RICE UNIVERSITY

LOWER PERMIAN STRATIGRAPHY OF SOUTHERN NEW MEXICO AND WEST TEXAS

CLIFTON F. JORDAN, JR.

Houston, Texas

May, 1971

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by

Clifton F. Jordan, Jr.

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Thesis Director's signature:

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ABSTRACT

LOWER PERMIAN STRATIGRAPHY OF SOUTHERN NEW MEXICO AND WEST TEXAS

CLIFTON F. JORDAN, JR.

Petrographic and biostratigraphic analyses of approximately 2,000 samples from ten measured sections of Lower Permian (Wolfcampian) strata throughout southern New Mexico and west Texas enable recognition of three fusulinid subzones, seven sedimentary facies, and three depositional phases that existed during the Wolfcampian. Samples were collected from the following rock units and location: Hueco Limestone and Abo Formation (Hueco, Franklin, Sierra Diablo, Robledo, San Andres, Sacramento, Florida, and Jarilla Mountains); and Horquilla Limestone, Earp Formation, Colina Limestone, and Epitaph Dolomite (Sierra Palomas and Big Hatchet Mountains).

A threefold biostratigraphic zonation of the Wolfcampian is defined by the following fusulinid assemblage subzones: 1) *Triticites*-*Schwagerina*-*Leptotriticites* Subzone (lower Wolfcampian), 2) *Pseudoschwagerina*-*Leptotriticies* Subzone (middle Wolfcampian), and 3) *Pseudoschwagerina*-*Monodiexodina* Subzone (upper Wolfcampian). However, owing to the absence of *Monodiexodina* in southern New Mexico, a more practical twofold division consists of 1) *Triticites*-*Schwagerina*-*Leptotriticites* Subzone (lower Wolfcampian) and 2) *Pseudoschwagerina*-*Paraschwagerina* Subzone (upper and middle Wolfcampian). Based on these subzones, Lower Permian formations are oldest in southeastern Arizona and central New Mexico and become younger eastward and southward into south-central

New Mexico and west Texas.

Petrographic studies indicate the presence of seven major sedimentary facies: shoal-water, shelf, shallow shelf, bioherm, lagoonal, nearshore-terrestrial, and slope. Relationships between bioclastic particle tyes and facies show that Tubiphytes and dasycladacean algae are related to bioherm or shallow shelf facies and that Tetrataxis is an indicator of bioherm environments.

Regional correlations based on facies recognition and biostratigraphic zonation indicate the equivalence of the Cerro Alto Limestone, Abo Formation, and Earp Formation. During Wolfcampian time, sedimentation occurred in three depositional phases: 1) pre-Abo shoal-water, bioherm and shelf carbonates, 2) red-beds, clastics, and normal marine limestone of the Abo and its equivalents, and 3) post-Abo lagoonal, biohermal, and shelf carbonates.

Regional extensions of stratigraphic data from sampled areas into southeastern Arizona, southeastern New Mexico, and northern Sonora and Chihuahua indicate that the Pedregosa and Orogrande Basins were narrow, elongate basins that extended northward from a large sea to the south. North and west of these basins, nearshore to terrestrial red-beds of the Abo Formation were deposited. The Diablo Platform, a southern extension of the Pedernal Uplift, was emergent in lower Wolfcampian time and slowly subsided throughout the rest of the Wolfcampian to receive shoal-water and biohermal limestones.

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INTRODUCTION

Since the beginning of this century, Permian strata of southern New Mexico and west Texas have been geologically investigated because of the great variety of sedimentary rocks and the rich faunas of fusulinids, foraminifera, algae, brachiopods, and molluscs that they contain. These beds include clastic and carbonate facies that range from continental red-beds through a variety of limestone types to dark basinal shales. The present arid climate and elongate block-faulted mountain ranges afford excellent stratigraphic exposures.

Classic examples of depositional models occur in the Permian of this region: Capitan Reef (Newell et al., 1953), Horseshoe Atoll with its subsurface counterpart, Scurry Reef (Myers, Stafford, and Burnside, 1956) and, of course, the Permian Basin (Galley, 1958).

Despite a long history of Permian studies, relatively little has been published regarding the regional distribution and the nature of earliest Permian strata deposited in this region. These strata, the Wolfcampian Series, are the subject of this investigation.

STUDY AREA

The study area (figure 1) includes parts of five states of the arid Southwest: west Texas, southern New Mexico, southeastern Arizona, northeastern Sonora, and northern Chihuahua. This part of the basin and range province is characterized by north-south chains of block-faulted mountain ranges, separated by long, wide desert basins.

Stratigraphic sections sampled for this report are from the following areas:

West Texas	Sierra Diablo Mountains (SD Section)
	Hueco Mountains (HM Section)
	Franklin Mountains (FM Section)
New Mexico	Southern Sacramento Mountains (SC Section)
	Robledo Mountains (R Sections)
	San Andres Mountains (SA Section)
	Jarilla Mountains (JM Section)
	Big Hatchet Mountains (BS, HT, & LS Sections)

In addition, two sections based on studies by Pemex geologists were redrafted and included in this report. Stratigraphic information from measured sections was compared with published reports of Lower Permian rocks in southeast Arizona, northern Mexico, and southeast New Mexico (Table 1).

GEOLOGIC SETTING

Early Permian sediments were deposited in this region upon an eroded and subdued late Pennsylvanian block-faulted topography (Kottlowski, 1963). The Pedernal Landmass (near the Sacramento Mountains of New Mexico) was periodically uplifted to a late Pennsylvanian-early Permian climax. A southerly expression of the uplift was the shoaling Diablo Platform which separated the Delaware and Midland Basins from the Orogrande Basin. Basins west of these positive elements received local accumulations of coarse sediments from the uplift. Highlands

Figure 1: Index Map of Study Area

Outcrop sections

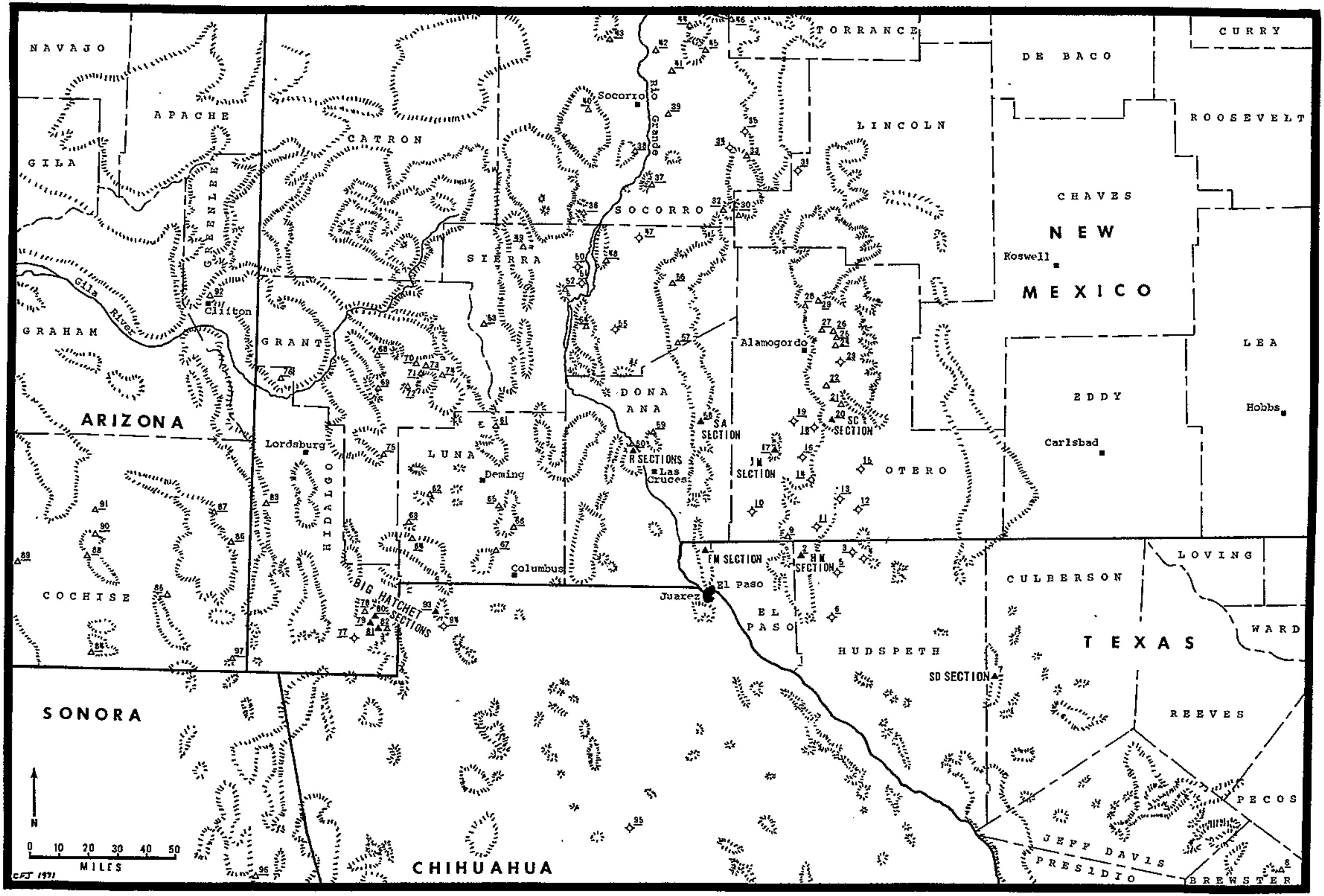
▲ this report

△ others

Oil tests ⌖

Type section of the Hueco Limestone is from the Hueco Mountains, West Texas (control point 2); standard Wolfcampian section is from the Glass Mountains of West Texas (control point 8).

See Table 1 for a listing of control points.



NAVAJO
APACHE
GILA
GRAHAM
GREENLEE
Gila River
Clifton
CATRON
GRANT
SIERRA
SOCORRO
Socorro
Rio Grande
TORRANCE
LINCOLN
DE BACO
CURRY
ROOSEVELT
CHAVES
NEW MEXICO
Roswell
LEA
Hobbs
EDDY
Carlsbad
Alamogordo
OTERO
DONA ANA
Las Cruces
R SECTIONS
SA SECTION
JM SECTION
SC SECTION
FM SECTION
HM SECTION
SD SECTION
LUNA
Deming
Columbus
HIDALGO
Lordsburg
BIG HATCHET SECTIONS
ARIZONA
COCHISE
SONORA
CHIHUAHUA
El Paso
Juarez
EL PASO
HUDSPETH
CULBERSON
LOVING
WARD
TEXAS
REEVES
PECOS
JEFF DAVIS
PRESIDIO
BREWSTER
N
0 10 20 30 40 50
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Table 1: Control Points shown on Index Map and Wolfcampian Isopach Map

No.	Name	Location	Source of Information
1	Franklin Mountains (FM Section)	El Paso Co., Tx.	this report
2	Hueco Mountains (HM Section)	Hudspeth Co., Tx.	this report
3	Magnolia Oil Co., No. 1-39881	Hudspeth Co., Tx.	Kottlowski, 1963
4	Seabord & Shamrock Oil Co. No. 1-C Univ.	Hudspeth Co., Tx.	Kottlowski, 1963
5	California Co. No. 1 Univ. Theisen	Hudspeth Co., Tx.	Kottlowski, 1963
6	Minnie Veal Oil Test	Hudspeth Co., Tx.	Kottlowski, 1963
7	Sierra Diablo Mountains (SD Section)	Culberson Co., Tx.	this report
8	Glass Mountains	Brewster Co., Tx.	Ross, 1963
9	Northern Hueco Mountains	Otero Co., N. M.	Hardie, 1958
10	Ernest No. 1 Located Land Co.	Otero Co., N. M.	Kottlowski, 1963
11	Seaboard Oil Co. No. 1 Trigg Federal	Otero Co., N. M.	Kottlowski, 1963
12	Union Oil Co. No. 1 McMillan	Otero Co., N. M.	Kottlowski, 1963
13	Turner No. 1 Evans	Otero Co., N. M.	Kottlowski, 1963
14	Kinney Oil & Gas Co. No. 1 State	Otero Co., N. M.	Kottlowski, 1963
15	Turner No. 1 Everett	Otero Co., N. M.	Kottlowski, 1963
16	Otero Oil Co. No. 1 McGregor	Otero Co., N. M.	Kottlowski, 1963
17	Jarilla Mountains (JM Section)	Otero Co., N. M.	this report
18	Sun Oil Co. No. 1 Pearson	Otero Co., N. M.	Kottlowski, 1963
19	Plymouth Oil Co. No. 1 Evans	Otero Co., N. M.	Kottlowski, 1963
20	Southern Sacramento Mountains (SC Section)	Otero Co., N. M.	this report
21	Southern Sacramento Mountains	Otero Co., N. M.	Kottlowski, 1963
22	Southern Sacramento Mountains	Otero Co., N. M.	Kottlowski, 1963
23	Southern Production Co. No. 1 Cloudcroft	Otero Co., N. M.	Kottlowski, 1963
24	Central Sacramento Mountains	Otero Co., N. M.	Kottlowski, 1963
25	Central Sacramento Mountains (Section 5)	Otero Co., N. M.	Otte, 1959
26	Central Sacramento Mountains	Otero Co., N. M.	Kottlowski, 1963
27	Central Sacramento Mountains	Otero Co., N. M.	Kottlowski, 1963
28	Northern Sacramento Mountains	Otero Co., N. M.	Kottlowski, 1963
29	Northern Sacramento Mountains	Otero Co., N. M.	Kottlowski, 1963
30	Southern Oscura Mountains	Lincoln Co., N. M.	Kottlowski, 1963

Table 1 (continued)

No.	Name	Location	Source of Information
31	Standard Oil Co. of Texas No. 1 Heard	Lincoln Co., N. M.	Kottlowski, 1963
32	Mockingbird Gap	Socorro Co., N. M.	Kottlowski, 1963
33	Northern Oscura Mountains	Socorro Co., N. M.	Kottlowski, 1963
34	Sun Oil Co. No. 1 Bingham State	Socorro Co., N. M.	Kottlowski, 1963
35	Lockhart No. 1	Socorro Co., N. M.	Kottlowski, 1963
36	Eaton Ranch	Socorro Co., N. M.	Kottlowski, 1963
37	Little San Pascual Mountain	Socorro Co., N. M.	Kottlowski, 1963
38	Coyote Hills	Socorro Co., N. M.	Kottlowski, 1963
39	Cerros de Amado	Socorro Co., N. M.	Kottlowski, 1963
40	Magdalena Mountains	Socorro Co., N. M.	Kottlowski, 1963
41	Canoncito de la Uva	Socorro Co., N. M.	Kottlowski & Stewart, 1970
42	Joyita Hills	Socorro Co., N. M.	Kottlowski & Stewart, 1970
43	Landron Mountains	Socorro Co., N. M.	Kottlowski & Stewart, 1970
44	Eastern Los Pinos Mountains	Socorro Co., N. M.	Kottlowski & Stewart, 1970
45	Palo Duro Canyon	Socorro Co., N. M.	Kottlowski & Stewart, 1970
46	Southern Manzano Mountains, Abo Canyon	Valencia & Torrance Co., N. M.	Needham & Bates, 1943
47	Sun Oil Co. No. 1 Victoria	Sierra Co., N. M.	Kottlowski, 1963
48	Fra Cristobal Mountains	Sierra Co., N. M.	Kottlowski, 1963
49	Sierra Cuchillo Mountains	Sierra Co., N. M.	Jahns, 1965
50	Gartland No. 1 Brister	Sierra Co., N. M.	Kottlowski, 1963
51	Summit Exploration No. 1-A Mims	Sierra Co., N. M.	Kottlowski, 1963
52	Mud Springs Mountains	Sierra Co., N. M.	Kottlowski, 1963
53	Black Range near Kingston, N. M.	Sierra Co., N. M.	Kuellmer, 1954
54	Caballo Mountains	Sierra Co., N. M.	Kelly & Silver, 1952
55	Sunray Mid-Continent Oil Co. No. 1-M Federal	Sierra Co., N. M.	Kottlowski, 1963
56	Northern San Andres Mountains, Rhodes Canyon	Sierra Co., N. M.	Kottlowski, 1956
57	Central San Andres Mountains, Hembrillo Canyon	Sierra Co., N.M.	Kottlowski, 1956
58	Southern San Andres Mountains (SA Section)	Dona Ana Co., N. M.	this report
59	Dona Ana Mountains	Dona Ana Co., N. M.	Kottlowski, 1963
60	Robledo Mountains (R Sections)	Dona Ana Co., N. M.	this report
61	Cooks Peak	Luna Co., N. M.	Jicha, 1954
62	Unnamed exposures NNW of Victoria Mtns.	Luna Co., N. M.	Kottlowski, 1963
63	Victorio Mountains	Luna Co., N. M.	Kottlowski, 1963

Table 1 (continued)

No.	Name	Location	Source of Information
64	Klondike Hills	Luna Co., N. M.	Kottlowski, 1963
65	Northern Florida Mountains	Luna Co., N. M.	Kottlowski, 1963
66	Southern Florida Mountains	Luna Co., N. M.	Kottlowski et al., 1969
67	Tres Hermanas Mountains	Luna Co., N. M.	Kottlowski & Foster, 1962
68	Pinos Altos Range	Grant Co., N. M.	Kottlowski, 1963
69	Little Burro Mountains	Grant Co., N. M.	Kottlowski, 1963
70	Pinos Altos Range	Grant Co., N. M.	Kottlowski, 1963
71	Pinos Altos Range	Grant Co., N. M.	Kottlowski, 1963
72	Unnamed exposures SE of Silver City, N.M.	Grant Co., N. M.	Kottlowski, 1963
73	Pinos Altos Range	Grant Co., N. M.	Kottlowski, 1963
74	Pinos Altos Range	Grant Co., N. M.	Kottlowski, 1963
75	Southern Burro Mountains	Grant Co., N. M.	Kottlowski, 1963
76	Black Mountain	Hidalgo Co., N. M.	Kottlowski, 1963
77	Humble No. 1 State BA	Hidalgo Co., N. M.	Zeller, 1965; Kottlowski, 1969
78	Big Hatchet Peak, Big Hatchet Mountains	Hidalgo Co., N. M.	Zeller, 1965
79	Borrego Section, Big Hatchet Mountains	Hidalgo Co., N. M.	this report
80	Bugle Ridge Section, Big Hatchet Mountains	Hidalgo Co., N. M.	this report
81	Lower Sheridan Tank & Hale Tank Sections, Big Hatchet Mountains	Hidalgo Co., N. M.	this report
82	New Well Peak Section, Big Hatchet Mtns.	Hidalgo Co., N. M.	Zeller, 1965
83	Peloncillo Mountains	Hidalgo Co., N. M.	Gillerman, 1958
84	Naco Hills	Cochise Co., Ariz.	Lodewick, 1970
85	Pedregosa Mountains	Cochise Co., Ariz.	Epis, 1956; Kottlowski, 1963
86	Chiricahua Mountains	Cochise Co., Ariz.	Sabins & Ross, 1963
87	Dos Cabezas Mountains	Cochise Co., Ariz.	Sabins & Ross, 1963
88	Tombstone Hills	Cochise Co., Ariz.	Gilluly, 1956
89	Whetstone Mountains	Cochise Co., Ariz.	Ross & Tyrell, 1965; Lodewick,1970
90	Dragoon Mountains	Cochise Co., Ariz.	Gilluly, 1956
91	Gunnison Hills	Cochise Co., Ariz.	Gilluly, 1956; Lodewick, 1970
92	Malpais Mountain	Greenlee Co., Ariz.	Kottlowski, 1963
93	Sierra de Palomas	Chihuahua, Mexico	this report
94	Los Chinos, Pemex Well	Chihuahua, Mexico	Petroleos Mexicanos
95	Villa Ahumada, Pemex Well	Chihuahua, Mexico	Wilson, Madrid & Malpica, 1969
96	Sierra de Teras Bavispe	Sonora, Mexico	Tovar, 1969
97	Quimby Hills	Cochise Co., Ariz.	Dirks, 1966

in northern New Mexico and southern Colorado provided finer clastics which were swept southward in great detrital floods of the Abo Formation. Farther west lay the Florida Islands, a positive element of low relief that probably was the precursor of the Mesozoic Burro Uplift to the northwest. In southwestern New Mexico's "bootheel area" was the deep Pedregosa Basin, in which accumulated as much as 6,000 feet of late Paleozoic sediments.

Carbonate sedimentation dominated southern parts of this region in the early Permian. A transition zone of interbedded carbonate and clastic rocks existed to the north of the basins; farther north this facies changed to thick red-bed deposits in north central New Mexico. These early Permian sediments were deposited by shallow seas over the Orogrande Basin, a sharp contrast with the deeper Pedregosa Basin to the southwest. Later Permian sediments include some evaporite and limestone deposits with sandstones more common to the southwest of the region. Many of these strata were later removed by erosion over the Burro Uplift during the Mesozoic. Superimposed on Paleozoic and earlier structures throughout the region are the effects of the Laramide orogeny which was predominantly of late Cretaceous and early Cenozoic age.

PREVIOUS WORK

Mineral deposits in widely separated districts sparked early geologic investigations in this area and, as a result, stratigraphic relationships were generalized. In more recent years, various mountain ranges were studied from a stratigraphic viewpoint. Correlations were based primarily upon lithologic descriptions, thicknesses of sedimentary units, and paleontologic zonation, using fusulinids, where present. Some of the more detailed studies of pre-Tertiary strata include work done in the following large ranges: Sacramento Mountains (Pray, 1961; Otte, 1959), San Andres Mountains (Kottlowski et al., 1956), Peloncillo Mountains (Gillerman, 1958), Hueco Mountains (Williams, 1963), Big Hatchet Mountains (Zeller, 1965), Chiricahua Mountains (Sabins, 1957), and Sierra Diablo Mountains (King, 1965). Geological societies in the region are active and several guidebooks with less comprehensive articles are available for these and other mountains. Other approaches include studies of rocks of a particular age: regional investigations have been made of the Devonian, Mississippian, and Pennsylvanian and, to lesser degrees, of the Cambrian, Ordovician and Silurian. Since a compilation by Kottlowski (1963) of previously studied systems, a report has been published by Meyer (1966) on Pennsylvanian and Lower Permian rocks in southeast New Mexico. Excellent summary articles on the pre-Tertiary stratigraphy of southern New Mexico and parts of west Texas have been written by Kottlowski (1963, 1965).

Biostratigraphic correlations of late Paleozoic sections in this area are critical, since numerous facies changes occur, formations are seldom synchronous units, and mountain ranges are isolated. Early fusulinid studies in this area (Dunbar and Skinner, 1931, 1937; White, 1932; Needham, 1937, Thompson, 1932, 1945) dealt with recognition of new genera and age relationships on the level of Pennsylvanian and Permian Series. Samples were generally not stratigraphically placed in detailed sections until studies by Thompson in 1954; hence, no finely zoned schemes were presented until later researchers examined specific areas. Recent studies of this type in southern New Mexico and west Texas have been made by Williams (1963) in the Hueco Mountains, Skinner and Wilde (1965) in the Big Hatchet Mountains, Williams (1966) and Stewart (1968) in the Franklin Mountains, Steiner and Williams (1968) in the Sacramento Mountains, and Kottlowski and Stewart (1970) in the Joyita Hills. Thompson has written two general texts on fusulinid paleontology that are applicable to the study area: Studies of American Fusulinids (1948) and American Wolfcampian Fusulinids (1954). Some of the most recent fusulinid research has been more theoretical, dealing with evolutionary trends (Dunbar, 1963) and the "species concept" as applied to fusulinids (Sanderson and Verville, 1970).

Considerably less has been done regarding facies and microfacies recognition. Studies are few and generally local in extent: Otte and Parks (1963) described algal reefs in the Sacramento Mountains near Tularosa, Wilson (1967) described carbonate-clastic cycles in the Pennsylvanian Holder Formation of the Sacramentos, and Wilson et al., (1969) correlated stratigraphic sections from southwestern New Mexico and northern Chihuahua to west Texas on the basis of detailed facies studies and fusulinid zonation.

In making regional interpretations, control points in the wide basins between mountainous outcrops are essential. Kottlowski et al., (1969) has compiled data from oil tests throughout New Mexico. Since then, recent drilling by Petroleos Mexicanos has yielded additional information in northern Mexico.

NATURE AND SCOPE OF INVESTIGATION

The goal of this study is to coordinate previous stratigraphic information with both stratigraphic and petrographic data acquired by the writer, so as to provide a regional interpretation of Wolfcampian sedimentation. Chief sources of new data are the measured sections of this report, unpublished stratigraphic investigations by Petroleos Mexicanos geologists, and recent exploratory drilling on both sides of the international border.

Major emphasis, however, is directed towards the recognition and interpretation of Wolfcampian sedimentary facies and to correlations of sedimentary units based on fusulinids. Approximately 2,000 samples were examined from eight composite sections (figure 1) by polished-slab and corresponding thin-section analysis. Several hundred slides were made to establish fusulinid zones. The main objectives are 1) to examine regional Wolfcampian carbonate and clastic facies and their variations across large structurally negative and positive areas, and 2) to define better the nature and limits of the Pedregosa and Orogrande Basins and the Diablo Platform.

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Dr. William E. King of New Mexico State University extended cordial hospitality in Las Cruces and temporarily stored samples from the field. Drs. John W. Skinner of Humble Oil Company and Wendell J. Stewart of Texaco, Inc. provided technical expertise regarding fusulinid ranges and biostratigraphic zonation and reviewed paleontologic sections of the text.

Dr. Frank E. Kottlowski, assistant director of the New Mexico Bureau of Mines and Mineral Resources, was instrumental in overall project planning, field logistics, and technical advice. As co-advisor of this thesis, he offered his tremendous experience and capability in this field of research through stimulating discussions and review of the manuscript. His detailed measuring and preliminary work in the Robledo Mountains formed the basis for sampling of a composite Robledo section.

Dr. James Lee Wilson of Rice University served as thesis advisor and offered relentless assistance throughout each phase of this study-- from numerous field trips to petrographic discussions behind the microscope, and to constructive criticism in this final presentation. The ideals set forth by him, both as a person and scientist, are worthy of the aspirations of his students.

Special thanks and appreciation is extended to my wife, Sherry, who not only tolerated me during this investigation, but also bore well the rigors of field work, tedious drafting, and typing of several versions of the manuscript.

BIOSTRATIGRAPHIC ZONATION OF THE WOLFCAMPIAN SERIES

Fusulinid foraminiferal zones of the Pennsylvanian and Permian are recognized on a worldwide basis (Thompson, 1948, 1954; Ross, 1962; Dunbar, 1963; and Skinner and Wilde, 1965, 1966). Ammonites and graptolites provide the only other means of macrofaunal zonation comparable to the precision and detail available with fusulinids, but are rarely identifiable in cores and cuttings. Lower Permian strata around the world contain fusulinids in the Zone of *Pseudoschwagerina*. In North America, strata with fusulinids of this zone are referred to the Wolfcampian Series which corresponds to the Asselian and Sakmarian Stages of Russia and Europe (Dunbar, 1960; Ross 1963; Rauser-Chernoussova, 1948). North American series below and above the Wolfcampian are, respectively, the Virgilian (uppermost Pennsylvanian) and Leonardian (lower middle Permian) Series.

THE WOLFCAMPIAN SERIES

Since this report primarily deals with Wolfcampian strata, recognition of the base and top of this series is critical. The Virgilian-Wolfcampian boundary can be difficult to determine; strata in question commonly contain only fusulinid genera that are common to both series. Somewhat subjective features, such as the degree of septal fluting, are used to identify fusulinid species whose stages of evolutionary advancement are more common or typical of Virgilian or Wolfcampian Series. For example, Wolfcampian *Triticites*, such as *T. creekensis*, generally exhibit a high degree of septal fluting and have slightly thick walls.

The upper extent of the range of Triticites is somewhat uncertain. Thompson (1954) stated that this genus occurs in the Wolfcampian, but disappeared before Pseudoschwagerina. Ross (1963), on the other hand, recognized a Pseudoschwagerina-Triticites Subzone in the Glass Mountains. Skinner (written communication, 1971) states that species of Triticites found in middle and upper Wolfcampian rocks are of two types: 1) those abundant in lower Wolfcampian strata that have been reworked and commonly occur in middle or upper Wolfcampian conglomerates, and 2) several "relatively small, simple, undescribed forms which, in the subsurface, occur in nonclastic limestones and are almost certainly contemporaneous with the enclosing rock." Oddly enough, this latter group of Triticites has the general appearance of species normally found low in the zone of Triticites, in the early Upper Pensylvanian. Stewart (written communication, 1971) also agress that "the upper range of Triticites, other than Leptotriticites, definetely extends into or overlaps that of Pseudoschwagerina".

In addition, part of the problem is due to personal preference involved in naming and identifying fusulinids that are intermediate evolutionary forms between Triticites and Schwagerina. For example, T. powwowensis was included in the genus Triticites on the basis of development of the chomata, whereas it could have been justifiably included with Schwagerina on the basis of its septal fluting. Since Triticites is one of the most prolific fusulinid genera, the Virgilian-Wolfcampian boundary is commonly based on species differentiation within this genus.

Some fusulinid genera evolved at or near the base of the Wolfcampian (figure 2) and, although they are usually not as abundant as Triticites, they too can be useful in determining this boundary. Leptotriticites, tentatively recognized as a subgenus of Triticites by Skinner and Wilde (1965), is the best single indicator of the base of the Permian. It is characterized by high, massive chomata with a narrow tunnel, thin schwagerinid-type walls, and intense septal fluting. As indicated by Skinner and Wilde (1965), Leptotriticites was previously included in the genus Dunbarinella by Thompson (1954). They demonstrated that Dunbarinella was exclusively Pennsylvanian and that Leptotriticites first occurred at the base of the Wolfcampian to continue throughout the series. Studies of this report substantiate the distinctive character of Leptotriticites and, in this report, it is treated as a genus separate from Triticites. Prior to the work of Skinner and Wilde (1965), several occurrences of Dunbarinella have incorrectly been reported from Wolfcampian strata (e.g. Steiner and Williams, 1968).

