DEPOSITIONAL ENVIRONMENTS AND INARTICULATE BRACHIOPODS OF THE LOWER WHEELER FORMATION, EAST-CENTRAL GREAT BASIN, WESTERN UNITED STATES

by

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For the Department

To the memory of my father

John E. McGee, Sr.

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ABSTRACT

The bases of the Middle Cambrian *Ptychagnostus gibbus* and *P. atavus* assemblage-zones are potential chronohorizons of series or stage magnitude. The uppermost Swasey Limestone and equivalents and the lower Wheeler Formation and equivalents in western Utah and eastern Nevada were sampled to provide data on the depositional environments and distributions of inarticulate brachiopods associated with these horizons.

Three different environments of deposition were recognized in these units: basin, deep sublittoral and slope, and shallow shelf. Basin facies are characterized by thick, predominately calcareous, shales. Deep sublittoral and slope facies are represented by four rocks types: mm laminated dark lime mudstones and wackestones, thin-bedded dark micropelletoidal wackestones and packstones, allocthonous thin skeletal packstones and grainstones, and thin carbonate conglomerates. Shallow shelf facies are characterized by medium-bedded oncolite pelletoidal wackestones and polymeroid wackestones, packstones, and grainstones.

A reciprocal sedimentation model for Swasey-Wheeler deposition is patterned after Kepper's (1976) model for Middle Cambrian Great Basin lithofacies. Terrigenous influx halted Swasey deposition (carbonates) and, coupled with more rapid subsidence in the House Embayment, led to the deposition of the Wheeler Formation and equivalents.

The base of the *P. gibbus* Assemblage-zone coincides with an abrupt lithologic change that is a diastem in at least one locality.

This coincidence precludes the use of this horizon as a time marker in the localities studied. The base of the *P. atavus* Assemblage-zone occurs in a continuously deposited monofacial sequence and appears to be potentially useful as a chronohorizon.

Ten taxa of inarticulate brachiopods were encountered in these rocks: *Lingulella* sp., *Prototreta* sp., *Linnarssonia ophirensis*, *Pegmatreta bellatula*, *Acrothyra minor*, *A. urania*, an unnamed genus of the subfamily Linnarssoniinae, *Acrothele subsidua*, *Micromitra* sp., and *Dictyonina* sp. The two species of *Acrothyra* and *Linnarssonia ophirensis* appear to be potentially useful for correlation of the base of the *Ptychagnostus gibbus* Assemblage-zone. However, their distribution may be facies-controlled in this study. Only the unnamed genus appears to have potential biostratigraphic usefulness for recognition of the base of the *P. atavus* Assemblage-zone. Other common taxa were found to be neither facies nor zonally restricted, thus preventing their usage in zonal correlation.

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INTRODUCTION

The Cambrian System has traditionally been subdivided into three parts, commonly designated as Lower, Middle, and Upper. The recognition of these series boundaries in the type Acado-Baltic province is based upon provincial polymeroid trilobite faunas. Such faunas do not provide geographically extensive chronohorizons and thus temporal correlation based on them is difficult (Robison and Rowell, 1976). The International Stratigraphic Guide (ISSC, 1976:84) recommends selection of boundary-stratotypes for chronostratigraphic units "at or near markers favorable for long distance time-correlation". Therefore, this tripartite subdivision may not be the best available system to employ (Robison and Rowell, 1976; Robison et al., 1977).

At present, a working group appointed by the Cambrian Subcommission of the International Commission on Stratigraphy is gathering data on the most widely recognizable chronohorizons within the Cambrian System. However, clear definition of the system boundaries is needed first to ensure that an orderly scheme may be devised for the placement of series and stage boundaries. After the system boundaries have been defined, this group will proceed to make recommendations on series and stage boundaries. Robison et al. (1977) furnished several examples of potentially useful chronohorizons that are recognizable on a global scale. Two of the chronohorizons discussed are the bases of the *Ptychagnostus gibbus* and *Ptychagnostus atavus* assemblage-zones (Figs. 1, 2). A boundary-stratotype of series or stage magnitude located at one of these agnostoid trilobite

Fig. 1 *Ptychagnostus gibbus* and *P. atavus*.

a. *P. gibbus* cephalon. Note cephalic border spines. KUMIP 145037, locality MC76-152, Drum Mountains.

b. *P. gibbus* pygidium. Note broken spine. KUMIP 145038, locality MC76-28, Eureka mining district.

c. *P. atavus* cephalon, with well developed genal scrobiculae. KUMIP 145032, locality MC76-45, Eureka mining district.

d. *P. atavus* pygidium. Note characteristic chevron-shaped F2 furrow. KUMIP 145033, locality MC76-121, House Range.

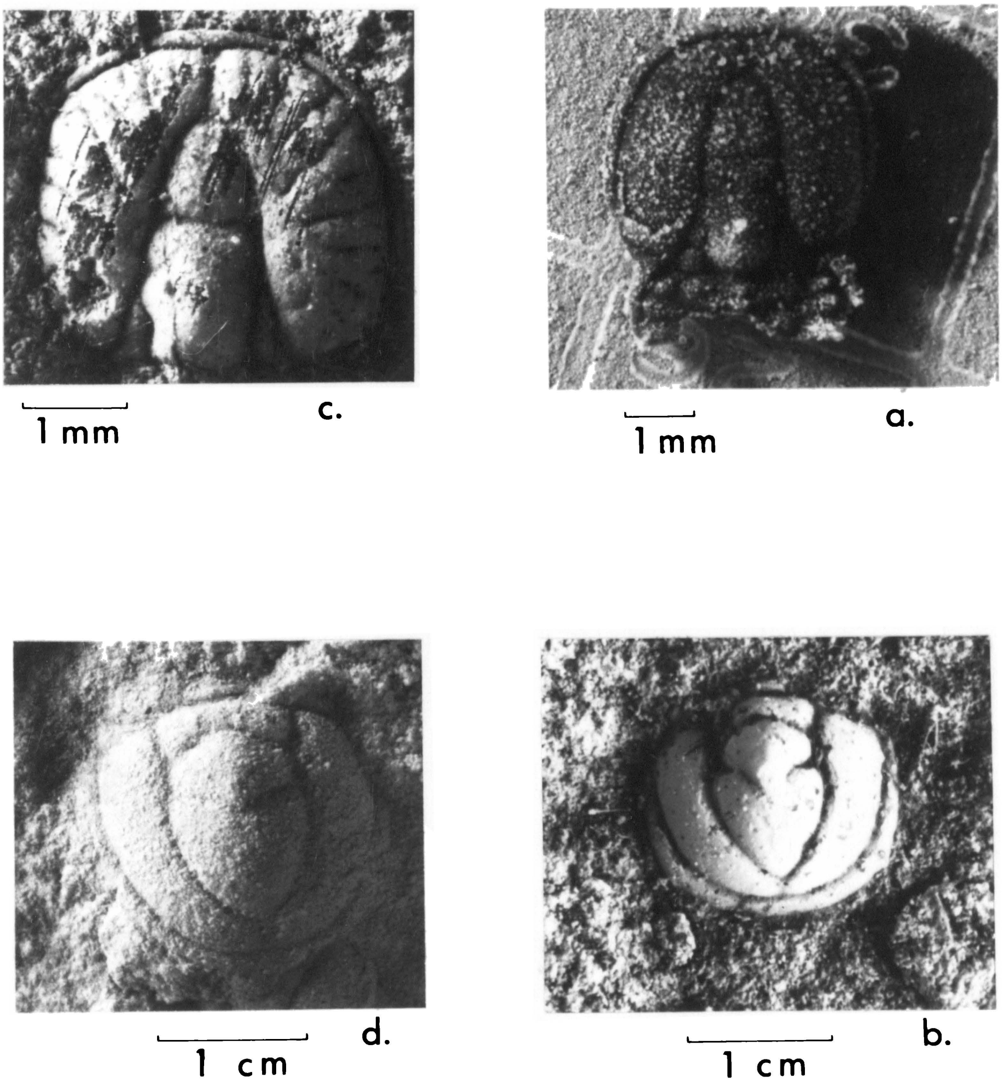


FIG. 1

	open-shelf polymeroid zonation	agnostoid zonation	Eureka Mining District	Northern Egan Range	House Range	Drum Mountains	Canyon Range
MIDDLE CAMBRIAN	<u>Bolaspidella</u>	<u>Ptychagnostus atavus</u>	Geddes Limestone	Secret Canyon Limestone	Wheeler Formation	Wheeler Formation (Limestone G)	"Wheeler Formation"
	<u>Orychtocephalus</u>	<u>Ptychagnostus gibbus</u>					
		barren interzone "A"	Eldorado Dolomite	Eldorado Formation	Swasey Limestone	Swasey Limestone	"Swasey Limestone"

Fig. 2 Biostratigraphic and Lithostratigraphic Terminology (after Hintze and Robison, 1975; Nolan, 1962; Crittenden et al., 1971; Fritz, 1968).

* for the purpose of this thesis, this barren interzone is informally termed barren interzone "A".

chronohorizons would comply with the previously mentioned ISSC recommendation for boundary-stratotypes.

The International Stratigraphic Guide suggests that boundary-stratotypes "be chosen in sequences of essentially continuous deposition" (ISSC, 1976:83). Additionally, Robison et al. (1977:260) suggested that possible boundary-stratotypes for Cambrian series be located "within continuous monofacial sequences of oceanic or open-shelf strata where cosmopolitan taxa are most likely to be encountered". Thus, the depositional environments of units containing these possible boundary-stratotypes need to be investigated before formal recommendations on them are made.

The base of the P. gibbus Assemblage-zone presently is known to coincide with the Swasey Limestone-Wheeler Formation contact in the east-central Great Basin (Fig. 2). The base of the P. atavus Assemblage-zone occurs in the lower Wheeler Formation and equivalents. Studies of these two units and their equivalents must be made to provide the necessary data to help formulate decisions on the suitability of these agnostoid chronohorizons as boundary-stratotypes for Cambrian series and stages. This study deals predominantly with the Wheeler Formation and equivalent units.

Secondarily, these chronohorizons are not everywhere easily recognizable because they are defined by occurrences of agnostoid trilobites. In the western United States, agnostoids are generally restricted to open-shelf lithofacies seaward of a carbonate platform (Robison, 1976) and thus, in beds deposited in areas of more restricted circulation, recognition of these chronohorizons may be difficult.

Another means of recognizing these potentially useful horizons is needed.

Inarticulate brachiopods may be more eurytopic in that they tend to occur more abundantly than agnostoids on inner shelf sites (Rowell and Brady, 1976). If the relationships of inarticulate brachiopod distributions to these chronohorizons were more clearly known, then the brachiopods might provide an additional correlation tool within inner-shelf lithofacies where agnostoids were not available. Inarticulate brachiopods have previously been used in correlation of Cambrian strata by Howe et al. (1972) and Kurtz et al. (1975).

Thus, the main objective of this study is to provide information on the depositional environments of the units associated with the bases of the *Ptychagnostus gibbus* and *P. atavus* assemblage-zones. The secondary objective is to ascertain the distribution of inarticulate brachiopods associated with these agnostoid horizons.

GENERAL SETTING

The area of study is located within the Great Basin of the western United States. The term "Great Basin", as used here, follows the usage employed by Nolan (1943), that is, the west-central portion of Utah, most of Nevada, and the southwestern portion of California (Fig. 3).

The paleogeography of the Early Paleozoic of the western United States is a subject of some debate. Two tectonic models have been suggested for this area. The first model proposes that western North America was bordered by a marginal sea, which, in turn, was

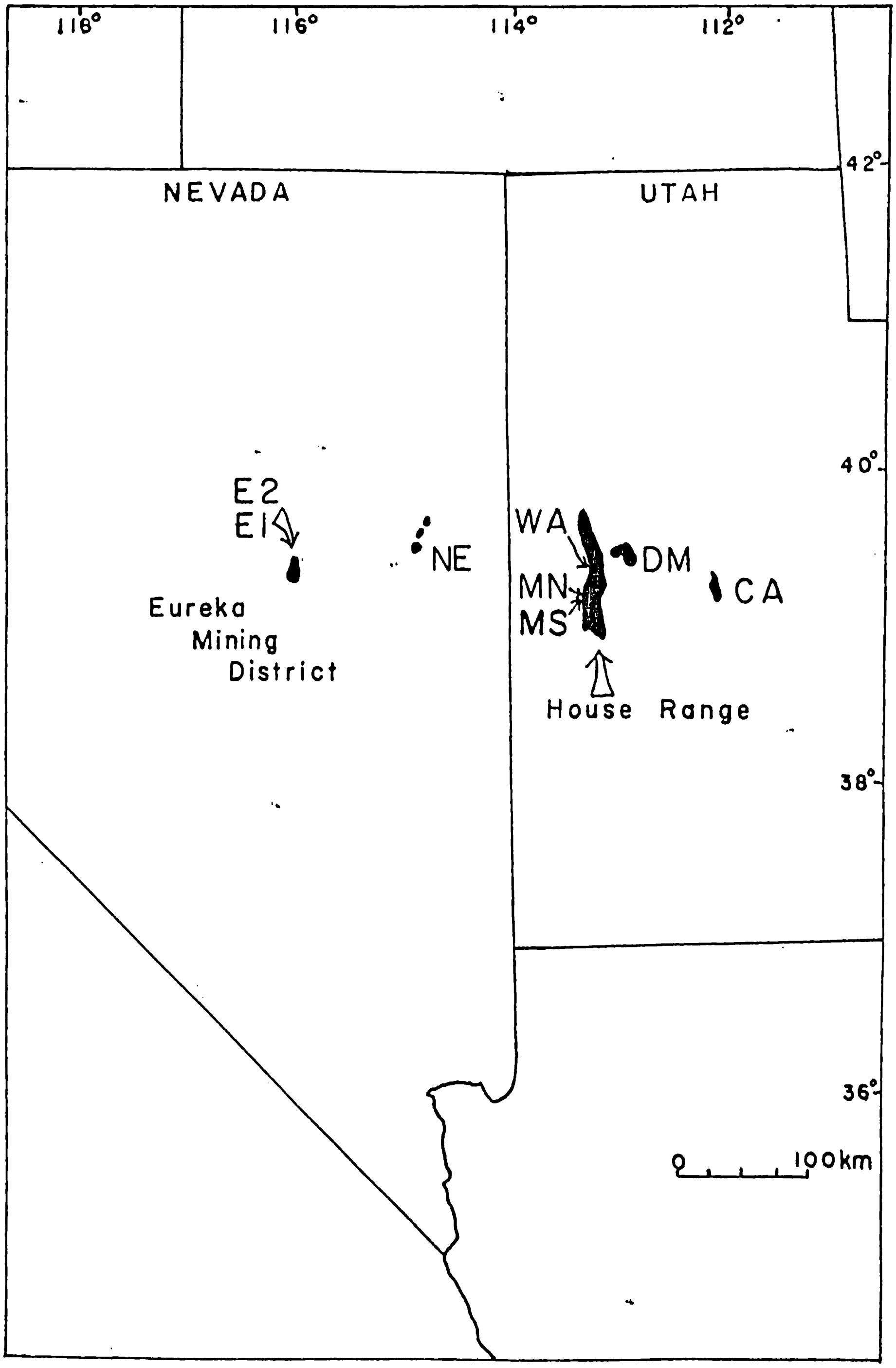


FIG. 3 INDEX MAP OF STUDY AREA (after Palmer, 1971)

KEY:

E1—EUREKA 1	WA—WHEELER AMPHITHEATER
E2—EUREKA 2	MN—MARJUM NORTH
NE—NORTHERN EGAN RANGE	MS—MARJUM SOUTH
	DM—DRUM MOUNTAINS
	CA—CANYON RANGE

bounded on the west by a tectonically active island-arc system (Burchfiel and Davis, 1972; 1975; Churkin, 1974). Burchfiel and Davis (1975) did not, however, postulate the formation of the island-arc system until the Middle Ordovician. Churkin (1974) suggested that the volcanic arc formed in northern California no later than the Late Ordovician, and in southeastern Alaska and western Washington it was in existence during the Precambrian and Cambrian. The lack of concrete evidence concerning the volcanic arc during the Cambrian Period in the latitudes of the Great Basin leaves Cambrian paleogeography in question.

The second model is that of a stable continental margin bounded on the west by an ocean basin (Steward and Poole, 1974; Burchfiel and Davis, 1972). Stewart and Suczek (1977) recently summarized the general paleogeography and tectonics for the Cambrian and latest Precambrian rocks of the western United States. Their tectonic model postulated rifting along western North America and development of a stable continental margin during latest Precambrian to Cambrian time. This model is particularly appealing in that rates of subsidence and sedimentation, associated with post-rifting thermal contraction, for the Precambrian-Cambrian sequence compare very favorably with rates of subsidence, associated with rifting, calculated for the Cretaceous to Holocene sequence in the Atlantic and Gulf coasts of the United States.

It should be noted that Stewart and Poole (1974) recognized that a stable continental margin could later develop into the "marginal sea, island-arc type" margin with the development of a subduction zone. Burchfiel and Davis (1972) favored the first model over the second. Both models are largely based upon the post-Cambrian stratigraphic record (Churkin, 1974) and at present the Cambrian rocks of western and central Nevada, which are the key to this problem, are not well enough understood to test either model.

On a smaller scale, the general lithofacies distributions and depositional environments for the Middle Cambrian of the Great Basin are relatively well known. Robison (1960) first summarized these patterns for the Middle Cambrian rocks. He divided the strata into three approximately north-south-trending lithofacies belts. This pattern consists of a middle belt of relatively pure carbonate rocks that interfinger with more argillaceous belts to the east and west. Palmer (1971) interpreted these medial carbonates as shallow water carbonate bank deposits, whereas the eastern, inner detrital belt rocks were considered to have been the result of sedimentation in shallower, more nearshore depositional environments, associated with the craton margin. Western, outer detrital belt rocks were inferred to represent deeper, open-marine depositional environments. This study dealt predominantly with outer detrital belt rocks.

Kepper (1972, 1976) has made a detailed lithologic study of Middle Cambrian units of the Great Basin and has further subdivided the lithofacies belts described by Robison (1960) and Palmer (1971). Kepper (1976) recognized peritidal, shallow-sublittoral, deep sublittoral and slope, and basin facies in the Middle Cambrian rocks of the Great Basin. Koepnick and Brady (1973) briefly described a shelf-to-basin transition in the Middle Cambrian Marjum Formation in the House Range of western Utah.

PURPOSES OF STUDY

1. To interpret the paleoenvironments of the lower Wheeler Formation, and its equivalents, in the areas shown on Fig. 3. This stratigraphic interval encompasses the Ptychagnostus gibbus Assemblage-zone and the base of the P. atavus Assemblage-zone. The areas for study were chosen because they provide an east-west transect approximately normal to depositional strike. These areas also exhibit reasonably accessible, well-exposed, fossiliferous strata that have not undergone extensive structural deformation.
2. To attempt to produce data on the distribution of brachiopods associated with the P. gibbus Assemblage-zone and the base of the P. atavus Assemblage-zone in the units and localities shown (Figs. 2 and 3), especially noting any significant changes in the brachiopod fauna at or near the bases of these two zones. The potential usefulness of the bases of these two zones as chronohorizons, in the study area, will also be assessed.

PREVIOUS WORK

C. D. Walcott (1912) was the first paleontologist to describe inarticulate brachiopods from Cambrian exposures within the Great Basin. Robison (1964a) presented a brief description of the Wheeler Formation fauna. The fauna is predominantly composed of trilobites, with inarticulate brachiopods being second in relative abundance. A detailed study of the inarticulate brachiopods in the Wheeler

Formation has not been done, and similar studies have not been attempted outside of the House Range on equivalent strata.

The stratigraphy of the Wheeler Formation was summarized by Robison (1960, 1964b) and subsequently revised by Hintze and Robison (1975). Stratigraphic studies of this formation and its equivalents outside of the House Range and Drum Mountains have been generally limited to short lithologic descriptions and brief faunal lists. Detailed biostratigraphic work has not been done. Christiansen (1952) described the stratigraphy of the Canyon Range, and the stratigraphy of the Eureka mining district in Nevada was described by Nolan (1962) (Fig. 3). Fritz (1960; 1968) discussed the structural geology and stratigraphy of the northern Egan Range.

Studies of depositional environments of the Wheeler Formation have not been extensive. White (1973) investigated the depositional environments of this formation in the Drum Mountains and noted a general change from carbonate-rich to shale-rich rocks in an east-west transect from the Drum Mountains to the House Range. White also observed evidence of penecontemporaneous slumping approximately 85 m above the base of the formation. He inferred that these contorted beds possibly indicate a shelf-edge position for the Wheeler Formation at that time. Robison (1964b) and Palmer (1971) both inferred that the Wheeler represented deposits of a deeper water embayment of the north-south-trending outer detrital belt into the medial carbonate belt environment. Thus, this change to a detrital-rich facies represents an eastward shift of the outer detrital belt (Hintze and

Robison, 1975). Kepper (1976) briefly discussed the Wheeler Formation in a larger study of Middle Cambrian facies in the Great Basin.

The depositional environments of the Wheeler Formation and equivalents in the Canyon Range, northern Egan Range, and the Eureka, Nevada mining district have not been studied, and, consequently, only gross paleogeographical interpretation of these areas for the *Ptychagnostus gibbus* and *P. atavus* chronozones have been previously presented (Robison, 1960).

SAMPLE COLLECTION AND PREPARATION

Samples for this study were collected by the writer during June, 1976. The collection areas are shown on Fig. 3. Specific collecting localities are given in Appendix A.

Data for this study were obtained from exposures of the Wheeler Formation and its temporal equivalents in the Canyon Range, Drum Mountains, House Range, northern Egan Range, and the Eureka, Nevada mining district. The study area (Fig. 3) lies between meridians 116° and 112° west and between parallels 39° and 40° north. The exposures form an approximate east-west transect across east-central Nevada and west-central Utah, nearly normal to the depositional strike of the lithofacies belts recognized by Robison (1960). The Eureka District marks the western border of the study area and the Canyon Range defines its eastern limit. The total length of the transect is about 310 km.

Two sections were measured in the Eureka District, three in the

House Range, and one each in the other areas. Spot sampling was employed at all the sections. Samples were primarily collected at fossiliferous horizons. Thick, apparently unfossiliferous portions were sampled at approximately 4 to 5 m intervals as such portions may contain brachiopods without the brachiopods being readily observable in the field. Sampling intervals for paleoenvironmental analysis were determined by the frequency of lithologic changes encountered in the stratigraphic sections.

Brachiopods were recovered by using a modified version of the technique described by Bell (1948). Samples were broken into small blocks approximately 5 to 6 cm in diameter and were then immersed in a 10 percent formic acid solution. After etching for one day, the solution was decanted and the residue was washed through sieves for approximately 15 minutes. The residue was then dried in an oven and the brachiopods were picked from it with a fine brush. If necessary, the procedure was repeated to find additional specimens. Because of the poor quality and the general paucity of brachiopods recovered from the writer's samples, additional specimens from the same localities were needed. These were generously loaned by R. A. Robison.

Oriented hand samples were slabbed and polished, and 90 petrographic thin-sections were prepared from the sample material. Petrographic data on the biotic and inorganic constituents, sedimentary textures, fabrics, structures, and diagenetic features were recorded for all thin-sections and polished slabs.

TERMINOLOGY and APPENDICES

Petrographic terminology for this study is based on Dunham's (1962) classification of carbonate rocks.

The terms chronozone and chron are used to identify the chronostratigraphic (time-stratigraphic) and geochronologic (geologic time) units in this study. Chronozone is defined as "a zonal unit embracing all rocks formed anywhere during the time range of some geologic feature or some specified interval of rock strata" (ISSC:67). Chron is the corresponding geochronologic term (ISSC:69). Examples of equivalent terms of higher rank are system (chronostratigraphic) and period (geochronologic).

Sample localities and informal locality names are given in Appendix A. The writer's samples are numbered with the prefix: "MC76-". R. A. Robison's collections are identified with a numeric symbol or are prefixed with the letters "UU-". Specific locations of all of these collections within the measured sections are given in Appendix B.

Appendices C and D illustrate, respectively, the facies and lithologies and the stratigraphic ranges of the brachiopods for the measured sections in this study. These should be referred to for the discussions on depositional environments and paleontology.

ENVIRONMENTS OF DEPOSITION

Introduction

Three different depositional environments may be reconstructed from the examination of the carbonate and shale units in this study. The uppermost few meters of the Swasey Limestone and the equivalent upper few meters of both the Eldorado Formation and Eldorado Dolomite accumulated in a shallow shelf environment. The lower 15 to 30 m of the Wheeler Formation in the House Range and Drum Mountains, consisting of shales, accumulated in a local basin environment in the House Range area. Additionally, thick shale units of the Wheeler Formation in the Drum Mountains (Fig. C-7) also were deposited in this basin. The term basin is used here not to refer to a physiographic depression, but to an area of predominantly shale formation, as opposed to equivalent areas of limestone deposition. The remainder of the interbedded shales and limestones of the lower one-third of the Wheeler Formation and the strata comprising the measured sections of the Secret Canyon Formation and Geddes Limestone (Fig. 2) formed in a deep sublittoral and slope environment seaward of this carbonate shelf. Kepper (1976) employed the three categories: 1)shallow sublittoral, 2)deep sublittoral and slope, and 3)basin for Middle Cambrian facies of the Great Basin (Fig. 4). In this paper, shallow shelf facies is roughly equivalent to shallow sublittoral facies and the terms basin and deep sublittoral and slope facies have generally the same implications in both studies. Unlike the depositional facies pattern inferred by Kepper, the westernmost lithologies that were studied belong to the deep sublittoral and slope facies rather than

	PERITIDAL	SHALLOW SUBLITTORAL	DEEP SUBLITTORAL AND SLOPE	BASIN
LITHOLOGY	Stromatolitic boundstones	Oolitic, oncolitic, bioclastic grainstones and packstones	Lime mudstone	
	Thrombolitic boundstones	Silty-sandy bioclastic, pelletal wackestones and lime mudstones	Bioclastic wackestone and packstone	
	Laminoid and irregular fenestral lime mudstone	Dolomitically laminated, thinly bedded and mottled lime mudstone	Pelletal wackestone	Mudstone
	Intraclastic calciruditic and calcarenitic packstones and wackestones	Sandy ferroan dolostone to dolomitic sandstone	Intraclastic calciruditic and calcarenitic packstone	
	Nodular and laminated chert	Intraclastic calcarenite wackestone and packstones	Bedded chert	Claystone
		Laminoid fenestral lime mudstone	Silt-clay laminations	
STRUCTURES	Channels < 0.5 m deep	Subhorizontal tubular burrows	Graded beds	
	Sun cracks	Burrow mottling	Slump structures	
	Fenestrae	Small-scale ripple marks	Small-scale scour	Laminated bedding
	Laminated to medium bedding	Small- and medium-scale tabular, tangential crossbeds and trough crossbeds	Burrow mottling	
	Isolated tabular to small mound-shaped algal structures	Laminated to very thick bedding	Laminated to thin bedding	
FOSSILS	Algae	Algae, trilobites, brachiopods	Trilobites (particularly agnostids) brachiopods, sponges	
	Trilobites generally scarce (Where present show low diversity characteristic of adjacent sublittoral)	(Invertebrate material generally uncommon; show low diversity)	(Abundance and diversity higher than shallow sublittoral)	

Fig. 4 Kepper's (1976) Middle Cambrian Depositional Facies

the basinal facies, and thus the presumed continental slope lay further to the west during this time.

With a few exceptions, thin-sections were made only for limestones, and little detailed study of the shales was attempted. Nonetheless, calcareous shales may in places comprise major portions of the Wheeler and equivalent formations. Thin shale interbeds are ubiquitous in the study sections associated with carbonates of the deep sublittoral and slope facies. As a whole, the shales exhibit a wider color variation than the associated limestones. Olive-green, pale red, gray, black, and purple shales are interbedded with the limestones of the deep sublittoral and slope facies. In the House Range and Drum Mountains sections these shales locally contain abundant, well-preserved, fully articulated trilobites and unbroken sponge spicules.

These shale interbeds are interpreted as deposits of intermittent periods of dominantly terrigenous mud influx into the depositional basin. The controlling mechanism of this influx remains unknown.

Basin Facies

Shale Lithology

Description

Of the three facies in this study, this is the least well known. Lithologies consist of evenly laminated mudstone and claystone (Figs. 4, 5). In the House Range and Drum Mountains sections the lower 15 to 30 m (Figs. C4 to C7) consist primarily of shales with few or no limestone interbeds. These predominantly shale sections,

Fig. 5 Basin Facies - calcareous shales. Wheeler Formation, Wheeler Amphitheater section, House Range. Toothbrush for scale is 16 cm in length.

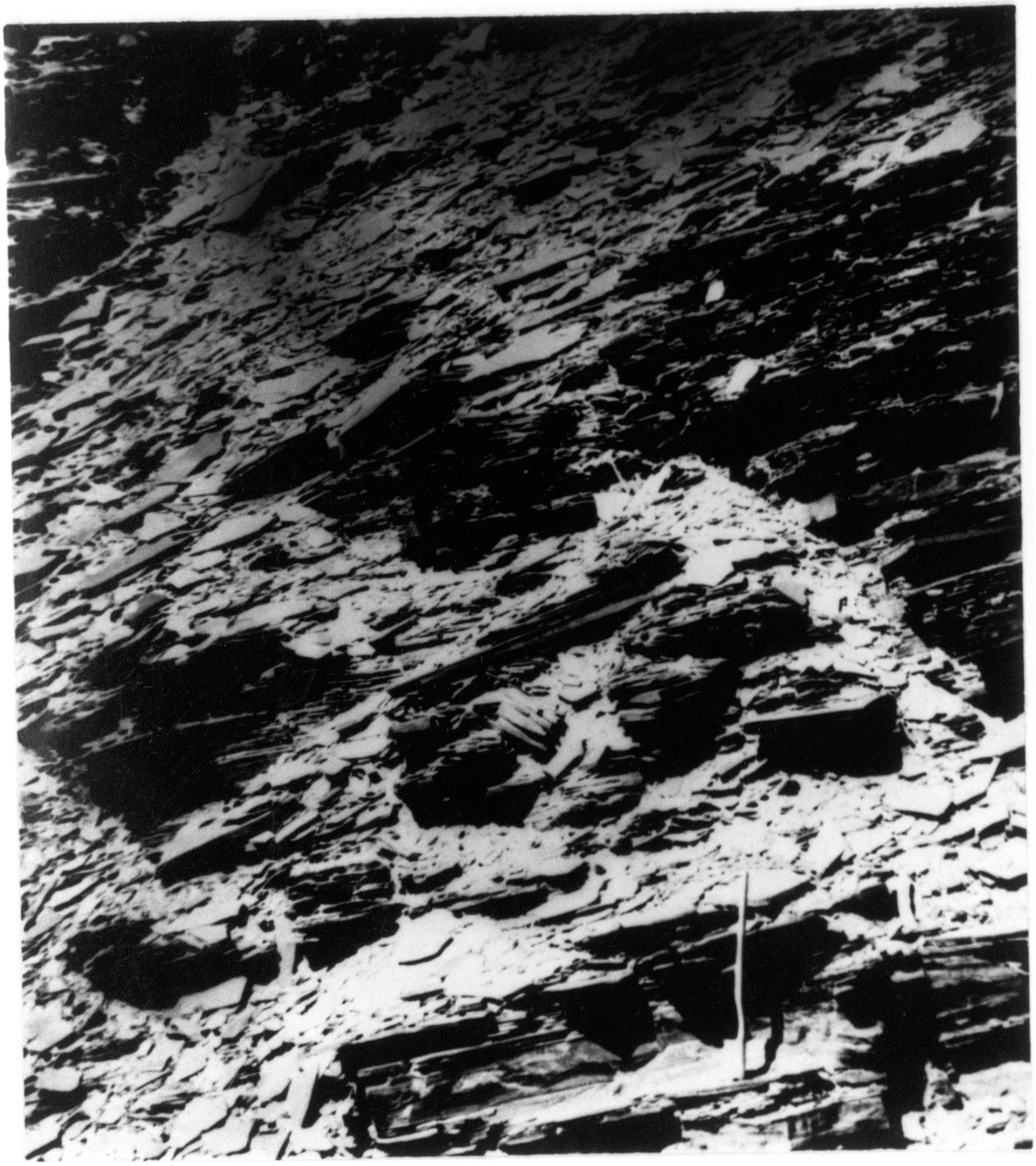


FIG. 5

as well as similar units located higher stratigraphically in the study sections are here assigned to the basin facies.

Laminated calcareous shale is the dominant lithology of this facies. The lower few meters of the Wheeler Amphitheater section consist of non-calcareous shale.

In the Drum Mountains and Marjum South sections, there are locally well-preserved fully articulated trilobites and unbroken sponge spicules.

These shales exhibit the same wide color variation as the shale interbeds of the deep sublittoral and slope facies.

Depositional Environment

The main basis for designating the laminated shales of the lower Wheeler as representing a separate environment is their lithologic integrity. Unlike the Wheeler equivalents elsewhere, shale is the dominant lithology for the lower part of the section or for nearly all of the measured section, as in the Marjum South or Drum Mountains localities. A local basin encompassing the central to south-central House Range and Drum Mountains primarily during the *Ptychagnostus gibbus* Chron has been reconstructed from these thick shale units, which are contemporaneous with laminated lime mudstones and micropelletoidal packstones to the east and west.

Depth estimates are on the same order of magnitude as that of the deep sublittoral and slope facies: 90 to 900 m (Wilson, 1969). Kepper (1976) estimated that in the House Embayment the basinal shales could have accumulated in depths less than 200 m. Depths below the

Cambrian carbonate compensation depth were not likely as most of the shales are carbonate bearing. A lengthier discussion of depth estimates is included in the discussion of the deep sublittoral and slope facies. Additionally, it cannot be inferred that the basin environment was necessarily deeper than the deep sublittoral and slope environment, only that carbonate deposition was secondary to terrigenous sedimentation in the basin environment.

Concretions

A striking feature of the basal Wheeler Formation in the Drum Mountains, Marjum South, and Marjum North sections is the presence of abundant large spherical to disk-shaped carbonate concretions. These occur both within thin shales and also within thin-bedded lime mudstones just above the Swasey-Wheeler contact. In the three localities in which they occur, they are present at the boundary between the basinal and deep sublittoral and slope facies. For convenience they are discussed with the basinal facies.

The concretions range in size from 20 cm to 1 or 2 m in length and 10 to 20 cm thick. In outline they are spherical or elliptical and occur along distinct horizons. Commonly two or more concretions have coalesced into very large bodies up to several meters across.

Concretions are dark gray to black, often evenly mm laminated, and show a faint concentrically layered structure. Abundant disarticulated agnostoid trilobites are common on bedding planes within concretions. Etching with formic acid failed to disaggregate the concretions due to their highly indurated nature. A thin-section of one of these highly indurated concretions shows that it is composed of a massive lime mudstone with very abundant sponge spicules. These sponge spicules probably contribute greatly to the induration of the concretion. Sass and Kolodny (1972) have noted that carbonate concretions are greatly enriched in $CaCO_3$ relative to the country rocks and that this enrichment also increases the induration of the concretions. Other concretions however, show no sponge spicules in thin-section, are evenly laminated and closely resemble the lime mudstones that are common in the deep sublittoral and slope facies. Both types of concretions were common where concretions were encountered in this study.

Contact relations with the surrounding strata are best seen in the Marjum North section of the south-central House Range. Here, the Swasey-Wheeler boundary is exposed in a dry stream bed (Fig. 6). At this locality the basal Wheeler consists of about 10 m of alternating thin lime mudstones and thinner calcareous shales. The concretions occur at the top of this sequence. Some concretions exhibit a gradational contact with the lime mudstones while others are clearly intercalated between thin calcareous shales. The original bedding has been disrupted around the concretions, obscuring contact relations. Another interesting feature of this sequence is the undulatory nature of the interbedded shales and mudstones below the concretions. Wavelengths are a few meters and amplitude of the wavy beds is on the order or 40 to 50 cm.

Outside of the Marjum North locality, the concretions occur as float along the poorly exposed Swasey-Wheeler boundary. No

Fig. 6 Carbonate concretions in lowermost Wheeler Formation, concretion horizon indicated by brackets. Marjum North section, House Range. Swasey Limestone underlies stream bed in foreground. Outcrop thickness about 2 m.

FIG. 6

laterally equivalent lime mudstone beds are noted from the Drum Mountains and Marjum South localities. Carbonate concretions are reported mainly from shales and marls and not from within limestone beds (Weeks, 1958; Dickson and Barber, 1976). Thus these concretions are somewhat unusual in their occurrence.

<u>Origin of Concretions</u>

Carbonate concretions have often been interpreted as being an early diagenetic feature (Dickson and Barber, 1976; Zangerl et al., 1969). Basically, there are two problems to be explained in connection with these concretions. These are: 1)the origin of the concretions and 2)the lack of fossils in the enclosing mudstones and shales, as contrasted to the fossiliferous concretions.

