular, delthyrial plates not observed;

sulcus shallow, with simple median costa and bifurcating lateral costae; 5 to 10 costae on fold, 20 to 25 on each flank, only a few of costae on flanks bifurcating, remainder simple; radial ornament consisting of numerous closely imbricate growth lamellae; capillae lacking; dimensions of a nearly complete pedicle valve; length, 15 mm.; width, 40 mm.; convexity, 7 mm.

INTERIOR: Not observed.

Imbrexia sp. B

(Plate 12, figures 1 to 4, 14 to 18)

MATERIAL: Locality 8243, samples 9, 14; 2 articulated specimens, 4 pedicle valves, 1 brachial valve.

OCCURRENCE: Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Units 3B, 4 of Lane (1974; 1978, in press; 1978, written comm.).

EXTERIOR: Shell of small-medium to medium-large size, biconvex, transverse, greatest width along hingeline, outline sub-elliptical to subtriangular; lateral profile lenticular; ventral interarea low, trapezoidal; delthyrium open, triangular, apsacline; commissure strongly uniplicate but fold and sulcus not prominently developed, fold with 10 to 12 bifurcating costae, flanks each with about 20 costae, only a few of which bifurcate; ornament consisting of numerous closely-spaced, imbricate growth lamellae; no capillae observed; dimensions of 2 articulated specimens: length of pedicle valve, 20 mm., 45 mm.; length of brachial valve, 18 mm., 36 mm.; width, 28 mm., 80 mm.; thickness, 13 mm., 35 mm. (estimated).

INTERIOR: Not observed.

DISCUSSION AND COMPARISONS: Imbrexia sp. B may be distinguished from I. sp. A by its shallow, ill-defined fold and sulcus, less transverse outline, and less numerous lateral costae.

Subfamily PROSPIRINAE Carter, 1974

Genus Unispirifer Campbell, 1957

Unispirifer sp. A

(Plate 12, figures 5 to 9)

MATERIAL: Locality 7722, sample 14; locality 8243, samples

3-5; locality 8244, sample 8; locality 8245, samples 17 (float) 18 (float), 19; 4 pedicle valves.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies and reef-derived allochthonous debris flows.

**EXTERIOR:** (Brachial valve not observed) Shell of medium-large size, biconvex (?); wider than long, greatest width along hinge line; outline subcircular; fold broad, deep, with simple median costa and 4 to 8 sulcal costae on either side, increasing by bifurcation on side of costa away from median costa; flanks with about 22 costae each; several costae adjacent to sulcus may bifurcate, remainder remain simple; ornament consisting of fine radial lirae, no suggestion of imbrication of growth lines; dimensions of a pedicle valve: length 30 mm.; width, 51 mm.; convexity, 14 mm.; width of sulcus, 20 mm.

**INTERIOR:** Not observed.

**DISCUSSION AND COMPARISONS:** In spite of the lack of any brachial valves in the available collections and the lack of interior details, it is reasonably certain that these specimens do belong in Unispirifer. The elongate hinge line, lack of imbricate growth lines, presence of lirae, and the pattern of costal bifurcation are all characteristic of Unispirifer.

Unispirifer sp. B

(Plate 12, figures 10 to 13; Plate 13, figures 1 to 6)

**MATERIAL:** Locality 8243, samples 5, 15; 2 articulated specimens.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Units 3B, 4 of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell of small-medium to medium size, biconvex, transverse, greatest width along hinge line, outline subelliptical; ventral interarea low, triangular, apsacline; delthyrium open, triangular; fold and sulcus well-developed, deep, narrow, with simple median costa and 2 to 4 costae on either side; flanks each with 17 to 20 costae which bifurcate uncommonly; ornament consisting of fine radial lirae; no apparent imbrication of growth lines; dimensions of

specimens: length of pedicle valve, 20 mm., 31 mm.; length of brachial valve, 18 mm., 30 mm.; width, 37 mm., 62 mm.; thickness, 15 mm., 28 mm.

INTERIOR: Not observed.

DISCUSSION AND COMPARISONS: Unispirifer sp. B may be distinguished from U. sp. A by its more transverse outline, narrower and deeper fold and sulcus, and by its having fewer lateral costae which bifurcate.

Family BRACHYTHYRIDIDAE Frederiks, 1919 (1924)

Genus Brachythyris McCoy, 1844

Brachythyris fernglenensis (Weller), 1909

(Plate 13, figures 18 to 27; Figure 53)

Spirifer fernglenensis Weller, 1909, p. 306; pl. 13, figs. 9, 10.

Brachythyris fernglenensis: Weller, 1914, p. 372, 373; pl. 52, figs. 5-11.

MATERIAL: Locality 7719, sample 10; locality 8242, sample 19; locality 8245, sample 5, Caballero (float); locality 8246, sample 12; locality 8248, samples 11 (float), 35; 11 articulated specimens (1 serially sectioned), 6 pedicle valves.

OCCURRENCE: Caballero and Lake Valley formations, Early Mississippian, Kinderhookian and Osagean (Tournaisian).

EXTERIOR: Shell small, ventribiconvex, wider than long, greatest width slightly anterior of hinge line; cardinal extremities slightly rounded; outline subtriangular in commissural plane; curvature of ventral valve increasing posteriorly, beak incurved, apsacline, partly covering delthyrium; dorsal beak small, tightly incurved, apsacline; thickness approximately 0.6 of width, lateral profile sub-circular, fold and sulcus narrow, shallow, smooth, originating at posterior extremity; radial ornament consisting of about 7 broad, low plications; concentric ornament very fine, closely-spaced lamellae; dimensions of three articulated specimens from sample 8248-35; length, 11.2 mm., 10.8 mm., 9.68 mm.; width, 13.3 mm., 12.2 mm., 10.9 mm.; thickness, 7.80 mm., 8.31 mm., 6.73 mm.

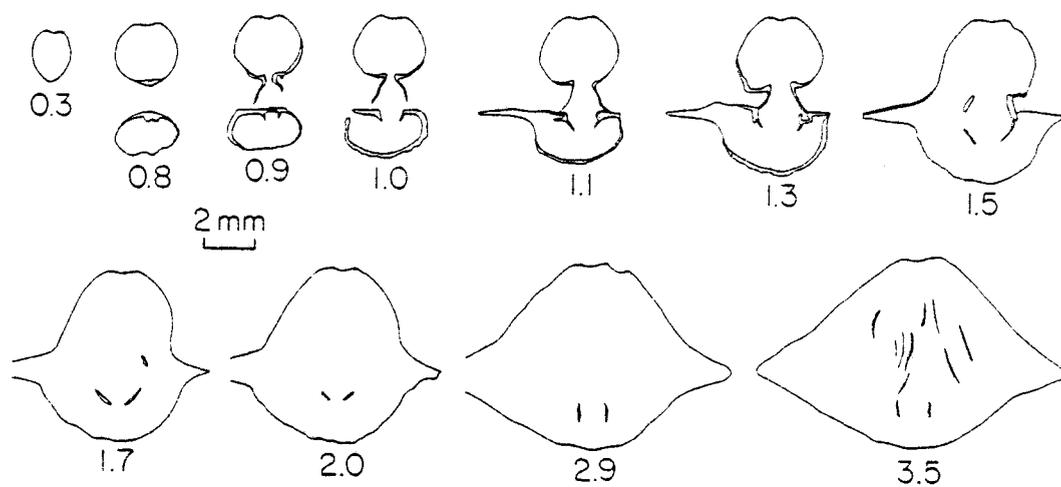


Figure 53. Transverse serial sections of Brachythyris fernglenensis (Weller), 1909; specimen from sample 7719-10 (distances in mm. from ventral beak).

INTERIOR: (Based on transverse serial sections, Figure 53) Ventral valve with low teeth ridges; dorsal valve with small cardinal process of comblike cross section; crural plates lacking.

Brachythyris suborbicularis (Hall), 1858

(Plate 13, figures 12 to 17; Figure 54)

Spirifer suborbicularis Hall, 1858, p. 644.

Brachythyris suborbicularis: Weller, 1914, p. 374-376; pl. 61, figs. 1-8; pl. 62, figs. 1-12.

Brachythyris suborbicularis Branson, 1938, p. 24, 25; pl. 22, figs. 21, 22.

MATERIAL: Locality 8243, samples 2, 3, 5-9, 11, 15; locality 8244, samples 3-5, 8-10; locality 8245, samples 9 (float), 17, 18; locality 8249, samples 13, 15; 7 articulated specimens (1 serially sectioned), 45 pedicle valves, 3 brachial valves.

OCCURRENCE: Lake Valley Formation, Early Mississippian, Osagean (=Tournaisian 3); reef core ecofacies and reef-derived allochthonous debris flows.

EXTERIOR: Shell of medium size, biconvex, wider than long, cardinal extremities rounded, greatest width anterior of hinge line, outline subcircular; convexity of valves increasing slightly posteriorly, beaks sharply incurved, apsacline, lateral profile oval to subcircular; fold and sulcus low, narrow, generally nearly smooth but may have one faint plication developed on either side of the fold, lateral plications usually 10 to 12 on each side; dimensions of 2 articulated specimens: length, 21.0 mm., 12.4 mm.; width 26.7 mm., 14.9 mm.; thickness, 14.5 mm., 10.3 mm.

INTERIOR: (Based on transverse serial sections, Figure 54) Ventral valve with well-developed teeth ridges; valve thickened by secondary shell material, muscle field deeply-impressed, wide, with vertical sides. Dorsal valve with cardinal process of comblike cross section, adjoining crural bases, crural plates lacking, crural processes oval in cross section.

DISCUSSION AND COMPARISONS: Brachythyris fernglenensis and B. suborbicularis are relatively easily distinguished. B. suborbicularis is larger, more strongly convex and has a much thicker shell than B. fernglenensis. In addition, there are more lateral plications (10 to 12, compared to about 7) and more prominent teeth ridges in B. suborbicularis than in B. fernglenensis.

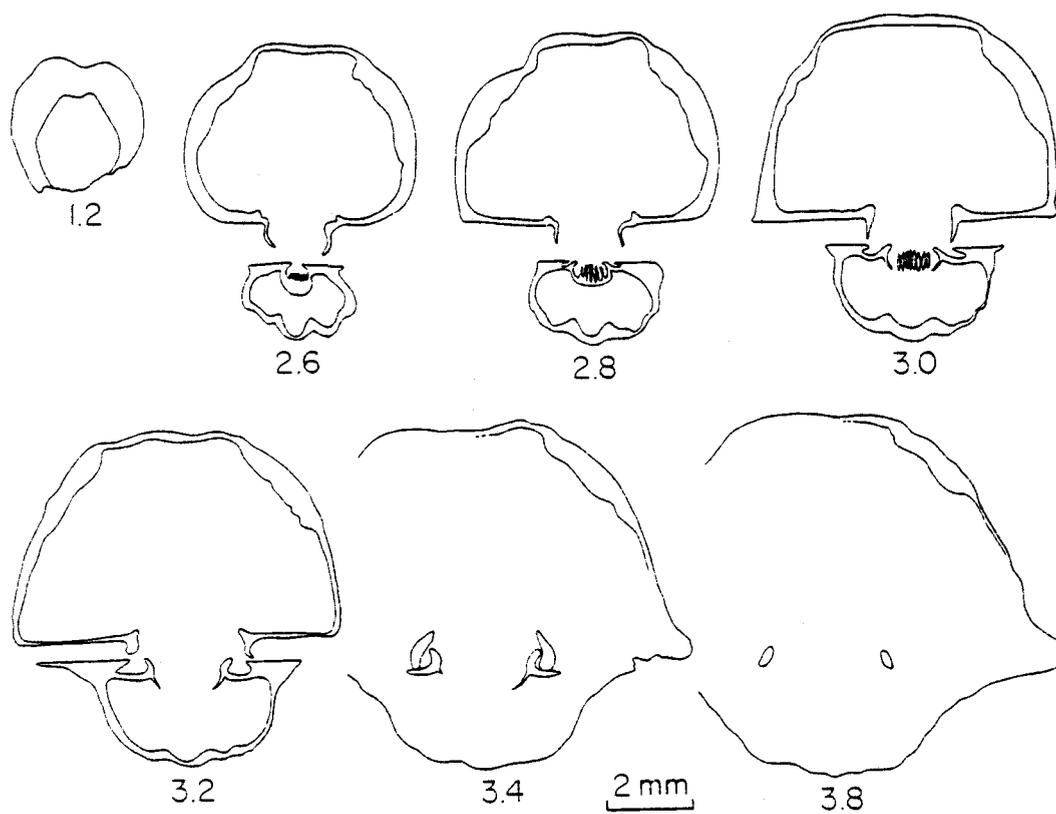


Figure 54. Transverse serial sections of *Brachythyris suborbicularis* (Hall), 1858; specimen from sample 8243-11 (distances in mm. from ventral beak).

## Superfamily SPIRIFERINACEA Davidson, 1884

## Family SPIRIFERINIDAE Davidson, 1884

Genus Punctospirifer North, 1920Punctospirifer sp. A

(Plate 13, figures 7 to 11)

**MATERIAL:** Locality 8245, sample 9 (float); locality 8248, samples 11 (float), 12; 4 articulated specimens, 1 pedicle valve, 1 brachial valve.

**OCCURRENCE:** Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); conodont Faunal Unit 1 of Lane (1974; 1978, written comm.).

**EXTERIOR:** Shell small, slightly ventribiconvex, slightly wider than long, greatest width along hinge line; outline of brachial valve subsemicircular; ventral interarea of moderate height, apsacline, to nearly orthocline; beak moderately incurved over interarea, delthyrium open, triangular; dorsal interarea not developed; fold and sulcus wide, smooth, sharply-delimited, each flank with about 4 undivided plications which decrease in size laterally; surface of both valves marked by distinct capillae and numerous, closely-spaced growth lines, giving shell a lamellose appearance; shell substance sparsely punctate; dimensions of a complete specimen: length of pedicle valve, 7.70 mm.; length of brachial valve, 6.15 mm.; width, 8.31 mm.; thickness, 5.77 mm.

**INTERIOR:** (Based on a calcined and scraped specimen) Ventral valve with short dental lamellae and median septum; dorsal valve with cardinal process of comblike cross section and low median ridge along fold; crural plate lacking.

**DISCUSSION AND COMPARISONS:** Punctospirifer sp. A most closely resembles P. globosa Sanders, 1958, from the Represo Limestone, Early Mississippian, of northwestern Sonora, Mexico. It differs from that species in lacking a median sulcus on the fold and a median fold in the sulcus. Although it may, therefore, represent a new species of Punctospirifer, there is insufficient material available on which to base such a description.

Punctospirifer sp. B

(Plate 14, figures 1 to 8)

**MATERIAL:** Locality 7722, sample 14; locality 8242, sample 19; locality 8243, samples 1-3, 6-8; locality 8244, sample 3; 1 articulated specimen, 75 pedicle valves, 74 brachial valves.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies and reef-derived allochthonous debris flows; conodont Faunal Unit 3 of Lane (1974; 1978, written comm.).

**EXTERIOR:** Shell of medium size, biconvex, wider than long, width about 2.25 length of pedicle valve; ventral interarea low, triangular, apsacline, delthyrium open, triangular; fold and sulcus prominent, deep and smooth, bounding plications high, flanks each with 5 to 8 undivided plications which decrease in size toward mucronate cardinal extremities; surface of shell with numerous, closely-spaced growth lines, capillae not observed; shell substance sparsely punctate; dimensions of a large pedicle valve and a large brachial valve, respectively; length, 10 mm., 9 mm.; width, 22 mm., 17 mm.; convexity, 6 mm., 3 mm.

**INTERIOR:** (Based on calcined and scraped specimens) Ventral valve with short dental lamellae and well-developed median septum; dorsal valve with spiriferoid cardinal process, comblike in cross section, and low median ridge along fold; crural plates lacking.

**DISCUSSION AND COMPARISONS:** Punctospirifer sp. B resembles P. sulcifer Sanders, 1958, from the Early Mississippian Represo Limestone of northwestern Sonora, Mexico. It lacks, however, any suggestion of a median furrow on the fold or a median plication on the sulcus.

Superfamily RETICULARIACEA Waagen, 1883

Family RETICULARIIDAE Waagen, 1883

Genus Reticularia McCoy, 1844

Reticularia cf. cooperensis (Swallow), 1860

(Plate 14, figures 9 to 16; Figure 55)

**MATERIAL:** Locality 8243, sample 11; 1 articulated specimen (serially sectioned), 3 pedicle valves.

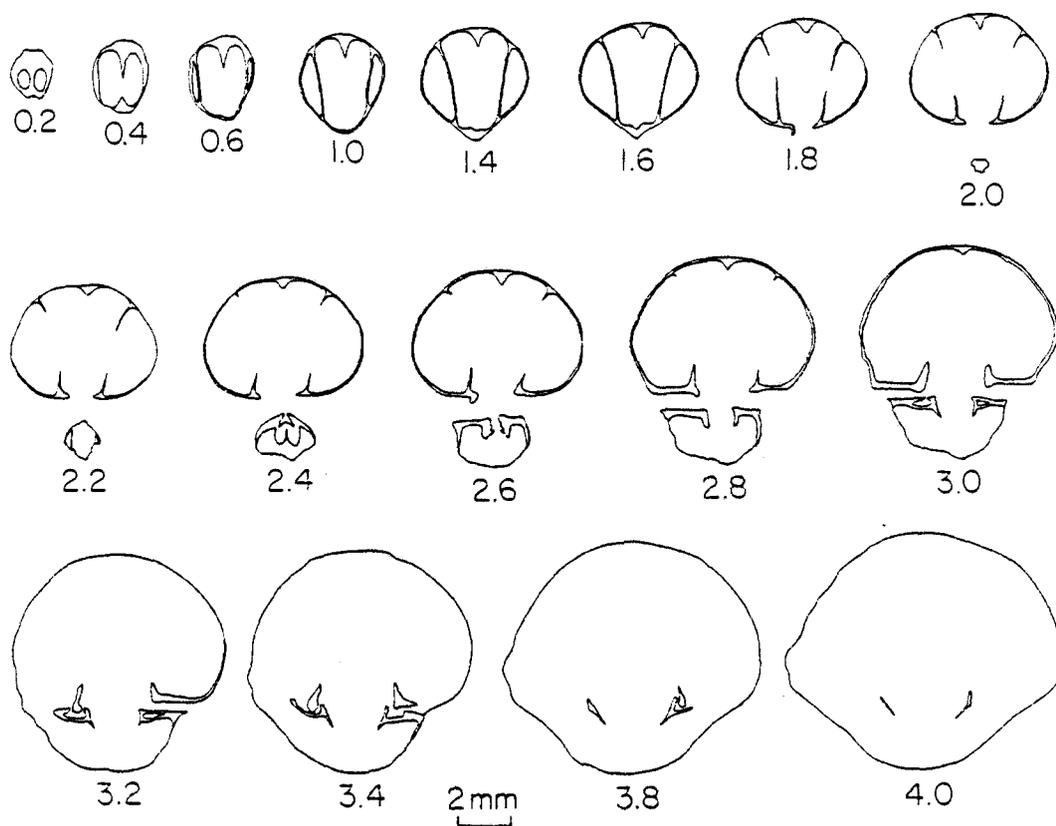


Figure 55. Transverse serial sections of *Reticularia cf. cooperensis* (Swallow), 1860; specimen from sample 8243-11 (distances in mm. from ventral beak).

OCCURRENCE: Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Unit 4 of Lane (1974; 1978, written comm.).

EXTERIOR: Shell of small to medium size, ventribiconvex, cardinal extremities broadly rounded, hinge line considerably less than maximum width; wider than long, outline suboval; lateral profile thick, lenticular to suboval; greatest thickness posterior to midlength; ventral beak of moderate size, sharply incurved over apsacline interarea, partly obscuring open, triangular delthyrium; fold and sulcus weakly-developed; much of shell material spalled off, but shells still show numerous closely-spaced growth lamellae; dimensions of serially-sectioned specimen: length, 16 mm.; width, 18 mm.; thickness, 10 mm.

INTERIOR: (Based on transverse serial sections, Figure 55) Ventral valve with dental lamellae and short, low median ridge; dorsal valve lacking crural plates and median septum.

DISCUSSION AND COMPARISONS: Based on external and internal features, these specimens are assignable to R. cooperensis. The only uncertainty in this assignment is the lack of preserved external ornament. The internal morphology of Reticularia is identical to Kitakamithyris of Minato (1951, in Pitrat, 1965, p. H717, H722). In its external ornament, however, Reticularia has concentric growth lamellae and uniramous spine bases while the spine bases in Kitakamithyris are reported to be biramous. R. cf. cooperensis is similar to R. pseudolineata (Hall), 1858; it may be distinguished from the latter species by its generally smaller size and its narrower, thicker shell.

Superfamily CYRTINACEA Frederiks, 1912

Family CYRTINIDAE Frederiks, 1912

Genus Cyrtina Davidson, 1858

Cyrtina burlingtonensis Rowley, 1893

(Plate 8, figures 7 to 11)

Cyrtina burlingtonensis Rowley, 1893, p. 308; pl. 14, figs. 15-17.

Cyrtina burlingtonensis: Weller, 1914, p. 288, 289; pl. 35, figs.

22-31.

Cyrtina burlingtonensis: Branson, 1938, p. 56, 57; pl. 9, figs. 37-41.

Cyrtina burlingtonensis: Sanders, 1958, p. 63; pl. 7C, figs. 9-24.

Cyrtina burlingtonensis: Carter, 1967, p. 354-357; pl. 34, figs. 1a-8e, text-figs. 25, 26.

Cyrtina burlingtonensis: Rodriguez and Gutschick, 1968, p. 1030, 1031; pl. 128, figs. 10-16, text-fig. 3.

**MATERIAL:** Locality 8248, sample 11 (float); 2 articulated specimens.

**OCCURRENCE:** Caballero Formation, Early Mississippian, Kinderhookian (Tournaisian); open marine, clastic shelf margin ecofacies; conodont Faunal Unit 1 of Lane (1974; 1978, written comm.).

**EXTERIOR:** Shell small, plicate, subpyramidal; commissural plane with straight anterior segment, straight lateral margins, and straight hinge line which is greatest shell width; cardinal area catacline, very high, triangular; delthyrium covered by convex pseudodeltidium having large apical foramen; ventral beak curving moderately over interarea but not so much as to obstruct pedicle opening; dorsal beak very small, not extending beyond deltidium; fold and sulcus smooth and prominent, 2 lateral plications on both specimens examined; shell substance densely punctate; dimensions of the larger, better-preserved specimen: length of pedicle valve, 7.78 mm.; length of brachial valve, 6.30 mm.; width, 7.75 mm.; thickness, 4.67 mm.

**INTERIOR:** (Based on one calcined and scraped specimen) Ventral valve with dental plates converging anteriorly, enclosing tichorhinum and meeting to form spondylium duplex; dorsal interior not observed.

**DISCUSSION AND COMPARISONS:** The two specimens present in the Sacramento Mountains Caballero collections agree well in all respects with Weller's (1914) illustrations of C. burlingtonensis with the single exception that, in the New Mexico specimens, the cardinal area might be slightly less posteriorly inclined.

## Order TEREBRATULIDA

## Suborder TEREBRATULIDINA

## Superfamily DIELOSMATACEA Schuchert, 1913

## Family CRANAENIDAE Cloud, 1942

## Subfamily CRANAENINAE Cloud, 1942

Genus Cranaena Hall and Clarke, 1894Cranaena longicrura, n. sp.

(Plate 15, figures 1 to 14, 20 to 24(?); Figures 56 to 59)

**MATERIAL:** Locality 8243, samples 2, 3, 5, 8(?); 6 articulated specimens (1 serially sectioned), 1 pedicle valve.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Unit 3B of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** Shell small, subequally biconvex; shell substance punctate; elongate, outline varying from subelliptical in small specimens to subpentagonal in larger specimens; greatest width slightly anterior to midlength; greatest thickness at or near midlength; lateral profile subelliptical; fold and sulcus weakly developed on larger specimens, best-developed in pedicle valve, causing indentation of anterior commissure; ventral beak erect; radial ornament lacking; concentric ornament consisting of fairly prominent, irregularly-spaced growth lines. For dimensions, see Figure 59.

**INTERIOR:** (Based on transverse serial sections and an isometric reconstruction of the dorsal valve, Figures 56 to 58) Ventral valve with weak dental plates situated close to shell walls; pedicle foramen partially closed by a single deltidial plate (= henidium of Cloud, 1942, p. 18) or by a pair of fused deltidial plates (Figure 56, interval 1.2 mm. to 2.3 mm.).

Dorsal valve with perforate cardinal plate which is distinctly divided into gently concave outer hinge plates and a single, deeply concave medial plate, crura curve ventrally and diverge anteriorly from crural bases to form prominent crural points, then descending

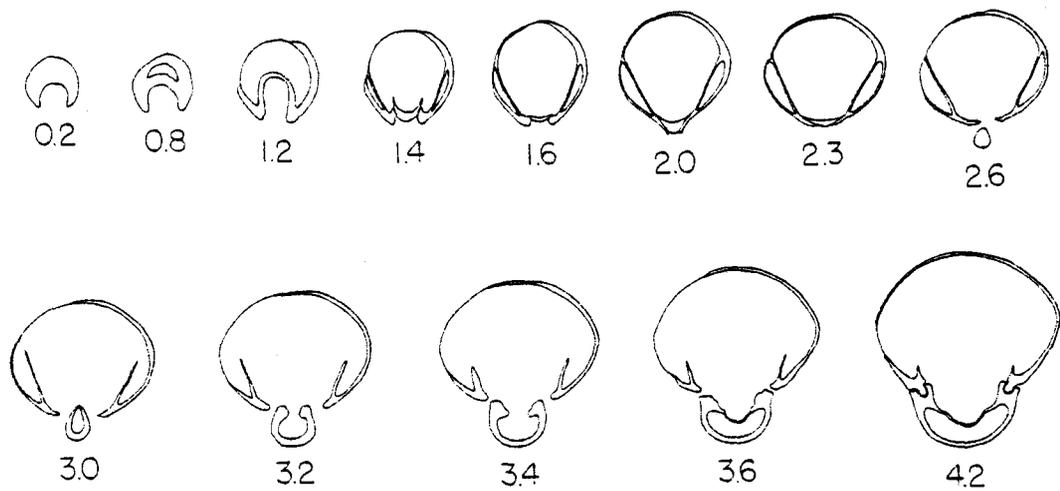


Figure 56. Transverse serial sections of posterior part of Cranaena longicrura n. sp.; specimen from sample 8243-2 (distances in mm. from ventral beak).

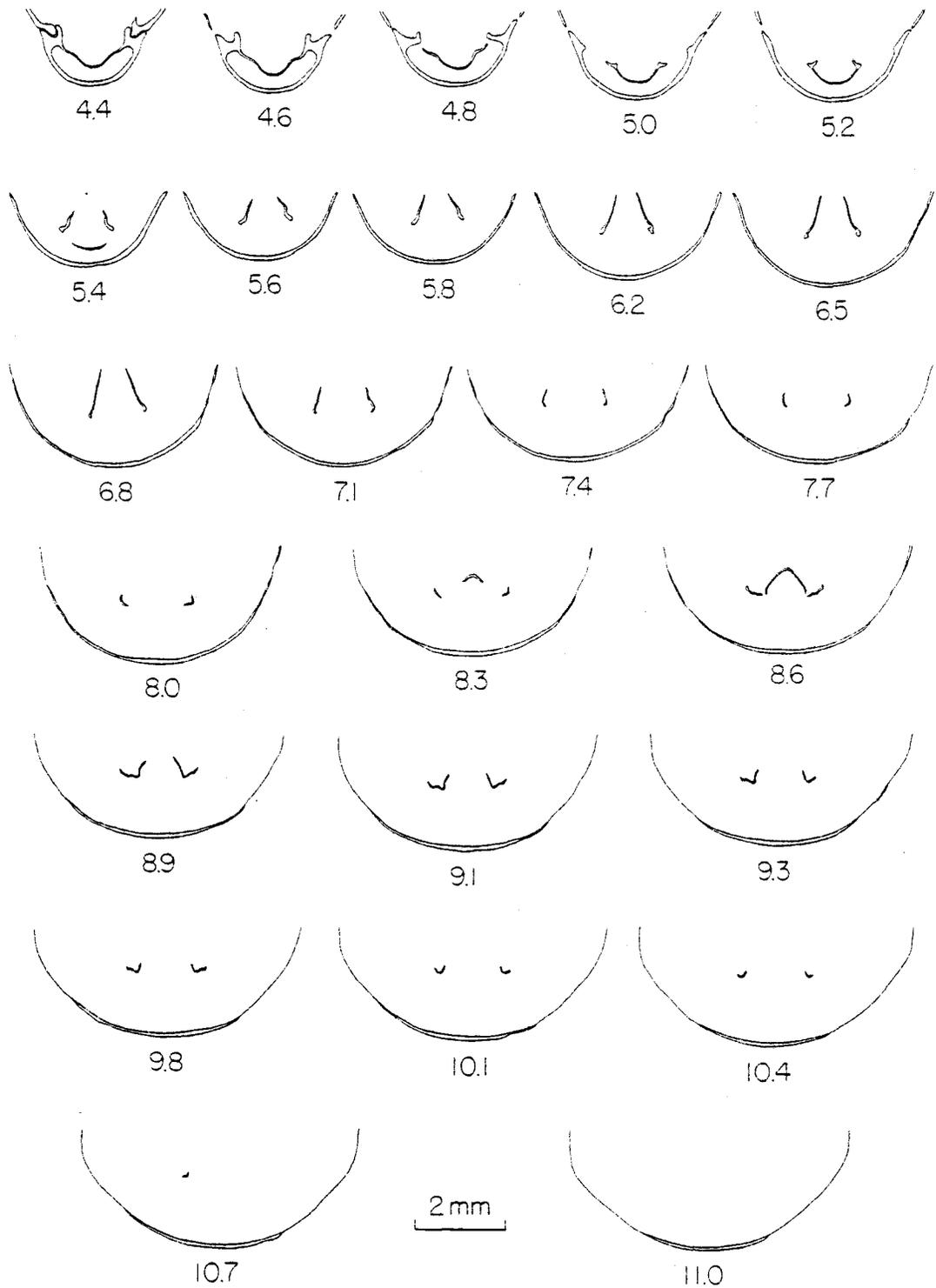


Figure 57. Transverse serial sections of anterior part of Cranaena longicrura n. sp.; specimen from sample 8243-2 (distances in mm. from ventral beak; continued from Figure 56).

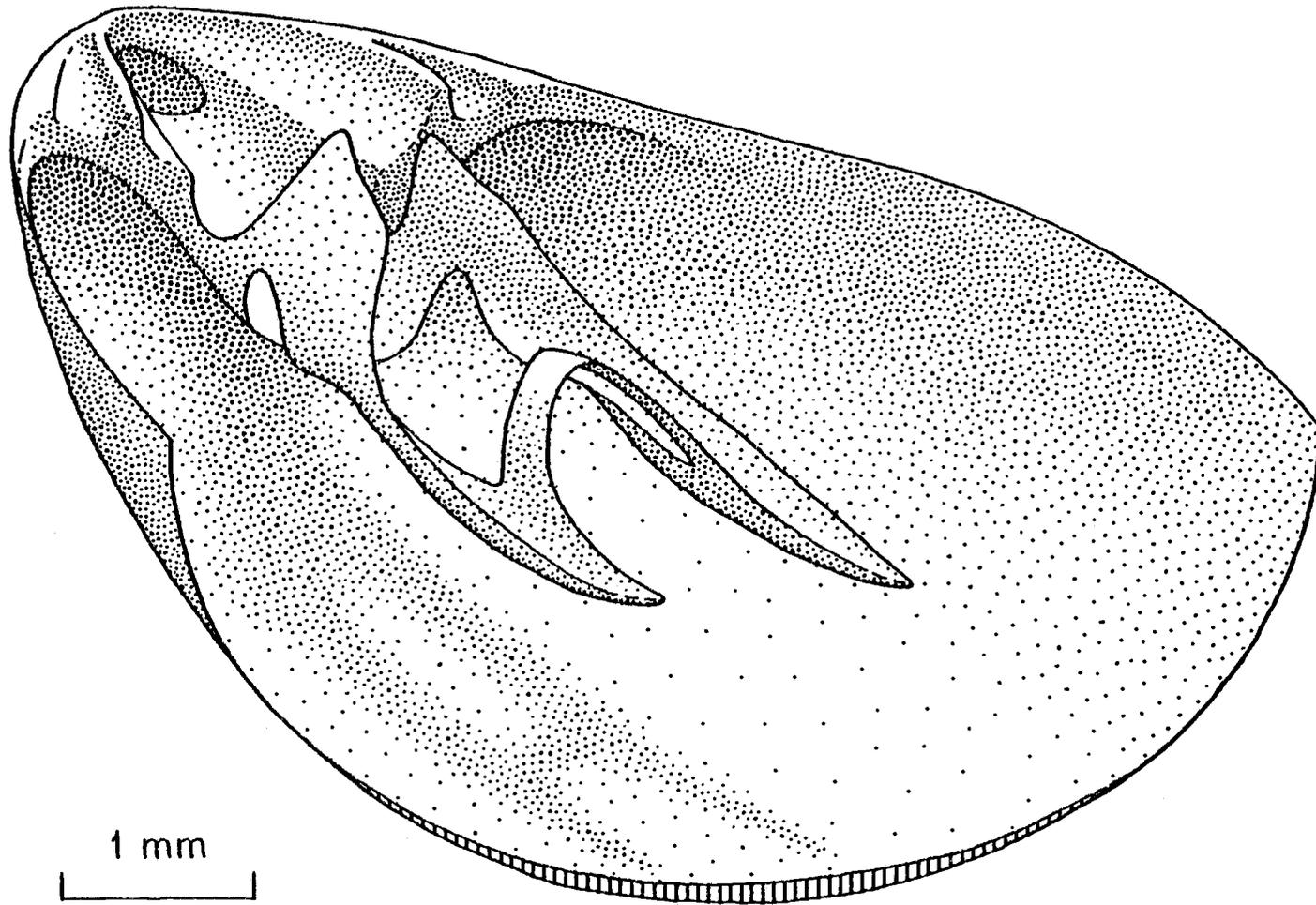


Figure 58. Isometric reconstruction of *Cranaena longicrura* n. sp.; based on transverse serial sections, Figures 56, 57.



toward floor of dorsal valve and converging; continuing anteriorly, crura gradually rotate toward horizontal before being joined by high, posteroventrally-directed transverse plate; crura extending anteriorly from transverse plate as slender, V-shaped processes (Figure 57, interval 9.1 mm. to 10.7 mm.; Figure 58), hence specific name.

DISCUSSION AND COMPARISONS: Cranaena longicrura n. sp. most closely resembles Cranaena texana Carter, 1967, from the Chappel Limestone, Early Mississippian, of central Texas. It differs from that species in being more equally biconvex, in having a weak fold and sulcus in larger specimens, and in possessing long extensions of the crura anterior of the transverse plate joining the crura. In C. texana, the transverse plate joining the crura is much lower and shorter and the crura do not at all extend beyond it. This feature was confirmed by serially sectioning two paratypes of C. texana, USNM 180969, USNM locality 9045. In one specimen, the crura are precisely as figured by Carter (1967, Text-figure 48); in the other, the loop is broken posteriorly from the transverse plate and these features could not be observed.

The presence of such anterior extensions of the crura beyond the transverse plate is nowhere reflected in the present Treatise definition of the genus Cranaena, Subfamily Cranaeninae, Family Cranaenidae, or Superfamily Dielasmatacea. A similar feature, however, is illustrated under the genus Centronelloidea (Stehli, 1965, p. H758, Figure 618) and is included under the discussion of the Subfamily Centronelloideinae Stehli, 1965. Although this is seemingly precedent for making the species under discussion the type of a new genus and the basis for a new subfamily within the Family Cranaenidae, this has not been done for the following reasons: (1) C. longicrura closely resembles C. texana Carter, 1967, in all particulars except the transverse plate and anterior crural extensions; (2) C. longicrura and C. texana are both of Early Mississippian (Tournaisian) age; (3) although fully and carefully figured and illustrated, C. longicrura is based on only 6 articulated specimens and its total stratigraphic range and geographic distribution are only poorly known; (4) it is conceivable that this feature could have originated by recurving and pronounced elongation of the transverse plate so that it would become recumbent on and fused to the crura; (5) a similar feature is present in Beecheria sp. A (see below, this report) and is the principal feature distinguishing that species from other, more typical species of that genus.

Subfamily GIRTYELLINAE Stehli, 1965

Genus Girtyella Weller, 1914

Girtyella sp. A

(Plate 15, figures 15 to 19; Figure 60)

**MATERIAL:** Locality 8243, sample 6; 2 articulated specimens (1 serially sectioned), 2 pedicle valve fragments.

**OCCURRENCE:** Lake Valley Formation, Early Mississippian, Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Unit 3B of Lane (1974; 1978, in press; 1978, written comm.).

**EXTERIOR:** (Based on one articulated specimen and a plaster cast of the serially-sectioned specimen) Shell of medium size, subequally biconvex; outline pryiform (subcircular, neglecting beaks); beak broken on both specimens, details of shape and curvature not observable; longer than wide, greatest thickness slightly posterior to midlength, lateral profile lenticular; anterior commissure recti-marginate; radial ornament lacking, concentric ornament consisting of widely-spaced growth lines; dimensions of the two articulated specimens: length, 31.5 mm., 21.4 mm.; width, 26.0 mm., 15.7 mm.; thickness, 16.3 mm., 10.9 mm.

**INTERIOR:** (Based on transverse serial sections, Figure 60) Ventral valve with at least partial pedicle sheath and narrow deltidium; dental lamellae present, diverging slightly anteriorly. Dorsal valve with continuous hinge plate supported by a low median septum to form two subtriangular cavities between it and the floor of the valve; crural bases on upper surface of hinge plate immediately adjacent to anterior end of plate; crura triangular in cross section, descending only gradually from crural bases; both crura broken shortly anterior from hinge plate, remainder of loop not known.