Schwagerina first occurs a short distance above the base of the Wolfcampian, and early forms of this genus commonly display characteristics transitional with Triticites. For example, chomata deposits evolved from thick triticitid forms, to low-lying, thin pseudochomata, and then finally disappeared. The absence of a well-defined chomata is a typical schwagerinid characteristic, but this transition sometimes makes recognition of the lowest occurring Schwagerina uncertain.

Pseudofusulina is also found in lower Permian strata. Several synonomies existed between this genus and some species of Schwagerina, but the validity of Pseudofusulina as a distinct genus was demonstrated

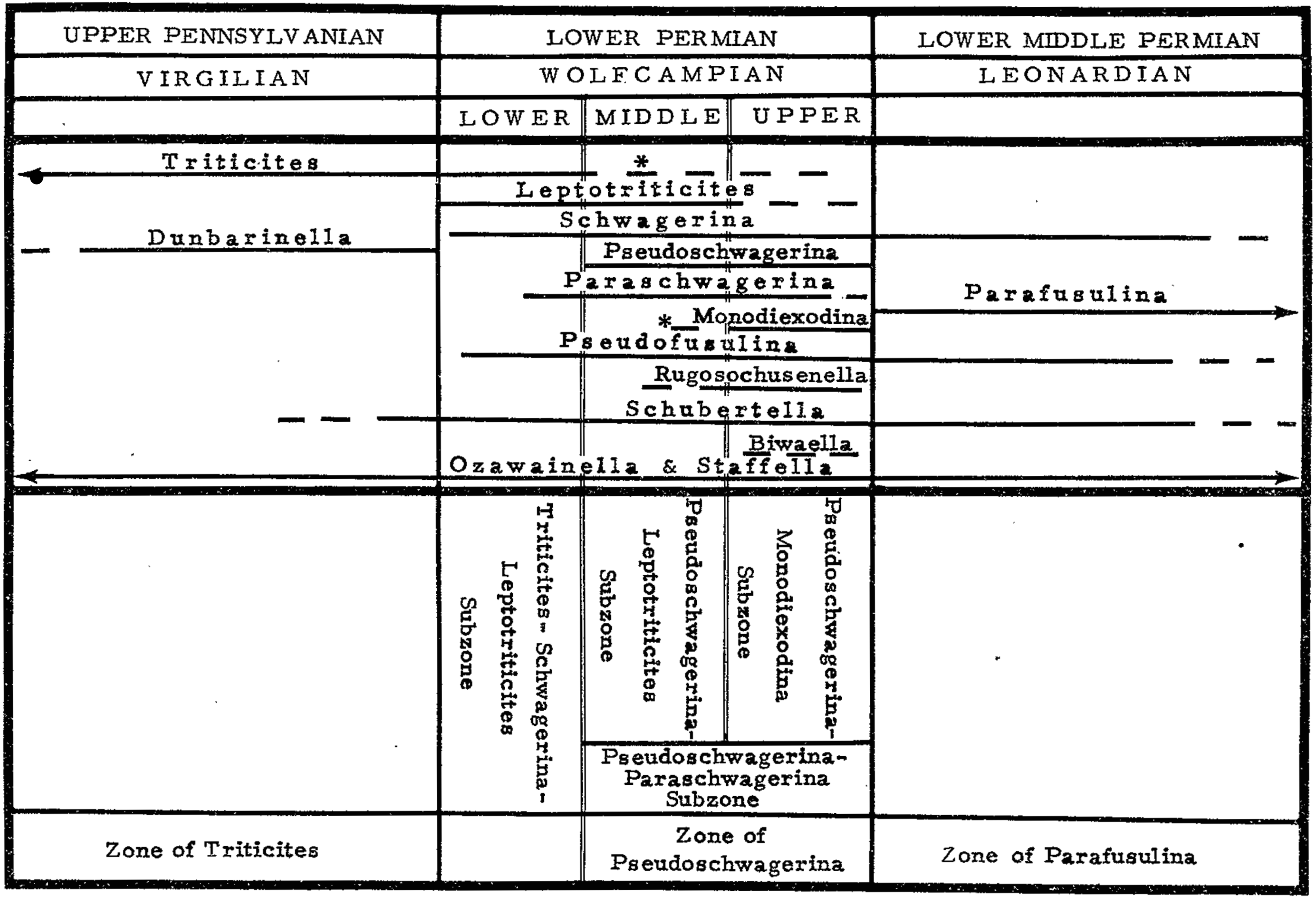


Figure 2: Zones and ranges of fusulinid genera in southern New Mexico and west Texas (asterisks indicate the presence of small, rare, undescribed forms)

by Skinner and Wilde (1966). Paraschwagerina evolved near the base of the Permian, but is more commonly found in younger Wolfcampian beds and is not generally used to determine the base of the series.

Pseudoschwagerina is considered a worldwide index fossil of the Wolfcampian Series. Dunbar (1963, p. 40) reports that Pseudoschwagerina evolved from Triticites "at the very base of the Permian"; Thompson (1948, p. 24), on the other hand, considers the range of Pseudoschwagerina to be merely "throughout most of the Wolfcampian in North America". Fusulinid successions studied in this report agree with Thompson; it has not been observed in lower Wolfcampian strata of southern New Mexico and west Texas. Hence, the Zone of Pseudoschwagerina is not exactly equivalent to the Wolfcampian Series. A peculiar exception to the range of Pseudoschwagerina from the Bone Springs Limestone of the Sierra Diablo Mountains was reported by Dunbar (1953) where a specialized form of Pseudoschwagerina (P. stanislavi) is found with Parafusulina, a Leonardian to Guadalupian indicator. Several explanations are possible for the complexity of this association, but many workers regarded this as a real extension of the range of Pseudoschwagerina until Thompson (1964) referred this form to the genus Robustoschwagerina.

Monodiexodina is basically upper Wolfcampian; a few smaller, rare, undescribed forms occur as this genus first evolved in the upper part of middle Wolfcampian time (Skinner, written communication, 1971). On a worldwide basis, a few occurrences of very early Leonardian Monodiexodina have been reported (Dunbar, 1963).

Rare or long-ranging fusulinids found in the Wolfcampian include Schubertella (Stewart, 1968), Ozawainella (Thompson, 1948), Rugosochusenella and Biwaella (Skinner and Wilde, 1965). Their occurrences are mainly useful in global Wolfcampian correlations and in determining phylogenetic relationships. Stewart (personal communication, 1971) states that some Wolfcampian and Leonardian species of Schubertella can be distinguished, but that no succession of Schubertella subzones can be recognized in the Wolfcampian at this time. Fusulinid studies of this report concentrated on members of the Family Schwagerininae.

The Wolfcampian-Leonardian boundary is recognized most accurately by the first occurrence of Parafusulina. Less reliable determinations of this boundary are based on Schwagerina species that are restricted only to the Leonardian. Often the latter method is subjective and some debate has centered about the proposed presence of Leonardian strata in the Hueco Mountains of west Texas (e.g. Williams, 1963 versus Kottlowski, 1963).

WOLFCAMPIAN SUBZONES

Ideally, three fusulinid subzones of the Wolfcampian can be distinguished from the ranges shown in figure 2: 1) a lower Triticites-Schwagerina-Leptotriticites Subzone, 2) a middle Pseudoschwagerina-Leptotriticites Subzone, and 3) an upper Pseudoschwagerina-Monodiexodina Subzone. However, Monodiexodina, a basic element of the uppermost subzone, is quite rare. Only two specimens were observed in this study and the few published occurrences are restricted to the west Texas part of the study area.

On a practical basis, the Wolfcampian is divided into a lower pre-*Pseudoschwagerina* subzone and an upper *Pseudoschwagerina* subzone. These zones are certainly not equal in their expanse of time or rock record. Since the *Pseudoschwagerina* subzone is much larger and since there is a theoretical basis for three subzones, the following definitions are proposed:

1) lower Wolfcampian for strata in the pre-*Pseudoschwagerina* subzone which is termed the *Triticites*-*Schwagerina*-*Leptotriticites* Subzone, and

2) middle-upper Wolfcampian for strata in the range of *Pseudoschwagerina*. To avoid confusion with the worldwide Zone of *Pseudoschwagerina*, this subzone is termed the *Pseudoschwagerina*-*Paraschwagerina* Subzone.

The *Triticites*-*Schwagerina*-*Leptotriticites* Subzone is recognized by the presence of these genera and by the general absence of *Pseudoschwagerina*, although there is some overlap between the upper range of *Triticites* and the lower range of *Pseudoschwagerina* (Stewart, written communication, 1971). *Leptotriticites*, *Paraschwagerina*, *Pseudofusulina*, *Schubertella*, *Staffella*, and *Ozawainella* may also occur as accessory fusulinids. Specific examples follow this discussion and show that, although the subzone exists throughout southern New Mexico, it is not always a simple fusulinid assemblage. In some cases, only *Triticites* or *Schwagerina* is found below the lowest occurrence of *Pseudoschwagerina*; in others, *Triticites* and *Schwagerina* occur, but *Triticites* disappears upwards, leaving a zone of *Schwagerina* below *Pseudoschwagerina*.

A common, but confusing, reference to the Triticites-Schwagerina-Leptotriticites Subzone is the term "Bursum fauna", with a corresponding "Bursum age". These terms originated from the common occurrences of Triticites and Schwagerina in the Bursum Formation of southern New Mexico. As recommended by Kottlowski and Stewart (1970, p. 23), the term "Bursum" is not a biostratigraphic zone and should be used only to refer to strata with an interbedded limestone and red-bed lithology, as found in the type Bursum section. In this report, the term "Bursum" will be restricted solely to lithic units with no faunal or time implication.

The Pseudoschwagerina-Paraschwagerina Subzone is characterized by the presence of Pseudoschwagerina; in the study area, Paraschwagerina is somewhat rare and its presence is not necessary for recognition of this subzone. Leptotriticites, Schwagerina, Monodiexodina, Pseudofusulina, Schubertella, Rugosochusenella, Staffella, Biwaella, and Ozawainella are also found in this subzone. The Pseudoschwagerina-Paraschwagerina Subzone corresponds with the range of Pseudoschwagerina; since Pseudoschwagerina does not occur in the lower Wolfcampian of the study area, this subzone does not correspond exactly with the worldwide Zone of Pseudoschwagerina.

Within the Pseudoschwagerina-Paraschwagerina Subzone, occurrences of a significantly less diverse Schwagerina fauna are found in parts of west Texas. Two species dominate the Cerro Alto Limestone in the Hueco Mountains (Schwagerina neolata and Schwagerina eolata) and their names are used to refer to this subzone. This can best be interpreted as a local to subregional interruption in the Pseudoschwagerina-Paraschwagerina Subzone and is not useful in distinguishing middle from upper Wolfcampian stages. Skinner (written communication) reports that certain Schwagerina species, although long-ranging, can be used in determining this boundary. S. emaciata, for example, marks the top of the middle Wolfcampian.

REGIONAL CORRELATIONS BASED ON FUSULINID SUBZONES

Lower and middle to upper stages of the Wolfcampian are recognized with certainty in nine of the ten measured sections described in this report. Middle and upper stages were differentiated only in the Franklin, Hueco, and Jarilla Mountains.

A threefold division of Wolfcampian time is incompletely represented in the standard Wolfcampian section in the Glass Mountains of west Texas (Ross, 1963). This section was designated by a special AAPG committee in 1939 as a reference for the Wolfcampian Series (Adams et al., 1939; Dunbar, 1960), before it was realized that there were more complete sections existing farther to the northwest. The Wolfcampian section in the Glass Mountains consists of 1) a basal unconformity (overlying the Virgilian Gaptank Formation); 2) the Neal Ranch Formation (about 300 feet of cyclic deposits of shales, siltstone, and calcarenites), 3) a medial unconformity (between the underlying Neal Ranch Formation and the overlying Lenox Hills Formation), 4) the Lenox Hills Formation (about 270 feet of conglomerate and interbedded limestone and shale), and 5) an upper unconformity (above the Lenox Hills Formation and below the Leonard Formation of Leonardian age). Fusulinids of the Neal Ranch Formation include several Pseudoschwagerina, Schwagerina, Triticites, and two Paraschwagerina species. According to Skinner (personal communication, 1971), some Triticites in the Neal Ranch Formation show definite signs of reworking. Even if this is not true for all Triticites found in this formation, their highly evolved forms (certainly of Permian age) do not conflict with a middle Wolfcampian interpretation based on the presence of Pseudoschwagerina and Paraschwagerina. The hiatus represented by the unconformity at the base of the Neal Ranch corresponds to the lower Wolfcampian (the Triticites-Schwagerina-Leptotriticites Subzone). The Lenox Hills fusulinid fauna consists of several Pseudoschwagerina and Schwagerina genera and one species of Monodiexodina, clearly indicating upper Wolfcampian age. However, neither the middle or upper Wolfcampian sections here are complete, due to unconformities above, below, and between the two fusulinid zones present in this area. Furthermore, it seems that this standard Wolfcampian section was poorly chosen due to its tectonic position on the flank of the Marathon orogenic belt. Table 2 lists various fusulinid species according to Wolfcampian stages that have been reported from the Glass Mountains. Similar data from New Mexico and west Texas are presented along with data from other parts of the western United States. The lower Wolfcampian is easily recognized, whereas middle and upper Wolfcampian are rarely distinguished owning to the scarcity of Monodiexodina.

Several fusulinid studies have been done in the Hueco Mountains (Dunbar and Skinner, 1937; Thompson, 1954; Williams, 1963). Fusulinids in stratigraphic samples from this area were examined and results of this and other reports are stratigraphically positioned in figure 3. Uppermost fusulinid-bearing beds of the section measured on Alacran Mountain were futilely searched for indications of the Leondardian Series, which was reported here by Williams (1963). The middle-upper Wolfcampian boundary is placed in the upper part of the Hueco Canyon Formation on the basis of Monodiexodina bispatulata in uppermost beds of this formation. The lower-middle boundary is tentatively based on the lowest occurrence of Pseudoschwagerina in upper beds of the Magdalena Limestone, as reported by Williams (1963).

He also described Triticites powwowensis above this horizon, from beds of the Powwow Member. This species is not a typical Triticites and shows several features transitional to Schwagerina. Stewart (written communication, 1971) states that "the forms published by Dunbar and Skinner (1937) should be referred to Schwagerina or Stewartina", a new genus recently proposed by Wilde. Thus, the presence of T. powwowensis in beds designated herein as middle Wolfcampian does not contradict the ideal threefold zonation described. Samples from the Powwow Member collected for the present study revealed only very thin-walled Pennsylvanian Triticites, reworked and deposited in conglomerate beds above a regional angular unconformity.

The Hueco Canyon Formation and the Neal Ranch Formation of the Glass Mountains both contain faunal elements of middle Wolfcampian time, namely Schwagerina and Pseudoschwagerina. Triticites found in each location, however, require interpretation. Triticites powwowensis (found only in the basal Hueco Canyon Formation of the Hueco Mountains)

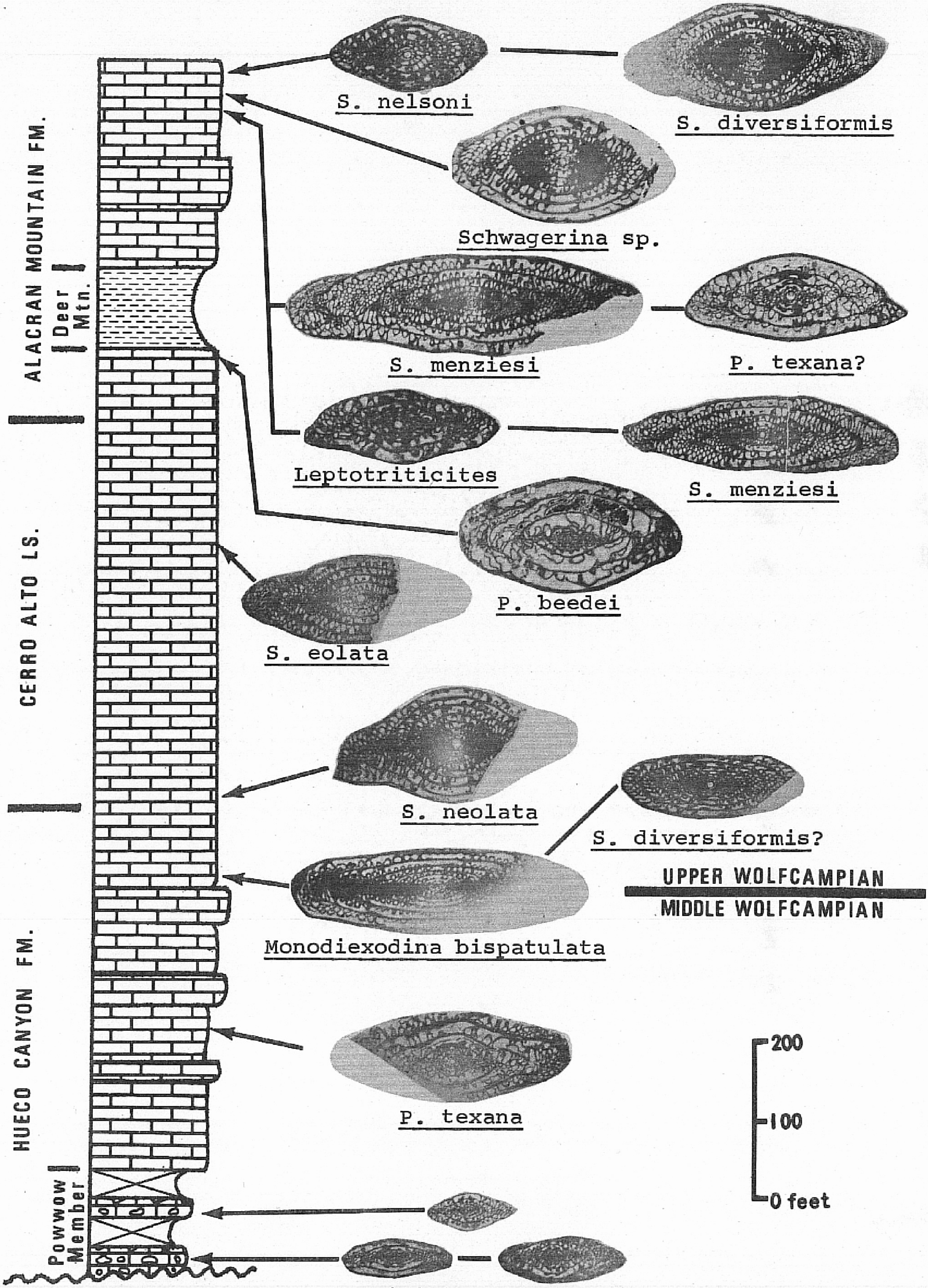


FIGURE 3

Fusulinid Zonation in the Hueco Mountains, West Texas
(all photographs x5)

is an advanced highly fluted form and is probably lower middle Wolfcampian, whereas Triticites species of the Neal Ranch Formation are considerably less complex and may have been reworked. The Powwow Member is probably younger and not precisely correlative with the Neal Ranch Formation; both sections, however, represent periods of middle Wolfcampian time.

Below the unconformable surface at the base of the Powwow lie beds ranging from the Ordovician El Paso Limestone to the predominantly Upper Pennsylvanian Magdalena Limestone. Below the uppermost Pseudoschwagerina-bearing beds of the Upper Division of the Magdalena Limestone, north of Powwow Canyon, Thompson (1954, p. 18) reported the occurrence of Triticites cellamagnus and Triticites and Schwagerina species, indicating that some strata of the Magdalena are lower Wolfcampian. These beds were not observed in the area where samples for this investigation were collected.

The Cerro Alto Formation is considered to be upper Wolfcampian mainly by its stratigraphic position. The Schwagerina neolata-Schwagerina eolata Subzone, best demonstrated in this section, contains no Pseudoschwagerina.

The succession of Wolfcampian fusulinid zones in the Franklin Mountains is similar to that of the Hueco Mountains, 25 miles to the east. Basically, the same thick interval of Alacran Mountain Formation down to the upper Hueco Canyon Formation is of late Wolfcampian age and displays a diverse fauna of Schwagerina and Pseudoschwagerina. The absence of large, unreplaced fusulinids in the Cerro Alto Limestone here correlates well with the low diversity *Schwagerina neolata*-*Schwagerina eolata* Subzone in the Hueco Mountains. The complete lack of *Schwagerina* in the Franklin Mountain Cerro Alto indicates that the *Schwagerina neolata*-*Schwagerina eolata* Subzone may be related closer to facies rather than time. The Powwow Conglomerate is not present here and Lower Permian strata apparently rest conformably over the Upper Pennsylvanian (Jordan and Wilson, 1971). It is possible that upper beds of the underlying Magdalena Group here are lower Wolfcampian. The top of the middle Wolfcampian stage is demonstrated by the occurrence of *Monodiexodina bispatulata* (reported by Williams, 1966) about 350 feet below the base of the Cerro Alto (figure 4). In the basal 320 feet of the Hueco Canyon Formation, only two or three unidentifiable fusulinid fragments were observed. Since deposition appears to be continuous in this area, the middle-lower Wolfcampian boundary is indeterminate. The Virgilian-Wolfcampian boundary in the Franklin Mountains was not recognized due to a lack of paleontological control in the southern part of the range and due to poor exposures and complex structure the farther north toward Vinton Canyon. Preliminary identification of a *Triticites* species about 300 feet above the base of the measured section (Jordan and Wilson, 1971) is now recognized to be *Leptotriticites* and is the lowest indication of Permian age in the Franklin Mountains.

In the southern San Andres Mountains, the bulk of Lower Permian strata are of upper and middle Wolfcampian age. The upper 350 feet of the sampled section (figure 5) are red-beds containing no fusulinids. Below this, in 1340 feet of Hueco Limestone, *Pseudoschwagerina*, *Schwagerina*, and *Leptotriticites* species were identified. Kottlowski (1963, p. 47) has found *Pseudoschwagerina* and *Schwagerina* species at

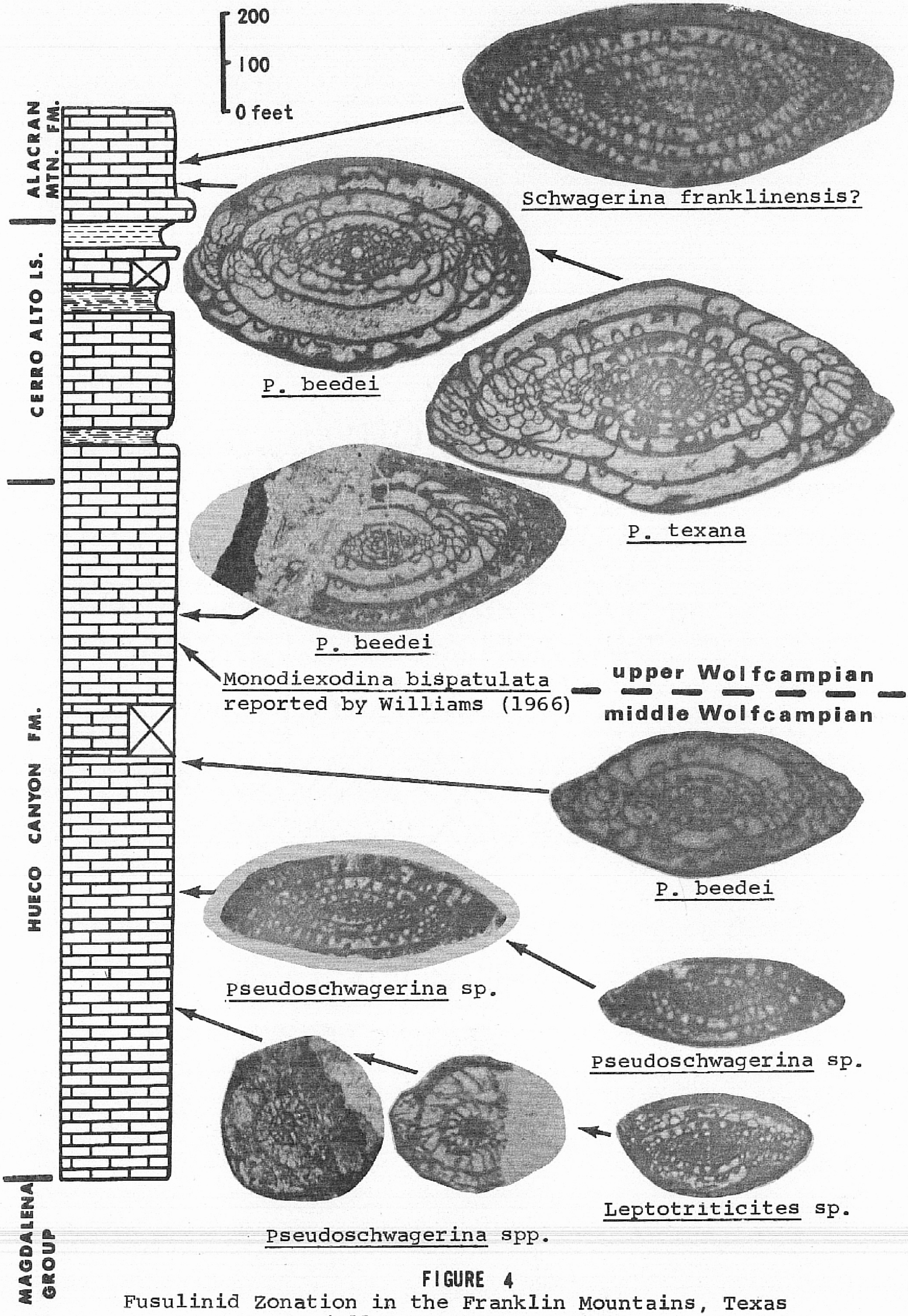


FIGURE 4
Fusulinid Zonation in the Franklin Mountains, Texas
(all photographs x10)

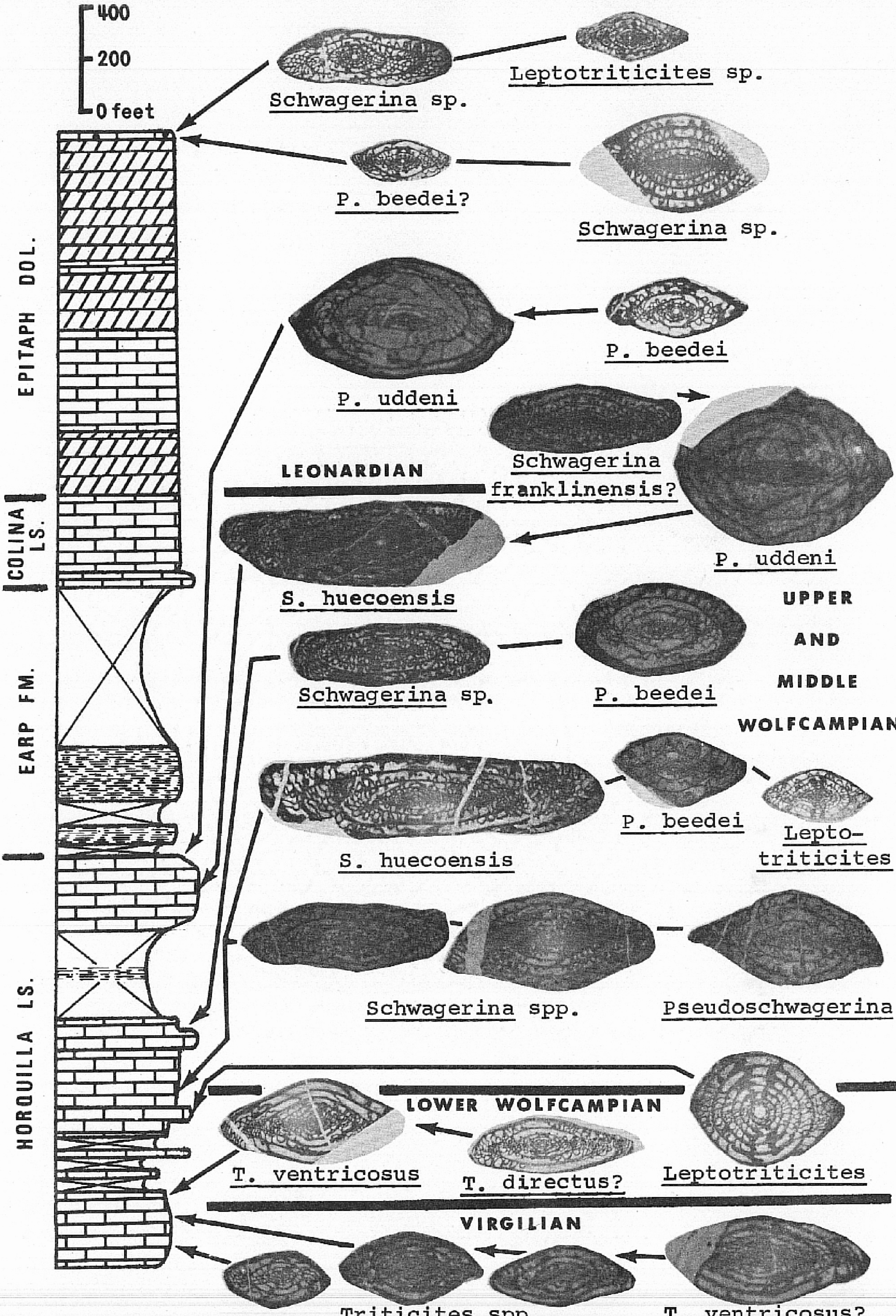


FIGURE 6

Fusulinid Zonation in the Big Hatchet Mountains, New Mexico
(all photographs x5)

the base of the Hueco in a "massive biostromal unit"; he remarked that conformable relationships exist between the basal biostrome and underlying beds which he tentatively assigned to the Bursum Formation. In fact, since no red-beds appear below the Hueco in the Love Ranch area, the term Bursum is inappropriate here (Kottlowski and Stewart, 1971). These strata are hereby included in the Hueco Limestone and underlying beds are referred to the Panther Seep Formation. Kottlowski (personal communication, 1971) observed only locally unconformable surfaces at the top of the Panther Seep in these outcrops. As reported by Mark Wilson (in stratigraphic studies for Shell Oil Company), Pseudoschwagerina occurs 170 feet below the base of the Hueco in the southern San Andres Mountains. Thus, the upper part of the Panther Seep is assumed to be middle Wolfcampian age. Stratigraphic interpretations of sedimentary thicknesses across the Orogrande Basin in this region (discussed later) further substantiate this assumption.