The excellent preservation of fossils within the concretions tends to support an early diagenetic origin for these concretions. Some of the concretion growth may have been a late diagenetic phenomenon however, disrupting bedding of already lithified country rock (Fig. 6). Sass and Kolodny (1972) proposed a model of adjacent microenvironments of anaerobic and aerobic conditions to explain concretion growth. Differences were presumably controlled by amounts of organic matter, or slight differences in permeability and access of oxygen. Aerobic sites were typified by decomposition of organic matter that released CO_2 and nitrates. The increased CO_2 lowered the pH, causing dissolution of $CaCO_3$ and thus destroying any record of calcareous fossils. Anaerobic sites released ammonia due to decomposition of carcasses, raising the pH, and thus precipitating $CaCO_3$, forming the concretions around the carcasses that were releasing ammonia. A gradient of CO_3 would result, with CO_3 being supplied to the concretion site due to the lower CO_3 concentrations in the waters surrounding the concretions. Silica was commonly precipitated on the margins and rarely within the concretions. On the margins the pH was probably low, permitting silica precipitation but the silica within the concretion would have required different conditions to develop for it to have been precipitated. The origin of these concretions is probably complex and requires a detailed geochemical study involving stable isotope distribution and compositional variation within and between concretions in order to fully understand them. The basic pH-controlled mechanism in relation to concentrated decomposing animal carcasses is probably valid and would explain the fossiliferous concretions and unfossiliferous country rocks. Primary depositional mechanisms were found to be lacking in explaining the fossil distribution both within and around the concretions. Slow rates of sedimentation, mass kills, or current sorting could lead to anomalous concentrations of fossils. No evidence of current sorting is seen in these rocks. The first two mechanisms could concentrate fossils but would not alone explain their absence in laterally equivalent rocks.

Deep Sublittoral and Slope Facies

Introduction

The carbonates of the deep sublittoral and slope facies consist of four lithologies: 1)lime mudstone-wackestone, 2)micropelletoidal wackestone-packstone, 3)skeletal packstone-grainstone, and 4)conglomerate.

Lime Mudstone-Wackestone Lithologies

Description

The most commonly developed carbonate rock type encountered from the deep sublittoral and slope facies in this study is a dark gray to black, thin-bedded lime mudstone (Fig. 7). This rock type is the preeminent carbonate lithology in the four easterly sections, comprising most of the limestones in the Wheeler and Secret Canyon Formations. Much less common are agnostoid wackestones which occur at the bases of these formations, especially in the Marjum North (House Range) and northern Egan Range sections. The wackestones are nearly indistinguishable from the lime mudstones in outcrop, but closer examination reveals the abundant fossil grains. This is the only notable difference between these two rock types of the Wheeler and Secret Canyon Formations.

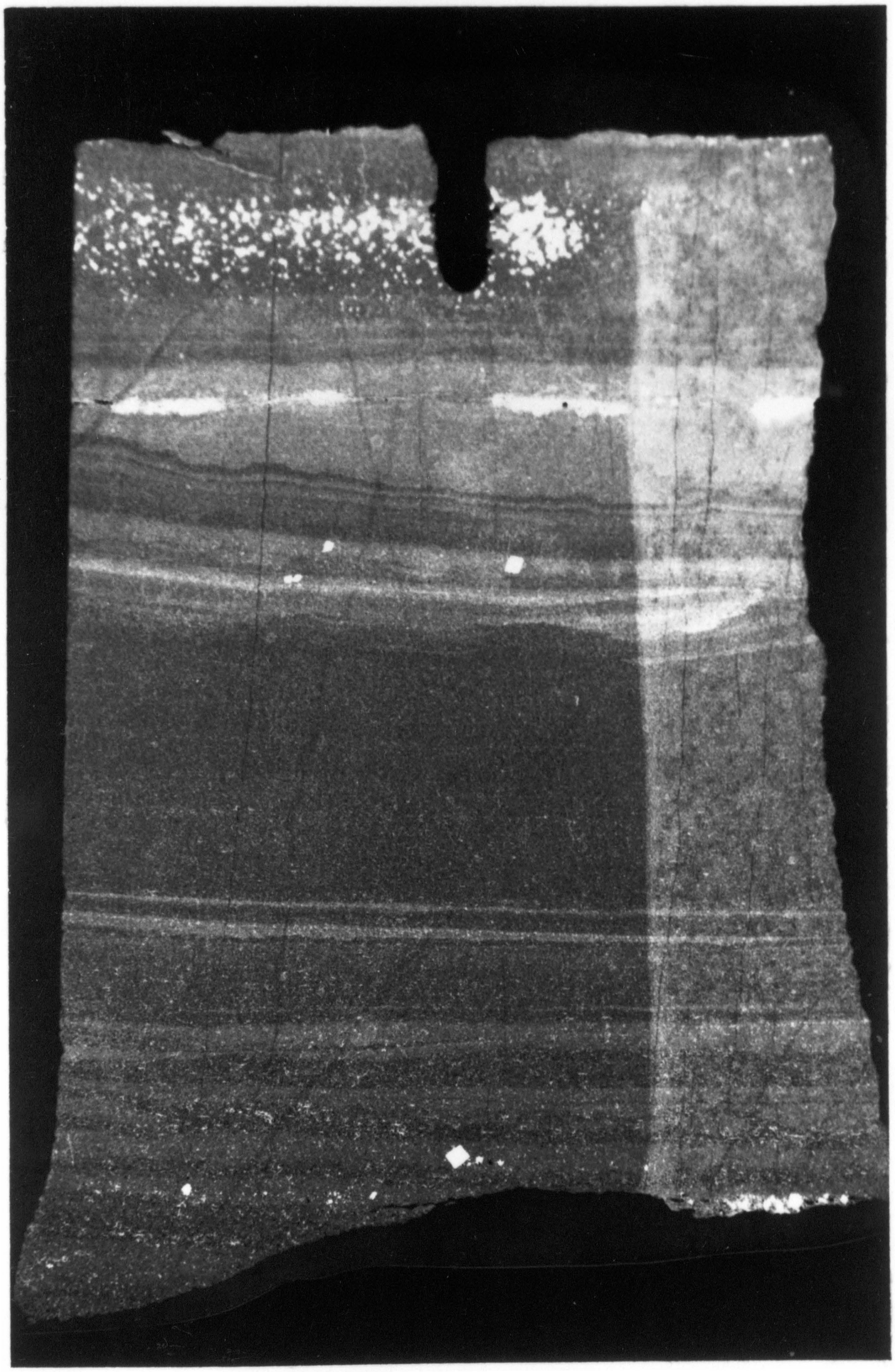
Thin, 5 to 30 cm, evenly bedded, laterally persistent strata characterize these lithologies. Dark gray to black is the most common color, although less common red to pink and pale green lime mudstones do occur with dominantly black lime mudstones in the House Range.

The most common sedimentary structure is even, mm-scale lamination. Less common structures include microscopic cut and fill (Fig. 8), micrograded bedding, and rare load structures (Fig. 9). A minority of the samples of this lithology are massive. Only one sample (MC76-189, Fig. 10) exhibited possible currow mottling, similar to that described by Rees (1976). Convolute bedding occurs in a widespread 6 m thick unit in the Drum Mountains.

Fig. 7 Thin-bedded lime mudstones, deep sublittoral and slope facies. Wheeler Formation, Wheeler Amphitheater section. Hammer for scale.

FIG. 7

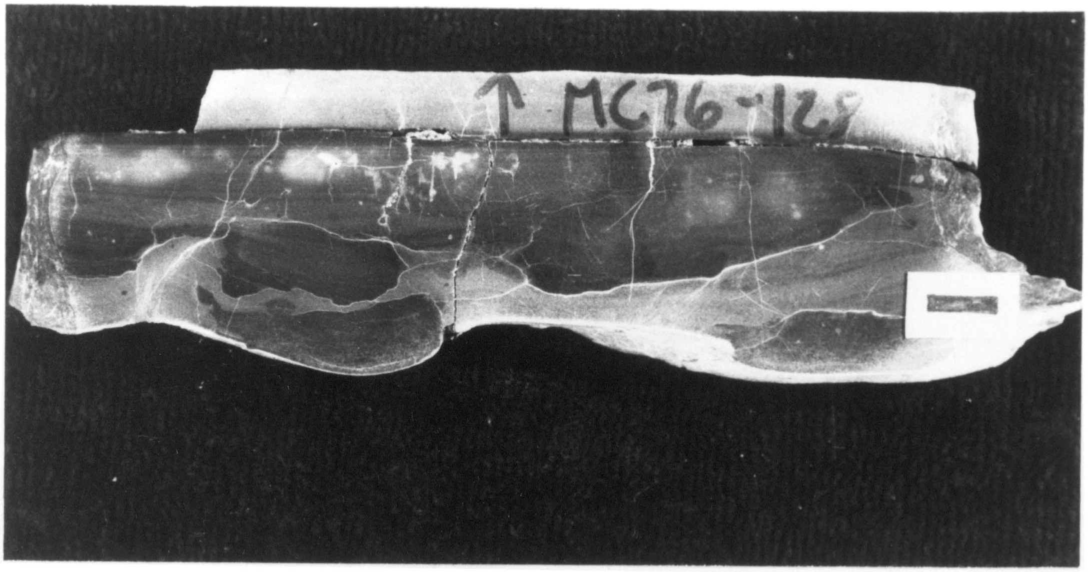
Fig. 8 Microscopic cut and fill. Negative print of a thin-section (MC76-119). Marjum South section, House Range. White patches are pyrite.



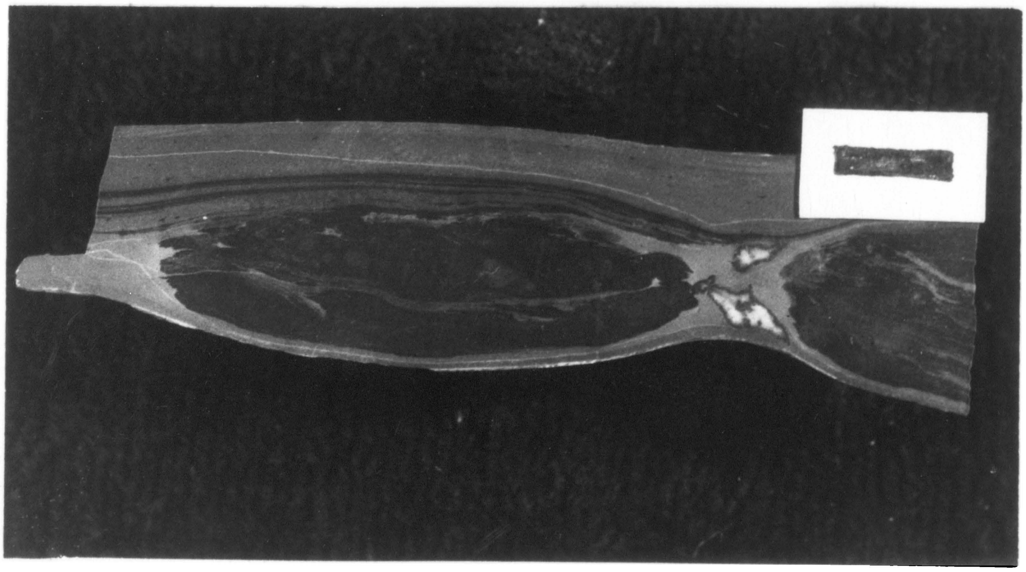
1 cm

FIG. 8

Fig. 9 Load (?) structures. Wheeler Formation, Wheeler Amphitheater section, House Range. Black bar scale = one cm.



a



b

FIG. 9

Fig. 10 Burrow (?) mottling. Wheeler Formation, Canyon Range. Note slight tonal variations just to left of bar scale. Black bar scale = one cm.

FIG. 10

The even, mm laminations are expressed as slight mud color differences, grain size differences, or concentrations or organic matter in laminae that alternate with organic-poor laminae. The micrite has undergone varying degrees of neomorphism, ranging from apparently unaltered, to micrite that has completely neomorphosed to microspar.

Insoluble residues were not recorded in this study. All deep sublittoral and slope facies limestones etched for brachiopods commonly exhibited a significant insoluble clay residue. Hintze and Robison (1975) noted that samples of the Wheeler Formation in the Marjum Canyon area of the central House Range averaged 45 percent insoluble residue, mostly clay, ranging from 10 to 70 percent insoluble residue.

The non-mud fraction of this rock type consists of skeletal grains and carbonate silt. The carbonate silt occurs as distinct laminae which grade upward into micrite or is present as disseminated silt grains throughout a mudstone bed.

Skeletal grains include inarticulate brachiopods, trilobites and sponge spicules. The lime mudstones vary in fossil content from barren to common. However, fossils are typically sparse. Polymeroid trilobites are commonly broken, but agnostoids are dominantly unbroken, although the majority are disarticulated. Sponge spicules are usually well preserved. Brachiopods are generally rare within the mudstones, but are locally abundant in the agnostoid wackestones of the lower Secret Canyon Formation.

In this study, pyrite and limonite pseudomorphs after pyrite occur most commonly in the lime mudstones, but in only about one-half of the samples, with no apparent pattern of distribution. The pyrite is usually developed as rare disseminated microscopic cubes.

Beds of this lithology are developed in two general outcrop settings: either as thin flaggy beds in dominantly shale sequences or as ledges of thin-bedded limestone. Aside from these shales, only rocks of the skeletal grainstone-packstone lithology are found associated with these lime mudstones and wackestone.

Depositional Environment

The characteristics of limestones deposited below wave base in deep sublittoral and slope environments have been described by several, including Wilson (1969, 1975), Cook et al. (1972), Taylor and Cook (1975), Kepper (1976), and Reinhardt (1974). The following list of criteria for limestones from the deep sublittoral and slope environments is based on Kepper (1976), with additional data from Wilson (1969, 1975).

1. Dominance of lime mud.
2. Relatively common calcisiltites and fine grainstones, usually showing small-scale grading or ripple cross-lamination.
3. Dark color, although pink and red limestones do occur in places.
4. Even, millimeter lamination.
5. Very even, planar ½- to one-foot-thick limestone beds intercalated with much thinner shales.

6. Generally very specialized benthonic fauna; much more commonly the fauna is entirely pelagic.
7. Major discontinuities in bedding appear to form large-scale cut and fill or slump structures. Soft sediment slumps tend to be rarer in carbonates than in terrigenous deposits, however.
8. Allodapic sands and exotic blocks interbedded with dark mudstones.
9. Flute casts.
10. Load casts.
11. Groove casts.
12. Mn-Fe crusts and nodules.
13. Resedimented clasts and retextured sediments.
14. Burrow mottling.

The lime mudstones of this study possess many of these characteristics, but no flute nor groove casts, nor Mn-Fe crusts and nodules were found within this lithology. Questionable load casts were observed only locally within the Wheeler Amphitheater section (Fig. 9). Load structures were not observed in the other sections. Criteria 2, 8, and 13 will be discussed later as they are applicable only to the other lithologies of the deep sublittoral and slope facies.

Most of the criteria in the list are self-explanatory, but 6 and 7 deserve more explanation.

6-Specialized benthic and pelagic fauna

The following discussion of faunas of the lime mudstones and wackestones will be restricted to the mode of life of these forms and will not include data on their biostratigraphic distribution and taxonomy. These topics will be covered in a separate section (p. 77).

The fauna of these mudstones and wackestones consists of inarticulate brachiopods, polymeroid and agnostoid trilobites, sponges, and rare molluscs.

The paleoecology of Cambrian inarticulate brachiopods is not well known. McBride (1976), in a study of Upper Cambrian communities of the outer detrital belt of Nevada and Utah, stated that inarticulate brachiopods were mostly epifaunally attached animals, although some were probably attached to animals, seaweed, or floating objects. Polymeroids probably were mostly burrowing or benthic crawling organisms. Some polymeroids have been interpreted as nektic (Bergström, 1973). Agnostoids have been interpreted as having been pelagic by some (Robison, 1972a). However, their mode of life is still in dispute, although it is agreed that major differences in the structure of the hypostoma suggest that agnostoids differed markedly in their feeding habits from polymeroid trilobites (Robison, 1972b). Sponges are exclusively benthic and Cambrian sponges apparently had only weakly constructed skeletal nets and therefore required generally quiet water for their preservation (Rigby, 1976). The one mollusc found in the lime mudstones is Hyolithes, a problematical form that was probably benthic (Yochelson, 1961).

Absence of bioturbation suggests only a limited benthic assemblage was present. Crimes (1974) concluded from the scarcity of deep-sea trace fossils in the Cambrian that the deep ocean floor was not extensively colonized until the Ordovician. Thus, the fossils suggest that the majority of the fauna was nekto-planktic and that the environment was one of low energy and below wave base.

7-Large-Scale Bedding Discontinuities

About 85 m above the base of the Wheeler Formation in the Drum Mountains section is a distinct ledge informally termed the "contorted unit" (White, 1973)(Fig. 11). Bedding within this unit is complexly folded and thrusted. However, this folding does not extend beyond the sharply defined upper and lower limits of this unit. This ledge is about 6 m thick and may be traced laterally on either side of the measured section for about 2 km. It abruptly overlies uncontorted, lithologically-similar lime mudstones and shales. This comprises a major discontinuity in bedding, as listed on page 31. Additionally, abundant fossils, especially brachiopods, are common in samples from the base of this unit, in contrast to the barren mudstones which underlie it. The abrupt increase in abundance of brachiopods at the base of this unit suggests environments differing from those in which the barren lime mudstones accumulated. Brachiopods tend to be most abundant just seaward of the Cambrian middle carbonate bank in the innermost outer detrital belt (Rowell and Brady, 1976). This contorted unit may have slumped downslope from a more shoreward position where more favorable conditions for biotic activity may have

Fig. 11 "Contorted Unit." Wheeler Formation, Drum Mountains. Stratigraphic top is towards top of picture. Tooth-brush for scale is 16 cm in length.

FIG. 11

existed. The proximity of this unit to the inferred margin of the House Embayment (Fig. 20) provides evidence of the required slopes to produce oversteepening and subsequent slumping. The highly complex nature of the folding and thrusting of beds within this unit matches closely descriptions of other slump structures described by Potter and Pettijohn (1963). Estimates of distance travelled cannot be made on the data collected, but the lithology of the unit suggests that it initially accumulated in the deep sublittoral and slope facies.

Conclusions

Depth estimates are difficult to provide for the lime mudstone-wackestone lithology. Wilson (1969) described similar occurrences which were thought to have been formed at depths as shallow as 300 feet (91 m) and some as deep as 3000 feet (910 m). Kepper (1976) concluded that "slope" and "basin" facies in the House Embayment could have developed within a deep sublittoral zone less than 200 m in depth. There are no criteria known at present to differentiate depths of facies within this range (200 m to 3000 m), as there are for inter-tidal and supratidal carbonate environments.

It does appear that depths of much more than 300 or 400 m were unlikely during deposition of the lime mudstones of the Wheeler. R. A. Robison (oral communication, 1977) has observed stromatolites at the top of the Wheeler Formation in the Drum Mountains. If these are in situ, they would imply water depths during their formation of only a few meters (Buthurst, 1975). Underlying the Wheeler, the topmost Swasey Limestone represents depths of a few tens of meters. (Refer to discussion on shallow shelf facies.) Allowing for compaction, the Wheeler in the Drum Mountains represents about 350 to 400 m of uncompacted sediments. If a simple infilling of the area reestablished shallow subtidal to intertidal conditions, such depths indicated by the stromatolites, then the maximum depth of the basin could not have exceeded this uncompacted thickness. This argument does assume that no uplift took place to aid shallowing and that shallowing was produced solely by sedimentation. However, the House Embayment was apparently active tectonically during the Cambrian, as evidenced by paleogeographic maps for the Middle and Upper Cambrian Series (Palmer, 1971). Facies distributions are often delineated by the margins of this feature. To assume no activity during Wheeler deposition may be unrealistic. If rapid subsidence accompanied sedimentation however, these depth estimates (300 to 400 m) would necessarily have to be decreased.

Finally, this argument may apply only to the Drum Mountains area. A "zero" sea level line above the Wheeler Formation would have to be established in the other areas in order to estimate water depths for this facies.

Fossils tend to be most abundant in the lower 20 m of the Secret Canyon Formation where this facies is well-developed, and again are more abundant at the base of the *Ptychagnostus atavus* Assemblage-zone. These more fossiliferous limestones may represent shallower depths than comparable unfossiliferous limestones. However, the abundance of fossils is the only detectable difference in the rocks and this faunal distribution may have been controlled by other factors at these levels, either environmental, e.g., salinity, temperature, etc. or diagenetic loss. If environmental, the controlling factor(s) appears to have affected equally all of the faunal elements.

In summary, the lime mudstones and wackestones accumulated in a deep sublittoral and slope environment, in depths below storm wave base. Depth figures cannot be assigned, although Wilson's (1969) lower figures and Kepper's (1976) estimates are probably of the right order or magnitude. Faunas were primarily nekto-planktic with a limited benthic assemblage.

Micropelletoidal Wackestone-Packstone Lithology

Description

This rock type is restricted to the Geddes Limestone in the Eureka mining district (Fig. 3). It consists of dark gray to black, evenly bedded, micropelletoidal packstones and wackestones (Fig. 12). A few beds of micropelletoidal wackestone do occur in the Secret Canyon Formation in the northern Egan Range section but these are volumetrically insignificant.

The lower 40 to 45 m of the Geddes occurs in thin beds, one to 15 cm thick, with thin intercalated shales. The upper 55 to 60 m of the Geddes Limestone consists of thicker beds, 20 to 50 cm thick, with thin intercalated shales. Nodular black chert is common above the basal 15 m of the formation.

Sedimentary structures include even, mm lamination, micrograded bedding, and rare microscopic cross-lamination. Even, mm laminations

Fig. 12 Micropelletoidal packstone. Geddes Limestone, Eureka-1 section, Eureka mining district. Thin-section photomicrograph, plain light.

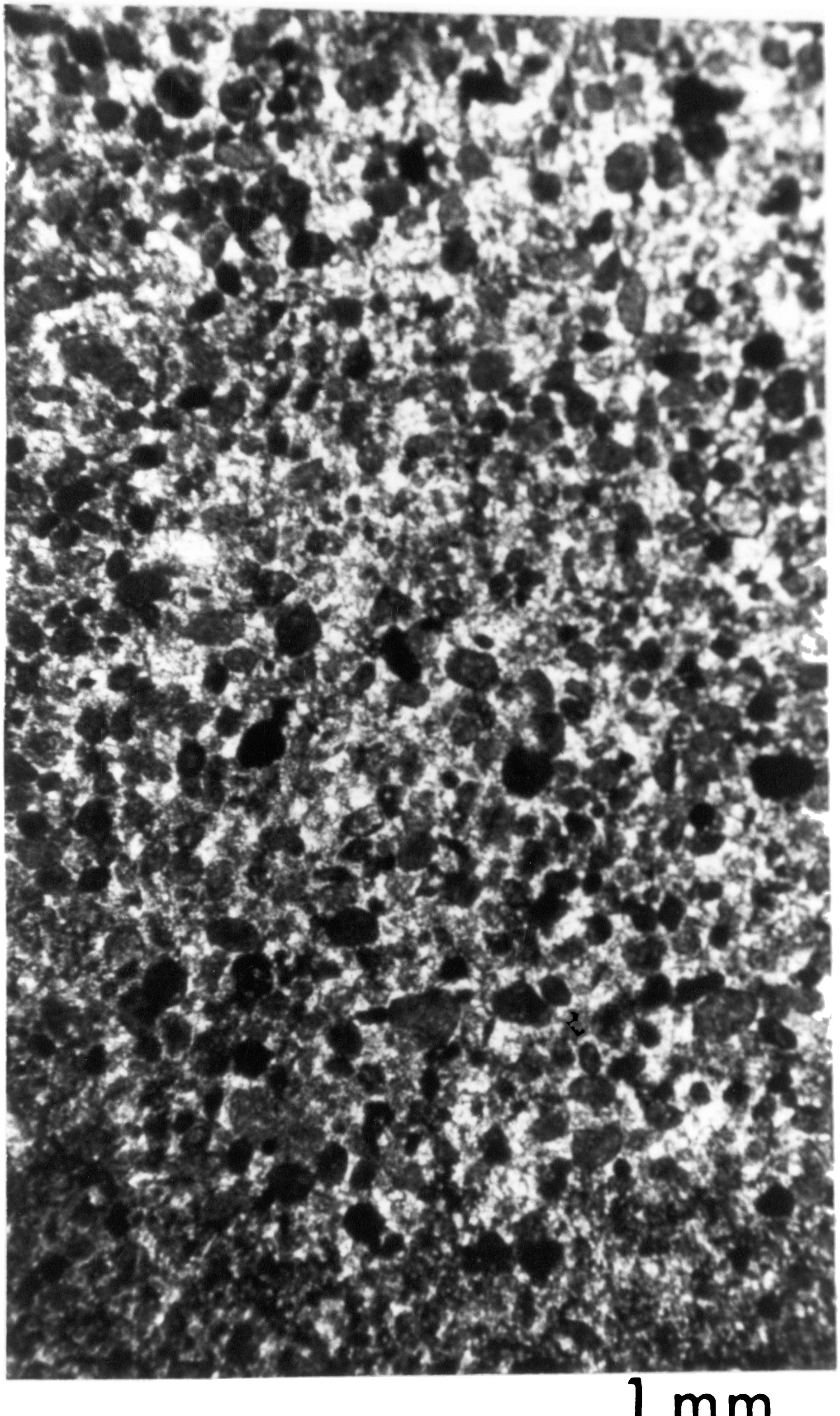


FIG. 12

are more common in the thinner beds, but are not ubiquitous. Micrograded bedding is recorded only from about one-third of the samples for which thin-sections were made. These are mostly from the lower 20 m of the section. Microscopic cross-lamination was observed in only one thin-section (MC76-4) out of 15 that were examined.

The dominant grain type is a micropelletoid, averaging slightly less than 0.1 mm in diameter. The micropelletoids exhibit no relict textures nor are nuclei preserved. Also relatively common are micro-intraclasts, micritic grains of the same size range but possessing much more irregular and varied outlines.

Agnostoids are common in the lower 20 m of the Geddes, as are brachiopods, but both are absent to rare higher in the section. Brachiopods are typically crushed in hand sample. Sponge spicules are rare to common throughout the section. A single specimen of a molluscan, Stenothecoides, was recovered from about 45 m above the base of the section.

As mentioned earlier, nodular black chert is abundant above the basal 15 m of the formation. The chert may also occur as disseminated grains within the matrix of the rock.

Rare beds of lime mudstone are associated with this lithology and occur with no apparent pattern. Carbonate conglomerates are found only with this rock type in this study. Other spatially associated rock types are thin intercalated pale red calcareous shales and the dolomite of the underlying Eldorado Dolomite.

Depositional Environment

This lithology is an example of the calcisiltite microfacies of deeper water limestones described by Wilson (1969). The bedding style, even, mm lamination, dark color, micrograded bedding, microscopic cross-lamination, restricted benthic fossils, and pelagic fossils all indicate a similar environment of deposition to that of the lime mudstone lithology. Wilson (1975) noted that such calcisiltites were found in starved geosynclinal troughs or centers of deep intra-cratonic and marginal cratonic basins, well-removed from coastlines and the influence of carbonate-producing shelf areas. The source of the carbonate is from outside the "basin", due to a rain of decaying plankton and the influx of fine argillaceous and siliceous material. Wind-blown material is a significant portion of the material deposited. A starved, relatively deep basin results.

Wilson's model is based on several examples and as such is not applicable in all its details to this study. The geographic extent and geometry of this lithic type is unknown. These deposits may be part of a geosynclinal trough, but the evidence for a basin is equivocal. Thus, they are here treated as a subdivision of the deep sublittoral and slope facies. Subsequent study may necessitate their reassignment to a different depositional facies.

It can be demonstrated that these micropelletoidal wackestones and packstones do represent relatively low sedimentation rates. Assuming uniform rates of subsidence over the study area, and that the bases of the Ptychagnostus gibbus and P. atavus assemblage-zones are good time markers in this region, then thickness comparisons of sediments accumulated during the P. gibbus Chron may be made for the units studied.

Assuming that the thickness of shale observed in the field is only one-fourth its original thickness (Weller, 1960) and that the limestone thickness observed is about equal to its depositional thickness (Bathurst, 1975), it is possible to estimate the original uncompacted thickness of sediments deposited at each measured section. Adding the estimated shale thicknesses to the thickness of limestone gives a figure representing the probable total thickness of sediment initially deposited at each section, during the P. gibbus Chron. Comparisons of these recalculated thicknesses yields information on relative rates of sedimentation. The calculations are given below:

Eureka - Geddes Limestone	-27m(lime)+4(5m)(shale)=47m
N. Egan Range - Secret Canyon Formation	-50m(lime)+4(25m)(shale)=150m
Marjum South - Wheeler Formation	-1.5m(lime)+4(26m)(shale)=105.5m
Wheeler Amphitheater - Wheeler Formation	-20m(lime)+4(20m)(shale)=100m
Drum Mountains - Wheeler Formation	-28m(lime)+4(37m)(shale)=176m

Estimates of lime and shale thicknesses are quite crude, but a difference of magnitude of two or three times is apparent and tends to indicate a much slower rate of sedimentation for this lithology than for any other rock type in this study.

Another of Wilson's (1975,p.355) criteria for recognition of such "starved" environments is the common presence of chert. These micro-pelletoidal wackestones and packstones are the only rock types in this study to have any chert associated with them, the chert being common as nodules and lenses throughout much of the section.

The "starved" environment existed because it was sheltered from sediment influx. This may have been due to a topographic barrier or extreme distance from the sediment source. There is no good evidence favoring the existence of a topographic high on any side of this locality during this time. If the sediment source were material that was transported seaward from the shallow shelf, then distance of transport might have been an inhibiting factor as this is the most westerly section examined and thus farthest from the shallower sites of high carbonate production on the shallow shelf.

In summary, the micropelletoidal packstones and wackestones accumulated in a relatively starved deep sublittoral environment that was supplied by slow influx of carbonates and terrigenous clastics from more shoreward regions. Biotic activity was relatively rare, except for inarticulate brachiopods and probably nekto-pelagic agnostoids. Depth was probably on the same order of magnitude as that of the lime mudstone and wackestone lithologies.

Skeletal Grainstone-Packstone Lithologies

Descriptions

These lithologies are limited in their distribution to a few thin beds in the Wheeler Formation at the Drum Mountains and Marjum South sections. They are treated collectively because of their similar modes of origin. However, each will be described separately.

Skeletal Grainstone-Drum Mountains Section

Beds of this lithic type are dark gray to black, evenly thin-bedded, 2 to 10 cm thick, and contain pelletoids. Polymeroid trilobite fragments are the dominant grain type.

A small-scale, 4 to 5 cm thick, Bouma A division sequence is exhibited in samples from one bed (Fig. 13). The Bouma A division sequence is a size-graded sequence deposited by turbidity currents. A basal one cm thick pelletoidal wackestone is overlain along an irregular contact, with relief of a few mm, by a pelletoidal polymeroid grainstone. Clasts of the basal wackestone are present in the lower portion of the grainstone. Grains in this part of the Bouma A sequence range from 1.5 to 2.0 mm in length. Grain size diminishes upward so that in the uppermost grainstone layer grains average 0.1 to 0.3 mm in length. The thickness of the grainstone layer is approximately 3 cm. The finer grainstone grades into pelletoidal polymeroid packstone and wackestone.

The matrix material consists predominantly of equigranular microspar with rare blocky anhedral spar. The cloudy microspar has gradational contacts with scattered micrite patches and with the grains. There is no dog-tooth spar, nor incompletely cemented areas. These characteristics point to a neomorphic origin for the sparry matrix, rather than it representing a void-filling cement.

Closely associated rock types include very fossiliferous calcareous shales immediately above and below. Lime mudstone beds also occur just below ledges of the skeletal grainstone.

Fig. 13 Bouma A division sequence, skeletal grainstone. Wheeler Formation, Drum Mountains. Sample MC76-163, negative print of a thin-section. Left-third of thin-section stained with alizarin red S.

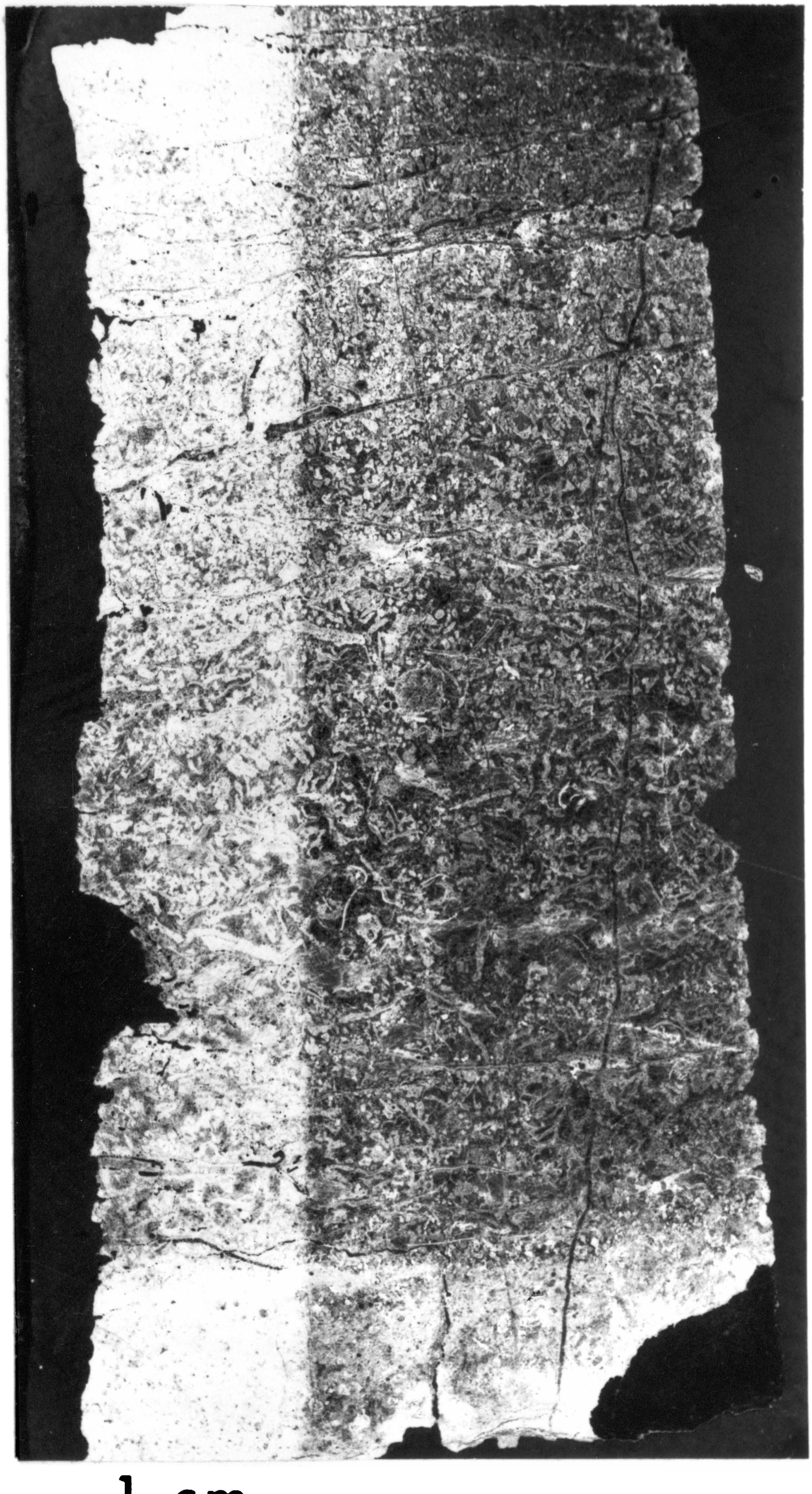


FIG. 13

Skeletal Packstone-Marjum South Section

The second example of this lithic group consists of dark gray to black, apparently thin-bedded, skeletal packstones. Samples are numbered MC76-121, 30 m above the base of the Wheeler Formation (Figs. 14a&b).

Due to the abundant, well-preserved fossils, this horizon has been an extremely popular site for fossil collectors as well as having been extensively samples by previous workers in studies of Wheeler Formation faunas. Therefore, contact relations with the surrounding shales and information on the bedding style have largely been destroyed. The horizon now exists as a layer of limestone blocks that caps a small ridge. Based on the size of the blocks and their limited distribution, the thickness of the unit was presumably less than one meter and probably comparable to the thickness of lime mudstone beds lower in the section.

It is not known what sedimentary structures characterize this unit, but polished slabs show that even, mm laminations are rare. Packstone lenses are interbedded with lime mudstone and wackestone. These lenses have abrupt, slightly irregular contacts with the associated unfossiliferous zones. Locally, the mudstone is laminated.