**DISCUSSION AND COMPARISONS:** Girtyella sp. A differs, externally from most other species of Girtyella in lacking any deflection of the anterior commissure. In this respect, it resembles G. cedarensis Weller, 1914, described from the Northview Shale and Upper Chouteau Limestone. The interior of neither species, however, is sufficiently well known to permit further comparison.

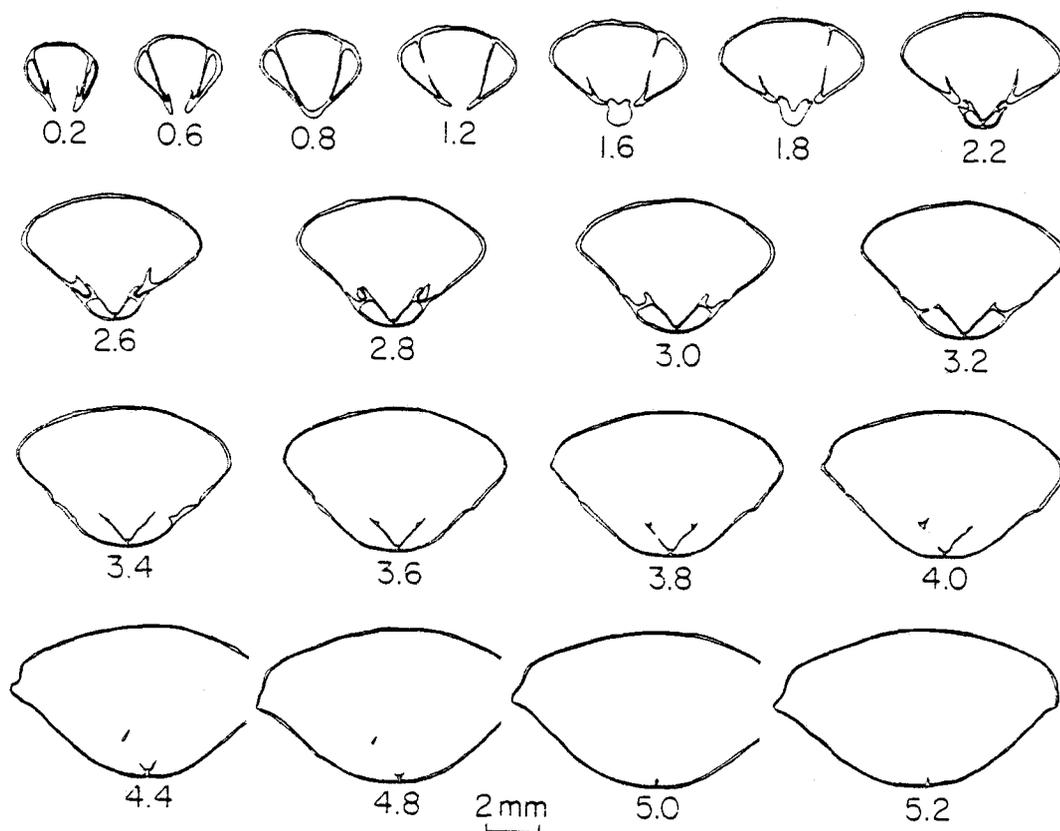


Figure 60. Transverse serial sections of *Girtyella* sp. A; specimen from sample 8243-6 (distances in mm. from ventral beak).

Family HETERELASMINIDAE Likharev, 1956

Genus Beecheria Hall and Clarke, 1894

Beecheria sp. A

(Plate 15, figures 25 to 29; Figures 61 to 63)

**MATERIAL:** Locality 8243, sample 11; 1 articulated specimen (serially sectioned, preserved as plaster cast).

**OCCURRENCE:** Lake Valley Formation, Early Mississippian Osagean (= Tournaisian 3); reef core ecofacies; conodont Faunal Unit 4 of Lane (1974; 1978, written comm.).

**EXTERIOR:** (Based on plaster cast of serially-sectioned specimen) Shell of medium size, biconvex, outline subpentagonal parallel to commissural plane, beaks suberect, pedicle foramen hypothyrid; delthyrium partially closed by either a pair of fused deltidial plates or by a single plate (= henidium of Cloud, 1942, p. 18), the preservation being inadequate to determine; lateral profile lenticular; longer than wide, greatest width near midlength, anterior profile lenticular to subovate; radial ornament lacking; concentric ornament consisting of prominent, widely-spaced growth lines; dimensions of specimen: length, 22.9 mm.; width, 17.0 mm.; thickness, 8.48 mm.

**INTERIOR:** (Based on transverse serial sections, Figures 61, 62, and an isometric reconstruction of the dorsal valve, Figure 63) Ventral valve with dental plates, lying close to shell walls, extending anteriorly almost to teeth before ending abruptly; sockets developed entirely within outer shell wall and unsupported by socket plates, this function being served by a thick accumulation of secondary shell material; crura beginning in posterior of valve as thin crural plates (= outer hinge plates of some authors, e. g., Campbell, 1965) supported by a single medial plate (interpreted as a pair of medially-fused inner hinge plates by some authors, e. g., Campbell, 1965); medial plate deeply concave and posteriorly sessile along midline, forming, with crural plates, a pair of triangular cavities; anteriorly, medial plate developing a slight median ridge (Figure 62, section 4.6 and following), then becoming entirely free of floor of valve and continuing forward as spoon-shaped structure (Figure 62, sections 6.0 mm. and following), finally terminating at a point approximately equal with greatest development of crural points (Figure 62, section 7.4 mm.; Figure 63). Crura rising directly from crural plates to

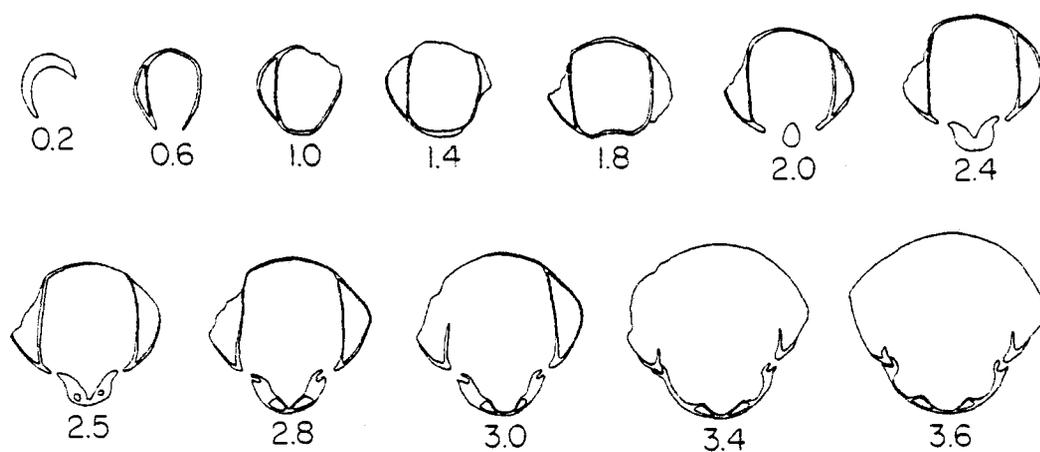


Figure 61. Transverse serial sections of posterior part of Beecheria sp. A; specimen from sample 8243-11 (distances in mm. from ventral beak).

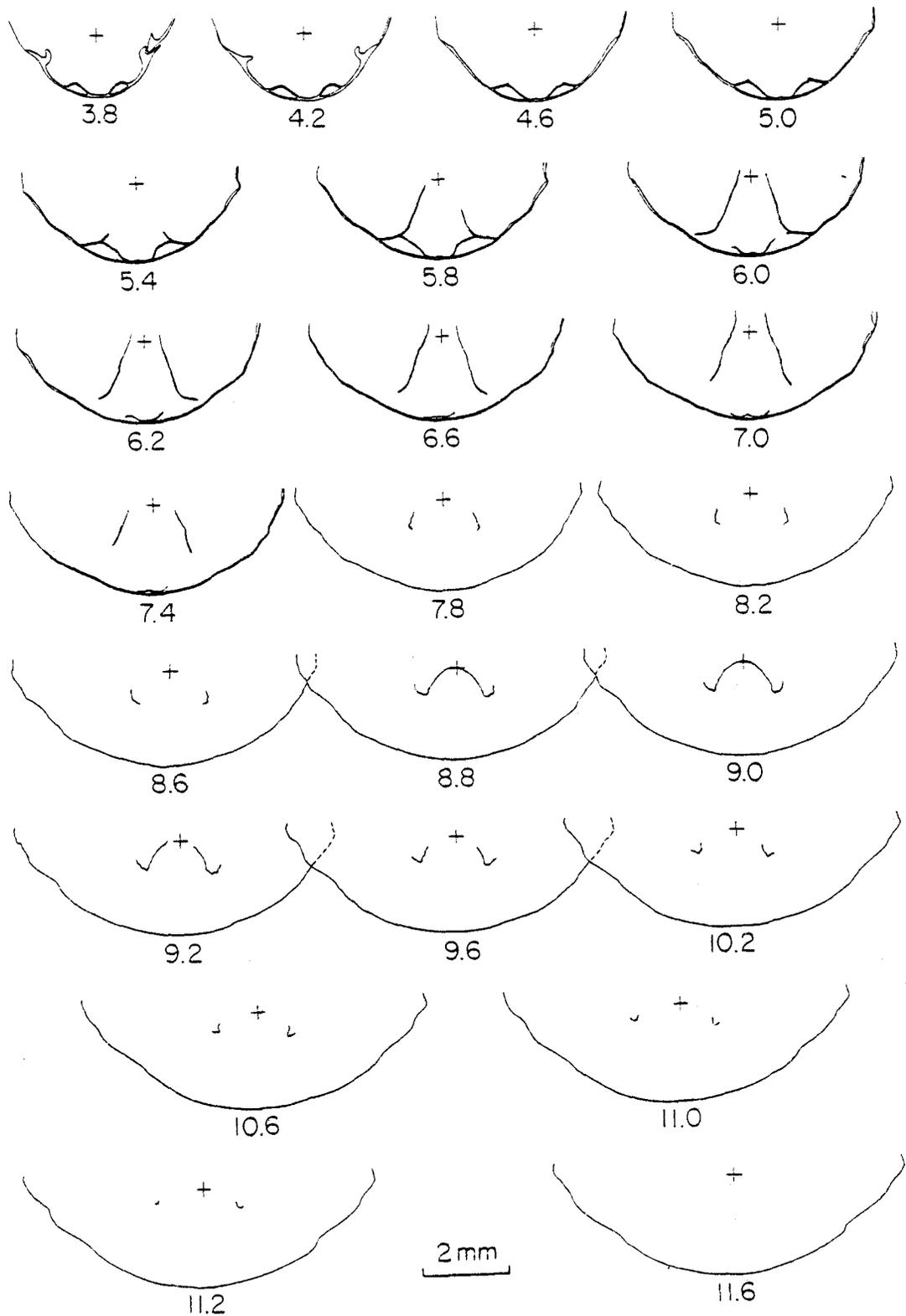


Figure 62. Transverse serial sections of the anterior part of *Beecheria* sp. A; specimen from sample 8243-11 (distances in mm. from ventral beak; continued from Figure 61).

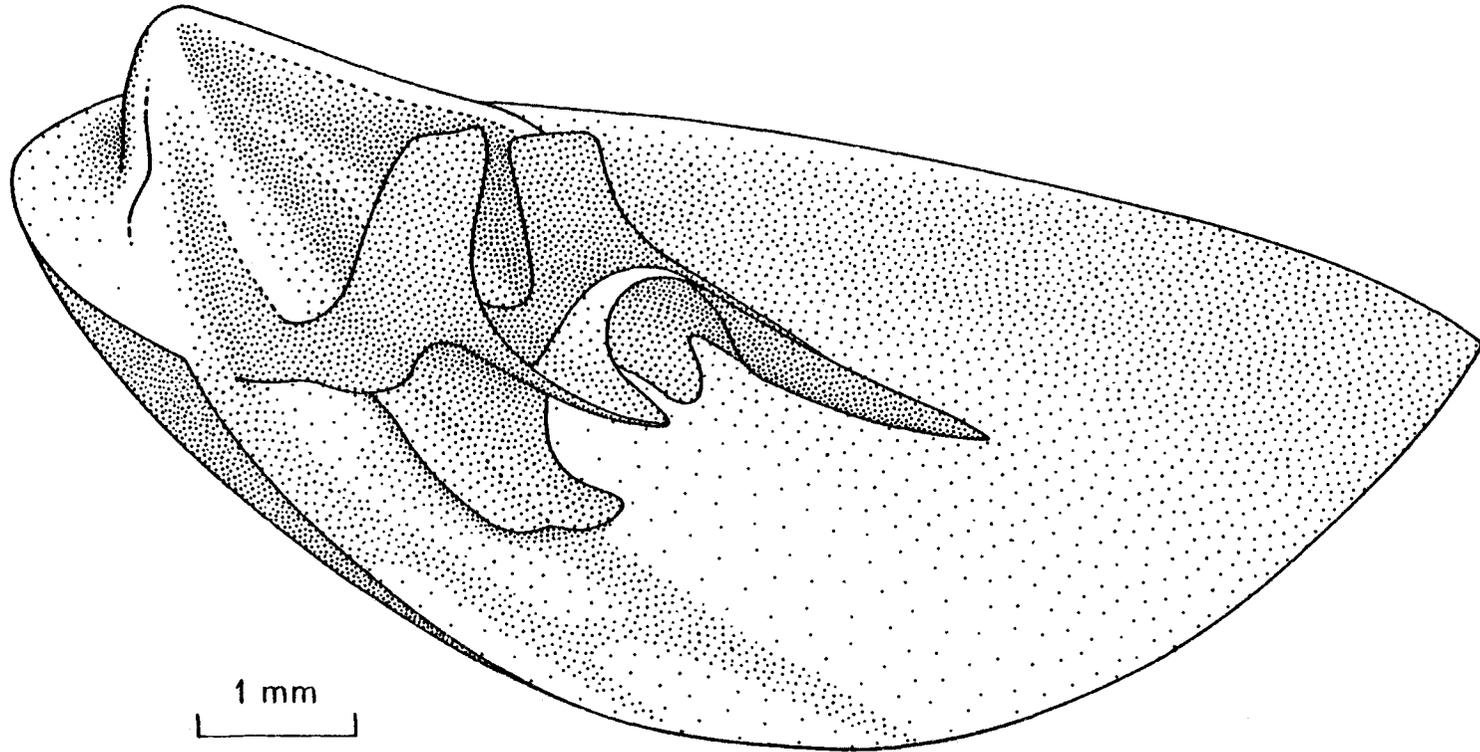


Figure 63. Isometric reconstruction of the dorsal valve of *Beecheria* sp. A; specimen from sample 8243-11 (Based on transverse serial sections, Figures 61, 62).

to form high, thin crural points, then gradually becoming slender and roughly L-shaped before being joined by a high, ventrally-directed transverse band; crura continuing anteriorly from transverse band as slender, U-shaped prongs (Figure 63).

DISCUSSION AND COMPARISONS: Externally, Beecheria sp. A reflects the same conservatism of size, shape and ornamentation characteristic of the Superfamily Dielasmatacea as a whole. Thus, externally, B. sp. A resembles many species of the genera Beecheria and Dielasma. Internally, however, B. sp. A is distinct from all described species for which adequate sections of internal features are available. The most distinctive feature of B. sp. A is the anterior extension of the crura beyond the transverse band or plate which joins them. As in the specimen of Cranaena longicrura De Keyser, n. sp., described above, there is no mention of such a feature in the descriptions of Beecheria or the Heterelasminidae and, if the variation, range and geographic distribution were better known, B. sp. A might very well serve as the type of a new genus and subfamily. On the other hand, considering the great intraspecific variability of living terebratulids and the poor knowledge of the interiors of many species, such crural extensions may prove to be much more common in their occurrence and significant only as a specific character. The latter course has been followed here.

A second point requiring discussion is the interpretation of the internal structures of Beecheria sp. A and the terminology used in the above description. The genus Beecheria was, for many years, considered a junior synonym of Dielasma, resulting from two errors made by Hall and Clarke (1894); (1) They apparently based their diagnosis of Dielasma King on Terebratula bovidens Morton and on illustrations of the type species of Dielasma, Terebratula elongatus Schlotheim, as illustrated by Davidson (1858), incorrectly assuming the two species to be congeneric (Stehli, 1956). (2) They selected and described Beecheria davidsoni as typical of the genus, based on the absence of dental lamellae in the pedicle valve. When it was later shown that B. davidsoni does, in fact, possess dental lamellae (Bell, 1929), the genus Beecheria was suppressed as a junior synonym of Dielasma. Stehli (1956) illustrated sections of the internal features of both species and resurrected Beecheria as a valid generic name.

In illustrating species of Beecheria, Hall and Clarke (1894), Weller (1914), Bell (1929), and Stehli (1956) all use the term crural plates for the thin plates forming the lateral supports of the medial plate. There is no use of the term outer hinge plate by any of these

authors. Campbell (1965), however, refers to the crural plates as outer hinge plates, interpreting them as the site of attachment for the crural bases. Examination of acetate peels of transverse serial sections of Beecheria sp. A suggests that the term crural plates accurately describes a condition in which the crura originate at the floor of the valve, descending without interruption to the crural processes; this was the interpretation of Hall and Clarke (1894, p. 295, 300) and Weller (1914, p. 256). The medial, hinge plate or cardinal plate has variously been interpreted as a single plate (Hall and Clarke (1894, p. 295, 300), a single concave plate supported by an obsolete or rudimentary septum (Bell, 1929, p. 145), or two discrete plates (Weller, 1914, p. 256; Stehli, 1956, p. 302; Campbell, 1965, p. 53). Study of acetate peels reveals no indication that this platform is other than a single, partially medially sessile, plate; in no section does it appear to result from fusion, along a median suture, of two distinct plates. Additional sectioning of other species of Beecheria should help to clarify this conflict in interpretations.

APPENDIX B

## FAUNAL LISTS

Explanation -- The following list of identified taxa is arranged in order of locality and sample numbers, e. g., 8243-5 designates locality 8243, sample number 5. The position of each sample in the stratigraphic section may be found by referring to the columnar section for that locality in APPENDIX C, following. It should be noted that the list in no way attempts to be complete for any other taxonomic group than BRACHIOPODA ARTICULATA; numerical abundances (by articulated specimen, brachial valve, or pedicle valve, abbreviated A, B, and P, respectively) are, therefore, given only for that group. For other taxonomic groups noted in the samples, e. g., "crinoid plates and columnals" or "indeterminate solitary tetracorals," presence only may be noted or a number if possible and meaningful. For each sample, the brachiopods will be listed first and in the same order as found in SYSTEMATIC PALEONTOLOGY, APPENDIX A, preceding.

## LOCALITY 7719

7719-10

Schizophoria cf. chouteauensis  
P1, B1

Leptagonia cf. analoga  
P1

Indet. strophomenacean  
P1

Productina sampsoni  
A3

Paraphorhynchus sp. A  
A2

Cyrtospirifer latior  
A4, P2

Brachythyris fernglenensis  
A1

Indet. (hereafter abbreviated "Indet.")  
solitary tetracoral  
1

7719-11

Indet. chonetacean  
A3

Productina sampsoni  
A2

Rhynchopora sp.  
A1

Indet. rhynchonellid  
1

Athyris cf. lamellosa  
A1

Cyrtospirifer latior  
B1

Indet. solitary tetracorals  
3

7720-3

Indet. burrow casts

7720-4

Cyrtospirifer latior  
P1

Indet. terebratulid  
A1

Crinoid plates and columnals

7720-5

Rhipidomella tenuicostata  
P1

Productina? sp.  
P1

Indet. productacean  
P1

Coledium sp.  
A1

Brachythyris sp.

7720-6 (float)

Indet. chonetacean  
P1

Rhynchopora sp.  
P1

Cleiothyridina sp.  
1

Cyrtospirifer latior  
B1

Indet. bryozoa  
Crinoid plates and columnals  
Indet. goniatite

7720-8

Schizophoria cf. chouteauensis  
A1, P1

Leptagonia cf. analoga  
P1, B1

Indet. strophomenid  
P1

Indet. productacean cf. Rhytiophora sp.  
P1

Syringothyris halli  
A1

Indet. solitary tetracorals  
4

7720-9

Rhipidomella tenuicostata  
P1, B1

Indet. strophomenid  
P1

Schwellwienella? sp.  
P1

Streptorhynchus? sp.

B1

Indet. chonetaceans

A4, P2, B1

Productina sampsoni

P2

Rhytiophora sp.

P1

Stegacanthia? sp.

\_1

Paraphorhynchus sp. A

A1

Cleiothyridina cf. glenparkensis

A6, P1

Crurithyris cf. parva

P1

Tylothyris sp.

B1

Syringothyris sp.

B1

Cyrtospirifer latior

P1

Cyrtospirifer sp. A

P2

Brachythyris sp.

P1, B1

Indet. spiriferacean

P1

Indet. solitary tetracorals

16

Indet. cryptostome bryozoan

Indet. trepostome bryozoan

Indet. fenestellid bryozoan

Crinoid plates and columnals

Indet. bivalve

1

7720-10Rhipidomella tenuicostata

P1

Indet. strophomenid

1

Spirifer sp.

P1

Indet. solitary tetracoral

1

Crinoid plates and columnals

7720-11

Indet. chonetacean

P1

Stegacanthia bowsheri

A1, B1

Indet. productacean

\_1

Brachythyris sp.

P1

## LOCALITY 7721

7721-2  
Shumardella obsolescens  
 A1  
Cyrtospirifer latior  
 A2, P5, B1

7721-5  
 Indet. solitary tetracorals  
 2

7721-9  
 Indet. productacean  
 P2  
Rhynchopora? sp.  
 \_1  
Cyrtospirifer latior  
 P8  
 Indet. solitary tetracoral  
 1  
 Indet. tabulate coral  
 2  
 Indet. bryozoan  
 Crinoid plates and columnals

7721-10  
 Indet. chonetacean  
 P1  
 Indet. rhynchonellid  
 P1  
Athyris cf. lamellosa  
 A2, P1  
Cyrtospirifer latior  
 P1  
Brachythyris? sp.  
 P1  
 Indet. solitary tetracoral  
 1  
 Indet. bryozoan  
 Indet. trilobite fragments

7721-12  
Schizophoria cf. chouteauensis  
 P1, B1  
Rhipidomella tenuicostata  
 A1

Rhytiophora sp.  
 P1  
Cyrtospirifer sp. A  
 P5  
 Indet. spiriferacean  
 B1  
 Crinoid plates and columnals  
 Indet. trilobite glabella  
 1

7721-13  
Productina sampsoni  
 P1

7721-14  
Cleiothyridina prouti  
 A1

7721-15  
Schizophoria? sp.  
 \_1  
Cyrtospirifer sp. A  
 P2  
 Crinoid plates and columnals

7721-16  
Schizophoria cf. chouteauensis  
 P3, B1  
Rhipidomella sp.  
 P2  
Leptagonia cf. analoga  
 P2  
 Indet. strophomenid  
 B1  
 Indet. chonetacean  
 P1  
Marginatia sp. A  
 P1, B1  
Athyris cf. lamellosa  
 Ap, P2  
Voiseyella? sp.  
 A1  
 Indet. spiriferacean  
 \_2  
 Crinoid plates and columnals

7721-17

Indet. nautiloid cephalopod

1

7721-19

Spirifer sp.

P2

Indet. solitary tetracorals

3

Indet. bryozoan

Crinoid plates and columnals

7721-21

Pseudosyrinx missouriensis

P2

## LOCALITY 7722

7722-3  
Indet. trilobite pygidium  
1

7722-7  
Rhipidomella tenuicostata  
A1, P1, \_3  
Indet. chonetacean  
A3, P2  
Indet. productacean  
P1  
Athyris cf. lamellosa  
A5, P3  
Cleiothyridina cf. glenparkensis  
P2  
Cyrtospirifer latior  
P1  
Cyrtospirifer sp. A  
P1  
Indet. solitary tetracorals  
5  
Crinoid plates and columnals  
Indet. trilobite pygidium  
1

7722-8  
Indet. chonetacean  
P1  
Rhytiophora cf. calhouensis  
P2  
Hustedia? sexplicata  
A1  
Athyris cf. lamellosa  
A7, B1, \_4  
Cleiothyridina cf. glenparkensis  
A3  
Tylothyris sp. A  
A1, P2  
Cyrtospirifer sp. A  
A2, P9  
Indet. brachiopod fragments  
\_3  
Indet. solitary tetracorals  
11  
Indet. fenestellid bryozoan  
Indet. bryozoan

Indet. platycrinid columnals  
Indet. cephalopod  
2

7722-9  
Rhipidomella sp.  
A1, P1  
Indet. strophomenid  
\_1  
Rhytiophora? sp.  
P1  
Indet. productacean  
\_3  
Athyris cf. lamellosa  
A2, \_1  
Cyrtospirifer sp. A  
A1, P4  
Indet. solitary tetracorals  
4  
Crinoid plates and columnals  
Indet. pectinid bivalve  
Indet. bivalve  
Indet. trilobite fragments  
Indet. ostracodes

7722-10  
Marginatia sp. A  
P1  
Spirifer sp.  
A1

7722-11  
Schizophoria cf. chouteauensis  
B1

7722-12  
Cyrtospirifer latior  
A1  
Cyrtospirifer sp. A  
A1  
Indet. solitary tetracorals  
2

- 7722-13  
 Indet. productacean  
     P1  
Hustedia (?) sexplicata  
     P1  
Tylothyris sp. A  
     B2  
Cyrtospirifer latior  
     B1  
 Indet. solitary tetracoral  
     1
- 7722-14  
Schizophoria cf. chouteauensis  
     A4, P4, B3, \_1  
Leptagonia cf. analoga  
     B1  
 Indet. strophomenid  
     B1  
Stegacanthia? sp.  
     P1, B1  
Marginatia sp. A  
     P2  
Athyris cf. lamellosa  
     P1  
Cleiothyridina? sp.  
     P2  
Pseudosyrinx? sp.  
     P3, B1  
Spirifer cf. logani/grimesi  
     P25  
Spirifer cf. gregeri  
     A2, P16, B6  
Spirifer sp.  
     A1, P16, B13  
Unispirifer sp. A  
     P1  
Brachythyris cf. suborbicularis  
     P15  
Brachythyris? sp.  
     P3  
Punctospirifer sp. B  
     P1  
Reticularia? sp.  
     P1, B1  
Martinia? sp.  
     A1  
 Indet. terebratulid  
     P5, B1  
 Indet. solitary tetracorals  
     4
- Indet. cryptosome bryozoans  
 Indet. camerate crinoid fragment  
     1  
Cryptoblastus cf. melo  
     2  
Orbitremites sp.  
     1  
 Indet. pentremiid blastoid  
     1  
 Indet. platyceratid gastropods  
     4

LOCALITY 82428242-19Marginatia sp. A

A2, P3

Rhynchopora sp.

A1

Cleiothyridina prouti

A1

Imbrexia sp. A

P1

Brachythyris fernglenensis

P1

Punctospirifer sp. B

P1

## LOCALITY 8243

8243-1Leptagonia cf. analoga

P1, B1

Productina sampsoni

A1, P1

Rhytiophora sp.

P1

Marginatia sp. A

A1, P3

Coledium sugarloafensis

B1

Rhynchopora sp. B

A2

Crurithyris sp.

A1

Cleiothyridina prouti

A1

Imbrexia sp. A

A1, B2

Punctospirifer sp. B

A1, P7, B4

Indet. inarticulate brachiopod

1

Indet. "button" rugose coral

1

Indet. fenestellid bryozoan

Crinoid plates and columnals

Indet. platyceratid gastropods

2

Pudoproetus chappelensis Hessler, 1963

(Identification by Allen R. Ormiston)

2 cranidia, 3 pygidia

Indet. phillipsid trilobite (Identification

by Allen R. Ormiston)

1 pygidium

8243-2Schizophoria cf. chouteauensis

A4, P13, B2

Marginatia sp. A

A3

Rhynchopora sp. B

A20, P2, B2

Cleiothyridina sp.

A1, P1

Imbrexia sp. A

P7, B3

Brachythyris suborbicularis

A2, P5

Punctospirifer sp. B

P3, B2

Cranaena longicrura

A3, P1

Indet. solitary tetracorals

2

Indet. bryozoan

Indet. platyceratid gastropods

6

Indet. cephalopod

1

8243-3Schizophoria cf. chouteauensis

P2

Indet. schuchertellid or orthotetid

P1

Productina sampsoni

A1

Rhytiophora cf. blairi

B3

Marginatia sp. A

A3, P1, B1

Coledium sugarloafensis

A1

Rhynchopora sp. C

A1

Cleiothyridina sp.

A1

Indet. syringothyrid

B1

Spirifer? sp.

A1

Imbrexia sp. A

A1, P2

Unispirifer sp. A

A1, P1

Brachythyris suborbicularis

A1, P2

Punctospirifer sp. B

P1, B1

Cranaena longicrura

A2

Dielasma sp.

P3

Punctospirifer sp. B

P1, B1

Cranaena longicrura

A2

Dielasma sp.

P3

Indet. solitary tetracoral

1

Crinoid plates and columnals

Indet. platyceratid gastropods

2

8243-4Schizophoria cf. chouteauensis

P1

Rhynchopora sp. B

A1

Cleiothyridina sp.

P1

Pseudosyrinx missouriensis

P4, B1

Unispirifer sp. A

P1

Unispirifer sp.

P1, B1

Indet. fenestellid bryozoan

Crinoid plates and columnals

8243-5Rhipidomella sp.

A2

Productina sampsoni

A1

Marginatia sp. A

A1

Rhynchopora sp. C

A4

Pseudosyrinx missouriensis

P2

Imbrexia sp. A

P2

Unispirifer sp. A

P1

Unispirifer sp. B

A1

Brachythyris suborbicularis

P2

Reticularia? glabra

P1, B1

Cranaena longicrura

A1

Indet. solitary tetracoral

1

Crinoid plates and columnals

8243-6Schizophoria cf. chouteauensis

P1

Leptagonia cf. analoga

P1, B2

Indet. chonetacean

P2

Rhytiophora cf. blairi

P1, B2

Rhytiophora sp. B

A1, P1

Coledium sugarloafensis

A39, P1, B4

Rhynchopora sp. B

A2

Cleiothyridina sp.

B4

Pseudosyrinx missouriensis

P1

Spirifer sp.

P1

Imbrexia sp. A

P1

Brachythyris suborbicularis

P3

Punctospirifer sp. B

P59, B64

Girtyella sp. A

A2, P2

Indet. camerate crinoid base

1

Crinoid plates and columnals

Indet. platyceratid gastropods

2

8243-7Schizophoria cf. chouteauensis

A1

Leptagonia cf. analoga

B3

Schellwienella? sp.

P4, B2

Rhytiophora cf. blairi

P1, B3

## Indet. productacean

B3

Coledium sugarloafensis

A2

Rhynchopora sp. B

A15

Cleiothyridina sp.

A2, P4, B1

Pseudosyrinx missouriensis

A4, P17, B3

Spirifer cf. logani/grimesi

P1

Unispirifer sp.

A1, P2, B1

Unispirifer? sp.

P1

Brachythyris suborbicularis

P1

Punctospirifer sp. B

P2, B1

## Indet. platyceratid gastropods

3

8243-8

Schizophoria cf. chouteauensis

A5, P6, B1

Leptagonia cf. analoga

B1

## Indet. schuchertellid

B2

Productina sampsoni

A1

Rhytiophora cf. blairi

A1, P1, B1

Marginatia sp. A

A6, P1, B4

Rhynchopora sp. D

A4

Athyris cf. lamellosa

A2

Pseudosyrinx missouriensis

A1, P2, B1

Imbrexia sp. A

P4

Imbrexia sp.

P3

Brachythyris suborbicularis

P1

Punctospirifer sp. B

P1, B2

Dielasma? sp.

A1

Lithostrotion (Siphonodendron) sp.

## Indet. favositid coral

## Indet. fenestellid bryozoan

## Indet. platyceratid gastropod

1

## Indet. euomphalid gastropod

1

## Indet. pectinid bivalve

1

## Indet. bivalve

1

## Indet. nautiloid cephalopod

1

8243-9

Schizophoria cf. chouteauensis

A1, P4, B2

Leptagonia cf. analoga

P1, B1

Productina sampsoni

A1

Rhytiophora sp. B

A1

Marginatia sp. A

A4, B1

Cleiothyridina sp.

P1

Spirifer sp.

P1

Imbrexia sp. A

P1

Imbrexia sp. B

A1, P3

Unispirifer sp.

P3

Brachythyris suborbicularis

P1

## Indet. spiriferacean

B1

Lithostrotion (Siphonodendron) sp.

## Indet. platyceratid gastropod

1

## Indet. pectinid bivalves

2

## Indet. bivalve

1

8243-11  
Schizophoria cf. chouteauensis  
 A2, P1  
 Indet. orthotetacean  
 A1  
 Indet. chonetacean  
 P1  
Productina sampsoni  
 A111, P1, B12  
Marginatia sp. A  
 A3, P2, B1  
 Indet. productacean  
 P1  
Atribonium (?) sp. A  
 A3  
Rhynchopora sp. D  
 A2  
Pseudosyrinx sp.  
 P1  
Spirifer sp.  
 P1, B1  
Unispirifer sp.  
 P1  
Brachythyris suborbicularis  
 A1, P1  
Reticularia or Torynifer sp.  
 A2, P3  
Beecheria sp. A  
 A1  
 Indet. platycrinid crinoid  
 1  
 Crinoid plates and columnals  
 Indet. platyceratid gastropod  
 1

8243-13  
Leptagonia cf. analoga  
 1  
 Indet. orthotetacean  
 1  
 Indet. productacean  
 B1  
Pseudosyrinx missouriensis  
 P3, B2  
Spirifer sp.  
 P1, B1  
 Indet. bivalve  
 1

8243-14  
Rhytiophora? sp.  
 P1  
Marginatia sp. A  
 A7, P4, B4  
Imbrexia sp. B  
 A1, P1, B1  
 Crinoid plates and columnals

8243-15  
Schizophoria cf. chouteauensis  
 P2  
Marginatia sp. A  
 A5, B3  
Coledium sp.  
 A1  
Rhynchopora sp. D  
 A1  
Spirifer sp.  
 A1  
Unispirifer sp. B  
 A1  
Brachythyris suborbicularis  
 P1  
Eomartinia? sp.  
 P1  
 Indet. terebratulid  
 B1  
 Indet. platyceratid gastropods  
 5  
 Indet. trilobite pygidia  
 3

## LOCALITY 8244

8244-2Schizophoria cf. chouteauensis

P1

Indet. chonetacean

P1

Indet. productacean

\_1

Crurithyris sp.

P3, B3

Indet. spiriferacean cf. Tylothyris sp.

P2

Brachythyris sp.

P1, B2

Indet. solitary tetracoral

1

Indet. fenestellid bryozoans

Crinoid plates and columnals

8244-3Schizophoria cf. chouteauensis

\_1

Rhynchopora sp.

A1, \_1

Indet. athyridid

A1

Crurithyris parva

P2

Brachythyris suborbicularis

P5, B2

Punctospirifer sp. B

B2

Indet. alate spiriferacean

\_1

Indet. mucronate spiriferacean

\_1

Indet. fenestellid bryozoan

Crinoid plates and columnals

Indet. gastropod

1

Indet. trilobite fragments

8244-4Schizophoria cf. chouteauensis

P1

Rhytiophora cf. blairi

P1, B1

Indet. stenoscismatacean?

P2

Indet. rhynchonellid or spiriferid

\_1

Brachythyris suborbicularis

A1

Indet. spiriferacean

P4

Indet. solitary tetracoral

1

Crinoid plates and columnals

8244-5Schizophoria cf. chouteauensis

B1

Indet. orthotetacean

\_1

Pseudosyrinx sp.

P1

Spirifer sp.

P5

Brachythyris suborbicularis

P6

Torynifer? sp.

P1, B1

Indet. terabratulid

A1, P3, \_2

Indet. brachiopod fragments

\_2

Indet. solitary tetracoral

1

Crinoid plates and columnals

Indet. platyceratid gastropods

3

8244-6Pseudosyrinx sp.

P1, B1

Indet. solitary tetracoral

1

Crinoid plates and columnals

8244-7Pseudosyrinx sp.

P1

Spirifer cf. logani/grimesi

P1

Spirifer cf. gregeri

P4, B1

Crinoid plates and columnals

Indet. platyceratid gastropod

1

8244-8Marginatia sp.

P1

Athyris cf. lamellosa

P1

Spirifer cf. logani/grimesi

P6

Spirifer cf. gregeri

P2

Unispirifer sp. A

P2

Brachythyris suborbicularis

P1

Indet. solitary tetracorals

5

Crinoid plates and columnals

Indet. gastropod?

1

8244-9Rhipidomella tenuicostata

A2

Rhytiophora cf. calhouensis

P1

Marginatia sp.

P3

Indet. productacean

\_1

Indet. stenoscismatacean cf.

Sedenticellula sp.

A1

Rhynchopora? sp.

\_1

Brachythyris suborbicularis

P1

Reticularia cf. pseudolineata

P3, B2

Cranaena sp.

A2, P1, \_1

Crinoid plates and columnals

Indet. bivalve

1

Triboloceras sp.

1

8244-10Schizophoria cf. chouteauensis

B1

Indet. orthotetacean

P1, B1

Marginatia sp.

P2

Indet. productacean

B1

Athyris cf. lamellosa

A2

Cleiothyridina? sp.

P1

Pseudosyrinx sp.

P3, B1

Spirifer cf. logani/grimesi

P6

Spirifer cf. gregeri

P14, B2, \_1

Spirifer sp.