Recognition of series and stage boundaries is clearly demonstrated in the Big Hatchet Mountains. Prior to this investigation, fusulinids have not been reported from the Epitaph Dolomite. Near the top of the measured section of this formation (figure 6), reworked fusulinids were deposited in a thin comglomerate unit. Relatively abundant Pseudoschwagerina and Leptotriticites were found and a few highly advanced Schwagerina specimens were tentatively identified. This is interpreted to date the Epitaph as post-Wolfcampian and probably Leonardian. The underlying Colina Formation contains very few

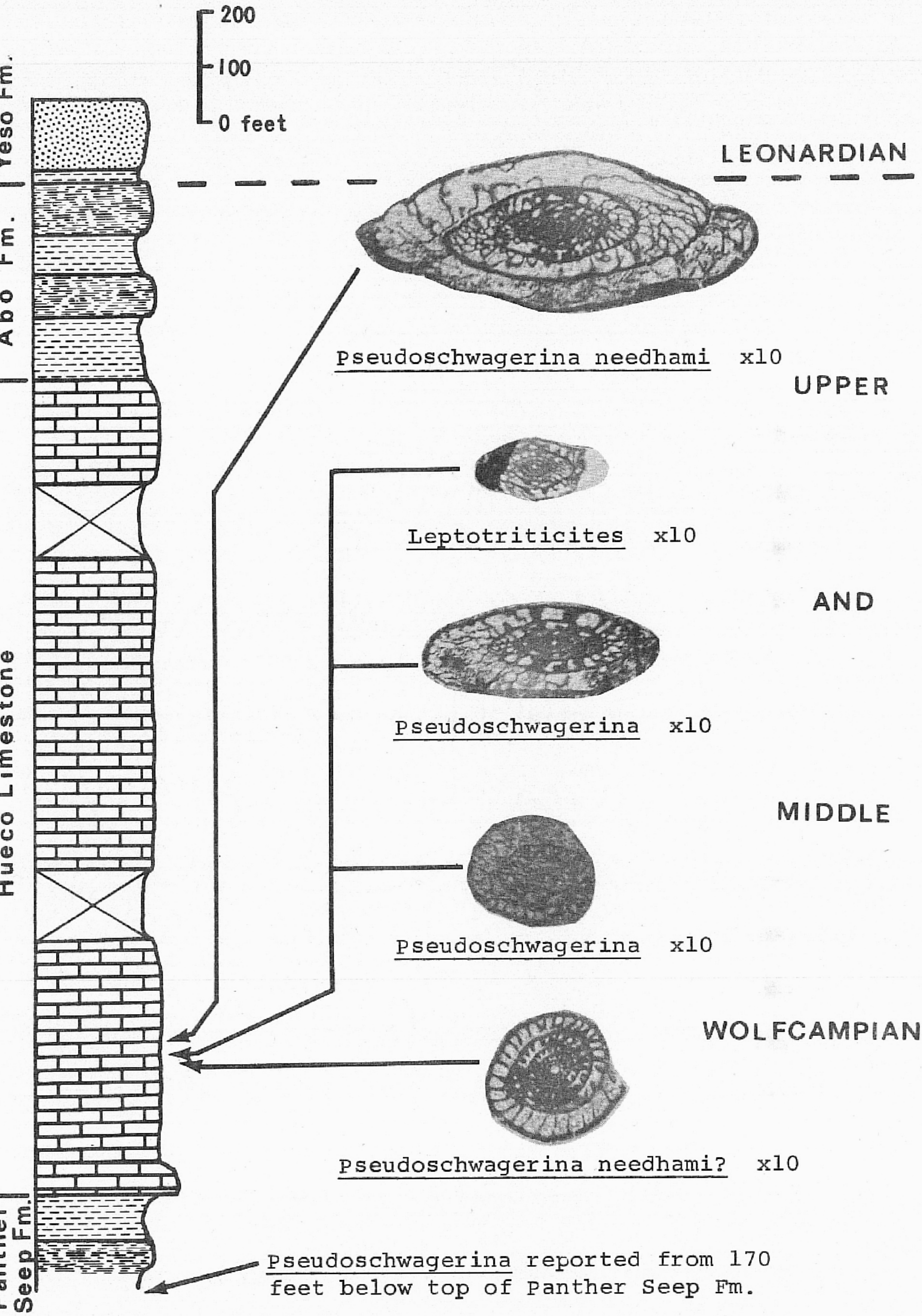


FIGURE 5

Fusulinid Zonation in the San Andres Mountains, New Mexico fusulinids; no precise information regarding the age of the formation is presently available. The underlying Earp Formation is barren of fusulinids. In this report, the Earp and Colina are tentatively considered upper Wolfcampian.

Complete stratigraphic sections of the underlying Horquilla Formation have not been studied; thick continuous sections crop out, but to include the upper contact with the Earp would require a considerable amount of lengthy bed-tracing. A recently prepared geologic map of the Big Hatchet Mountains by Zeller (on open file in the New Mexico Bureau of Mines and Mineral Resources at Socorro) should help in obtaining complete Horquilla sections. The total thickness of this formation is estimated to be "no greater than 3600 feet" by Zeller (1965).

In the measured section of this report (which is equivalent to the upper and middle parts of Zeller's Borrego Section), upper and middle Wolfcampian stages could not be differentiated. The top of the lower Wolfcampian was chosen at the lowest occurrence of Pseudoschwagerina, about 850 feet above the base of the section (figure 6). The Wolfcampian-Virgilian boundary is based upon advanced forms of Triticites. Zeller's New Well Peak and Bugle Ridge sections of the Horquilla (about 2, 250 feet thick) indicate continuous deposition through Desmoinesian, Missourian, Virgilian, and Wolfcampian time; this section, in figure 6 of this report, correlates well with the upper 2/3 of Zeller's Borrego Section (1965), and with correlations by Skinner and Wilde (1965). The base of the author's section is a fault in the lower Horquilla that brings upper or middle Wolfcampian beds in contact with Virgilian beds. This is based on field recognition of the fault, its appearance on Zeller's map (where a sliver of the Horquilla is displaced near the base of a thrust fault), and the presence of Pseudoschwagerina in beds below the fault.

Lower Permian strata in the Jarilla Mountains consist of the Laborcita Formation (about 1,500 feet) which is overlain by the Hueco Limestone (about 1,000 feet). Laborcita sediments here have been metamorphosed, but Schmidt and Craddock (1964) have identified a Schwagerina-Triticites fauna from the middle of the section. This, plus the occurrence of a Triticites-Schwagerina-Leptotriticites fauna in the Laborcita of the Sacramento Mountains (Steiner and Williams, 1968), indicates a lower Wolfcampian age for this formation. In the Hueco Limestone of the Jarilla Mountains, Schwagerina emaciata and Pseudoschwagerina morsei indicate middle Wolfcampian. No unconformities exist in this section, and fusulinids were not observed in strata between the two faunas mentioned above. The middle-upper Wolfcampian boundary is intuitively placed in the upper third of the Hueco Limesone on a stratigraphic basis.

Two subdivisions of Wolfcampian strata occur in the Robledo Mountians. Data from Thompson (1954, p. 23) and from this report recognize the following sequence: 1) lower Wolfcampian as indicated by Schwagerina and Leptotriticites species in the lower Hueco Limestone, and 2) middle and upper Wolfcampian as indicated by Leptotriticites, Schwagerina and Pseudoschwagerina species in the middle and upper Hueco.

The Hueco Limestone in the measured section from the Sierra Diablo Mountains of west Texas is considered upper Wolfcampian on the basis of Pseudoschwagerina and highly advanced Schwagerina species.

Schwagerina specimens from the SD section display incipient cuniculi near the tunnel in outer whorls. Development of cuniculi in Parafusulina is one of the most diagonostic features of this Leonardian to Guadalupian genus. Since Parafusulina evolved from Schwagerina, upper Wolfcampian age is assigned to strata containing intermediate evolutionary forms of Schwagerina. These species are undescribed but Skinner (written communication, 1971) has found several in the Lenox Hills Formation in the Glass Mountains: they are "similar to, but more robust than, the form figured by Ross (1963, pl. 20, fig. 10) as Schwagerina pugunculus, which incidentally should have been S. puguncula". Reports of Triticites, Schwagerina, and Pseudoschwagerina from the Hueco Limestone in the Wylie Mountains (10 to 15 miles southeast of the Sierra Diablo Mountains) suggest that part of the Hueco in this area may be lower Wolfcampian (Hay-Roe, 1957).

The occurrences of fusulinid genera found in southern New Mexico, and west Texas, and other areas of the western United States are listed in Table 2 according to Wolfcampian stages. The recognition of three stages is limited and is best displayed in sections from west Texas. The lower Wolfcampian is clearly distinguished from upper and middle Wolfcampian throughout southern New Mexico. In this report, use of the term "stage" has been informal; a formal proposal of these stages would necessitate a more extensive study of fusulinid collections and literature than is within the scope of this report. These subdivisions of Wolfcampian time are established primarily for correlation in the area of investigation.

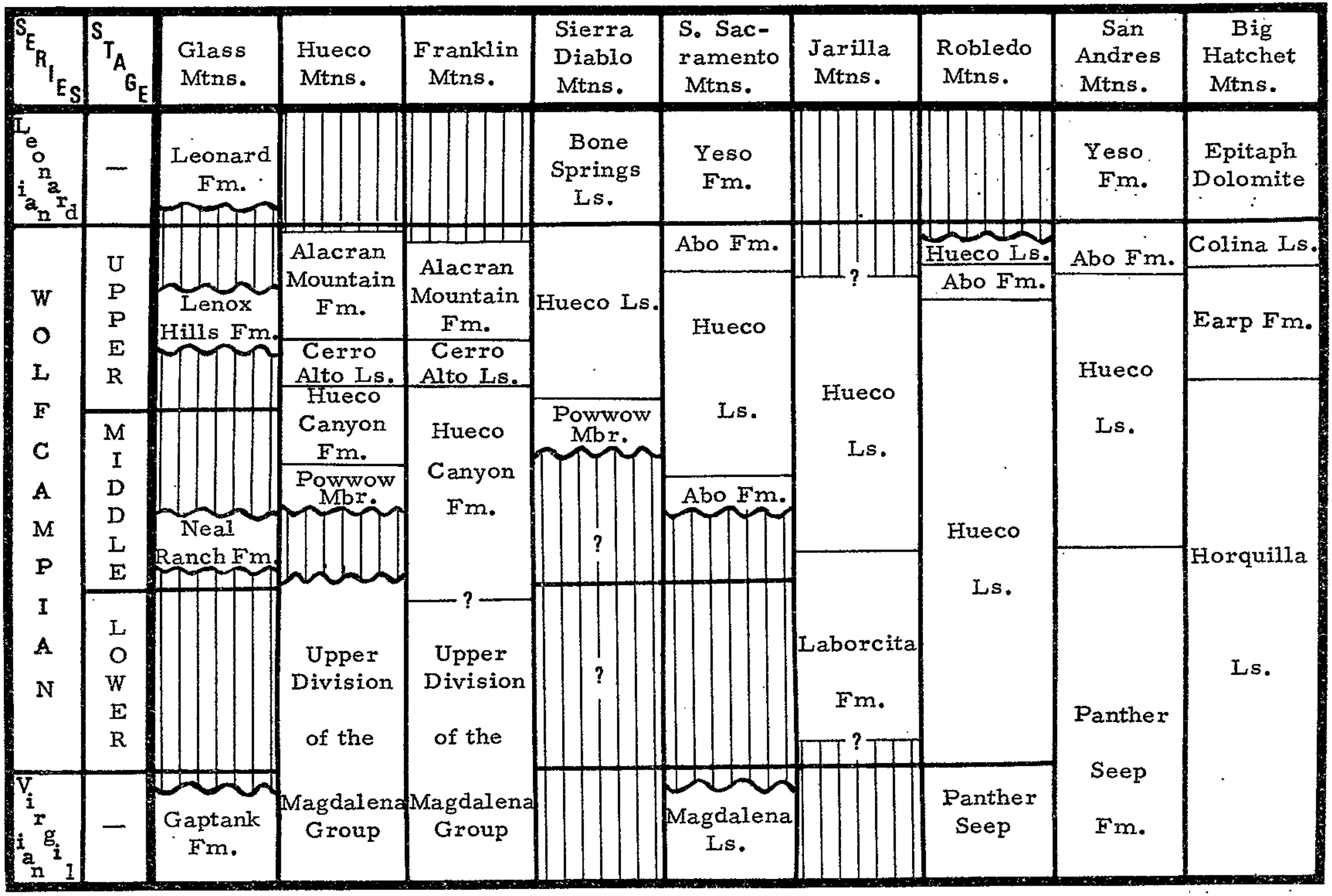


Figure 7: Regional Wolfcampian Correlations Based on Fusulinids in Southern New Mexico and West Texas

Table 2

Examples of Wolfcampian Fusulinid Subzones

Location	Source of Data	Rock Units	lower Wolfcampian (*Triticites*-*Schwagerina*-*Leptotriticites* Subzone)	middle Wolfcampian (*Pseudoschwagerina*-*Leptotriticites* Subzone)	upper Wolfcampian (*Pseudoschwagerina*-*Monodiexodina* Subzone)
Glass Mountains, W. Texas	Ross, 1963	Neal Ranch & Lenox Hills Formations	Unconformity	*Par. gigantea*, *Par. acuminata*, *Pss. parabeedei*, *Pss. uddeni*, *Pss. texana*, *Pss. beedei*, *S.* spp., *S. pugunculа*, *S. gracilitatis*, *S. emaciata*, *S. compacta*, (*T. uddeni*, *T. ventricosus*, *T. pinguis*, and *T. koschmanni* probably reworked)	*M. linearis*, *Par. plena*, *Pss. convexa*, *Pss. parabeedei*, *Pss.* cf. *Pss. texana*, *S.* spp., *Pss. tumidosa*, *Pss. robusta*, *S. bellula*, *S. lineanoda*, *S. dispansa*, *S. extumida*, *S. lineanoda*, *S. tersa*, *Staffella*?, *S. laxissima*, *S. diversiformis*, *S. crebrisepta*, *S. nelsoni*
Hueco Mountains, W. Texas	Thompson, 1954, Williams, 1966; and this report	Hueco Ls. & upper Magdalena Group	*T.* sp., *T. cellamagnus*, *S.* sp.	*Pss.* sp., *T. powwowensis*	*Pss. uddeni*, *Pss. texana*, *S. bellula*, *S. huecoensis*, *Pss. beedei*, *S. fax*, *S. neolata*, *S. eolata*, *S. diversiformis*, *Pss. convexa*, *S. nelsoni*, *Pss. gerontica*, *M. bispatulata*
Franklin Mountains, W. Texas	Williams, 1966, & this report	Hueco Limestone	fusulinid-barren?	*Leptotriticites*, *Pss. beedei*, *Pss. texana*, *Pss. uddeni*, *S. emaciata*, *Pf. huecoensis*, *S. bellula*, *Pss. ultima*, *S. thompsoni*	*Pss. gerontica*, *Pss. texana*, *Pss. beedei*, *Pss. ultima*, *Pss. uddeni*, *M. bispatulata*, *S. huecoensis*, *S. bellula*, *S. nelsoni*, *S. crassitectoria*?, *S. thompsoni*, *Pss. convexa*, *S. franklinensis*, *S. eolata*, *Chusenella*
Big Hatchet Mountains, New Mexico	Zeller, 1965, Skinner & Wilde, 1965 & this report	Horquilla Formation	*Triticites* spp.; *T. ventricosus*, *Schwagerina* spp.	*L. hatchetensis*, *L. gracilitatis*, *Pss.* spp.; *Pss. uddeni*, *Pss. beedei*, *S.* spp., *Pseudofusulina* sp., *Rugosochusenella* sp., *Par.* sp., *Biwaella* spp., *Schubertella* spp.	

Table 2 (continued)

Location	Source of Data	Rock Units	lower Wolfcampian (*Triticites-Schwagerina-Leptotriticites* Subzone)	middle Wolfcampian (*Pseudoschwagerina-Leptotriticites* Subzone)	upper Wolfcampian (*Pseudoschwagerina-Monodiexodina* Subzone)
Jarilla Mountains, New Mexico	Schmidt & Craddock, 1964 and this report	Laborcita Fm. & Hueco Ls.	*S.* aff. *S. emaciata*, *S.* sp., *T. ventricosus*, *T.* cf. *T. gallowayi*, *T.* cf. *T. cellamagnus*, *T.* cf. *T. rhodesi*	*S. emaciata*, *Pss. morsei*	fusulind-barren
Robledo Mountains, New Mexico	Thompson, 1954 & this report	Hueco Ls.	*L. hughesensis*, *L.* aff. *L. glenensis*, *Pf. robleda*, *S. grandensis*	*Pss. uddeni*, *Pss. texana*, *S. andresensis*, *L.* aff., *L. tumidus*	
S. San Andres Mtns. New Mexico	Kottlowski, 1963; Thompson, 1954; & this report	Hueco Ls.	probably upper part of the Panther Seep Fm. (no fusulinid data available)	*S. andresensis*, *Pss. texana*, *Leptotriticites* sp., *Pss. needhami*, *Pss. morsei*, *Pf.* aff. *Pf. huecoensis*	
Central San Andres Mtns., New Mexico	Kottlowski, 1963	Hueco Ls.	probably upper part of the Panther Seep Fm. (no fusulinid available); also some erosion at the base of the Hueco Ls.	*S. andresensis*, *Pss. needhami*, *Pss. texana*, *S. bellula*	
Northern San Andres Mtns., New Mexico	Kottlowski, 1963 Thompson, 1954	Hueco Ls.	probably upper part of the Panther Seep Fm. (no fusulinid data available); also some erosion at the base of the Hueco Ls.	*S. andresensis*, *Pss. rhodesi*, *S. andresensis*	
Abo Canyon, Manzanno Mtns., New Mexico	Thompson, 1954	Bursum Fm.	*T. creekensis*, *S. pinosensis* *S. grandensis*?, *L. eoextenta*	not present	not present

Table 2 (continued)

Location	Source of Data	Rock Units	lower Wolfcampian (*Triticites*-*Schwagerina*-*Leptotriticites* Subzone)	middle Wolfcampian (*Pseudoschwagerina*-*Leptotriticites* Subzone)	upper Wolfcampian (*Pseudoschwagerina*-*Monodiexodina* Subzone)
Oscura Mtns., New Mexico	Thompson, 1954	Bursum Fm.	*T. creekensis*, *S.* sp., *S.* aff., *S. grandensis*	not present	
Sacramento Mtns., New Mexico	Thompson, 1954	Laborcita Fm.	*T. creekensis* *S.* aff. *S. grandensis*	not present	
Sacramento Mtns., New Mexico	Steiner & Williams, 1968	Laborcita Fm.	*T. ventricosus*, *T. creekensis*, *L. americana*, *S. emaciata*, *S. campensis*	not present	
North Central Texas	Thompson, 1954	Wichita Group	*L. extenta*, *L. eoextenta*, *T. confertus*, *S. longissimoidea*, *T. directus*, *T.* sp., *T. ventricosus*, *L. wetherensis*, *S. campensis*, *T. creekensis*	*S. complexa*, *Pf? moranensis*, *Pss. texana*, *S. minuta*, *S. colemani*	
Generalized Wolfcamp of Kansas	Thompson, 1954	Council Grove Group	*T. pointensis*, *T. confertus*, *L. fivensis*, *L. americana*, *T. meeki*, *L. eoextenta*, *L. hughensis*, *T. ventricosis*, *S. longissimoidea*, *L. glenensis*, *T. rockensis*, *S. campa*, *L. tumida*, *L. koschmanni*	*S. longissimoidea*, *Par. kansasensis*, *L. obesa*, *T.* sp., *S. jewetti*, *S. emaciata*, *S. vervillei*, *Pf? moranensis*, *Pss. texana*	fusulinid-barren
Wasatch Mtns., Utah	Thompson, 1954	unnamed strata	*T. cellamagnus*, *T. meeki*, *Pf.* sp., *S.* sp., *Pf. utahensis*, *L. hughensis*, *S. elkoensis*	*S.* sp., *Pss. uddeni*?	

Abbreviations: T. = *Triticites*; S. = *Schwagerina*; L. = *Leptotriticites*; Pss. = *Pseudoschwagerina*; Par. = *Paraschwagerina*; Pf. = *Pseudofusulina*; M. = *Monodiexodina*

Resolution of the boundary between the middle and upper Wolfcampian might possibly be based on successions of Pseudoschwagerina species. Ross (1961) suggested a phylogeny for species complexes of this genus, each complex being defined as a morphologic grouping of certain Pseudoschwagerina species. He proposed that a "beedei complex" appeared first and gave rise to seven other complexes. The species observed in west Texas and southern New Mexico belong to two of the complexes proposed by Ross. In the beedei complex are included P. morsei, P. texana, P. beedei, and others. From this complex evolved the "uddeni complex", which contains P. robusta, P. uddeni, and others.

Thus, it appears that the lowest occurrence of a member of the uddeni complex might have biostratigraphic significance in the upper and middle Wolfcampian. This possibility was tested in southern New Mexico and west Texas with data from published sources and from this report. Results are inconclusive in sections from the Franklin, Hueco, Jarilla, and San Andres Mountains. Because P. uddeni is the lowest reported Pseudoschwagerina species from the Robledo Mountains (Thompson, 1954, p. 23) and the Glass Mountains (Ross, 1963, p. 42), some doubt is cast upon the biostratigraphic value of this species. More negative evidence is found in the occurrences of only two Pseudoschwagerina species in the McCloud Limestone of California (Skinner and Wilde, 1965), both of which belong to the uddeni complex. However, in the Big Hatchet Mountains of New Mexico, the lowest Pseudoschwagerina belong to the beedei complex and about 1650 feet above the base of the section occurs *P. uddeni,* as predicted. Certainly, this idea of upper and middle Wolfcampian zonation based on *Pseudoschwagerina* species should be attempted in other areas and with other species. It is unfortunate that *Monodiexodina,* a clear indication of the upper Wolfcampian, is not more abundant and widespread. It appears that on a worldwide basis, its distribution is related to a preference for sandy or calcarenite environments.

In summary, the sections measured in west Texas and southern New Mexico largely represent upper and middle Wolfcampian time, with thinner (or missing) lower Wolfcampian sections. These sections are correlated with the standard Wolfcampian sections in figure 7. Although no fusulinids occur in the section of the southern Sacramento Mountains, this section is included for completeness and its correlation is stratigraphically positioned.

Wolfcampian stages are best recognized by the lowest occurrences of *Leptotriticites* (base of lower stage) *Pseudoschwagerina* (base of middle stage), and *Monodiexodina* (base of upper stage).

PETROLOGY AND PARTICLE TYPES

Carbonate strata often contain bioclastic particles indicative of environmental conditions which can be used to characterize various rock facies. To better understand subsequent descriptions of stratigraphic sequences, this special chapter on particle types and rock facies has been prepared.

LOWER PERMIAN BIOCLASTS

The extremely diverse fauna of Wolfcampian time precludes description of each bioclastic type. The reader is referred to Majewske (1969) and Horowitz and Potter (1971) for excellent illustrations of common long-ranging invertebrate bioclasts such as gastropods, echinoids, bivalves, ostracods, brachiopods, trilobites, bryozoa, and corals. These particle types will be discussed here only as they define sedimentary facies.

Algae and foraminifera, however, are abundant and have evolved to various stages of advancement in Permian time and require special treatment. Johnson (1963) described numerous Permian algae species; of these, only a limited number are observed to be quantitatively important as rock forming organisms.

Epimastopora is a commonly occurring green algae of the family Dasycladaceae and ranges from Middle Pennsylvanian through Permian. The whole plant was probably large, but fossil occurrences are predominantly fragmented plates. Calcification of the algae was such that a crust formed on the outer edges of the plant and only these crusts or plates are recognized in sediments. A section tangential to an Epimastopora plate (figure 8a) shows the abundance of large pore spaces on the plant's outer surface. A transverse section (figure 8b) shows that these pores generally extend through the plate. This characteristic distinguishes Dasycladaceae from other common Wolfcampian algae, but is often masked by recrystallization. Based on analogies with recent dasycladacean species, the presence of such algae indicates extremely shallow marine environments with water depths of 10-15 feet. It is interesting to note, however, that modern members of this family are not heavily calcified and hence do not contribute significantly (at least, not sand-size particles) to Recent sediments.

Other occurrences of algal plates in Wolfcampian sediments of the study area have been referred to the Family Codiaceae. These green algae display an undulating blade form and have a thin outer calcified cortex. Generally, the whole plate is recrystallized (figure 8d). With good preservation, utricles are seen to be restricted to the plate's surface and do not penetrate its inner portions (figure 8e). Generic identifications are difficult owing to replacement; however, Eugonophyllum probably accounts for a large portion of Codiaceae algae in Wolfcampian strata (Konishi and Wray, 1961). Based on thin-section studies of these sediments, it is evident that codiacean algae volumetrically contributed more to the sediment than any other type of algae in the Lower Permian. It is restricted to water depths within the photic zone, and apparently had a wider distribution than shallow water dasycladacean algae.

FIGURE 8

ALGAE FROM THE HUECO LIMESTONE

All thin-sections x 50

A) dasycladacean algae, Epimastopora, tangential section; sample no. HM 16, Hueco Canyon Formation, Hueco Mountains

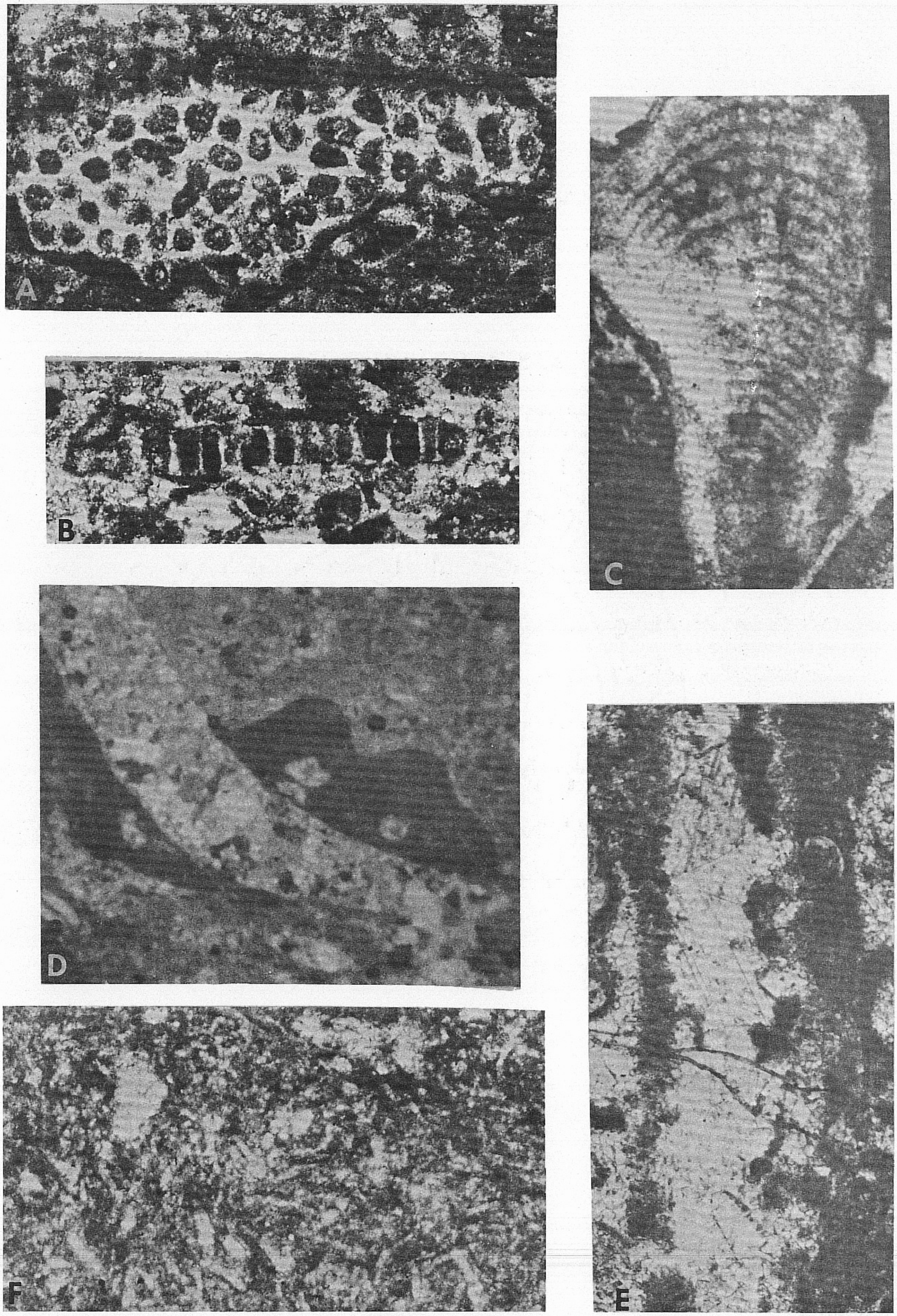
B) dasycladacean algae, Epimastopora, transverse section: sample HM 73, Hueco Canyon Formation, Hueco Mountains

C) red algae; sample no. HM 267, Alacran Mountain Formation, Hueco Mountains

D) codiacean algae (recrystallized), encrusted by Tubiphytes; sample no. FM 89, Hueco Canyon Formation, Franklin Mountains

E) codiacean algae (Eugonophyllum?), showing utricles in thin outer cortex; sample no. HM 25, Hueco Canyon Formation, Hueco Mountains

F) blue-green algae, Girvanella; sample no. SA 6, Hueco Limestone, San Andres Mountains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Numerous occurrences of less common algae were observed and include various red algae species and the blue-green? algae Girvanella. The reticulate cellular pattern, characteristic of the red algae, is easily recognized (figure 8c) in thin-section. Red algae, however, was rarely observed and is considered to be of minor importance as a binding agent in bioherms and adjacent sediments. Their scarcity corresponds with the lack of bound or ridgidly attached organisms found in the buildups of loose bioclastic mudmounds and adds further reason to believe that these structures were not wave-resistant. Girvanella (figure 8f) is a Cambrian to Cretaceous algae of unknown systematic position; it is considered by most researchers to be a blue-green Porostomata algae based on its morphological features (Johnson, 1946, 1963, and Klement and Toomey, 1967). It is rare to common in many Lower Permian sediments, but is not a significant limestone-building organism. Little is known of its environmental distribution, but it certainly must have lived in clear, well-lighted waters. Perhaps it has an encrusting and boring habitat.