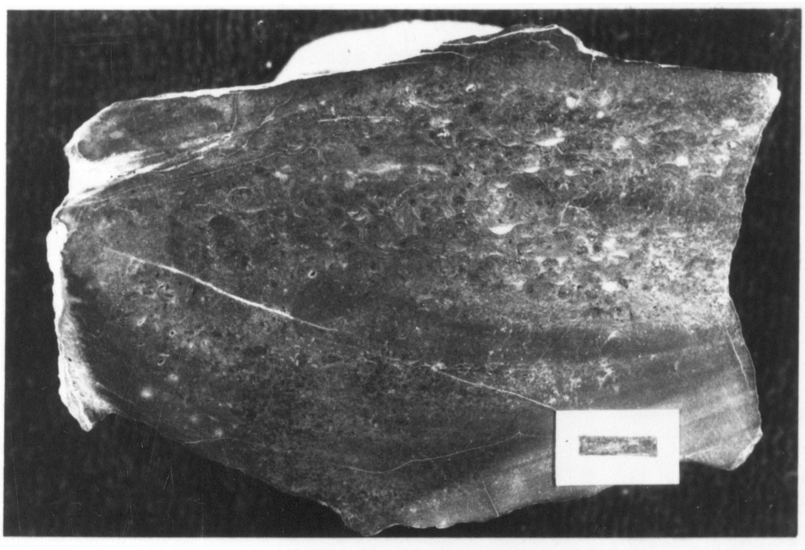
The matrix consists primarily of micrite with shelter cements of dog-tooth spar developed on the apparent undersides of some trilobite grains.

Grains are predominantly disarticulated agnostoids, broken polymeroids and rare broken to nearly complete brachiopods. Size of

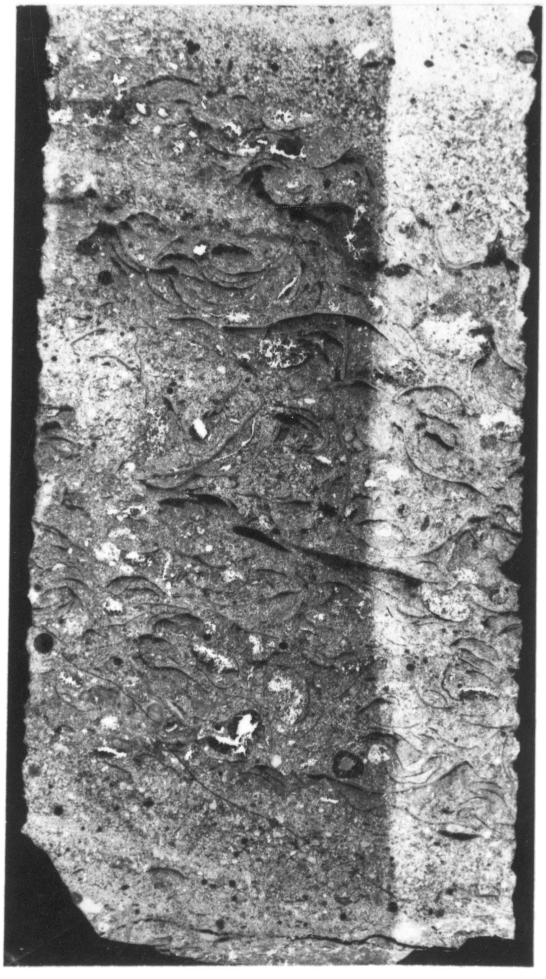
Fig. 14 Skeletal packstone. Wheeler Formation, Marjum South section, House Range.

a. Polished slab. Note sparry areas on apparent undersides of trilobite grains. Black bar scale = one cm.

b. Negative print of thin-section. Lighter right-hand third of thin-section stained with alizarin red S. Sparry areas are black.



a.



b.

1 cm

FIG. 14

grains ranges from medium-sand to coarse-sand. There seems to be little segregation of fossil types on any particular slab, all types occur mixed together in close proximity.

As mentioned earlier, this bed occurs in a sequence of dominantly calcareous shales. A few scattered flaggy lime mudstone beds are the only other rock types represented in this section.

Depositional Environments

Both of these lithic types represent anomalous accumulations of fossils and are rock types which are rare in the Wheeler Formation. The grainstones will be discussed first. White (1973) suggested that the grainstones of this area developed due to shoaling conditions, but large-scale depth fluctuations are required to explain the sudden shift from lime mudstones to these grainstones and then back to lime mudstones and shales again. Shoaling textures are absent, such as intraformational conglomerates or cross-stratification. An alternative model is needed.

The small-scale Bouma A division sequence in the Drum Mountains section suggests deposition by waning turbidity currents. A source outside of the immediate area is suggested by the presence of echinoderm grains and brachiopods, which are absent in the super- and subjacent lime mudstones and shales. In this study, echinoderms were noted from only two horizons: the topmost Swasey Limestone and this grainstone in the Wheeler Formation. Sprinkle (1976) stated, however, that echinoderms are commonest in the Cambrian rocks of the western United States in outer detrital belt facies. Brachiopods are similarly abundant in topmost Swasey Limestone rocks and are relatively rare in rocks of the Wheeler Formation. The abundance of polymeroids and absence of agnostoids is anomalous for Wheeler lithologies and is also suggestive of shallow shelf lithologies.

These grainstones were probably deposited by sediment gravity flows,[1] possibly turbidity currents, from the shallow shelf or more shoreward portions of the deep sublittoral and slope environment into the more seaward deep sublittoral and slope environment. Their limited distribution suggests a localized and relatively uncommon phenomenon. Mud filled in the majority of the void space after the flows had ceased. These muds were subsequently neomorphosed to pseudospar.

The skeletal packstone found in the Marjum South section of the central House Range is an example of a similar deposit. However, it shows neither grading nor even, mm lamination. Scoured contacts between packstone and mudstone indicate current deposition, as does the well-sorted character of the medium- and coarse-sand fraction.

While the fauna in the skeletal packstone is not as exotic as that of the skeletal grainstone in the Drum Mountains, the depositional mechanism is similar. Sediment gravity flows deposited abundant fossils in lime mud. Subsequent to flow, mud infilled the pore spaces, except for shelter porosity developed on the undersides of some grains.

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[1] "Sediment gravity flows" (Middleton and Hampton, 1973) refers collectively to the processes of turbidity flow, grain flow, fluidized sediment flow, and debris flow. Due to the gradational nature of these mechanisms it is often difficult to confidently assign a unique depositional process to rocks formed by such processes. This is true in this study, although some evidence suggests dominance of one of these processes over the others.

Unlike the micrite in the skeletal grainstone, the micrite of the packstone has not been extensively neomorphosed.

In summary, these grainstones and packstones are allochthonous in origin, although distance of transport is difficult to estimate. Waning turbidity currents or flows of related origin deposited thin anomalous carbonate beds in dominantly laminated sparsely fossiliferous muds.

Conglomerate Lithologies

Descriptions

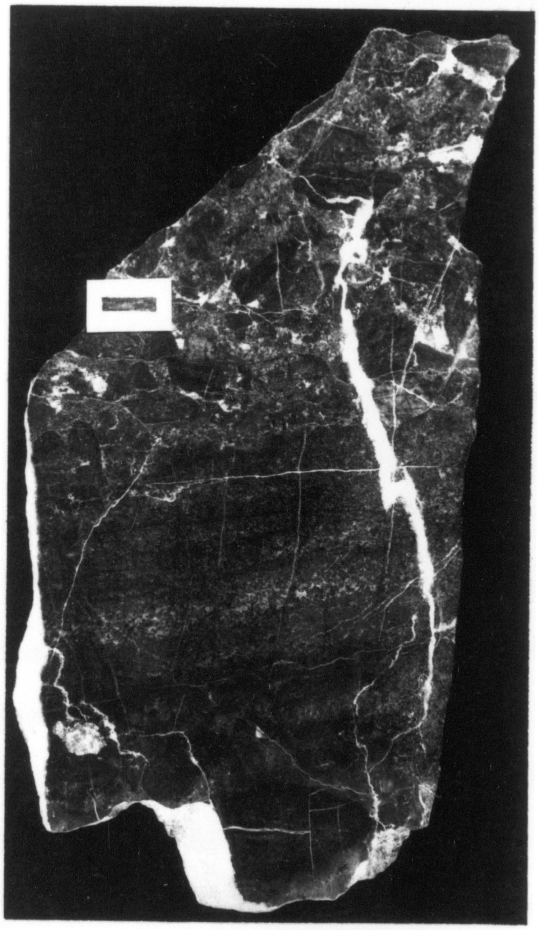
These lithologies are developed only within the sequence of micropelletoidal packstones and wackestones of the Geddes Limestone at the Eureka, Nevada localities. It should be emphasized that their occurrence is a very localized phenomenon and that the lateral extent of these rock types are very limited, a few meters along strike at most. Clast-supported conglomerates occur in a small channel-form deposit in the lower part of the formation in a sequence of black, chert-bearing, mm laminated micropelletoidal packstones and wackestones. The channel is approximately 2 m wide, along regional strike, and 30 to 40 cm thick.

Samples consist of dark gray to black, clast-supported, carbonate conglomerates (Fig. 15). Clasts range in size from a few mm to rare clasts over 10 cm in length. Average clast size is one to 2 cm in length. Sorting of clasts and matrix is generally poor. No size grading is apparent. Orientation of the long axes of clasts may parallel bedding, although typically they show no preferred orientation.

Fig. 15 Carbonate conglomerates. Geddes Limestone, Eureka-1 section, Eureka mining district. Black bar scale = one cm.

a. Unoriented slab. Note laminated zone between brackets, this is a clast of over 10 cm in length.

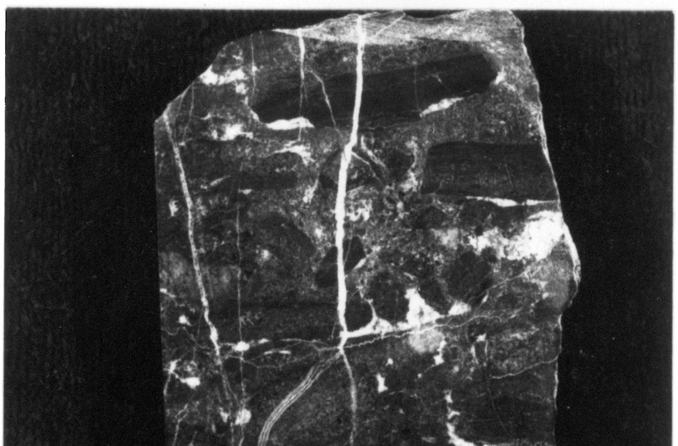
b. Stratigraphic top is towards top of figure. Note clast orientation parallel to bedding.



a.

clast

FIG. 15



b.

The majority of the clasts are composed of black micropelletoidal packstones, the same material as the enclosing country rock, although rare cream-colored carbonate clasts are present.

The matrix consists of micrite to fine carbonate sand that commonly has been neomorphosed. The coarser matrix material grades into the fine clast fraction of the conglomerate, making distinction of clasts and matrix difficult.

According to Walker's (1975) classification, the conglomerates of this channel may be classified as primarily clast-supported disorganized bed conglomerate.

A second occurrence of conglomerate was noted from the Eureka-2 section (Fig. C-2), just south of the Eureka-1 section. The conglomeratic texture was not noted until the sample was slabbed and polished so that relationships to country rock are unknown. This conglomerate is much finer-grained than that previously described and is matrix-supported. Clasts are poorly sorted, ranging from 2 cm to silt-sized. No preferred fabric exists and the clasts tend to be more spherical in outline, as opposed to the rectangular cross-sections of the previously discussed conglomerate. Rare clasts of cream-colored carbonate material are present, as in the clast-supported conglomerate discussed previously. This example may be termed a matrix-supported disorganized bed conglomerate.

Depositional Environments

The compositions and textures of the clasts and matrix of these conglomerates are very similar to those of the surrounding rocks.

Only rare clasts of exotic material appear to be present and a local source for the majority of the material in these conglomerates seems probable.

Disorganized clast-supported conglomerates have been postulated by Walker (1975) as the most proximal representatives of submarine fan conglomerates deposited by turbidity currents. The rapidity of emplacement results in the disorganized fabric. Additionally, Walker (oral communication, 1977) has suggested that for the geologic setting of these conglomerates they may be either 1)a thin distal portion of a large conglomerate deposit that thickens upslope or 2)they are the proximal conglomeratic portion of a turbidity current deposit that becomes progressively more fine-grained basinward. The latter theory seems more probably because of two observations: 1)no large conglomeratic deposits have been noted in this unit in this area and 2)several calcisiltites that occur in the super- and subjacent rocks are graded and could be the distal counterparts of more proximal conglomerates.

Matrix-supported disorganized conglomerates are thought to be emplaced by debris flows (Middleton and Hampton, 1973). A local debris flow may have deposited the matrix-supported conglomerate but the gradational nature of sediment gravity flows with each other over the time and space of an individual flow makes interpretation difficult. The small sample size of the matrix-supported conglomerate makes a firm interpretation impossible.

In summary, sediment gravity flows seem to have been the agents of deposition of these conglomerates. Rapidity of emplacement by the proximal portions of a local turbidity current probably deposited the majority of the conglomerate at Eureka. A minor amount may have been deposited by a debris flow.

Shallow-Shelf Facies

Introduction

The shallow-shelf facies is represented by two similar rock groups: 1)oncolite pelletoidal wackestones and 2)polymeroid wackestones, and rare grainstones.

Oncolite Pelletoidal Wackestone Lithology

Description

This lithology is developed only in the uppermost Eldorado Formation in the northern Egan Range. The Eldorado Formation is the approximate chronostratigraphic equivalent of the more easterly Swasey Limestone and the more westerly Eldorado Dolomite of Eureka (Fig. 3).

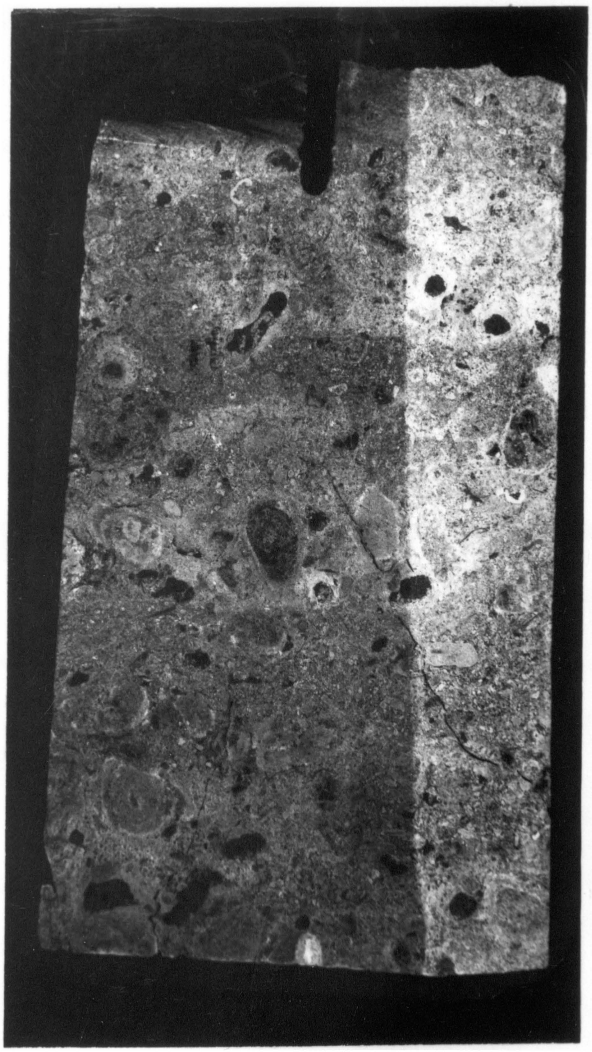
This lithic type consists of ledge-forming, medium-bedded oncolite pelletoidal wackestones (Fig. 16a) characterized by uniformly thick beds, 20 to 40 cm thick. In contrast to its aforementioned equivalent units, the uppermost Eldorado Formation is dark-colored. No sedimentary structures were observed and the beds appeared to be massive.

The matrix of micrite exhibits varying degrees of alteration to microspar, similar to the micrite found in many of the thin-sections in this study.

Grains include oncolites, pelletoids, fragmental polymeroids, intraclasts, and sponge spicules. The most common grains are pelletoids which average 0.1 mm in diameter. Oncolites are one to

Fig. 16 a. Oncolite pelletoidal wackestone. Eldorado Formation, northern Egan Range MC76-75. Negative print of thin-section, right-hand third stained with alizarin red S. Notch in thin-section indicates stratigraphic top. Oncolites have sparry centers (black) with light gray micritic envelopes.

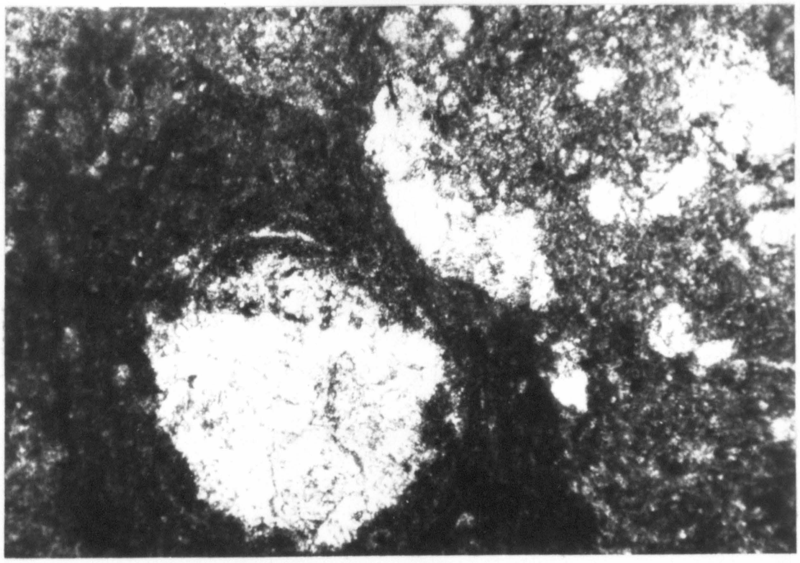
b. Photomicrograph of an oncolite. Oncolite, with sparry nucleus, nucleus about 2 mm in diameter. Plain light. Sample MC76-75.



a.

1 cm

FIG. 16



b.

1mm

2 mm in diameter and consist of sparry centers, averaging three-fourths of the total diameter, with irregular concentrically laminated envelopes of micrite (Fig. 16b). Rare micritic intraclasts range in size from 0.1 to 2.0 mm in length. Highly comminuted polymeroid fragments, 2 to 3 mm in length, are locally abundant. Sponge spicules are very rare, being detected only in acid residues. Brachiopods are not present in these rocks, in contrast to their great abundance in equivalent Swasey Limestone samples.

The only associated rock types collected and described in this study are from the superjacent lime mudstone-wackestone lithology of the Secret Canyon Formation. The lower portions of the Eldorado Formation in this area were not studied.

Depositional Environment

Oncolites are thought to form by the coating of particles by algae, foraminifera, and serpulids in areas of at least moderate water circulation (Wilson, 1975, p. 79, citing Folk, Leighton, Powers, and Pendexter _in_ AAPG Memoir I, 1962). Bathurst (1975) ascribed their origin to accretionary growth of blue-green algae about a nucleus on a mobile substrate.

The abundant lime mud in association with the oncolites is a textural inversion. It seems likely that the relatively sparse oncolites were washed into broad areas of quiet water that had accumulated abundant lime mud (Wilson, 1975, p. 79).

The intraclasts found in these rocks are also believed to have been washed in. These clasts represent penecontemporaneous mudstones that were broken up by storm activity and were washed into the relatively low-energy environment where the mud was accumulating.

The pelletoids could have originated in a number of ways. They may be fecal in origin, bioclasts that have been altered to micritic grains, or inorganic accretions of mud (Bathurst, 1975).

The lack of sedimentary structures, abundant pelletoids, and highly broken fossils may be a result of extensive reworking by burrowing organisms in the organic-rich mud. The pelletoids might represent fecal material in this case. Bathurst (1975) described unstructured pellet-bearing lime muds that are accumulating west of Andros Island in the Bahamas that may be analogous to these rocks. Only a sparse biota inhabits the pellet-mud habitat of this latter region and the majority of the pellets are fecal. The origin of this Bahamian mud remains in dispute, being either a precipitate or due to the breakdown of larger carbonate grains.

In summary, the oncolite pelletoidal wackestones accumulated in broad shallow areas of quiet water with a relatively sparse biota which produced the fecal pellets and reworked the sediments. Occasional sotrm activity or currents generated by other means washed in small amounts of coarser material such as the oncolites and intraclasts.

Polymeroid Wackestone-Packstone-Grainstone Lithologies

Descriptions

These rock types characterize the uppermost few meters of the Swasey Limestone in both the central House Range and Drum Mountains.

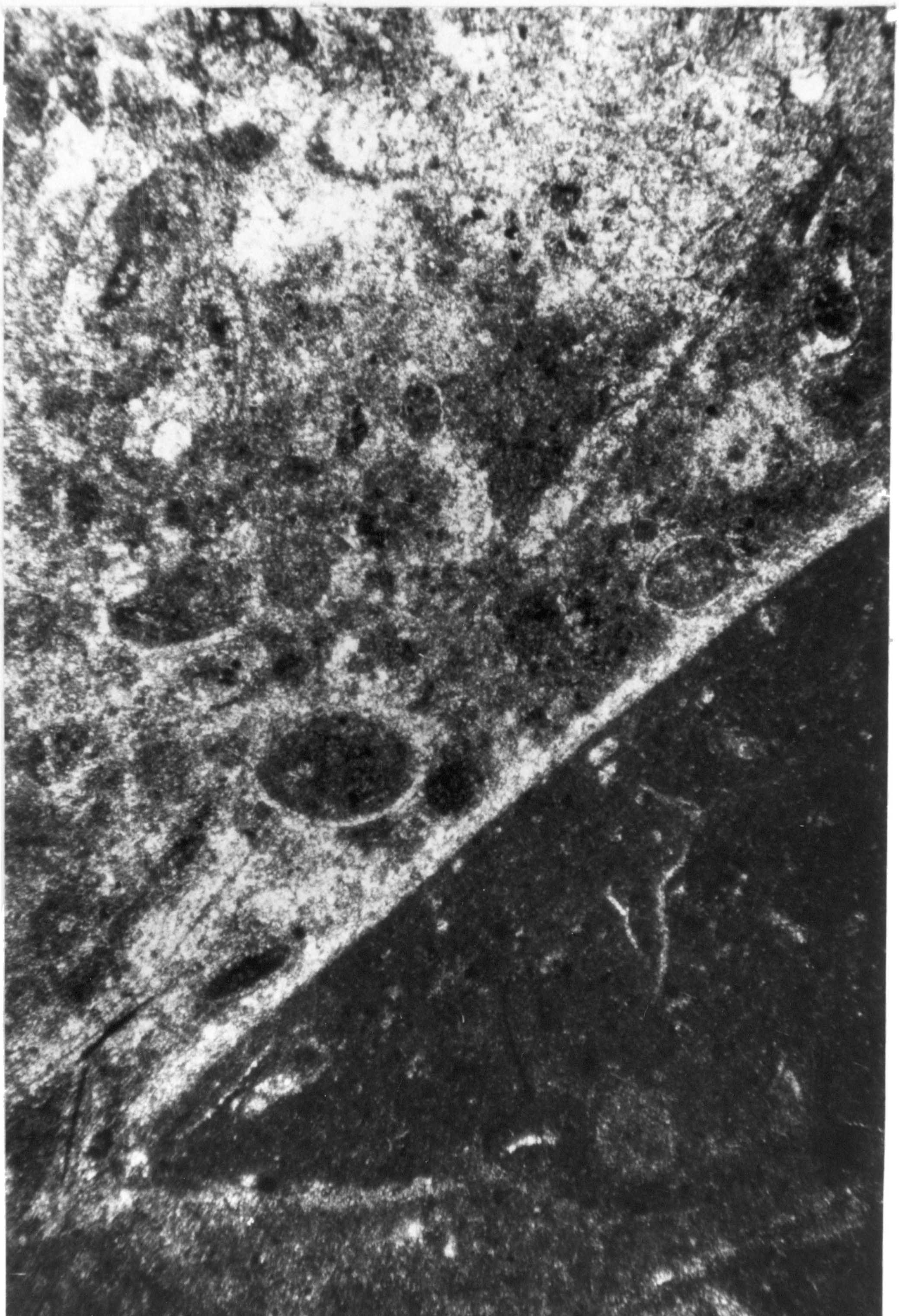
They consist of light gray, medium-bedded, commonly bioturbated, polymeroid wackestones and packstones. Individual beds are 10 to 30 cm thick, evenly bedded, and form resistent ledges in outcrop.

Etched hand samples locally reveal a crudely layered distribution of skeletal fragments, but this is not mm-scale lamination comparable to that seen in the rocks of the deep sublittoral and slope facies. Bioturbation has commonly destroyed or obscured any original fabric. No cross-stratification was seen in this lithology.

Overall sorting of grains is good, being in the fine sand to silt range. The most common grain types are highly comminuted polymeroid fragments, ranging from 0.1 to 2.0 mm in length. Grains are more common in burrows (Fig. 17). Preservation of these grains is generally good, with few grains having micrite envelopes. Micropelletoids are locally abundant within burrows, they are 0.1 to 0.2 mm in diameter, Echinoderm grains, 0.5 to 1.0 mm diameter, occur only in these lithologies. These grains appear to be dominantly columnal plates. Excellent collections of brachiopods were obtained by etching samples in formic acid. Less common were broken sponge spicules.

A rare rock type that will be discussed with these wackestones and packstones is patchily distributed polymeroid grainstone. These grainstones occur in the topmost Swasey Limestone in the Marjum North (central House Range) and Drum Moutains sections. Despite the close proximity of the Marjum South and Marjum North sections, only the latter contained this lithic type. C. D. Caldwell (oral communication, 1977) noted a similar patchy distribution of grainstones in his

Fig. 17 Burrowed polymeroid wackestone, burrow in upper left sparry portion of figure. Swasey Limestone, Drum Mountains. Plain light.



1 mm

FIG. 17

studies of the Swasey Limestone in the same geographic areas at the same stratigraphic levels.

The grain types are identical to those of the polymeroid packstones and wackestones. However, the matrix is clear blocky spar. Burrow structures were not observed. Thickness of these grainstone units is not known, but cannot exceed more than one meter, as samples collected from one meter below these grainstones are the typical packstones and wackestones of this formation. Field observations revealed no change in bedding style or thickness at locations where this rock type was encountered.

Superjacent to the polymeroid packstones and wackestones of the Swasey Limestone are the lime mudstones, wackestones, and shales of the lowermost Wheeler Formation. This contact is a diastem at the Marjum North locality. Small-scale erosion is exhibited in thin-sections of this contact (Fig. 18). No evidence of this diastem was found at the Wheeler Amphitheater section where exposures of this contact were relatively good. It is poorly exposed elsewhere and may or may not be a diastem. Subjacent to the polymeroid packstones and wackestones are silty oncolitic and oolitic mudstones (Kepper, 1976).

Depositional Environments

Abundance of lime mud and extensive bioturbation indicate a well-oxygenated, relatively low-energy environment for the formation of these rock types.

These lithologies are quite unlike those of the Wheeler Formation. They possess none of the characteristics of "deeper water" limestones.

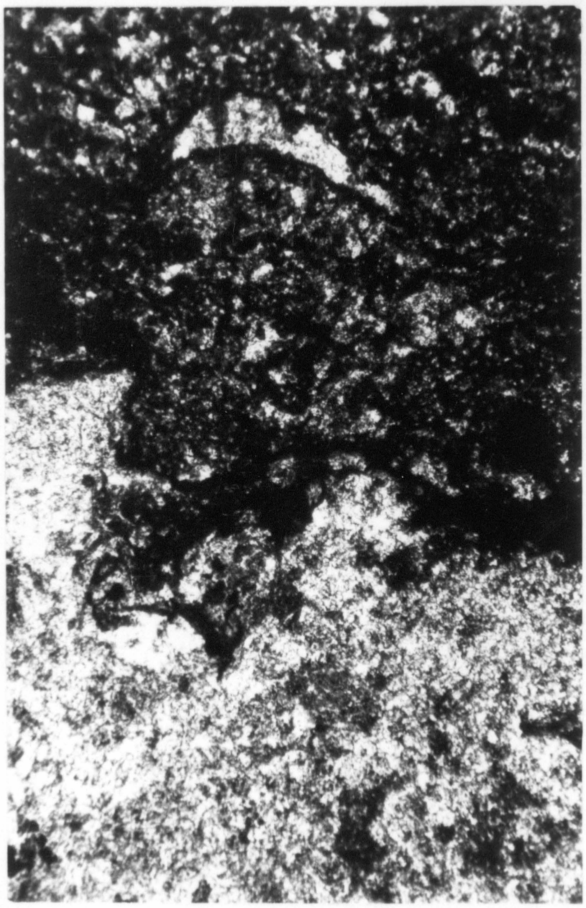
Fig. 18 Swasey Limestone - Wheeler Formation contact. Marjum North section, House Range.

a. Negative print of thin-section. Agnostoid wackestone (Wheeler) is thin light layer in upper right overlying polymeroid grainstone (Swasey). Note irregular contact.

b. Photomicrograph of contact. Crossed nicols. Wheeler is dark zone on top. Note irregular contact.

a.

1 cm



b.

1 mm

FIG. 18

However, they do not contain stromatolites, fenestral fabric, mud cracks, or other features of supratidal environments. It seems likely that they are shallow subtidal deposits. Highly bioturbated fossiliferous mudstones to grainstones have been noted from open marine platform environments by Wilson (1975, p. 358). Irwin (1965) proposed a model of epeiric clear-water sedimentation, that was subsequently supported by Laporte (1969). Laporte suggested that sediments of this type were formed in shallow subtidal open-shelf environments. In Laporte's study, the Kalkberg Formation appears to have been formed in an environment similar to that of the Swasey Limestone. However, it should be noted that no modern analogs of such extensive shallow open-shelf environments exist today and the model proposed is based on both extrapolations of Holocene carbonate environments and the stratigraphic record.

In summary, a shallow open-shelf environment of low energy supported an abundant and diverse biota of polymeroid trilobites and inarticulate brachiopods. Local currents, developed due to patchy shoals, winnowed mud away, forming rare grainstones.

PALEOGEOGRAPHY

Figures 20, 21 and 22 illustrate the inferred paleogeography for the uppermost barren interzone "A", lowermost *Ptychagnostus gibbus* Chronozone and the lowermost part of the *P. atavus* Chronozone. Figure 2 shows the relationships of these zones to the lithic units previously described. Distributions of specific lithologies are given where known, either from the writer's field work or Kepper (1976). Detailed information on lithic distributions for the other areas in the figures were not available.

Figure 20 illustrates the paleogeography for uppermost barren interzone "A". This figure differs from Palmer (1971) only by the addition of the known lithologic distributions. A shallow carbonate shelf environment existed over much of the area shown during this time. To the south, water circulation on the shelf was restricted, as evidenced by extensive stromatolite development. Open-shelf environments typify the House Embayment area, characterized by the very fossiliferous, commonly burrowed wackestones and packstones of the uppermost Swasey Limestone.

By the earliest *Ptychagnostus gibbus* Chron (Fig. 21), a significant shift of facies had taken place. Deep sublittoral and slope environments extended as far east as the Canyon Range and Wasatch Mountains. A basinal facies can be recognized in the House Range and Drum Mountains region. Shelf facies persisted to the south, characterized by dolomitic sandstones and sandy dolomites (Kepper, 1976).

Figure 19 Index map of data points for paleogeographic reconstruction.

Key:

Ca-Canyon Range	P-Pioche District
CM-Cricket Mountains	PR-Pavant Range
DC-Deep Creek Range	QS-Quartz Springs area
DD-Delamar District	RC-Provo Rock Canyon
DM-Drum Mountains	SC-Schell Creek Range
E-Eureka Mining District	SM-Stansbury Mountains
FS-Fish Springs Range	Sr-Sheeprock Mountains
HR-Central House Range	SR-Snake Range
IR-Indian Ridge	T-Toiyabe Range
La-Lakeside Mountains	TD-Tintic District
MM-Mormon Mountains	VM-Virgin Mountains
NE-Northern Egan Range	Wa-Wasatch Mountains
NR-Nopah Range	WW-Wah Wah Mountains
OD-Ophir District	YF-Yucca Flat

X-Y - approximate line of differential subsidence

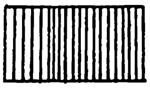
Figure 20 Paleogeography of uppermost barren interzone "A" (after Robison, 1960; Palmer, 1971; Kepper, 1976).

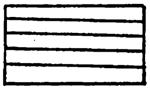
Figure 21 Paleogeography of lowermost Ptychagnostus gibbus Chronozone (after Palmer, 1971; Kepper, 1976; Robison, oral communication, 1977).

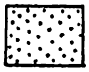
Note that the basin and deep sublittoral and slope facies alternated irregularly as the dominant facies in the central House Range and Drum Mountains from earliest P. gibbus to earliest P. atavus Chron. Only at the Marjum South locality did the basin facies persist throughout this interval.

Figure 22 Paleogeography of lowermost P. atavus Chronozone (after Robison, oral communication, 1977; Palmer, 1971; Kepper, 1976).

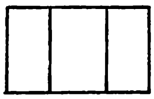
Legend

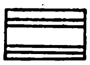

Basin Facies


Deep Sublittoral and Slope Facies

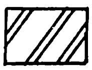

Micropelletoidal wackestone-packstone lithology

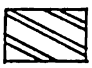

Interbedded thin lime mudstones and shales

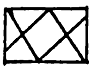

Shallow-Shelf Facies


Dolomite


Oncolite pelletoidal wackestone


Polymeroid wackestones, packstones, grainstones


Stromatolites


Dolomitic sandstones

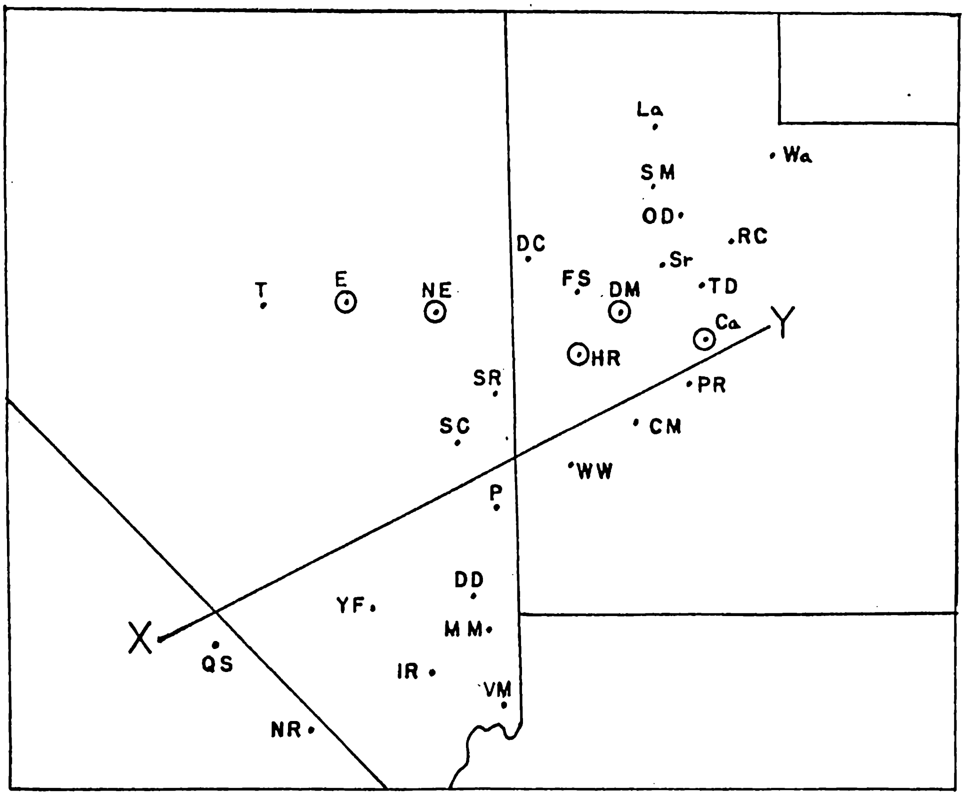

La
Wa
SM
OD
RC
DC
Sr
T
E
NE
FS
DM
TD
Ca
Y
HR
SR
PR
SC
CM
WW
P
DD
YF
X
MM
QS
IR
VM
NR

FIG. 19.