P6, B2

Unispirifer sp.

P5, B1

Brachythyris suborbicularis

P6

Indet. terebratulid

A1, P2, B3

Crinoid plates and columnals

Indet. platyceratid gastropods

5

Indet. euomphalacean gastropod

1

## LOCALITY 8245

8245-5 (float)

Rhipidomella? sp.

P1

Rhytiophora sp.

P1

Indet. productacean

B1

Brachythyris fernglenensis

P1

Indet. solitary tetracorals

4

Crinoid plates and columnals

8245-6

Indet. chonetacean

P1

Paraphorhynchus sp. A

A1

Crurithyris parva

P1

Cyrtospirifer latior

A1, P1

Indet. solitary tetracoral

1

Crinoid plates and columnals

8245-7

Indet. chonetacean

2

Productina sampsoni

P2

Cyrtospirifer latior

P11, B3

Indet. solitary tetracoral

1

Indet. bryozoan

Crinoid plates and columnals

8245-9 (float)Schizophoria cf. chouteauensis

A1, P3, B1

Rhipidomella tenuicostata

A3

Leptagonia cf. analoga

A2, P2, B2, \_2

Productina sampsoni

A3, P2

Rhytiophora cf. blairi

P2, B1

Indet. productacean

P1

Athyris cf. lamellosa

A2

Tylothyris sp. A

A1, P5

Cyrtospirifer latior

A1, P2

Unispirifer sp.

P1

Brachythyris suborbicularis

A3, P6, B1

Punctospirifer sp. A

P1

Indet. solitary tetracorals

31

Indet. fenestellid bryozoans

Indet. monobathrid camerate  
crinoid fragment

Crinoid plates and columnals

Indet. platyceratid gastropods

3

Indet. trilobite pygidium and glabella

1 each

8245-10Schizophoria cf. chouteauensis

P2

Leptagonia cf. analoga

P1

Productina sampsoni

P1

Marginatia sp.

P1

Tylothyris sp. A

A1, P2

Spirifer sp.

P2

Brachythyris sp.

P1

8245-11  
Schizophoria cf. chouteauensis  
A1, P1, B2

Leptagonia cf. analoga  
A2, P3, B1

Productina sampsoni  
P1

Indet. productacean  
B1

Cleiothyridina cf. glenparkensis  
A1

Cyrtospirifer latior  
P1

Brachythyris sp.  
A1, P2

Indet solitary tetracorals  
13

Indet. encrusting bryozoan

Indet trilobite pygidium  
1

8245-12 (float)  
Schizophoria cf. chouteauensis  
A1

Leptagonia cf. analoga  
A2

Productina sampsoni  
P2

Rhytiophora? sp.  
A1, P2, B1

Marginatia? sp.  
1

Voiseyella novamexicana  
P1, B1

Cyrtospirifer latior  
A1

Indet. spiriferacean  
A1

Indet. solitary tetracorals  
12

Indet. fenestellid bryozoans

Crinoid plates and columnals

8245-13  
Indet. productacean

2  
Spirifer sp.  
P1

Brachythyris sp.  
P1

Indet. solitary tetracorals  
3

Indet. tabulate coral  
1

8245-15 (float)  
Rhipidomella tenuicostata  
A1, P1

Indet. orthotetid  
P3

Indet. productaceans  
P1, B3

Cleiothyridina cf. glenparkensis  
A2, P1

Imbrexia sp.  
A1

Indet. solitary tetracorals  
17

Indet. fenestellid bryozoan

Indet. bryozoan

Crinoid plates and columnals

Indet. low-spined gastropod  
1

Indet. trilobite fragments  
3

8245-16  
Schizophoria cf. chouteauensis  
A1, P2

Rhytiophora cf. blairi  
P1, B1

Tylothyris sp. A  
P1

Spirifer sp.  
P2

Imbrexia sp.  
B1

Indet. solitary tetracorals  
3

Crinoid plates and columnals

8245-17 (float)

Schizophoria cf. chouteauensis

A1

Rhytiophora? sp.

B1

Marginatia sp. A

A2, B1

Athyris cf. lamellosa

A1, P2

Cleiothyridina sp.

A1

Spirifer sp.

A1, P1, B1

Imbrexia sp.

A1

Unispirifer sp. A

P3, B4

Brachythyris suborbicularis

A1, P2

## Indet. terabratulid

P1

## Indet. solitary tetracorals

11

## Indet. tabulate coral

## Indet. massive, encrusting bryozoan

Platycrinites sp.

1

## Crinoid plates and columnals

## Indet. platyceratid gastropods

2

8245-18 (float)Schizophoria cf. chouteauensis

B1

Leptagonia cf. analoga

P1

Marginatia sp. A

P1, B1

Pseudosyrinx missouriensis

P1, B1

Spirifer sp.

P1, B1

Unispirifer sp. A

P1

## Indet. terabratulid

B1

## Indet. camerate crinoid (fragment of calyx)

1

Orbitremites sp.

1

## Indet. platyceratid gastropods

4

8245-19Spirifer sp.

A2, P2, \_1

Unispirifer sp. A

A1, P3, B1

## Indet. terebratulid

A1, P1

## Crinoid plates and columnals

## Indet. platyceratid gastropods

3

8245-20 (top of Phantom Mound)

## Indet. orthotetid

P1

Pseudosyrinx? sp.

B1

Imbrexia sp. A

P2

## Crinoid plates and columnals

8245-(Caballero, float)Schizophoria cf. chouteauensis

\_1

Rhipidomella tenuicostata

A2, \_1

Rhytiophora cf. calhouensis

P1, B1

Stegacanthia bowsheri

P1

## Indet. productacean

\_1

Athyris cf. lamellosa

A5

Cleiothyridina cf. glenparkensis

A10

Cleiothyridina prouti

A1

Cyrtospirifer sp. A

A1, P12

Brachythyris fernghlenensis

A2

Punctospirifer sp. A

B1

## Indet. spiriferacean

A1

Reticularia sp.

P1

Crania sp.

1

Indet. solitary tetracorals

15

Indet. gastropods

5

## LOCALITY 8246

8246-3  
Crurithyris parva  
 P1  
 Indet. solitary tetracorals  
 3

8246-4  
Schizophoria cf. chouteauensis  
 A1  
Leptagonia cf. analoga  
 P1  
 Indet. rhynchonellid  
 \_1  
Crurithyris parva  
 P1  
 Crinoid plates and columnals

8246-5  
Schizophoria cf. chouteauensis  
 A4, P2, \_3  
Leptagonia cf. analoga  
 \_1  
 Indet. strophomenid  
 \_2  
 Indet. chonetacean  
 P2, B1  
Productina sampsoni  
 A4, P2  
Athyris cf. lamellosa  
 A2  
Cleiothyridina cf. glenparkensis  
 A4, P1  
Crurithyris parva  
 A1, B1  
Cyrtospirifer latior  
 A4, P1  
Cyrtospirifer sp. A  
 P14  
Brachythyris sp.  
 P1  
 Indet. solitary tetracorals  
 19  
Cleistopora typa  
 1  
 Indet. bryozoa  
 3

Indet. camerate crinoid  
 1  
 Indet. platyceratid gastropod  
 1  
 Indet. gastropod  
 1

8246-6  
Schizophoria cf. chouteauensis  
 P1  
 Indet. solitary tetracoral  
 1  
 Indet. trilobite pygidium  
 1

8246-7  
 Indet. chonetacean  
 P1  
Productina? sp.  
 P1  
Athyris cf. lamellosa  
 B1  
Cyrtospirifer latior  
 P1  
 Indet. spiriferacean  
 P1

8246-8  
 Indet. trilobite pygidium

8246-9  
 Indet. spiriferacean  
 \_1

8246-10  
 Crinoid plates and columnals

8246-12  
Tylothyris sp. A  
 A1  
Cyrtospirifer latior  
 A1, P4

Cyrtospirifer sp. A

A3, P5

Indet. solitary tetracorals

6

Indet. low-spired gastropod

1

8246-13Athyris cf. lamellosa

P2

Pseudosyrinx sp.

P1

Unispirifer sp.

B2

Brachythyris sp.

P2

Indet. spiriferacean

\_2

Indet. terebratulid

B1

Indet. solitary tetracorals

2

Indet. camerate crinoid

(fragment of calyx)

1

Crinoid plates and columnals

8246-16Marginatia sp.

P2

Indet. rhychonellid

\_1

Brachythyris sp.

A1

Indet. aulopodid coral

1

8246-26

Indet. chonetacean

P1

Productina sp.

P1

Shumardella obsolescens

A2

Coledium sp.

A1

Crurithyris parva

P1

Syringothyris sp.

P1

Cyrtospirifer latior

P2, B1

Indet. solitary tetracoral

1

Indet. platycrinid camerate crinoid

1

## LOCALITY 8248

8248-(float)  
Geniculifera boonensis  
 A1  
Shumardella obsolescens  
 A1  
Cyrtospirifer latior  
 A1  
 Indet. solitary tetracorals  
 2

8248-9  
Schizophoria cf. chouteauensis  
 B1  
Rhytiophora sp. A  
 P2  
Shumardella obsolescens  
 A1  
Composita cf. globosa  
 A1  
Cyrtospirifer latior  
 A4, B1  
 In det. spiriferacean  
 P1  
 Indet. solitary tetracorals  
 5  
 Indet. trilobite pygidia  
 2

8248-11 (float)  
Schizophoria cf. chouteauensis  
 A9, P4, B1  
Rhipidomella tenuicostata  
 A4  
Leptagonia cf. analoga  
 A9, P1, B1, \_1  
 Indet. strophomenid  
 \_1  
Schuchertella? sp.  
 A2, \_1  
 Indet. davidsoniacean?  
 \_1  
Productina sampsoni  
 A4, P4  
Rhytiophora sp. A  
 A2, P2, B1  
 Indet. productacean  
 \_1

Shumardella obsolescens  
 A3  
Paraphorhynchus sp. A  
 A2  
Coledium sp.  
 A4  
Ptychomaletoechia (?) sp. A  
 A2  
Cleiothyridina cf. glenparkensis  
 A15, \_1  
Composita cf. globosa  
 A3  
Crurithyris parva  
 A7, P2  
Cyrtina burlingtonensis  
 A2  
 Indet. syringothyridid  
 P1  
Cyrtospirifer latior  
 A13, P4, B1  
Brachythyris fernglenensis  
 A2, P2  
Punctospirifer sp. A  
 A3  
 Indet. articulate  
 A2  
 Indet. lingulid  
 \_1  
 Indet. encrusting inarticulate brachiopods  
 2  
 Indet. solitary tetracorals  
 17  
 Indet. encrusting bryozoan  
 Indet. bellerophontid gastropod  
 1  
 Indet. platyceratid gastropod  
 1  
 Indet. nautiloid cephalopod  
 1  
 Indet. trilobite pygidium  
 1

8248-12  
Schizophoria cf. chouteauensis  
 A1, P1  
Rhipidomella tenuicostata  
 A2

- Leptagonia cf. analoga  
 B1  
 Indet. strophomenid  
 \_1  
Productina sampsoni  
 A1, P1  
Geniculifera boonensis  
 A4  
Stegacanthia bowsheri  
 P2  
 Indet. productacean  
 \_1  
Shumardella obsolescens  
 A4  
Paraphorhynchus sp. A  
 A1  
Coledium sp.  
 A1  
 Indet. athyridid  
 P1  
Crurithyris parva  
 P1  
Cyrtospirifer lator  
 A16, P7  
Brachythyris sp.  
 P1  
Punctospirifer sp. A  
 B1  
 Indet. terebratulid  
 A4, P1  
 Indet. solitary tetracorals  
 19  
 Indet. bryozoan  
 1  
 Crinoid plates and columnals  
 Indet. platyceratid gastropod  
 1  
  
 8248-17  
Marginatia sp. A  
 P2  
 Indet. productacean cf. Avonia sp.  
 P1  
Pseudosyrinx sp.  
 P4  
Spirifer sp.  
 B1  
 Indet. terebratulid  
 A1  
 Crinoid plates and columnals  
  
 Indet. trilobite fragment  
 1  
  
 8248-25  
Leptagonia cf. analoga  
 \_2  
Productina sampsoni  
 P3  
Rhytiophora sp. A  
 P3  
Shumardella obsolescens  
 A2  
Paraphorhynchus sp. A  
 A1  
Crurithyris parva  
 P1  
Syringothyris halli  
 A1  
Cyrtospirifer lator  
 A1, P5, B1  
 Indet. solitary tetracoral  
 1  
  
 8248-27  
Schizophoria? sp.  
 \_1  
Productina sp.  
 P2  
 Indet. stenoscismatacean?  
 \_1  
 Indet. trepostome bryozoan  
 Crinoid plates and columnals  
  
 8248-30 (float)  
Rhipidomella tenuicostata  
 A2, \_1  
Leptagonia sp.  
 A1, P1, B1  
 Indet. chonetacean  
 P2  
Rhytiophora? sp.  
 P1  
Cleiothyridina cf. glenparkensis  
 A2  
Crurithyris parva  
 A1  
Orbinaria cf. pyxidata  
 A1

Indet. solitary tetracorals

4

Triboloceras diagonum

1

Indet. nautiloid cephalopod

1

8248-31

Schizophoria cf. chouteauensis

A1

Leptagonia cf. analoga

A2, P1

8248-35

Schizophoria cf. chouteauensis

A2

Rhipidomella tenuicostata

A4

Leptagonia cf. analoga

\_1

Productina sampsoni

P2

Ptychomaletoechia (?) sp. A

A1

Cleiothyridina cf. glenparkensis

A2

Composita cf. globosa

A1

Tylothyris sp. A

P1

Syringothyris halli

A1, P1, \_1

Cyrtospirifer latior

A3

Brachythyris fernglenensis

A3

Indet. lamellose spiriferacean

\_1

Cleistophora typa gorbyi

1

Indet. trepostome bryozoan

Indet. fenestellid bryozoan

Indet. bryozoan

1

Crinoid plates and columnals

Indet. platyceratid gastropods

2

## LOCALITY 8249

8249-8Schizophoria cf. chouteauensis

P1, B1

Rhytiophora? sp.

A1

Cyrtospirifer latior

A3, B1

Indet. solitary tetracorals

3

Crinoid plates and columnals

Indet. ostrocode

1

8249-10Leptagonia cf. analoga

A1

Indet. orthotetid

P1

Cyrtospirifer latior

B1

Indet. solitary tetracoral

1

Crinoid plates and columnals

8249-11

Crinoid plates and columnals

8249-12

Indet. solitary tetracorals

2

Indet. bryozoan

1

Crinoid plates and columnals

Indet. bivalve

1

8249-13Brachythyris suborbicularis

P1

8249-15Marginatia sp. A

P1

Pseudosyrinx? sp.

B1

Spirifer sp.

P7

Brachythyris suborbicularis

P1

Indet. spiriferacean

P1

Crinoid plates and columnals

## LOCALITY 9130

9130-8Rhytiophora cf. calhounensis

A1, P5

Athyris cf. lamellosa

A4, P1

Cyrtospirifer latior

P1

Cyrtospirifer sp. A

P2

Indet. spiriferacean

1

Indet. gastropod

1

Indet. trilobite

1

9130-11 (float)

Rhynchopora sp. A

A1

Cleiothyridina cf. glenparkensis

A1

APPENDIX C

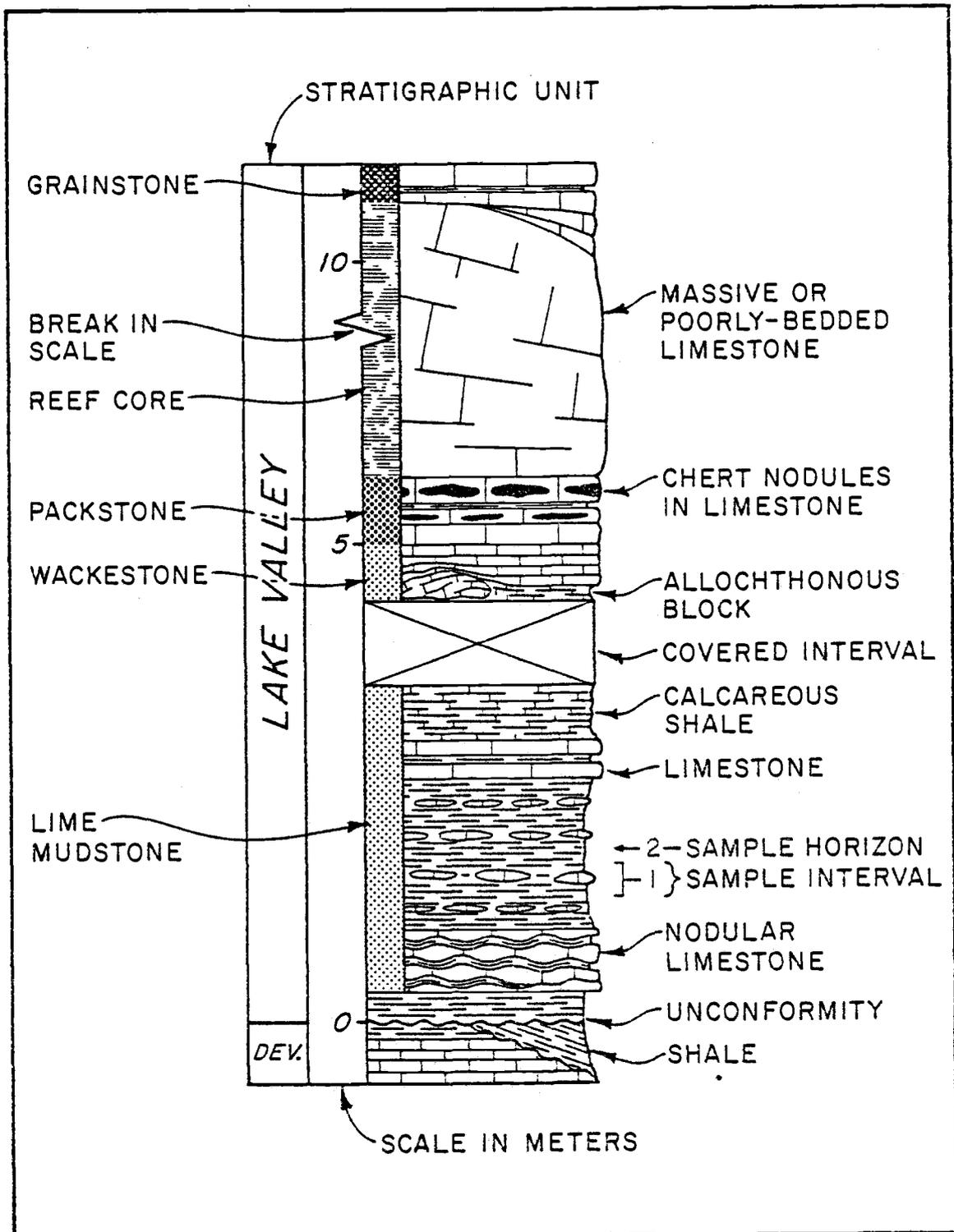
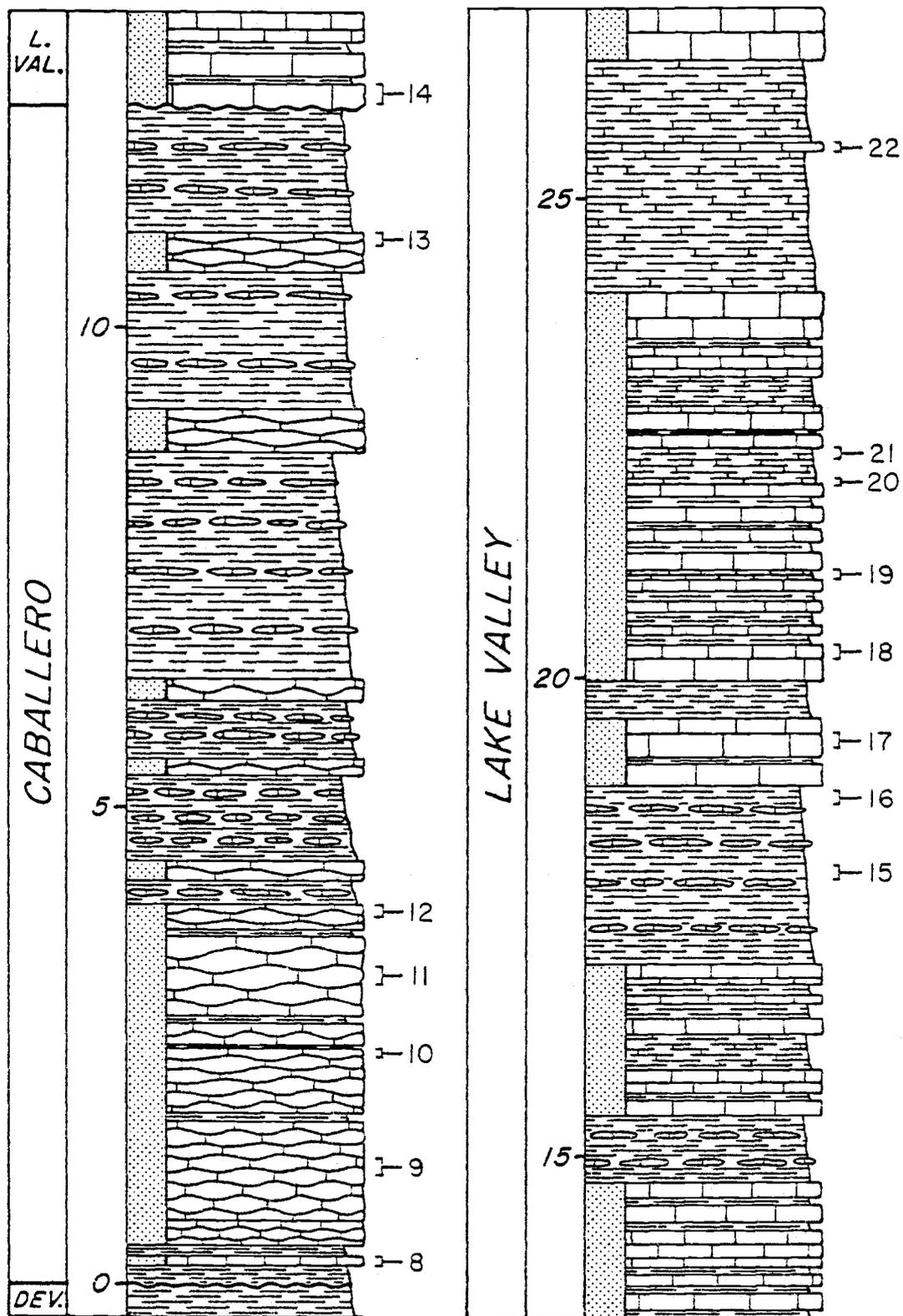
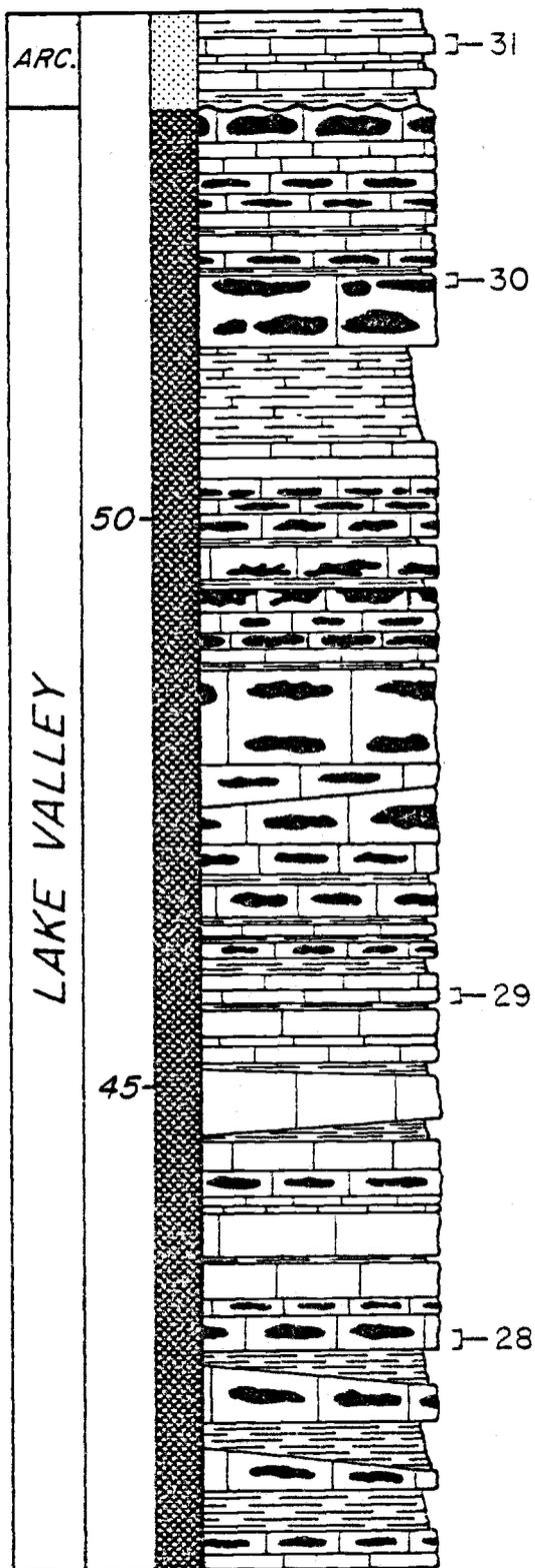
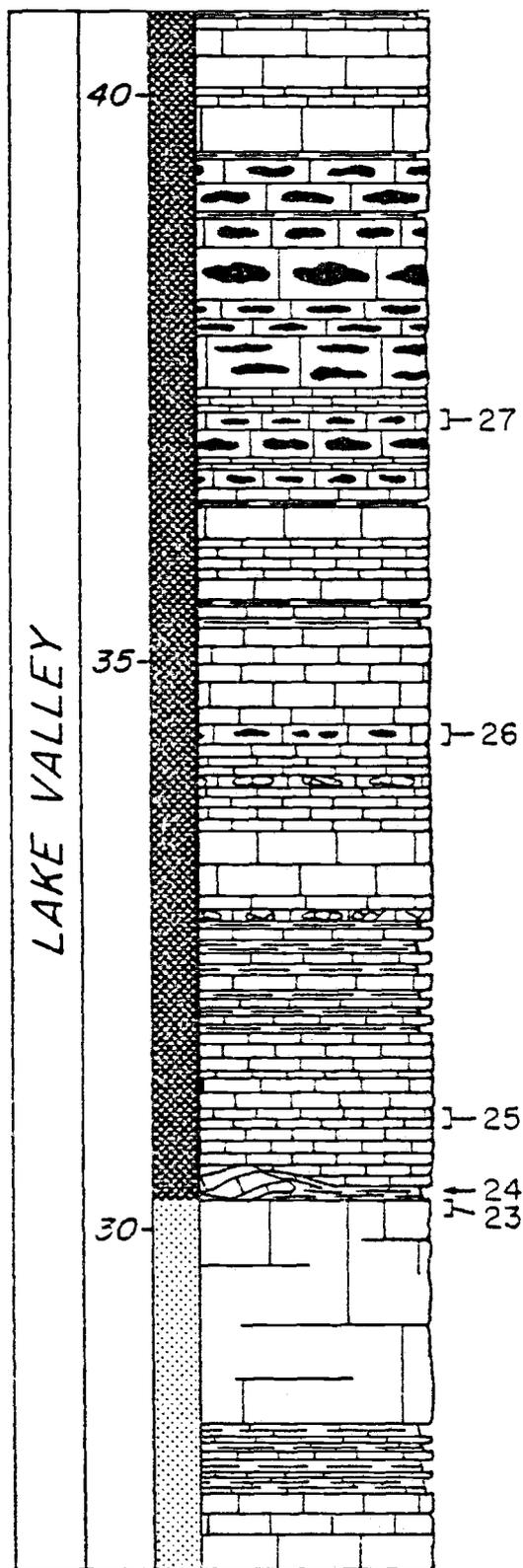
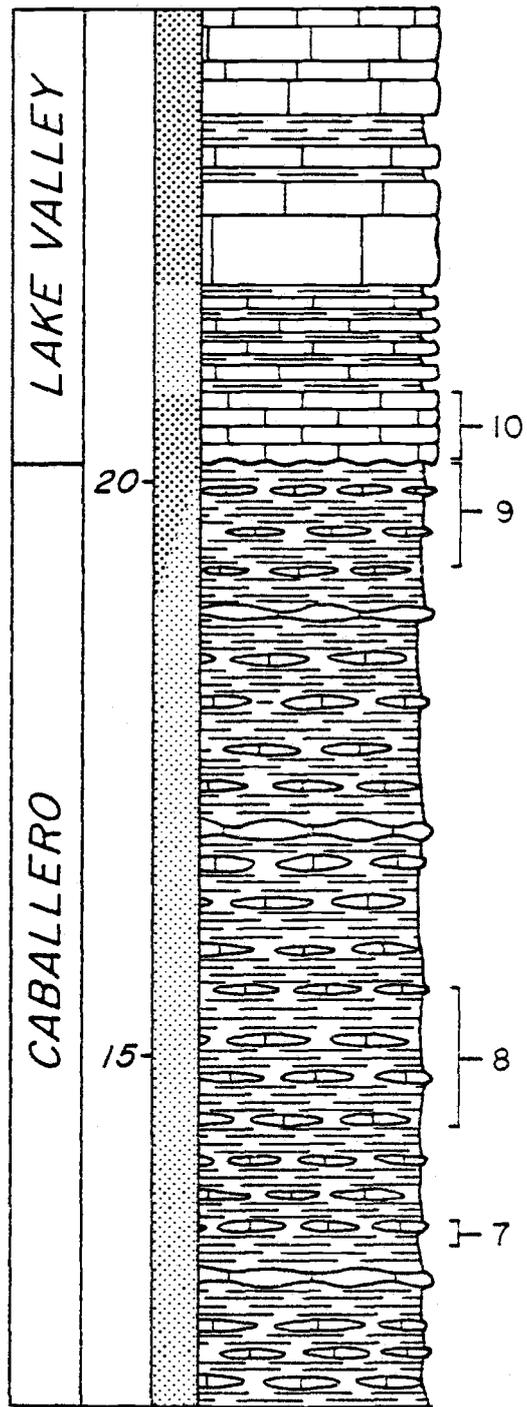
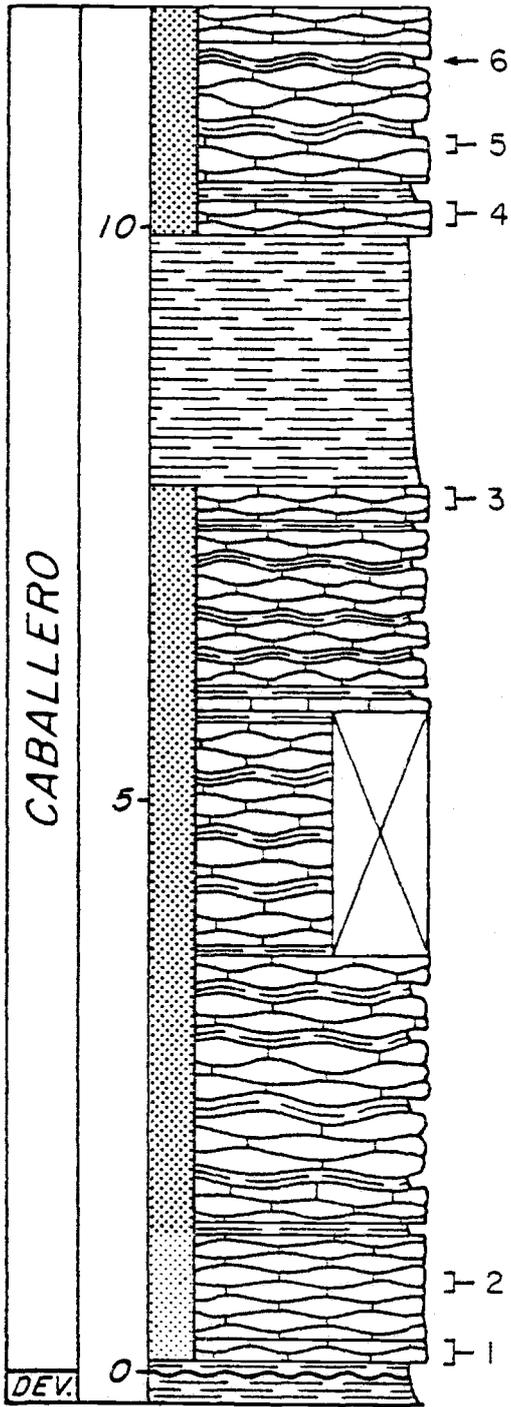


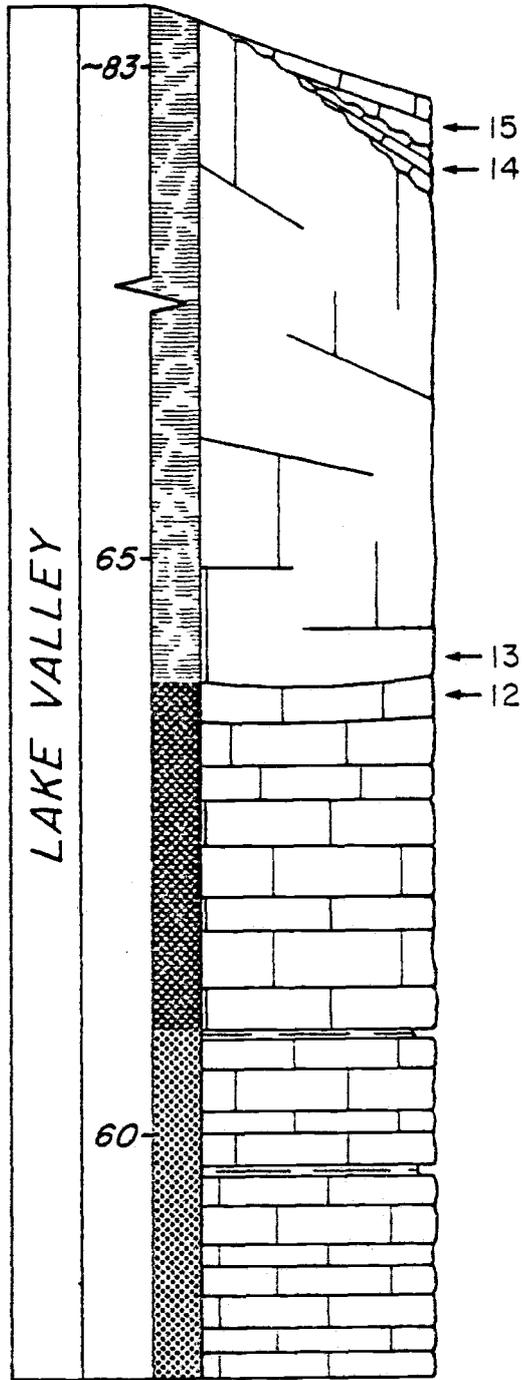
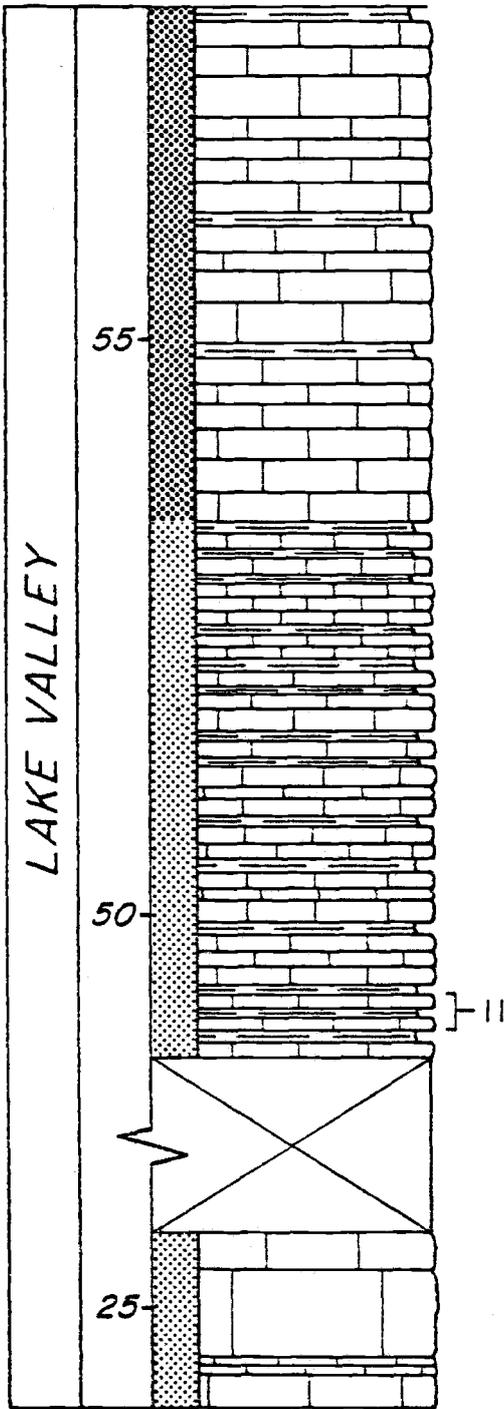
Figure 64. Legend to accompany columnar sections.