Several foraminifera were routinely observed in the course of thin-section analysis. Previous experience with late Paleozoic rocks suggested recognition of the following types or species: Globivavulina, paleotexturlarids, Tetrataxis, Tuberitina, tubular foraminifera, fusulinids of the Subfamily Schwagerina, and other less advanced fusulinids of the Families Staffellinae and Boultoninae. Tubiphytes (of unknown biological affinity) is also discussed below with foraminifera.

Globivalvulina (figure 9) ranges from Pennsylvanian through Permian and is one of the most abundant genera found in Wolfcampian rocks of the study area. It is associated with normal marine waters and is not observed in restricted lagoon or nearshore clastic environments.

Certain Permian foraminifera of the Family Textularidae were combined in the informal category "paleotextularids", alluding primarily to late Paleozoic genera such as Geinitzina and Climacammina (figure 9). Paleotextularids were observed throughout Wolfcampian sections in minor abundances, usually two or three per sample when present. Slight enrichments occur in bioherms and adjacent sediments; this relationship may prove useful on the species level of identification. Since paleotextularids occur in some near-shore and bioherm environments where Globivalvulina is less abundant their tolerance to shallow water conditions may be greater, or they may have been more easily transported by wave and current action.

Tetrataxis (figure 10) is a conical, attached foraminifera that ranges from Pennsylvanian to Triassic. It frequently is attached to algal plates, algal balls, and tubular foraminiferal colonies; shell material, however, apparently was not a suitable surface for attachment. Tetrataxis is a useful paleocological indicator, as it occurs primarily in algal bioherms and secondarily in their flanking beds.

Tuberitina (figure 10) is another attached foraminifera or late Paleozoic age. Rich (1970) described Tuberitina species from the Middle Pennsylvanian and concluded that it is generally associated with the Pennsylvanian algae Dvinella and Komia in wackestones and packstones.

FIGURE 9

GLOBIVALVULINA AND PALEOTEXTULARIDS

A) Globivalvulina (x200), sample no. RM 34, Hueco Limestone; Robledo Mountains

B) Globivalvulina (x200), sample no. JM 282, Hueco Limestone, Jarilla Mountains

C) Globivalvulina (x200), sample no. SC 50, Hueco Limestone, Sacramento Mountains

D) Globivalvulina (x200), sample no. SC 49, Hueco Limestone, Sacramento Mountain

E) paleotextularid (x50), sample no. JM 235, Hueco Limestone, Jarilla Mountains

F) paleotextularid, Climacammina (x50), sample no. Hm 50, Hueco Canyon Formation, Hueco Mountains

G) paleotextularid (x50), sample no. HM 225, Cerro Alto Limestone Hueco Mountains

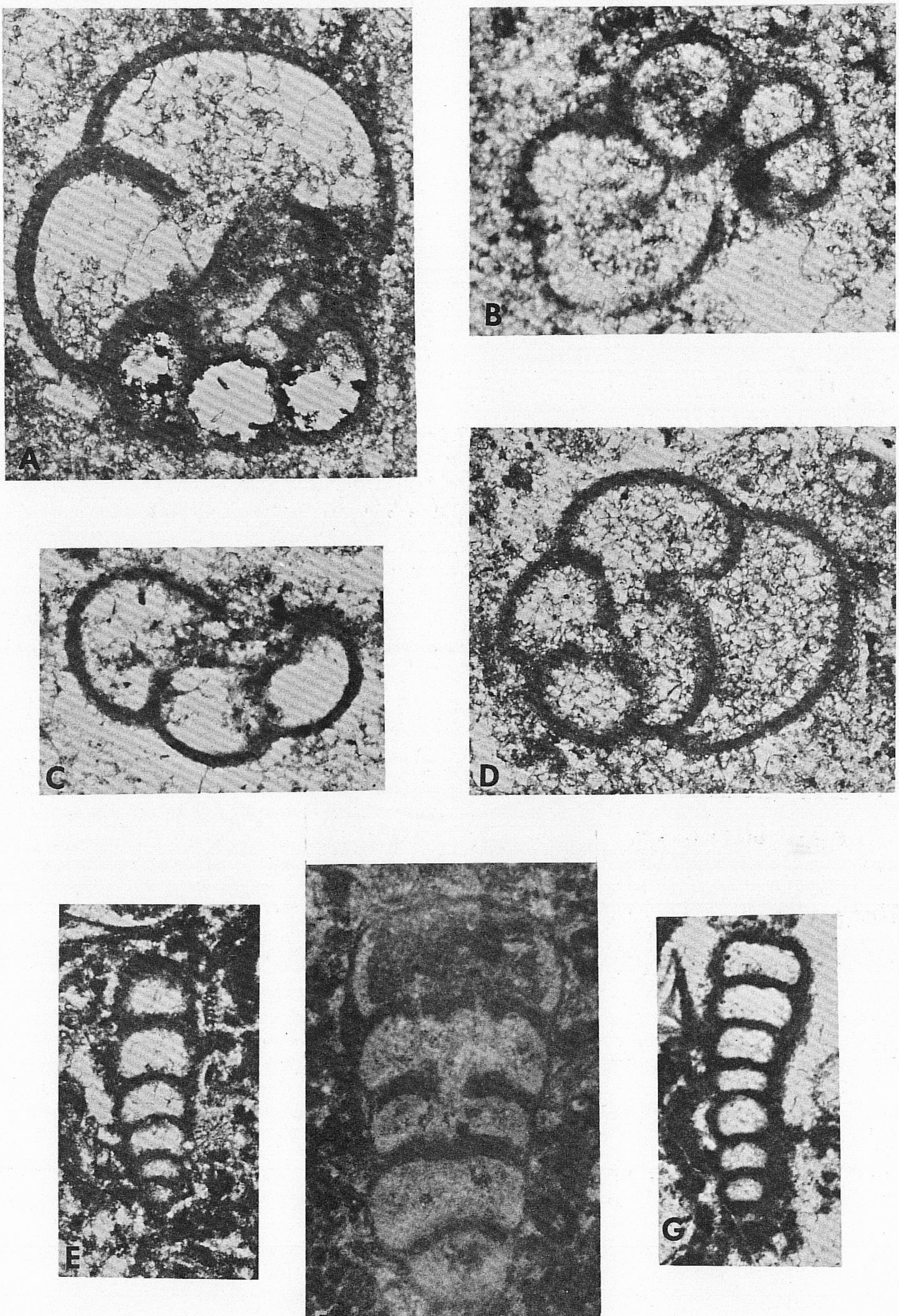
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FIGURE 10

TETRATAXIS AND TUBERITINA

A) Tetrataxis (x50), sample no. RH 17, Hueco Limestone, Robledo Mountains

B) Tetrataxis (x50), sample no. HM 70, Hueco Canyon Formation, Hueco Mountains

C) Tetrataxis (x50), sample no. JM 200, Hueco Limestone, Jarilla Mountains

D) Tetrataxis (x50), sample no. SA 2, Hueco Limestone, San Andres Mountains

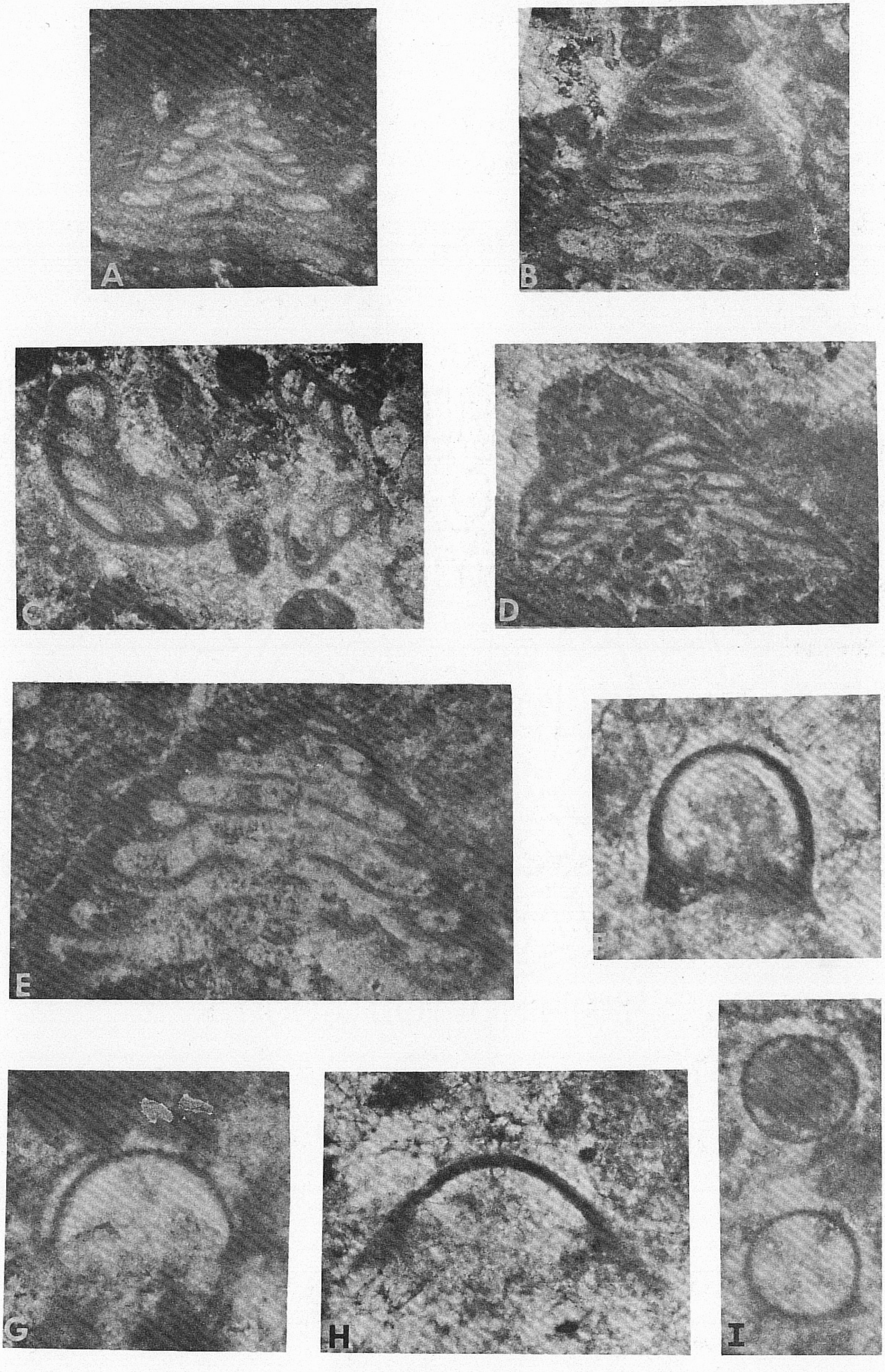
E) Tetrataxis (x50), sample no. HM 301, Alacran Mountain Formation, Hueco Mountains

F) Tuberitina (x200), sample no. SA 5, Hueco Limestone, San Andres Mountains

G) Tuberitina (x200), sample no. HM 61, Hueco Canyon Formation, Hueco Mountains

H) Tuberitina (x200), sample no. SA 5, Hueco Limestone, San Andres Mountains

I) Tuberitina (x200), sample no. FM 130, Hueco Canyon Formation, Franklin Mountains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He states that this indicates "relatively shallow to moderate water depths, of low to moderate energy, and of low terrigenous influx". Studies of this report generally substantiate these environmental conditions and show a common association of Tubertina with dasycladacean and codiacean algae. Quite often, however, Tubertina is also found in normal marine deposits with no algae. This foraminifera is conspicuiously absent in restricted lagoons and must have required conditions of normal marine salinity and oxygenation.

Tubiphytes has unknown biological affinities, having been considered by various workers as an algae, a foraminifera, and a hydrozoa. Probably, the latter is more correct, and discussion here is more conveniently than scientifically placed with the foraminifera. Rigby (1958) found Tubiphytes (or Nigriporella as he described it) throughout the western United States in Mississippian through Permian strata. It is a bluntly rounded, lobose to tabular encrusting organism (figure 11), that contributes coarse sand-size particles to sediments. It is characterized by open zooidal tubes that are often filled with carbonate cement. The bulk of the organism, the coenosteum, is porous and hence opaque brown in thin-section, but white in polished slabs. Commonly encrusted surfaces include algal plates, shell fragments, and other Tubiphytes; usually, unattached specimens are most common. Malek-Aslani (1970) described Wolfcampian Tubiphytes reefs on the northeastern edge of the Delaware Basin. He believed the structures were ecological reefs (Dunham, 1970) and reports 30-40% Tubiphytes in the reef-wall facies.

FIGURE 11

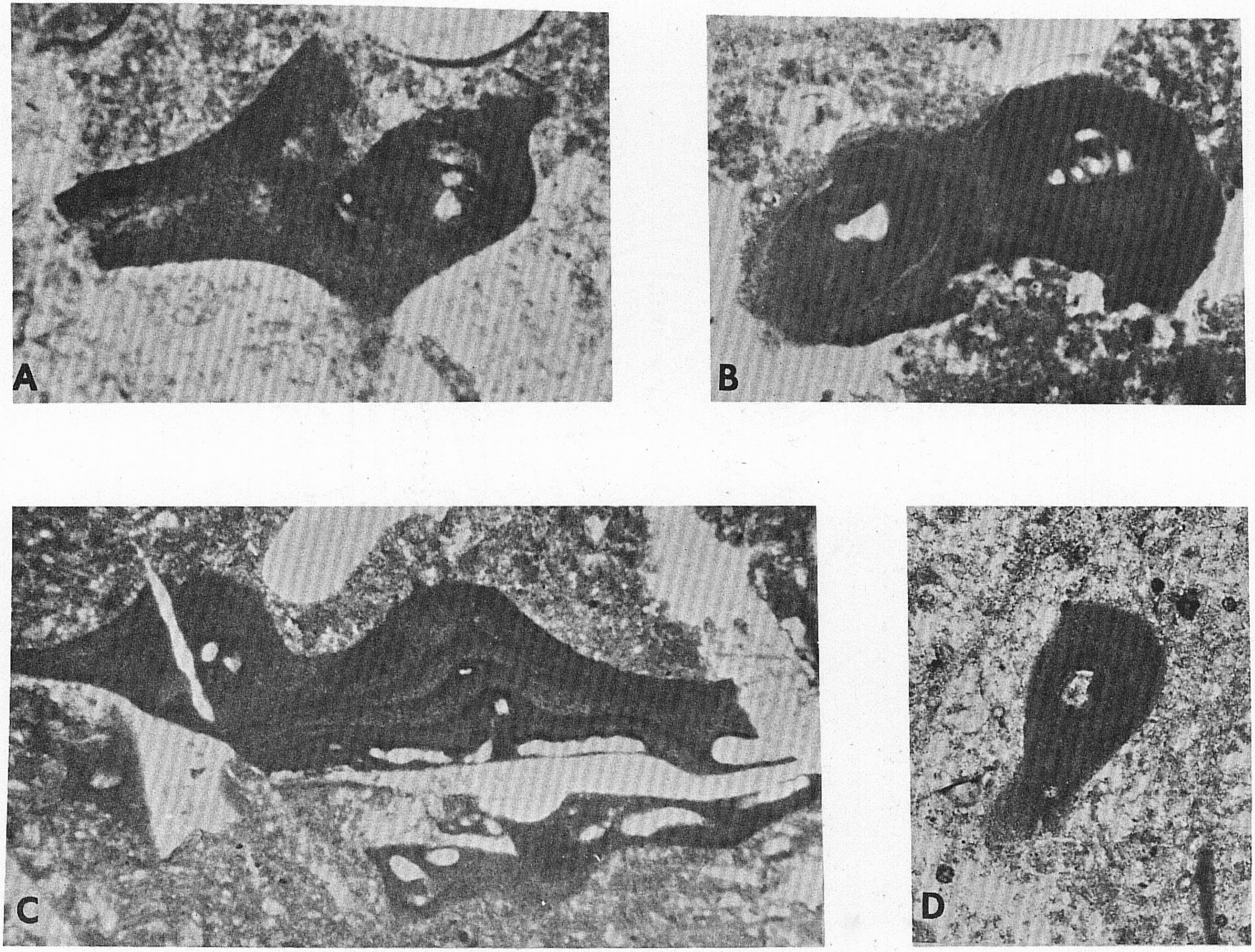
TUBIPHYTES

A) Tubiphytes (x40), sample no. HM 294, Alacran Mountain Formation, Hueco Mountains

B) Tubiphytes (x40), sample no. HM 225, Cerro Alto Limestone Hueco Mountains

C) Tubiphytes (x40), sample no. RH 22, Hueco Limestone, Robledo Mountains

D) Tubiphytes (x40), sample no. FM 191, Alacran Mountain Formation Franklin Mountains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Somewhat similar colonies of Tubiphytes have been observed in this study, but they are not so abundant. Possibly this is due to the common association of Tubiphytes with algal plates which dilutes their overall abundance. Generally, Tubiphytes is an excellent indicator to aid in the recognition of platform-edge bioherms or patch reef complexes on shallow shelves.

The informal category of tubular foraminifera was designed to encompass all tubular encrusting foraminifera of the Families Tolypammininae and Cornuspirinae (Henbest, 1963). Growth forms are irregular, complex interweavings of tubes and suggest highly variable appearances within single species. Although the wall structure of each of the two families represented is different, replacement of this structure is common and homeomorphic growth forms found in each family make generic identification difficult. Tubular foraminifera show no preference regarding the surface they encrust; Henbest (1963) includes shell material, seaweed, brachiopod and echinoid spines, and algal plates as encrusted surfaces. In sediments, tubular foraminifera occur predominantly as broken fragments, rarely showing the organism that was encrusted (figure 12). Their environmental distribution is difficult to assess: they occur in abundance with Tubiphytes in bioherms, also occur in normal marine sequence, and often dominate lagoonal environments. They show a tolerance for clastic influx as well as the variations in salinity and oxygenation levels of lagoons. Locally, their erosional debris forms complete masses of tubules several feet thick (figures 15d and 22c).

FIGURE 12

TUBULAR FORAMINIFERA

A) tubular foraminifera (x200), sample no. FM 164, Cerro Alto Limestone, Franklin Mountains

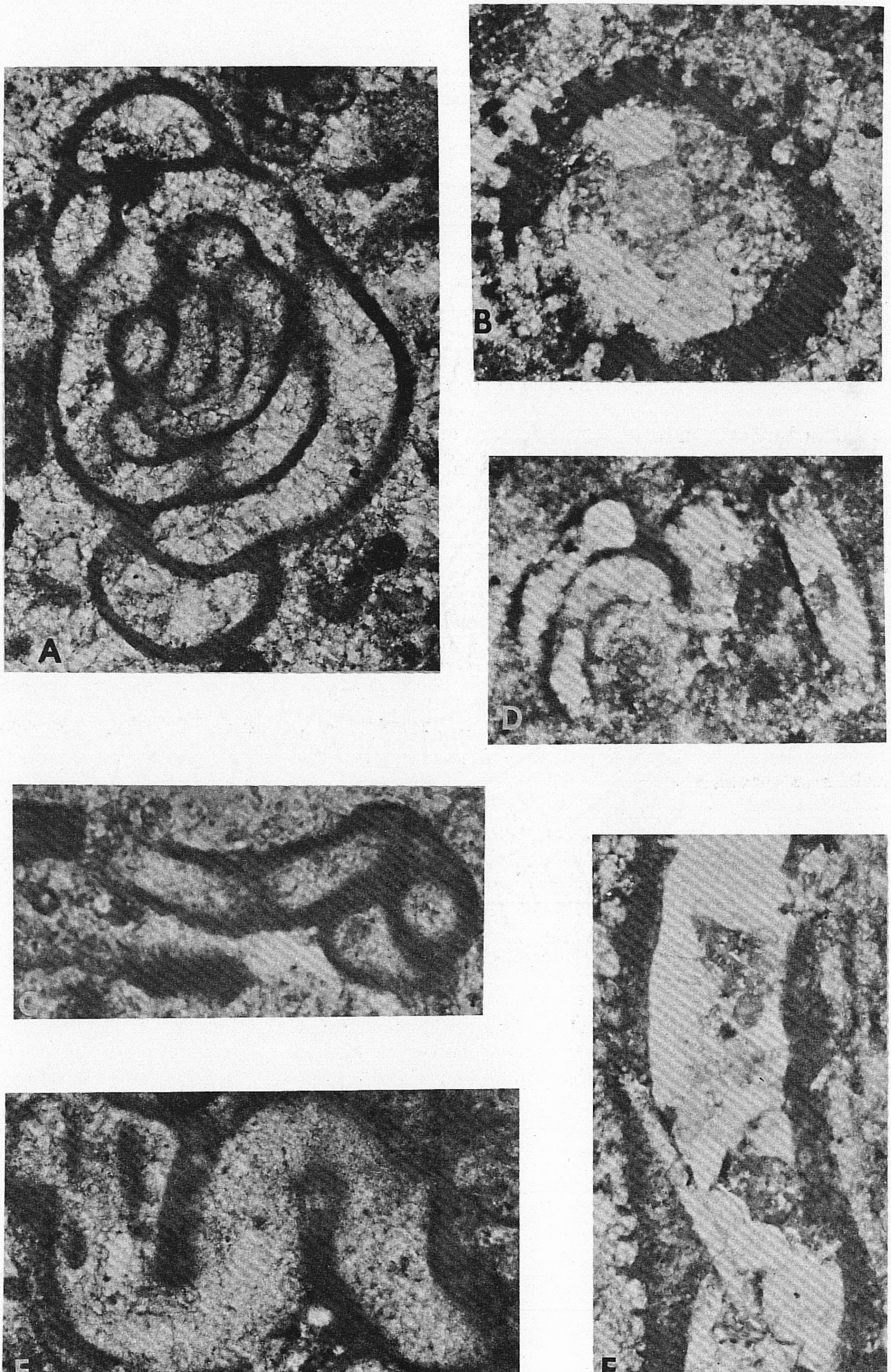
B) tubular foraminifera (x200), sample no. SC 49, Hueco Limestone, Sacramento Mountains

C) tubular foraminifera (x200), broken fragments as commonly observed in Wolfcampian sediments; sample no. FM 145, Cerro Alto Limestone, Franklin Mountains

D) tubular foraminifera (x200), sample no. FM 145, Cerro Alto Limestone, Franklin Mountains

E) tubular foraminifera (x200), sample no. FM 164, Cerro Alto Limestone, Franklin Mountains

F) tubular foraminifera (x200), sample no. SC 49, Hueco Limestone, Sacramento Mountains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Fusulinids have been previously discussed with regard to generic characteristics and biostratigraphic zonation. Merely as particle types, Wolfcampian fusulinids (figure 13) can be divided into two groups: 1) the larger, commonly fluted fusulinids with thick, schwagerinid wall structure that belong to the Subfamily Schwagerininae, and 2) the small, thin-walled, apparently primitive fusulinids. Identification of genera in this latter group is difficult and usually not worth the effort, since many are long-ranging, less advanced organisms which at present have minor biostratigraphic significance.

Certain genera of these smaller fusulinids are completely replaced by calcite (figure 13) and suggest an original aragonite composition. Certainly, some of these "primitive" fusulinids were more robust and hardy than the Schwagerininae, as they have long geologic ranges and are found in stress environments that excluded larger fusulines.

SEDIMENTARY FACIES

Recognition of rock types is based on thin-section and polished-slab analysis of approximately 2,000 samples. Textural terms describing carbonates are from Dunham (1962) with the following modification: the percentage of grains appears after the textural term. For example, P-50 refers to a packstone with 50% grains. Clastic terminology is based on Wentworth's scale of particle sizes.

Seven facies are distinguished and are recognized by the presence of certain faunal and textural characteristics. In the following list of facies, certain rock types such as tubular foraminiferal packstones and fusulinid packstones are least definitive, as they occur in more

FIGURE 13

MISCELLANEOUS FUSULINIDS

A) Schubertella, axial section (x50), sample no. HM 205, Cerro Alto Limestone, Hueco Mountains

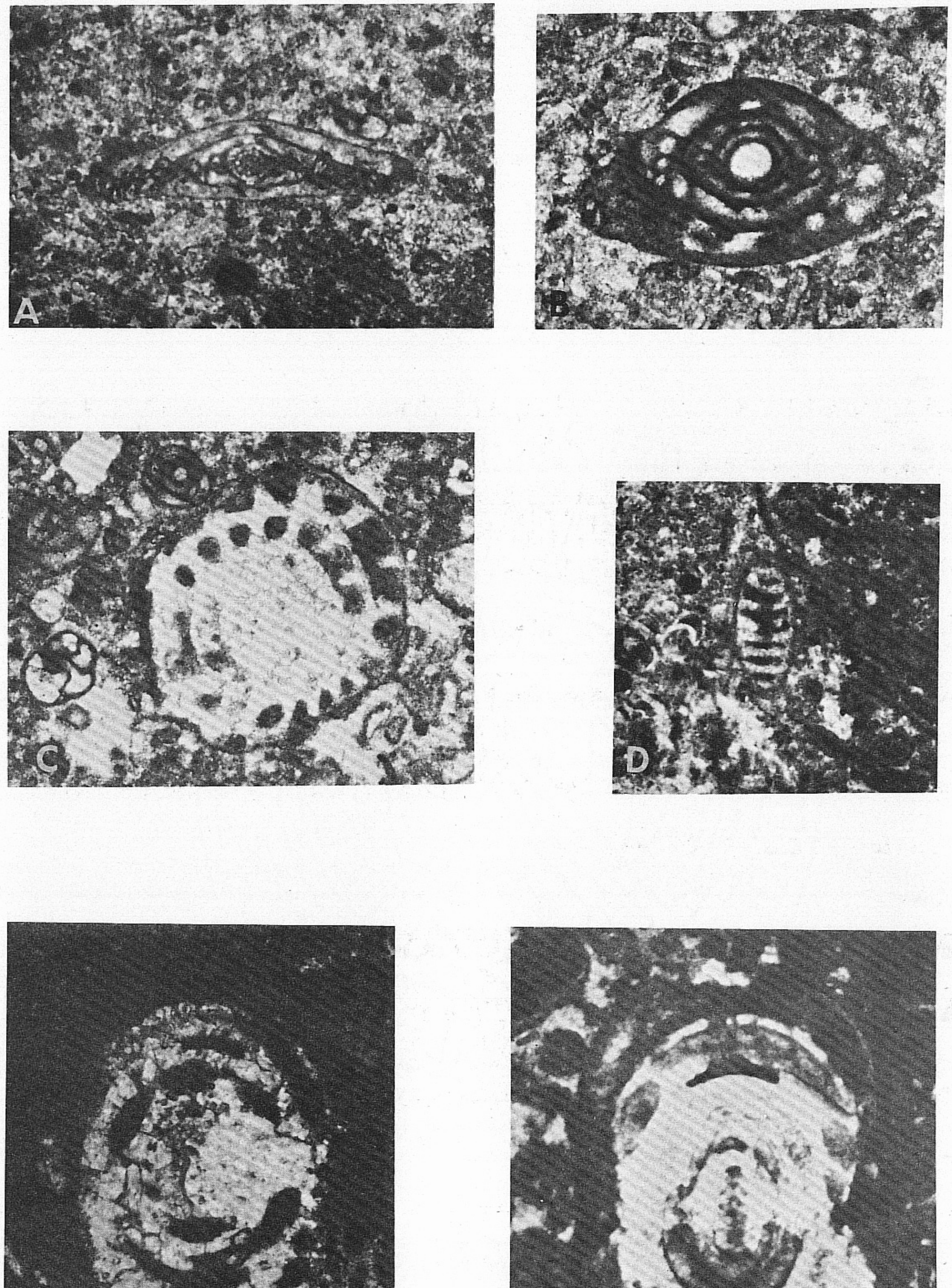
B) Schubertella?, axial section (x50), sample no. HM 71, Hueco Canyon Formation, Hueco Mountains

C) recrystallized Staffella?, sagittal section (x50), commonly found in wornstone of the shoal-water facies; sample no. HM 72, Hueco Canyon Formation, Hueco Mountains

D) Staffella?, tangential section (x50), sample no. HM 34, Hueco Canyon Formation, Hueco Mountains

E) Staffella, nearly an axial section (x50), sample no. HM 72, Hueco Canyon Formation, Hueco Mountains

F) Staffella, axial section (x50), sample no. HM 150, Cerro Alto Limestone, Hueco Mountains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than one environment. Figures below refer to typical examples of the described facies.

1) shoal-water facies (figure 14)
   - a) oolitic grainstones or packstones
   - b) wornstones (rounded-particle grainstones and packstones)

2) shelf facies (figures 15 and 16)
   - a) normal marine wackestones and packstones
   - b) tubular foraminiferal packstones
   - c) fusulinid packstones
   - d) crinoidal packstones

3) shallow shelf facies (figure 17)
   - a) algal-foraminiferal packstones and wackestones
   - b) normal marine wackestones and packstones
   - c) fine gray to brown calcareous siltstones and shales

4) bioherm and biostrome (figure 18, 19, and 20)
   - a) lime mudstone (commonly brecciated)
   - b) algal wackestones and packstones (platy algal beds)
   - c) *Tubiphytes* packstones
   - d) some boundstones
   - e) tubular foraminiferal packstones

5) lagoonal facies (figure 21 and 22)
   - a) ostracod-molluscan mudstones, wackestones, and packstones (commonly pelleted)
   - b) gray shales and siltstones (commonly cross-bedded)
   - c) tubular foraminiferal packstones
   - d) crinoid-ostracod-molluscan wackestones and packstones

6) <u>slope facies (figure 23 a, b, c)</u>

a) fossiliferous, detrital breccias, wackestones, and packstones

b) fusulinid packstones (with current orientation)

c) unfossiliferous, silty, lime mudstones, siltstones, and dark shales

7) <u>nearshore-terrestrial facies (figure 24)</u>

a) limestone pebble conglomerates (chert pebbles common)

b) silty unfossiliferous lime mudstones

c) cross-bedded siltstones and red shales

Shoal-water facies reflect high energy environments with relatively mud-free sediments. Oolitic grainstones and packstones are the best indicators of this facies and can often be recognized in the field. Thinly coated bioclasts and lithoclasts are commonly admixed in oolitic sediments, indicating erosion and reworking by shoaling waters. More common, however, are thick sequences of packstone and grainstone, rich in rounded bioclastic fragments. Foraminifera make up the bulk of these rocks; but dasycladacean algae, crinoids, brachiopods, and mollusca are also common constituents. The descriptive term "wornstone" seems appropriate in referring to such textures.