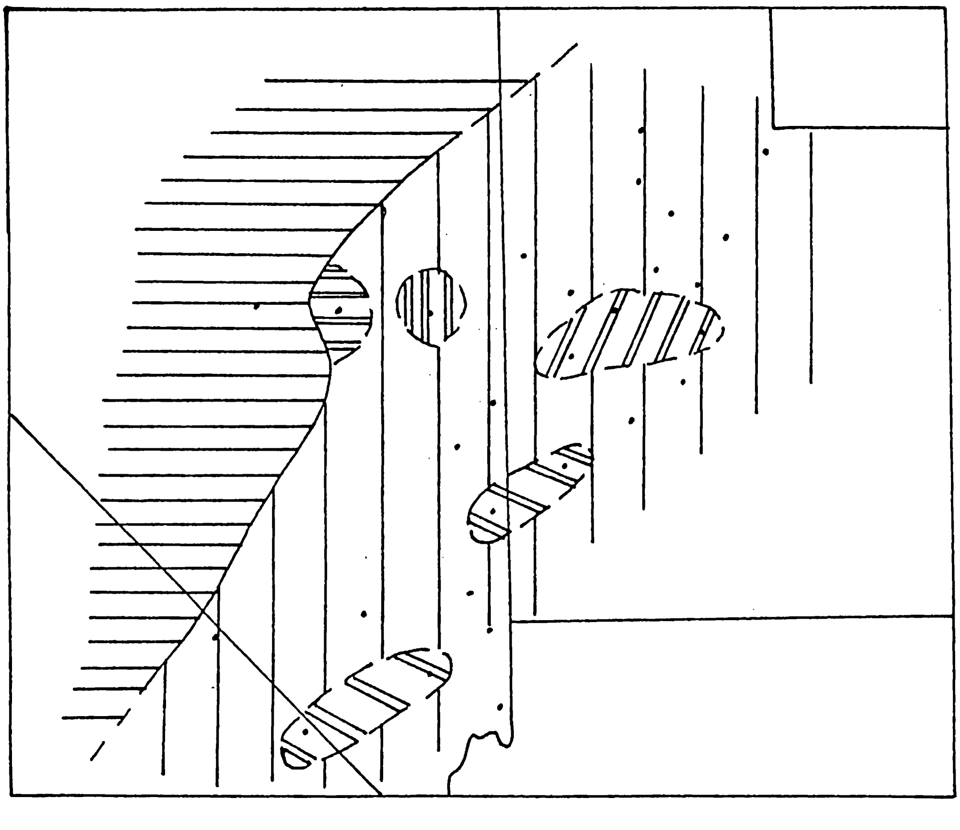


FIG. 20

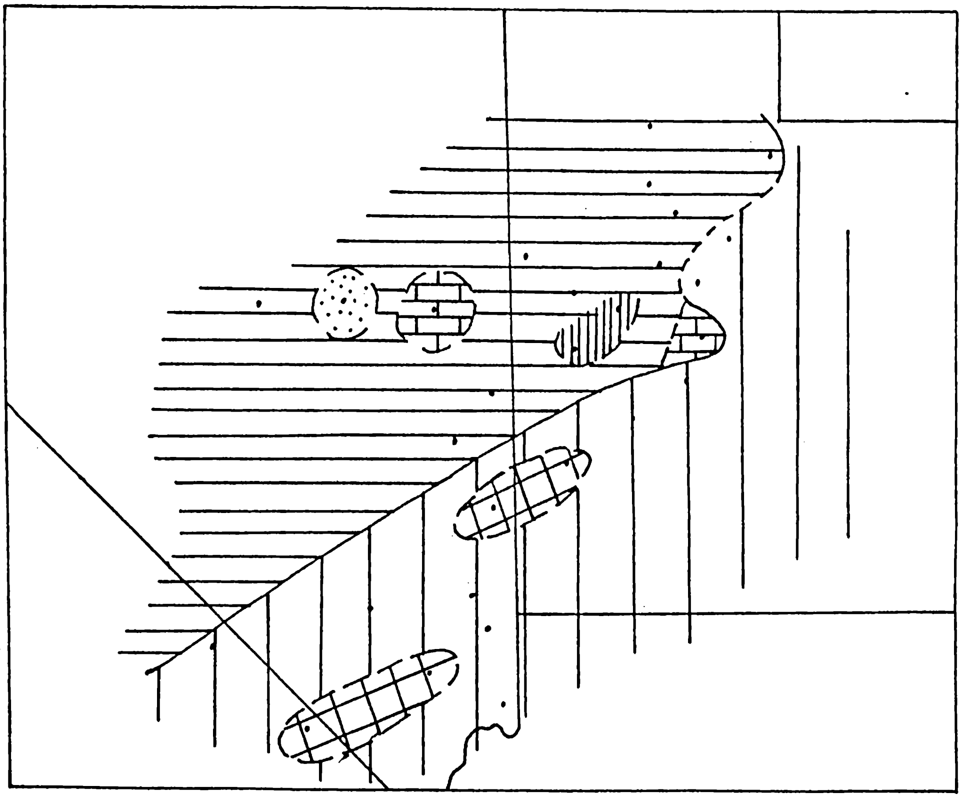


FIG. 21

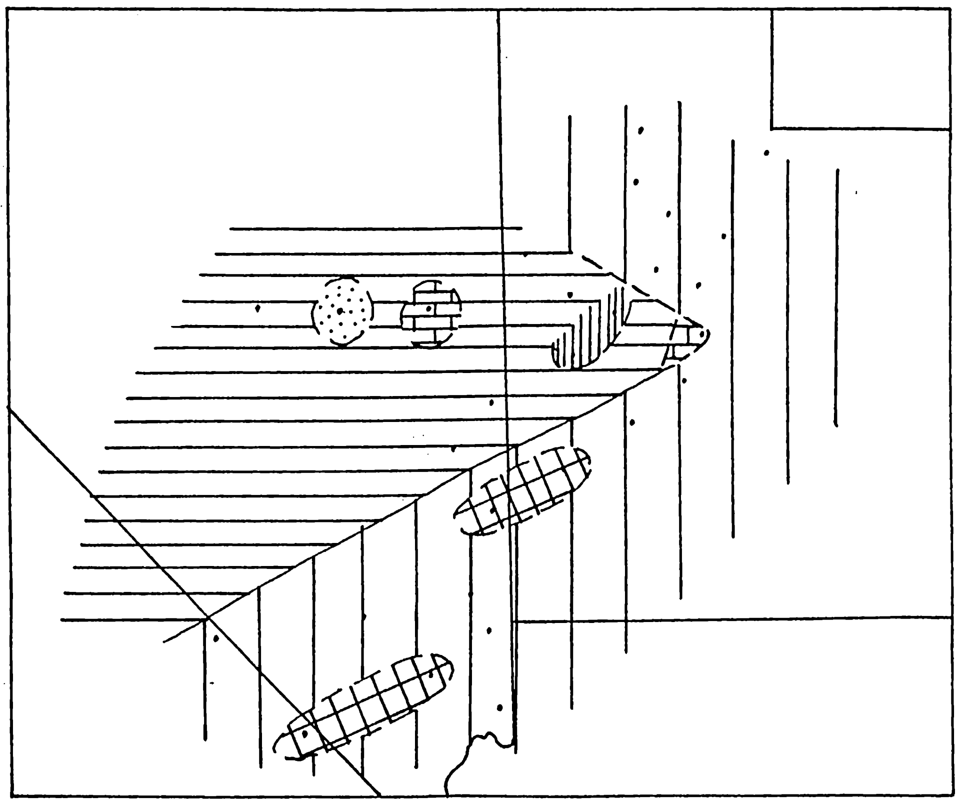


FIG. 22

By the start of the P. atavus Chron (Fig. 22), shallow shelf facies had again developed north of the House Embayment. In this latter area, no P. atavus fauna is known from rocks overlying the P. gibbus-bearing deep sublittoral and slope facies. Massive unfossiliferous limestones which characterize this interval, presumably representing shelf environments, are inferred to be P. atavus Chronozone equivalents (R. A. Robison, oral communication, 1977).

The Canyon Range probably lay along the break between the shelf and deep sublittoral and slope environments. No P. atavus fauna is known from the Canyon Range, but specimens of the polymeroid trilobites Modocia convexa and Spencella drumensis were collected from 65 m above the base of the Wheeler Formation at this locality. These two forms are known only from the Wheeler Formation in the Drum Mountains, immediately below the base of the P. atavus Assemblage-zone (White, 1973). Therefore, the boundary between deep sublittoral and slope and shallow shelf facies is placed in the Canyon Range area at the start of the P. atavus Chron. It should be noted that the utility of these two aforementioned polymeroids as guide fossils is by no means well-established and that this correlation is tentative.

Basinal facies became restricted to the Marjum South region of the House Range by the P. atavus Chron. Basinal and deep sublittoral and slope facies fluctuated as the dominant facies in the Drum Mountains area. Interbedded shales and limestones of the deep sublittoral and slope facies replaced the basinal facies shales in the Wheeler Amphitheater section at this time.

Shelf environments persisted in the region to the south of the House Embayment during the *P. atavus* Chron (Kepper, 1976).

DEPOSITIONAL MODEL

Any model for the study interval must incorporate the following: 1)The equivalents of the Swasey Limestone exhibit a shoaling-upward sequence in the Wah Wah Mountains, Pioche District, Indian Ridge, and Nopah Range (Kepper, 1976). The Swasey Limestone and equivalents in this study appear to exhibit a deepening-upward sequence, with open-marine shelf deposits overlying cross-bedded oolites. 2)The formational contact between the Swasey Limestone and Wheeler Formation, and their equivalents in the areas sampled, is an abrupt facies change, reflecting a shift from shallow open-shelf to deep sublittoral and slope or basinal environments. At one locality (Marjum North, House Range) this contact is a diastem. This contact is rarely exposed at the other localities sampled because of the slope-forming nature of the Wheeler Formation and its equivalents. No comparable evidence of a diastem exists at the Wheeler Amphitheater locality where this contact is exposed. 3)Fossils are most abundant in the topmost Swasey Limestone and in the lowermost Wheeler and equivalents in the Eureka, Nevada, and northern Egan Range sections. In the central House Range, the Wheeler Formation sections are only sparsely fossiliferous. Fossils become common in this unit in the central House Range sections only with the appearance of _Ptychagnostus atavus_. In the Drum Mountains section, the _P. gibbus_ Assemblage-zone is similarly sparsely fossiliferous. The Wheeler in the Canyon Range is barren only in the basal 7 or 8 m.

Kepper (1976) suggested a depositional model for Middle Cambrian rocks of the Great Basin based on Meissner's (1972) reciprocal sedimentation model for Permian carbonates of West Texas. With only minor modification, Kepper's model explains well the facies patterns and fossil distributions of the units sampled in this study.

Figure 23 is a modification of the sedimentological model which Kepper proposed for the Middle Cambrian facies of the House Range and areas to the south and southwest. Submergence of the shelf led to the development of an oolite belt on the shelf margin with a deeper water basin in the seaward direction and a leeward shelf-lagoon (Fig. 23A). Carbonate production formed a shoaling-upward sequence that eventually led to emergence on inner parts of the shelf (Fig. 23B). Emergence of this carbonate shelf occurred outside of the areas sampled, to the south of the central House Range. Carbonate open-shelf environments, represented by the topmost Swasey Limestone and equivalents at Eureka and in the northern Egan Range, persisted over the study area exhibiting a deepening-upward sequence. This wide, shallow open-shelf environment (Fig. 23A), located seaward of the oolite shoal differs from Kepper's model, in which this environment is depicted as only a very narrow band separating the basin from the shelf. The shoaling developed a depositional topography with a zone of bypass on the upper slope with erosion occurring locally represented by the diastem of the Swasey-Wheeler boundary at the Marjum North locality. A relatively starved basin developed in the seaward direction. Emergence was coupled with reworking of near-shore detritus (Kepper, 1972) which flooded the shelf and terminated carbonate production, depositing thin, shallow-water dolomitic

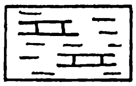
Figure 23 Depositional Model, approximate north-south cross-section.
HR=House Range WW=Wah Wah Mountains
Not drawn to scale, vertical exaggeration enormous.
Swasey Limestone=Swasey Limestone and equivalents.
Wheeler Formation=Wheeler Formation and equivalents.

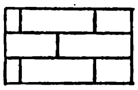
Figure 23A Submergence, beginning of carbonate sedimentation, oolite belt with leeward shelf-lagoon, seaward shelf carbonates and fine clastics.

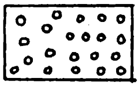
Figure 23B Emergence, shoaling upward sequence on inner shelf, upward-deepening sequence in House Embayment, development of starved basin and depositional topography with zone of nondeposition and local scour on upper slope.

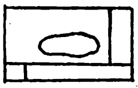
Figure 23C Terrigenous influx across shelf (dolomitic sandstones), accompanied by more rapid subsidence along a line between the central House Range and Wah Wah Mountains (X-Y). Deposition of the Wheeler Formation and equivalents.

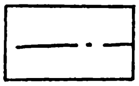
LEGEND

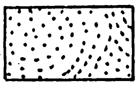
 interbedded thin limestones and shales

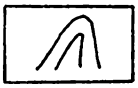
 open-shelf limestones (Swasey Limestone)

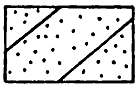
 oolitic limestones

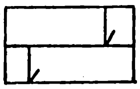
 fenestral limestones

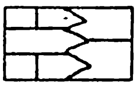
 silty limestone

 sandy limestone

 stromatolitic limestone

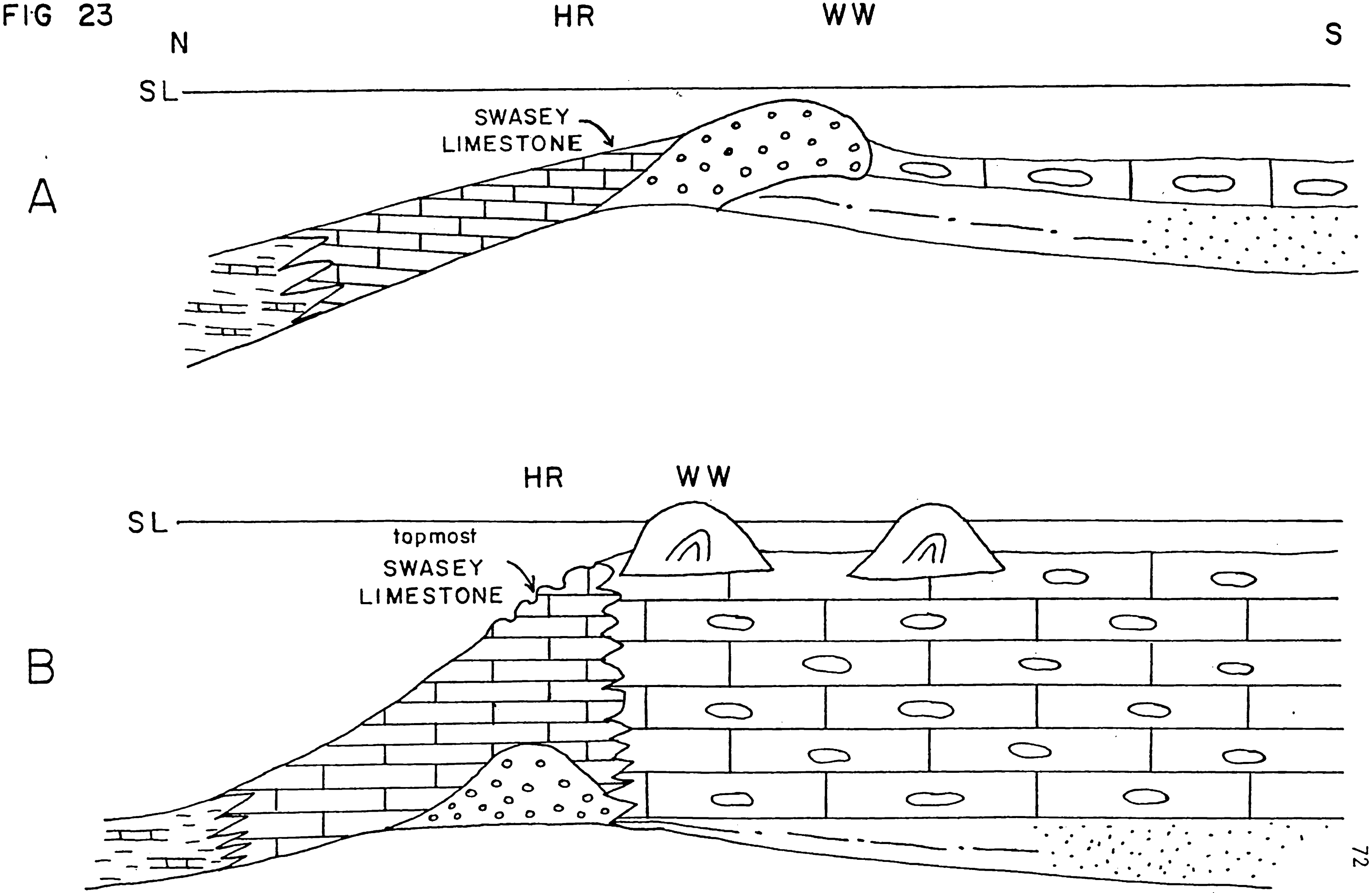
 sandy dolomite to dolomitic sandstone

 dolomitic mudstone

 interfingering along line X-Y (see Fig. 19)

 local erosional surface

FIG 23


A
N
S
HR
WW
SL
SWASEY
LIMESTONE
B
HR
WW
SL
topmost
SWASEY
LIMESTONE

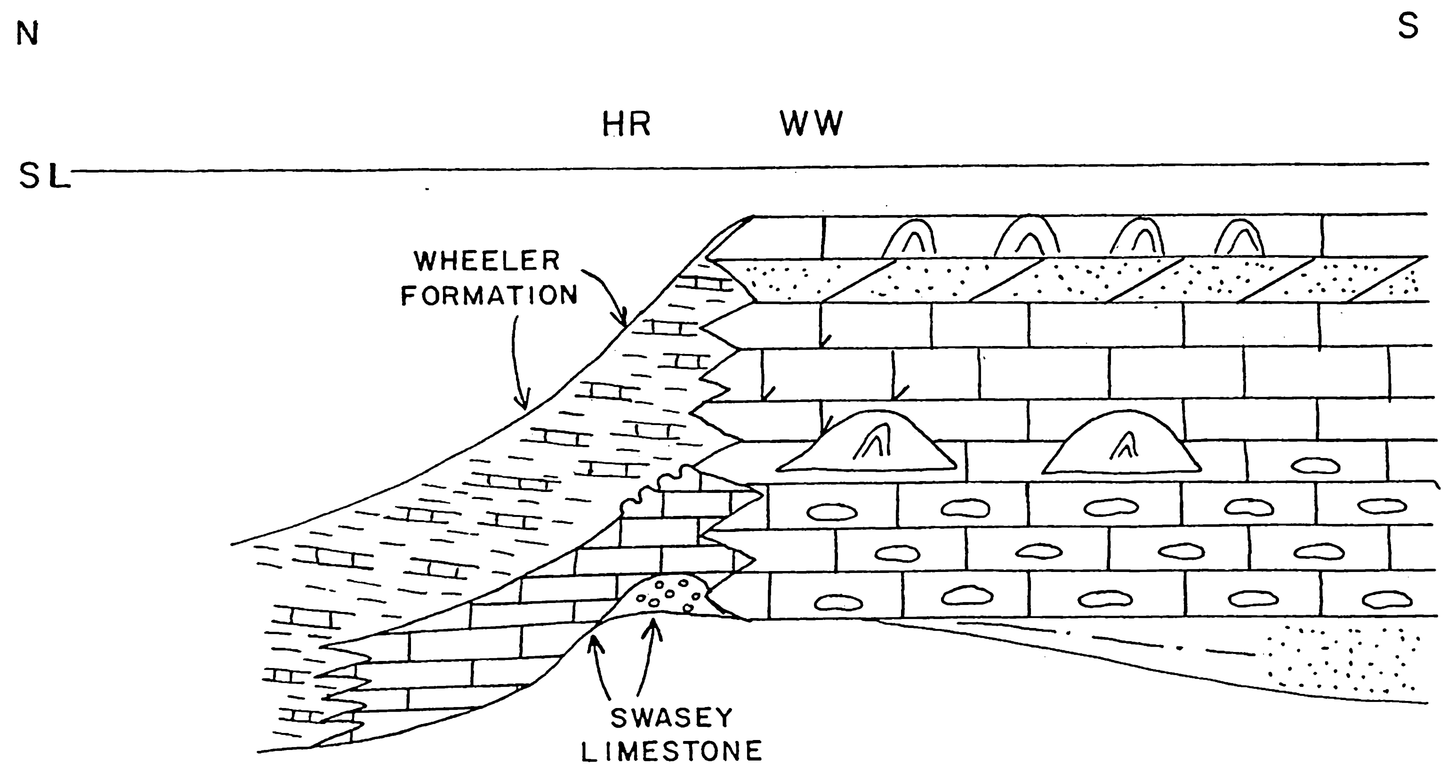


FIG. 23C

sandstones and sandy dolomites in the Wah Wah, Pioche, Indian Ridge, and Nopah Range areas. Carbonate production resumed in these areas shortly after this influx. In the House Embayment however, carbonate production was halted and was followed by deep sublittoral and slope or basinal deposition of thin limestones and shales. More rapid subsidence (Fig. 23C) north of a line X-Y (Fig. 19) separating the Wah Wah-Nopah Range area and the House Embayment areas produced a markedly different sequence represented by the Wheeler Formation and its equivalents. This deepening was also reflected in the Swasey Limestone. The deepening prevented reestablishment of shallow subtidal carbonate production in the House Embayment. In the Eureka and northern Egan Range areas this progressive deepening may be represented by the fossiliferous basal limestones of the Geddes Limestone and Secret Canyon Formations, respectively, overlain by sparsely fossiliferous to barren limestones.

Basinal environments developed in the area of the House Range and Drum Mountains and fluctuated with slope and deep sublittoral environments through the beginning of the *P. atavus* Chron. This is reflected by thick shales interbedded with thin limestones and shales.

By the beginning of the *P. atavus* Chron shallow shelf conditions were reestablished in the area north of the House Embayment (Palmer, 1971, Robison, oral communication, 1977). The Canyon Range area lay close to the shelf-slope break. In the House Embayment subsidence apparently kept pace with sedimentation as deep sublittoral and slope and basinal facies persisted.

In Kepper's model Wheeler deposition was followed by a gradual infilling of the House Embayment with lime mudstones of the Marjum Formation, a slope deposit (Brady and Koepnick, 1973). This infilling prograded from east to west. Submergence of the shelf renewed the cycle.

The distribution of fossils needs to be explained in the context of this model. As mentioned earlier, brachiopods tend to be most abundant just seaward of the carbonate shoal (Rowell and Brady, 1976). The Canyon Range is the easternmost section studied and was probably most proximal to the carbonate bank during deposition of the Wheeler Formation. Fossils, especially brachiopods, are present above the basal 7 or 8 m of the Wheeler Formation in the Canyon Range, consistent with its proximity to the carbonate shelf edge.

The lack of abundant fossils in the House and Drum Mountains is associated with the basinal facies shales in these sections. This may reflect a higher percentage of suspended solids in these areas associated with the greater terrigenous influx. Fossils become common above the intervals in which the basinal shales are the dominant lithology, and within the intervals in which deep sublittoral and slope facies are dominant.

As mentioned earlier, abundant fossils in the basal limestones of the Geddes Limestone at Eureka and in the Secret Canyon Formation in the northern Egan Range may reflect a progressive deepening of the House Embayment. Fossils are generally sparse or absent in the upper half of the _P. gibbus_ Assemblage-zone. These barren intervals may represent depths or environmental conditions in which biotic activity was greatly curtailed. The change in fossil abundances ~~in~~ is the only tangible change in these rocks when compared to the fossiliferous strata that underly them. A number of environmental factors may have controlled the fossil distribution (Brouwer, 1968). These include temperature, water movement, amounts of solid substances in suspension, salinity, oxygen content, and presence of other gases in solution. For benthic biota depth and substrate are additional controlling factors. Data to confirm or deny these factors in these limestones appears to be absent, with the exception of substrate, which does not appear to have varied between barren and fossiliferous intervals. Whatever the cause, it equally affected all taxa. In the Marjum North and Drum Mountains sections only the basal bed is similarly fossiliferous, rather than much thicker basal fossiliferous sections.

Summarizing the fossil distributions, proximity to the shallow carbonate shelf appears to have favored a higher degree of biotic activity. Nearly barren intervals characterize the upper half of the *P. gibbus* Assemblage-zone.

EVALUATION OF THE POTENTIAL
P. gibbus and *P. atavus* CHRONOHORIZONS

As discussed in the introduction, the secondary aim of this thesis was to obtain data on the distribution of inarticulate brachiopods in relation to the *Ptychagnostus gibbus* and *P. atavus* assemblage-zones. The potential utility of the bases of these two zones as chronohorizons was also to be discussed.

Ten different taxa of inarticulate brachiopods were encountered in this study. These are *Lingulella* sp., *Prototreta* sp. *Linnarssonia ophirensis*, *Pegmatreta bellatula*, *Acrothyra minor*, *Acrothyra urania*, an unnamed genus of the subfamily Linnarssoniinae, *Acrothele subsidua*, *Micromitra* sp., and *Dictyonina* sp.

In this study, the base of the *Ptychagnostus gibbus* Assemblage-zone coincides with a diastem in at least one locality. The faunas above and below this diastem show no appreciable differences in comparison to the faunas collected at the other localities, where evidence of this diastem is lacking. Therefore, no major break in deposition appears to have been associated with this local erosional surface. Hence, the base of this assemblage-zone at this locality probably does not differ from the other localities in its geochronologic and chronostratigraphic implications. More importantly, however, at all of the localities sampled the base of the *P. gibbus* Assemblage-zone is marked by an abrupt lithologic change, the Swasey-Wheeler contact. An ideal chronostratigraphic boundary-stratotype should be defined from a continuously deposited monofacial sequence (Robison et al., 1977). Thus, at the localities studied, the base of the *P. gibbus*

Assemblage-zone would be a poor choice for a chronohorizon.

The base of the P. atavus Assemblage-zone does occur in a continuously deposited monofacial sequence in all but one of the areas studies (Fig. 3). At the Marjum South locality, the first occurrence of P. atavus is in a thin allodapic skeletal packstone (Figs. C-5, D-5). There is no evidence for an appreciable age difference between this allodapic unit and the enclosing shales. Therefore, this change of lithologies does not appear to be significant in terms of the recommendation by Robison et al. (1977) on choosing such boundary-stratotypes in monofacial sequences. It is concluded from the facies data gathered in this study that the base of the Ptychagnostus atavus Assemblage-zone satifies the ISSC recommendations on boundary-stratotypes for chronostratigraphic units.

Zonal Correlation Using Brachiopods

The need for an additional correlation tool for the agnostoid zones being studied was discussed in the introduction (p. 5). It was hoped that inarticulate brachiopods would fulfill this need. Unfortunately, the stratigraphic ranges of the majority of the brachiopods found in this study preclude their usage for correlation of the bases of the P. gibbus and P. atavus assemblage-zones (Fig. 24). Linnarssonia ophirensis is always restricted to occurrences above the base of the P. gibbus Assemblage-zone. Both species of Acrothyra are restricted to occurrences below this horizon, with the exception of sample MC76-94 from the Marjum North locality (Fig. G4). These three species may be potentially useful in correlation. However, the abrupt shift of

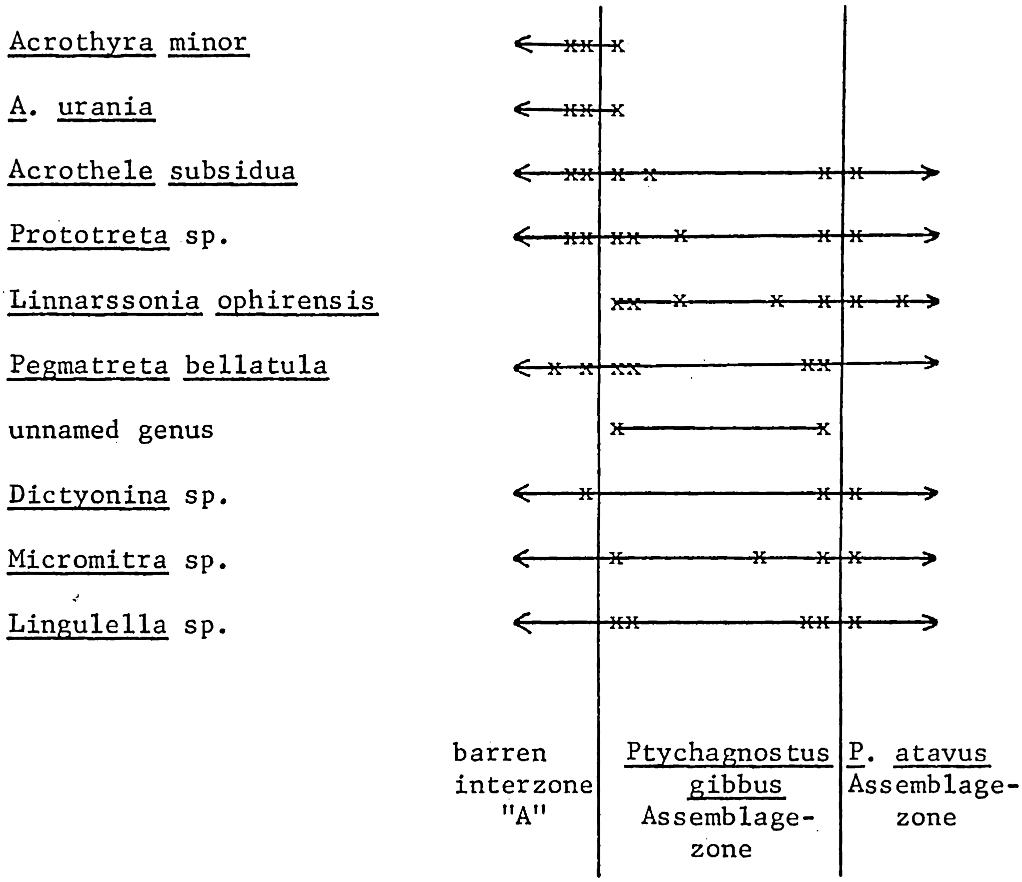


Fig. 24 Composite Rnage Chart of Brachiopod Taxa

x=brachiopod collections in this study.

Supplemental range information from Robison (1964a) and Rowell (1966); (oral communication, 1977).

facies associated with the base of the P. gibbus Assemblage-zone may indicate a facies-controlled distribution of these taxa. Their actual stratigraphic ranges may extend beyond this boundary.

For correlation of the base of the P. atavus Assemblage-zone, only the new genus of brachiopod in this study has potential usefulness (excluding the use of the defining agnostoids). Its stratigraphic range coincides with the P. gibbus Assemblage-zone (Fig. 24). However, more data on its occurrence are needed to establish its usefulness for this purpose.

Brachiopod Distribution

In terms of the areas sampled, most of these forms were ubiquitous. Figure 25 shows the distributions of these taxa plotted against geographic area for, respectively, the shelf and the deep sublittoral and slope facies.

Distribution of Shallow Shelf Brachiopods

Of the more common taxa, only *Linnarssonia ophirensis* was not found in rocks of the shelf facies. The less common taxa were not encountered commonly enough to reach conclusions about possible geographic or facies restrictions. One curious observation is the lack of *Lingulella* sp. from all of these shelf localities. While linguloid brachiopods do not often occur in great abundance in Cambrian rocks, they commonly occur above the lower Lower Cambrian and the total lack of even shell fragments of linguloids is surprising. No brachiopods were recovered from the Eldorado Dolomite at Eureka and the Swasey Limestone in the Canyon Range because of extensive

Brachiopod Taxa	Localities: Eureka Mining District	northern Egan Range	Wheeler Amphitheater	Marjum North	Marjum South	Drum Mountains	Canyon Range
Acrothyra minor	0	0	X	X	X	X	0
A. urania	0	0	X	X	0	X	0
Acrothele subsidua	0	0	X	X	X	X	0
Prototreta sp.	0	0	X	X	X	X	0
Linnarssonia ophirensis	0	0	0	0	0	0	0
Pegmatreta bellatula	0	0	X	X	0	X	0
unnamed genus	0	0	0	0	0	0	0
Dictyonina sp.	0	0	X	0	0	0	0
Micromitra sp.	0	0	0	0	0	0	0
Lingulella sp.	0	0	0	0	0	0	0

(a) Shallow Shelf Facies

Acrothyra minor	0	0	0	X	0	0	0
A. urania	0	0	0	X	0	0	0
Acrothele subsidua	0	X	0	0	X	X	0
Prototreta sp.	X	X	0	X	0	X	0
Linnarssonia ophirensis	X	X	0	X	X	X	X
Pegmatreta bellatula	X	X	0	0	0	X	X
unnamed genus	0	0	0	0	0	X	X
Dictyonina sp.	X	0	0	0	X	X	0
Micromitra sp.	X	X	0	0	X	X	X
Lingulella sp.	X	X	0	X	0	X	X

(b) Deep Sublittoral and Slope Facies

Fig. 25 Brachiopod Occurrences according to Facies and Localities.
X=present O=absent

diagenetic alteration of these rocks. The topmost Eldorado Formation in the northern Egan Range was only sparsely fossiliferous and yielded no brachiopods.

Distribution of Deep Sublittoral and Slope Brachiopods

Examining Fig. 25b, there are four patterns that deserve discussion. First, the rocks of this facies in the Wheeler Amphitheater section yielded no brachiopods. Second, the genus *Acrothyra* occurs in this facies in only the Marjum North locality. At this locality only (MC76-94) are *Linnarssonia ophirensis* and *Acrothyra* found together, immediately above the Swasey-Wheeler contact. Third, the new genus of brachiopod was found exclusively in rocks of the deep sublittoral and slope facies, in only the eastern localities. However, future collections could conceivably extend this geographic and stratigraphic range. Fourth, *Prototreta* was not recorded from the Canyon Range collections, but was common in all the other study sections of the deep sublittoral and slope facies. This absence is enigmatic in light of the abundance of this taxon in the other localities. The remaining taxa represented in the deep sublittoral and slope facies were too sparsely distributed to speculate on possible geographic or facies controls.

Brachiopod Distributions vs. Rock Types

In terms of rock types, no taxon was represented in all of the lithologies (Fig. 26). *Acrothele subsidua*, *Prototreta* sp., and *Pegmatreta bellatula* were found in rocks of both the shallow shelf and the deep sublittoral and slope facies. The genus *Acrothyra* was found

	Lime Mudstone-Wackestone	Micropelletoidal Wackestone-Packstone	Conglomerate	Skeletal Packstone-Grainstone	Polymeroid Wackestone-Packstone-Grainstone	Oncolite Pelletoidal Wackestone
Acrothyra minor	X	0	0	0	X	0
A. urania	X	0	0	0	X	0
Acrothele subsidua	X	0	0	X	X	0
Prototreta sp.	X	X	0	X	X	0
Linnarssonia ophirensis	X	X	0	X	0	0
Pegmatreta bellatula	X	X	0	0	X	0
unnamed genus	X	0	0	0	0	0
Dictyonina sp.	X	X	0	X	X	0
Micromitra sp.	X	X	0	0	0	0
Lingulella sp.	X	0	0	0	0	0

Fig. 26 Brachiopod Distribution plotted relative to Rock Type

X=present
0=absent

in the latter facies in one sample only. <u>Linnarssonia ophirensis</u> was not found in the shallow shelf facies. Most species of brachiopods in this study appeared to have been more eurytopic than the associated trilobites. As seen in Figs. 23 and 25, several forms were present in both carbonate and outer detrital belt rocks. The trilobite faunas, however, showed a marked change in character between the two facies, from polymeroid-dominated to agnostoid-dominated assemblages.

Interestingly, <u>Acrothele subsidua</u> was not encountered in the micropelletoidal packstones and wackestones of the Geddes Limestone near Eureka, Nevada, but was in all of the other common lithologies. Brachiopods were not found in the conglomerates, dolomite, or oncolite-pelletoidal wackestones.

The remaining taxa were only sparsely represented and definite conclusions concerning lithologic control on their distribution could not be reached.

SYSTEMATIC PALEONTOLOGY

Phylum Brachiopoda Cuvier, 1805
Class Inarticulata Huxley, 1869
Order Lingulida Waagen, 1885
Superfamily Lingulacea Menke, 1828
Family Obolidae King, 1846
Subfamily Lingulellinae Schuchert, 1893

Genus *Lingulella* Salter, 1866

Rowell's (1965, p. H266) description of the genus is followed here.

Lingulella sp.

Plate 1, Figs. 1-5.

DISCUSSION: Fragments of valves that are assigned to *Lingulella* were encountered in several collections in this study. These were elongate oval to subtriangular in outline, subacuminate, ornamented by concentric growth lines, and often pitted in the posterior sector of the valve interiors. Due to the quality of the material and the general uncertainty in the classification of linguloid brachiopods, no specific identification was made. *Lingulella* sp. was generally sparsely represented where present.

AGE: Middle Cambrian, uppermost barren interzone "A" through *Ptychagnostus atavus* Assemblage-zone.

OCCURRENCE: MC76-32, MC76-33, MC76-94, MC76-164, MC76-189, MC76-190, UU-132, UU-256, UU-257, UU-130.

Order Acrotretida Kuhn, 1949
Suborder Acrotretidina Kuhn, 1949
Superfamily Acrotretacea Schuchert, 1893
Family Acrotretidae Schuchert, 1893
Subfamily Acrotretinae Schuchert, 1893

Genus *Prototreta* Bell, 1938

The description of the genus, as given in Robison (1964), is followed here.