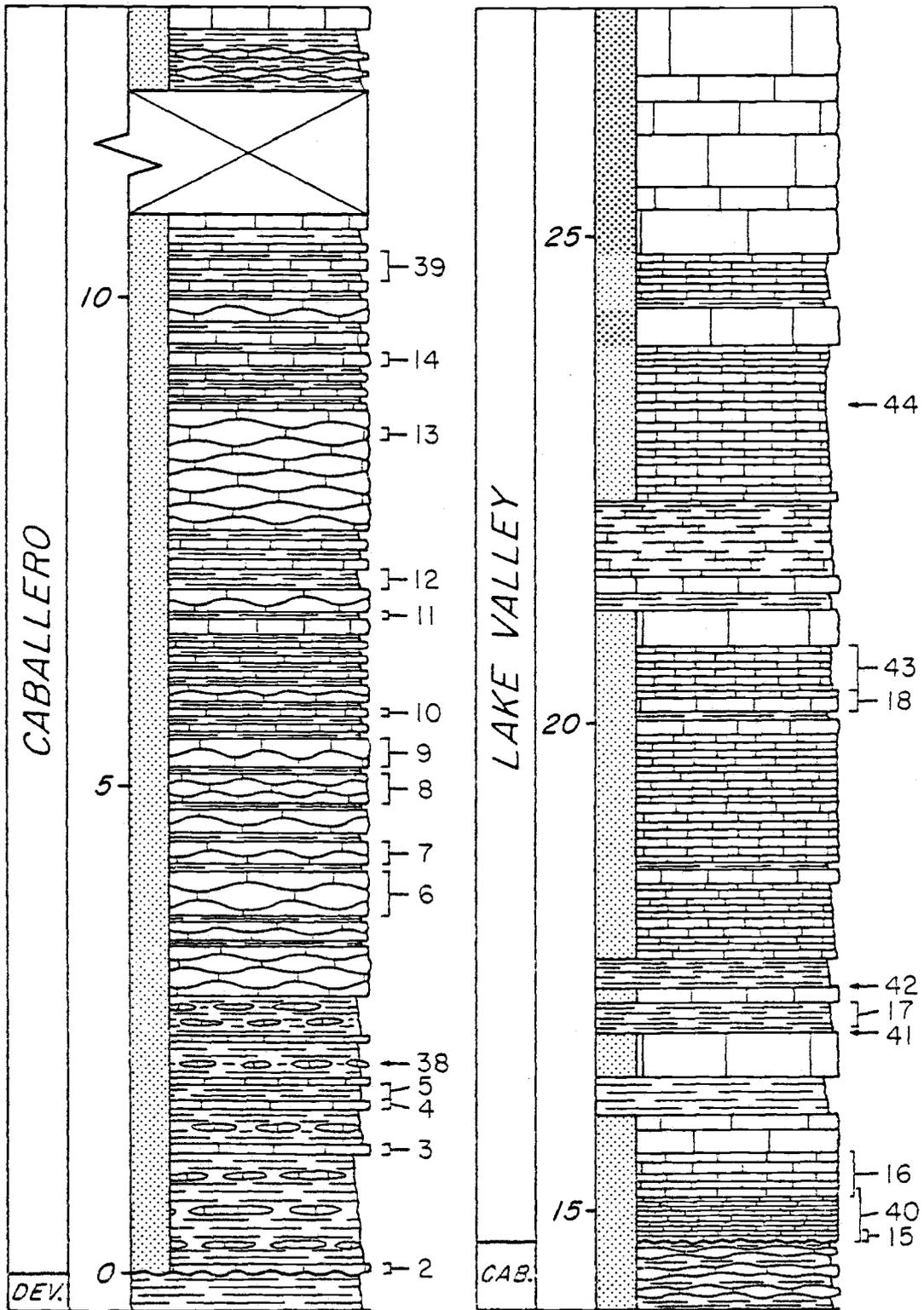


Locality 7719, Deadman Canyon Branch, Alamo Canyon, South Draw

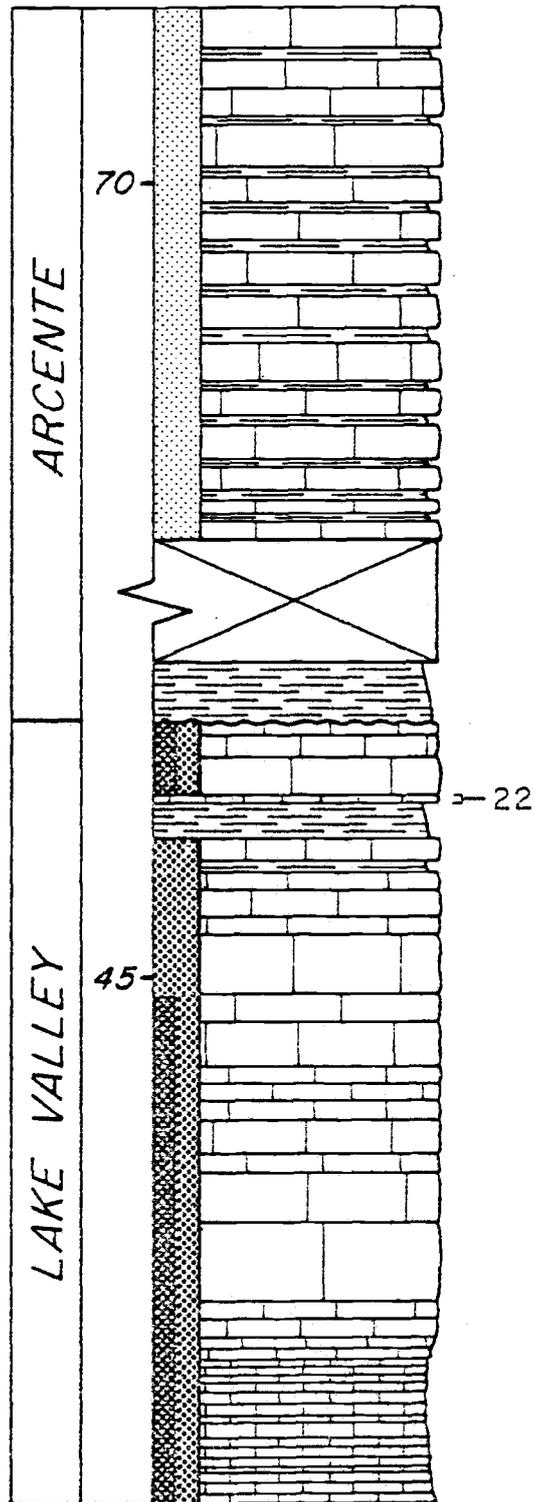
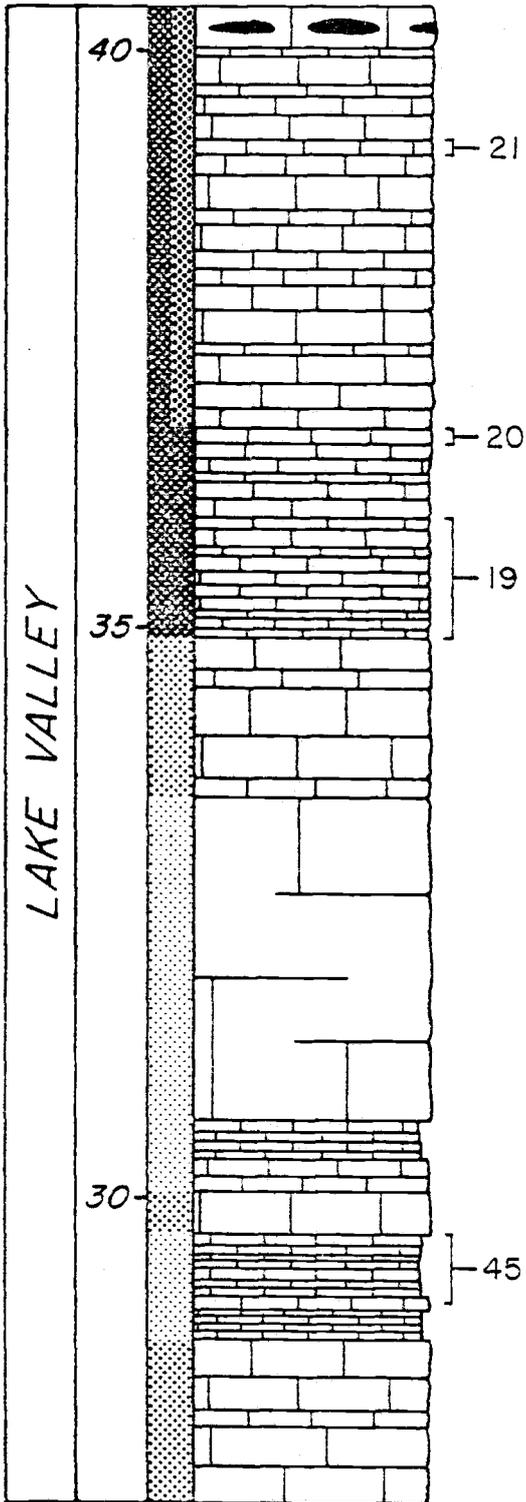


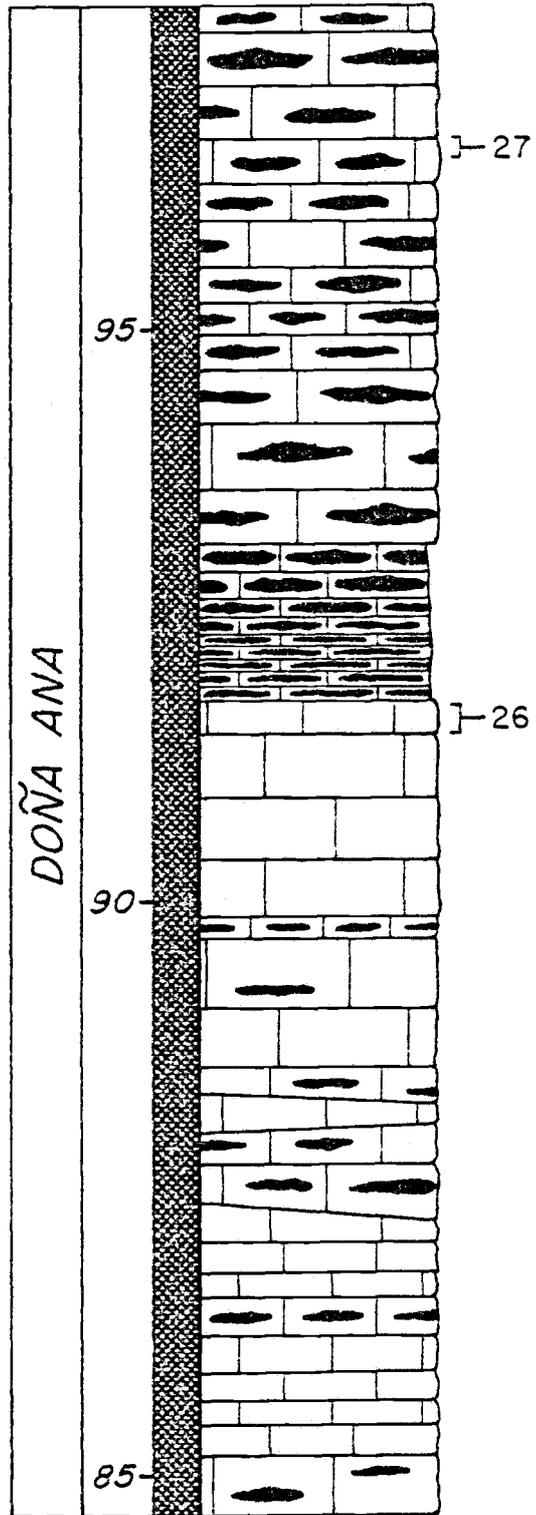
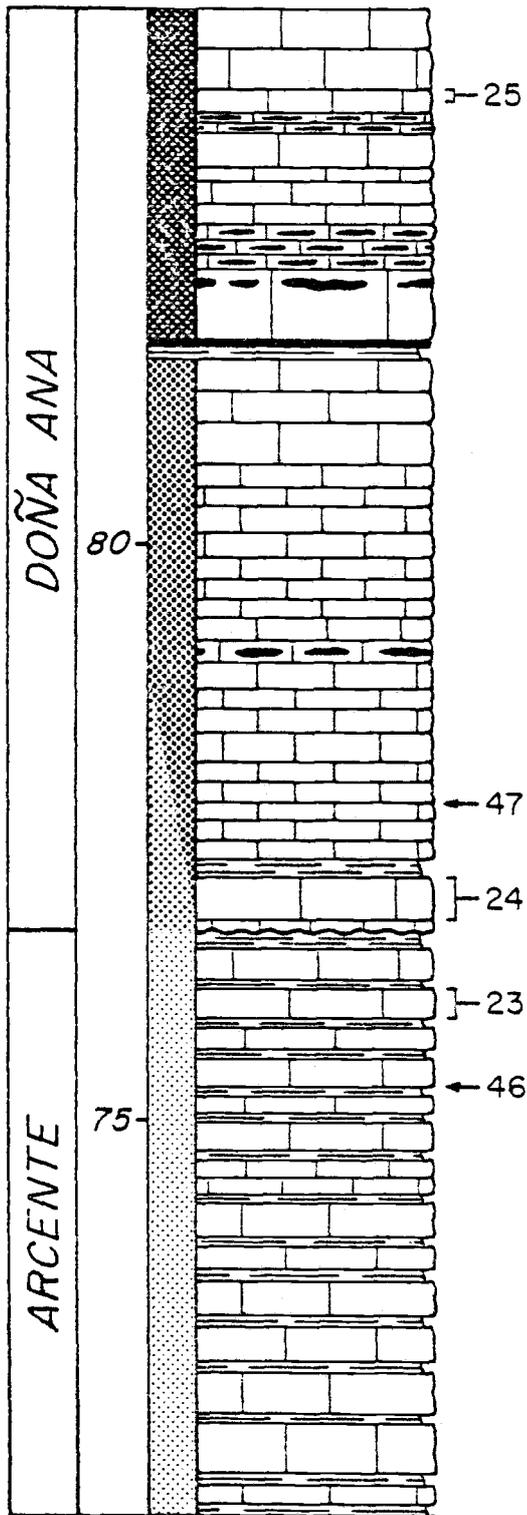


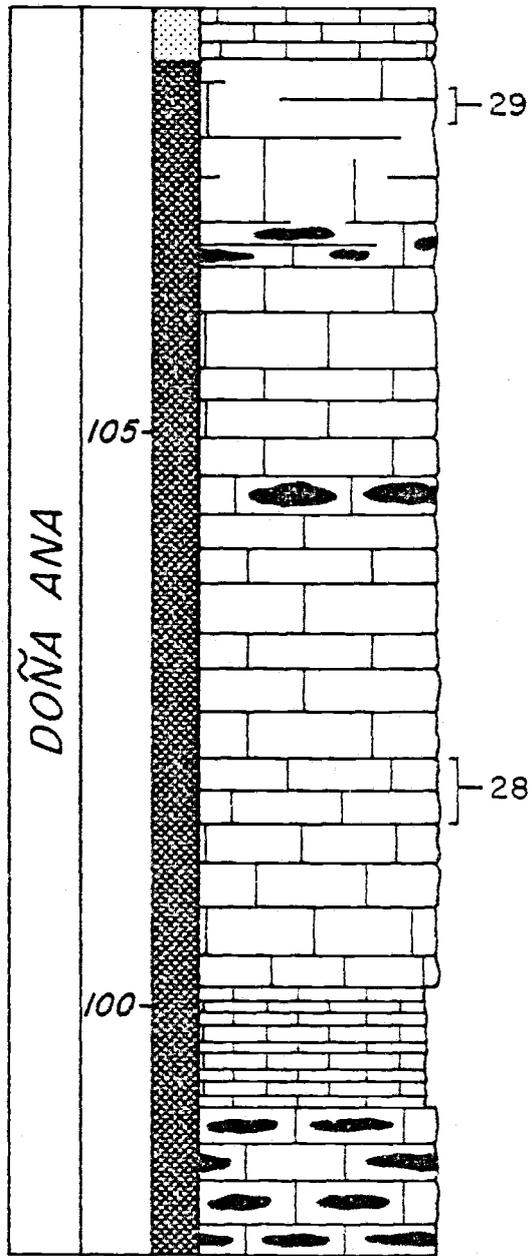


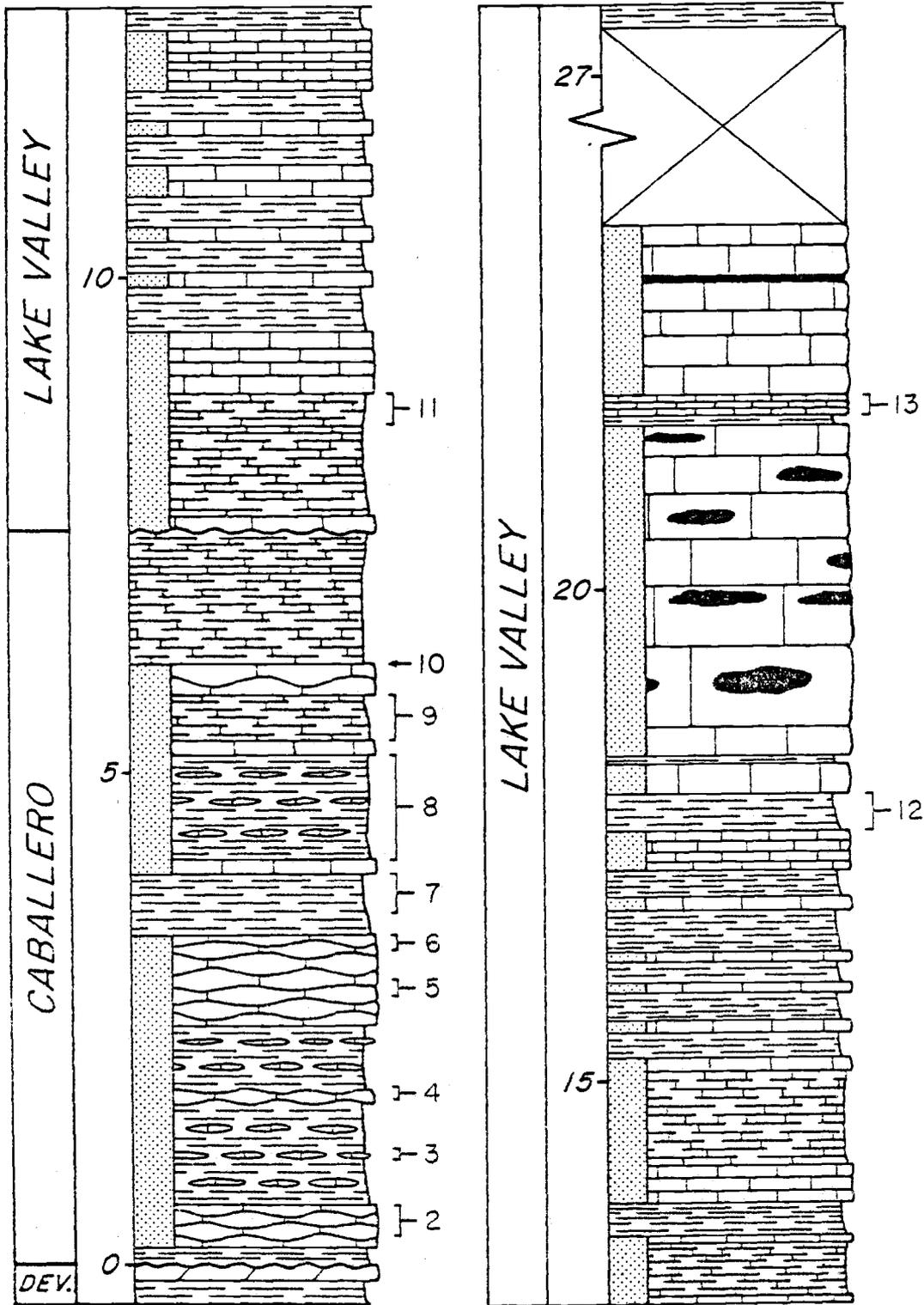


Locality 7721, Muleshoe Canyon, North Section



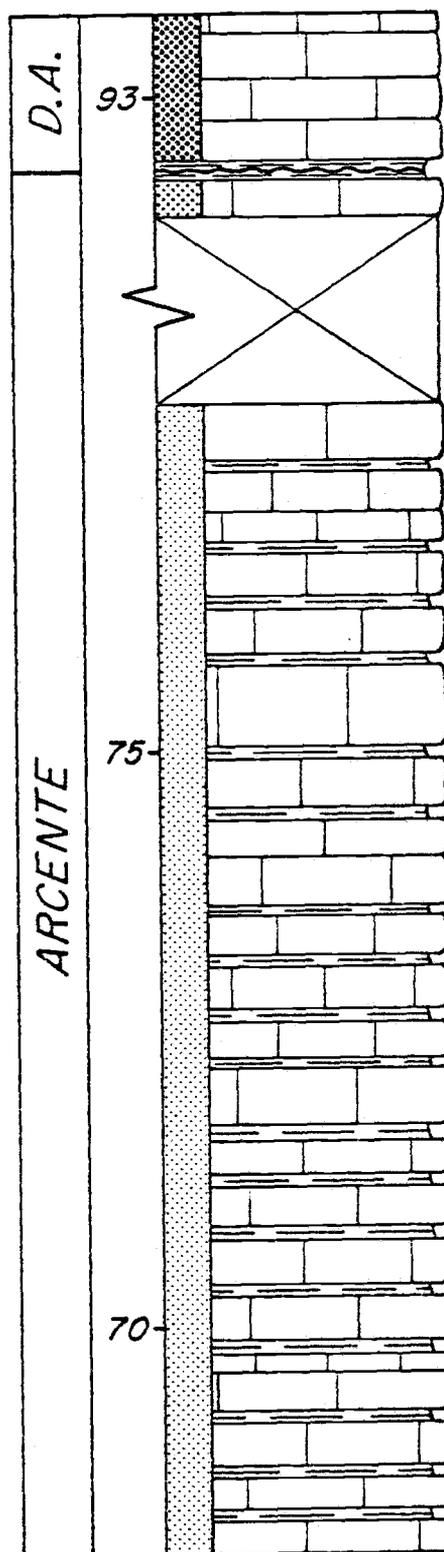
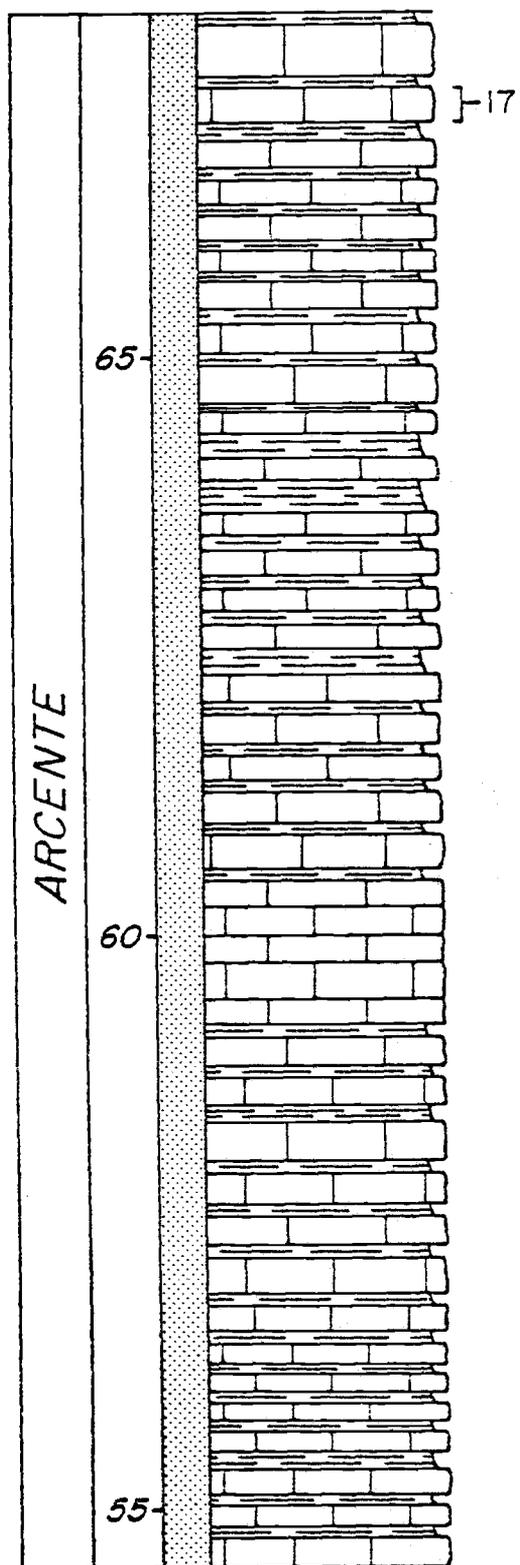


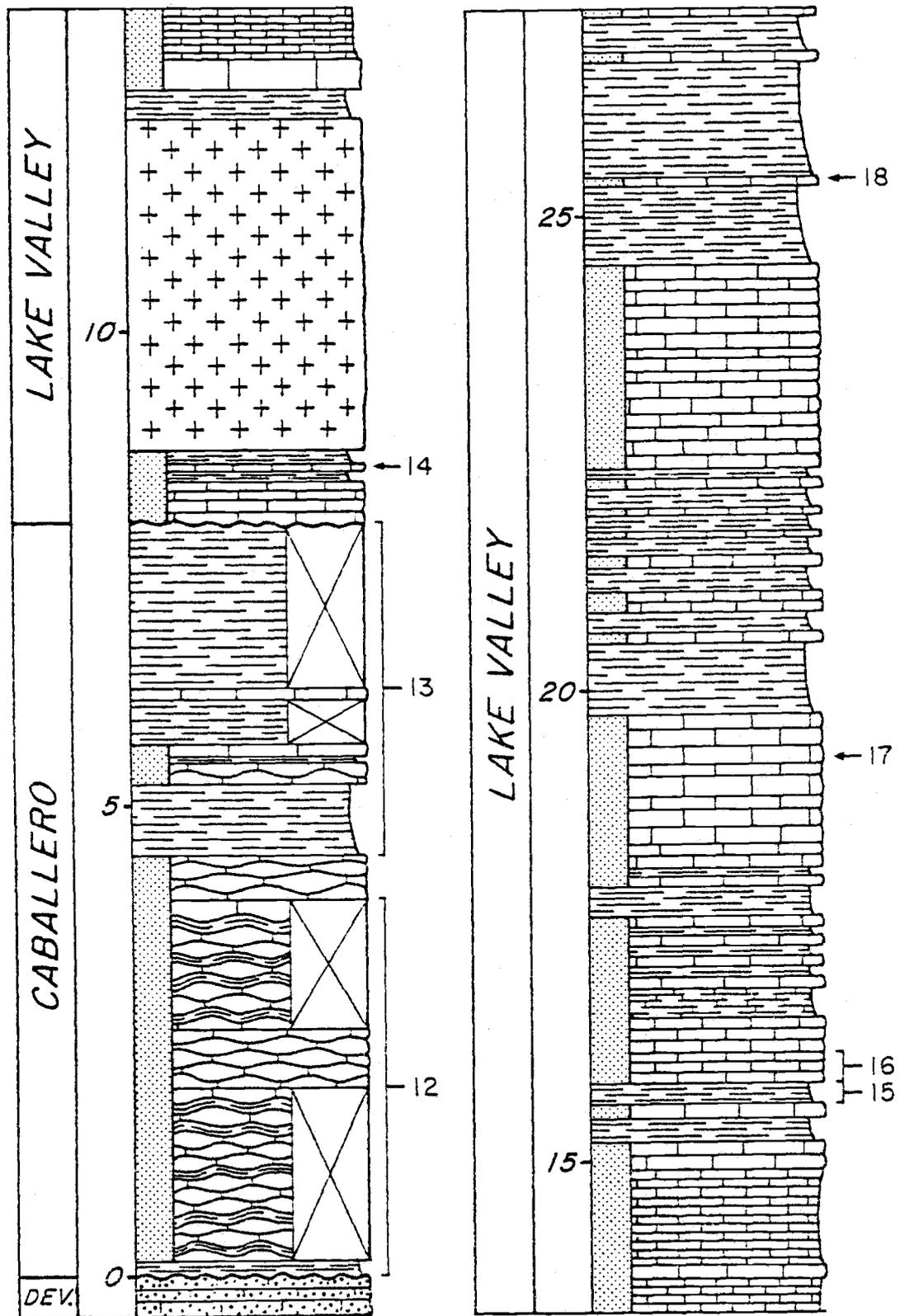




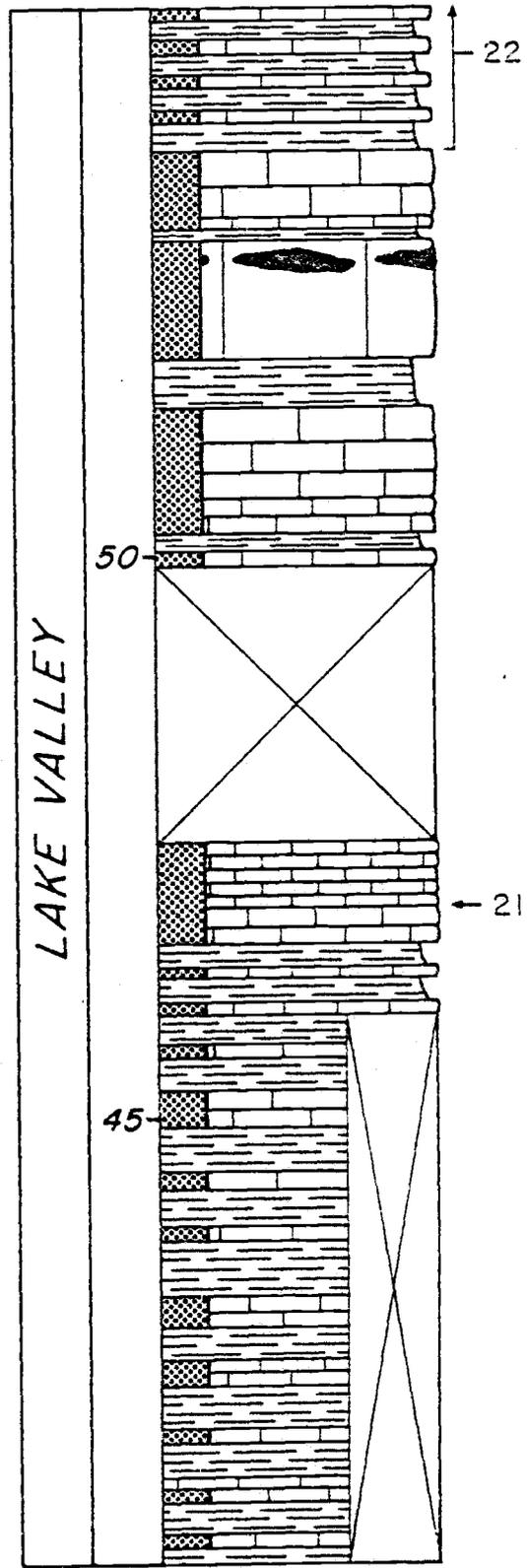
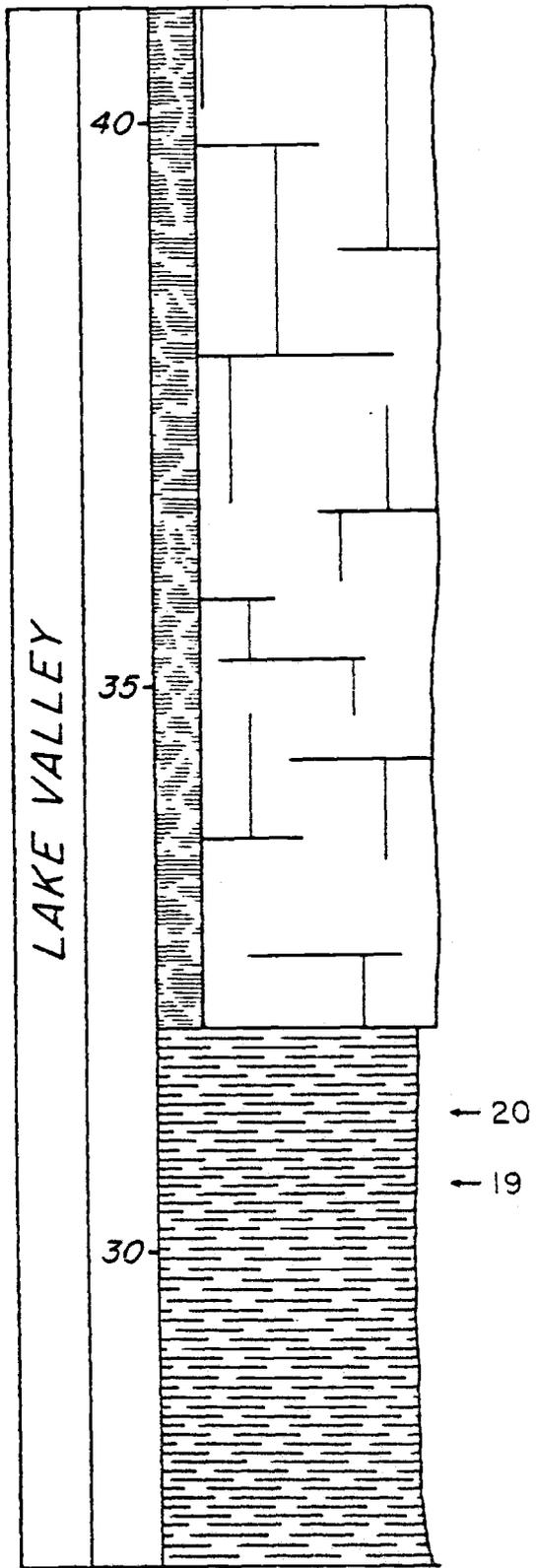
Locality 7722, Muleshoe South Section

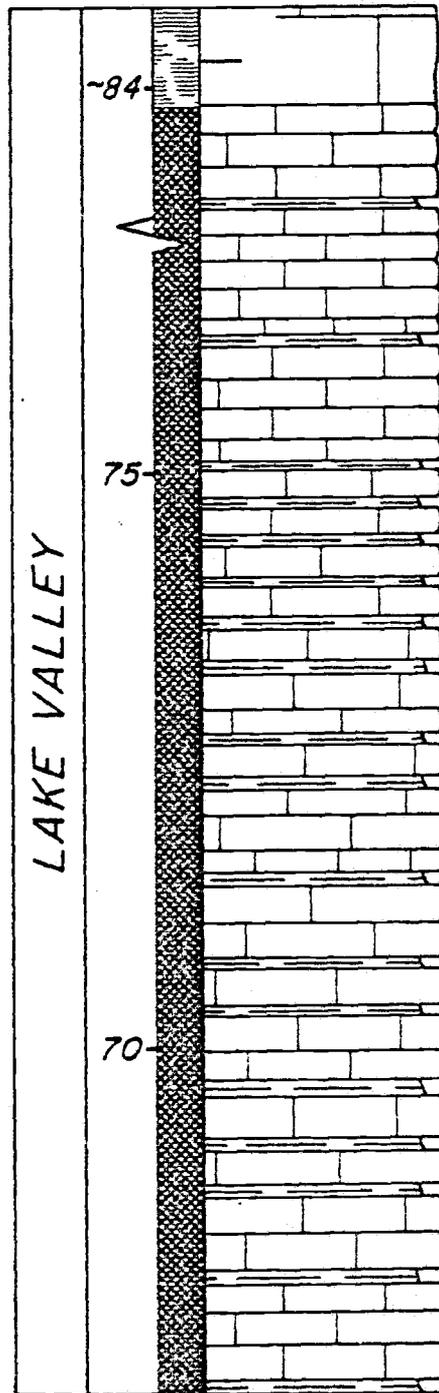
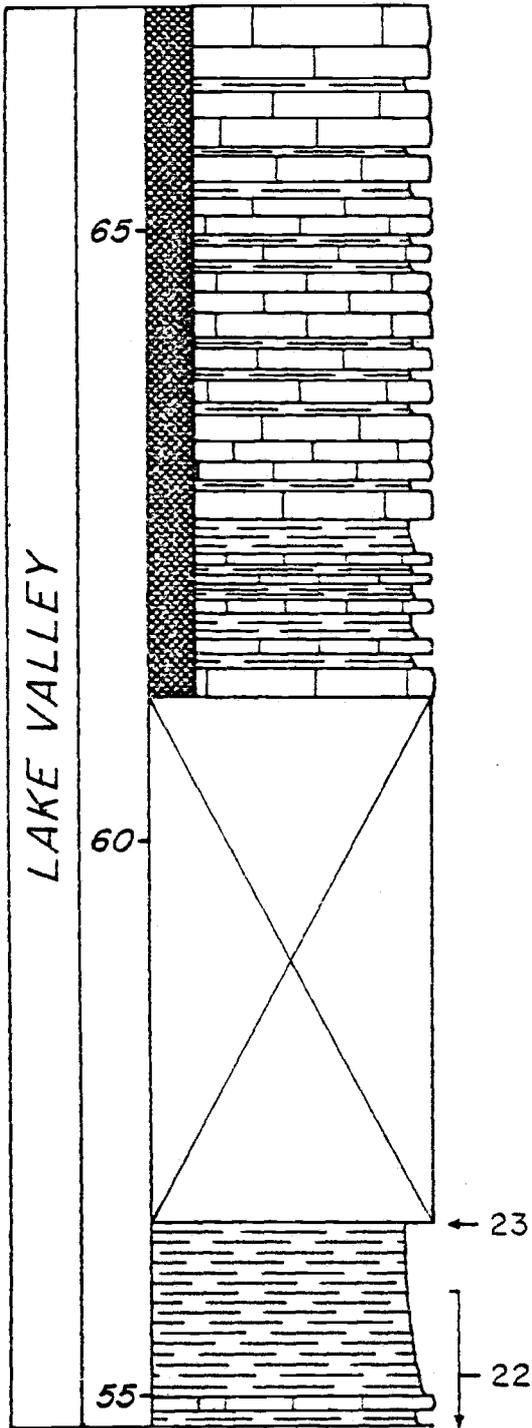