Shelf facies contain a diverse suite of rock textures and faunal compositions generally characterized by micritic carbonates with normal marine organisms. A great variety of normal marine wackestones and packstones account for the majority of rock types observed in this study. Certain distinctive microfacies are recognized and appear to be local enrichments of a particular bioclastic type. Fusulinid packstones, crinoidal lenses, concentrations of tubular foraminiferal fragments are common examples. Shelf environments are extremely variable and are difficult to delineate in tectonically unstable areas. Often the problem is made easier by first recognizing near-shore, slope, and basinal facies: the rest are generally considered shelf deposits.

Shallow water environments of the shelf are indicated by the presence of algal plate-foraminiferal wackestones and packstones. Crinoids, brachiopods, fusulinids, and other normal marine biota also occur in these sediments and reflect transitional environments between shelf, bioherm and shoaling-water conditions. Such limestones with a highly diverse fauna are commonly termed "normal marine". The shallow shelf facies is characterized by normal marine limestones that contain abundant green algae and minor amounts of Tubiphytes. Tabular, medium-bedded strata of this facies contain many broken, detrital bioclasts and by this and a lower content of algae and Tubiphytes can be distinguished from biostromes.

Wolfcampian bioherms of lime mudstone and algal plate wackestone usually outcrop as massive to thick-bedded lenses. Sediments of the bioherm core commonly consist of lime mudstones and algal plate wackestones. Angular fragments of brecciated mudstone show small displacements of broken algal plates, indicating in situ brecciation. Thin, irregular cracks in some mud fragments suggest desiccation due to subaerial exposure. Rare accumulations of boundstone fabric (coral or bryozoan) have been observed, but the high mud content of these bioherms indicates structures generally not resistant to wave action. Samples from stratigraphic sections of this study are solely from isolated vertical successions of strata. As a result, biohermal flanking beds were encountered more often than interior biohermal beds and these deposits were commonly recognized as biostromes, the chief difference being one of tabular bedding versus mound development. Flank deposits consist of Tubiphytes and algal packstones and wackestones. Some tubular foraminiferal packstones, similar to those described by Wilson (1967) and Otte (1954), also occur as flanking sediments. This indicates the existence of capping biohermal beds composed almost entirely of tubular foraminifera that reflected major changes in biotic composition due to regressing seas.

Stress conditions of the lagoonal facies are indicated by abundant numbers of organisms of a low faunal diversity. In restricted lagoonal environments, ostracods, bivalves, gastropods, and tubular foraminifera dominate; there is a conspicuious absence of crinoids, brachiopods, fusulinids, and green algae. The addition of crinoids and a few Globivalvulina to this facies is indicative of lagoons with open circulation. Mudstones and wackestones are the most common rock fabrics of lagoonal facies, although some packstones are found. These limestones commonly contain 1-5% quartz silt similar to that found in interbeds of gray shales and cross-bedded siltstones. Locally, thin beds of tubular foraminiferal packstones occur with minor amounts of ostracods and bivalves. Preliminary investigation suggests that these tubular foraminifera may belong to a special genus or family and that they differ from tubular foraminifera common in other environments.

Slope facies are best characterized by thick fossiliferous breccia beds, sometimes with blocks up to 6 feet in diameter. Clasts of shelf deposits in these breccias are angular and commonly contain crushed bioclasts. Thick beds of oriented fusulinids in a packstone texture and flame structures in thin clastic units attest to flowage down the slope. Midst beds of breccias and "megabreccias" occur bioclastic packstones and wackestones, so jumbled that distinguishing matrix from clasts is difficult. Interbedded with beds of the slope facies are tongues of dark basinal shales and thick bioherms prograding basinward from the shelf edge.

Transitional facies of nearshore to terrestrial environments consist of red and gray shales, siltstones, and pebble conglomerates interbedded with relatively unfossiliferous silty limestones (M-0 to W-25). Sedimentary structures indicative of these environments include oscillation ripples, cross-bedding, crenulated laminations, and birdseye structures. Occurrences of vertebrate remains, fossil wood, and tetrapod tracks have been reported from terrestrial red-bed sequences, but were not observed in stratigraphic sampling for this report.

FIGURE 14

SHOAL-WATER FACIES

Thin-sections oriented up, with millimeter scale shown at right.

A) oolitic grainstone, sample no. SA 51, Hueco Limestone, San Andres Mountains

B) oolitic grainstone with coated lithoclasts, sample no. SA 19, Hueco Limestone, San Andres Mountains

C) foraminiferal wornstone, rich in recrystallized staffellids, other fusulinids, and tubular foraminifera; sample no. HM 63, Hueco Canyon Formation, Hueco Mountains

D) algal-foraminiferal wornstone, showing broken dasycladacean algal plates and worn, rounded foraminifera; sample no. HM 50, Hueco Canyon Formation, Hueco Mountains

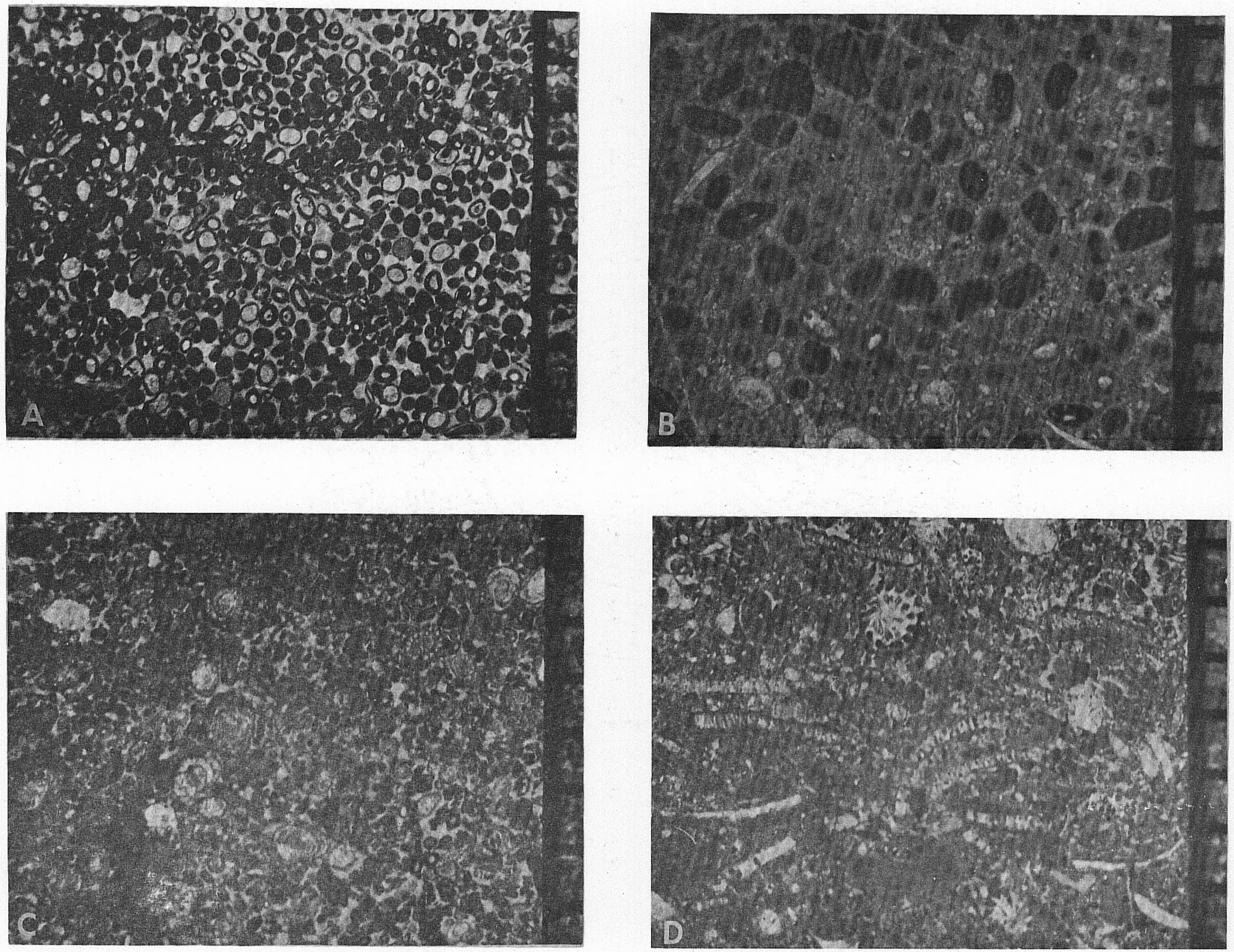
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FIGURE 15

SHELF FACIES

Thin-sections oriented up, with millimeter scale shown at right.

A) normal marine wackestone with crinoids, molluscs, and ostracods in a clotted micrite matrix; sample no. JM 295, Hueco Limestone, Jarilla Mountains

B) normal marine wackestone with brachiopods, gastropods, crinoids, and shell material; sample no SA 80, Hueco Limestone, San Andres Mountains

C) fusulinid packstone (Pseudoschwagerina), sample no. JM 233, Hueco Limestone, Jarilla Mountains

D) tubular foraminiferal grainstone, sample no. FM 164, Cerro Alto Limestone, Franklin Mountains

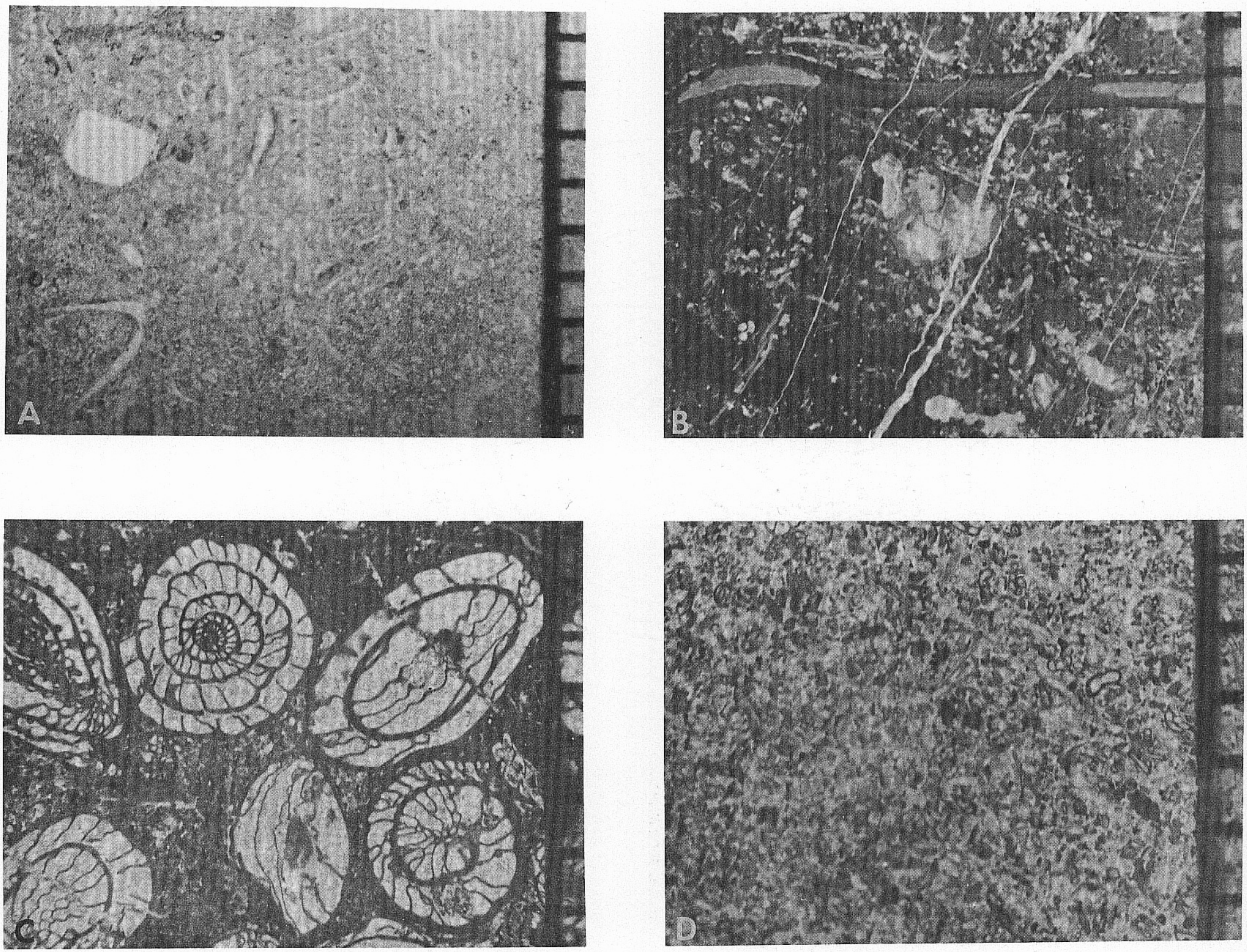
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FIGURE 16

SHELF FACIES

Thin-sections oriented up, with millimeter scale shown at right.

A) normal marine packstone rich in crinoids and brachiopods, sample no. SA 219, Hueco Limestone, San Andres Mountains

B) normal marine packstone with fusulinids, trilobites, and ostracods; sample no. HM 245, Cerro Alto Limestone, Hueco Mountains

C) normal marine packstone with diverse fauna of crinoids, foraminifera, molluscs, and ostracods; sample no. RK 5, Hueco Limestone, Robledo Mountains

D) polished slab with abundant brachiopods, sample no. HM 253, Cerro Alto Limestone, Hueco Mountains

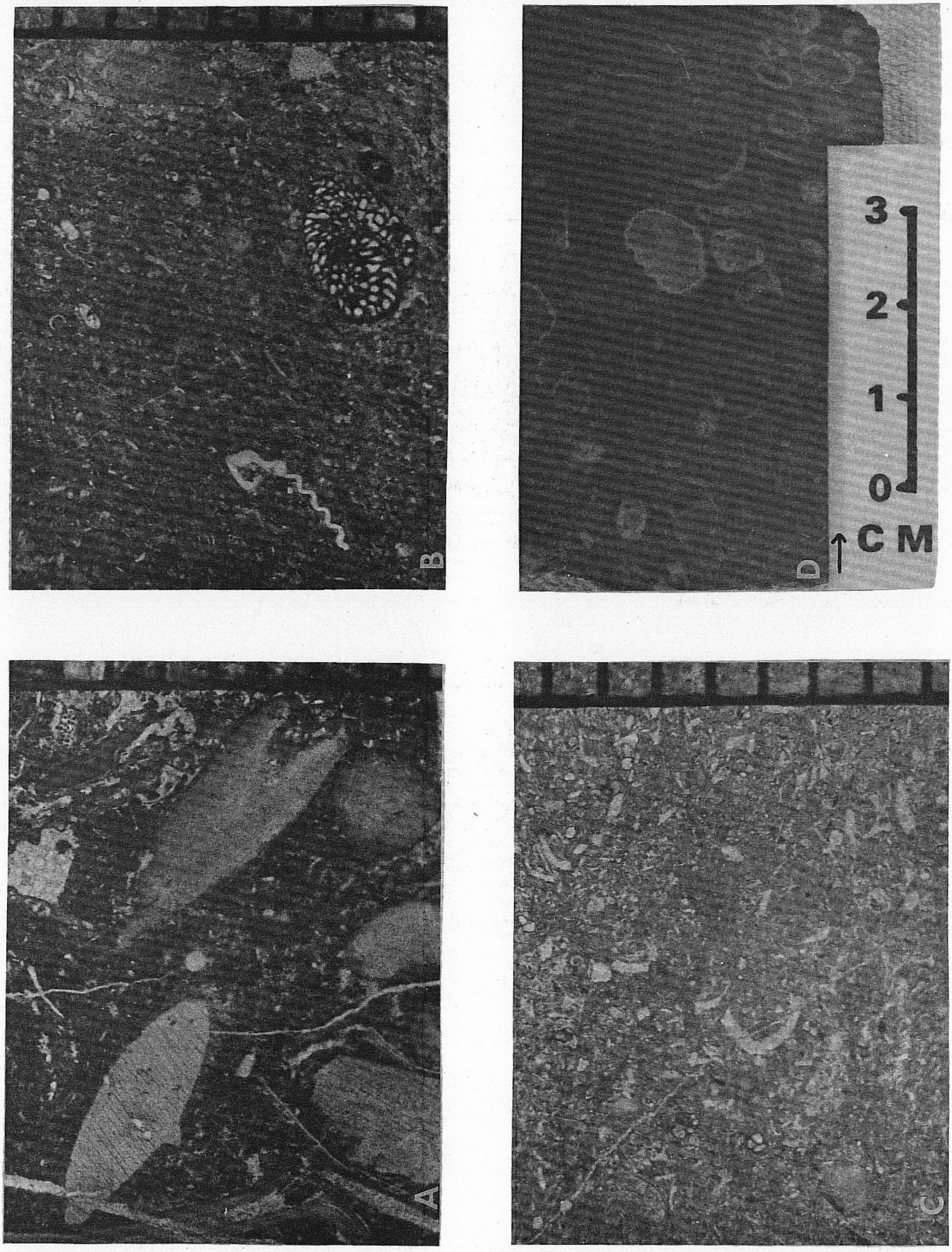

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FIGURE 17

SHALLOW SHELF FACIES

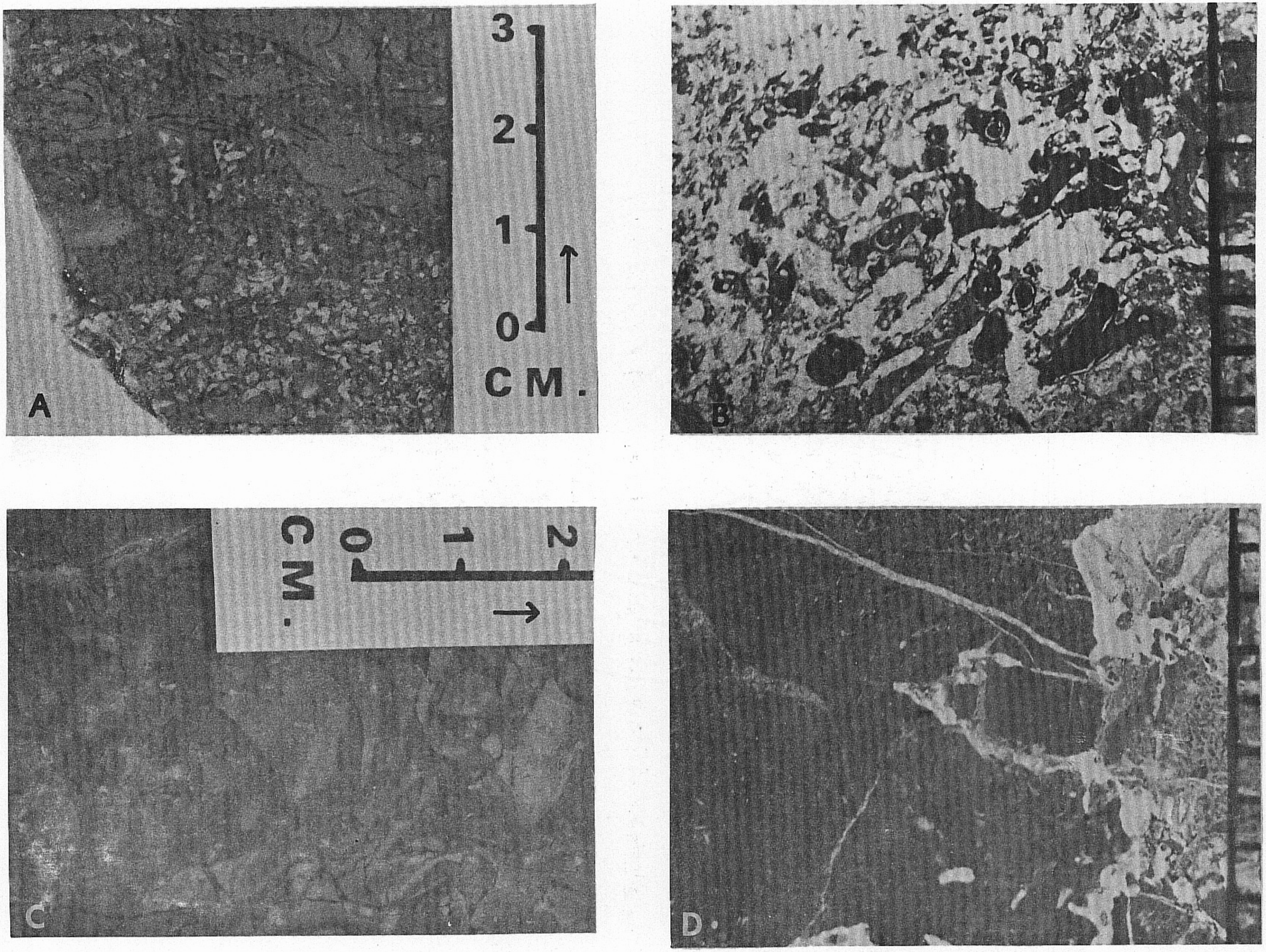
Thin-sections oriented up, with millimeter scale shown at right.

A) Tubiphytes-algal packstone (with dasycladacean algae), sample no. HM 299, Alacran Mountain Formation, Hueco Mountains

B) Tubiphytes-algal wackestone,(with dasycladacean algae), sample no. FM 207, Alacran Mountain Formation, Franklin Mountains

C) algal-foraminiferal packstone (with dasycladacean algae), sample no. FM 166, Cerro Alto Limestone, Franklin Mountains

D) calcareous siltstone, sample no. FM 176, Cerro Alto Formation, Franklin Mountains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D.

FIGURE 18

BIOHERM FACIES

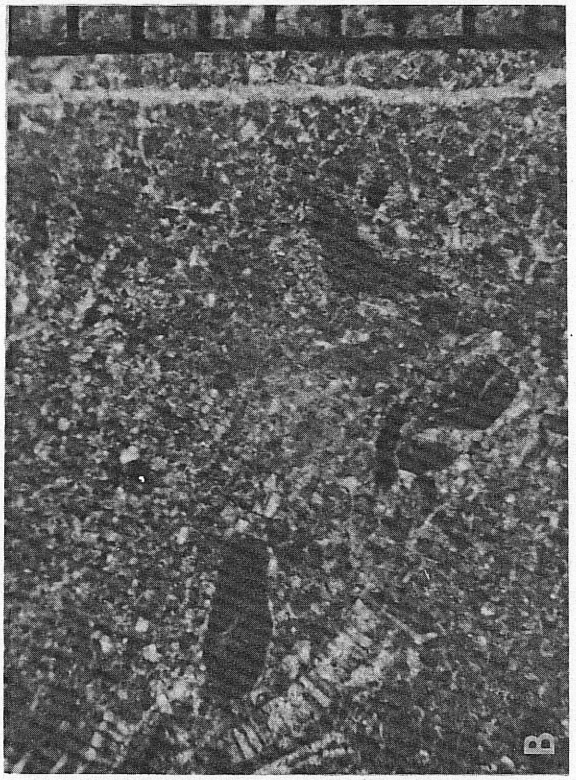
A & C oriented by arrows; B & D oriented in up position with millimeter scale shown at right.

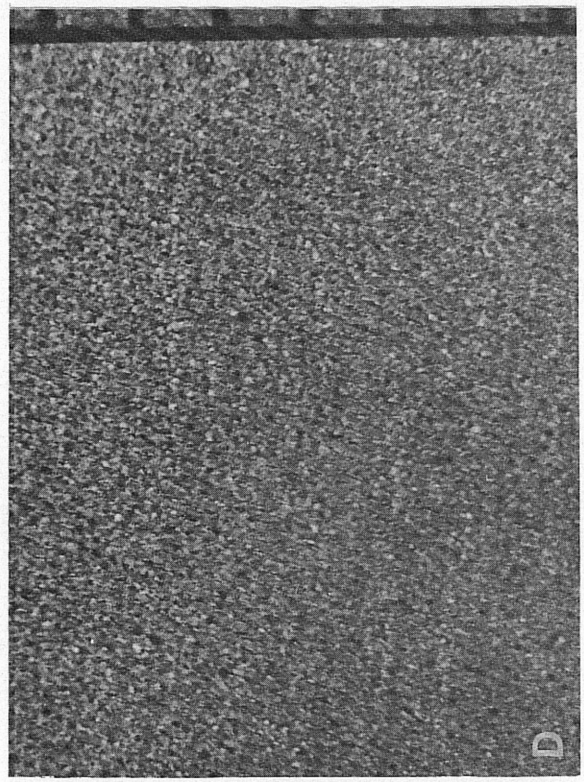
A) algal plate-Tubiphytes packstone (polished slab); sample no. RH 17, Hueco Limestone, Robledo Mountains

B) Tubiphytes packstone, thin-section of lower portion of previous sample (no. RH 17), Hueco Limestone, Robledo Mountains

C) brecciated lime mudstone, (polished slab) sample no. FM 27, Hueco Canyon Formation, Franklin Mountains

D) brecciated lime mudstone, thin-section of previous sample (no. FM 27), Hueco Canyon Formation, Franklin Mountains; fine cracks in breccia fragments are possibly due to exposure of bioherm crest.


B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A

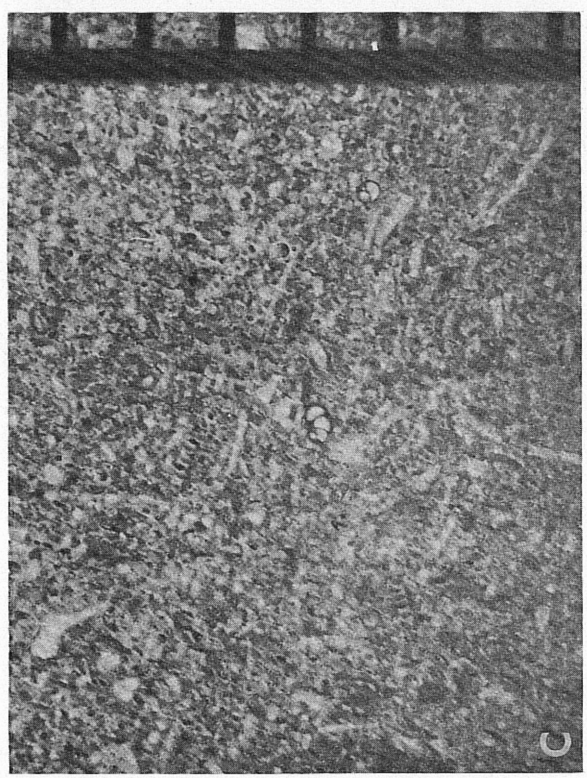

C

FIGURE 19

BIOHERM FACIES

All samples oriented in up direction.