Prototreta sp.

Plate 2, Figs. 1-8.

DESCRIPTION: Outline subcircular, subtrapezoidal, or transversely subelliptical; Pedicle valve conical, brachial valve slightly convex, flat, or slightly concave; posterior margin nearly straight in plan. Exterior surface of valves ornamented by fine concentric growth lines.

Pedicle Valve: Posterior margin indented at midpoint, profile subtriangular; procline to catacline, pseudointerarea depressed at center, forming intertrough, intertrough widens adapically, intertrough has faint central ridge extending from apex to commissural plane; foramen circular, situated posterior to apex. Shell laminae in apical portion of valve project into interior, forming an imperfect "cone-in-cone" structure which is revealed when apical process is weathered or broken away. Interior pedicle opening directed postero-dorsally, interior opening circular (although rarely well preserved). Apical process small, rectangular-shaped, located on posterior slope. Intertrough reflected in valve interior as low ramp. Pedicle opening and apical process bounded by bacculate *vascula lateralia*. Paired apical pits usually well-developed, located immediately antero-laterally of pedicle opening, adjacent to reflected intertrough. Cardinal muscle scars expressed as low rounded callosities, elongate parallel to posterior slope, adjacent to *vascula lateralia*.

Brachial Valve: Apex minute, marginal, grooved at summit, extended beyond margin of pedicle valve. Posterior margin possesses well-defined triangular median groove and prominent smooth propareas. Median septum blade-like to digitate, with apex anterior from middle of shell.

DISCUSSION: In general, the specimens of Prototreta found in this study were not well-enough preserved, especially the pedicle interiors and valve margins, to permit specific identification. Robison (1964) noted only one species of Prototreta from the Wheeler Formation in the House Range and Drum Mountains of Utah. This species, Prototreta attenuata (Meek) was also recorded from the upper Bathyuriscus-Elrathina Zone. This distribution coincides with that of Prototreta sp. in this study. Specimens loaned by R. A. Robison could not be positively identified as P. attenuata. Robison (1964) distinguished P. attenuata from P. mimica Bell by the former having a convex rather than a concave anterior pedicle profile, fewer prongs on the median septum, and a convex rather than a flat brachial profile. The specimens of Prototreta examined in this study did not possess a definitely identifiable convex anterior pedicle profile. The median septa were poorly preserved and usually broken. Brachial valves examined were either flat, concave, or convex in profile. Thus, the assignment of these specimens to P. attenuata or P. mimica was not thought to have been justified. The specimens in this study closely resemble P. attenuata in many aspects, but the question of some morphological characters precludes this assignment.

AGE: Middle Cambrian, common in uppermost barren interzone "A", rare to common in Ptychagnostus gibbus Assemblage-zone, rare in P. atavus Assemblage-zone.

OCCURRENCE: MC76-29, MC76-30, MC76-32, MC76-35, MC76-52, MC76-82b, MC76-91, MC76-93, MC76-94, MC76-104, MC76-105, MC76-125, MC76-141, MC76-142, MC76-163, UU-123, UU-129, UU-130, UU-131, UU-132, UU-133, UU-194, UU-256, UU-257, 372.

Subfamily Linnarssoniinae Rowell, 1965

Genus Linnarssonia Walcott, 1885

DISCUSSION: A brief historical outline of the generic names Linnarssonia and Pegmatreta is given below. Rowell (1966) presented this discussion in greater detail and that paper served as the source for much of the following.

Walcott (1885), in his original definition of the genus Linnarssonia, noted many of the characteristic features of the genus that are used to define the genus today. Among these were the convex pedicle valve, eccentric apex, subapical foramen, and an apical process located in front of the pedicle opening. He also noted the low median ridge and absence of a pseudointerarea in the convex brachial valve.

In 1912, Walcott rejected Linnarssonia as a valid generic name, being unable to distinguish it from "Acrotreta", which was defined primarily from exterior features. Bell (1941, p. 231) erected the genus Pegmatreta which was characterized by "strong internal thickening of the ventral apex, pedicle foramen posterior to apex, obsolete dorsal propareas, and low median ridge in the dorsal valve." Robison (1964) used the name Pegmatreta for species having an apical boss just anterior from the pedicle opening.

Rowell (1966) noted the basic similarities between Walcott's original descriptions of Linnarssonia and Bell's and Robison's descriptions of Pegmatreta. Comparison of type materials of these genera led Rowell to conclude that Pegmatreta was a junior synonym of Linnarssonia.

Penley (1974) compared the type species of Linnarssonia (L. transversa(Hartt)) with descriptions of the type species of Pegmatreta (P. perplexa Bell, 1941) and concluded that both generic names were valid. Linnarssonia is characterized by a relatively much larger apical process that projected away from the inner valve surfaces. Pegmatreta has a small apical process, relative to valve size, which is confined to the deeper part of the apical area and is flatter. Bell's (1941) original description of the genus Pegmatreta did not state that species of Pegmatreta were characterized by a well-developed apical boss. Rather, a "strong internal thickening of the ventral apex" was the description used. Robison (1964) apparently was the first to emphasize the presence of a well-developed apical boss as a distinguishing feature of Pegmatreta. From this discussion it may be concluded that both Pegmatreta and Linnarssonia are valid generic names based on differences in the development of the apical process. The presence of specimens in this study that may be assigned to Pegmatreta bellatula, which have very weakly-developed apical bosses, is considered additional support for the validity of the generic name Pegmatreta. Alternatively, Pegmatreta ophirensis (Walcott) possesses the characteristics of the type species of Linnarssonia and was correctly assigned to this latter genus by Rowell (1966).

The description of the genus, as given in Penley (1974), is followed here.

Linnarssonia ophirensis (Walcott)

Plate 3, Figs. 1-8.

DESCRIPTION: The following is after Rowell (1966, p. 24-26). Subcircular to transversely oval in outline, length typically about 0.8 of maximum width; pedicle valve convex to low subconical, catacline to gently procline, maximum height about 0.3 of valve length, occurring at or slightly in front of beak; pseudointerarea flat or gently concave, divided by narrow, moderately developed intertrough; external pedicle foramen small, circular, immediately posterior of beak; anterior slope of valve convex, in lateral profile more strongly rounded posteriorly than anteriorly, maximum height about 0.3 of its length, occurring near mid-length of valve; beak lacking nodes, slightly inflated above shell lateral to it. Both valves ornamented by exceedingly fine growth lines and commonly with strong concentric interruptions of profile whilst radial growth component temporarily was in abeyance, these being more abundant peripherally.

Ventral interior with subtriangular thickening on anterior slope, bounded laterally by vascula lateralia, culminating posteromedially in strong, bosslike apical process with posterior slope descending abruptly to define anterior margin of apical cavity, internal pedicle opening anterodorsally directed in cavity; apical pits close together in cavity, lateral of internal foramen; cardinal muscle scars commonly elevated, on posterior slope of valve, subcircular in outline.

Brachial valve interior with narrow median plate, width typically about 0.2 maximum width of valve and very short anteroposteriorly, propareas obsolescent to absent; median ridge low, buttressing median plate posteriorly, extending forward slightly more than 0.5 of valve length, cardinal muscle scars on elevated callosities, relatively close together, their anterior margins occurring at about 0.12 of valve length. Anterior muscle scars elongated, near center of valve, separated by vascula lateralia from median ridge.

DISCUSSION: No new information on the nature of L. ophirensis was obtained from examination of specimens in this study. The majority of the specimens showed a catacline to very gently procline pedicle profile, but specimens from collection MC76-174 were generally more procline than in any other collection. It is not known if this is a significant difference in terms of classification, but based on the generally fair quality of preservation and rarity of this feature, these specimens were assigned to this species.

The most notable information about L. ophirensis gained in this study is that it does not occur in the Swasey Limestone nor equivalent units.

AGE: Middle Cambrian, Ptychagnostus gibbus and P. atavus assemblage-zones.

OCCURRENCE: MC76-30-32, MC76-56, MC76-94, MC76-82b, MC76-143, MC76-174, MC76-182-185, UU-130-133, UU-256, UU-257, UU-265, UU-271.

Genus Pegmatreta Bell, 1941

The description of the genus, as given on Penley (1974), is followed here.

Pegmatreta bellatula (Walcott)

Plate 4, Figs. 1-6, Plate 5, Figs. 1-5.

DESCRIPTION: Marginal outline subcircular to subquadrate. Maximum length about 2 mm. Shell relatively thin. Biconvex, ornamented by fine concentric growth lines.

Pedicle Valve: Weakly developed apical process, variable in development from subtriangular, widening posteriorly, to rectangular-shaped callosity. Circular dimple in center of process. Apical process relatively much larger in juveniles, may occupy nearly whole valve interior, being sub-trapezoidal in plan. Pair of apical pits located anterolaterally from apical process and lateral to pedicle opening. Internal pedicle opening circular; exterior pedicle opening circular, located immediately dorsal to apex on posterior slope. Inter-trough reflected as low ridge on interior of valve. Anterior margin of pedicle valve may have "lip" developed due to slightly greater shell thickness. Posterior margin nearly straight to slightly convex. Maximum valve height just anterior of posterior margin. Apex thickened. Anterior slope flat to slightly convex. No muscle scars noted.

Brachial Valve: Subquadrate to subcircular in outline. Convex profile. Maximum height of valve located about one-third of valve length from posterior margin. Marginal beak incurved. Propareas very weakly defined. Very weakly developed median ridge. Margin of valve may be slightly thickened, forming lip around entire margin.

No muscle scars noted.

DISCUSSION: The validity of the generic name Pegmatreta was discussed earlier. In addition to the differences in the apical processes, other comparisons of the two genera may be now given. Pegmatreta is generally small, thin-shelled, with muscle scars and median ridge weakly developed or lacking. Linnarssonia is generally larger, more robust, with well-developed muscle scars and median ridge. Additionally, L. ophirensis is not found below the base of the Ptychagnostus gibbus Assemblage-zone in this study, whereas Pegmatreta bellatula is found both below and above this boundary.

Robison (1964, p. 558) noted that P. bellatula had weakly developed "pallial sinuses" but no indication of such markings were found in specimens in this study. Robison also noted that whereas P. bellatula and Linnarssonia [=Pegmatreta] ophirensis had concurrent range zones that they had not been found associated in the same collections. Specimens of both were recovered from samples MC76-182 (Wheeler Formation, Canyon Range) and UU-132 (Secret Canyon Formation, northern Egan Range).

AGE: Middle Cambrian, uppermost barren interzone "A" through Ptychagnostus atavus Assemblage-zone.

OCCURRENCE: MC76-33, MC76-35, MC76-46, MC76-91, MC76-124, MC76-125, MC76-141, MC76-164, MC76-182, MC76-191, UU-132, 245', 372.

Genus Acrothyra Matthew, 1901

DISCUSSION: Two species of Acrothyra; A. minor and A. urania, have been described from etched material (Rowell, 1966). Other species of this genus are described from crack-out material only. Most specimens of Acrothyra in this study can be confidently assigned to A. minor. A small proportion of the specimens resemble A. urania in that the beak is strongly incurved, the external foramen faces posteriorly, rather than dorsally, and possess small but distinct ventral propareas. However, some specimens appear to have the external foramen facing in a direction between dorsal and posterior, making these forms transitional between the species mentioned in this respect. Unfortunately, the generally poor quality of the collections in this study prevent specific identification of these "transitional" forms. They are definitely the genus Acrothyra but are too fragmentary to identify further. Summarizing, A. minor is an extremely confident identification. Specimens of A. urania are identified less confidently but possess the characters that distinguish it from A. minor. The few remaining specimens of this genus are assigned to Acrothyra sp. and will not be discussed further as the degree of incurvature of the beak is the only notable difference from these two species.

A. minor is much more common in collections in this study than A. urania, in about a 3:1 ratio. A. urania always occurs with A. minor. However, about 0.75 of the collections containing Acrothyra contain A. minor only.

The occurrence of Acrothyra minor and A. urania in the lowermost Ptychagnostus gibbus Assemblage-zone at the Marjum North locality is the stratigraphically highest recorded occurrence of this genus (Rowell, oral communication, 1977). Rowell (1966, p. 28) noted that A. minor occurred at least as low as the Albertella Zone (Fig. 27) and that

FIG. 27

BIOSTRATIGRAPHIC ZONATION OF THE MIDDLE CAMBRIAN (after ROBISON, 1976)

	Lochman-Balk & Wilson 1958	PROPOSED ZONES - GREAT BASIN		
		Restricted-shelf	Open-shelf	
		polymeroids	polymeroids	agnostoids
MIDDLE CAMBRIAN	*Bolaspidella*	*Eldoradia*	*Bolaspidella*	*Lejopyge calva*
		barren interzone		unnamed
				Ptychagnostus punctuosus
				Ptychagnostus atavus
	Bathyuriscus-Elrathina		*Oryctocephalus*	*Ptych. gibbus*
		Ehmaniella		barren interzone
				Ptych. praecur.
	Glossopleura	*Glossopleura*		barren interzone
				Peronopsis bonnerensis
	Albertella	*Albertella*		
	Plagiura-Poliella	*Plagiura*		

A. urania was recorded from the post-Glossopleura Zone, probably medial Middle Cambrian.

The description of the genus, as discussed in Rowell (1966), is followed here.

Acrothyra minor Walcott, 1905

Plate 6, Figs. 1-7.

The description of this species is taken primarily from Rowell (1966).

DESCRIPTION: Subequally biconvex, typically rounded, subtrigonal in outline, ornamented by fine concentric growth lines.

Pedicle Valve: About 3 times as long as high, maximum height occurring about 0.3 of valve length anterior from beak; beak small but prominent, not incurved, foramen facing posteriorly; posterior sector of valve short, about 0.1 mm in inclined length, pseudointerarea well-developed, posterior slope divided by triangular deltoid pseudointer-area with small but distinct propareas. Pseudointerarea slightly, but abruptly depressed below level of adjacent shell. Ventral interior with pedicle aperture widening and curving in its passage through shell, internal foramen facing anteriorly; apical process arising in front of foramen, confined to anterior slope of valve, extending forward between 0.3 and 0.5 of valve length, variation in detail of shape, but basically subtriangular in outline, expanding in width and becoming higher anteriorly, anterior face of process steep, sharply defined, bounded laterally by bacculate vascula lateralia; cardinal muscle scars elon-gate subelliptical on posterolateral flanks of valve, lateral to vascula lateralia; apical pits not deeply impressed on lateral flanks of apical process about midway along its length.

Brachial Valve: Smooth beak, inflated above general level of adjacent shell; very shallow median sulcus; lateral commissure bowed dorsally. Dorsal interior with small, slightly depressed, subtriangular median plate separating narrowly triangular to almost linear propareas; median ridge high in central part of valve extending forward about 0.75 of valve length, highest anteriorly, posteriorly becoming lower and covered by later shell layers associated with lateral margins of <u>vascula lateralia</u>, posteriorly buttressing median plate; subelliptical cardinal muscle scars diverging anterolaterally, extending forward about 0.25 of valve length, separated by <u>vascula lateralia</u> from median ridge.

DISCUSSION: Rowell (1966) suggested that the brachial valve of <u>A. minor</u> may be shallower than that of <u>A. urania</u>, but was unable to confirm this due to the limited amount of material he had for study. In collections containing pedicle valves of <u>A. minor</u> only, the brachial valves were commonly shallow and not strongly curved. In collections containing pedicle valves of both species, some brachial valves appeared to be more strongly curved and deeper. The posterior part of the valve steepened abruptly at a point about 0.25 of the valve length from the posterior margin producing a deeper valve interior. While this may be a distinguishing feature of <u>A. urania</u>, it is felt that a more thorough study entailing measurements of many valves is required to firmly establish this possibility. This is emphasized by the "transitional" forms of <u>Acrothyra</u> found in this study as well.

AGE: Middle Cambrian, common in uppermost barren interzone "A", very rare in lowermost Ptychagnostus gibbus Assemblage-zone.

OCCURRENCE: MC76-91, MC76-93, MC76-94, MC76-104, MC76-105, MC76-124, MC76-125, MC76-141, MC76-142, UU-123, UU-194.

Acrothyra urania (Walcott)

Plate 7, Figs. 1-7.

DISCUSSION: The description of A. urania is nearly identical to that of A. minor, with the following exceptions: The pedicle beak of A. urania is strongly incurved and thus the pedicle foramen faces dorsally, rather than posteriorly. The pseudointerarea is thus also weakly developed because of the strongly incurved beak. As discussed earlier, the brachial valve of A. urania may be deeper than that of A. minor.

In all other aspects the two species are nearly identical. Well preserved pedicle foramens and beaks are required to differentiate the two species.

AGE: Middle Cambrian, rare in the uppermost barren interzone "A", very rare in lowermost Ptychagnostus gibbus Assemblage-zone.

OCCURRENCE: MC76-94, MC76-124, UU-123, UU-194.

new genus, new species

Plate 8, Figs. 1-8.

DESCRIPTION: Resembles Hadrotreta externally, but brachial valve unknown.

Pedicle Valve: Procline, shell outline transversely subelliptical to subcircular, faint intertrough, foramen circular to vertically elongate, located immediately below apex on posterior slope. Ornamented by fine concentric growth lines. Apex just posterior of center of valve. Apex is faintly indented. Height is about 0.67 to 0.5 of valve length.

Interior of pedicle valve dominated by tube-shaped apical process. Interior pedicle opening directed posteriorly, parallel to posterior slope. Intertrough weakly reflected from commissural plane to pedicle opening. Apical process low, merging smoothly with shell interior near apex. Shell otherwise featureless; no identifiable muscle scars on most specimens. One specimen (KUMIP 145002) exhibits a pair of rounded callosities posterolaterally to the internal pedicle opening. These may be cardinal muscle scars.

DISCUSSION: This form is represented in very few collections and commonly by broken material. The lack of a positively identified brachial valve and the paucity of specimens precludes assignment of a generic or specific identification. It is thought that this form is previously undescribed.

AGE: Middle Cambrian, rare in the *Ptychagnostus gibbus* Assemblage-zone.

OCCURRENCE: MC76-164, MC76-184, 367.

Family Acrothelidae Walcott and Schuchert, 1908
Subfamily Acrothelinae Walcott and Schuchert, 1908

Genus *Acrothele* Linnarsson, 1876

The description of the genus, as given in the Treatise on Invertebrate Paleontology (Part H, Brachiopoda (1), p. H280), is followed here.

Acrothele subsidua (White)

Plate 9, Figs. 1-6.

DESCRIPTION: Shells subcircular to transversely elliptical in outline; diameter ranges up to about 8 mm, but most of the material is broken and incomplete. Surface marked by concentric fine to moderate growth lines and fine irregularly arranged granules of variable prominence.

Pedicle Valve: Flatly procline with apex located 0.2 to 0.3 of length from posterior margin. Apex possesses two prominent tubercles oriented anterolaterally from small but prominent foraminal tube that may extend above surrounding surface of apex. Deltoid pseudointerarea rarely visible and usually poorly defined. Interior possesses a sagitally elongate, oval pedicle opening, two anterolateral pits. No other muscle scars noted.

Brachial Valve: Nearly flat except for slightly convex marginal apex. Exterior protegulum divided by sagittal elongate depression with two tubercles on each side; posterior pair often extended into short posteriorly curved spines. Anterior pair usually consists of low nodes but may be obsolescent. Interior marked by low median septum.

DISCUSSION: The holotype of this species came from the Wheeler Formation at the Wheeler Amphitheater in the House Range and was discussed by Walcott (1912). The only significant difference encountered in specimens of this study was that neither muscle scars nor *vascula lateralia* were visible, due to the quality of the material recovered. All other features coincide with Robison's (1964) and

Walcott's (1912) descriptions of this species.

No specimens of _Acrothele_ were found at the Eureka, Nevada, nor Canyon Range localities. This observation may be misleading as _Acrothele_ was never encountered in great abundance nor were the specimens well preserved. Specimens of _Acrothele_ from the same stratigraphic interval in the Wasatch Mountains have been collected by R. A. Robison (oral communication, 1977). Thus, the lack of specimens in the Canyon Range may be more likely due to chance than a real absence, as equivalent strata in the surrounding areas contain this fossil. However, at Eureka, Nevada, the dominant carbonate lithology is a micropelletoidal wackestone-packstone and an antipathetic relationship with _Acrothele_ may exist. It should be noted that preservation of fossils in this lithology was generally poorer that in equivalent mudstones and wackestones to the east. In conclusion, the general scarcity of specimens of _Acrothele_ in rocks of this study make any statements about the presence or absence of this taxon at a given locality tenuous.

AGE: Middle Cambrian, rare to common in uppermost barren interzone "A", rare in _Ptychagnostus gibbus_ Assemblage-zone, rare in _P. atavus_ Assemblage-zone.

OCCURRENCE: MC76-82b, MC76-91, MC76-93, MC76-104, MC76-121, MC76-125, MC76-141, MC76-142, MC76-163, UU-123, UU-131, UU-134, UU-256, UU-194.

Order Paterinida Rowell, 1965

Superfamily Paterinacea Schuchert, 1893

Family Paterinidae Schuchert, 1893

Genus _Micromitra_ Meek, 1873

The description of the genus, as given in the Treatise on Invertebrate Paleontology (Part H, Brachiopoda, 1965), is followed here.

Micromitra sp.

Plate 10, Figs. 1-6.

DESCRIPTION: Shell outline subelliptical to subquadrate. Ornament variably developed, dominantly reticulate. Biconvex. Pedicle valve deeper than brachial valve.

Pedicle Valve: Well-developed homodeltidium, valve length approximately equal to width. Maximum height of valve located about 0.2 of length from posterior margin at protegulum. Apex has two well-developed lateral nodes divided by narrow furrow. Interior lacks muscle scars. Apical nodes and furrow weakly reflected on interior surface. Valve depth about 0.5 of length.

Brachial Valve: Slightly to moderately convex, posterior margin nearly straight, sulcate. Homeochilidium well developed. Interior surface featureless.

DISCUSSION: Specimens of *Micromitra* were rare in rocks of this study. Additionally they were poorly preserved. Specimens loaned by R. A. Robison were likewise too poorly preserved to permit specific identification. Robison (1964) described specimens of *Micromitra modesta* from the Wheeler and Marjum Formations in the House Range and Drum Mountains. His description of this species are similar to the species of this study, but the fragmentary nature of these fossils preclude confident specific identification.

AGE: Middle Cambrian, *Ptychagnostus gibbus* and *P. atavus* assemblage-zones.

OCCURRENCE: MC76-31, MC76-33, MC76-121, MC76-131, MC76-174, MC76-190, MC76-191.

Genus Dictyonina Cooper, 1942

The description of the genus, as given in Cooper et al. (1952), is followed here.

Dictyonina sp.

Plate 11, Figs. 1-6.

DESCRIPTION: Shell outline subcircular to subelliptical, pedicle valve deeper than brachial valve. Shell exterior ornamented by quincunxial arrangement of pits produced by obliquely raised lines. Faint radial costae broadly spaced present in some specimens.

Pedicle Valve: Hemiconical, with moderately well-developed homeodeltidium. Apex at beak, just anterior of posterior margin. Valve interiors generally featureless.

Brachial Valve: Slightly convex, posterior margin nearly straight, sulcate. Cardinal extremities extend beyond those of pedicle valve. Interior featureless.

DISCUSSION: Specimens of Dictyonina sp. are rare in rocks of this study. They are commonly broken, consisting of a portion of a valve with the easily-recognized quincunxial pattern of ornamentation. Specimens are more commonly found in the Swasey Limestone than in the Wheeler Formation or equivalents.

AGE: Middle Cambrian, rare in uppermost barren interzone "A", rare in Ptychagnostus gibbus and P. atavus assemblage-zones.

OCCURRENCE: MC76-28, MC76-121, MC76-125, MC76-163, UU-256.

PLATES

Explanation of Plate 1.
Figs. 1-5: Lingulella sp.

Fig. 1 Apical area of damaged PV interior. KUMIP 145011, collection UU-132. (11x)

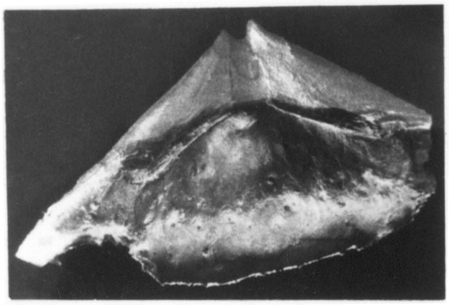
Fig. 2 Brachial valve interior. KUMIP 145012, collection UU-257. (18.3x)

Fig. 3 Oblique posterior view of brachial valve. KUMIP 145012, collection UU-257. (11x)

Fig. 4 Oblique lateral, brachial valve. KUMIP 145012, collection UU-257. (11x)

Fig. 5 Magnified view of Fig. 3. (18.3x)

PLATE 1



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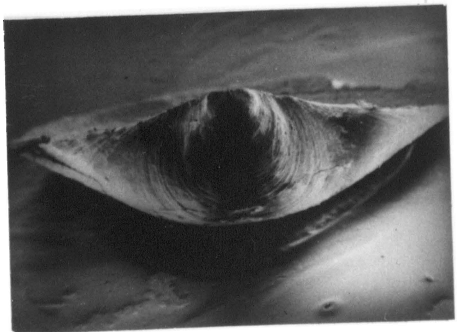

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Explanation of Plate 2.
Figs. 1-8: *Prototreta* sp.

Fig. 1 Anterior profile of pedicle valve. KUMIP 145032, UU-256. (37x)

Fig. 2 Oblique view, posterior slope pedicle valve. KUMIP 145031, collection UU-256. (18.3x)

Fig. 3 Apical view, pedicle valve; posterior to top. KUMIP 145032, collection UU-256. (37x)

Fig. 4 Oblique apical view, damaged pedicle valve, posterior towards top. KUMIP 145027, collection MC76-91. (37x)

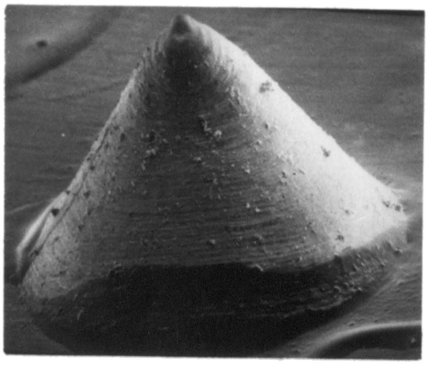
Fig. 5 Oblique damaged pedicle valve interior. Posterior located in 10 o'clock position. KUMIP 145031, collection UU-256. (18.3x)

Fig. 6 Damaged brachial valve exterior, posterior towards top, oblique plan view. KUMIP 145030, collection UU-194. (18.3x)

Fig. 7 Damaged brachial valve interior, plan view. KUMIP 145028, collection UU-194. (18.3x)

Fig. 8 Damaged brachial valve, oblique posterior view, posterior end towards bottom of photograph. Prominent protuberance is median septum, digitate prongs have been broken off. KUMIP 145028, collection UU-194. (18.3x)

PLATE 2



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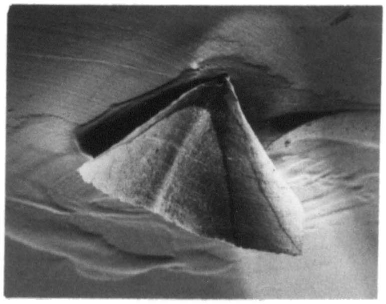

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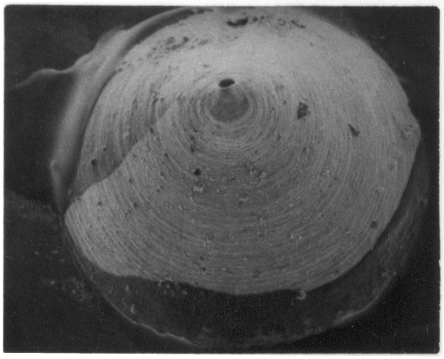

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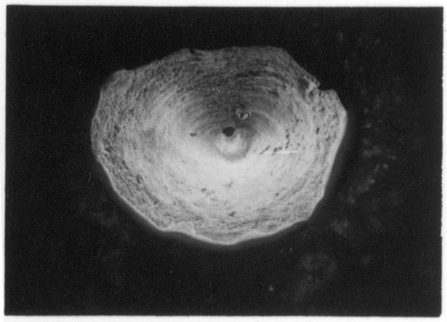

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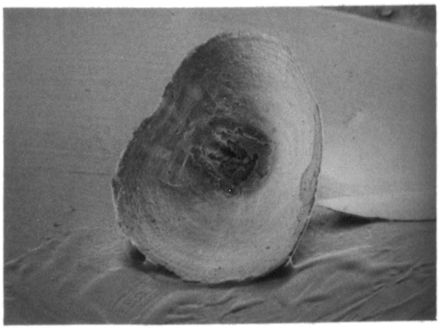

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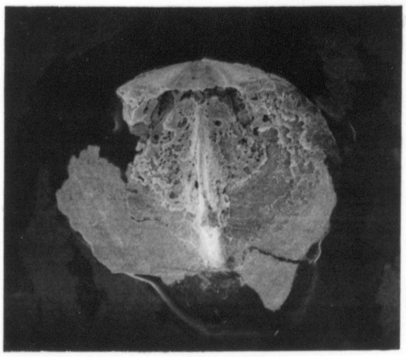

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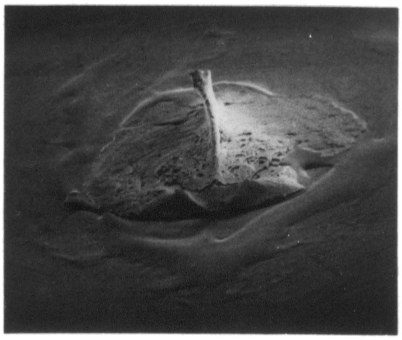

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Explanation of Plate 3.
Figs. 1-8: Linnarssonia ophirensis (Walcott)

Fig. 1 Pedicle valve interior, oblique plan. KUMIP 144990, collection UU-256. (11x)

Fig. 2 Pedicle valve oblique posterior slope. KUMIP 144991, collection UU-256. (18.3x)

Fig. 3 Pedicle valve interior, detail of apical process, internal pedicle opening and vascula lateralia. KUMIP 144990, collection UU-256. (37x)

Fig. 4 Apical view pedicle valve exterior, posterior towards top. KUMIP 144991, collection UU-256. (18.3x)

Fig. 5 Oblique lateral pedicle valve exterior. KUMIP 144991, collection UU-256. (18.3x)

Fig. 6 Brachial valve exterior, plan view. KUMIP 144993, collection UU-256. (11x)

Fig. 7 Brachial valve interior, plan view. KUMIP 144992, collection UU-256. (18.3x)

Fig. 8 Oblique lateral, brachial valve interior, posterior to left. KUMIP 144992, collection UU-256. (18.3x)

PLATE 3

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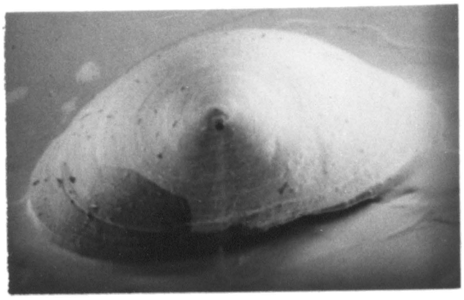

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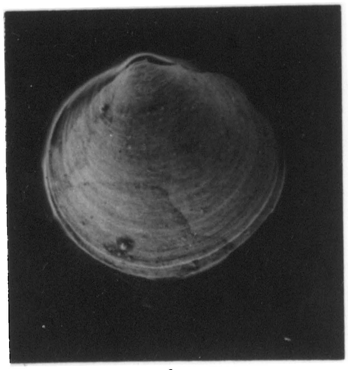

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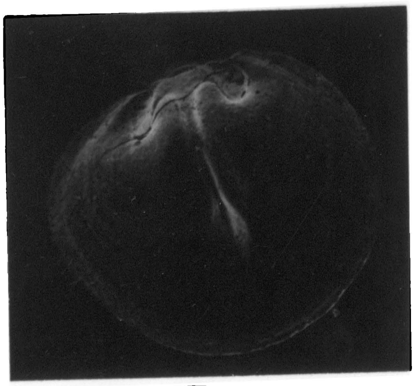

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Explanation of Plate 4.
Figs. 1-6: <u>Pegmatreta</u> <u>bellatula</u> (Walcott)

Fig. 1 Oblique lateral profile, posterior to right, pedicle valve exterior. KUMIP 144994, collection MC76-125. (40.4x)

Fig. 2 Oblique apical view, posterior to bottom, pedicle valve exterior. KUMIP 144994, collection MC76-125. (40.4x)

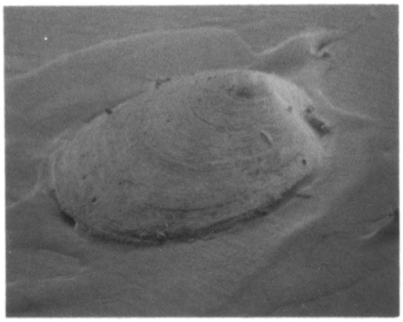
Fig. 3 Apical view, posterior at 11 o'clock, pedicle valve exterior. KUMIP 144994, collection MC76-125. (40.4x)

Fig. 4 Posterior profile, pedicle valve exterior. KUMIP 144996, collection MC76-141. (40.4x)

Fig. 5 Pedicle valve interior, posterior to top, plan view. Intertrough indicated by indentation in posterior margin. KUMIP 144996, collection MC76-141. (40.4x)

Fig. 6 Close-up of pedicle valve interior. Same as Fig. 5. (80.7x)

PLATE 4



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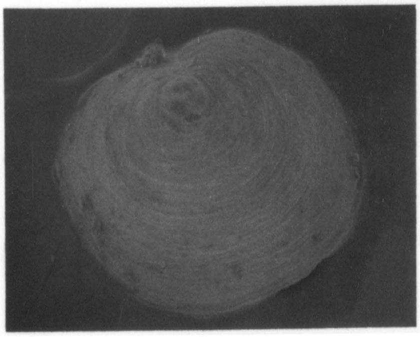

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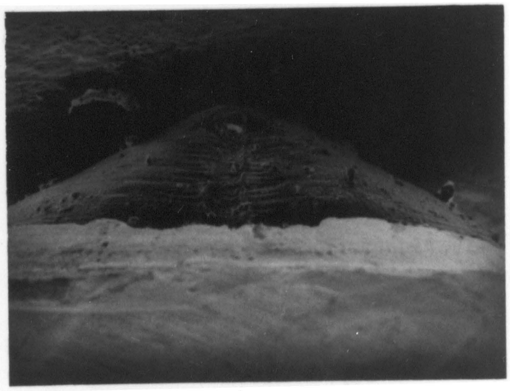

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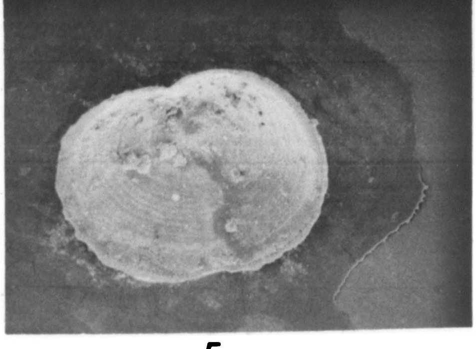

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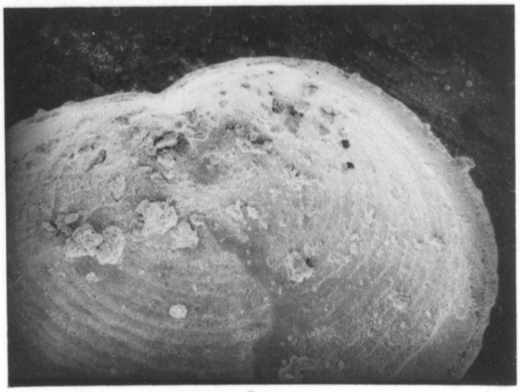

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Explanation of Plate 5.
Figs. 1-5: _Pegmatreta_ _bellatula_ (Walcott)

Fig. 1 Oblique lateral profile, brachial valve exterior, posterior to right. KUMIP 145019, collection MC76-141. (42x)

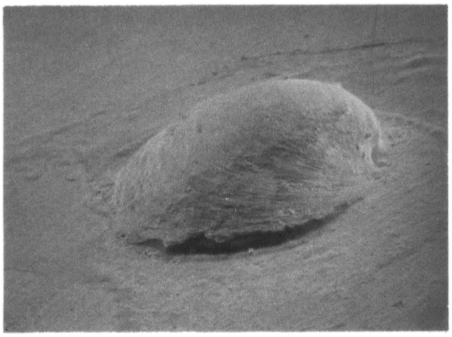
Fig. 2 Oblique posterior profile. Brachial valve exterior, silt encrusted valve exterior. KUMIP 145020, collection MC76-141. (42x)

Fig. 3 Brachial valve exterior, plan view, damaged and silt encrusted valve. KUMIP 145020, collection MC76-141. (42x)