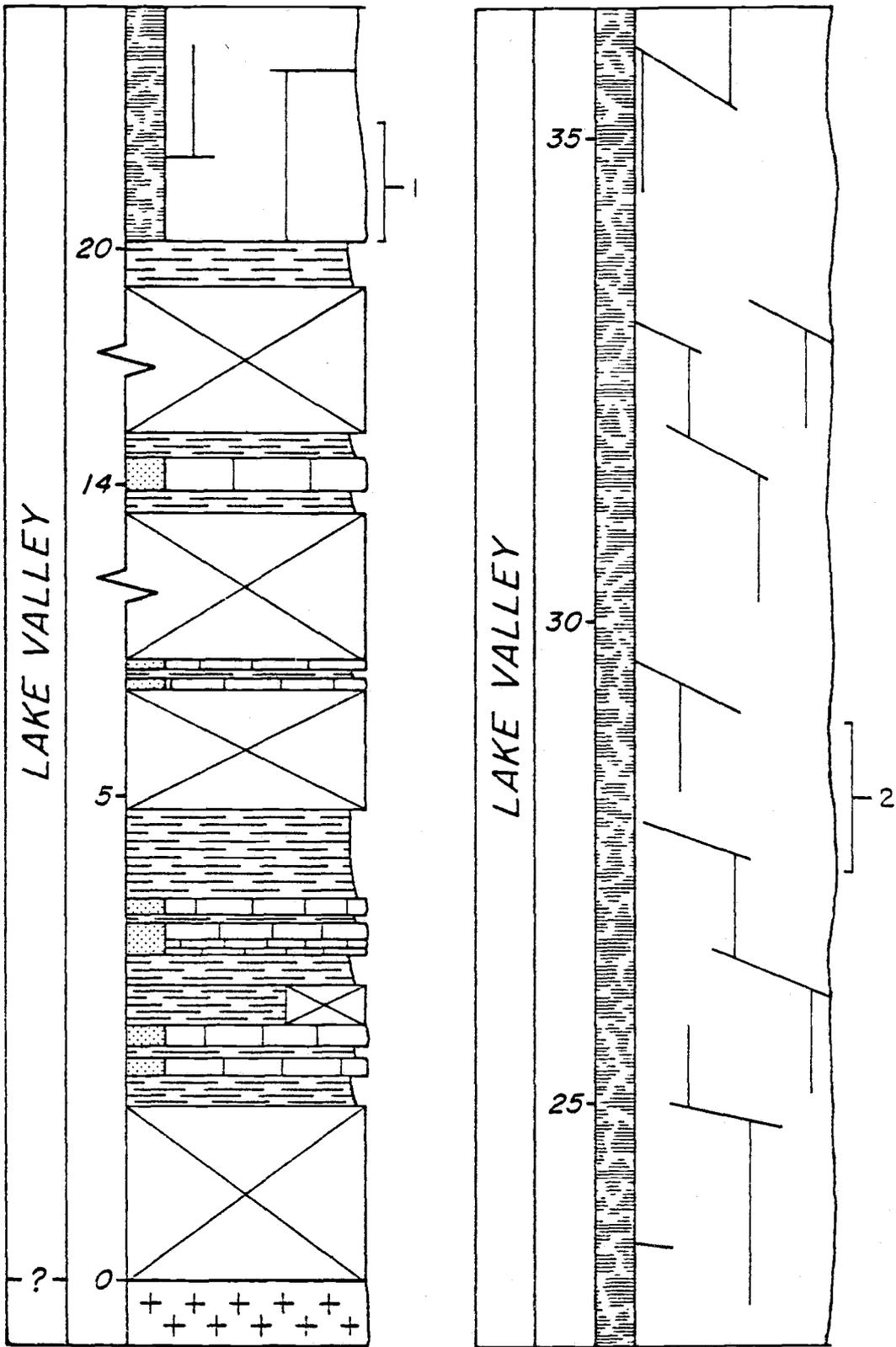




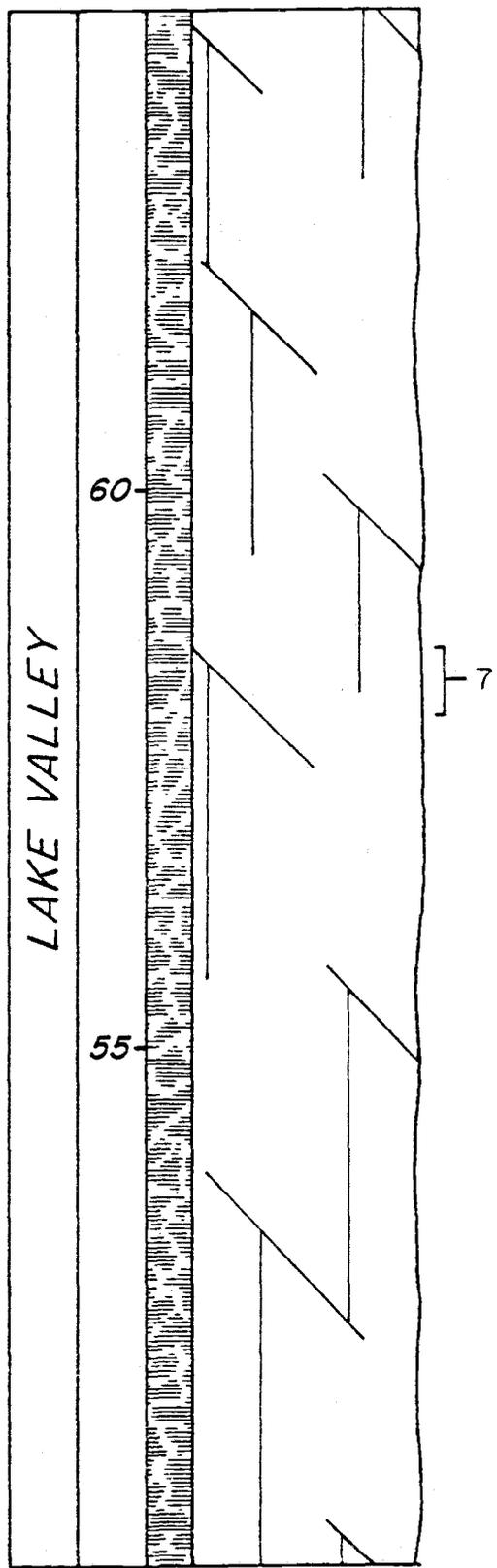
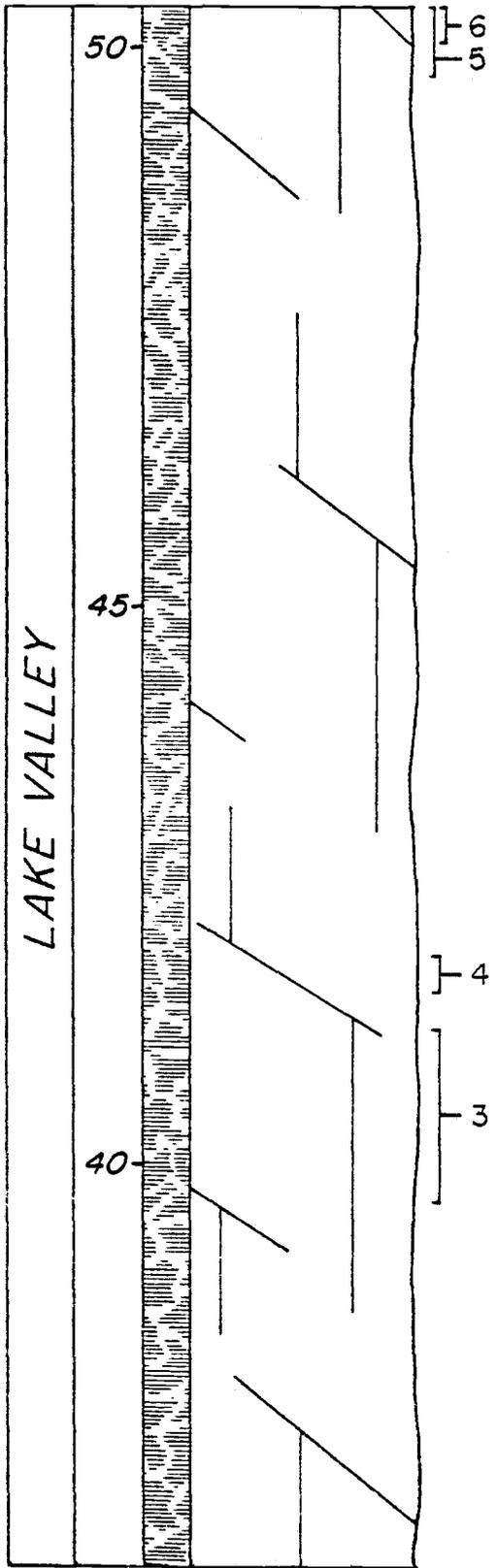
Locality 8242, Lower Little Sugarloaf Mound Section

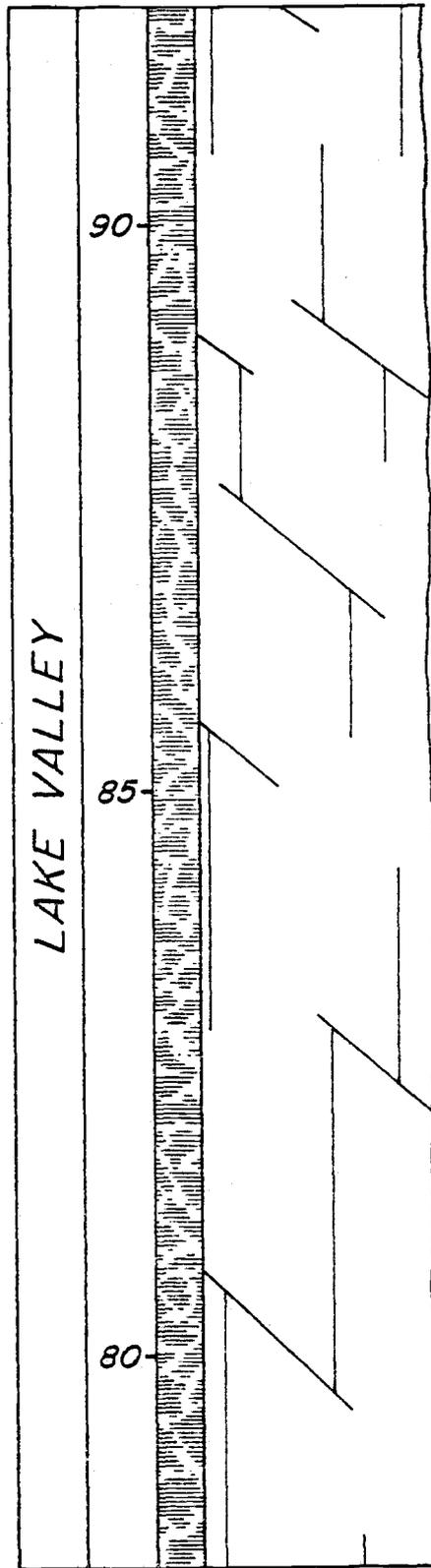
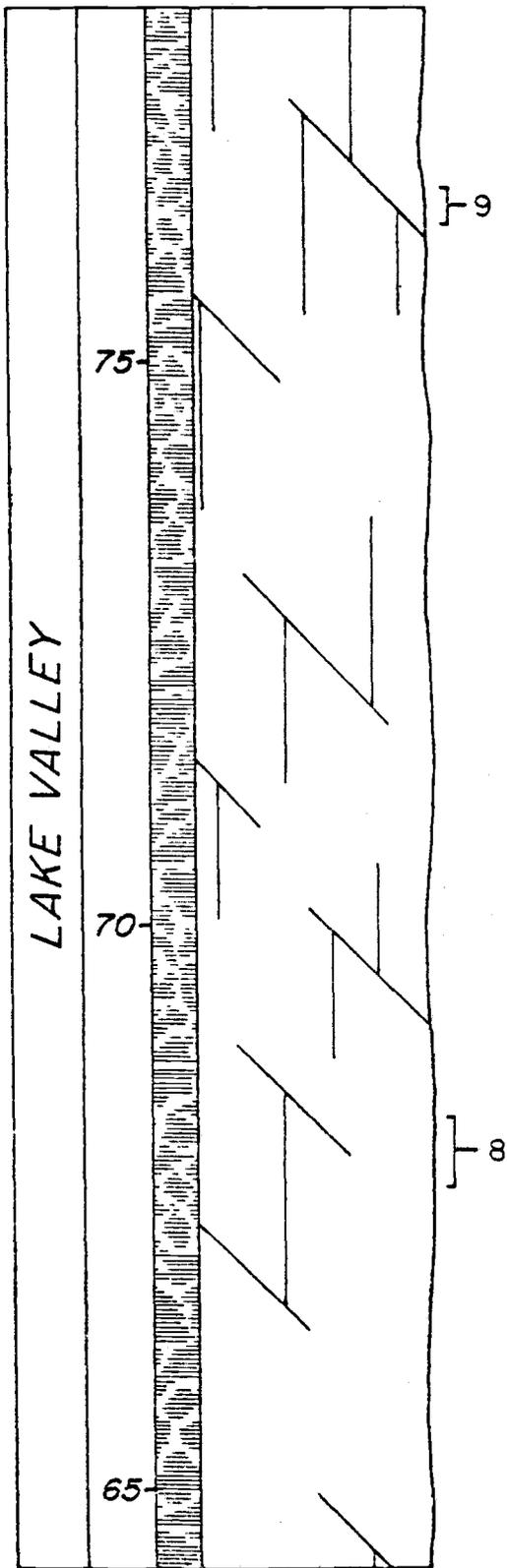


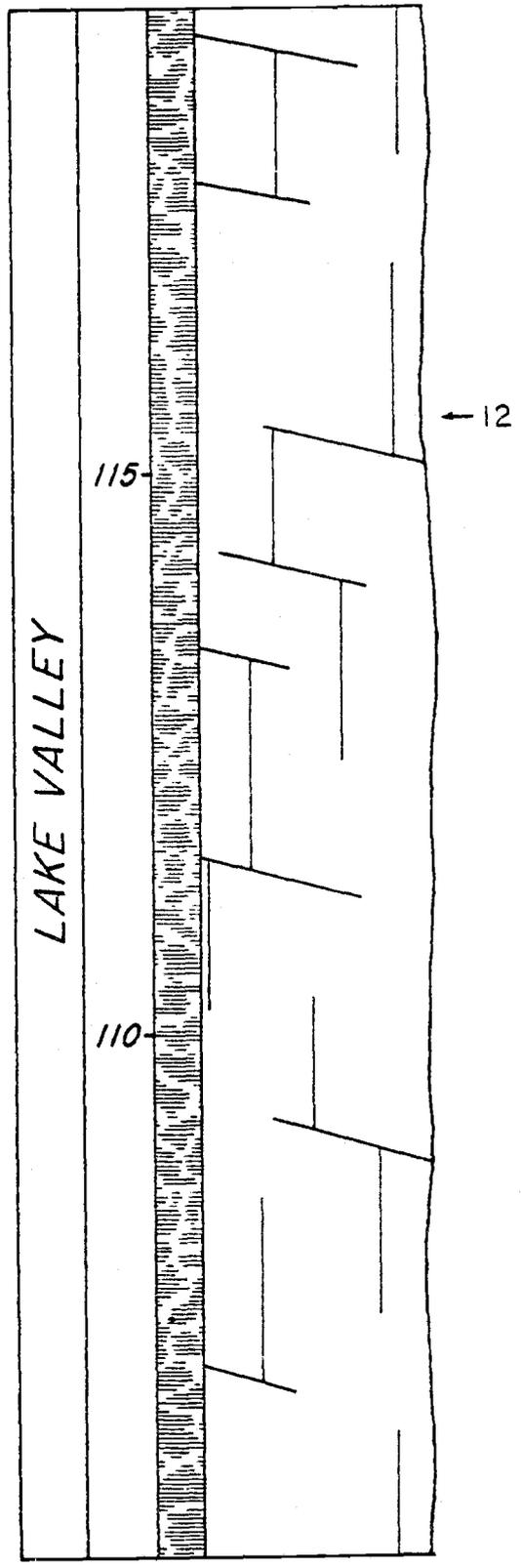
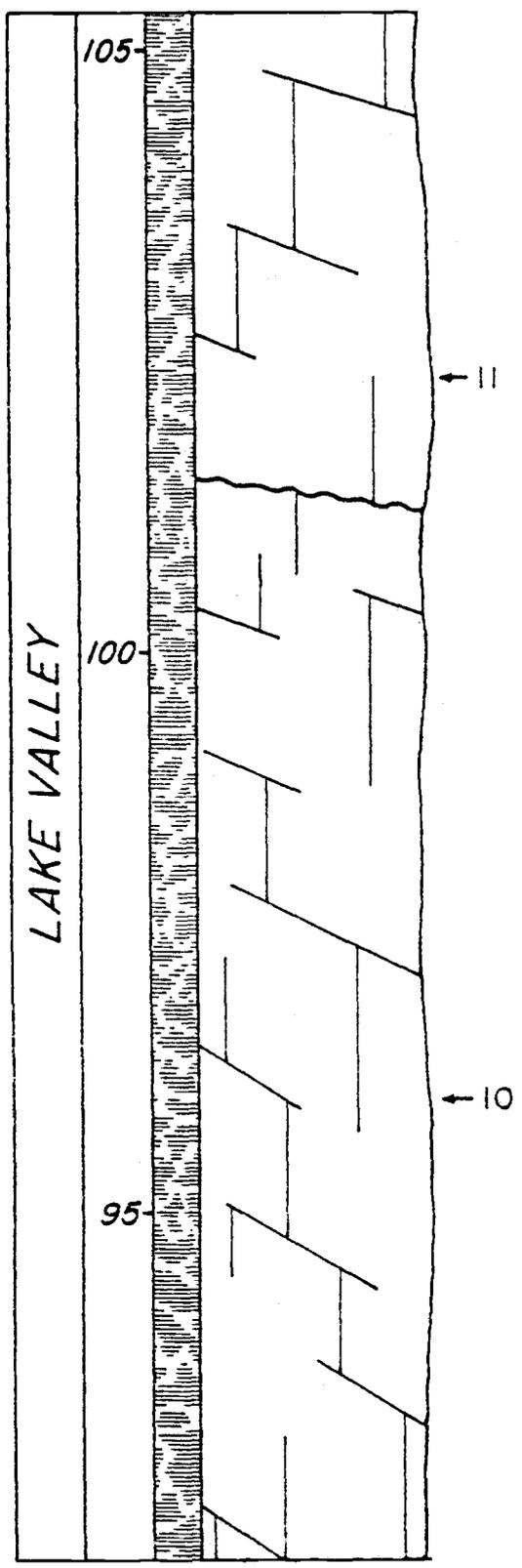


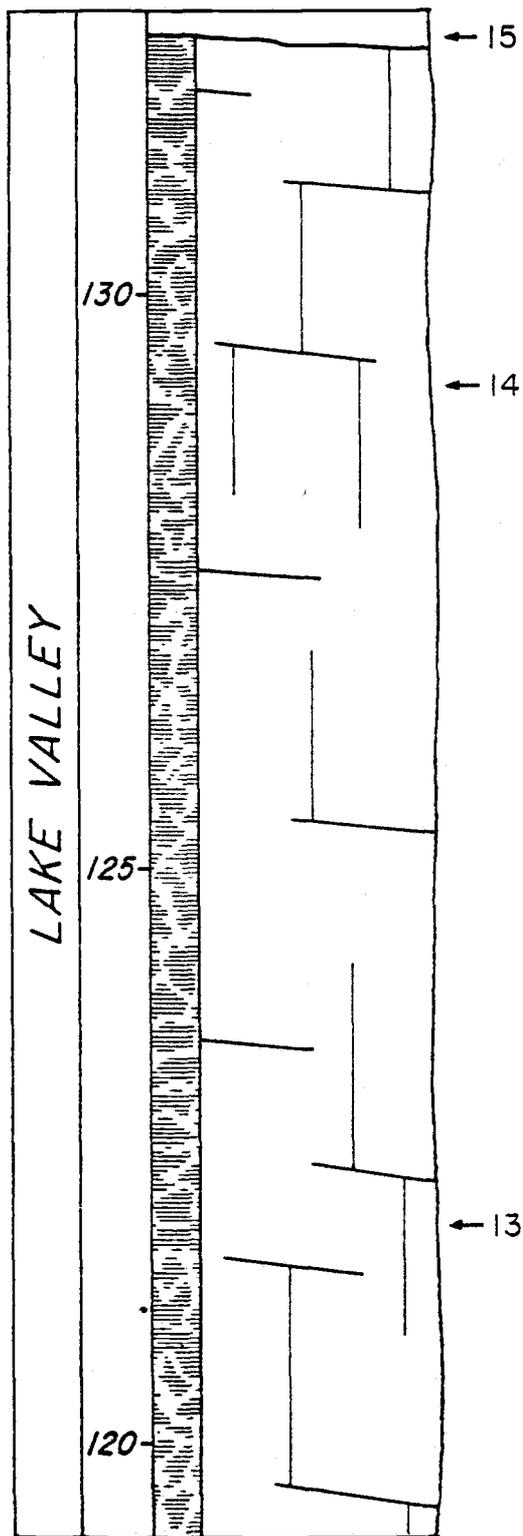


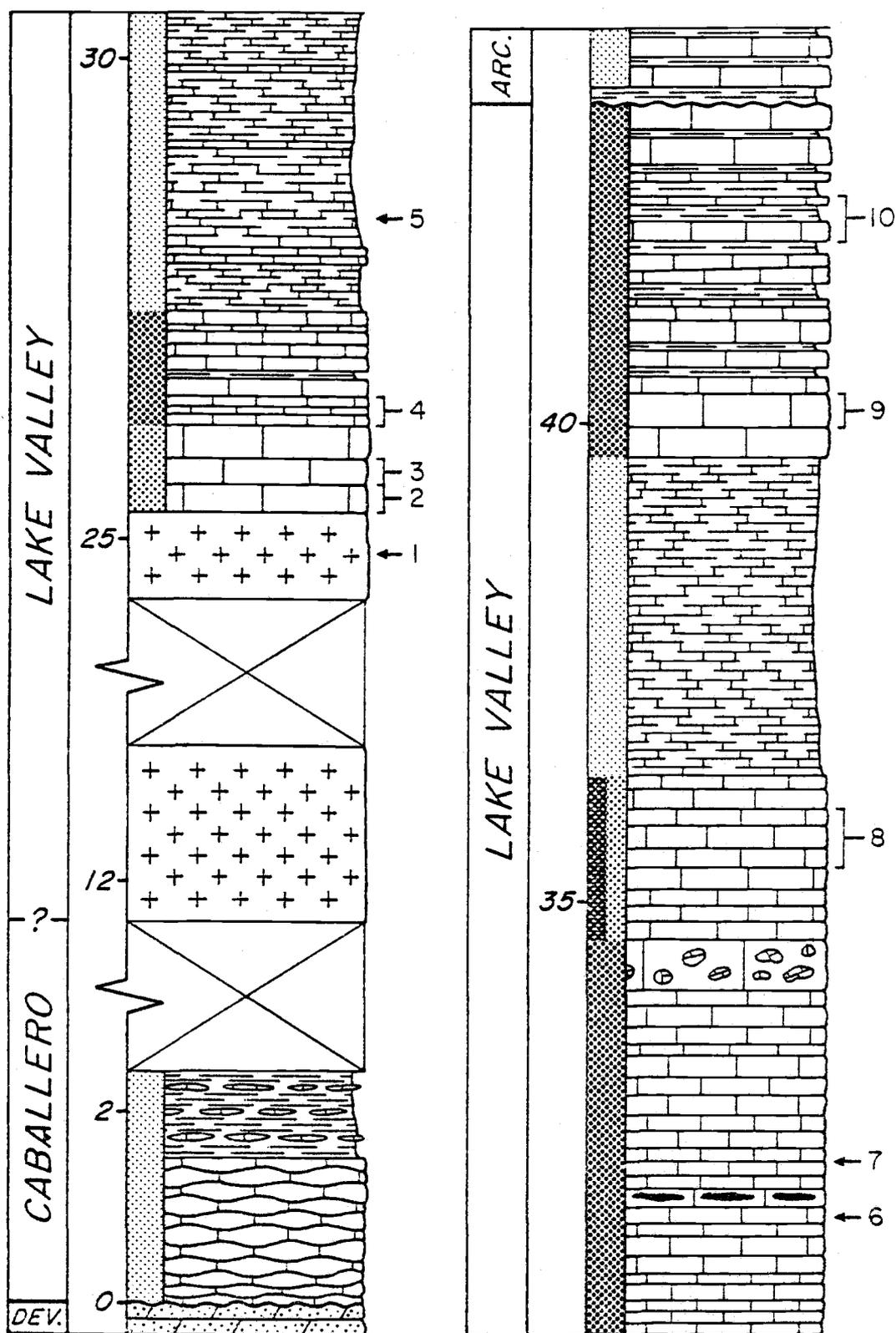
Locality 8243, Little Sugarloaf Mound Section



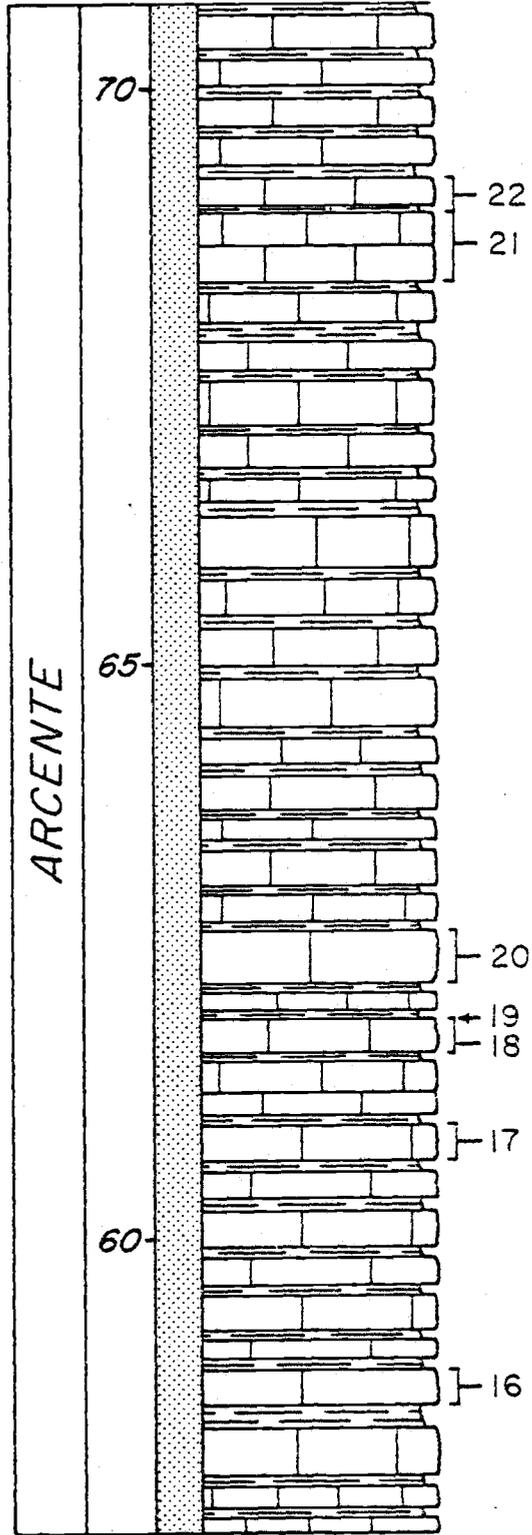
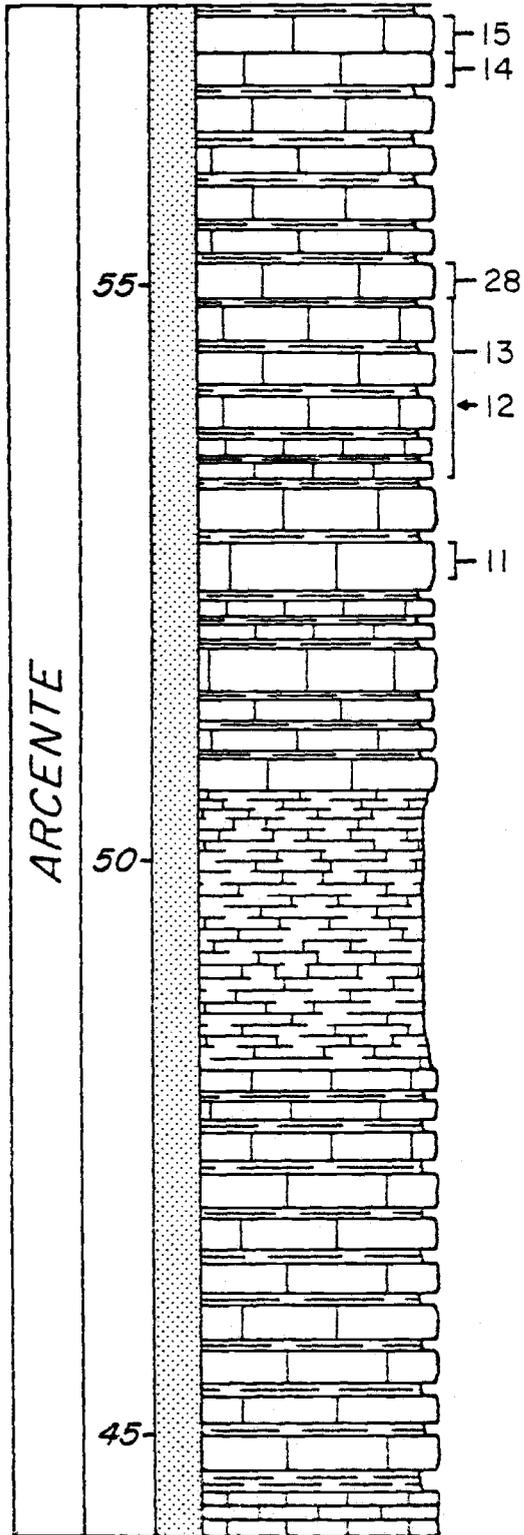


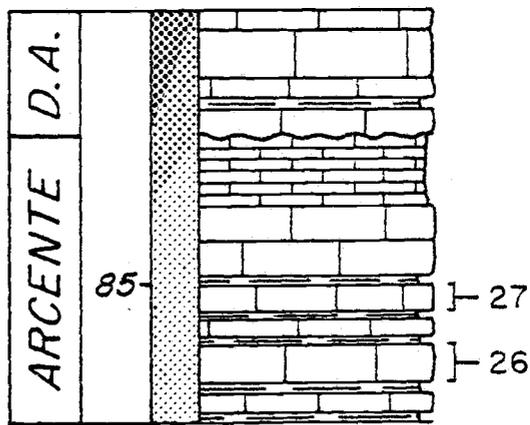
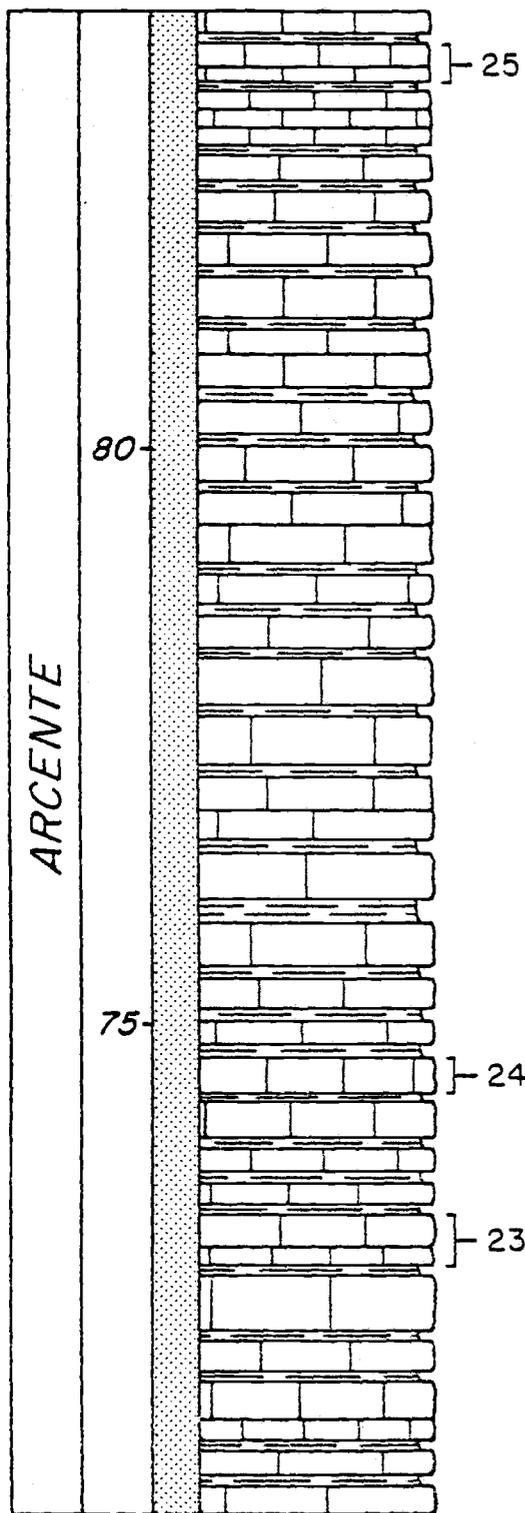


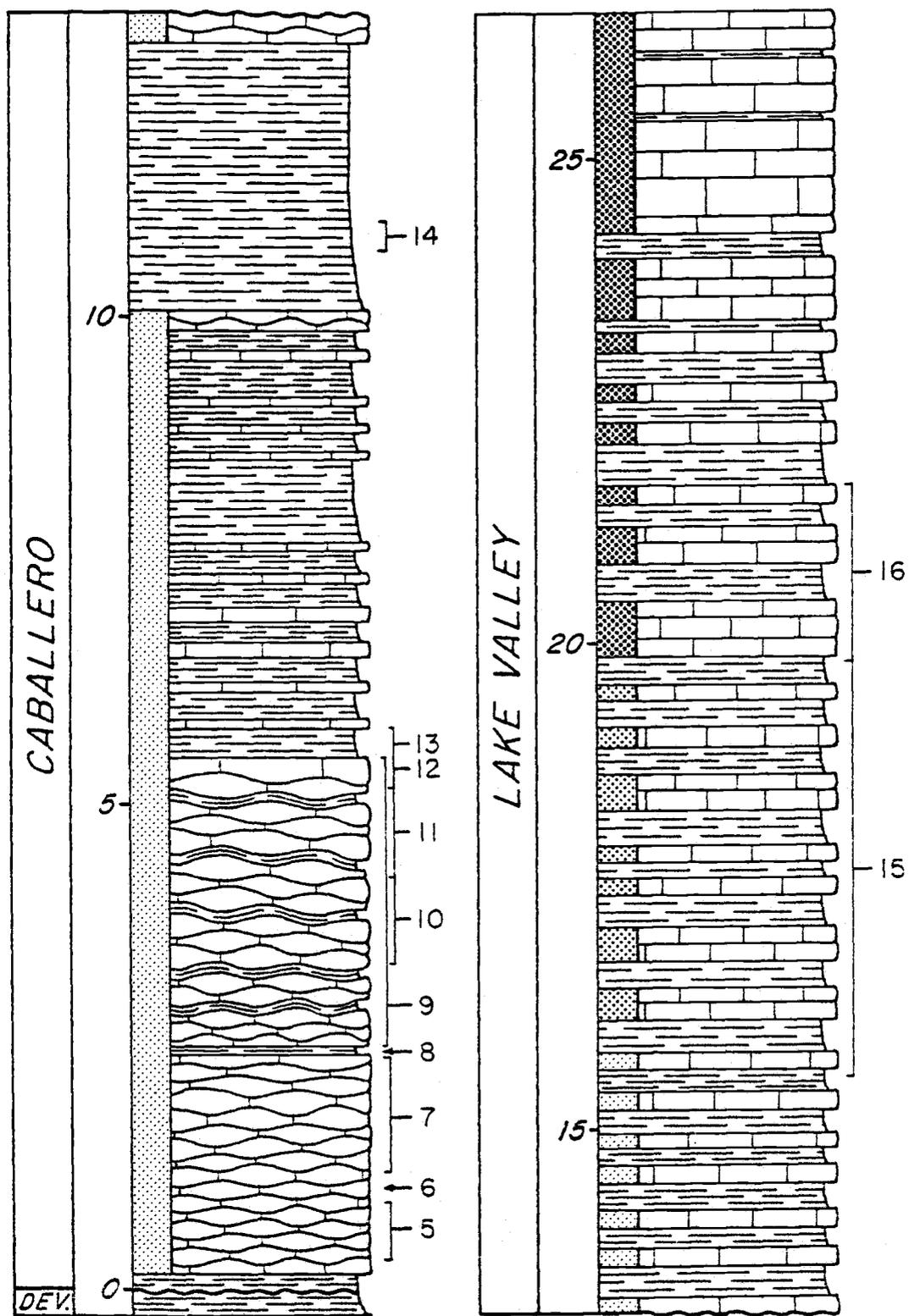




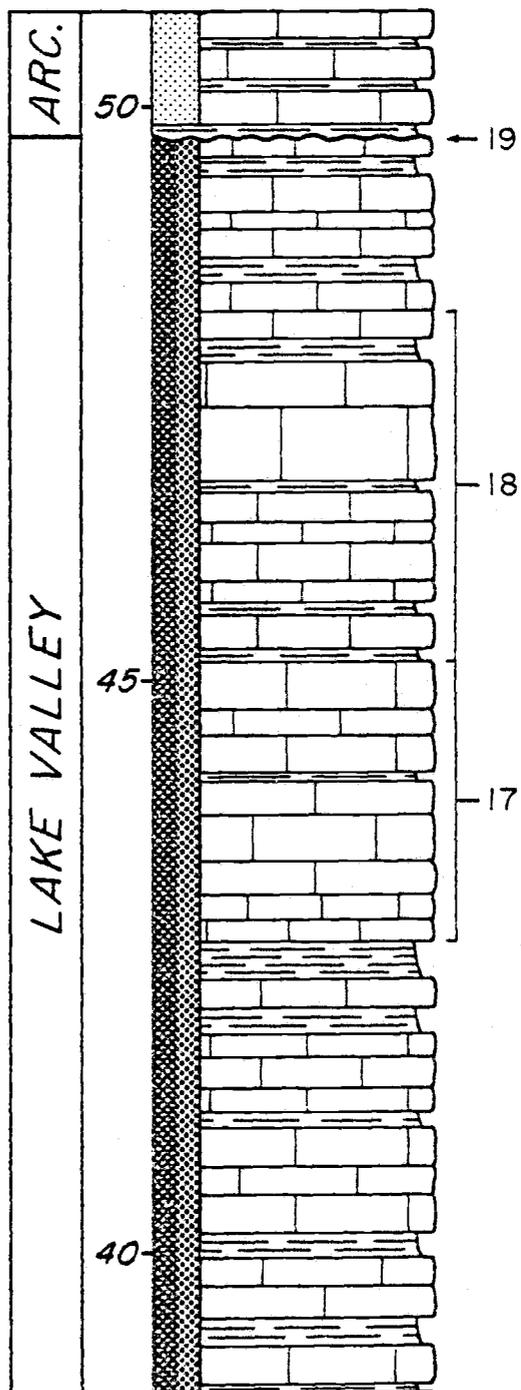
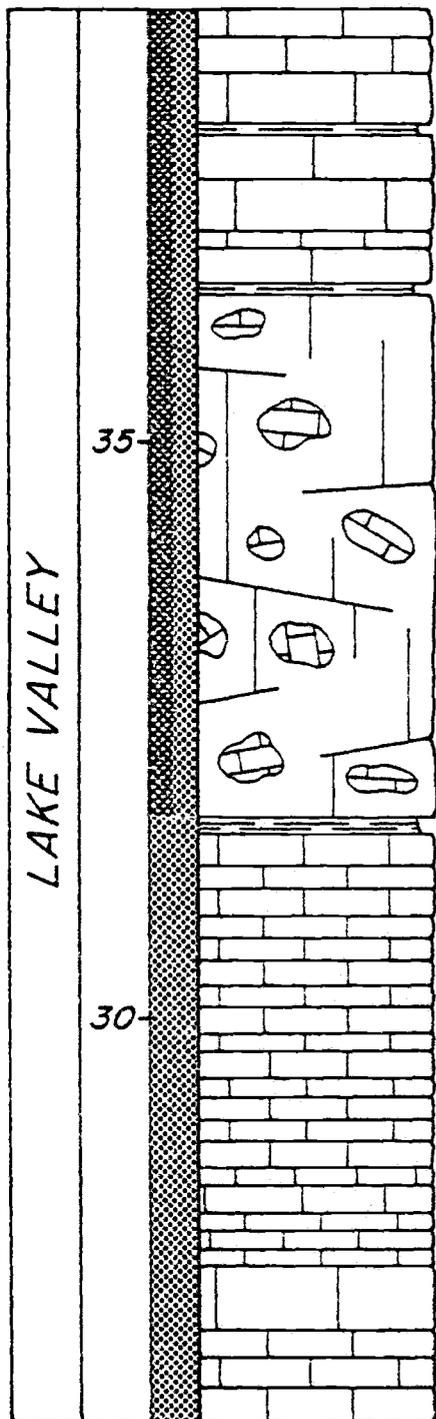
Locality 8244, South Little Sugarloaf Mound Section