A) brecciated lime mudstone with encrusting algal (?) layers (polished slab), sample no. HM 265, Alacran Mountain Formation, Hueco Mountains

B) brecciated lime mudstone, millimeter scale shown at left; displacements along fractures are possibly due to exposure of bioherm; thin-section of previous sample (no. HM 265), Alacran Mountain Formation, Hueco Mountains

C) lime mudstone with abundant spicules, thin-section with millimeter scale shown at right; sample no. HM 281, Alacran Mountain Formation, Hueco Mountains

D) bryozoa boundstone with transverse sections through bryozoan fronds, thin-section with millimeter scale shown at right, sample no. FM 81, Hueco Canyon Formation, Franklin Mountains

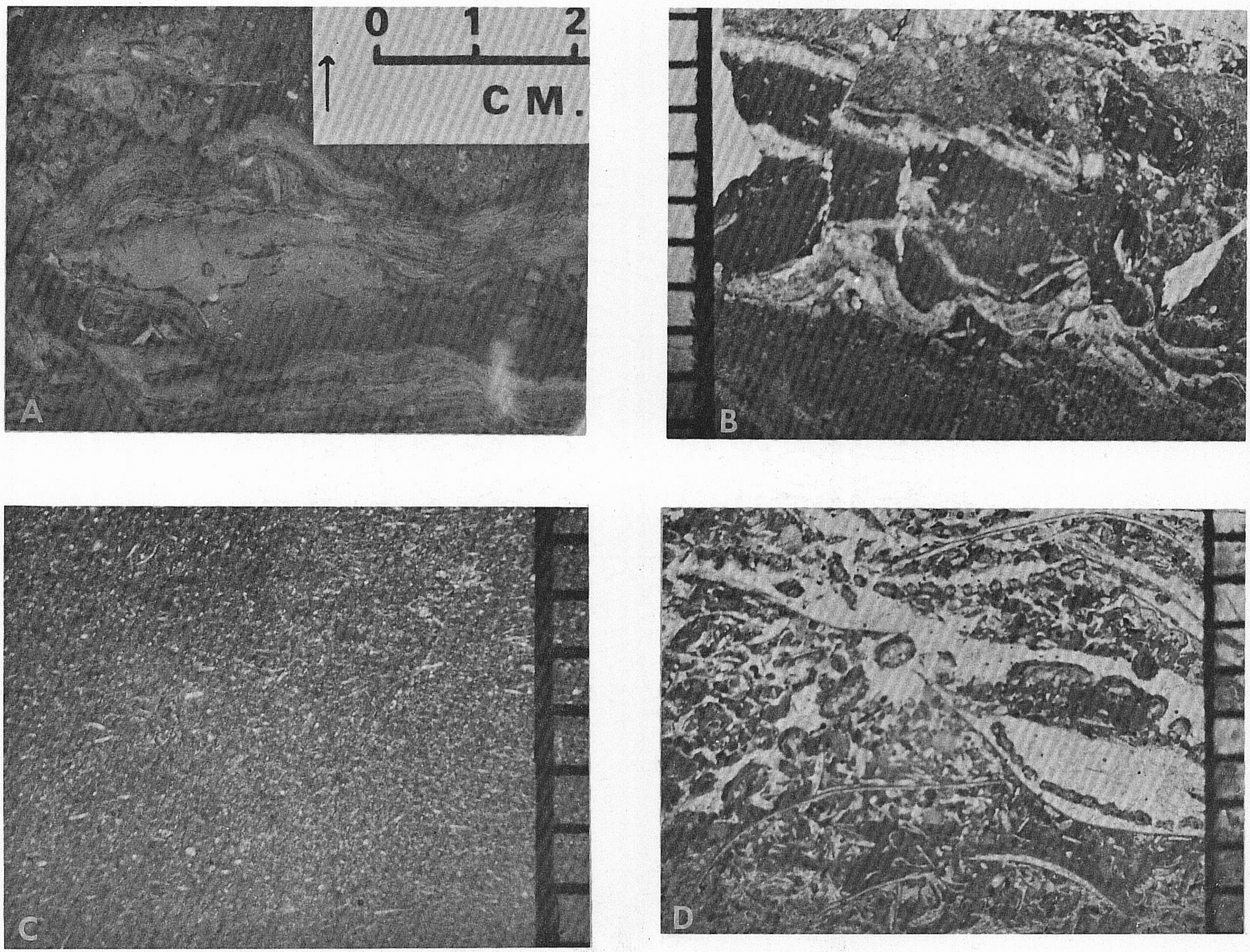

0 1 2
CM.
A
B
C
D

FIGURE 20

BIOHERM FACIES

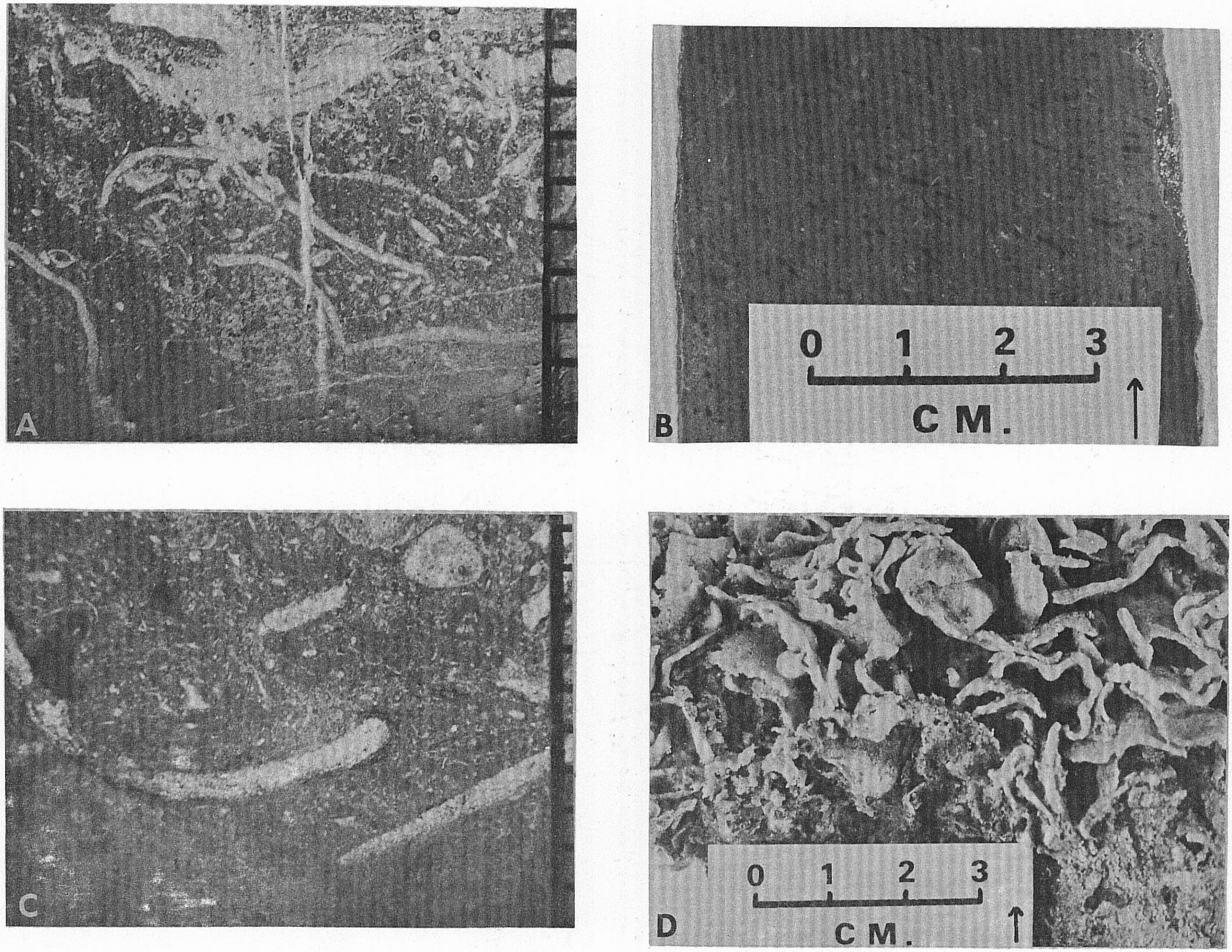
All samples oriented in up direction with millimeter scale shown at right in A and C.

A) algal plate wackestone, thin-section of sample no. FM 183, Alacran Mountain Formation, Franklin Mountains

B) algal plate wackestone (polished slab), sample no. HM 219, Cerro Alto Limestone, Hueco Mountains; broken algal plates indicate flanking beds.

C) algal plate-Tubiphytes wackestone, thin-section of sample no. HM 220, Cerro Alto Limestone, Hueco Mountains

D) silicified algal plates, etched from hand sample of algal plate packstone, Alacran Mountain Formation, Franklin Mountains



A
B
0 1 2 3
CM.
C
D
0 1 2 3
CM.

FIGURE 21

LAGOONAL FACIES

Thin-sections oriented up, with millimeter scale shown at right.

A) unfossiliferous lime mudstone, sample no. LS 12, Colina Limestone, Big Hatchet Mountains

B) ostracod mudstone, sample no. SC 11, Hueco Limestone, Sacramento Mountains

C) ostracod-molluscan packstone, sample no. SC 41, Hueco Limestone, Sacramento Mountains

D) ostracod packstone, sample no. SC 39, Hueco Limestone, Sacramento Mountains

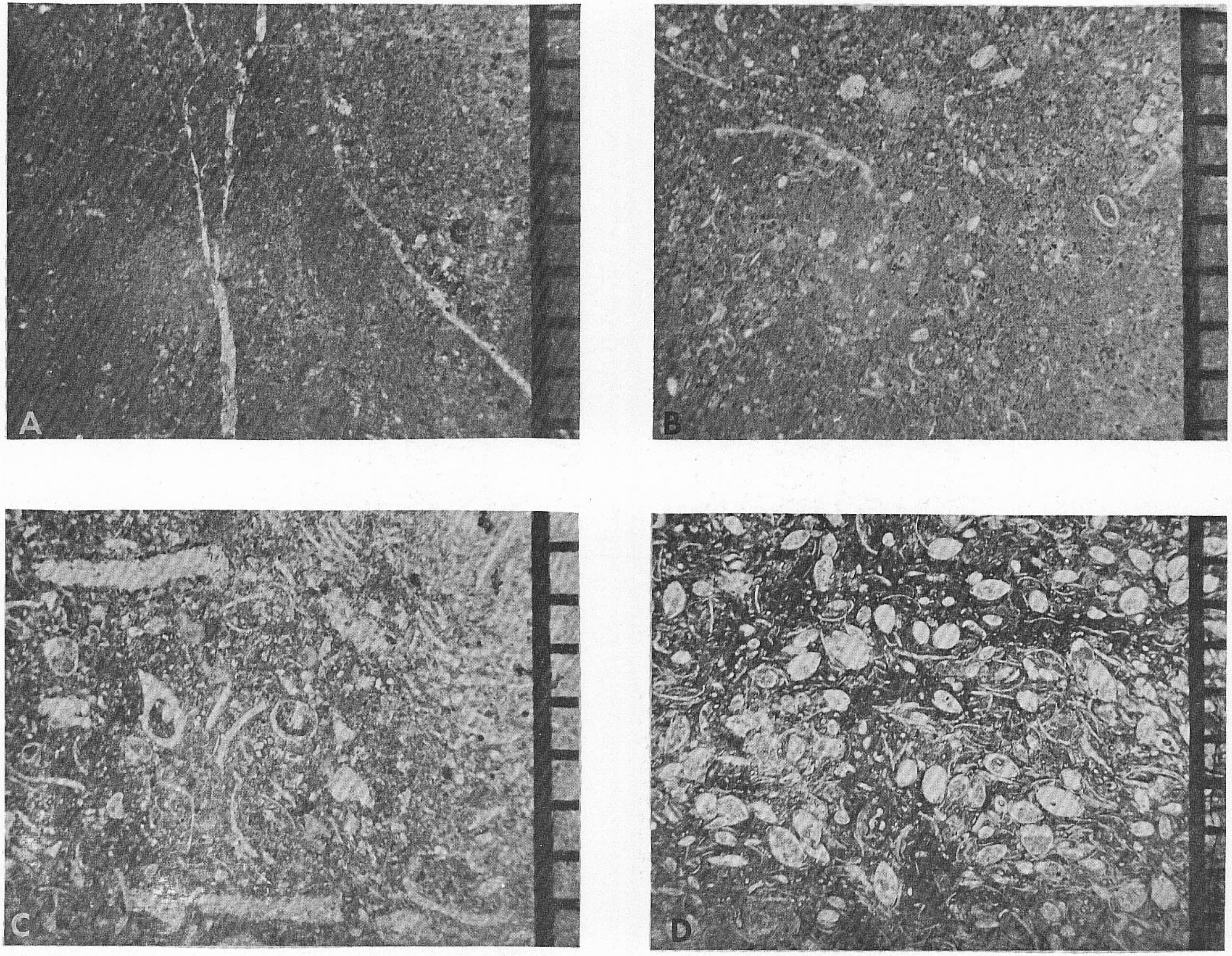

A
B
C
D

FIGURE 22

LAGOONAL FACIES

Thin-sections oriented up with millimeter scale shown at right.

A) ostracod-molluscan packstone, sample no. SC 37, Hueco Limestone Sacramento Mountains

B) cross-bedded siltstone, sample no. SC 18, Hueco Limestone, Sacramento Mountains

C) tubular foraminiferal packstone, sample no. SC 29, Hueco Limestone Sacramento Mountains

D) open lagoonal crinoid-ostracod-molluscan wackestone, sample no. SC 55, Hueco Limestone, Sacramento Mountains

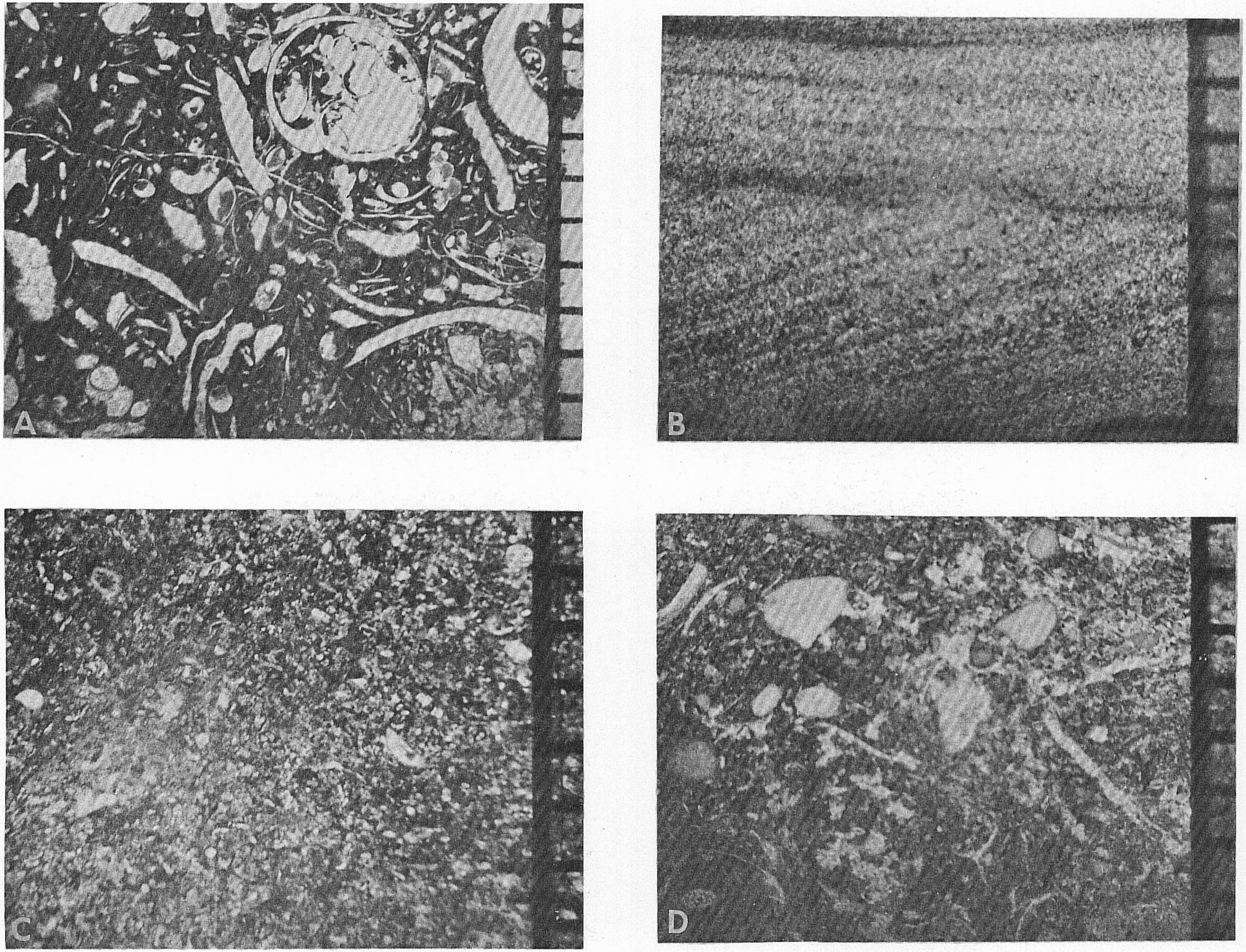

A
B
C
D

FIGURE 23

SLOPE FACIES

Thin-sections oriented up with millimeter scale shown at right.

A) limestone breccia, sample no. BS 39, Horquilla Limestone, Big Hatchet Mountains

B) fusulinid packstone with crushed fusulinids, sample no. BS 88, Horquilla Limestone, Big Hatchet Mountains

C) evenly lamminated siltstone, representing upslope extensions of basinal tongues, sample no. BS 107, Horquilla Limestone, Big Hatchet Mountains

D) nearshore-terrestrial facies: hand sample of oscillation ripples with 3 cm. wavelength, sample no. SA 256, Hueco Limestone, San Andres Mountains

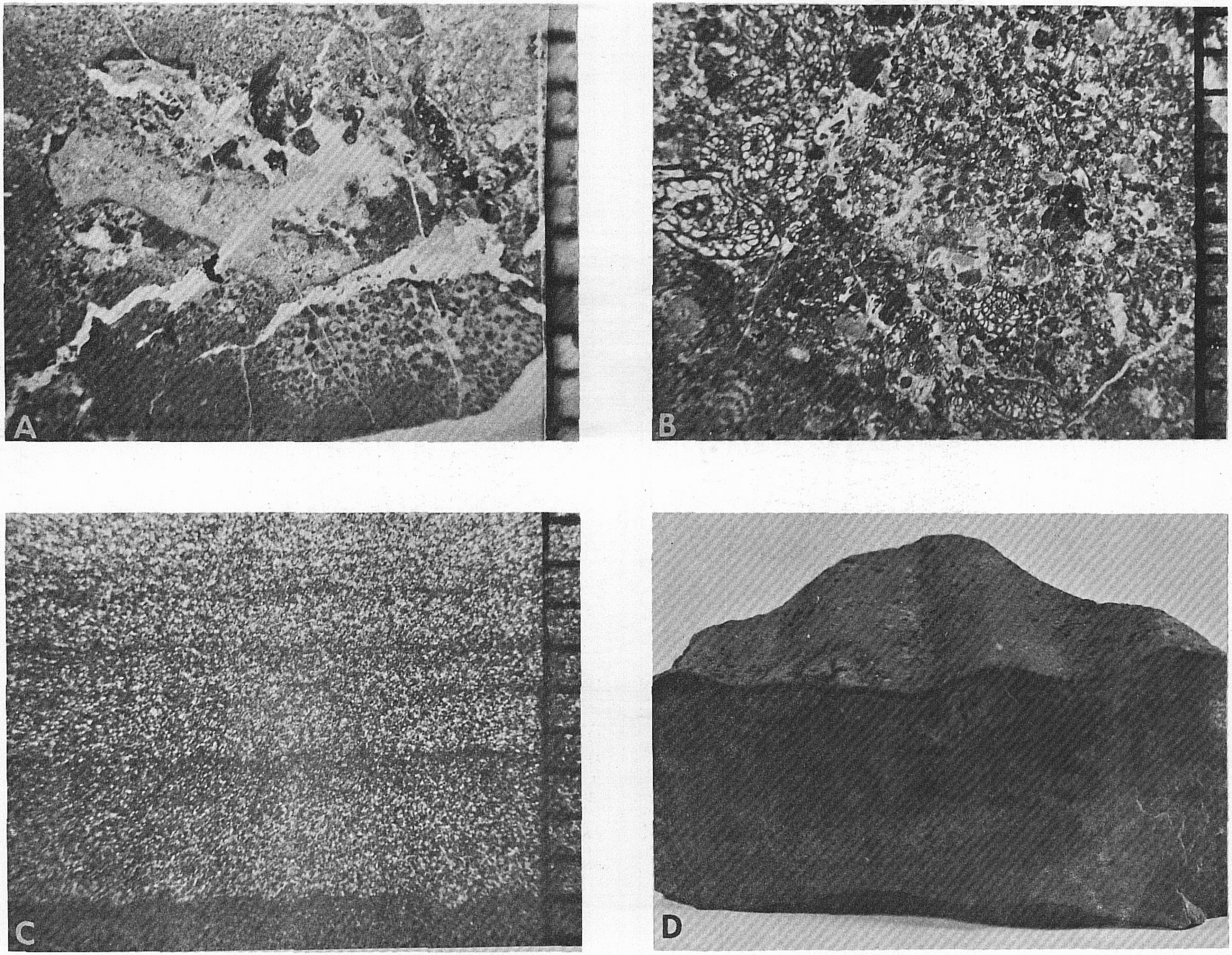

A
B
C
D

FIGURE 24

NEARSHORE - TERRESTRIAL FACIES

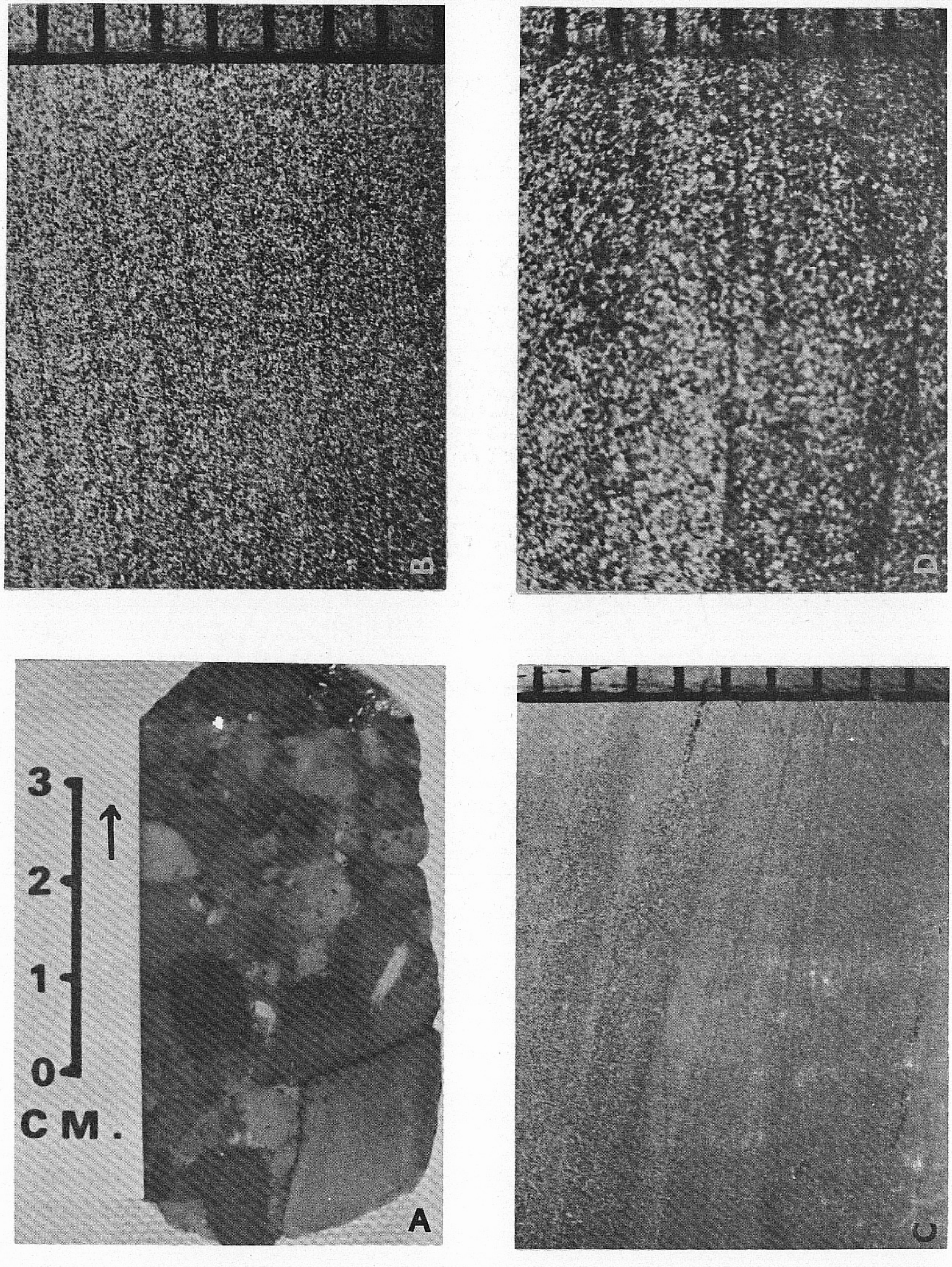
Thin sections oriented in up direction with millimeter scale shown at right.

A) limestone pebble conglomerate, sample no. HM 9, Powwow Member of the Hueco Canyon Formation, Hueco Mountains

B) unfossiliferous, silty lime mudstone, sample no. HT 6, Earp Formation, Big Hatchet Mountains

C) cross-bedded silty lime mudstone, sample no. HT 15, Earp Formation, Big Hatchet Mountains

D) cross-bedded red siltstone, sample no. SA 313, Abo Formation, San Andres, Mountains


B
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C

LOWER PERMIAN STRATA

Lower Permian units of southern New Mexico, west Texas, southeastern Arizona, and northern Mexico are referred to the following units: Bursum Formation, Laborcita Formation, Abo Formation, Hueco Limestone, Horquilla Limestone, Earp Formation, Colina Limestone and Epitaph Dolomite. General lithologies of these units are clastic or carbonate, or interbeds of the two; however, complex intertonguing of these basic rock types makes regional correlations difficult. In addition, formation names change across southern New Mexico to terminology more common in Arizona. Many of these units have been demonstrated to be asynchronous and to become younger eastward. Stratigraphic synthesis is further complicated by different types of data which consist of bits and pieces of stratigraphic data from numerous referenced publications and detailed petrographic studies from eight measured sections of this report and two from Pemex field studies. The following section therefore describes the various formations present and regional stratigraphic interpretations are discussed later.

BURSUM FORMATION

The type section of this formation, near the Oscura Mountains (Wilpolt et al., 1946), is an interbedded sequence of marine limestone and red-beds (arkosic sandstones, conglomerates, siltstones, and shales). The Bursum has been recognized throughout south-central New Mexico generally in very early Permian strata: in the Sierra Cuchillos (Jahns, 1965), in Mockingbird Gap, north of the San Andres range (Kottlowski, 1963), in Abo Canyon of the Manzano Mountains (Thompson, 1954), and in the Joyita Hills (Kottlowski and Stewart, 1970). Use of the term "Bursum" in referring to lowest Permian rocks in the San Andres Mountains (Kottlowski, 1956) and Robledo Mountains is not justified, for mappable lithic equivalents of the Bursum Formation are not found here. These strata are now included in the Hueco Limestone, in an attempt to remedy the Bursum Formation-Bursum fauna problem. Generally, an erosional unconformity bounds the base of the Bursum; locally, as in the Oscura Mountains, apparently conformably relationships are observed. The Abo Formation gradationally overlies the Bursum, the contact being placed at the top of the highest limestone in the Bursum interbeds. Thickness variations of the Bursum range from thin incomplete sections in eastern Socorro County, to 75 feet in Abo Canyon, to 120-135 feet in the Oscura Mountains, to 325 feet in Mockingbird Gap. Generally the Bursum becomes thicker to the southeast; to the north and northwest, it apparently pinches out under the Abo Redbeds (Kottlowski and Stewart, 1970).

Limestone units of the Bursum thicken southward where they are recognized as the Hueco Limestone. Thus, the Bursum Formation is a zone of transition between marine limestone of the Hueco and terrestrial sediments of the Abo. The presence of the Bursum marks the northernmost encroachment of Lower Permian seas. Such transgressions were intermittent and of shorter duration to the north; the best interpretation of the Bursum then is to consider it a basal Abo facies that reflects oscillations between marine and continental conditions.

The Bursum Formation, although essentially lower Wolfcampian is not a synchronous unit despite the common sursurface use of the term in the Delaware Basin for earliest Permian pre-*Pseudoschwagerina* beds. In westernmost outcrops of the Bursum, Jahns (1965) reported Virgilian fusulinids, whereas to the north and east, lower Wolfcampian fusulinids were identified from the Bursum by Thompson (1954). The *Triticites*-*Schwagerina* fauna of Wolfcampian sections of the Bursum permits correlation of the Bursum with the Laborcita Formation in the Sacramento and Jarilla Mountains, where similar faunas have been found (Steiner and Williams, 1968; Schmidt and Craddock, 1964).

LABORCITA FORMATION:

Otte (1959) proposed the name Laborcita for Lower Permian strata in the northern Sacramento Mountains that consist of rapidly changing facies of mudstone, limestone, sandstone, and conglomerate. The boundaries of the type section in Laborcita Canyon are the conformably underlying Holder Formation and the highest limestone in the Laborcita below the overlying Abo Redbeds. Sedimentary units of the type Laborcita are thin and quite variable, both laterally and vertically. Otte measured over thirty sections of Pennsylvanian-Permian strata in the Sacramentos and recognized a southward thining of the Laborcita. The thickest section in the northern area measured over 750 feet of Laborcita; the thinnest complete southern section was 535 feet. Immediately, south of here, Oppel (1959) measured ten stratigraphic sections within a total range of 2 1/2 miles to show that the formation is bound at its top and bottom by unconformities. Above the upper unconformity is about 50 feet of conglomerate that may be local equivalents of the Powwow Conglomerate. The lower unconformity is of regional extent and continues southward into Texas.

The Laborcita is also recognized in the Jarilla Mountains (Schmidt & Craddock, 1964). The section here, however, has been rather thoroughly metamorphosed by intrusives of probable Tertiary age. Since the base of the Laborcita has been assimilated by igneous intrusions, the 1,526 feet of measured section here is a minimum thickness. The measured section of the Laborcita (Plate 5 and figure 25) is based on Schmidt and Craddock's work; a few of the relatively less metamorphosed units were sampled and examined petrographically in this report. The lower half of the section contains conspicuously cross-bedded clastic metasediments (sandstones and siltstones) and marbleized limestones. The upper half consists of a very large covered area (Monte Carlo Gap, shown in Appendix Map V) overlain by about 150 feet of dark gray unmetamorphosed limestone with minor amounts of siltstone. Both rock types are cross-bedded, fine grained, and low in bioclastic content. Carbonate rocks are either mudstones or wackestones with a low percentage of grains. Ostracods are most abundant in the sparse fauna; a few crinoids and shell fragments were also observed.