Fig. 4 Brachial valve exterior, plan view, damaged valve. KUMIP 145019, collection MC76-141. (42x)

Fig. 5 Brachial valve interior, plan view. KUMIP 144995, collection UU-132. (42x)

PLATE 5



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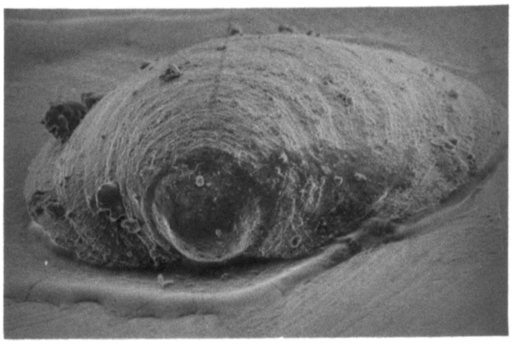

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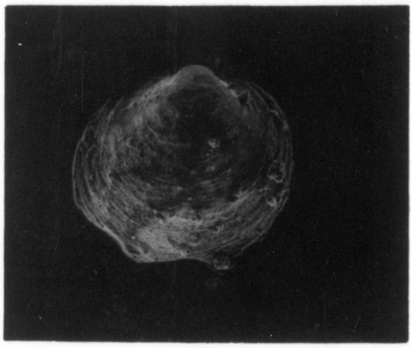

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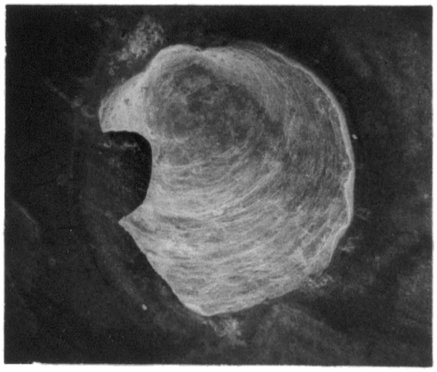

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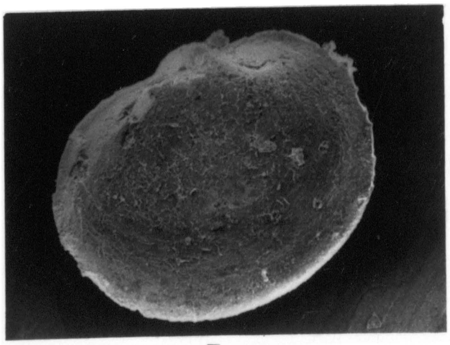

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Explanation of Plate 6.
Figs. 1-6: *Acrothyra minor* Walcott

Fig. 1 Pedicle valve exterior, valve is silt-encrusted, damaged, rotated plan view. KUMIP 145026, collection MC76-91. (41x)

Fig. 2 Oblique lateral profile, pedicle valve exterior, posterior to right. KUMIP 145026, collection MC76-91. (41x)

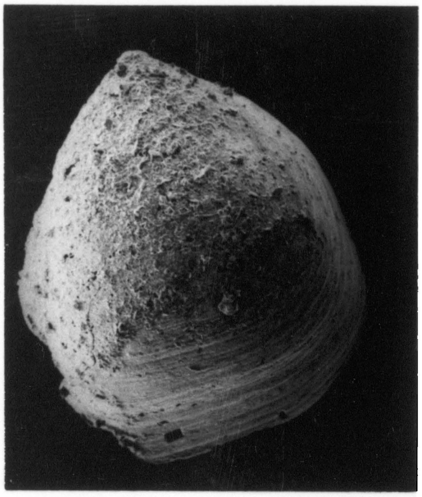
Fig. 3 Pedicle valve interior, plan view, damaged valve. KUMIP 145024, collection MC76-91. (41x)

Fig. 4 Brachial valve exterior, plan view. KUMIP 145023, collection UU-123. (20.3x)

Fig. 5 Brachial valve interior, plan view. KUMIP 145022, collection UU-123. (20.3x)

Fig. 6 Oblique posterior profile, brachial valve. Posterior towards bottom. KUMIP 145023, collection UU-123. (20.3x)

PLATE 6



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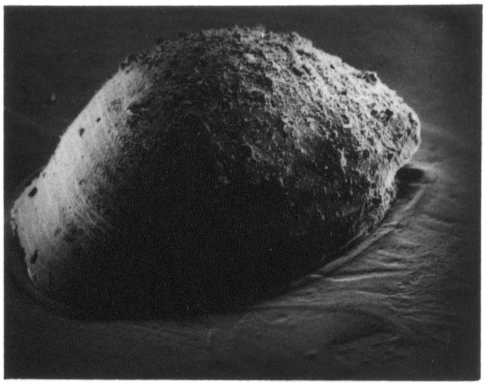

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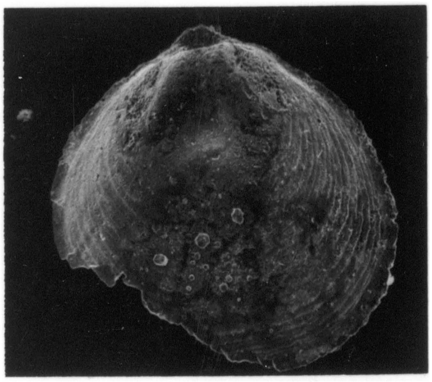

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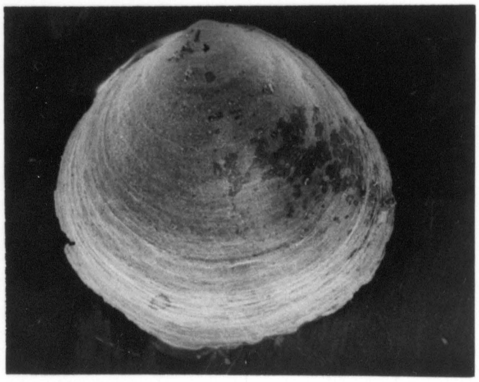

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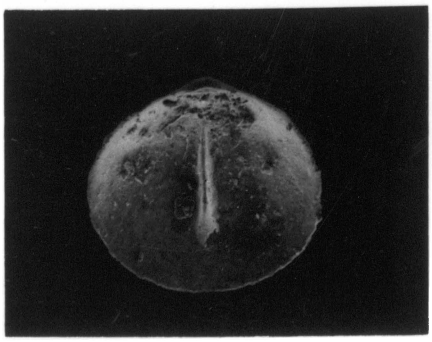

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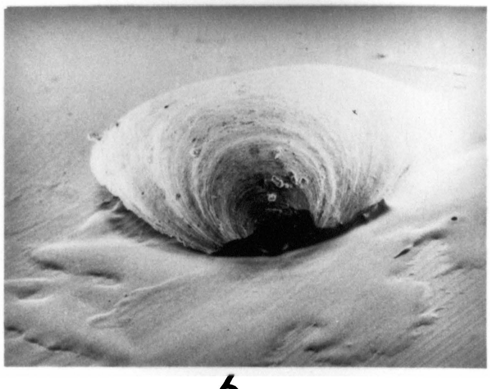

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Explanation of Plate 7.
Figs. 1-7: Acrothyra urania (Walcott)

Fig. 1 Pedicle valve interior, oblique plan view. KUMIP 144998, collection UU-123. (17.7x)

Fig. 2 Detail of beak, pedicle valve. KUMIP 144998, collection UU-123. (35.7x)

Fig. 3 Rotated pedicle valve, posterior profile. KUMIP 144998, collection UU-123. (17.7x)

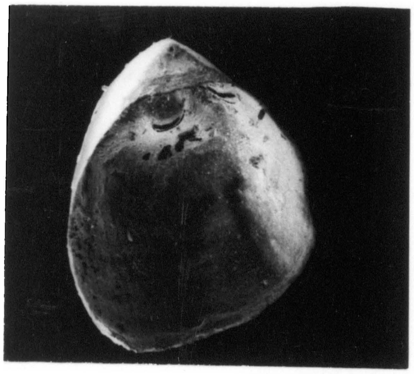
Fig. 4 Brachial valve, oblique posterior profile, damaged valve. KUMIP 144999, collection UU-194. (35.7x)

Fig. 5 Brachial valve anterior slope. KUMIP 144999, collection UU-194. (17.7x)

Fig. 6 Oblique lateral profile, damaged brachial valve, posterior to right. KUMIP 144999, collection UU-194. (17.7x)

Fig. 7 Rotated plan view, damaged brachial valve. KUMIP 144999, collection UU-194. (17.7x)

PLATE 7



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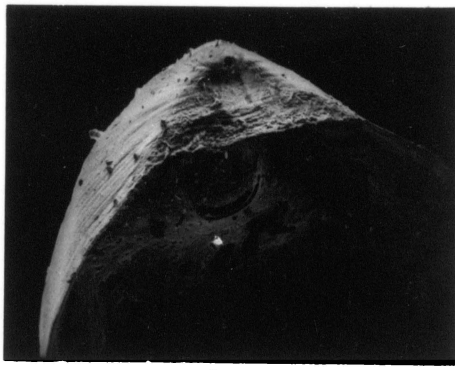

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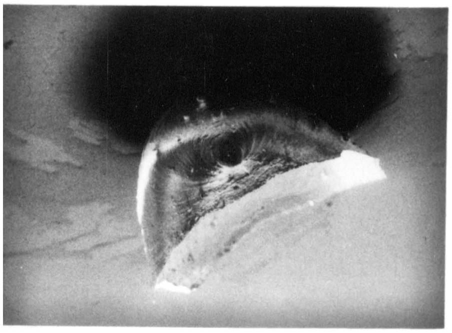

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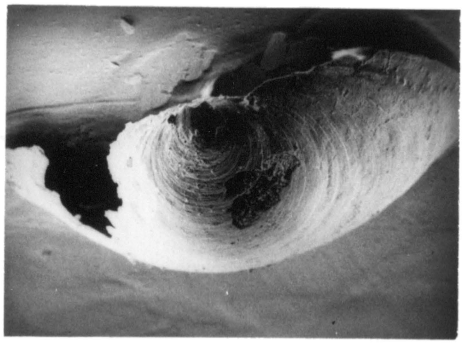

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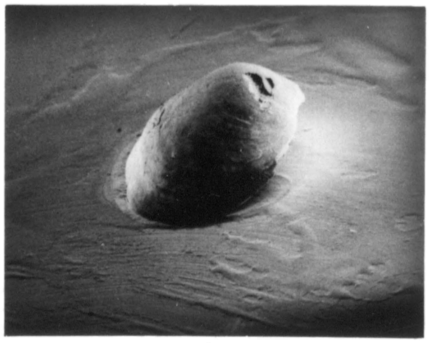

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Explanation of Plate 8.
Figs. 1-8: new genus, new species; all pedicle valves.

Fig. 1 Apical view, damaged valve. KUMIP 145000, collection MC76-164. (18x)

Fig. 2 Oblique lateral profile, posterior to left. Damaged valve. KUMIP 145000, collection MC76-164. (36.3x)

Fig. 3 Oblique posterior profile, damaged valve. KUMIP 145000, collection MC76-164. (36.3x)

Fig. 4 45^{o} view, lateral to apical view, damaged valve. KUMIP 145000, collection MC76-164. (36.3x)

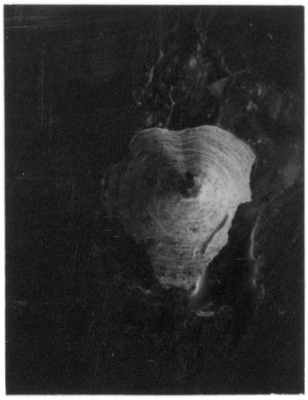
Fig. 5 Detail of pedicle foramen. KUMIP 145000, collection MC76-164. (73.5x)

Fig. 6 Interior, plan view, partly crushed valve. KUMIP 145002, collection MC76-184. (36.3x)

Fig. 7 Oblique pedicle valve interior, posterior towards right, damaged valve. KUMIP 145003, collection MC76-184. (36.3x)

Fig. 8 Oblique pedicle valve interior, posterior towards top, damaged valve. KUMIP 145003, collection MC76-184. (36.3x)

PLATE 8



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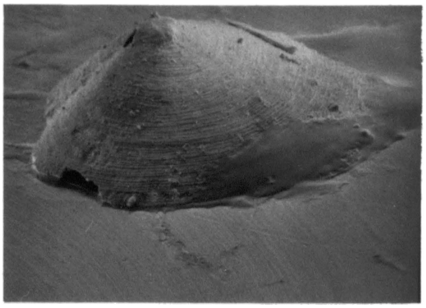

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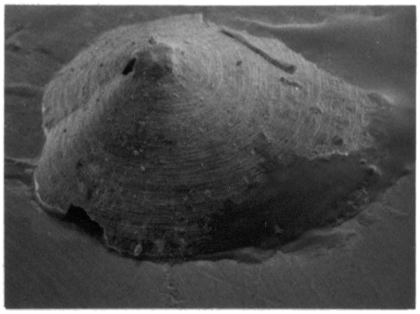

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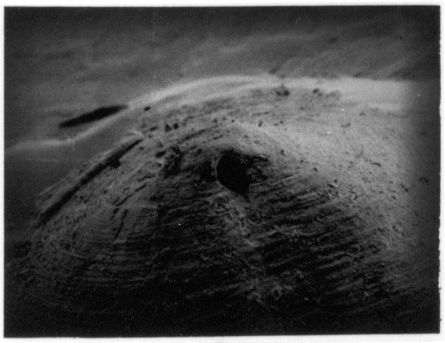

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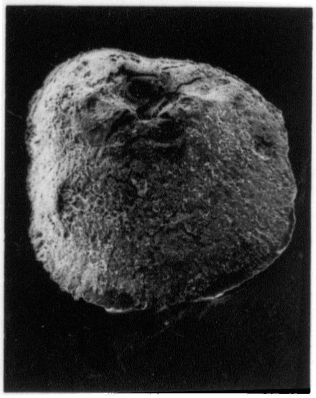

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Explanation of Plate 9.
Figs. 1-6: Acrothele subsidua (White)

Fig. 1 Pedicle valve exterior, plan view, damaged shell. KUMIP 145015, collection UU-256. (20.3x)

Fig. 2 Pedicle valve exterior, oblique plan view, damaged valve, posterior towards bottom. KUMIP 145015, collection UU-256. (20.3x)

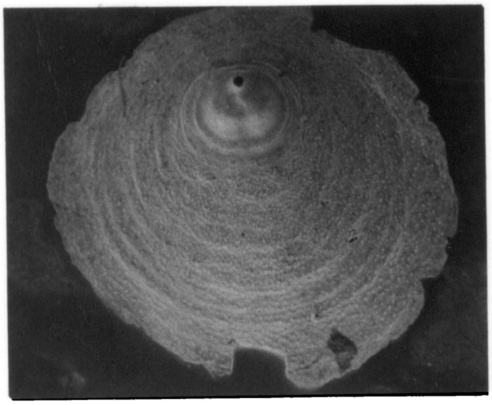
Fig. 3 Brachial valve, detail of protegulum. Note 4 nodes, 2 posterior are broken spines (Fig. 6). KUMIP 145017, collection UU-256. (41x)

Fig. 4 Detail of pedicle valve protegulum. Posterior towards top. KUMIP 145015, collection UU-256. (41x)

Fig. 5 Brachial valve interior, plan view, damaged valve. KUMIP 145018, collection UU-134. (41x)

Fig. 6 Brachial valve, oblique posterior view, note two spines extending towards bottom of picture, from protegulum. KUMIP 145018, collection UU-134. (41x)

PLATE 9



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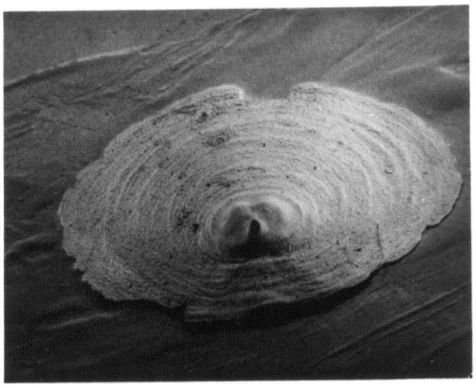

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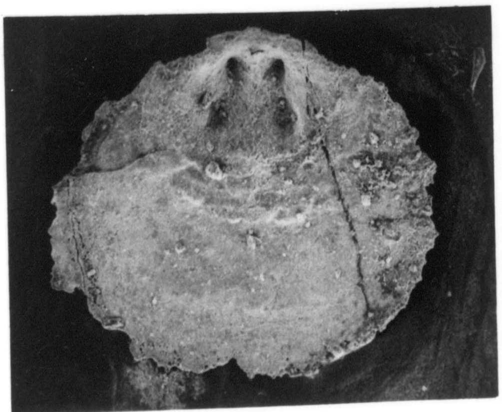

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Explanation of Plate 10.
Figs. 1-6: *Micromitra* sp.

Fig. 1 Oblique lateral profile, posterior to left, damaged pedicle valve. KUMIP 145005, collection MC76-31. (35.1x)

Fig. 2 Oblique apical view, posterior to left, damaged pedicle valve. KUMIP 145005, collection MC76-31. (35.1x)

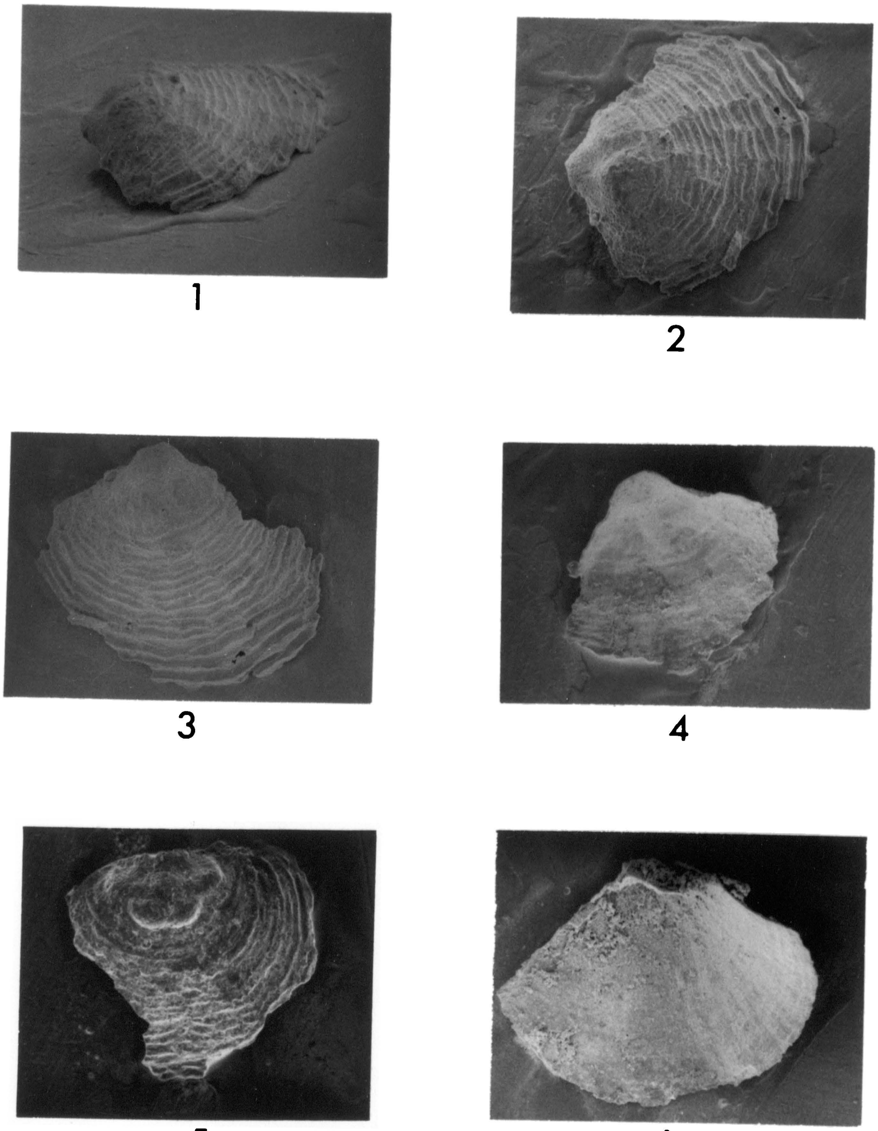
Fig. 3 Apical view, damaged pedicle valve. KUMIP 145005, collection MC76-31. (35.1x)

Fig. 4 Damaged pedicle valve interior, posterior towards top. KUMIP 145004, collection MC76-31. (35.1x)

Fig. 5 Brachial valve exterior, plan view, damaged valve. KUMIP 145006, collection MC76-121. (35.1x)

Fig. 6 Brachial valve interior, damaged valve, posterior towards top. KUMIP 145007, collection UU-256. (17.4x)

PLATE 10



1 2 3 4 5 6

Explanation of Plate 11.
Figs. 1-6: Dictyonina sp.

Fig. 1 Pedicle valve exterior, damaged valve. KUMIP 145010, collection UU-256. (12.3x)

Fig. 2 Detail of protegulum, damaged pedicle valve. KUMIP 145010, collection UU-256. (41x)

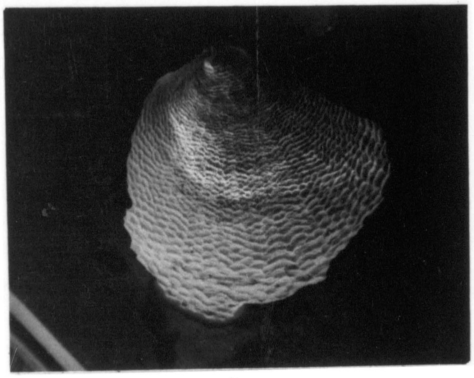
Fig. 3 Pedicle valve interior, oblique anterior view, posterior towards top, damaged valve. KUMIP 145009, collection MC76-125. (20.3x)

Fig. 4 Damaged brachial valve, oblique apical view, posterior towards top. KUMIP 145008, collection MC76-125. (41x)

Fig. 5 Damaged brachial valve, oblique posterior view, posterior towards bottom. KUMIP 145008, collection MC76-125. (41x)

Fig. 6 Detail of pedicle valve - shell ornamentation. KUMIP 145008, collection UU-256. (163x)

PLATE 11



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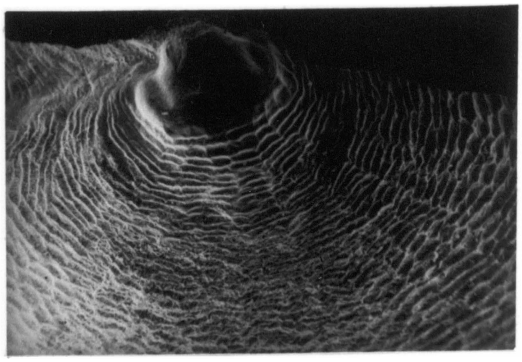

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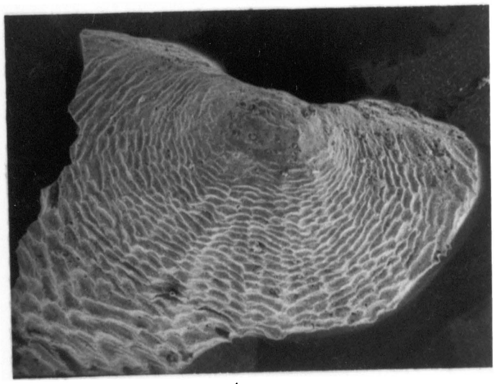

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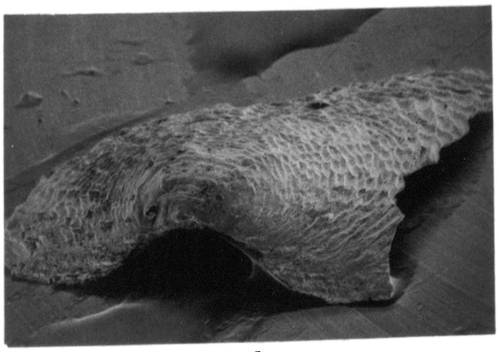

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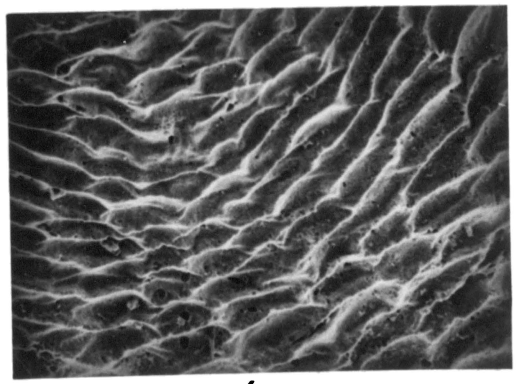

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APPENDIX A
Location of Measured Sections

Eureka-1:39°27'43"N-115°59'08"W, T18N-R53E, Eureka Co., Nevada; Geologic Map of Pinto Summit Quad., 1974 ed., 1:31680; W. side of Secret Canyon on N-S trending ridge, about 9.3 mi. (20.5 km) N. on dirt road through Secret Canyon, entrance to dirt road off U. S. Highway 50, S. of Eureka.

Eureka-2:39°27'30"N-115°59'12"W, T18N-R53E, Eureka Co., Nevada; Geologic Map of Pinto Summit Quad., 1974 ed., 1:31680; W. side of Secret Canyon on N-S trending ridge about 9.2 mi. (20.3 km) N. on dirt road through Secret Canyon, located just S. of Eureka-1 section. Abandoned stone house lies in narrow low-lying re-entrant between two hillsides on which sections are located.

Northern Egan Range:39°33'30"N-114°56'40"W, SE¼-SE¼-T20N-R62E (unsurveyed), White Pine Co., Nevada; Nevada Bureau of Mines Map 35-Geologic Map and sections of the Southern Cherry Creek and Northern Egan Ranges-White Pine Co., Nevada by W. H. Fritz, 1968. First E-W trending ridge N. of stream valley shown on map crossed by line G'-G". Section located in saddle-shaped depression on ridge, stratigraphic top to west.

Marjum North:39°14'47"N-113°22'30"W; S½-NE¼-SE¼-Sec. 14-T18S-R14W, Millard Co., Utah; Notch Peak Quad., 15 min. series. 1:62500; E. side of Rainbow Valley, stream cut located where power lines last cross road in southerly direction.

Marjum South:39°14'47"N-113°22'30"W, S½-NE¼-NE¼-Sec. 14-T18S-R14W, Millard Co., Utah; Notch Peak Quad., 15 min. series, 1:62500; E.

side of Rainbow Valley, first ridge on roadside where power lines last cross road in a southerly direction, W. W. White (1973) measured section; painted with yellow highway paint, located few hundred meters S. of Marjum North section.

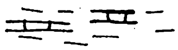
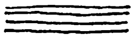
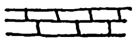
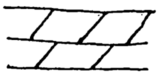
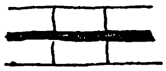
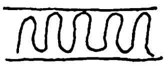
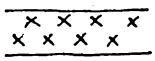
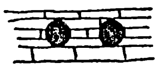
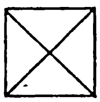
Wheeler Amphitheater: $39^{o}22'13''N-113^{o}18'35''W$, T16S-R13W, Millard Co., Utah; Marjum Pass Quad., 7.5 min. series, 1:24000, section commences at dirt road and trends N. up hillside, 0.3 mi. E. of Stove Spring on flank of Swasey Mountain.

Drum Mountain: $39^{o}30'45''N-112^{o}59'25''W$; E½-SE¼-Sec. 17-T15S-R10W (survey in progress), Millard Co., Utah, Drum Mts. Well Quad., 7.5 min. series, ridge crest of first prominent N-S trending spur E. of "Sawtooth Ridge" (informal name of prominent "Marjum" cliffs immediately W. of study area). White's (1973) Sec. 1.

Canyon Range: $39^{o}29'44''N-112^{o}13'03''W$, E½-E½-Sec. 19&20-T15S-R3W, Millard Co., Utah; Scipio North Quad., 15 min. series, 1:62500, S. side of Leamington Pass Rd. on ridge located a few hundred meters E. of abandoned mine shafts in Howell Limestone equivalent. Sec. trends E.

APPENDICES B, C, D

LEGEND

	INTERBEDDED THIN LIMESTONES AND SHALES
	SHALE
	THIN-BEDDED LIMESTONE
	MEDIUM-BEDDED LEDGE-FORMING LIMESTONE
	MASSIVE LEDGE-FORMING DOLOMITE
	INTERBEDDED SHALES AND THIN- AND MEDIUM-BEDDED LIMESTONES
	CONTORTED BEDDING
	IGNEOUS SILL
	CONCRETIONS
▲	NODULAR BLACK CHERT
	TALUS-COVERED INTERVAL
● MC76-91	SAMPLE LOCATION AND NUMBER