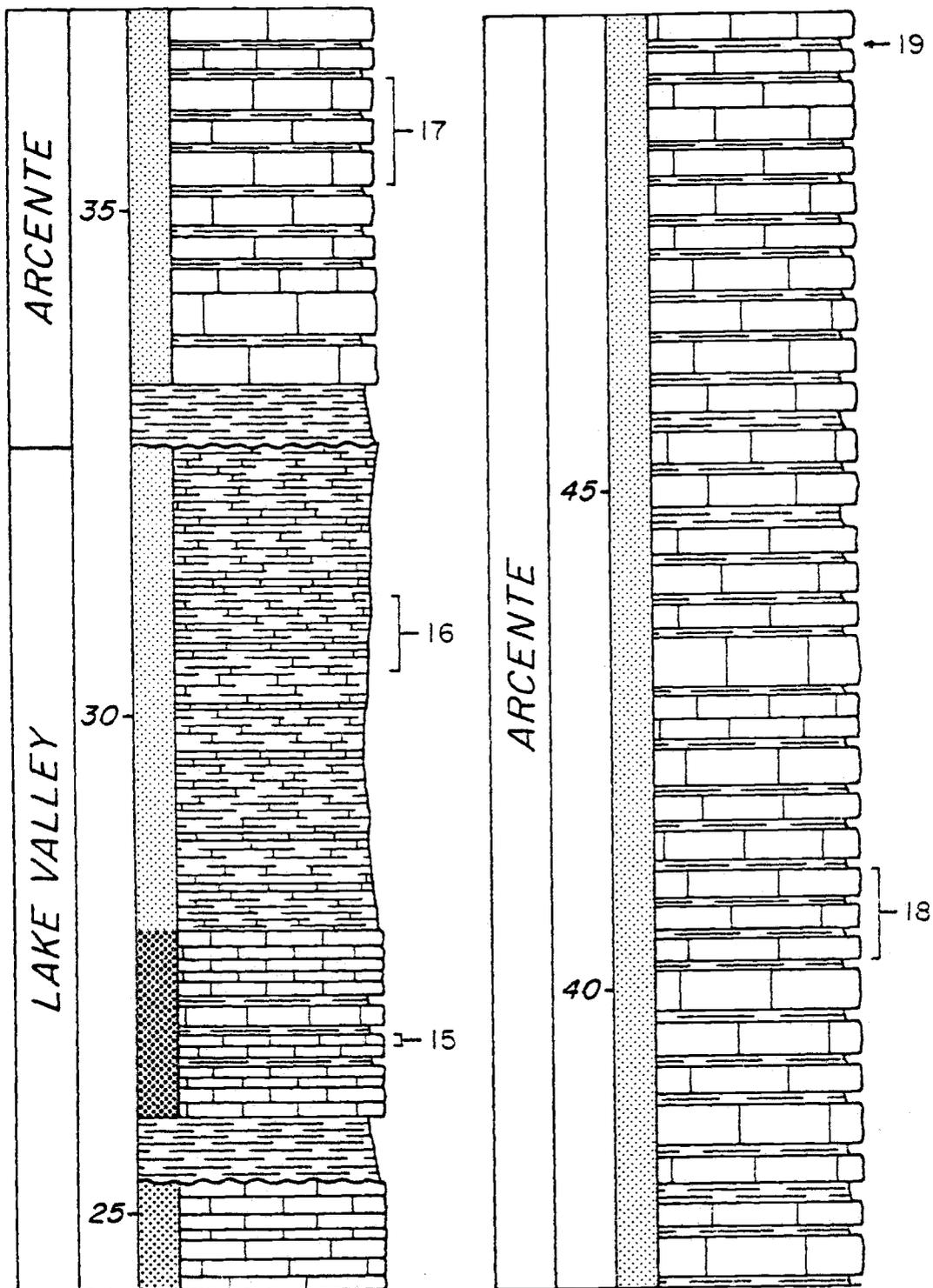


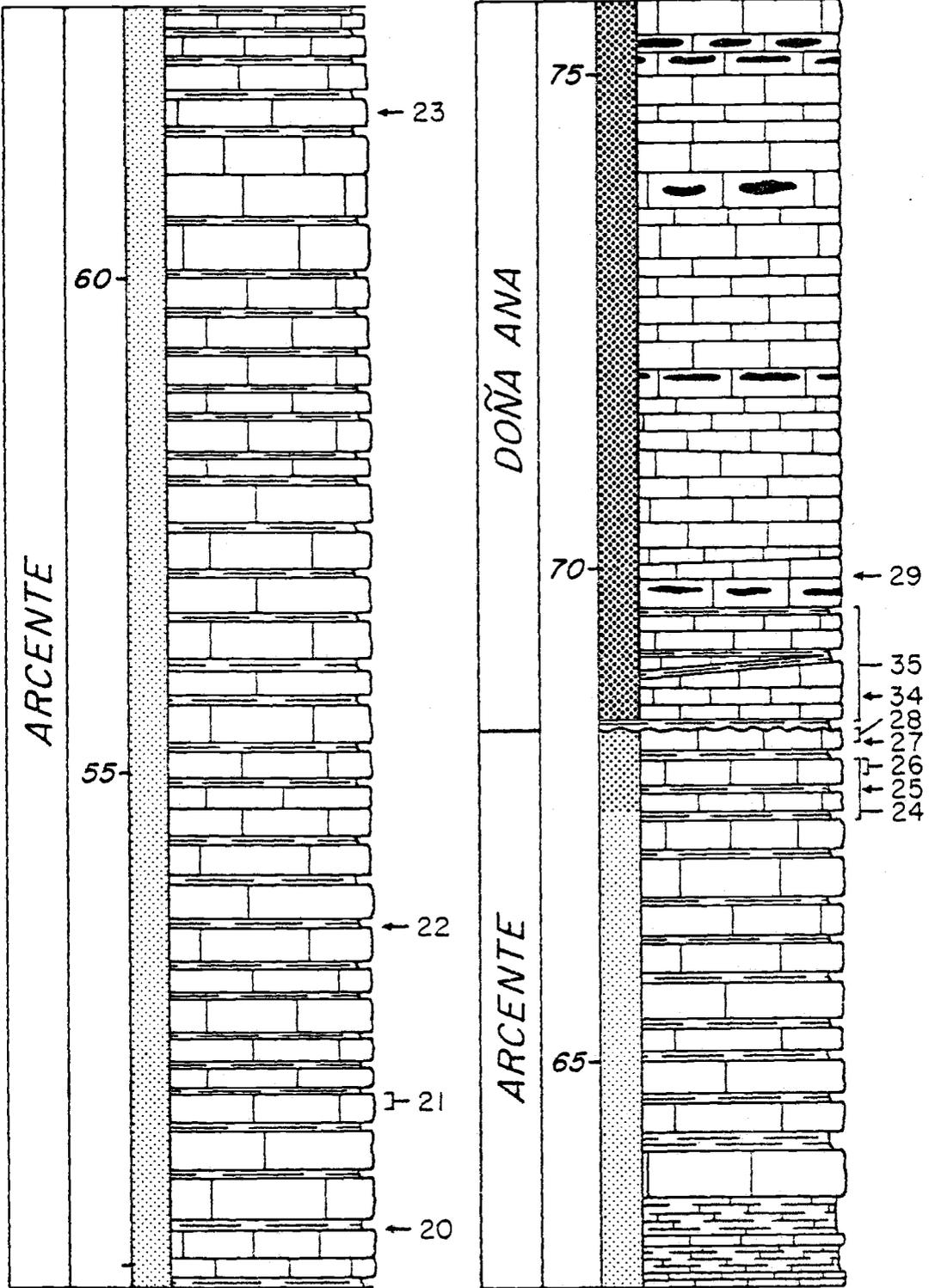


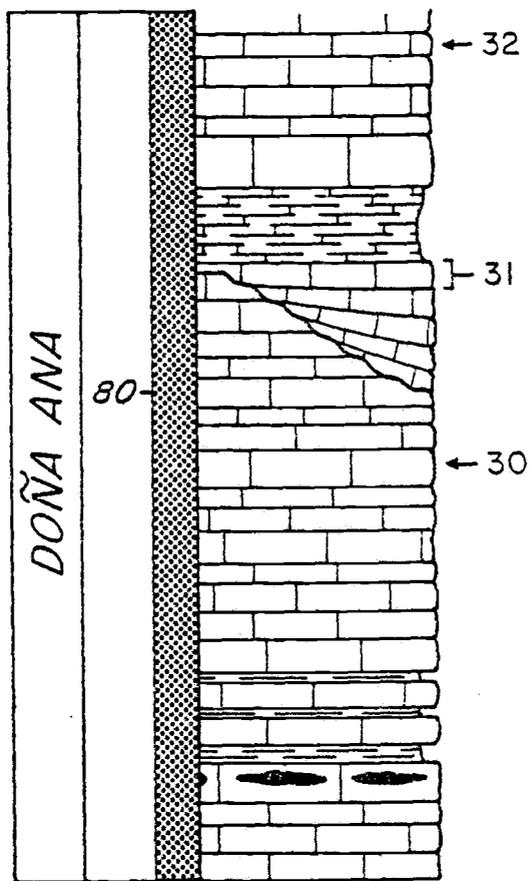
Locality 8245, San Andres Canyon Section

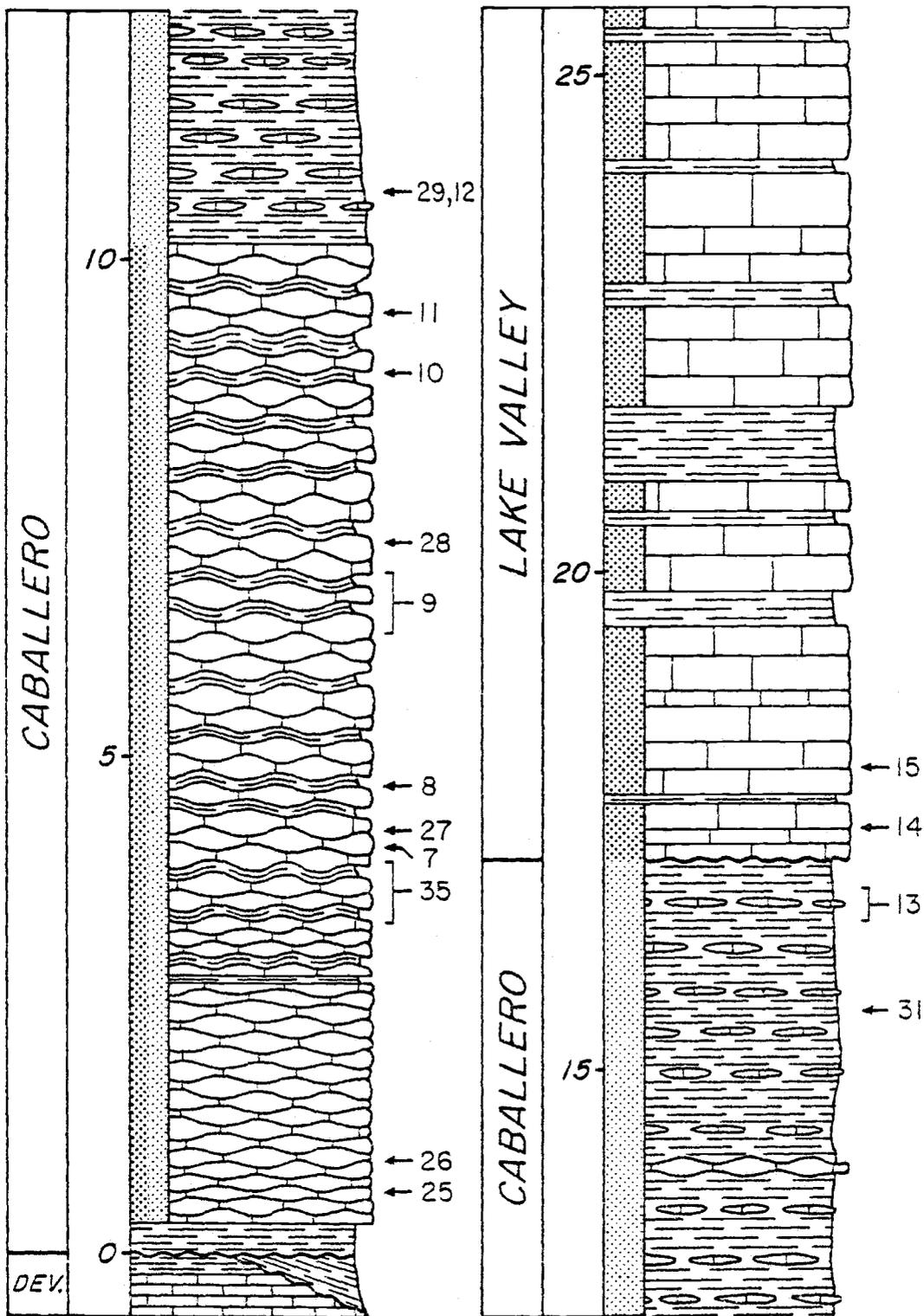




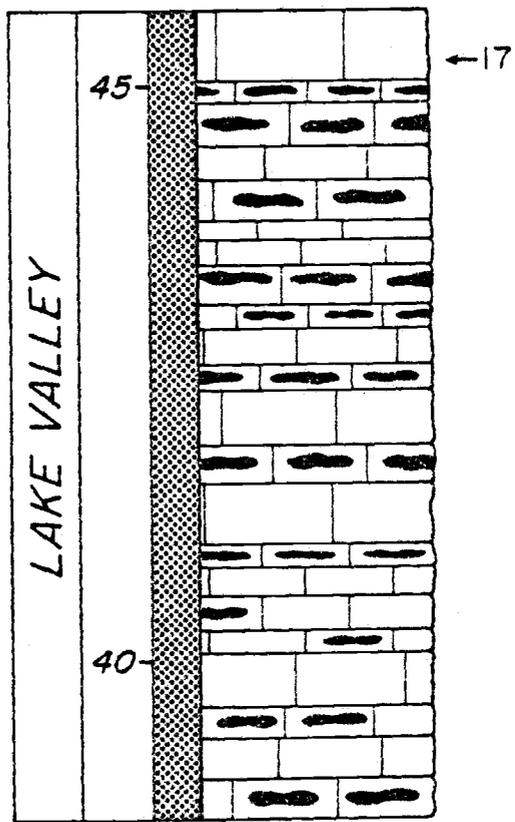
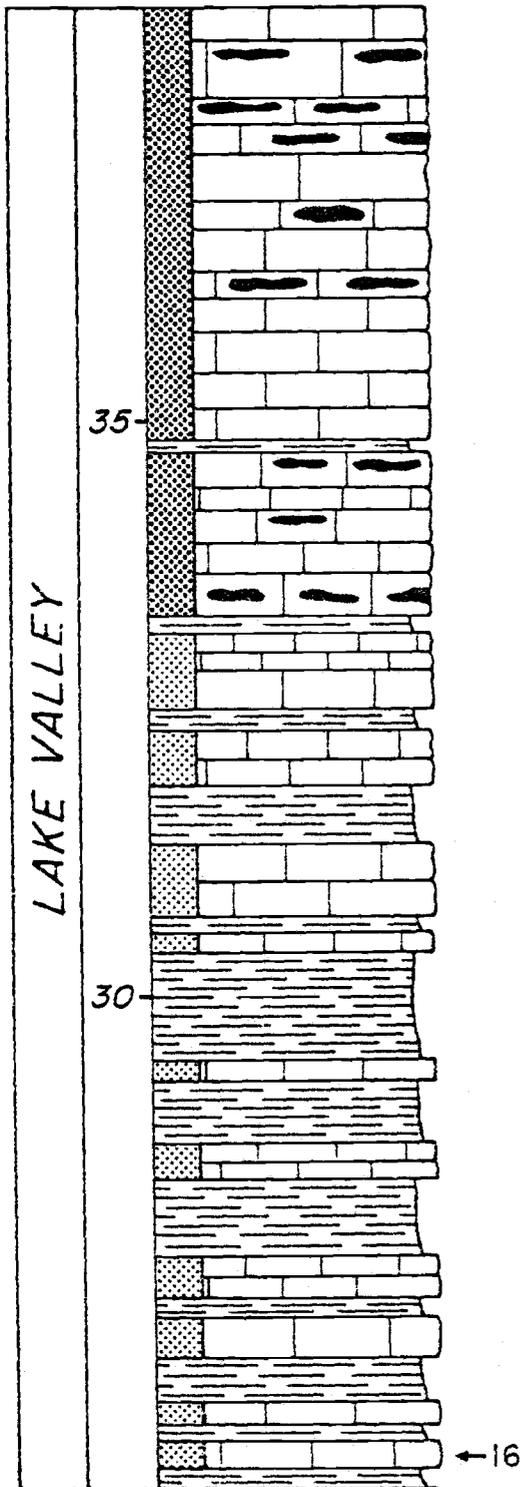


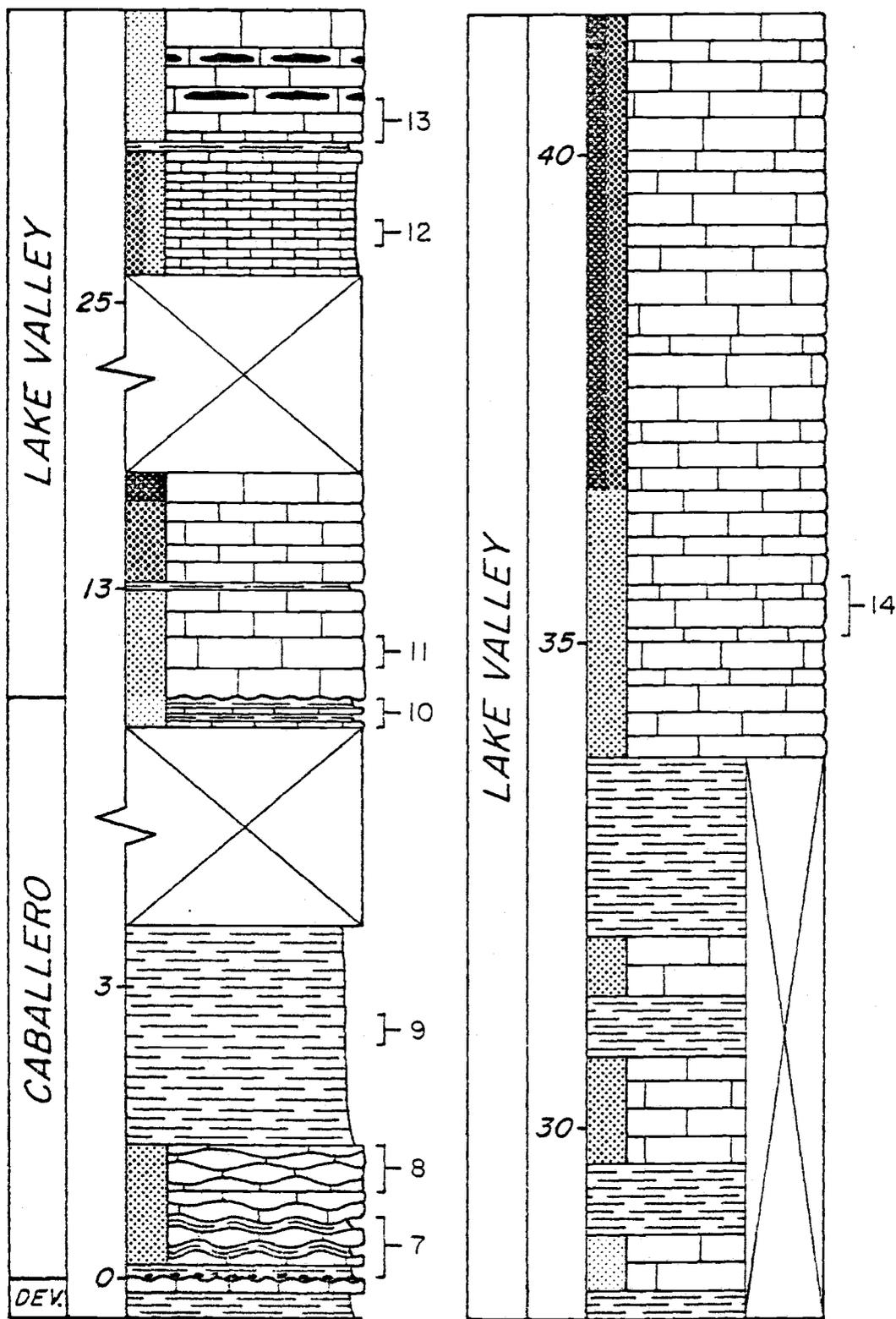




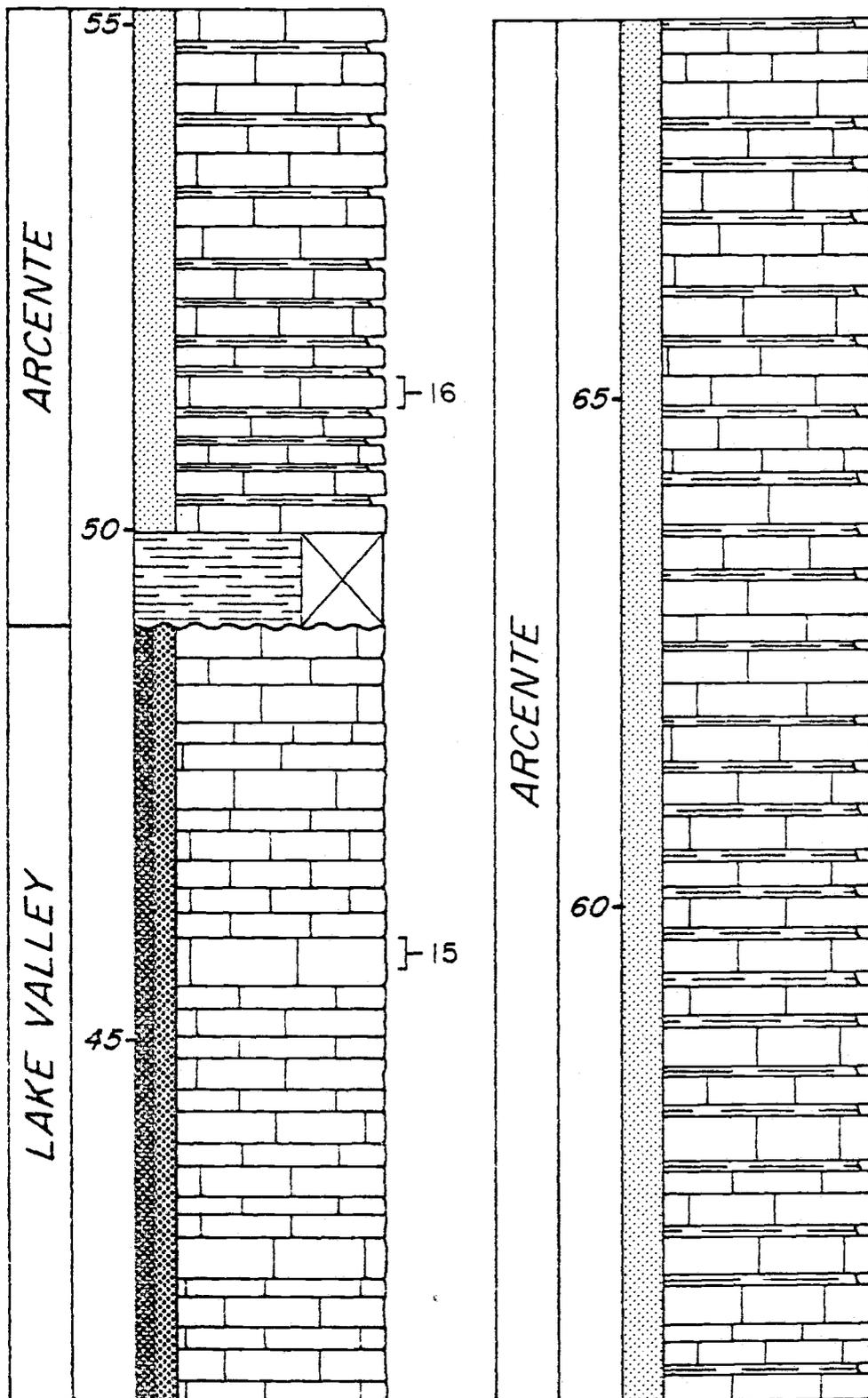


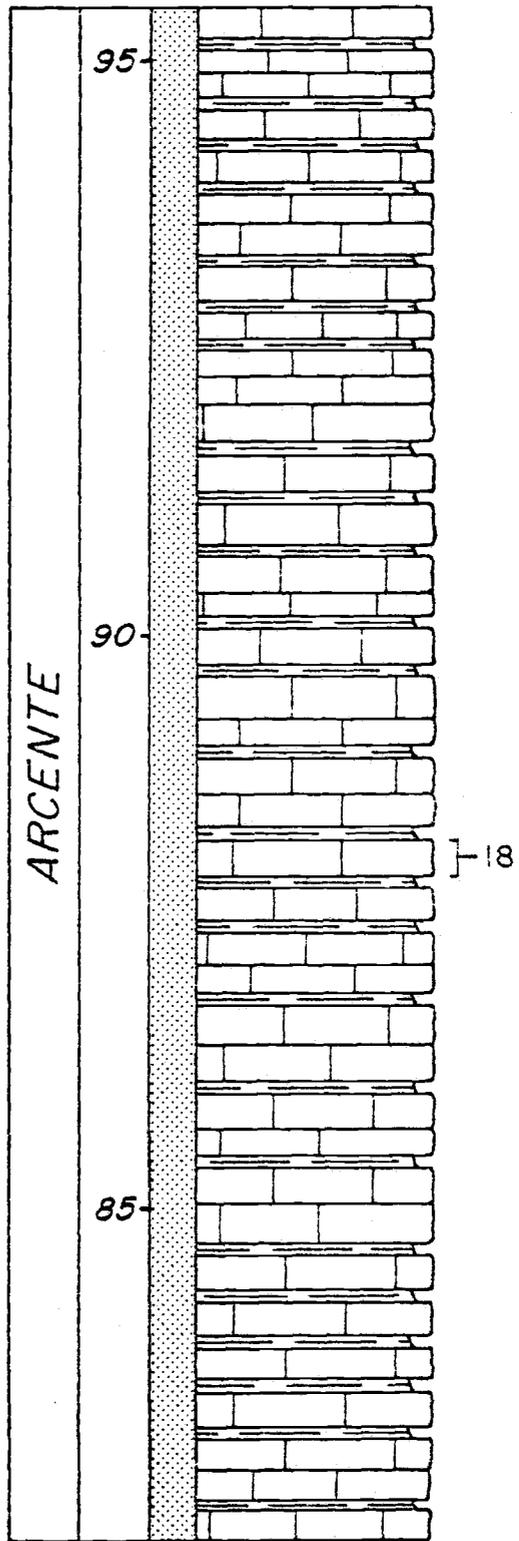
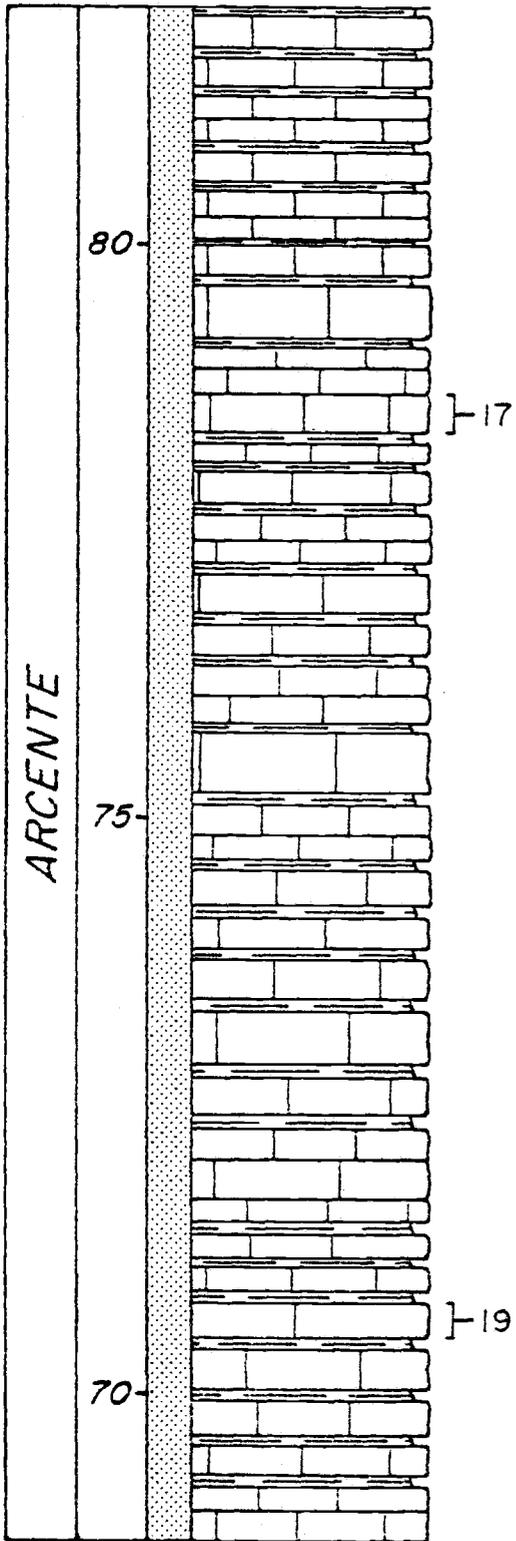
Locality 8248, Marble Canyon Section

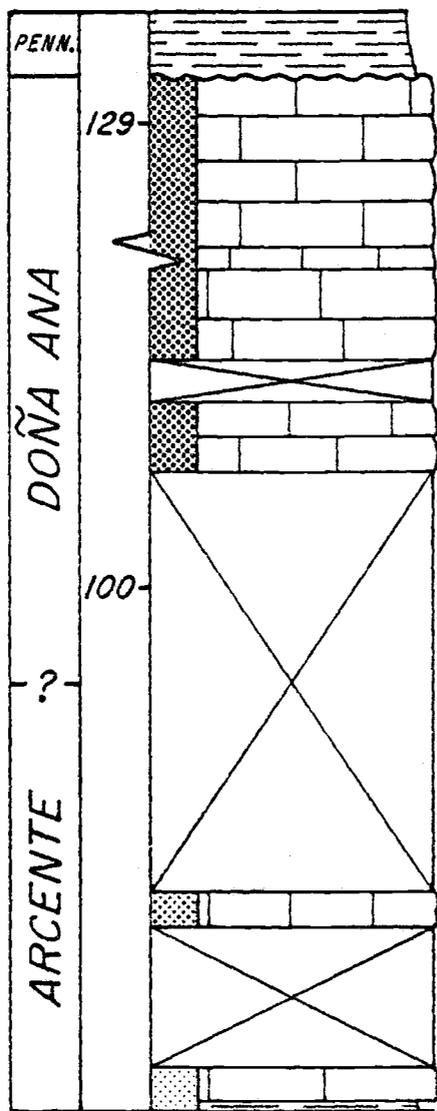


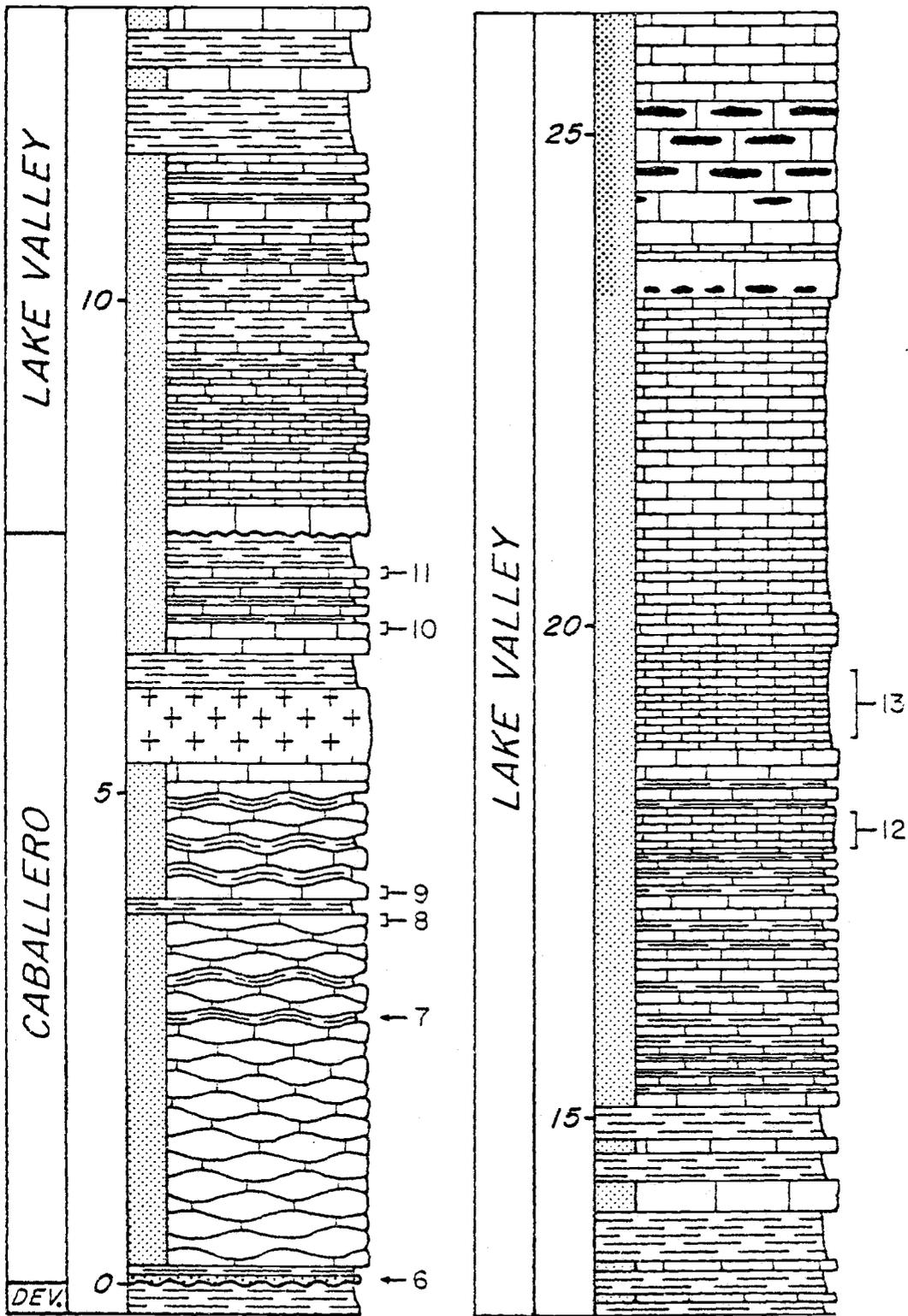


Locality 8249, East Alamo Canyon Section

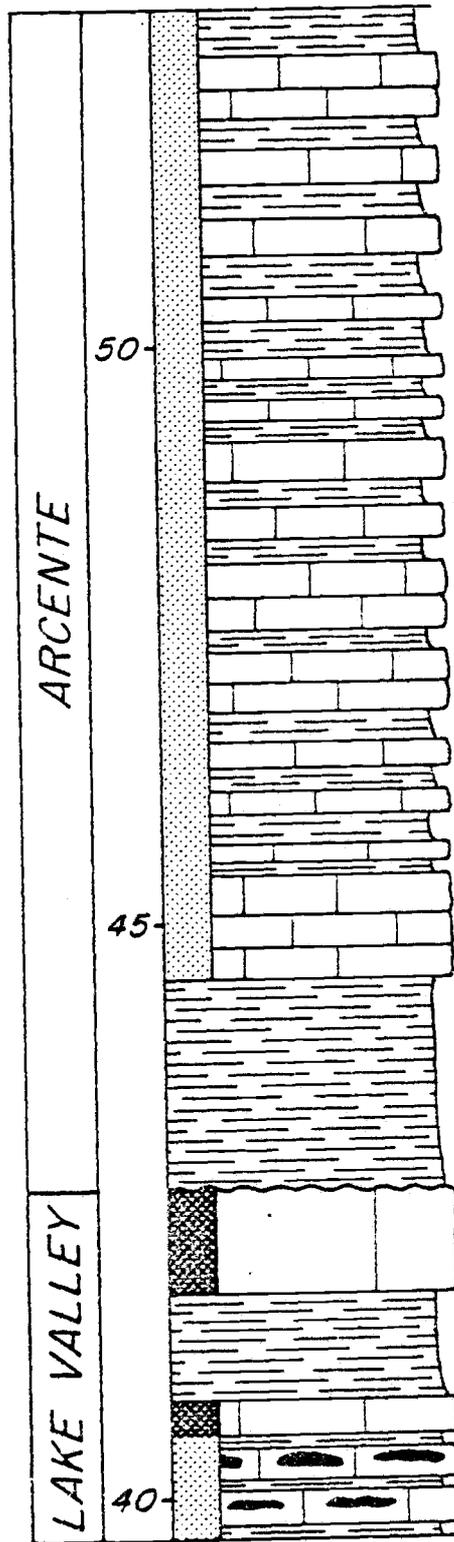
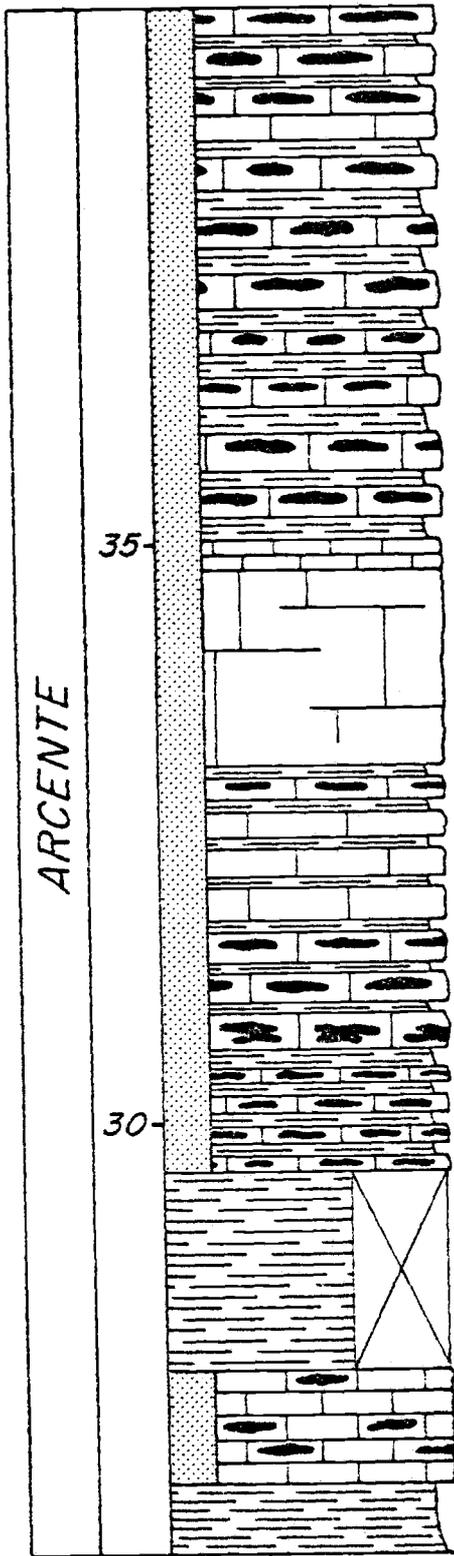