Evidence regarding the depositional environment of these sediments is limited. Extensive development of cross-bedding throughout the Laborcita suggests shallow water deposition. The great sedimentary thickness here, along with these other clues, suggests shallow-water

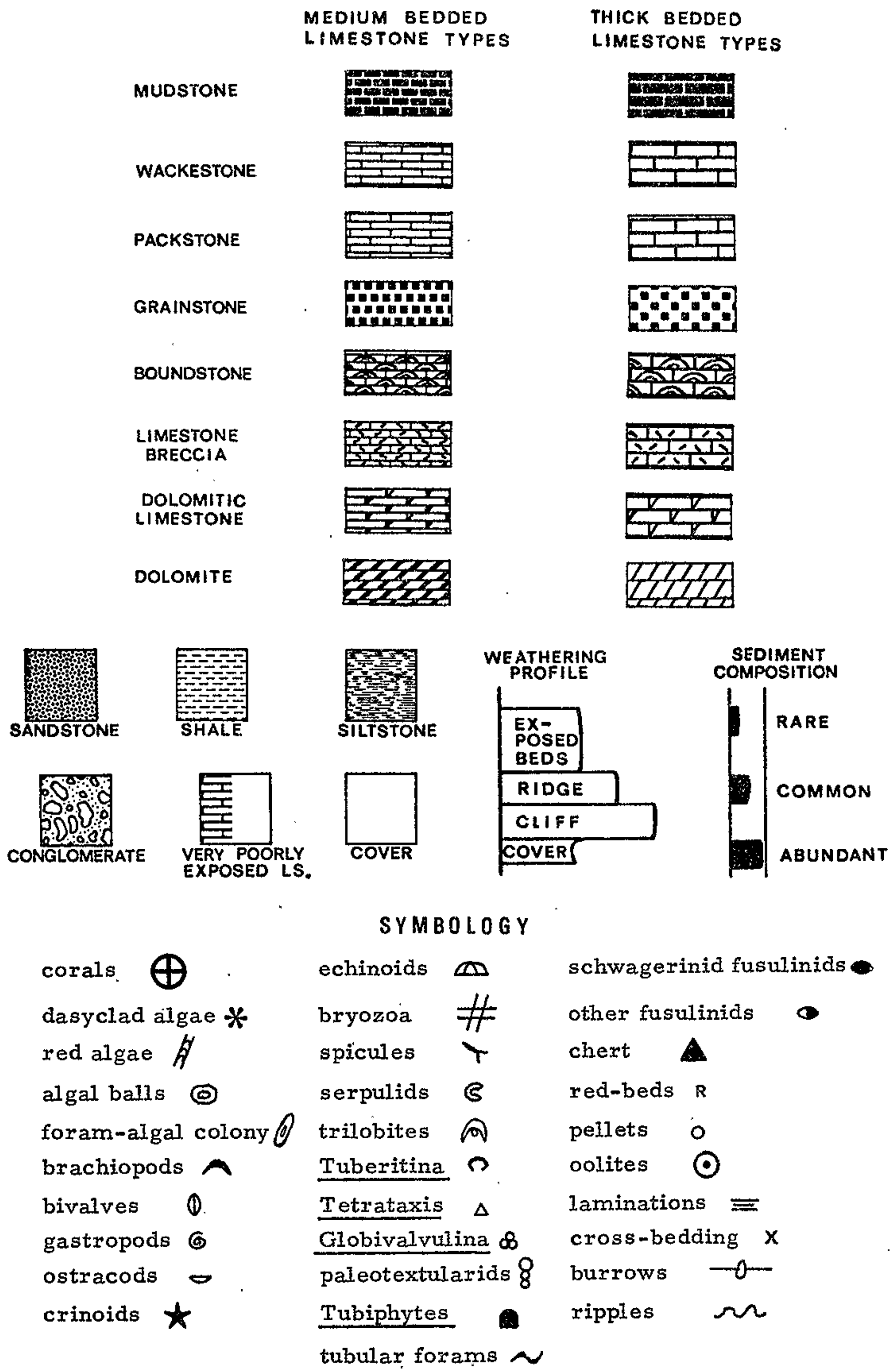

Figure 25: Legend for measured sections in Plates 1 - 10

conditions in a rapidly subsiding depocenter. Schmidt and Craddock (1964) report fusulinids from beds near the center of the formation; this, plus a few crinoids present near the top, indicate normal marine conditions for at least part of the formation. The fusulinids belong to the Triticites-Schwagerina Subzone and indicate a lower Wolfcampian age for the Laborcita. This establishes correlation of the Laborcita with eastern outcrops of the Bursum which it very much resembles lithologically.

ABO FORMATION

The type section for the Abo Formation was described by Needham and Bates (1943) from Abo Canyon in the Manzano Mountains as 915 feet of red-beds with about 60% red shale and 40% sandstone, arkose, and conglomerate; they note that no limestones are included in the formation. The Abo is present throughout central and southern New Mexico. Its lower contact is sometimes unconformable (e.g. in the southern Sacramentos); the upper contact is gradational in central New Mexico where it intertongues with the overlying Yeso Formation. The Abo thins southward from 1,100 feet at its thickest in the northern Sacramentos to zero in the Franklin Mountains (Jordan and Wilson, 1971). Where it intertongues with the Hueco Limestone, conformable relationships exist. This southward intertonguing is complex: Abo tongues occur both as medial or upper units in thick Hueco sections and northward projecting tongues of the Hueco occur both as basal or medial units in thick Abo sections. There are no obvious correlations of red-bed or limestone tongues.

The Abo Formation was encountered in petrographic-stratigraphic sections taken from the San Andres Mountains, Robledo Mountains, southern Sacramento Mountains, and the Big Hatchet and Hueco Mountains where its equivalents are recognized. Stratigraphic sections of the Abo in these areas are shown in Plates 3, 6, and 7. Lithologic changes in the Abo of these areas are presented in Table 3 which tabulates the percent of conglomerate, sandstone, siltstone, shale, and limestone.

Abo sections in the southern San Andres and Robledo Mountains are generally similar sequences of red shales and red and yellow-brown, cross-bedded siltstones; less commonly, interbedded thin limestone units occur. In the San Andres Mountains, the Abo section is interpreted as an upward transition from the normal marine environment of the Hueco Limestone through an interval representing somewhat restricted conditions, finally to predominantly terrigenous sedimentation. Thin limestone units near the base of the Abo are wackestones with crinoids, pelecypods and foraminifera; calcareous interbeds in the middle of the Abo are silty, argillaceous mudstones with a sparse ostracod fauna; in upper Abo beds, no limestones were observed. In contrast, limestone units in the Abo of the Robledo Mountains are consistently normal marine interbeds throughout Abo deposition. Fossiliferous packstones here indicate shallow normal marine conditions by the presence of dasycladacean algae, crinoids, ostracods, coral, and foraminifera. Thickness relationships and the general fineness of the Abo clastics in these areas suggest a distant northern source (Kottlowski, 1963).

In the southern Sacramento Mountains, the Abo is recognized as upper and lower tongues that enclose the Pendejo Tongue. Type sections for each were described from this area by Bachman and Hayes (1958). Otte (1959) and Pray (1961) demonstrated that the Pendejo Tongue correlates with the Hueco Limestone in the Hueco Mountains. As shown in Table 3, the general rock types of each red-bed tongue are distinct. Basically, the upper tongue contains finer sediments and is entirely clastic; the lower tongue is texturally much more variable and includes interbedded limestone units. Thickness variations are great in both tongues as they thin southward into progressively thicker Hueco Limestone sequences. Below the lower tongue exists an unconformity of regional extent. Studies in the Sacramento Mountains by Otte (1959) and Pray (1961) have clearly shown that coarse clastics of the lower tongue came from the nearby Pedernal Landmass. No fossils have been found in the lower Danley Ranch Tongue by the writer or by Bachman and Hayes (1958). From the upper Lee Ranch Tongue the latter report fossil plants that have been interpreted as an indication of Leonardian age by Read (1957). Kottlowski (1963) and the writer, among others, doubt this interpretation and correlate the Lee Ranch Tongue with the Deer Mountain Red Shale Member of the Wolfcampian Alacran Mountain Formation in the Hueco Mountains.

Equivalents of Abo Red-beds in the Huecos consist of this red shale and of a basal conglomerate (the Powwow Member of the Hueco Canyon Formation). Cobble and pebble conglomerates here contain chert and highly fossiliferous limestone clasts. As discussed previously, these beds are middle Wolfcampian age.

Table 3

General Lithologies of Wolfcampian clastic red-bed units

Location	Rock Unit	Mode	Thickness	Conglomerates	Sandstone	Siltstone	Shale	Limestone
southern San Andres Mtns.	Abo Fm.	overlies Hueco Ls.	355'	0	0	25%	68%	7%
Robledo Mtns.	Abo Fm.	medial tongue in Hueco Ls.	414'	1%	0	26%	62%	11%
Big Hatchet Mtns.	Earp Fm.	medial tongue in Hueco Ls. equivalent	997' (lower 395' exposed)	0	9%	12%	75%	4%
Southern Sacramento Mtns.	Lee Ranch Tongue	overlies Hueco Ls.	106'	0	6%	61%	33%	0
"	Danley Ranch Tongue	underlies Hueco Ls.	variable (15-180')	(4% (but variable)	9%	69%	0%	22%
Hueco Mtns.	Deer Mtn. Mbr.	medial tongue in Hueco Ls.	103'	0	0	0	100%	0
"	Pow-wow Mbr.	basal conglom-erate	125'	44%	0?	0?	52%	4%

Table 3

General Lithologies of Wolfcampian clastic red-bed units

HUECO LIMESTONE

The Hueco Limestone is widespread throughout the study area except in the north where red-bed sequences form continental equivalents. South of the Abo Redbeds, occurs the Bursum Formation, an intertonguing belt of clastics from the north and Hueco carbonates from the south. Thick, almost entirely carbonate sections of the Hueco are present in west Texas and continue westward into southern Arizona. All measured sections of this report (figure 1) include strata of the Hueco Limestone or its equivalents. The term "Hueco Group" will be used only when various formations are recognized within the overall Hueco lithology.

Hueco Mountains:

The type section of the Hueco Limestone is from the Hueco Mountains of west Texas. Williams (1963) here referred the following formations and members to the Hueco Group (from youngest to oldest): Alacran Mountain Formation with the Deer Mountain Red Shale Member, Cerro Alto Limestone, and Hueco Canyon Formation with its basal Powwow Member. Total thickness of these units is about 1,600 feet. Youngest Paleozoic exposures available in this area are the top beds of the Alacran Mountain Formation. The bottom contact of the Hueco Group is a regional angular unconformity, on which the Powwow conglomerates rest. The Hueco Group here is predominantly upper Wolfcampian and upper middle Wolfcampian age (figure 3).

The petrographic-stratigraphic section of these units is shown on Plate 1. The Powwow Member is overlain by about 500 feet of alternating packstone-grainstone couplets with thick to medium bedding.

Wornstone textures are indicated by very high grain contents, consisting of worn, well-rounded, and commonly recrystallized bioclasts. Major constituents are foraminiferal tests, including fusulinids, staffellids, Globivalvulina, Tuberitina, cornuspirids, with lesser amounts of paleotextularids, Textrataxis, and Tubiphytes. Dasycladacean algal fragments, shell debris, and crinoid columnals are also present, but their abundance is greatly outweighed by the high foraminiferal content. The Hueco Canyon Formation is basically a blanket of foraminiferal detritus deposited in a shoaling environment and is the best example of the shoal-water facies encountered in the study area.

The overlying Cerro Alto Limestone crops out mainly in medium to thin beds which contain much more micritic limestones and differ faunally from the underlying shoal-water facies. Limestones transitional between wackestone and packstone categories make up the bulk of the Cerro Alto; no mudstones, however, were found in this formation. The biotic content is diverse and includes algae (codiacean and dasycladacean), foraminifera (especially Tubiphytes and Tuberitina), bivalves, crinoids, bryozoa, and some corals. These platy algal beds resemble bioherm facies, but well-developed mounds rarely occur. Tabular bedding suggests that most of these units are biostromes, rather than biohermal build-ups. About ten such units are recognized in the Cerro Alto. The uppermost one extends into the overlying Alacran Mountain Formation and continues up to the base of the Deer Mountain Red Shale Member. Between these platy algal beds occur sequences of algal-foraminiferal limestones of the shallow shelf facies. Sedimentary cycles apparently consist of alterations of covered intervals and biostromal and shallow shelf limestones.

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These covered intervals are common and possibly represent non-resistant shale or siltstone beds.

Above this lie thick and medium beds of the Alacran Mountain Formation. Their bioclastic content is similar to that of the Cerro Alto (diverse fauna with abundant algae and Tubiphytes), but rock textures are mainly wackestones (with only about 15-25% grains) and lime mudstones. Mudstone breccias occur and, together with mound development, indicate a period of bioherm buildup. Shallow shelf carbonates are found above this unit up to the highest exposures.

In summary, the type Hueco section begins with a basal conglomerate deposited on a unconformable surface; these rocks are followed by a thick sequence of interbedded biostromal and shallow shelf limestones with intercalated covered intervals presumed to be shales. Next above is the Deer Mountain Red Shale Member which is overlain by biohermal and shallow-shelf sediments. Generally, lime mud and bioherm development increase from the base to the top of the measured section.

Franklin Mountains:

Preliminary results of the petrographic-stratigraphic Hueco section in the Franklin Mountains were presented by Jordan and Wilson, (1971). The Hueco Group here totals 2,100 feet and consists of the same formations observed in the type section; however, the Deer Mountain Red Shale and Powwow Members are not recognized in the Franklins. No unconformities were observed and continuous sedimentation persisted through the Upper Pennsylvanian and Lower Permian. As shown in figure 4, the Hueco Limestone in this area is chiefly upper and middle Wolfcampian.

Throughout the measured section (Plate 2), shallow shelf facies dominate over lesser amounts of biohermal and shoal-water facies. In the Hueco Canyon Formation 1, 350 feet of normal marine wackestones and packstones contain thin interbeds of algal plate biostromes (0-350 feet interval), grainstones of the shoal-water facies (350-650 feet), and more biostromal units (650-1, 100 feet). Uppermost beds of this formation consist of shallow shelf limestones (1, 100-1, 350 feet).

Sedimentary cycles on a small scale are recognized in the Hueco Canyon Formation. A typical cycle, consists of an upward succession from normal marine bioclastic wackestone, to wackestone-packstone, to packstone, and commonly to a capping grainstone, bioherm, or mud-mound. The sequence represents a shallowing or regressive phase. The presence of intraformational biohermal breccias (similar to those in the Hueco Mountains) suggests that intermittent exposure of capping beds occurred. At least 20 regressive cycles exist in the Hueco Canyon Formation in the Franklin Mountains. Transgressive deposits are rare and, when found, exhibit reverse lithologic successions. Usually these sequences are not detected, possibly indicating rapid transgressive phases.

In the overlying Cerro Alto Formation, medium bedded shallow shelf carbonates are separated by siltstones and shales that become thicker towards the top of the formation. Clastic influx is believed to account for the following changes in faunal composition between the Hueco Canyon Formation and the Cerro Alto Limestone: in the Cerro Alto, 1) brachiopods and Tubiphytes are considerably less abundant; 2) general abundance of foraminifera is the same, but tubular foraminifera dominate; and 3) a small number of smaller, long-ranging, more robust fusulinids (e.g. Staffella) replace the diverse Schwagerina and Pseudoschwagerina fauna of the Hueco Canyon Formation. Crinoids and dasycladacean algae, common in the Cerro Alto, indicate shallow, normal marine conditions. Cycles in the Cerro Alto are similar to those in the Hueco Canyon, except that they lack capping biostromal units and that the lowest parts of the cycles here are shales or siltstones.

The Alacran Mountain Formtion in the Franklins begins with a thick, cherty algal plate biostrome in the lower 50 feet of the formation. Above this occurs about 175 feet of shallow shelf limestones with a few thin platy algal beds in the highest exposures. Wackestone and packstone textures were observed with a complete absence of grainstone. The Deer Mountain Red Shale Member (described in the Franklin Mountains by Williams, 1966) was not observed in the Alacran Mountain Formation. Despite a re-tracing of Williams' section northwest of Tom Mays Park, no red-beds were encountered in stratigraphic sampling here. Plate 2 shows thick basal platy algal beds of this formation. It is possible that the thick covered interval below this (with thin siltstone ledges) may have been mistaken for a red shale sequence. Correlation of the Franklin Mountain section of this report with Williams' section (1966) is good when based on fusulinid zones, but lithologic correlations are more complex than considered earlier by Williams and by Wilson (1971).

The Franklin Mountain Hueco section thus represents continuous Wolfcampian deposition, beginning with a thick cyclic sequence of shallow shelf limestones that becomes more clastic upward and ending with platy algal biostromal deposits. As observed in the Hueco Mountains, a general increase in lime mud occurs upward throughout the section and a basal shoaling sequence is present.

Sierra Diablo Mountains:

A stratigraphic section of the Hueco Limestone was measured in the Sierra Diablo Mountains, north of Van Horn, Texas. Although the section is thicker than reported by King (1965) and although the Hueco here is the youngest Wolfcampian encountered in this study, the following discussion is presented as a possible basis for future research. About 660 feet of Hueco Limestone was measured in the area south of Victorio Peak (Appendix map VI); in comparison, King (1965) reported only 380 feet. Certainly, no samples with the characteristic black appearance of the Bone Springs Limestone were observed in the measured section of this report (Plate 4). Perhaps, faulting has repeated the Hueco sequence here, although general lithologic successions do not suggest this. There is no doubt that the lower part of the section is accurate; the Hazel sandstone is distinctive and the Powwow interval corresponds with King's data.

The Hueco strata here are grossly divisible into a thick, lower, normal-marine limestone sequence overlain by about 100 feet of dolomite. The limestones contain an abundance of fusulinids, many crinoids and brachiopods, some algal fragments, and a diverse foraminiferal assemblage. In the carbonate section, a thick wackestone sequence grades upward to a slightly thinner packstone sequence. Detrital, brecciated textures occur sporadically throughout the carbonates.

Wornstone textures are common and often occur within angular breccia clasts. Other indicators of current action are fusulinid packstones with current-oriented fusulinids.

According to King's (1965, p. 51) paleotectonic map of the Hueco Limestone, this Hueco section is situated on the platform edge of the west side of the Delaware Basin. Shoal-water conditions are indicated by the observed sedimentary structures, breccias, and wornstone textures.

Southern Sacramento Mountains:

The Hueco section here is shown on Plate 3 and is located in Appendix Map IV. About 625 feet of the Pendejo Tongue of the Hueco Limestone (Pray, 1961) conformably lie between upper and lower tongues of the Abo. Fusulinids and ammonites were used by Pray in correlating the Pendejo Tongue with the Hueco Formation to the south. No age-significant fossils were observed in the petrographic-stratigraphic section of this report.

Three subdivisions of the Hueco are recognized in the basis of lithologic and faunal characteristics. The lower 300 feet are mostly interbedded shales, siltstones, and mudstones or wackestones with low grain percentages. The faunal content is limited to gastropods, bivalves, ostracods, and tubular foraminifera. Towards the top of this lower unit is a 25 feet thick series of cornuspirid packstones that may represent a nearby buildup of tubular foraminifera (figure 22c). Limestones in the next 100 feet are rich in crinoids and, in addition to the fauna of underlying strata, contain a much more diverse foraminiferal assemblage. Above this occurs about 200 feet of shale with thin limestone interbeds. The high shale to limestone ratio characterizes this interval, for some of the thin carbonates are similar in texture and composition to crinoid-rich beds lower in the section, and some to basal strata barren of crinoids.

Cyclic sedimentation here is reflected in thin clastic-carbonate couplets, of which there are probably more than 35 in this section. The environments of deposition is interpreted to have changed from restricted to open lagoonal conditions, and finally to intermittent oscillations between the two. This is primarily based upon the first appearance (at 380 feet) of normal marine organisms, and their distribution in the upper two-thirds of the section. In some of the thicker limestone units, a transition from a basal mudstone to a capping packstone was observed.

Jarilla Mountains:

The Hueco section in the Jarilla Mountains is shown on Plate 5 and the line of section appears in Appendix Map V. About 900 feet of Hueco Limestone was measured, but as much as 130 feet more are exposed farther to the northwest, where the section of Schmidt and Craddock (1964) was taken. The top of the Hueco here is concealed by an igneous intrusion and total thickness is related to the amount of assimilation by intrusives rather than to depositional thickness. The lower contact of the Hueco is conformable upon the underlying Laborcita Formation. Fusulinids in the Hueco here date it as middle and upper Wolfcampian.

Basically, the lithology is one of alternating clastic and carbonate units; covered intervals and shale and siltstone saddles are common in the weathering profile between resistant limestone beds. Normal marine faunas persist throughout limestone sequences which consist primarily of fossiliferous packstones and wackestones, with minor amounts of grainstone and mudstone. Sediments here are predominantly dark to very dark gray, a characteristic found only in this and the Hueco section in the San Andres Mountains.

A 33 feet thick cliff of platy algal beds marks the base of the Hueco Limestone in the Jarilla Mountains. Above this lie about 350 feet of shallow shelf sediments with a thin upper bioherm 160-180 feet above the base of the Hueco. Indications of shallow water deposition include limestone pebble and granule conglomerate, cross-bedding, wavy laminations, scour marks, and the presence of *Tubiphytes* and dasycladacean algae. Above this occur about 200 feet of shoal-water facies. Grainstones, although relatively rare in the Jarilla section of the Hueco Limestone, seem to be most common in this interval. Seven grainstone units were found here interbedded with cross-bedded siltstones or shallow shelf carbonates. Algal plates and *Tubiphytes* are abundant in beds above the shoaling units and indicate shallow shelf conditions for the upper 300 feet of the Hueco Limestone.

San Andres Mountains:

About 1450 feet of Hueco Limestone were sampled in the San Andres range (Plate 6 and Appendix Map VII). The Hueco here overlies the Panther Seep Formation and is upper and middle Wolfcampian age. As previously mentioned, fusulinids indicate that part of the Panther Seep is middle Wolfcampian. The upper contact of the Hueco is transitional with the Abo Formation, as interbedded siltstones become dominant over interbedded limestones.

The lower Hueco Limestone here consists of thick alternations of biohermal and shoal-water limestones. The section begins with a thick-bedded, cliff-forming, algal plate unit, about 60 feet thick; in addition to codiacean algae, Tubiphytes and Tetrataxis are particularly abundant in these beds. Overlying this are about 150 feet of shoal-water facies carbonates, as indicated by oolitic grainstones (figure 14b). Next occurs 150 feet of bioherm and bioherm flank deposits, very rich in Tubiphytes and Textrataxis. Another oolitic sequence of about 125 feet follows (figure 14a).

The upper two-thirds of the Hueco Limestone consists of interbedded shelf carbonates and cross-bedded siltstones. Limestones are generally dark to very dark gray and display wackestone and packstone textures with normal marine faunas. Although no significant amounts of Tubiphytes or algal plates occur in these beds, shallow water deposition is indicated by sedimentary structures such as oscillation ripples (figure 23d) and cross-bedding, which is common throughout the entire sequence.

Robledo Mountains:

The measured section in the Robledo Mountains (Plate 7) represents the westernmost outcrops of the Hueco Limestone. The basal 175 feet, previously termed the Bursum Formation, is hereby referred to the Hueco Limestone, since the lithology is not one of interbedded limestones and red-beds. A thick Pennsylvanian carbonate section (Atokan through Virgilian) conformably underlies the Wolfcampian. Upper strata of the

Hueco here are unconformably overlain by Tertiary clastics and volcanics (Kottlowski, 1969). A lack of thick, continuous Wolfcampian exposures necessitated the assembling of a composite section which is based on nine components (Appendix Map III). Location of these sections was based on aerial photo interpretations and preliminary field studies by Dr. Frank E. Kottlowski. The Hueco Limestone here contains a 414 feet thick medial Abo Tongue, with about 1,050 feet of limestone below it and 400 feet above.

The pre-Abo section of the Hueco contains two major facies. The lower half represents shoal-water deposition of oolitic grainstones and calcirudites. In the center of this interval occurs 35 feet of relatively unfossiliferous lime mudstone, possibly a mud-mound. Cross-bedded siltstones and sandstones are common above this and thicken towards the top a second major shoaling sequence. Next occur beds rich in Tubiphytes and algal plates. Although the composite section does not show stratigraphic overlaps of component sections, these beds are recognized in the RC and RH sections which are about a mile apart. In the upper half of the Hueco, shallow shelf environments are interpreted for interbedded limestones and fine clastics. Carbonate units are chiefly mudstones, with less common packstones and grainstones. Cycles consist basically of transitions from clastic to carbonate deposition. At the base of a cycle occur siltstones or shales which are overlain by thick lime mudstones. Wackestones in some places occur next, but more commonly packstones and grainstones follow to cap the cylce. Hueco strata below the Abo are generally unfossiliferous, but indications of normal marine faunas persist throughout the section; the scarcity of green algae and Tubiphytes is attributed to the large amount of clastics present. Coated grains and even a few oolites occur in the limited number of grainstones in this interval. Thus textural evidence, rather than faunal, indicates shallow shelf conditions below the Abo.

About 400 feet of Hueco Limestone overlies the nearshore to terrestrial facies of the Abo Tongue. The lowest Hueco beds here contain a series of algal plate beds, a total thickness of about 75 feet. Shallow shelf limestones with interbedded siltstones then continue to a 30 feet thick series of thin biostromes near the highest exposures in the section.

In summary, the following shallow water facies are observed in the Hueco Limestone of the Robledo Mountains: from the base upward, 1) shoaling facies, with medial and upper biostromes; 2) shallow shelf; 3) nearshore to terrestrial facies of the Abo; and 4) shallow shelf with basal and capping algal plate beds.

Florida Mountains:

Kottlowski (1958, 1963) reported a partial thickness of the Hueco Limestone of at least 350 feet from exposures in the southern Florida Mountains. In the basal part of the Hueco, he recognized black calcarenites with some fragments and lenses of chert-limestone granule conglomerate (with angular to subrounded clasts), overlain by black fossiliferous limestone, which in turn is overlain by light brown cross-bedded siltstones and calcareous sandstones. The upper Hueco here he considered "typical Hueco Limestone" with medium to thick beds of dark gray limestone.

Preliminary investigation of this area suggests that the black color of these strata, together with the occurrence of large gastropods and the scarcity of algal plates, tubular foraminifera, and brachiopods, is atypical of the Hueco Limestone and is very similar to the lagoonal facies of the Colina Limestone in the Sierra Palomas and Big Hatchet Mountains. At present, samples have been taken, but petrographic studies have not yet been made. No fusulinids were observed in the Hueco Limestone in this area, although two fusulinid-bearing horizons were indicated by Mark Wilson in stratigraphic studies for Shell Oil Company.

HORQUILLA LIMESTONE

In southwestern New Mexico and southeastern Arizona, a thickness of about 3,000 feet of limestone is referred to the Naco Group of Pennsylvanian and Permian age. The Horquilla Limestone, the lowest formation of this group, has its type section in the Tombstone Hills of Cochise County, Arizona. General characteristics of the Horquilla include predominantly carbonate rock types, a widely recognized pinkish-gray tinge, and a high content of marine fossils. The age of the Horquilla becomes younger southward and eastward; it is Middle Pennsylvanian in central Cochise County (Gilluly, 1956) and Pennsylvanian and Early Permian in the Big Hatchet Mountains in New Mexico (Zeller, 1965). In this report, only Wolfcampian intervals of the Naco Group are considered; thus, recognition of fusulinid zones is critical in establishing correlations. Fortunately, the Horquilla contains abundant fusulinids and several biostratigraphic studies of the Naco Group have been published (Skinner and Wilde, 1965;

Sabins, 1957; Thompson, 1954; Sabins and Ross, 1963; and Diaz and Navarro, 1964).

For this report, the Horquilla Limestone was sampled in the Big Hatchet Mountains. Detailed petrographic studies by Pemex geologists (and some of their samples and acetate peels) from this range and from Sierra Palomas in northern Chihuahua were also available to the writer.

Geological investigations in the Big Hatchet Mountains by Zeller (1965) form the basis for detailed stratigraphic sampling of the Horquilla Limestone. Wolfcampian portions of Zeller's Borrego Section were remeasured and care was taken to obtain better exposures in the lower half of the section. The base of the Horquilla section (Plate 8), is in fault contact with about 80 feet of upper Horquilla beds, as indicated by field evidence and the presence of middle and upper Wolfcampian fusulinids. As reported by Zeller, the total Horquilla is no greater than 3, 600 feet, about 1, 400 feet of which are Wolfcampian in age. Only by lengthy bed tracing can the upper contact of the Horquilla Limestone be included with the overlying Earp Formation. Highest exposures of the Horquilla in the measured section probably exclude no more than 100 feet of section.

Upper Virgilian and lower Wolfcampian parts of the Horquilla, the basal 700 feet of the measured section, consist of coarse limestone breccias with interbedded dark siltstones and silty lime mudstones. The lower 400 feet are dominated by limestone breccia beds, whereas shales and siltstones are more common in the upper 300 feet. The entire sequence is interpreted as slope facies sediments as indicated by interbeds of fine-grained dark basinal deposits and lighter breccias composed of clasts derived from the shelf, some of which are as large as six feet in diameter. Numerous indications of down-slope slumping and flowage are observed. In addition to thick accumulations of breccias and megabreccias, there occur thick beds of current-oriented fusulinids and siltstone flame structures. In many of the coarse carbonate units, bioclasts from the shelf (mainly Tubiphytes, algal plates, fusulinids and crinoids) are commonly crushed and so jumbled and mixed, that distinguishing matrix from clasts is difficult. It appears that evidence can be found for down-slope mass wasting as well as turbidity flows.

In the 700-1, 050 feet interval, similar breccias occur with algal plate-Tubiphytes bioherms. At least four thin bioherms and several sets of flanking bed deposits are observed, the thickest of which is 40 feet, at the base of this interval. Next occurs about 330 feet of cover, from which a few samples of dark, argillaceous siltstone were collected. Zeller (1965) interpreted this as a thick tongue of basinal deposits.

Uppermost Horquilla beds are predominantly bioherm and associated flanking deposits with abundant Tubiphytes and algal plates. A series of four cliff-forming bioherms were observed, but due to their steepness sampling was often restricted to flanking beds. The change from underlying basinal facies to these bioherms seems abrupt. Some beds of the slope facies most likely occur in the large covered interval below the bioherms.

Shelf sections of the Horquilla Limestone were originally described by Zeller (1965). Subsequent studies by Pemex geologist included detailed petrographic analysis of Zeller's Bugle Ridge Section, which lies about 2 1/2 miles northeast of his Borrego Section. The Wolfcampian part of their work has been redrafted (Plate 9) to compare with other stratigraphic sections in this report. Fusulinid zones in the Bugle Ridge section are based on a limited number of fusulinid determinations made by the author, and stuides by Zeller (1965) and Skinner and Wilde (1965).