APPENDIX B

SAMPLE LOCATIONS

FIG. BI EUREKA I

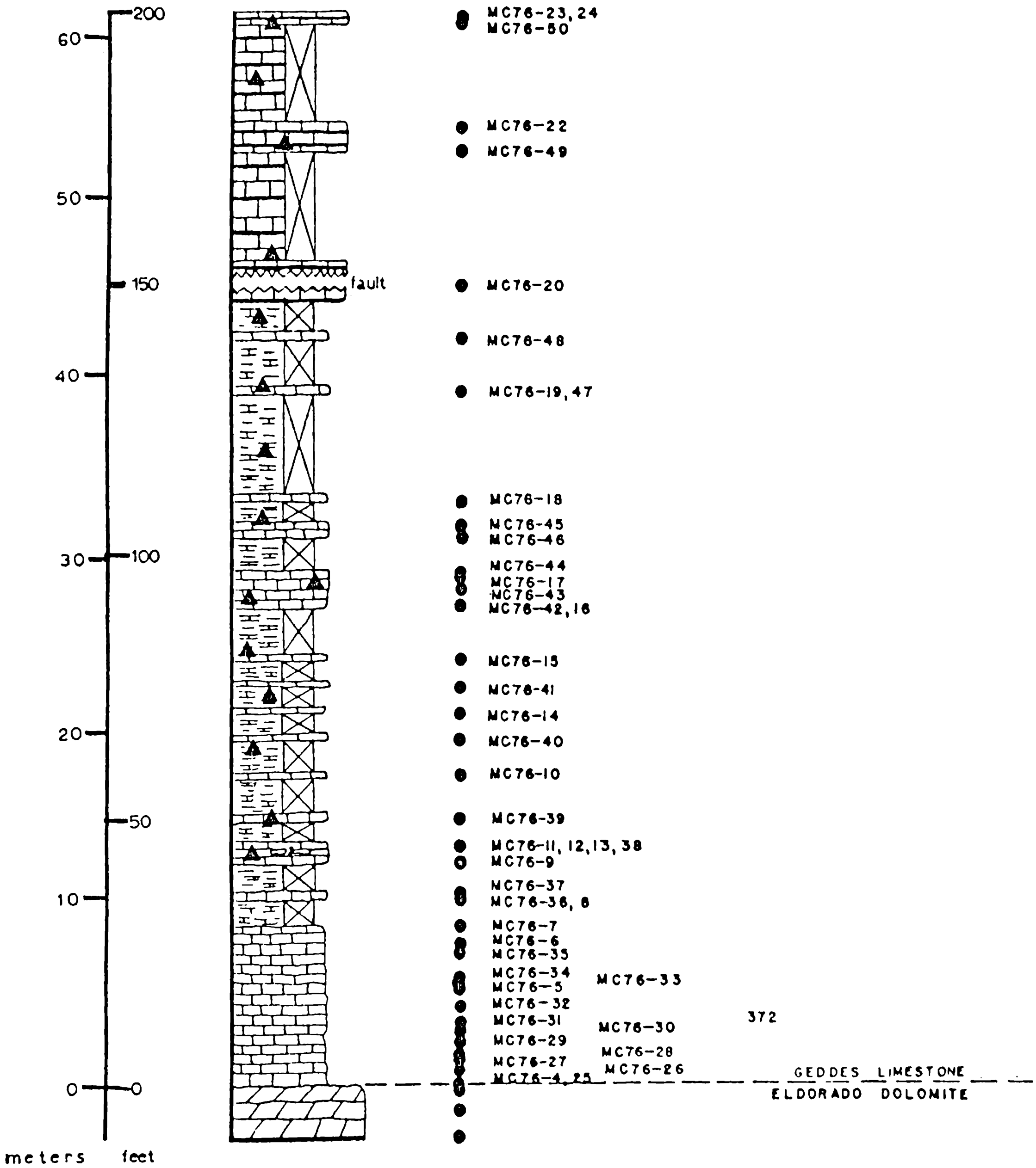


FIG. B2 EUREKA 2

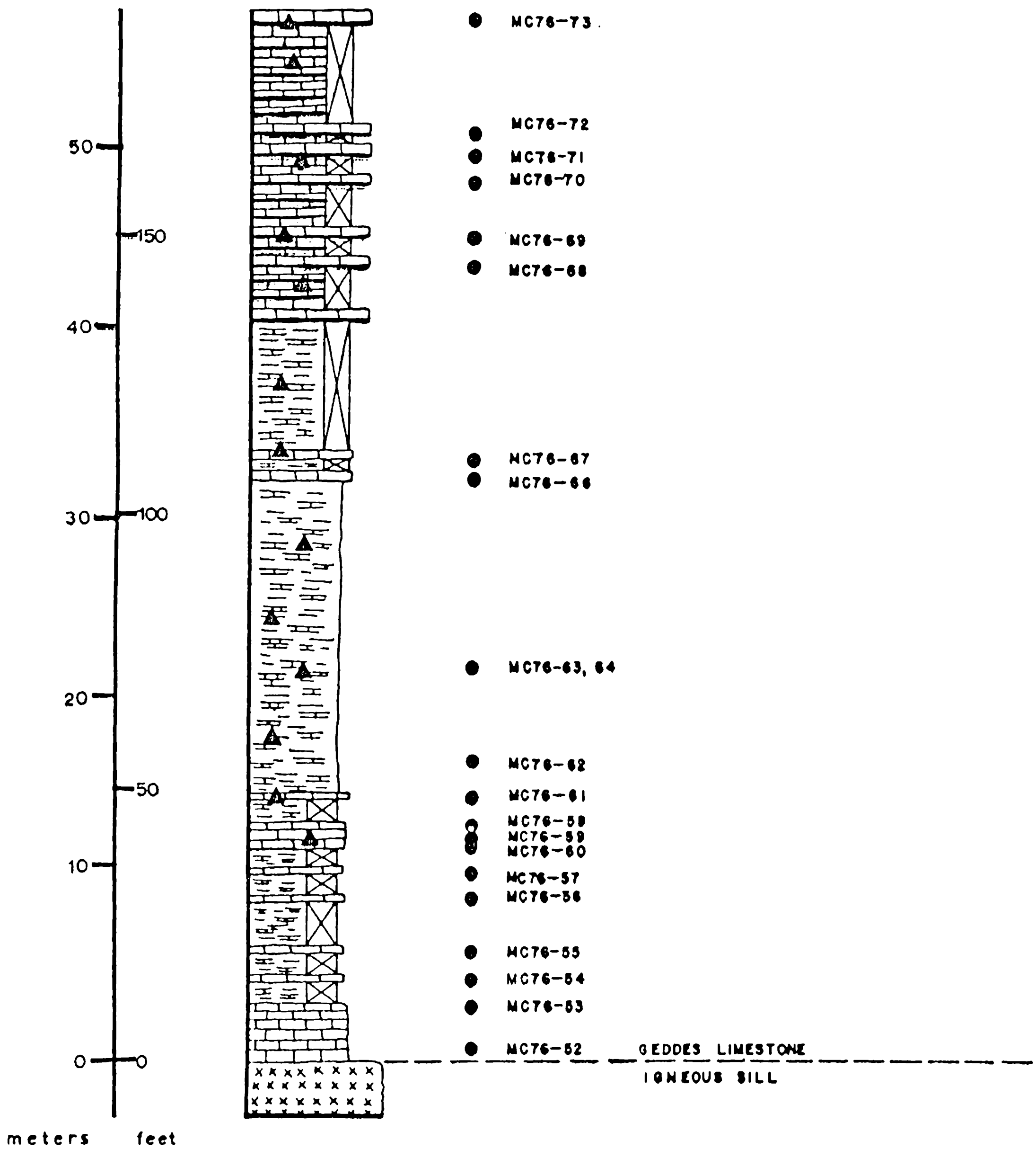


FIG. B3 NORTHERN EGAN RANGE

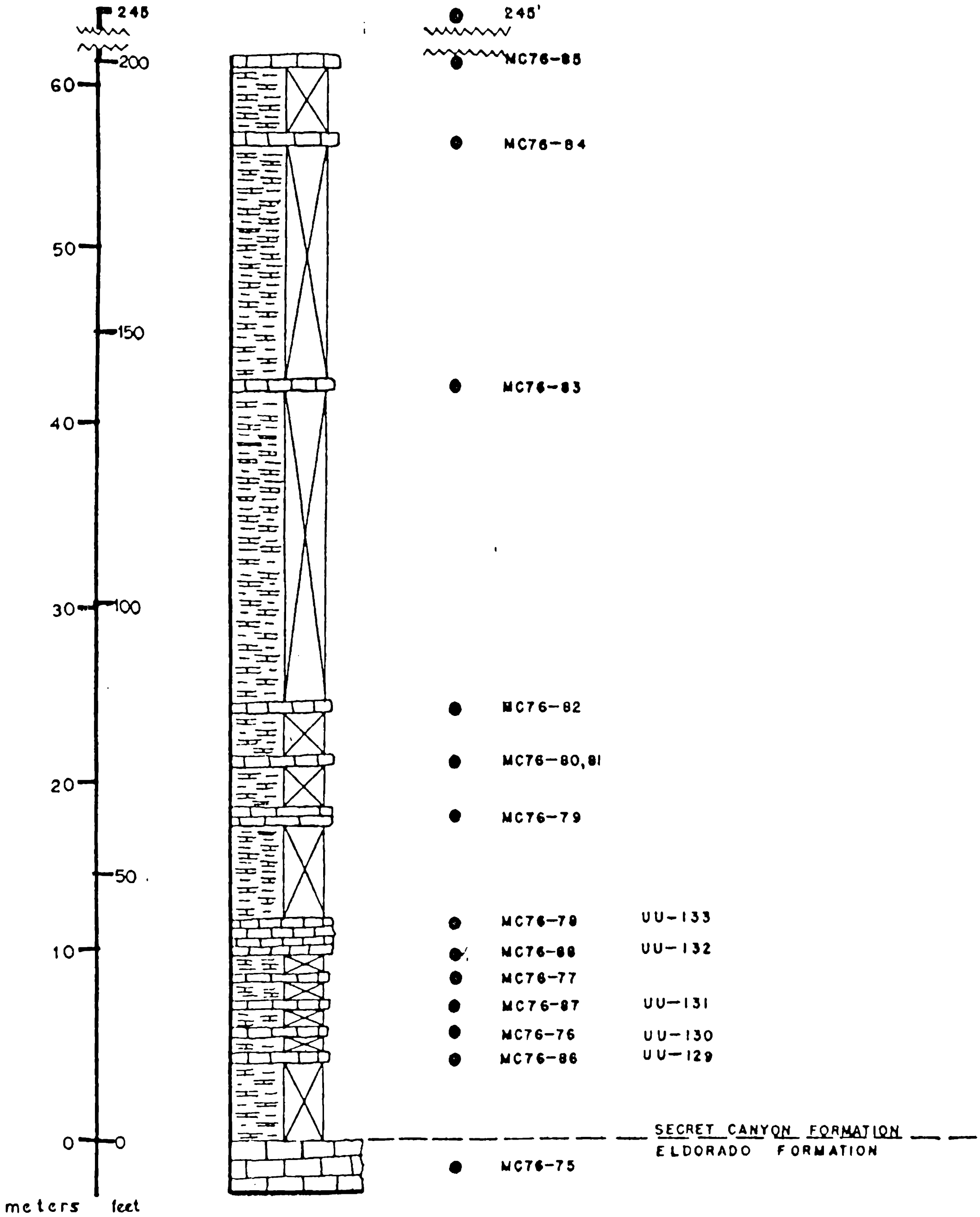


FIG. B4 MARJUM NORTH

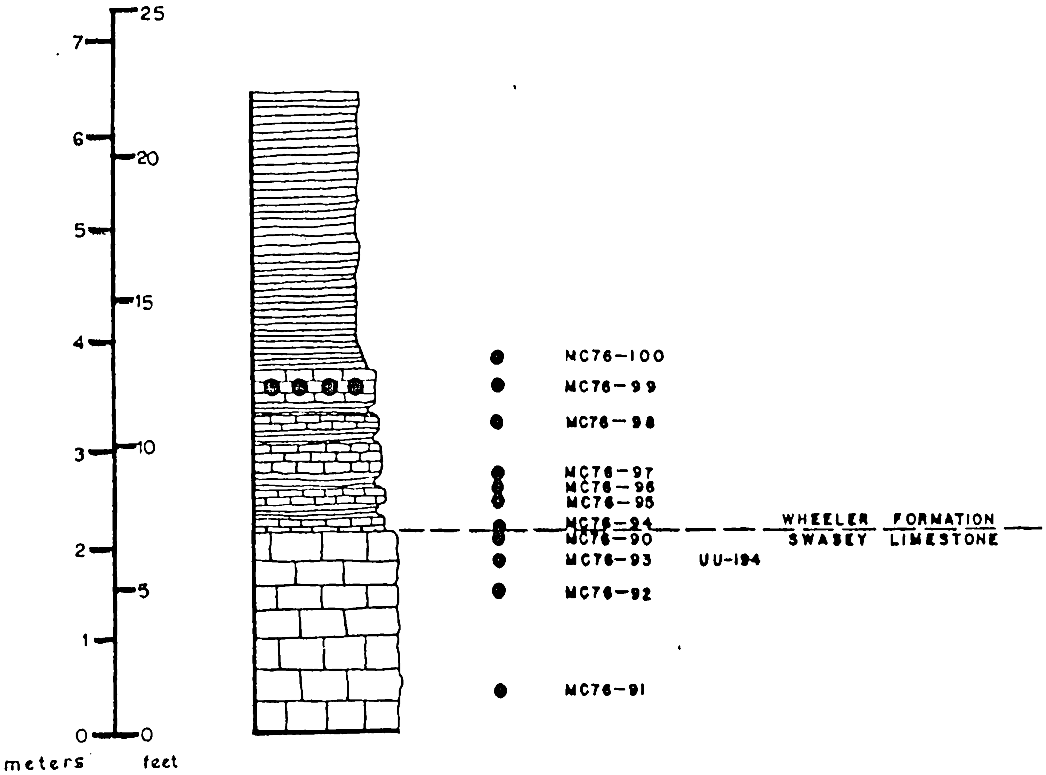


FIG. B5 MARJUM SOUTH

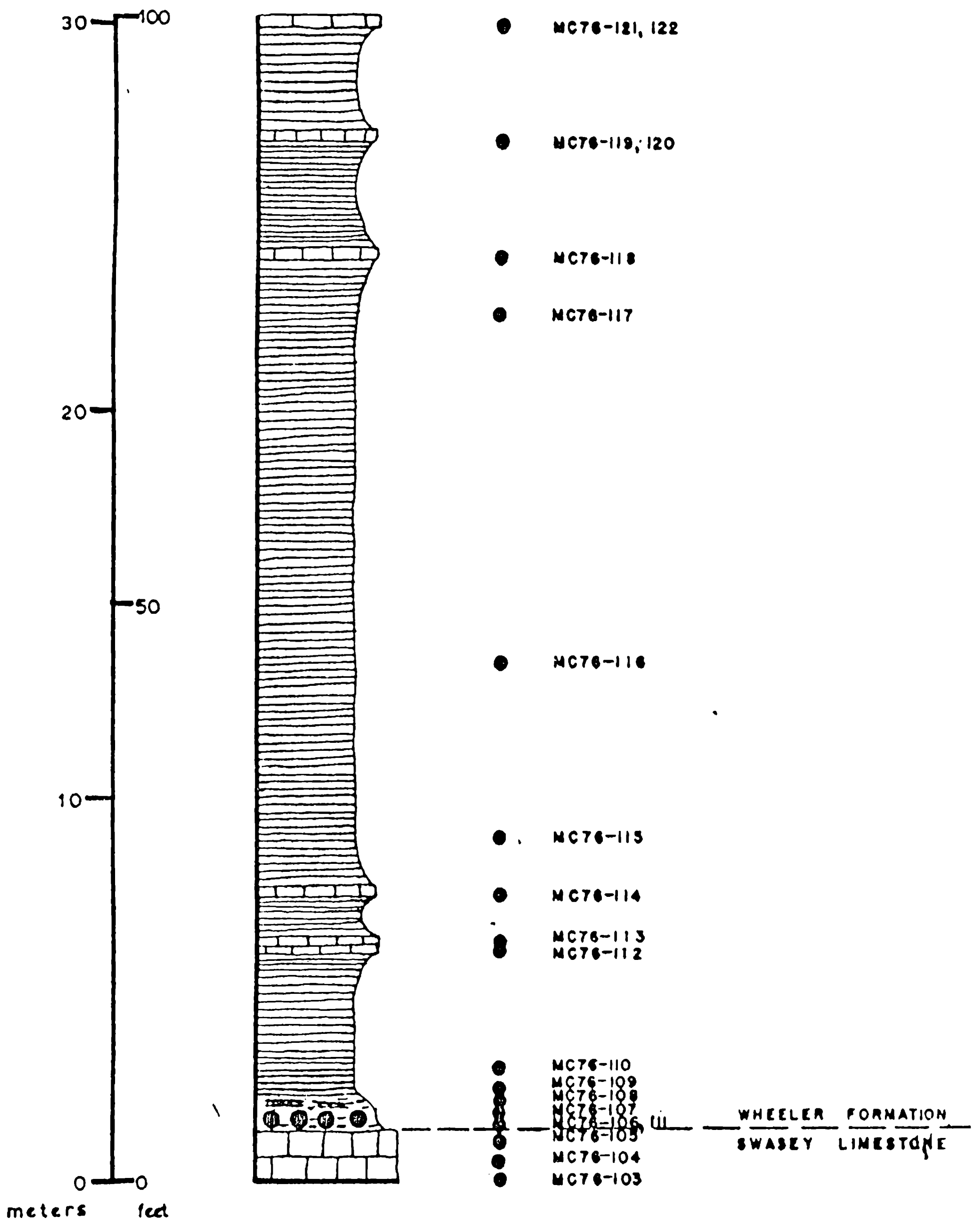


FIG. B6 WHEELER AMPHITHEATER

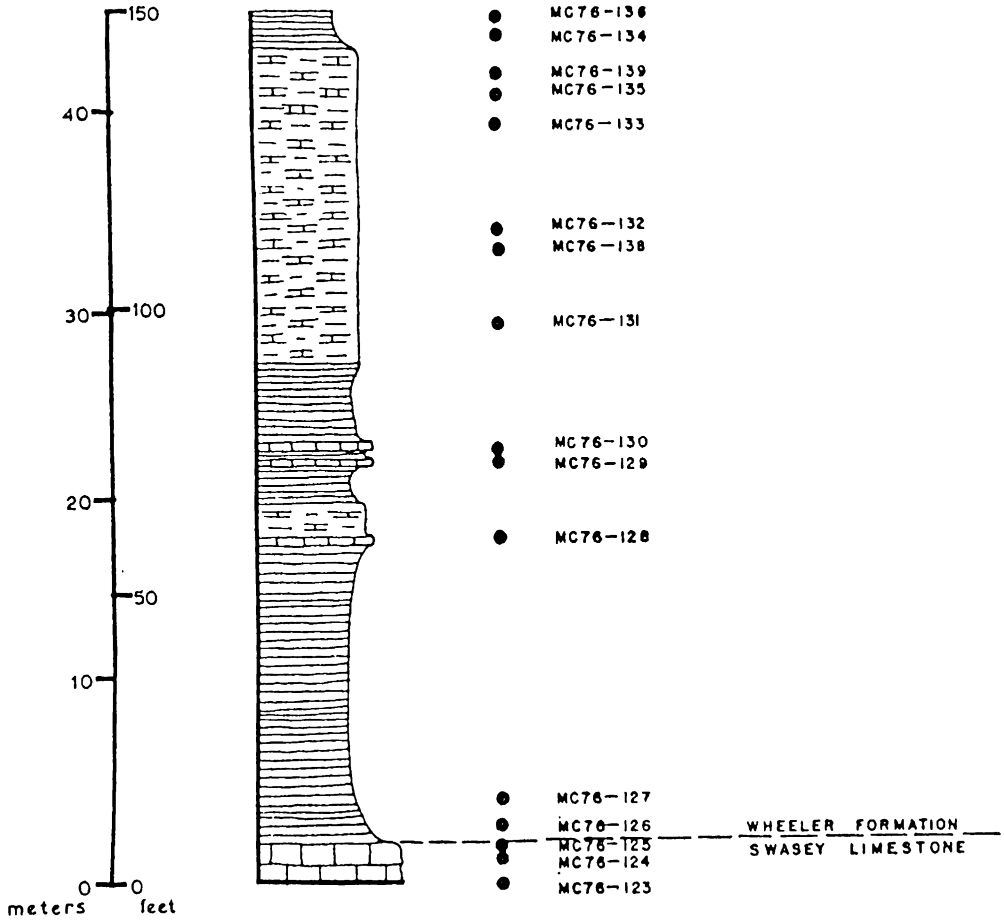


FIG. B7 DRUM MOUNTAINS

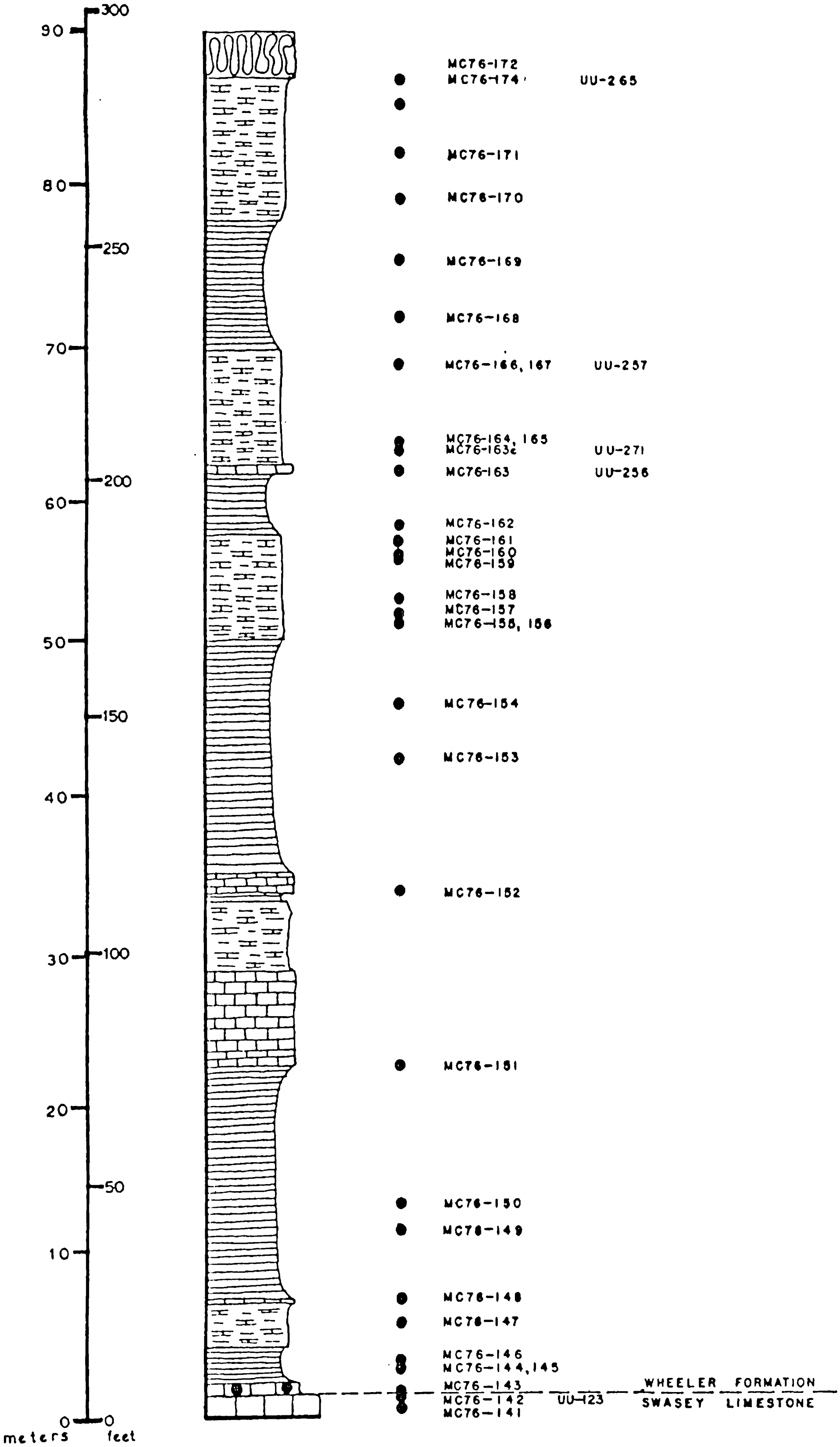
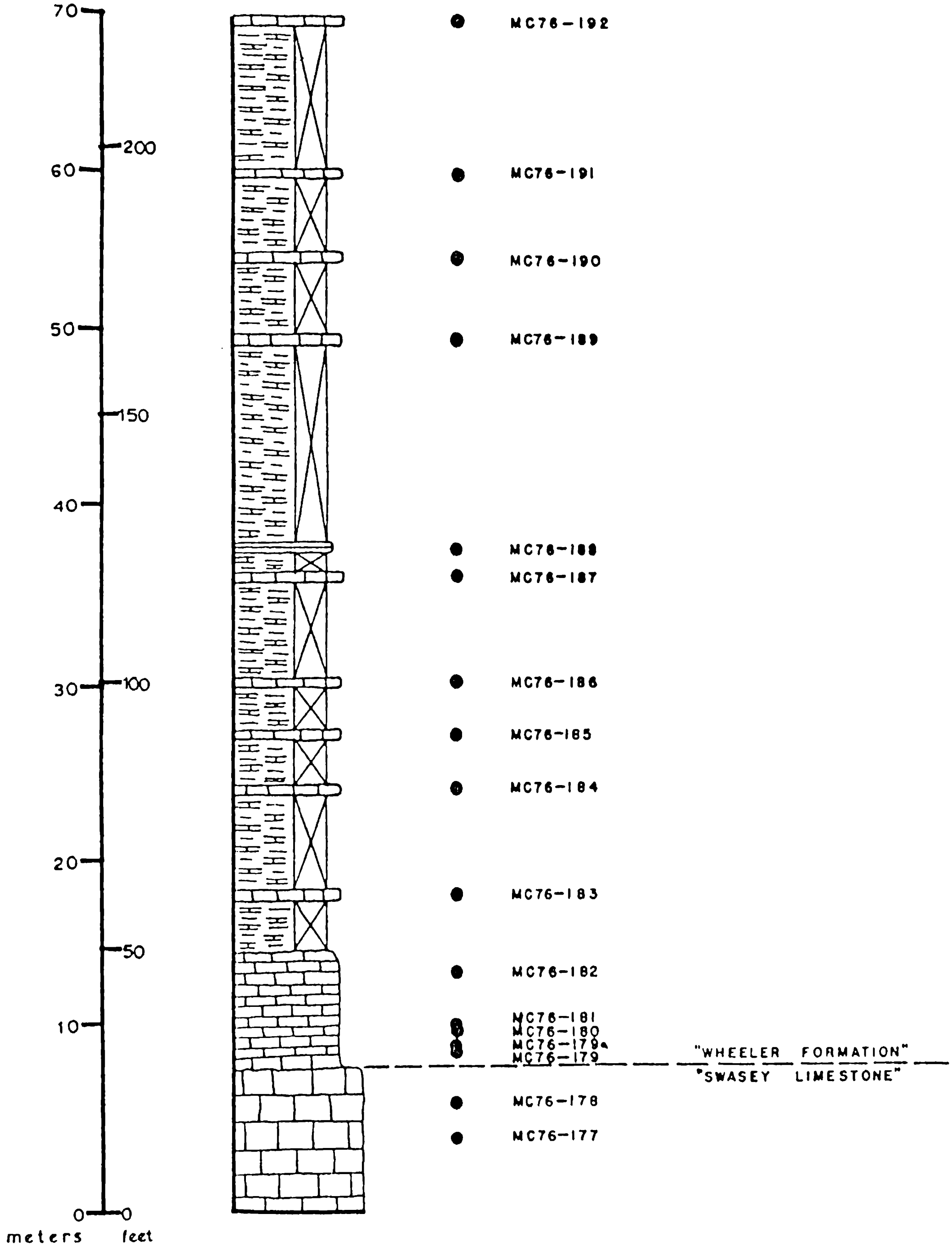


FIG. B8 CANYON RANGE



APPENDIX C

FACIES AND LITHOLOGIES

LEGEND

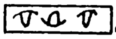
	LIME MUDSTONE
	LIME WACKESTONE
	MICROPELLETOIDAL WACKESTONE PACKSTONE
 ALLOC	SKELETAL GRAINSTONE
 ALLOC	SKELETAL PACKSTONE
	CONGLOMERATE
	ONCOLITE PELLETOIDAL WACKESTONE
	POLYMEROID WACKESTONE
	" PACKSTONE
	" GRAINSTONE
DS+S	DEEP SUBLITTORAL AND SLOPE
B	BASIN
SS	SHALLOW SHELF

FIG. CI

EUREKA-I

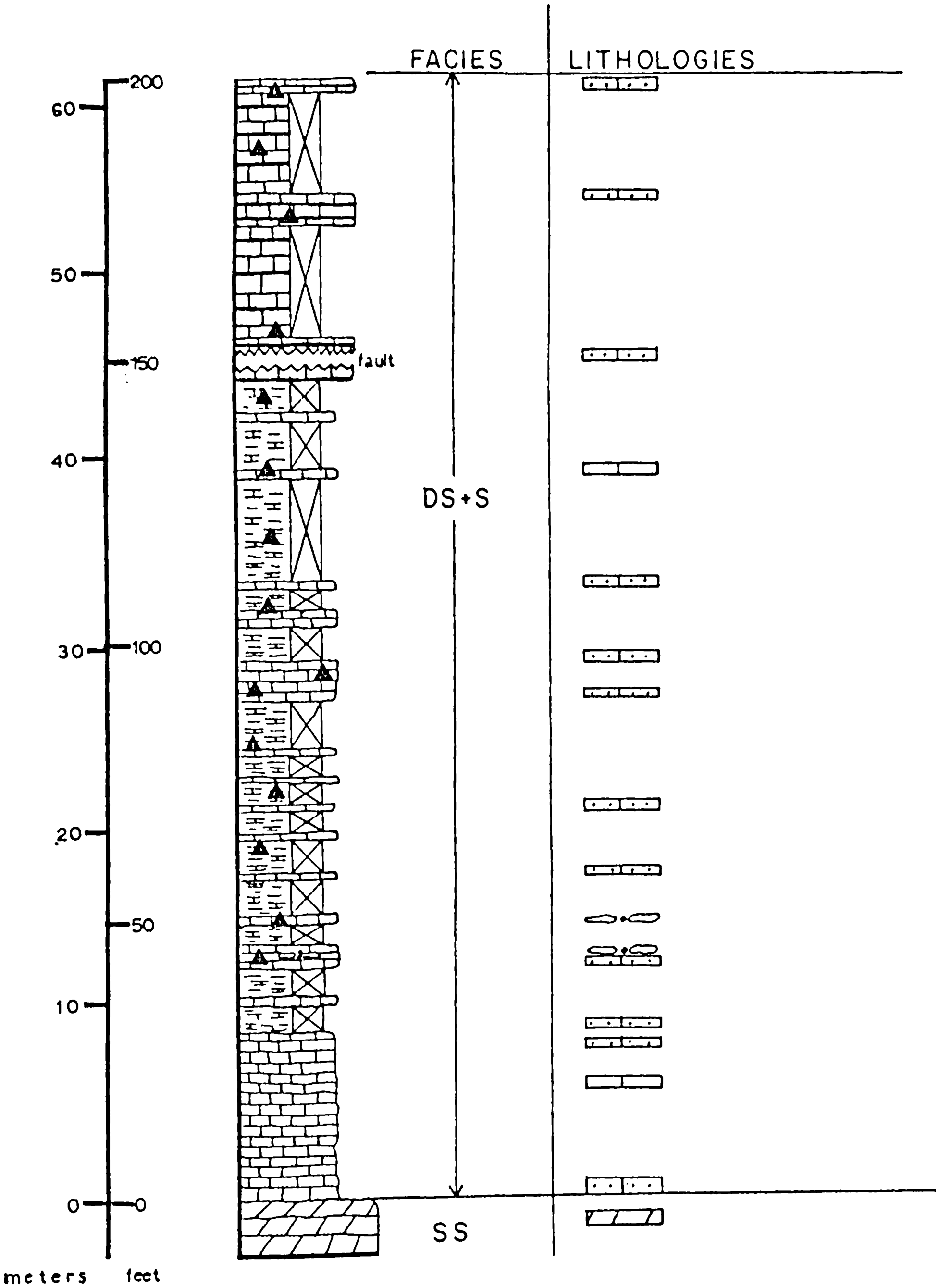


FIG. C2 EUREKA-2

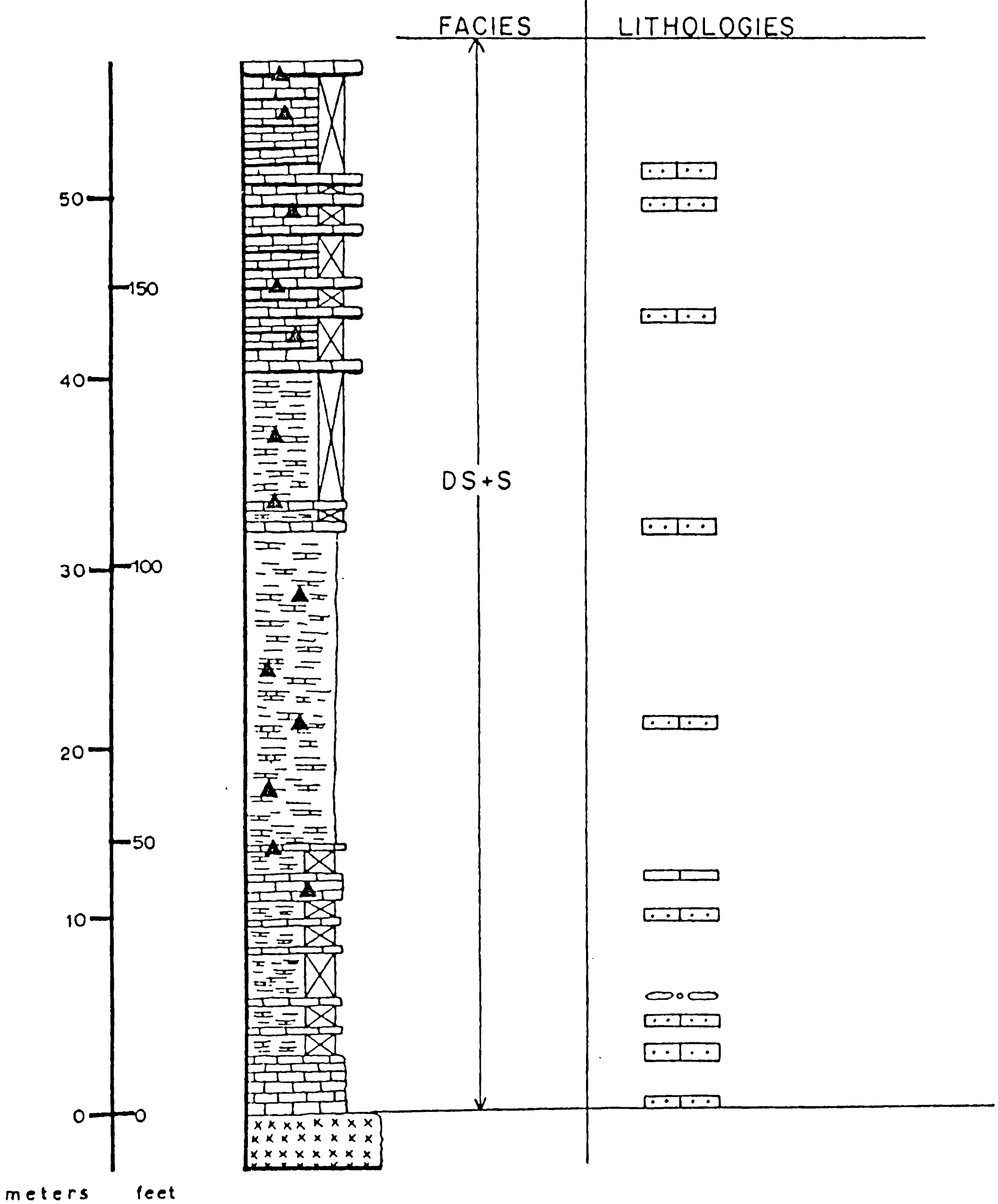


FIG. C3

NORTHERN EGAN RANGE

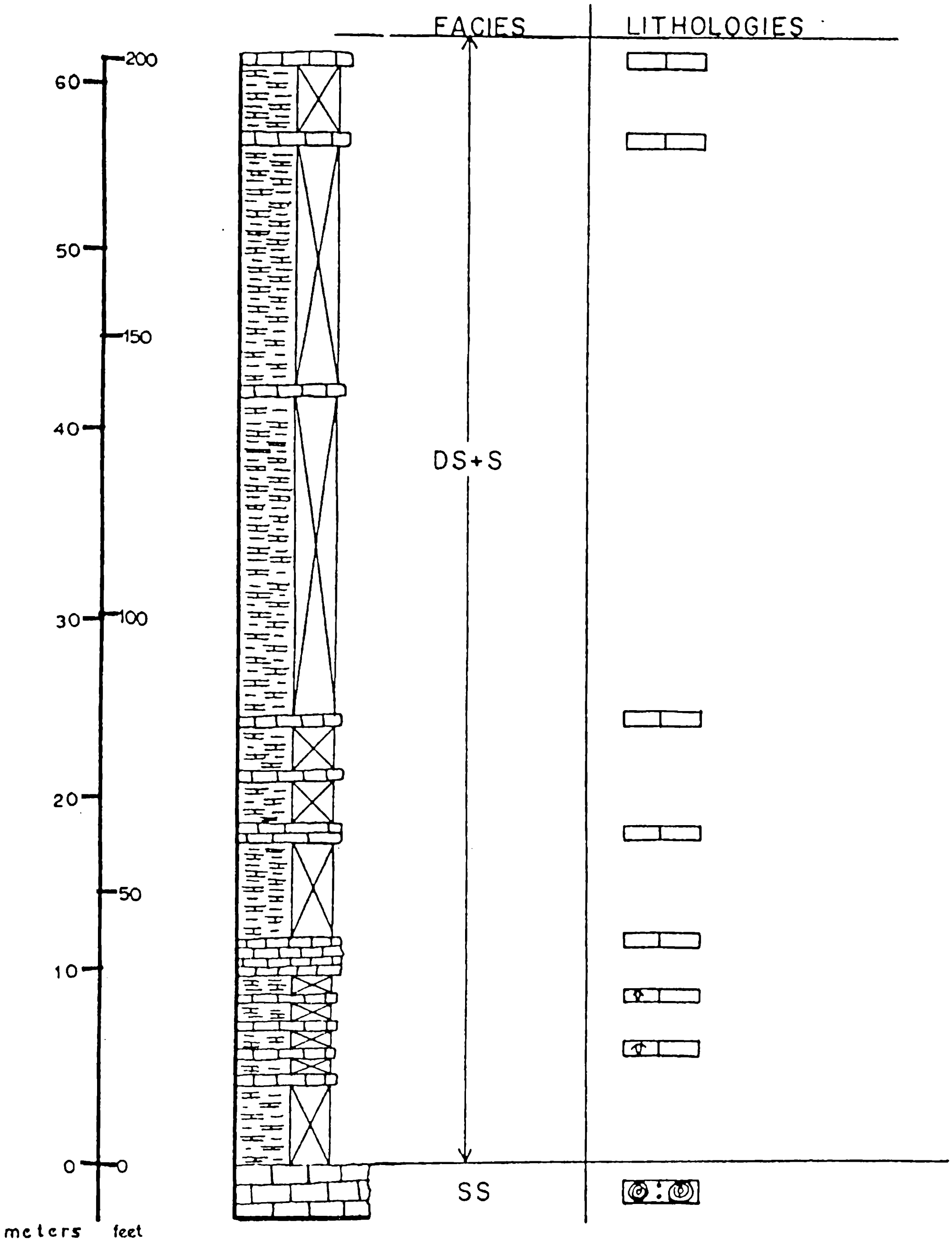


FIG. C4 MARJUM NORTH

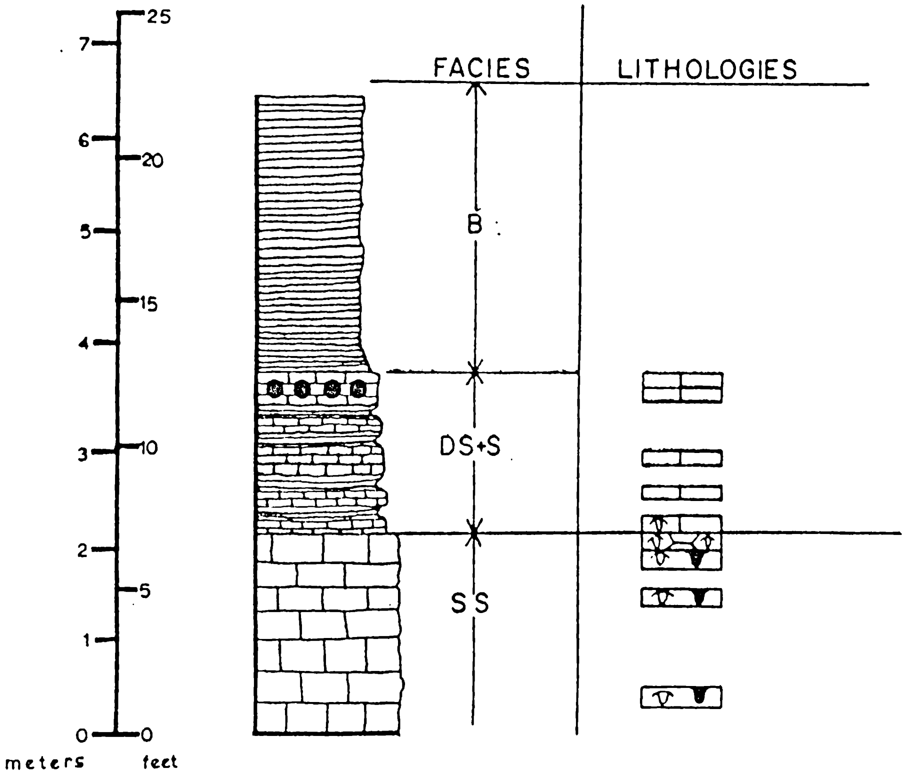
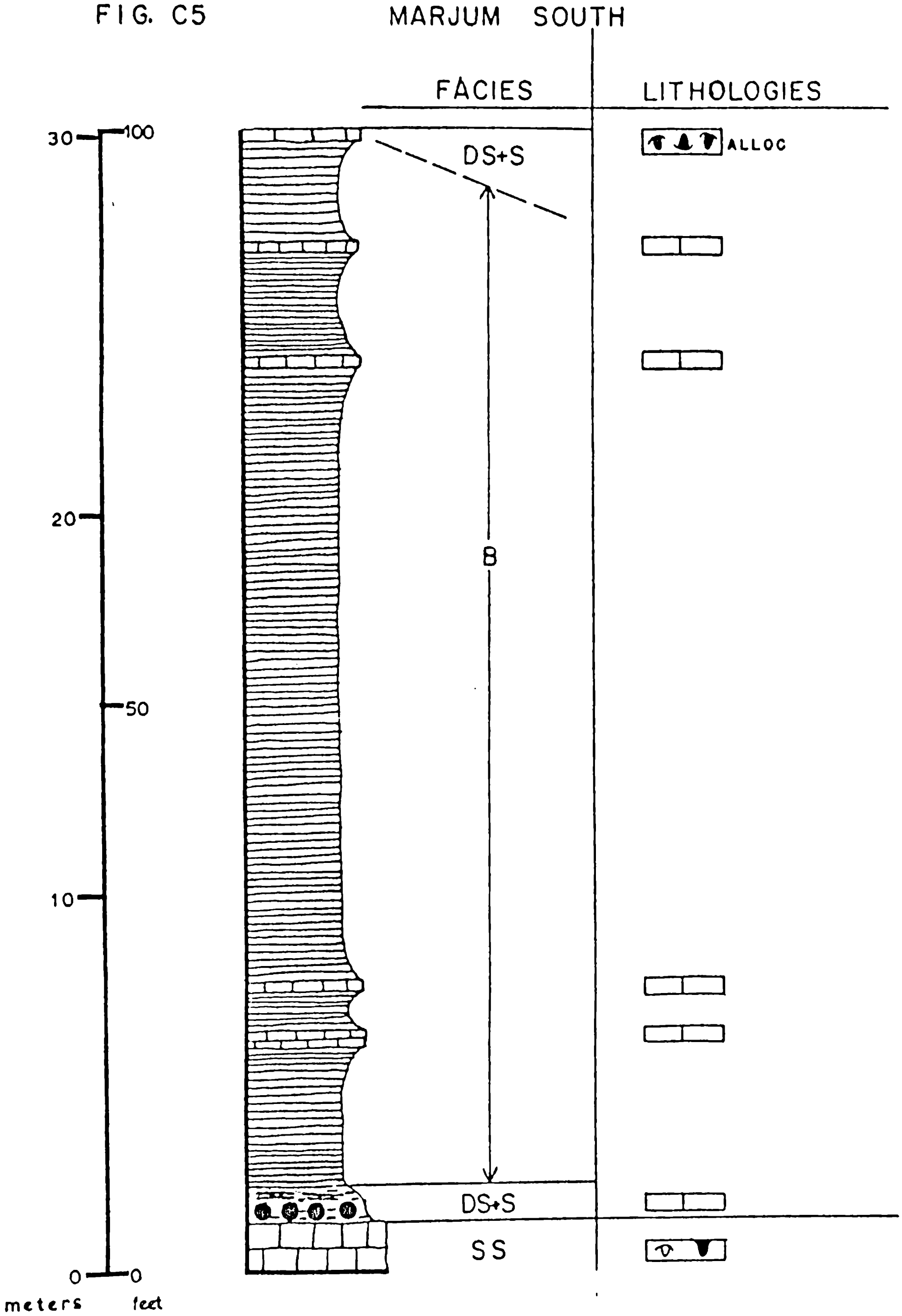
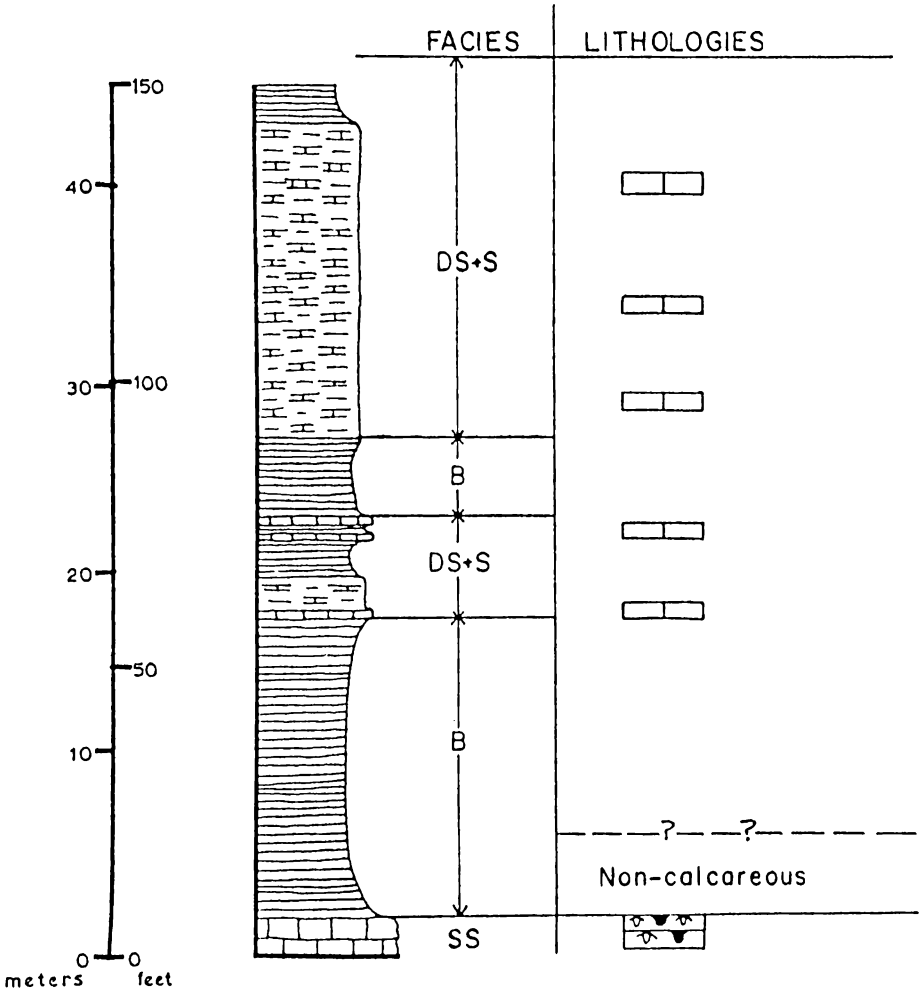