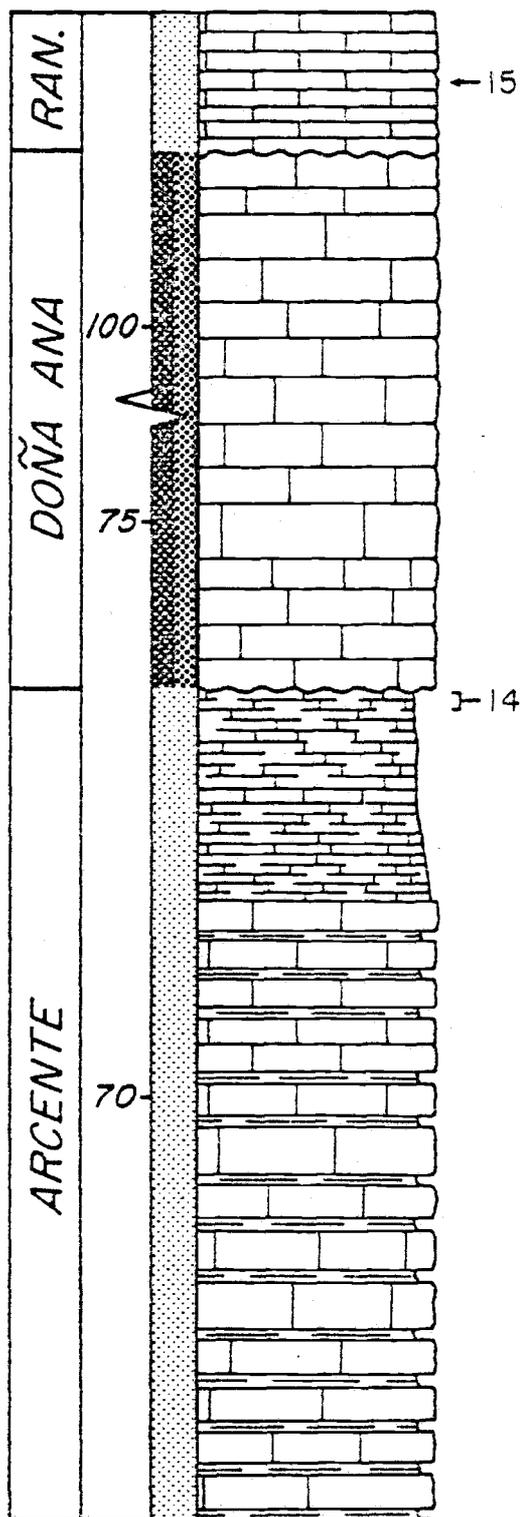
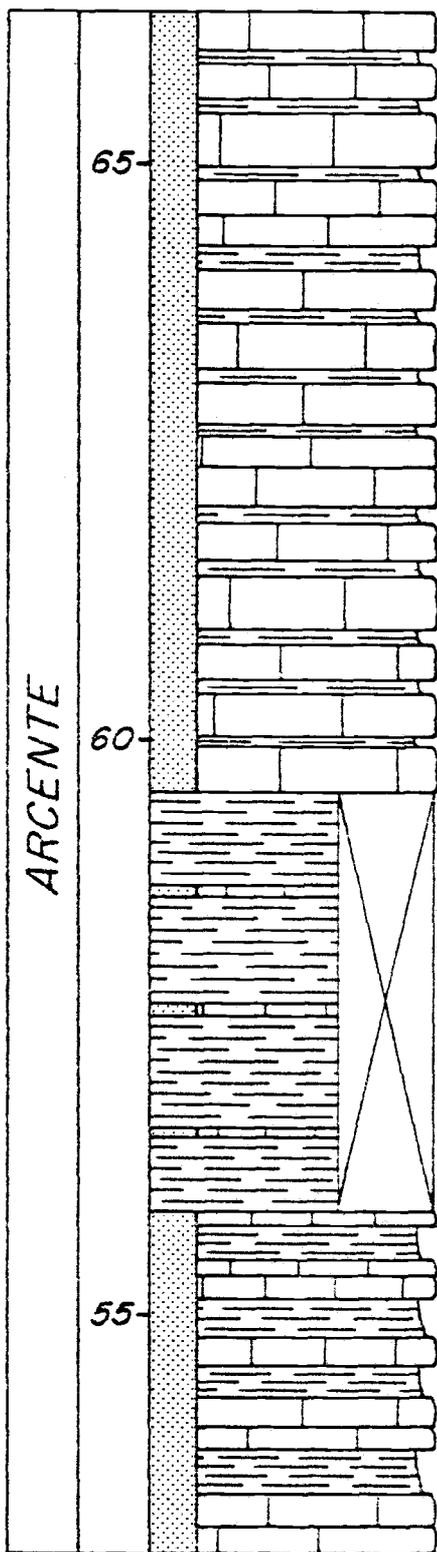






Locality 9130, Lead Canyon Section



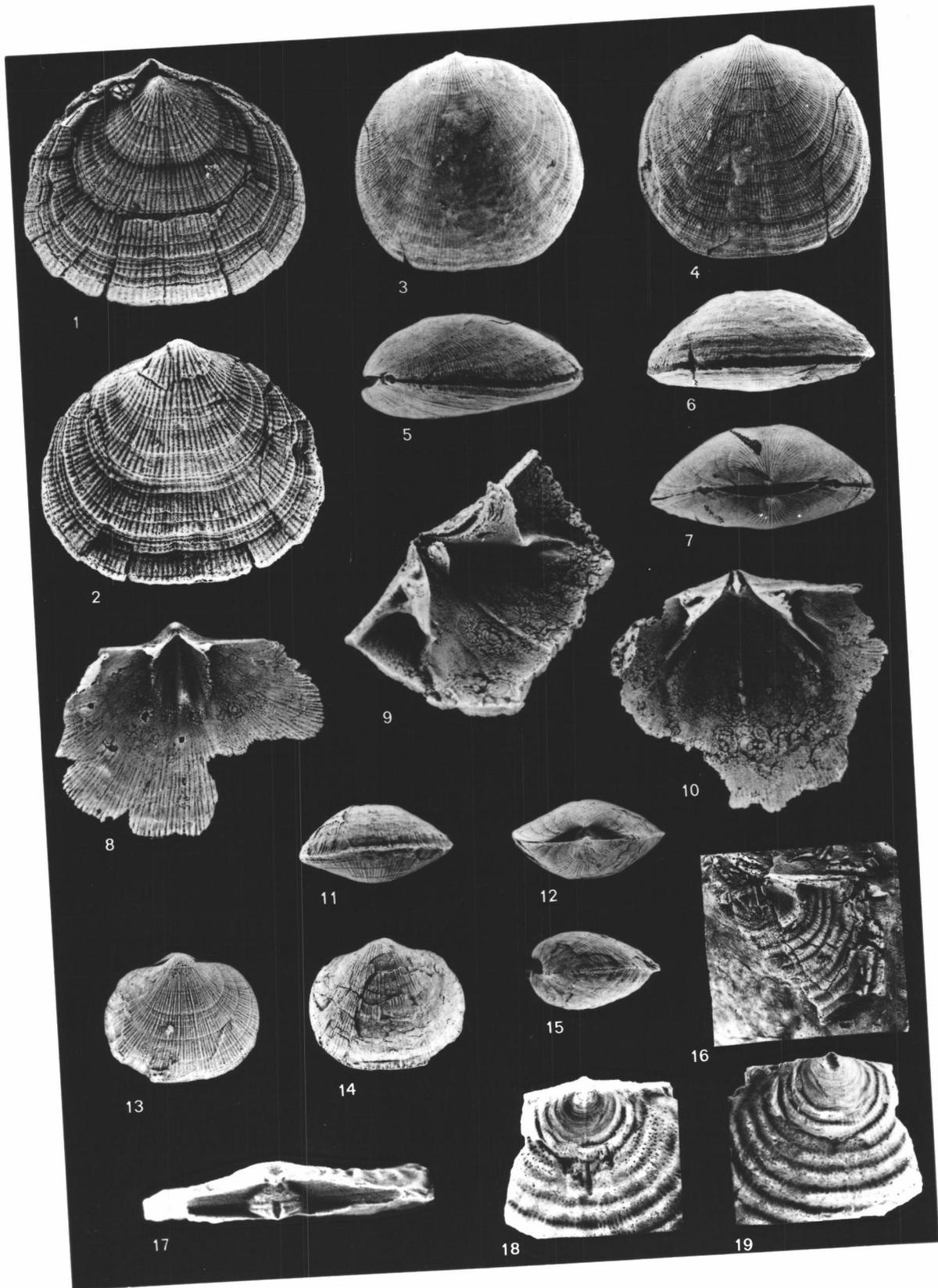


APPENDIX D

PLATES

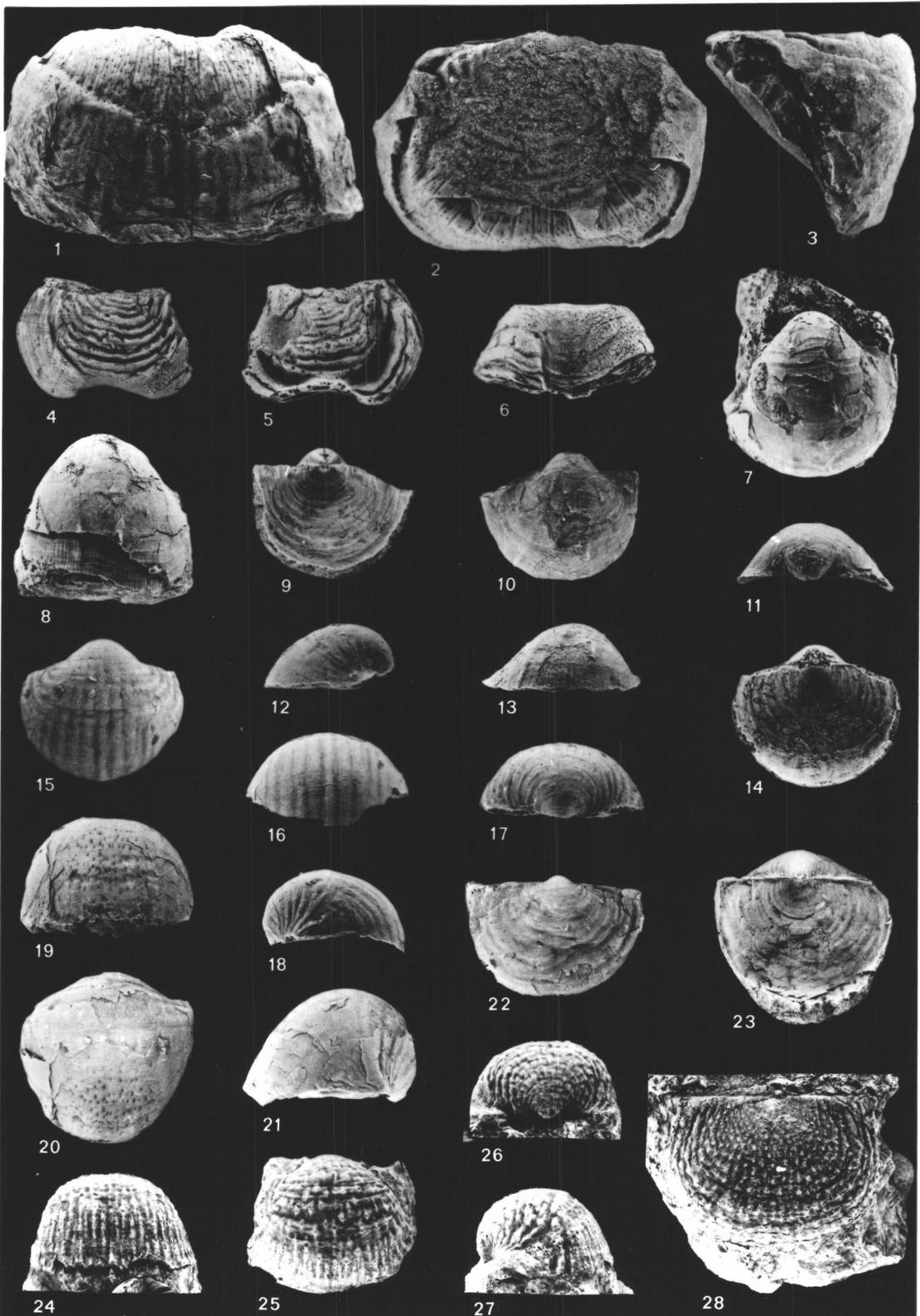
## EXPLANATION OF PLATE 1

- Figures 1, 2 Rhipidomella tenuicostata Weller, 1914.  
Dorsal and ventral views, X4, 8248-35.
- 3-7 Rhipidomella tenuicostata Weller, 1914.  
Dorsal, ventral, lateral, anterior, and  
posterior views, X2, 8248-35.
- 8-10 Schizophoria cf. chouteauensis Weller, 1914.  
Ventral interior, oblique dorsal interior, and  
dorsal interior views, X2, 8243-2.
- 11-15 Schizophoria cf. chouteauensis Weller, 1914.  
Anterior, posterior, dorsal, ventral, and  
lateral views, X2, 8248-11 (float).
- 16 Leptagonia cf. analoga (Phillips), 1836.  
Ventral muscle scar, X3, 8248-11 (float).
- 17-19 Leptagonia cf. analoga (Phillips), 1836.  
Posterior, dorsal, and ventral views, X6.  
8248-11 (float).



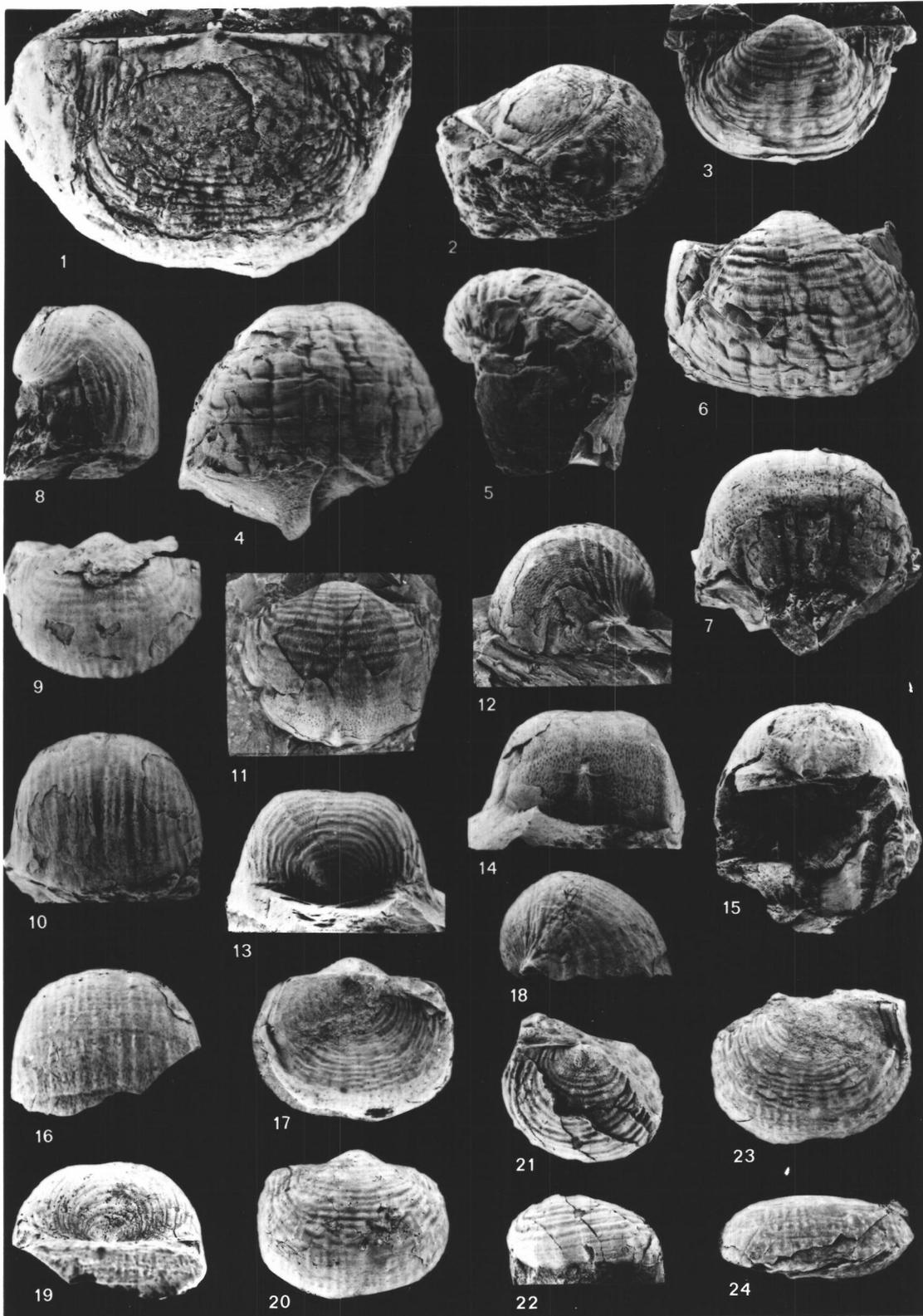
## EXPLANATION OF PLATE 2

- Figures 1-3 Leptagonia cf. analoga (Phillips), 1836. Anterior, ventral, and lateral views, X2, 8248-31.
- 4-6 Leptagonia cf. analoga (Phillips), 1836. Ventral, dorsal, and anterior views, X2, 8248-11 (float).
- 7, 8 Productina sampsoni (Weller), 1909. Ventral, and anterior views, X2, 8243-11.
- 9-13 Productina sampsoni (Weller), 1909. Dorsal, ventral, posterior, lateral, and anterior views, X3, 8243-11.
- 14-18 ?Productina sampsoni (Weller), 1909. Dorsal, ventral, anterior, posterior, and lateral views, X2, 8243-11.
- 19-23 Geniculifera boonensis (E. H. Branson), 1938. Anterior, ventral, lateral, posterior, and dorsal views, X2, 8248- (float).
- 24-27 Rhytiophora cf. blairi (Miller), 1891. Anterior, ventral, posterior, and lateral views, X1, 8245-9.
- 28 Rhytiophora cf. blairi (Miller), 1891. Dorsal interior view, X1, 8243-8.



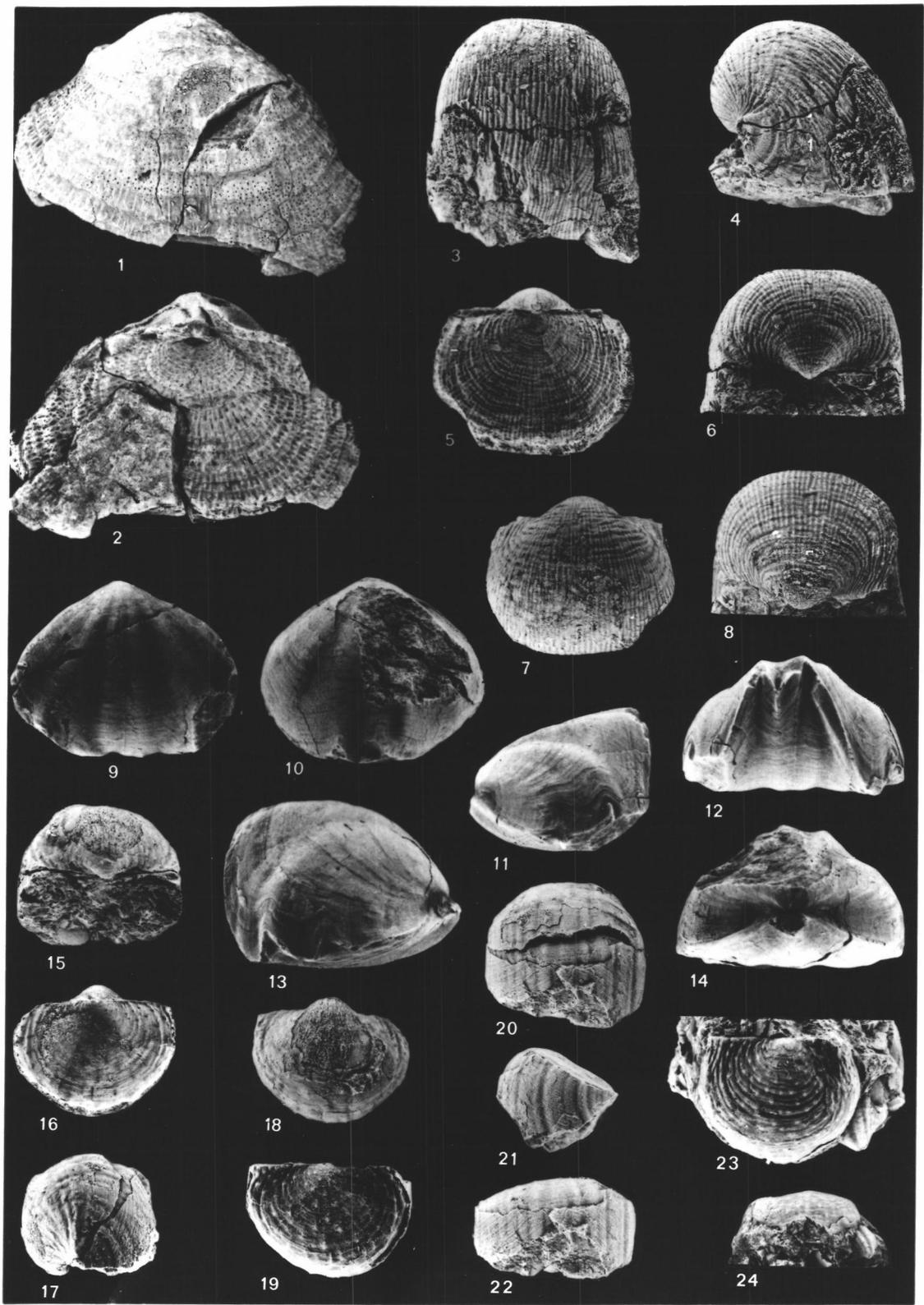
## EXPLANATION OF PLATE 3

- Figures 1, 2 Rhytiophora cf. calhouensis (Moore), 1928.  
Dorsal interior and dorsal interior oblique views, X1.5 and X1, respectively, 8245-16.
- 3 Rhytiophora cf. calhouensis (Moore), 1928.  
Posterior view, X1, 7722-8.
- 4-6 Rhytiophora cf. calhouensis (Moore), 1928.  
Anterior, lateral, and ventral views, X1, 9130-8.
- 7, 15 Rhytiophora cf. calhouensis (Moore), 1928.  
Anterior and posterior views, X1, 7722-8.
- 8-10 Rhytiophora sp. A. Lateral, ventral, and anterior views, X1.5, 8248-25.
- 11-14 Rhytiophora cf. calhouensis (Moore), 1928.  
Ventral, lateral, posterior, and anterior views, X1, 8244-9.
- 16-20 Rhytiophora sp. A. Anterior, dorsal, lateral, posterior, and ventral views, X1.5, 8248-9.
- 21, 22 Rhytiophora sp. A. Dorsal interior and dorsal anterior views, X2, 8248-25.
- 23, 24 Rhytiophora sp. A. Dorsal interior and dorsal anterior views, X1.5, 8248-9.



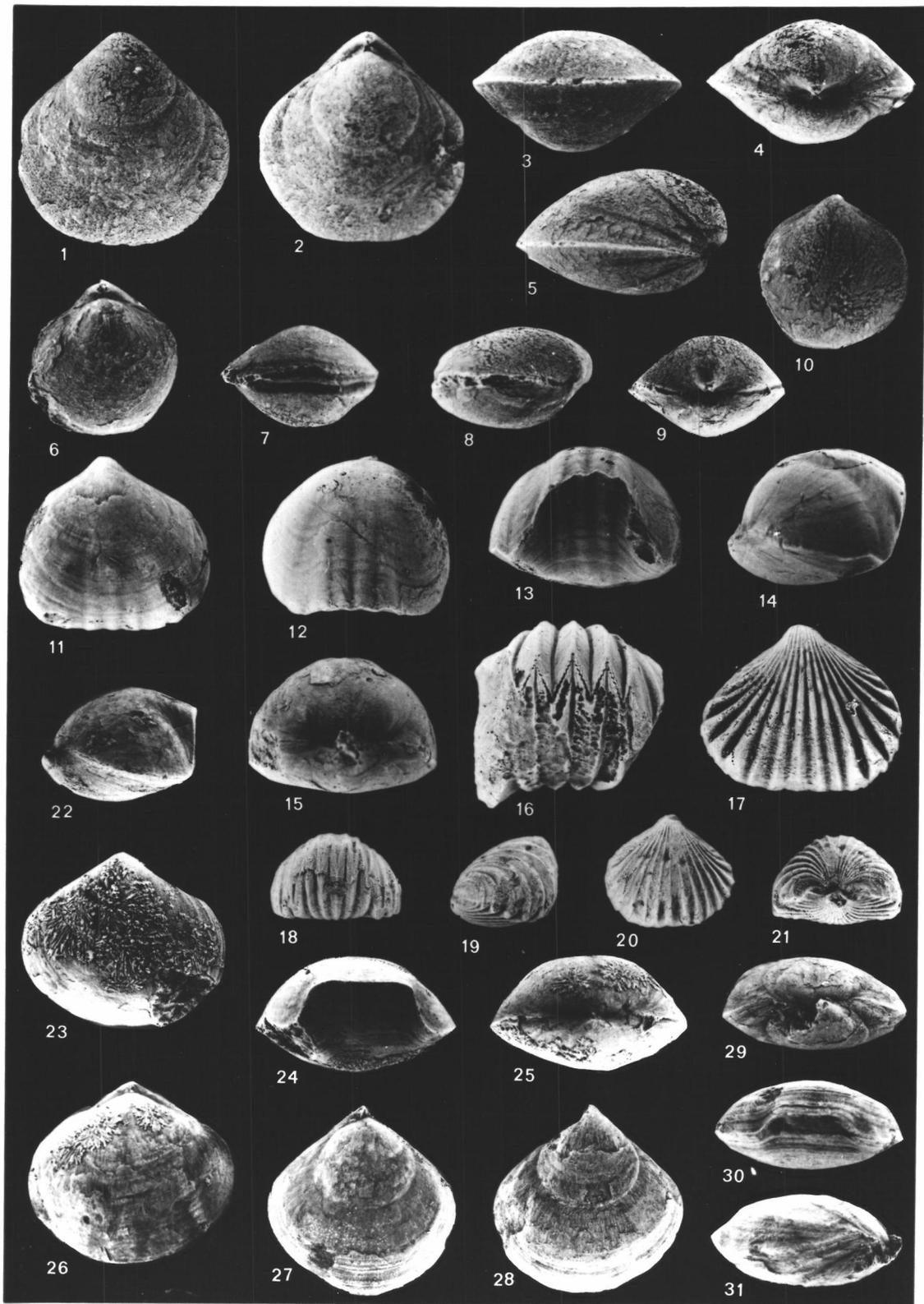
## EXPLANATION OF PLATE 4

- Figures 1, 2 Stegacanthia bowsheri Muir-Wood and Cooper, 1960. Ventral and dorsal views, X1.5, 7720-11.
- 3-6 Marginatia sp. A. Anterior, lateral, dorsal, and posterior views, X1, 8243-14.
- 7, 8 Marginatia sp. A. Ventral and posterior views, X1, 8243-2.
- 9-12, 14 Paraphorhynchus sp. A. Ventral, dorsal, lateral, anterior, and posterior views, X2, 8248-25.
- 13 Paraphorhynchus sp. A. Lateral view, X2, 8245-6.
- 15-22 Rhytiophora sp. B. Posterior, dorsal, lateral, dorsal, anterior, lateral, and anterior views of a specimen broken to reveal dorsal valve, X2, 8243-9.
- 23, 24 Rhytiophora sp. B. Ventral and anterior views of a dorsal valve, X1.5 and X1, respectively. 8243-6.



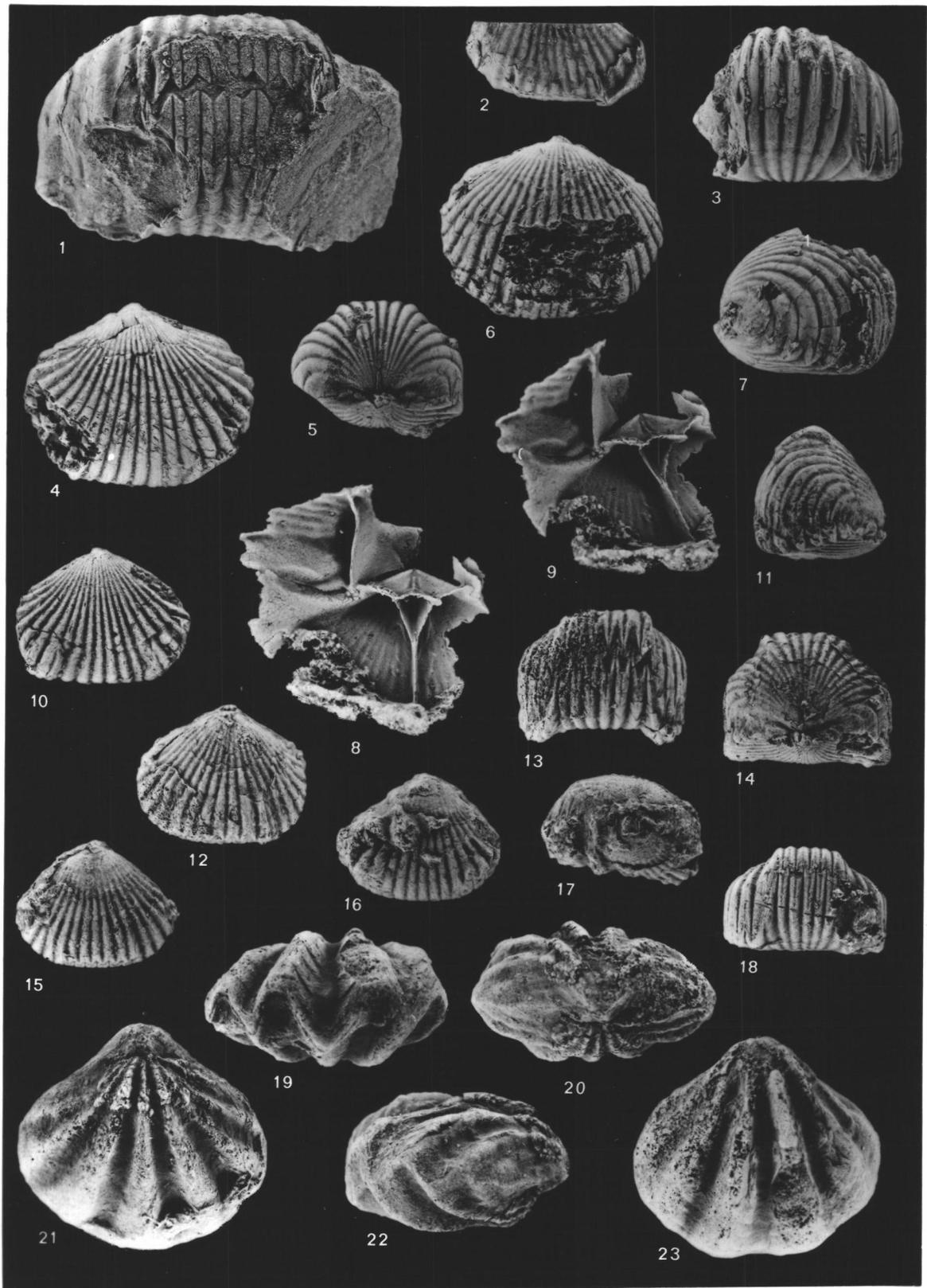
## EXPLANATION OF PLATE 5

- Figures 1-5 Atribonium (?) sp. A. Ventral, dorsal, anterior, posterior, and lateral views, X4, 8243-11.
- 6-10 Atribonium (?) sp. A. Dorsal, anterior, lateral, posterior, and ventral views, X4, 8243-11.
- 11-15 Shumardella obsolescens Weller, 1910. Ventral, dorsal, anterior, lateral, and posterior views, X3, 8248-25.
- 16 Ptychomaletoechia (?) sp. A. Anterior view, X3, showing serrated commissure, 8248-11 (float).
- 17-21 Ptychomaletoechia (?) sp. A. Ventral view, X3; anterior, lateral, dorsal, and posterior views, X2; 8248-35.
- 22-26 Coledium sugarloafensis n. sp. Lateral, ventral, anterior, posterior, and dorsal views, X3, 8243-6.
- 27-31 Coledium sugarloafensis n. sp. Dorsal, ventral, posterior, anterior, and lateral views. X4, 8243-6.