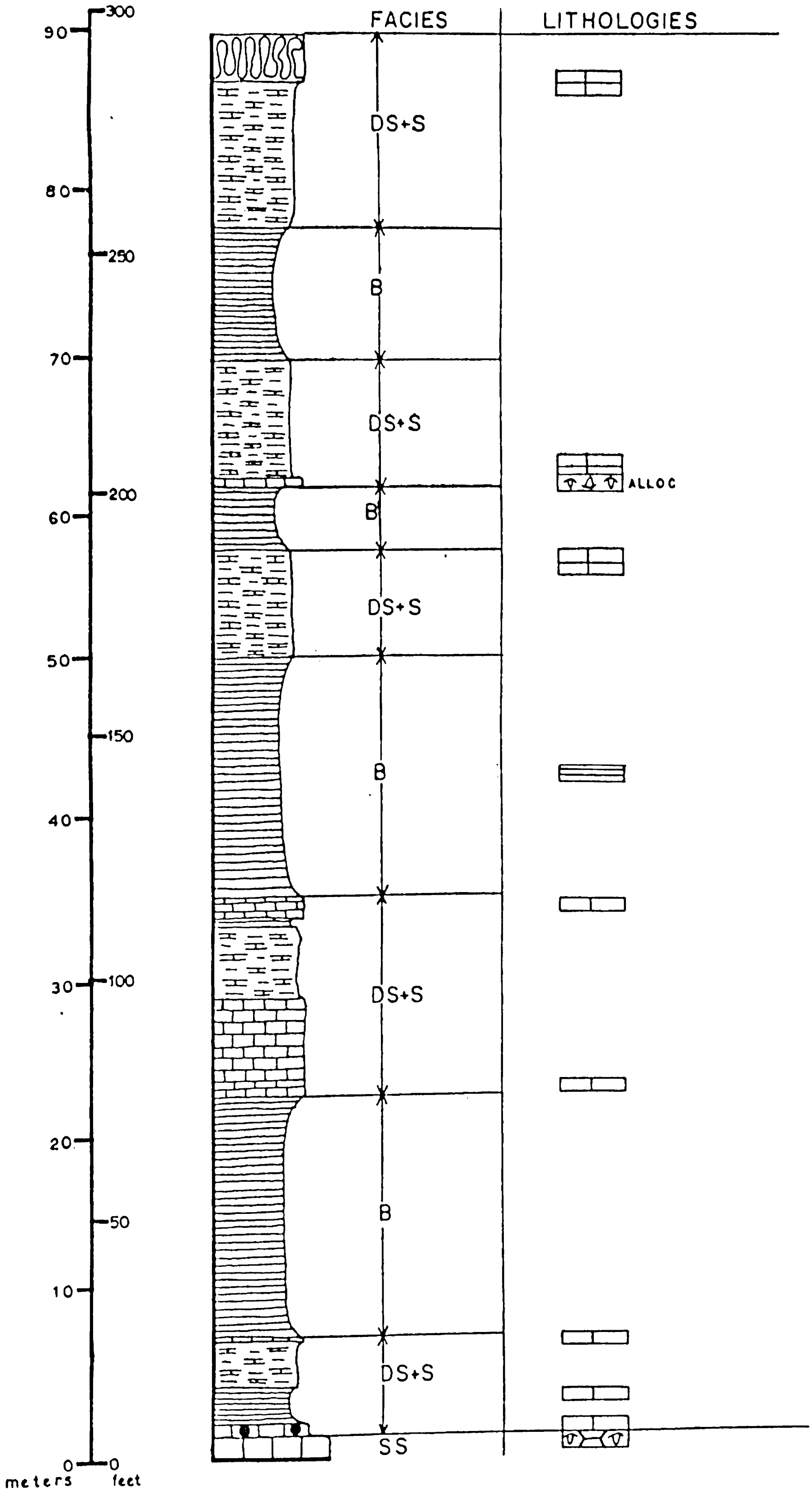
FIG. C5



MARJUM SOUTH
FACIES
LITHOLOGIES
30
100
20
50
10
0
0
meters
feet
DS+S
ALLOC
B
DS+S
SS

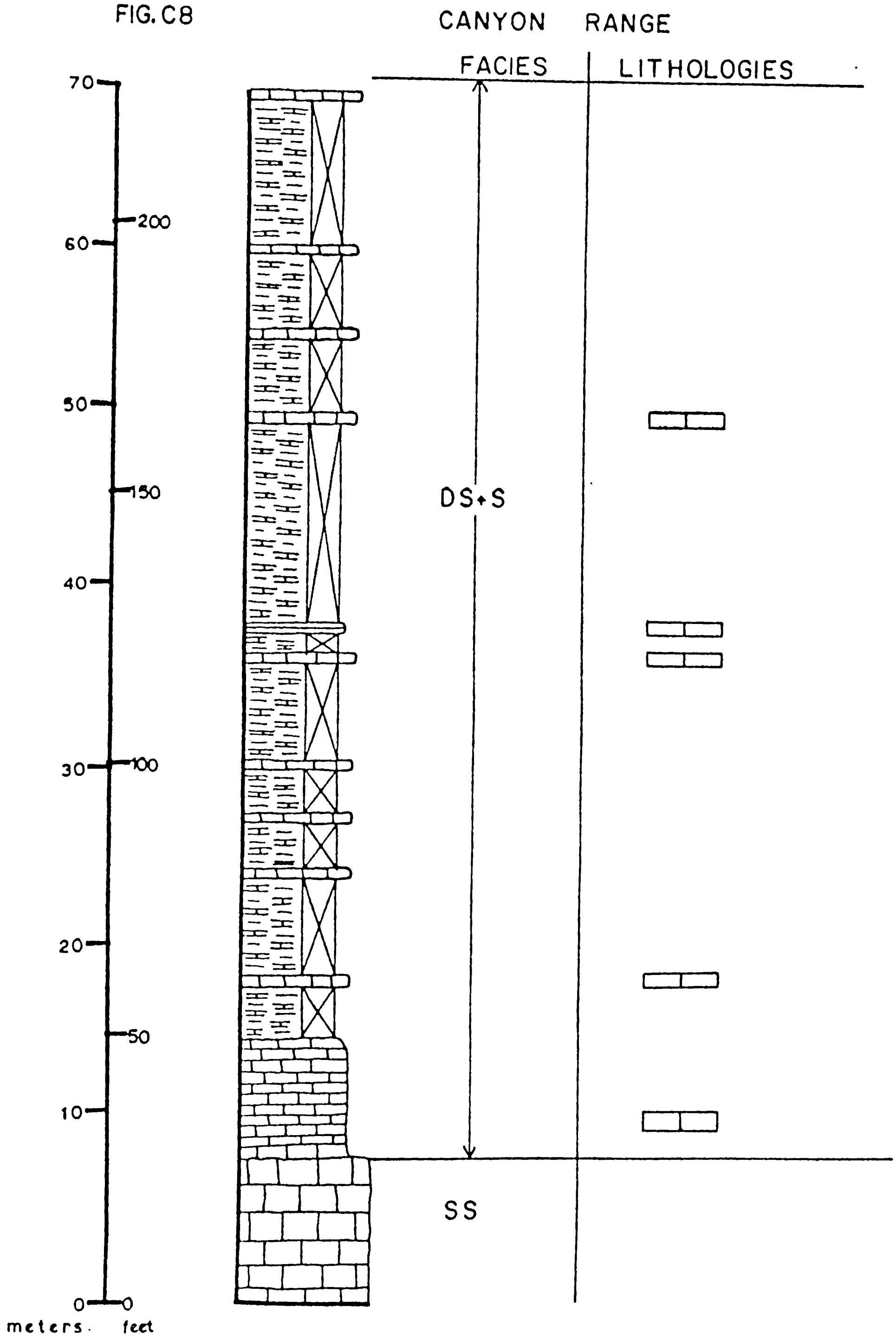
FIG. C6 WHEELER AMPHITHEATER





FACIES
LITHOLOGIES
DS+S
B
DS+S
ALLOC
B
DS+S
B
DS+S
B
DS+S
SS
90
80
70
60
50
40
30
20
10
0
meters
300
250
200
150
100
50
0
feet

FIG. C8


CANYON RANGE
FACIES
LITHOLOGIES
DS+S
SS
70
60
50
40
30
20
10
0
200
150
100
50
0
meters
feet

APPENDIX D

BRACHIOPOD COLLECTIONS

FIG. DI EUREKA-I

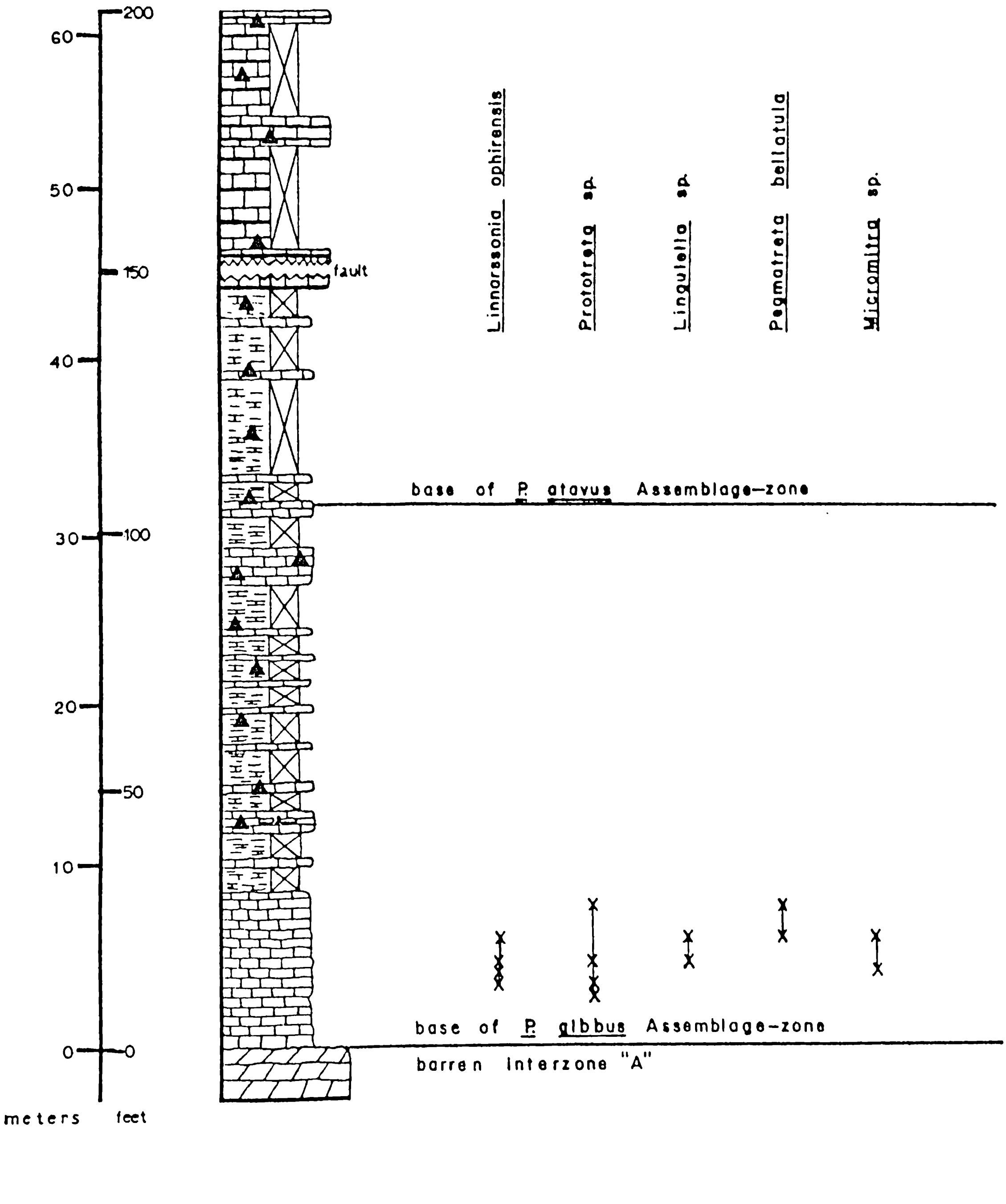


FIG. D2 EUREKA-2

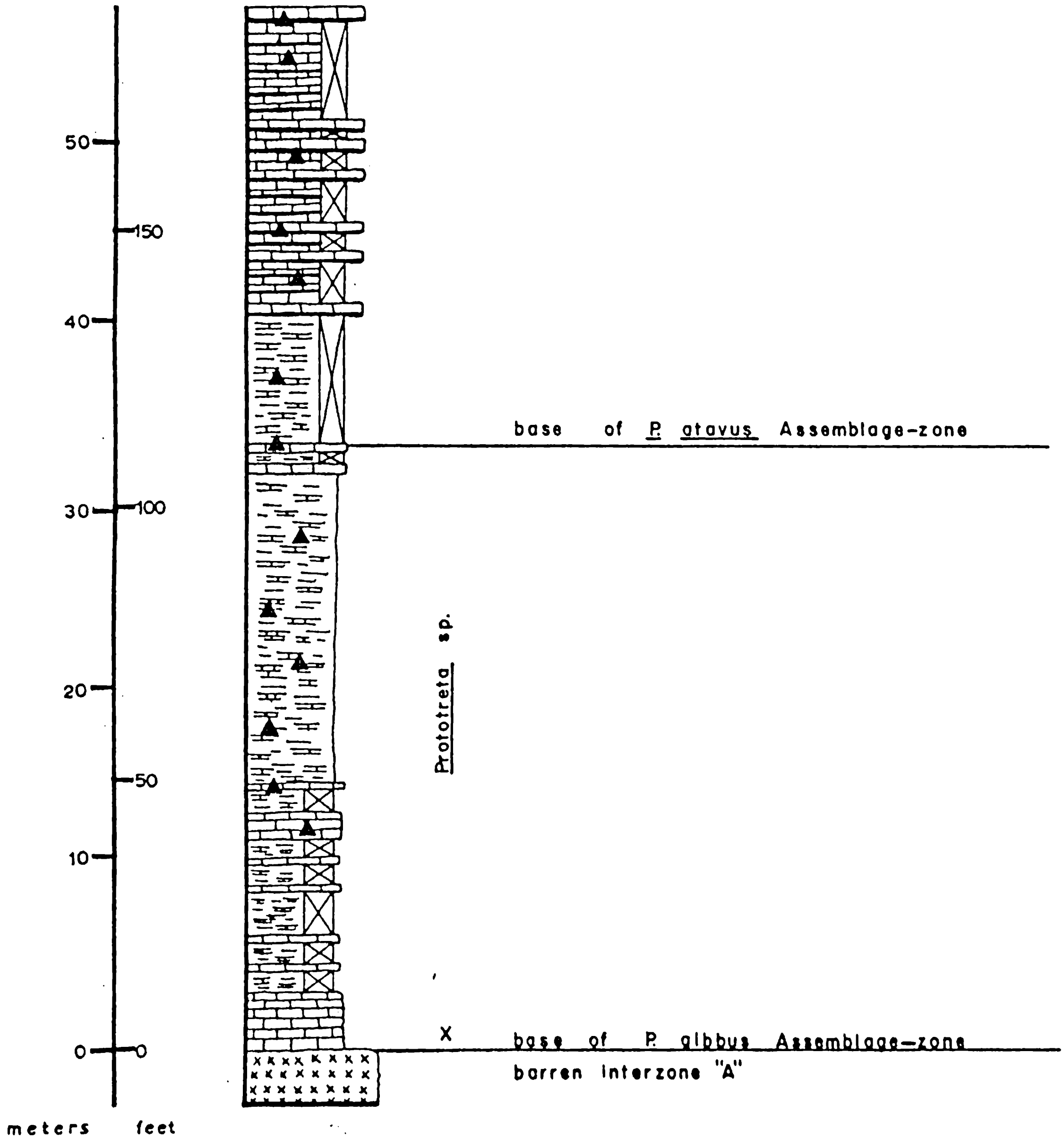


FIG. D3 NORTHERN EGAN RANGE

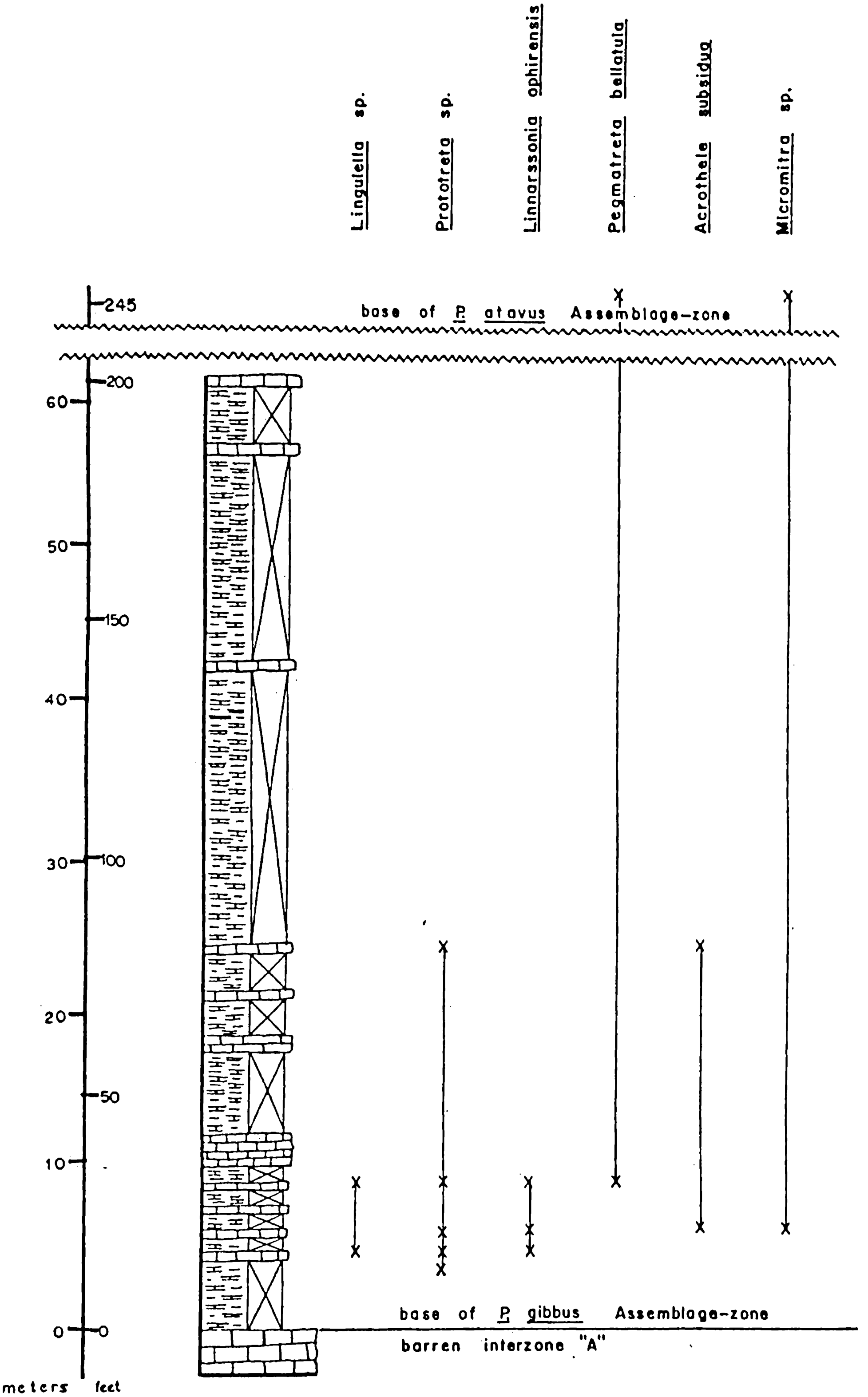


FIG. D4 MARJUM NORTH

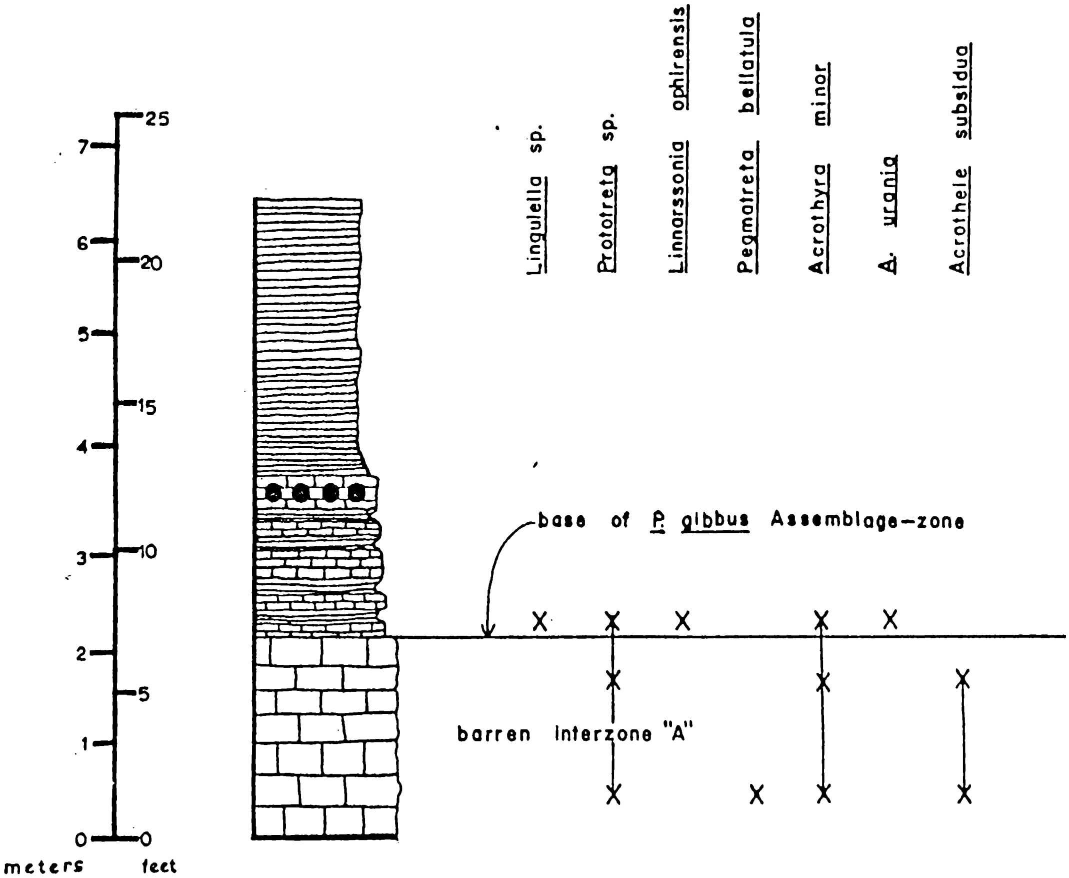


FIG. D5

MARJUM SOUTH

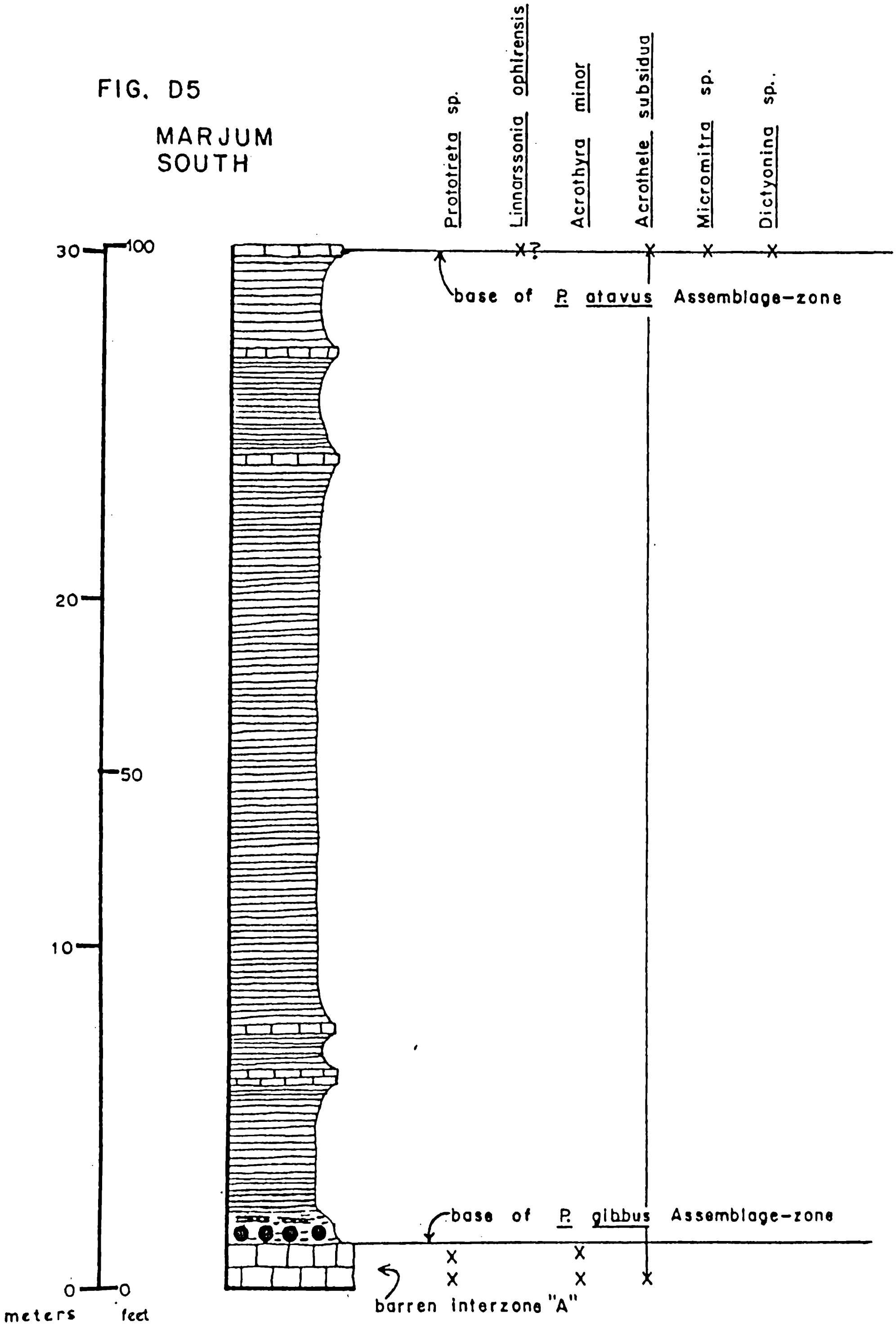


FIG. D6 WHEELER AMPHITHEATER

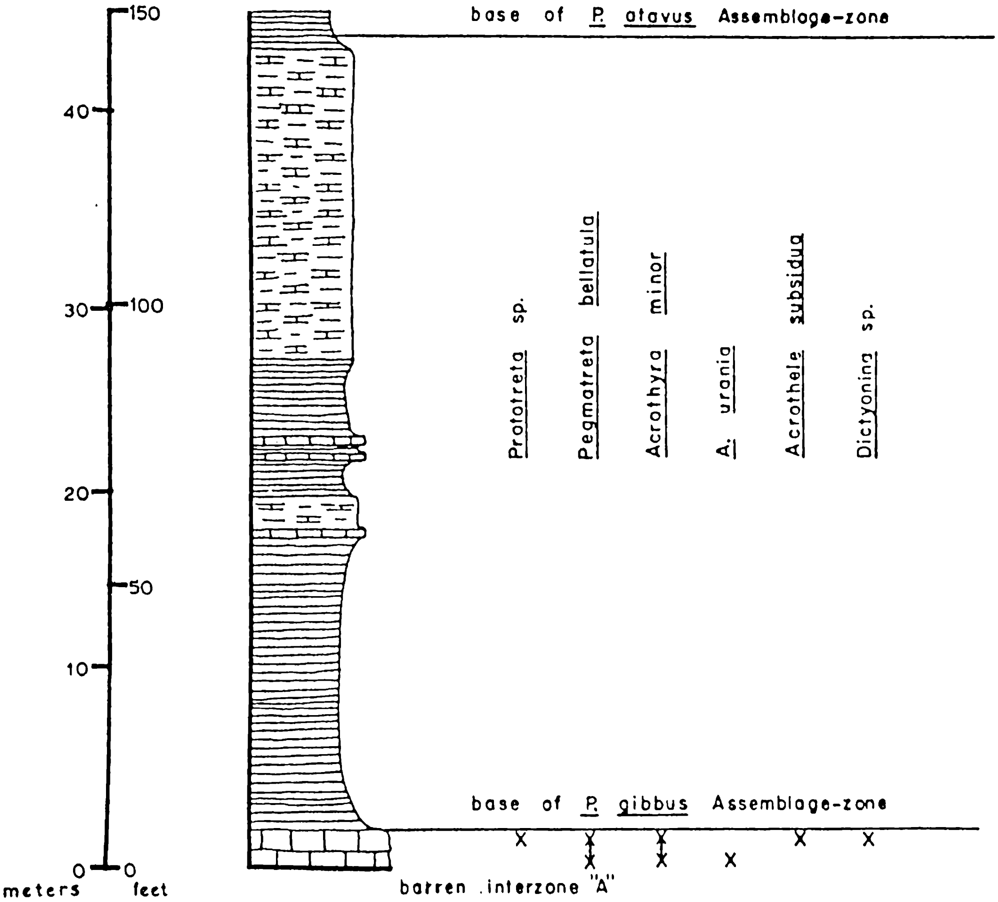


FIG. D7

DRUM MOUNTAINS

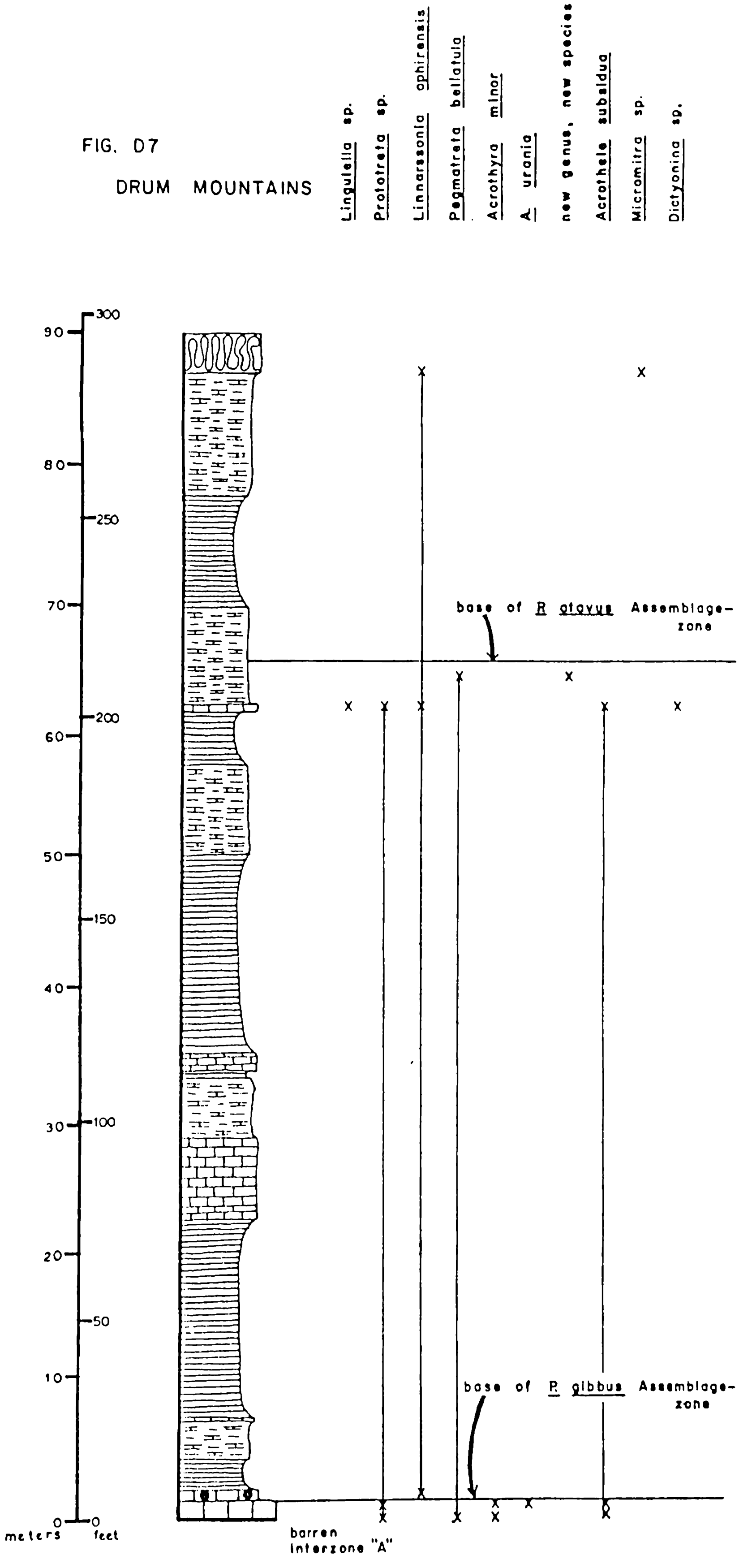


FIG. D8

CANYON RANGE