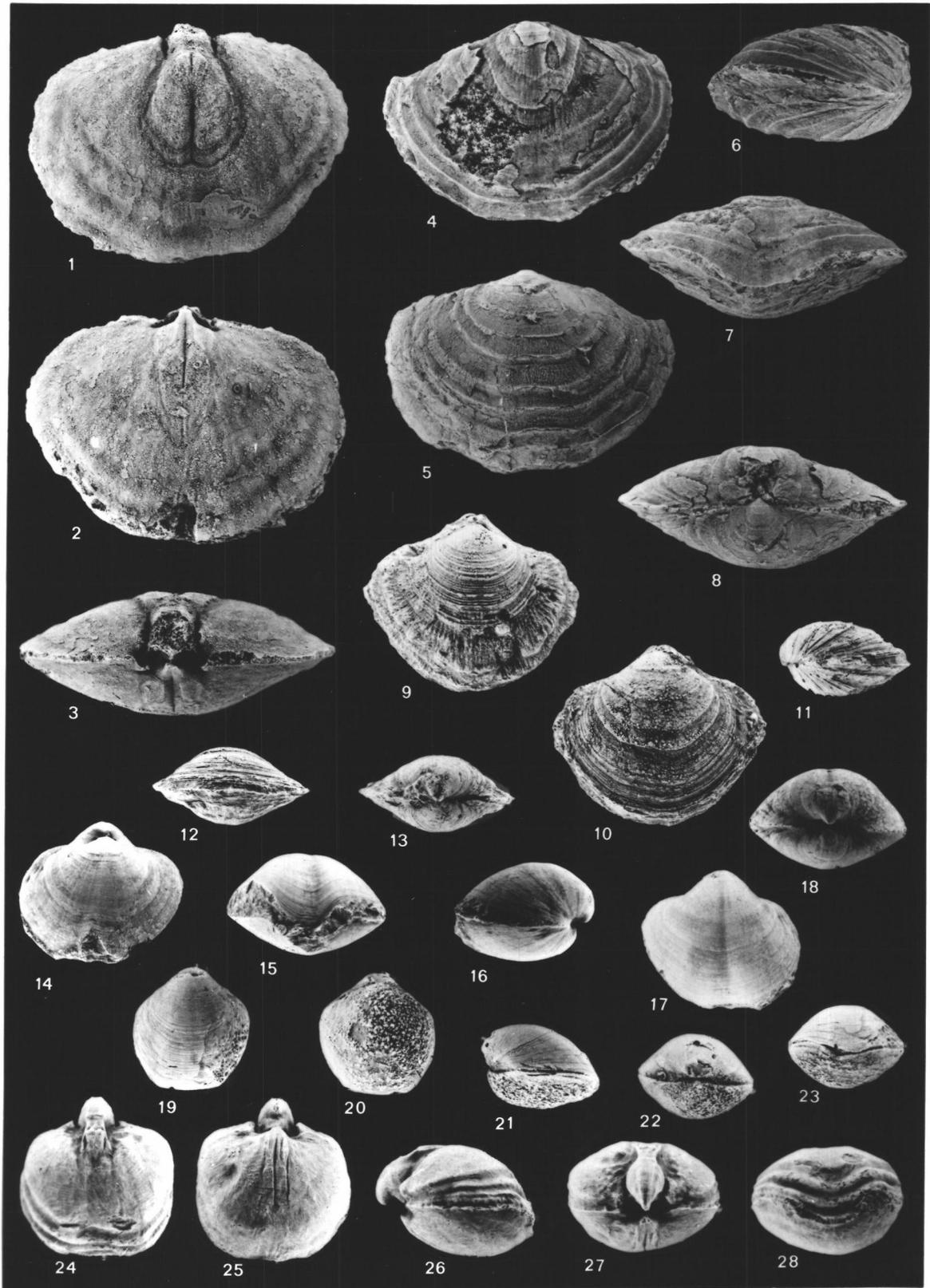
## EXPLANATION OF PLATE 6

- Figures 1, 2 Rhynchopora sp. A. Anterior and ventral views of sectioned specimen, X3 and X1.5, respectively, 9130-11.
- 4-7 Rhynchopora sp. B. Ventral, posterior, dorsal, and lateral views; figure 5, X1.33, all others X1.5; 8243-2.
- 8, 9 Rhynchopora sp. B. Interior and interior oblique views of a broken silicified specimen, X3, 8243-2.
- 10-14 Rhynchopora sp. C. Ventral, lateral, dorsal, anterior, and posterior views, X1.5, 8243-5.
- 15-18 Rhynchopora sp. D. Dorsal, ventral, posterior, and anterior views, X2, 8243-8.
- 19-23 Hustedia (?) sexplicata (White and Whitfield), 1862. Anterior, posterior, dorsal, lateral, and ventral views, X4, 7722-8.



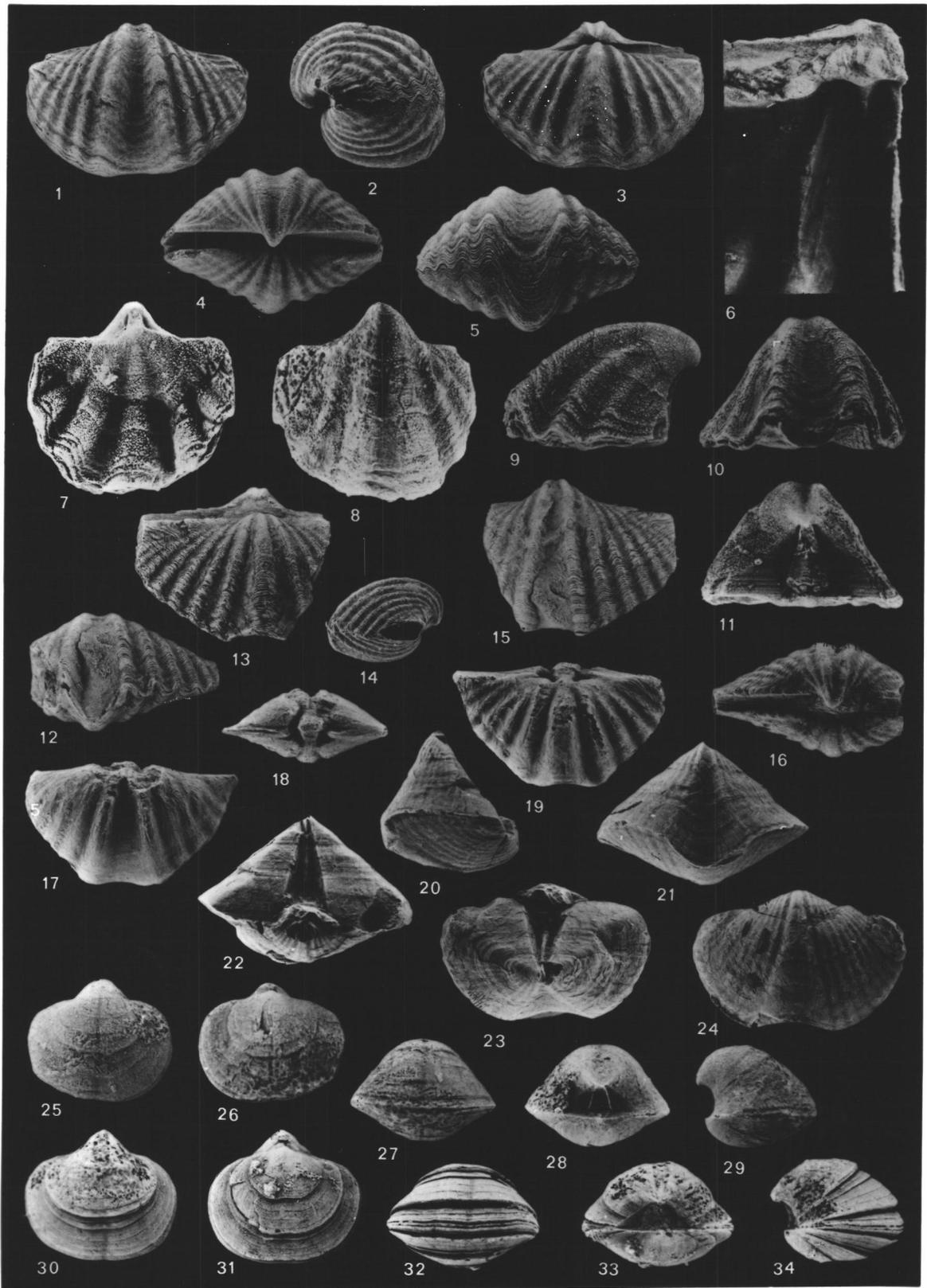
## EXPLANATION OF PLATE 7

- Figures 1-3 Athyris cf. lamellosa (Leveille), 1835. Ventral, dorsal, and posterior views of an internal mold, X3, 8245-(Caballero, float).
- 4-8 Athyris cf. lamellosa (Leveille), 1835. Dorsal, ventral, lateral, anterior, and posterior views, X1.5, 8243-8.
- 9-13 Cleiothyridina cf. glenparkensis Weller, 1914. Dorsal and ventral views, X2; lateral, anterior, and posterior views, X1.5; 8245-(Caballero, float).
- 14-18 Cleiothyridina prouti (Swallow), 1860. Dorsal, anterior, lateral, ventral, and posterior views, X1, 8242-19.
- 19-23 Composita cf. globosa Weller, 1914. Ventral, dorsal, lateral, posterior, and anterior views, X2.4, 8248-11 (float).
- 24-28 Composita cf. globosa Weller, 1914. Ventral, dorsal, lateral, posterior, and anterior views of a calcined and scraped specimen, X3, 8248-11 (float).



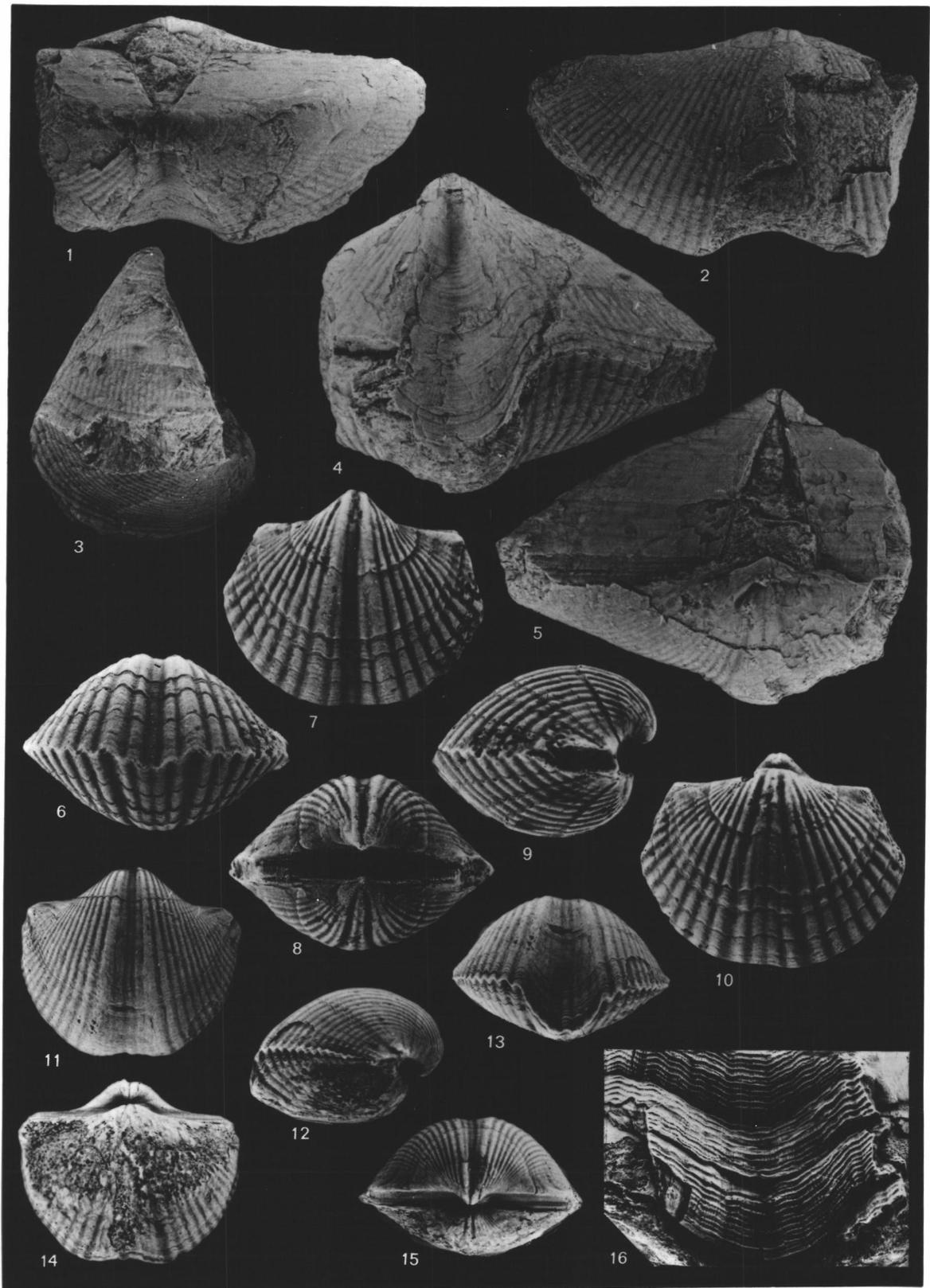
## EXPLANATION OF PLATE 8

- Figures 1-5 Voiseyella novamexicana (Miller), 1881. Ventral, lateral, dorsal, posterior, and anterior views, X2, 8245-(Caballero, float).
- 6 Voiseyella novamexicana (Miller), 1881. Enlarged view of dorsal interior, showing cardinal process, X6, 8245-12.
- 7-11 Cyrtina burlingtonensis Rowley, 1893. Dorsal, ventral, lateral, anterior, and posterior views, X4, 8248-11 (float).
- 12-16 Tylothyris sp. A. Anterior, dorsal, lateral, ventral, and posterior views; figure 14, X1.5, all others X2; 7722-8.
- 17-19 Tylothyris sp. A. Ventral, X3, posterior, X2, and dorsal, X3, views of a calcined and scraped specimen; 8246-12.
- 20-24 Syringothyris halli Winchell, 1863. Lateral, anterior, posterior, ventral, and dorsal views, X2, 8248-25.
- 25-34 Crurithyris parva (Weller), 1899. Ventral, dorsal, anterior, posterior, and lateral views of two specimens, X3, 8248-11 (float).



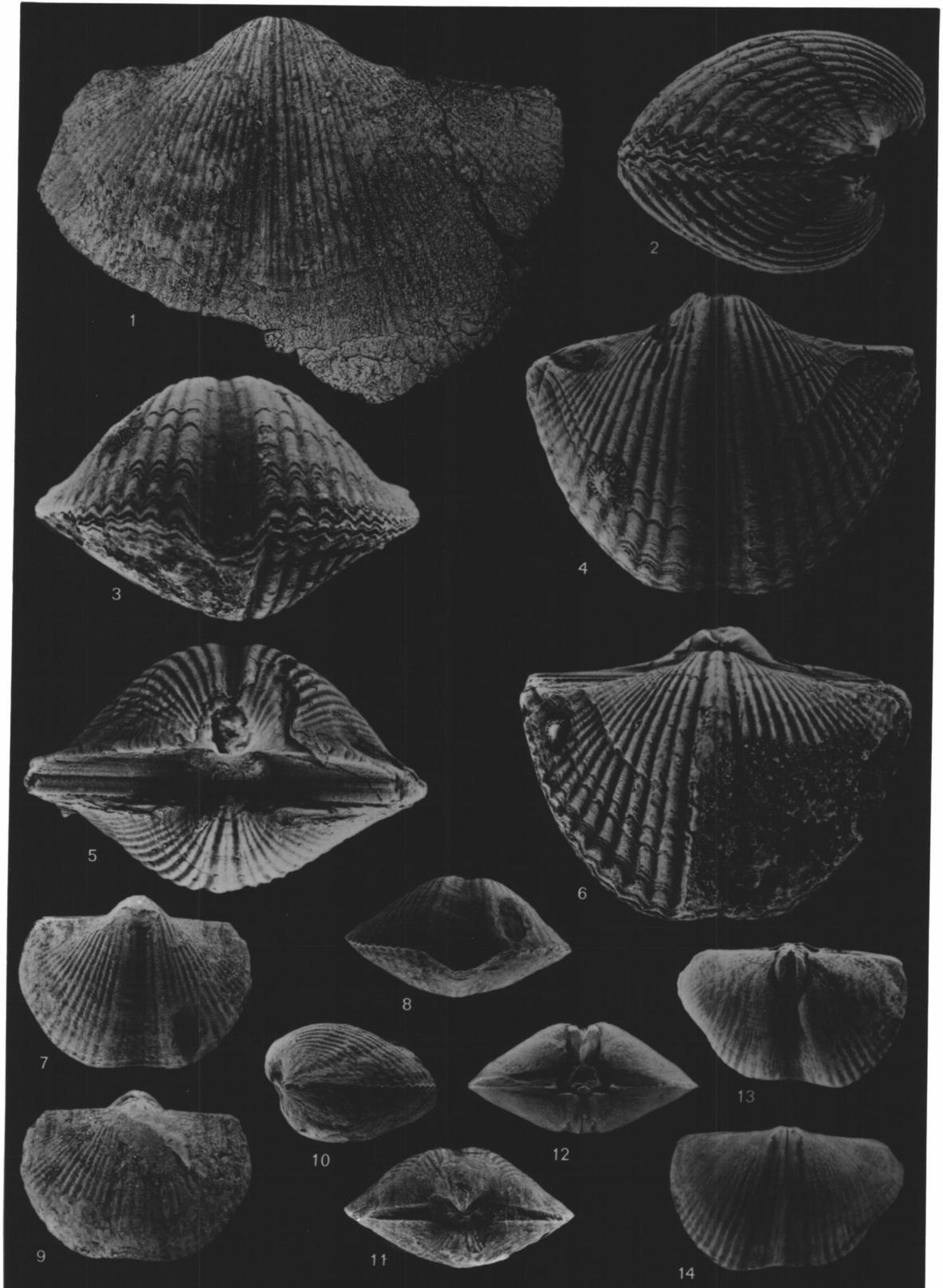
## EXPLANATION OF PLATE 9

- Figures 1-5 Pseudosyrinx missouriensis Weller, 1914.  
Ventral, dorsal, lateral, anterior, and  
posterior views, X1, 8243-8.
- 6-10 Cyrtospirifer latior (Swallow), 1863.  
Anterior, ventral, posterior, lateral, and  
dorsal views, X4, 8248-11 (float).
- 11-15 Cyrtospirifer latior (Swallow), 1863. Ventral,  
lateral, anterior, dorsal, and posterior views,  
X2, 8248-11 (float).
- 16 Cyrtospirifer sp. A. Anterior view of sulcus,  
showing ornament, X3, 8245-(Caballero,  
float).



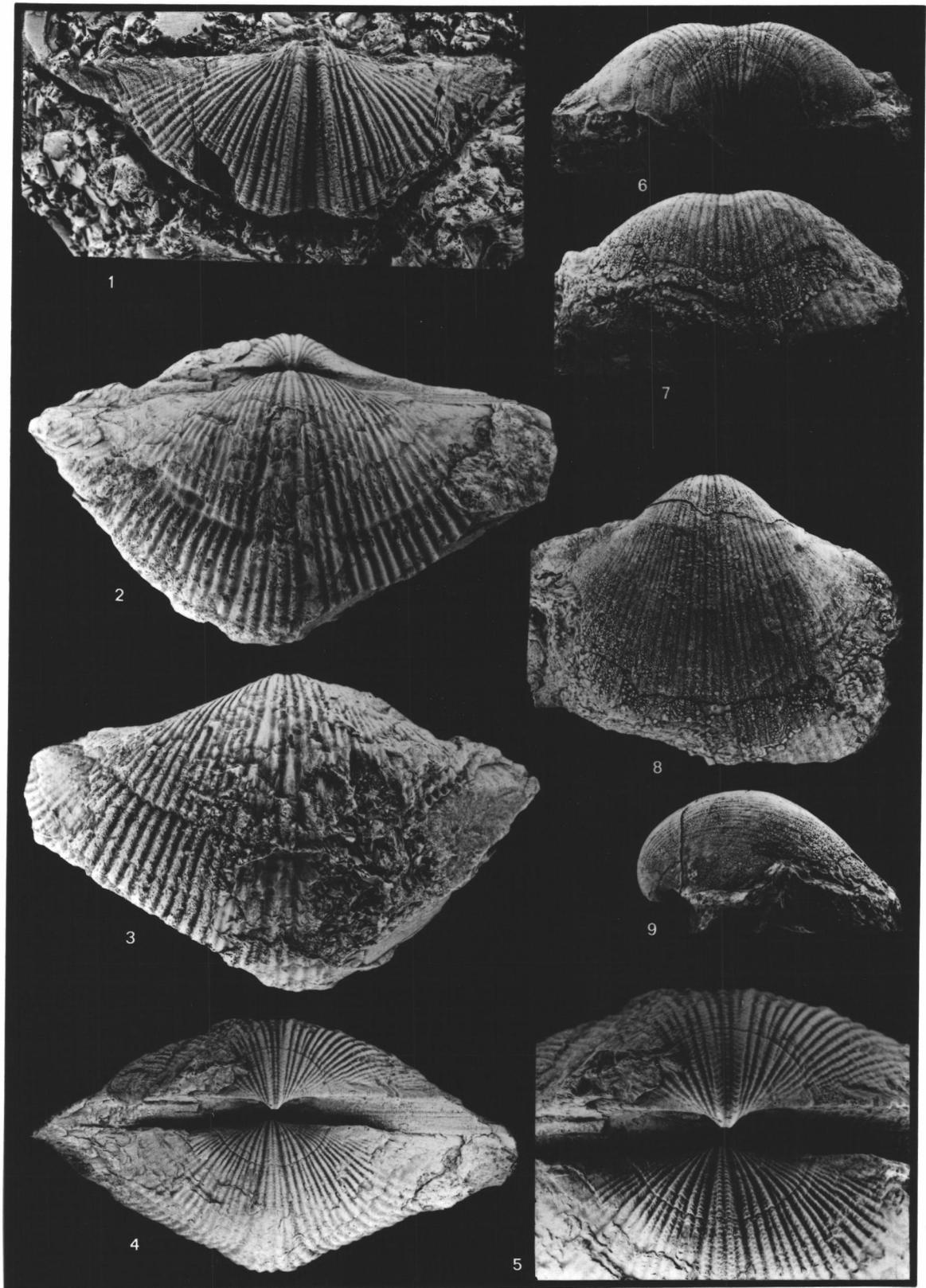
## EXPLANATION OF PLATE 10

- Figures      1    Spirifer cf. logani/grimesi Hall, 1858.  
Ventral view, X1, 8244-10.
- 2-6   Cyrtospirifer latior (Swallow), 1863.  
Lateral, anterior, ventral, posterior,  
and dorsal views, X4.5, 8248-11 (float).
- 7-11   Cyrtospirifer sp. A. Ventral, anterior,  
dorsal, lateral, and posterior views, X1.67,  
8246-12.
- 12-14   Cyrtospirifer sp. A. Posterior, ventral,  
and dorsal views of a calcined and scraped  
specimen, X1.67, 8246-12.



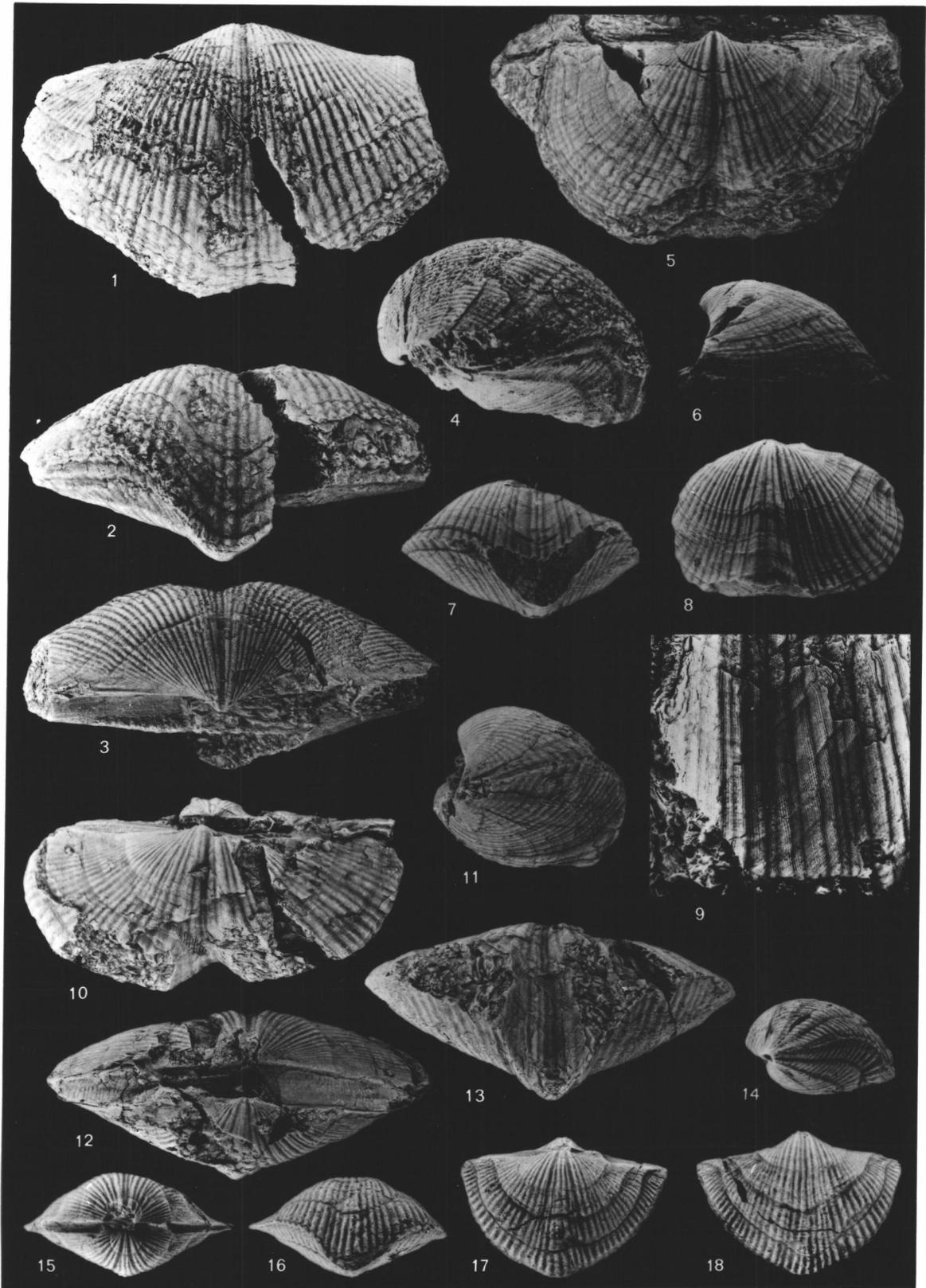
## EXPLANATION OF PLATE 11

- Figures      1    Imbrexia sp. A. Ventral view, X2, 8243-8.
- 2-5    Imbrexia sp. A. Dorsal, ventral, posterior,  
                  and posterior close-up views; figure 5, X2,  
                  all others X1.5; 8243-3.
- 6-9    Spirifer cf. gregeri Weller, 1914. Posterior,  
                  anterior, ventral, and lateral views, X1,  
                  7722-14.



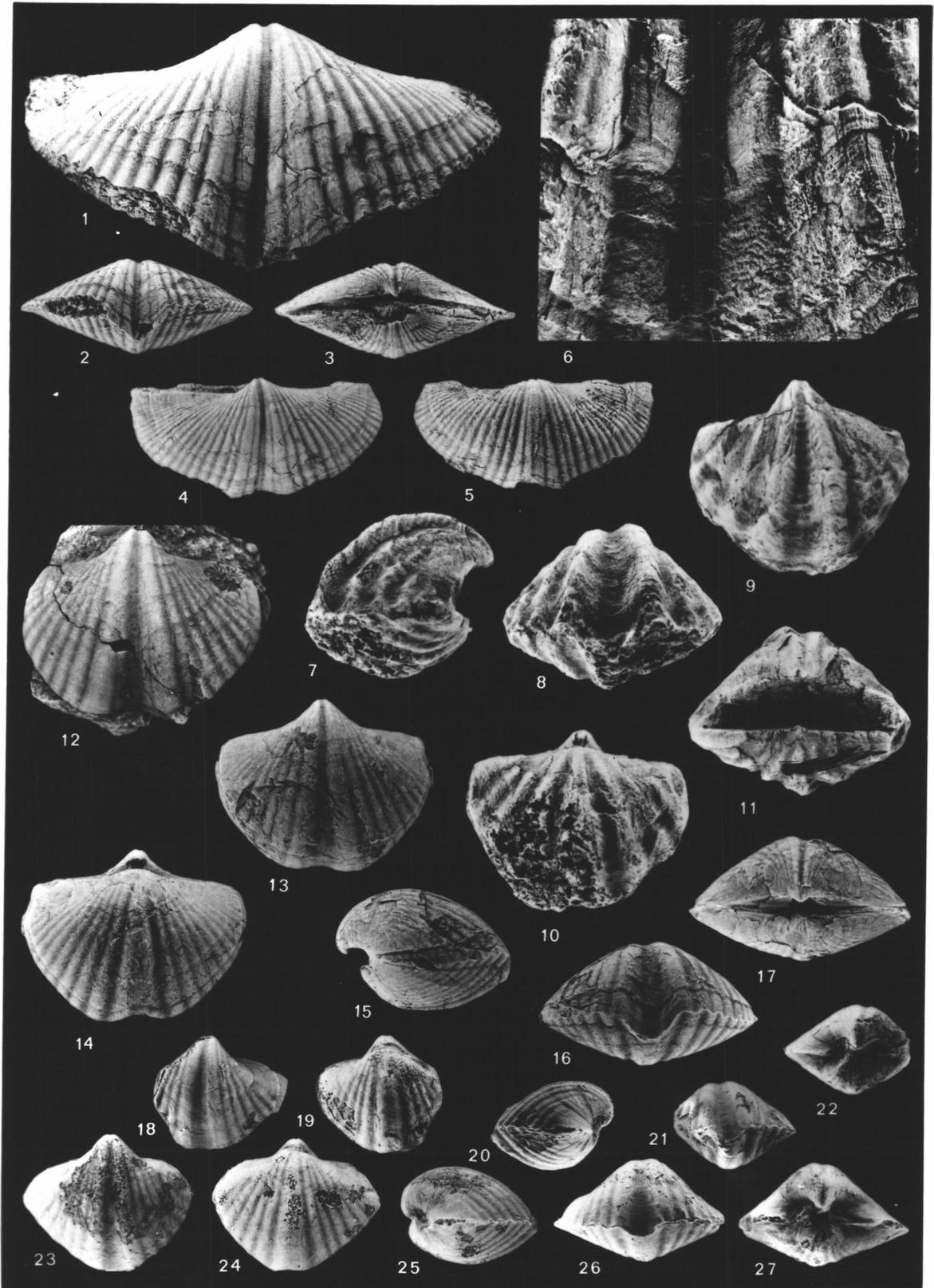
## EXPLANATION OF PLATE 12

- Figures 1-4 Imbrexia sp. B. Ventral, anterior, posterior, and lateral views, X1, 8243-9.
- 5, 6 Unispirifer sp. A. Ventral and lateral views of a pedicle valve, X1, 8243-4.
- 7, 8 Unispirifer sp. A. Anterior and dorsal views, X1, 8243-3.
- 9 Unispirifer sp. A. Enlarged view of anterior part of sulcus, showing ornament, X2, 8243-5.
- 10-13 Unispirifer sp. B. Ventral, lateral, posterior, and anterior views, X1, 8243-15.
- 14-18 Imbrexia sp. B. Lateral, posterior, anterior, dorsal, and ventral views, X1, 8243-14.



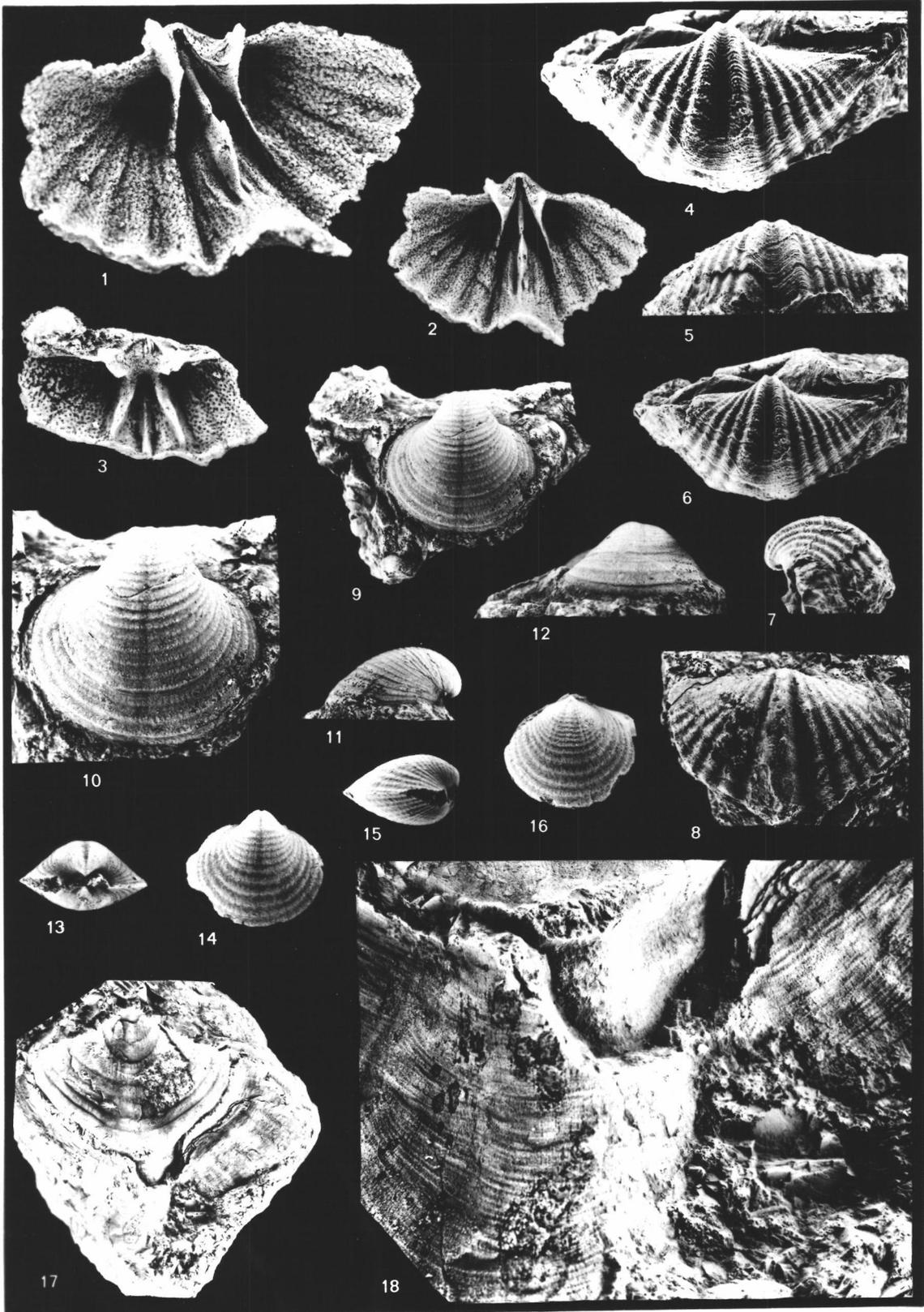
## EXPLANATION OF PLATE 13

- Figures 1 Unispirifer sp. B. Anteroventral view, X2, 8243-15.
- 2-5 Unispirifer sp. B. Anterior, posterior, ventral, and dorsal views, X1, 8243-15.
- 6 Unispirifer sp. B. Enlarged view of anterior part of sulcus of figures 1, 2, X6, 8243-15.
- 7-11 Punctospirifer sp. A. Lateral, anterior, ventral, dorsal, and posterior views, X4, 8248-11 (float).
- 12 Brachythyris suborbicularis (Hall), 1858. Pedicle valve, X2, 8243-2.
- 13-17 Brachythyris suborbicularis (Hall), 1858. Ventral, dorsal, lateral, anterior, and posterior views, X1.33, 8243-2.
- 18-27 Brachythyris fernglenensis (Weller), 1909. Ventral, dorsal, lateral, anterior, and posterior views of two specimens, X2, 8248-35.



## EXPLANATION OF PLATE 14

- Figures 1, 2 Punctospirifer sp. B. Anterolateral and dorsal views of a silicified pedicle valve interior, X5 and X3, respectively, 8243-2.
- 3 Punctospirifer sp. B. Ventral view of interior of a silicified dorsal valve, X5, 8243-2.
- 4-7 Punctospirifer sp. B. Ventral view, X3; anterior, ventral, and lateral views, X2; 8243-2.
- 8 Punctospirifer sp. B. Dorsal view, X2, 8243-6.
- 9-12 Reticularia cf. cooperensis (Swallow), 1860. Pedicle valve, X2, X3; lateral and anterior views, X2; 8243-11.
- 13-15 Reticularia cf. cooperensis (Swallow), 1860. Posterior, ventral, lateral, and dorsal views, X3, 8243-11.
- 17, 18 Athyris cf. lamellosa (Leveille), 1835. Dorsal exterior, showing wide frills, and largement of same, showing ornament, X1 and X4, respectively. 8243-8.



## EXPLANATION OF PLATE 15

- Figures Cranaena longicrura n. sp. Ventral, dorsal, lateral, anterior, and posterior views, X3, 8243-2.
- 6-9 Cranaena longicrura n. sp. Ventral, dorsal, lateral, and anterior views, X2, 8243-2.
- 10-14 Cranaena longicrura n. sp. Anterior, ventral, dorsal, lateral, and posterior views, X2, 8243-5.
- 15-19 Girtyella sp. Anterior, ventral, dorsal, lateral, and posterior views, X1, 8243-6.
- 20-24 ?Cranaena longicrura n. sp. Ventral, dorsal, lateral, posterior, and anterior views, X1.5, 8243-8.
- 25-29 Beecheria sp. A. Anterior, ventral, lateral, posterior, and dorsal views of a plaster cast, X1.6, 8243-11.