A total of 1,550 feet of Wolfcampian strata were measured and sampled on Bugle Ridge. The sequence is basically one of cyclic shelf carbonates with thin interbeds of platy algae beds. In addition to algae, tubular foraminifera, crinoids, and corals occur throughout the predominantly limestone sequence. Carbonate textures define rhythmic cycles of wackestone and packstone couplets. In places, lime mudstones occur at the base of the cycle, below thicker accumulations of wackestone; and sometimes thin grainstone units overlie packstones and cap the cycle. Thin platy algal beds commonly occur in the middle of these shelf cycles. One particularly well-developed bioherm, occurring 1,100-1,175 feet above the Virgilian-Wolfcampian boundary, correlates with bioherms found in the upper Horquilla beds of the Borrego Section.

Pemex studies in northern Chihuahua reveal over 3,700 feet of Horquilla Limestone in the Sierra Palomas, 1,235 feet of which is Wolfcampian age (Diaz and Navarro, 1964). To aid in comparison of stratigraphic information, their original data has been reviewed and redrafted (Plate 10) in the format of sections measured for this report. The Horquilla Limestone in this area consists entirely of well developed normal marine shelf cycles that begin with thick shale or lime mudstone sequences and proceed upwards to thinner wackestones or packstones. Dolomites occur sporadically throughout the Horquilla, but appear to be more abundant in upper parts of cycles. Grainstones although relatively rare, occur solely as capping beds and are useful in recognizing the tops of sedimentary cycles. Regressive seas are indicated by progressively shallower depositional environments from the base to the top of cycles. Such sequences are generally thick (about 200 feet) and few in number, but compare well with regressive cycles in the Hueco Limestone. No biohermal or shoal-water carbonates occur in this Horquilla section.

EARP FORMATION

The type Earp is from Earp Hill in Southern Arizona, where about 600 feet of interbedded sandstone and limestones with minor amounts of shale and dolomite are exposed below the overlying dark limestones of the Colina Formation. The contact at the base of the Earp is with a thick carbonate sequence (the Horquilla Formation); regarding this contact, Gilluly (1956, p. 39) states "there appears to be no erosional or other discordance with the underlying Horquilla Limestone." The Earp thickens northward from its type section and eastward where Sabins (1957) reports about 2, 700 feet in the Chiracahua Mountains. In the Big Hatchets, Zeller (1965) measured 997 feet of Earp and in the Sierra Palomas of northern Chihuahua, about 800 feet is reported by Diaz and Navarro (1964).

The Earp Formation in southwestern New Mexico is considered by Zeller (1965) and somewhat by Kottlowski (1963) as an equivalent unit of the Abo Formation (Table III). Only the lower third of the formation is well exposed in the measured section in the Big Hatchet Mountains (Plate 8). A sharp lithological break is observed with the underlying Horquilla here, but no evidence is offered for the existence of an unconformity at this horizon. In the lower 400 feet, red shales dominate lesser amounts of cross-bedded siltstone and unfossiliferous lime mudstone. The following features found in the Earp by Zeller (1965) indicate near-shore, predominantly terrestrial conditions; possible tracks of reptiles and crabs, fossil plants, some ostracods and fish scales, conifer branches, and fossil wood. Thin limestone interbeds with some ostracods and high-spired gastropods represent minor incursions of a shallow sea that may have established intermittent lagoonal complexes. This interpretation agrees with deltaic environments of the Earp in southwestern Arizona described by Lodewick (1970). Other than a few ostracods, no fossils were found in the Earp section by the writer.

In the Sierra Palomas of northern Chihuahua, the Earp Formation is about 750 feet thick (Plate 10). Dolomites and interbedded gypsum layers in the lower 300 feet suggest tidal flat or restricted marine environments. Alternating shales and highly pelleted normal marine limestones (with crinoids and green algae) comprise the upper 450 feet of section and indicate a transgression between these and underlying strata. Pelleted grainstones, common in lower strata of this upper interval, are replaced by normal marine limestones with a highly diverse fauna near the top of the Earp. Cyclic sediments of the upper Earp (i.e. above the dolomite and gypsum beds) consist of basal shales or lime mudstones, medial wackestones or packstones, and upper grainstone or packstone units. Generally, sediments become more mud-free and grain-rich towards the tops of cycles. This appears to be one of the least clastic Earp sections measured.

The age of the Earp is tentatively considered to be upper Wolfcampian on a stratigraphic basis. Underlying beds of the Horquilla are upper to middle Wolfcampian and the nearest probable indications of the Leonardian are in upper Epitaph beds, of the Big Hatchet Mountains about 1,800 feet above the top of the Earp. The generally clastic lithology and probable upper Wolfcampian age indicate correlation with the Abo Formation of central New Mexico.

COLINA LIMESTONE

The type section of the Colina Limestone is in the Tombstone Hills of Arizona (Gilluly, 1956). General characteristics of the Colina Limestone are a dense, dark gray appearance on fresh fracture and a relatively low fossil content that includes many gastropods. In the type locality this formation conformably overlies the Earp Formation; its upper contact is somewhat variable and is chosen at the highest limestone of Colina lithology below the overlying Epitaph Dolomite. The Colina Limestone is recognized throughout southeastern Arizona and southwestern New Mexico. The following variations in thickness have been reported:

633 feet in the Tombstone Hills (Gilluly, 1956), 1,000 feet in the Pedregosa Mountains (Epis, 1956), 535 feet in the Chiricahua Mountains (Sabins, 1957), 500+ feet in the Peloncillo Mountains (Gillerman, 1958), variation from 355 to 505 feet in the Big Hatchet Mountains (Zeller, 1965), and 374 feet in Sierra Palomas (Diaz and Navarro, 1964). Like the underlying Earp Formation and Horquilla Limestone, the Colina becomes younger eastward. Owing to the scarcity of age-significant fossils, precise determinations are impossible. The Colina is most likely Leonardian in the Tombstone Hills and Wolfcampian in the Big Hatchet Mountains.

In the Big Hatchet Mountains, where the Colina was sampled for this report, it thickness is only 275 feet owing to a fault about 180 feet above the base of the formation. Medium and thick-bedded cliffs of dark gray limestone occur at the base of the measured section (Plate 8) and yield to poorer exposures that continue throughout the rest of the formation. Except for a relatively pure limestone base, the sequence consists of interbedded shales and dark limestones. Several carbonate units containing 1-3% quartz silt display faint hints of cross-bedding in thin-section. The faunal content of the Colina here includes abundant ostracods, bivalves and gastropods; foraminifera and crinoids occur throughout the section in lesser amounts. These occurrences indicate open lagoonal conditions during Colina deposition. A slight enrichment of crinoids and an increase in foraminiferal diversity in a 40 feet thick interval in the middle Colina represents conditions of maximum circulation of normal marine waters.

In the Sierra Palomas section, the Colina is about 360 feet thick (Plate 10). Limestones, shales, and minor amounts of sandstone form alternating clastic-carbonate couplets. Carbonates in this area are the most normal marine Colina Limestones yet encountered. Crinoids and green algae are relatively abundant and, near the top of the Colina, thin algal plate beds suggest shallow shelf environments.

EPITAPH DOLOMITE

The Epitaph Dolomite is the uppermost formation of the Naco Group and, like underlying units, was originally described in the Tombstone Hills of Arizona (Gilluly, 1956). At its type section, the base is defined by the lowest massive dolomite above a zone of limestone-dolomite transition that is assigned to the top of the Colina Limestone. The upper limit of the Epitaph here is an unconformity above which lie Cretaceous conglomerates. The Epitaph Dolomite has been recognized to extend eastward from its type locality into southwestern New Mexico and northern Chihuahua. Its thickness ranges from 783 feet in the Tombstone Hills (Gilluly, 1956), to 1,500 feet in the Big Hatchet Mountains (Zeller, 1965), to 1,462 feet in the Sierra Palomas (Diaz and Navarro, 1964). The age of the Epitaph is uncertain and has been referred to as "Wolfcampian or Leonardian?" by most stratigraphers. Reworked late Wolfcampian species of Schwagerina were found in uppermost outcrops sampled in this report (figure 6) and suggest Leonardian age.

Zeller's Lower Sheridan Tank Section was sampled for petrographic studies of this report (Plate 8). The sequence is predominantly dolomite but contains significant amounts of limestone. The following lithologic succession is recognized, beginning with the base of the section: 1) 240 feet of unfossiliferous gray dolomite, 2) 400 feet of very sparsely fossiliferous lime mudstones, 3) 320 feet of interbedded unfossiliferous lime mudstones, dolomite limestones, and dolomites, and 4) 520 feet of dolomite. Sparse faunas include mainly ostracods, bivalves, gastropods, and a few foraminifera.

REGIONAL WOLFCAMPIAN STRATIGRAPHY

Construction of an isopach map for the Wolfcampian Series naturally involves recognition of time-stratigraphic units, as determined by fusulinid zonation. As previously discussed, Lower Permian formations are generally oldest in southeastern Arizona and become younger eastward and northward into south-central New Mexico and west Texas. The isopach map of the Wolfcampian Series presented in figure 26 is based on the data in Table 5 and includes at least partial thicknesses of the following formations: Hueco Limestone, Abo Redbeds, Bursum Formation, Laborcita Formation, Horquilla Limestone, Earp Formation, Colina Limestone, and upper portions of the Panther Seep Formation and Magdalena Group. The Yeso Formation of New Mexico is almost entirely Leonardian, although the exact age of its basal strata is somewhat in doubt (Kottlowski, 1963). No new evidence is presented here and the Yeso is tentatively excluded from the Wolfcampian. So is the Epitaph Dolomite of Arizona, as determined by the presence of reworked upper Wolfcampian species of *Schwagerina* and *Pseudoschwagerina*

Figure 26: Wolfcampian Isopach Map

Outcrop sections ▲ this study

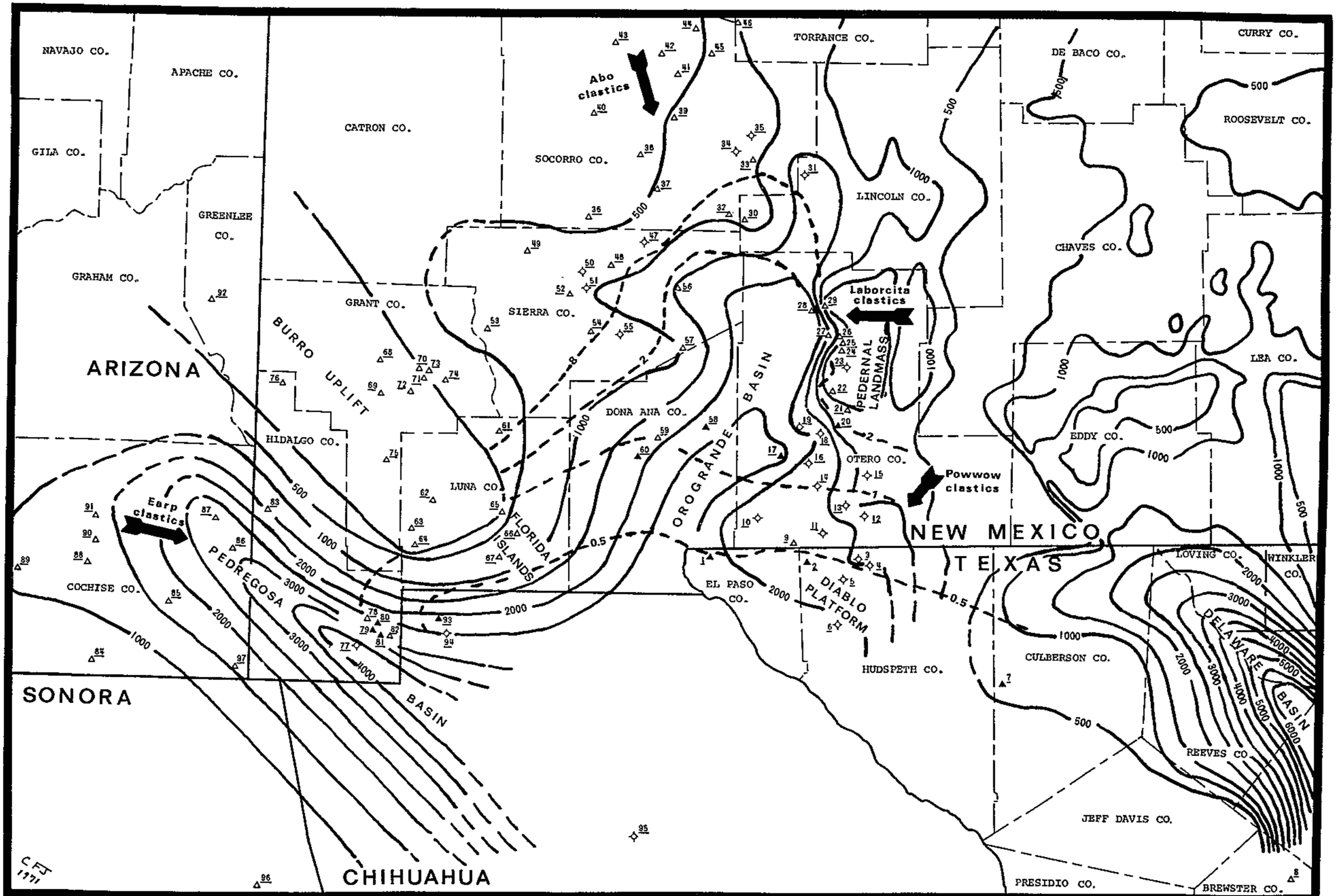
△ others

Oil tests ⌖

—— Isopach interval 500 feet

— — Clastic ratio

48 Control point number (see Tables 1 & 5)



NAVAJO CO.
APACHE CO.
GILA CO.
GRAHAM CO.
GREENLEE CO.
CATRON CO.
SOCORRO CO.
TORRANCE CO.
DE BACO CO.
CURRY CO.
ROOSEVELT CO.
LINCOLN CO.
CHAVES CO.
GRANT CO.
SIERRA CO.
LEA CO.
DONA ANA CO.
HIDALGO CO.
LUNA CO.
OTERO CO.
EDDY CO.
COCHISE CO.
EL PASO CO.
HUDSPETH CO.
CULBERSON CO.
LOVING CO.
WINKLER CO.
REEVES CO.
JEFF DAVIS CO.
PRESIDIO CO.
BREWSTER CO.
ARIZONA
NEW MEXICO
TEXAS
SONORA
CHIHUAHUA
Abo clastics
Laborcita clastics
Powwow clastics
Earp clastics
BURRO UPLIFT
FLORIDA ISLANDS
PEDREGOSA BASIN
OROGRANDE BASIN
PEDERNAL LANDMASS
DIABLO PLATFORM
DELAWARE BASIN
CFJ 1971

	WEST TEXAS		SOUTHERN NEW MEXICO							NORTHERN CHIHUAHUA
MEASURED SECTIONS	Hueco Mountains	Franklin Mountains	Sierra Diablo	South Sacramento Mountains	Jarilla Mountains	South San Andres Mountains	Robledo Mountains	Big Hatchet Mountains Borrego Section	Big Hatchet Mountains Bugle Ridge	Sierra Palomas
FORMATIONS CONSIDERED	Hueco Group	Hueco Group	Hueco Ls. w/ Powwow Mbr.	Hueco Ls. Abo Fm.	LaBorcita Fm. Hueco Ls.	Hueco Ls. Abo Fm.	Hueco Ls. Abo Fm.	Horquilla Ls. Colina Ls. Earp Fm.	Horquilla Ls. Colina Ls. Earp Fm.	Horquilla Fm Colina Ls. Earp Fm.
TOTAL THICKNESS	1515'	2092'	660'	880'	2505'	1792'	1818'	2827'	2902'	2315'
% conglomerate	4	0	2	1	2	0	0	0	0	0
% sandstone	0	0	2	2	15	0	1	3	3	2
% red siltstone	0	0	0	19	0	5	6	5	4	0
% gray siltstone	0	4	0	2	2	6	5	2	0	0
% red shale	11	0	15	4	0	10	14	27	27	6
% gray shale	17	28	6	40	48	40	23	27	9	21
TOTAL CLASTICS	32	32	25	68	67	61	49	64	43	29
TOTAL LIMESTONE	68	68	75	32	33	39	51	36	57	71
CLASTIC RATIO	0.47	0.47	0.33	2.12	2.03	1.51	0.96	1.77	0.76	0.41
Limestone Proportions:										
Normal marine	38	87	36	30	90	71	70	51	89	83
Shoal-water	43	3	38	0	4	16	17	0	0	0
Biohermal	19	10	0	0	6	13	13	38	4	0
Restricted	0	0	26	70	0	0	0	11	7	17

Table 4

Table 5

Stratigraphic Units comprising total thickness of Wolfcampian interval shown on isopach map

Key:

H = Hueco Lb.
Ht = Hueco tongue
A = Abo Fm.
At = Abo tongue

B = Bursum Fm.
L = Laborcita Fm.
Hr = Horquilla Ls.
E = Earp Fm.

C = Colina Ls.
PS = Panther Seep Fm.
UM = Upper Magdalena
LH = Lenox Hills Fm.

NR = Neal Ranch Fm.
\+ = incomplete sections
e = eroded
TW = Total Wolfcampian

No.	Wolfcampian Formations & Thicknesses (feet)	TW (in feet)
1	H 2092, PS ?	2092 +
2	H 1515, UM ?	1515 +
3	H 1243	1243
4	H 1710	1710
5	H 315 +	315 +
6	H 2149 ?	2149 ?
7	H 660	660
8	LH 270, NR 300	570 e
9	H 1140, UM ?	1140 +
10	H 420 +	420 +
11	AH 2788	2788
12	H 1110, A 156	1266
13	AH 1050	1050
14	H 1000 +	1000 +
15	H 915	915
16	H 815 +	815 +
17	H 980 +, L&PS 1525	2505 +
18	B 470, AH 1520	1990
19	AHB 1940	1940
20	A 150?, Ht 625, A 106	880
21	Ht 335, A 220	555
22	Ht 50, A 300	350
23	Ht 40, A 230	270
24	A 250	250
25	L0, A 430	430
26	L 75, A 770	845
27	L540, A 990	1530
28	L1000, A1400	2400
29	L0, A 200	200
30	B235, A585	820
31	B?, A1545	1545 +
32	B325, A610 +	935 +
33	B150, A790	940
34	B?, A706	706 +
35	B?, A840	840 +
36	A +	+
37	B+, A+	+
38	oe	0
39	B 95, A 500	595
40	A 175 e	175 +
41	B 177, A +	177 +
42	B 30, A +	30 +
43	B +, A +	+
44	B200, A +	200 +
45	B125, A +	125 +
46	A915	915
47	A705	705
48	A +	+
49	A920	920

No.	Wolfcampian Formations & Thicknesses (feet)	TW (in feet)
50	A1390 ?	1390 ?
51	A940	940
52	A +	+
53	A 700 e	700 +
54	A 750	750
55	Ht220, A585	805
56	B267, H417, A835	1519
57	B 76, H325, A613	1014
58	PS170 +, H1440, A352	1962 +
59	H1550 ?, At 300 ?	1850 +
60	H1054, A414, H350	1818 +
61	A 150 e	150 +
62	0	0
63	0	0
64	0	0
65	0	0
66	H350+	350 +
67	H525+	525 +
68	0	0
69	0	0
70	0	0
71	0	0
72	0	0
73	A120e	120 +
74	A207e	207 +
75	0	0
76	0	0
77	Hr2550, E1020,C800	4370
78	Hr1550? (E 997, C 355)	2902 ?
79	Hr1475+ (E 997, C 355)	2827 +
80	Hr1550+ (E 997, C 355)	2902 +
81	Hr ?, E 997, C 355	--
82	Hr 855+ (E997, C355)	2207 +
83	Hr 200, E 830+,C500+	1530 +
84	E 143, C ?	143 +
85	E 680, C 1000	1680
86	E2400, C 500	2900
87	E2400, C 535	2935
88	E 595, C 633	1228
89	E 780, C 600	1380
90	E 577, C 450+	1027+
91	E 960, C 441	1401
92	0	0
93	Hr 1245, E 730, C 340	2315
94	Hr 1453, C&E 1043	2496
95	Hr 1000-6500?, E 0, C 0	1000-6500?
96	0	0
97	E 671 +, C 300 +	971 +

(figure 6). Table 1 lists the sources of data for each control point on the map. Isopachs in southeastern New Mexico are from Meyer (1966) and those in west Texas are from Galley (1958). Their control points are too numerous to be shown on the map and do not appear in Table 1.

Geometric configurations of major tectonic elements are illustrated by isopach lines in figure 26. The core of the Pedernal Landmass is located in northeastern Otero County where Wolfcampian strata thin primarily by stratigraphic convergence to 200 feet. A major unconformity below these strata over the Pedernal Uplift commonly places Wolfcampian over Precambrian rocks. Evidently this area displayed considerable relief in the early Permian and was the source area for coarse clastics of the Laborcita Formation, the Powwow Member, and lower Abo Redbeds. Only in a few localities in the Sacramento Mountains does the Yeso Formation overlie Precambrian rocks(Kottlowski, written communication); thus, sheets of fine Abo clastics nearly buried the irregular paleotopography of the Pedernal Landmass prior to Yeso deposition. In the area of the present southern Sacramento Mountains, the Pedernal Landmass was a source only for lower Wolfcampian sediments.

The Diablo Platform in west Texas is a southern extension of the uplift associated with the Pedernal Landmass. This positive area was submerged in Wolfcampian time but separated the Delaware Basin to the east from the Orogrande Basin to the northwest. Oldest Permian strata were probably not deposited over the platform, as a regional unconformity below upper and middle Wolfcampian strata in this area is overlain by pebble and cobble conglomerates constituting the Powwow Member. The platform subsided in upper Wolfcampian time and shoal-water limestones were deposited across it. Water depth is thought to have increased slightly for subsequent development of micritic algal plate bioherms which formed below effective wave base. A minor pulse of renewed uplift is indicated by about 100 feet of red shale in upper strata over the platform.

Less is known about the late Paleozoic Florida Islands in southern Luna County, New Mexico. Kottlowski (1958, 1963) reported thin sections of Wolfcampian with basal conglomerates resting unconformably over pre-Virgilian strata. No fusulinid data are presently available, but carbonate deposition in this area probably occurred in middle to upper Wolfcampian time. Precise determination of the age of late Paleozoic uplift here is complicated by Mesozoic erosion associated with the Burro Uplift to the northwest which stripped the top off Permian strata in the Florida area. Kottlowski (1965) considered the Florida islands as the forerunner of the much larger positive feature, the Burro Uplift.

West of the Pedernal Landmass, the Orogrande Basin received thick deposits of Mississippian through Wolfcampian sediments. Permian deposits represent final filling stages of the basin; shallow water features are found in the Laborcita Formation and Hueco Limestone of the Jarilla Mountains, near the center of the basin and may indicate drastic sea level fluctuations within the basin (Wilson, 1967). Minimum thicknesses are shown in figure 26, since the upper and lower boundaries of the Wolfcampian cannot be readily determined in the San Andres and Jarilla Mountains. The Orogrande Basin has a very narrow eastern shelf adjacent to the Pedernal Landmass, along which local occurrences of Wolfcampian patch reefs have been described (Otte 1954). Although data is somewhat sparse, wide shelves apparently existed on the western side of the Orogrande Basin. Generally, the axis of the basin runs north-south; at the southern end, however, a westward protrusion of the Diablo Platform offsets the axis to the west. Wolfcampian sedimentary fill in the basin initially consisted of Laborcita clastics shed from the Pedernal Landmass. By middle Wolfcampian time, the Pedernal had stopped rising and shallow water carbonates of the Hueco Limestone were deposited. Finally, floods of fine red clastics came from distant northern sources to nearly fill the basin. The overlying Yeso Formation here represents a post-basinal stage of evaporite deposition.

Continuous deposition persisted from Lower Mississippian through Middle Permian in the Pedregosa Basin in extreme southwestern New Mexico. (Zeller, 1965; Kottlowski, 1965). Excellent exposures of the Wolfcampian shelf-to-basin transition occur in the Big Hatchet Mountains, and oil tests by Humble and Pemex indicate thick basinal sequences, possibly as much as 4,500 feet of Wolfcampian sediments in the Villa Ahumada well in Chihuahua (Wilson et al., 1969). Control is sparse northwest and southwest of the basin; Sierra de Teras Bavispe in Sonora, with no Wolfcampian sediments, does limit the southwestern flank of the basin. The total Pennsylvanian section here thins by convergence, indicating a basin flank at least this early; thin Wolfcampian sediments (if ever present) were apparently eroded in pre-Leonardian time. As formations become younger eastward in this area, all Wolfcampian thicknesses in Arizona (Table 5) exclude the Horquilla Limestone. Zeller (1965) stated that eastward progressions of Earp clastics prohibited development of the Horquilla facies; Earp clastics did not reach New Mexico until middle or upper Wolfcampian time. Actually, later parts of this progradation are quite rapid: uppermost Horquilla beds are Virgilian to upper Derryan in the Peloncillos (Gillerman, 1958) and middle Wolfcampian in the Big Hatchet Mountains, 50 miles to the south (figure 6).

Relative amounts of red clastics, nonred clastics, and carbonates (figure 28) observed in Wolfcampian sections of this report reflect different source areas for the Earp, Abo, Laborcita, and Powwow clastics. In earliest Wolfcampian time, fine sand and silt of the Laborcita Formation were shed from the Pedernal into the Orogrande Basin. Middle to upper Wolfcampian red shales and fine-grained siltstones of the Abo Formation originated from distant highlands in northern New Mexico and southern Colorado. Great floods of this fine red detritus were transported down the axis of the Orogrande Basin, resulting in complex north to south intertonguing relationships with the Hueco Limestone (e.g. Danley Ranch Tongue, Lee Ranch Tongue, Deer Mountain Red Shale Member). At this same time, locally derived conglomerates were deposited as the Powwow Member of the Hueco Limestone on the Diablo Platform. Westward, in southern Arizona, during Virgilian time, red siltstones, shales, and silty limestones of the Earp Formation were deposited in a deltaic environment (Lodewick, 1970); Earp clastics advanced eastward through the middle to upper Wolfcampian. Kottlowski (1963) suggested that the clastic ratio of 8 : 1, shown in figure 26, is a reasonable estimate of average Wolfcampian shorelines.

Since only relative proportions of limestone are indicated by clastic ratios, figure 27 was designed to show the distribution and major types of limestone observed in measured sections. Shoal, bioherm, and normal marine facies have been discussed previously in this report; restricted

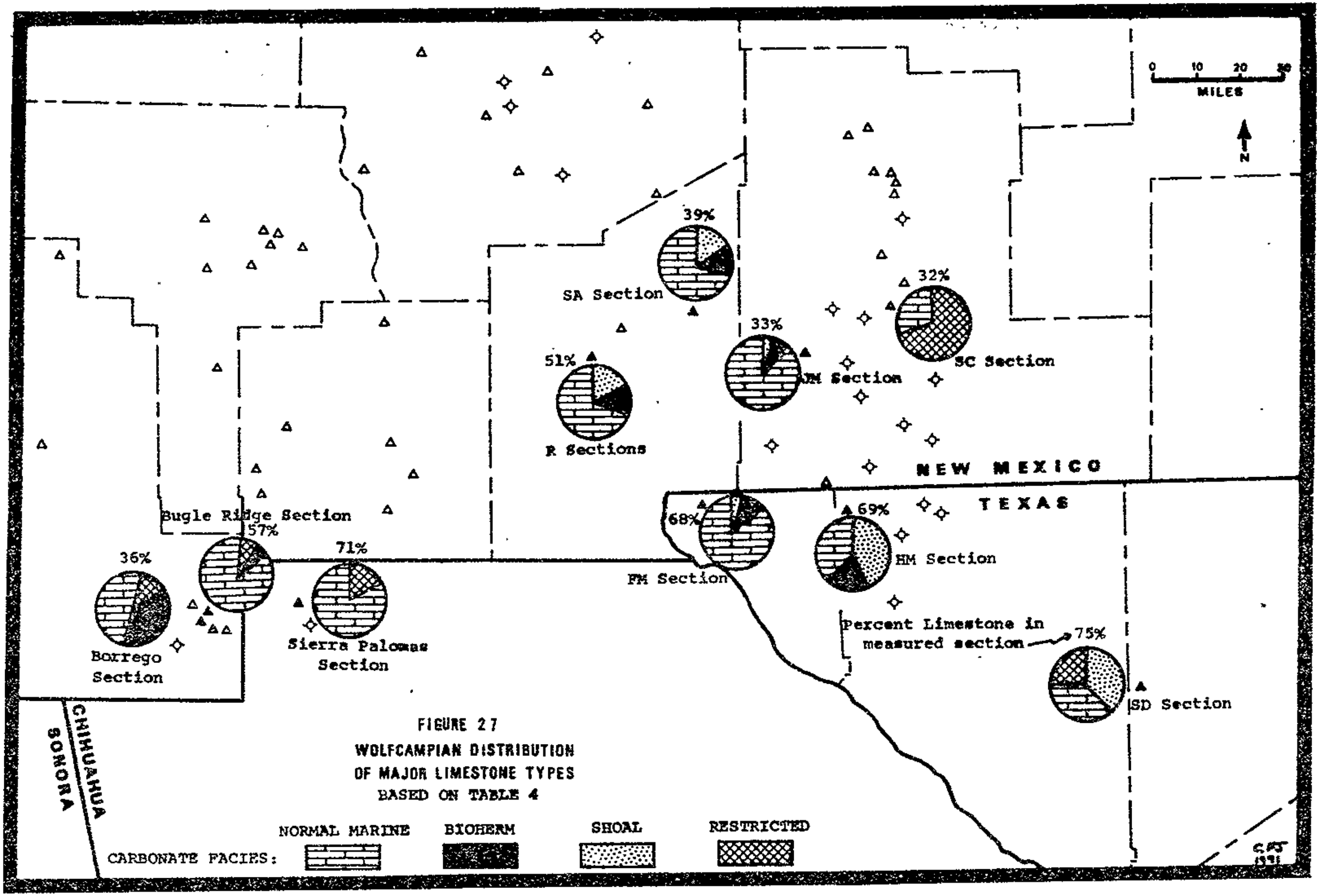


FIGURE 27
WOLFCAMPIAN DISTRIBUTION
OF MAJOR LIMESTONE TYPES
BASED ON TABLE 4

Figure 28: Ternary diagram showing relative proportions of sedimentary rock types and the characteristic effects of clastic units on total Wolfcampian sections.

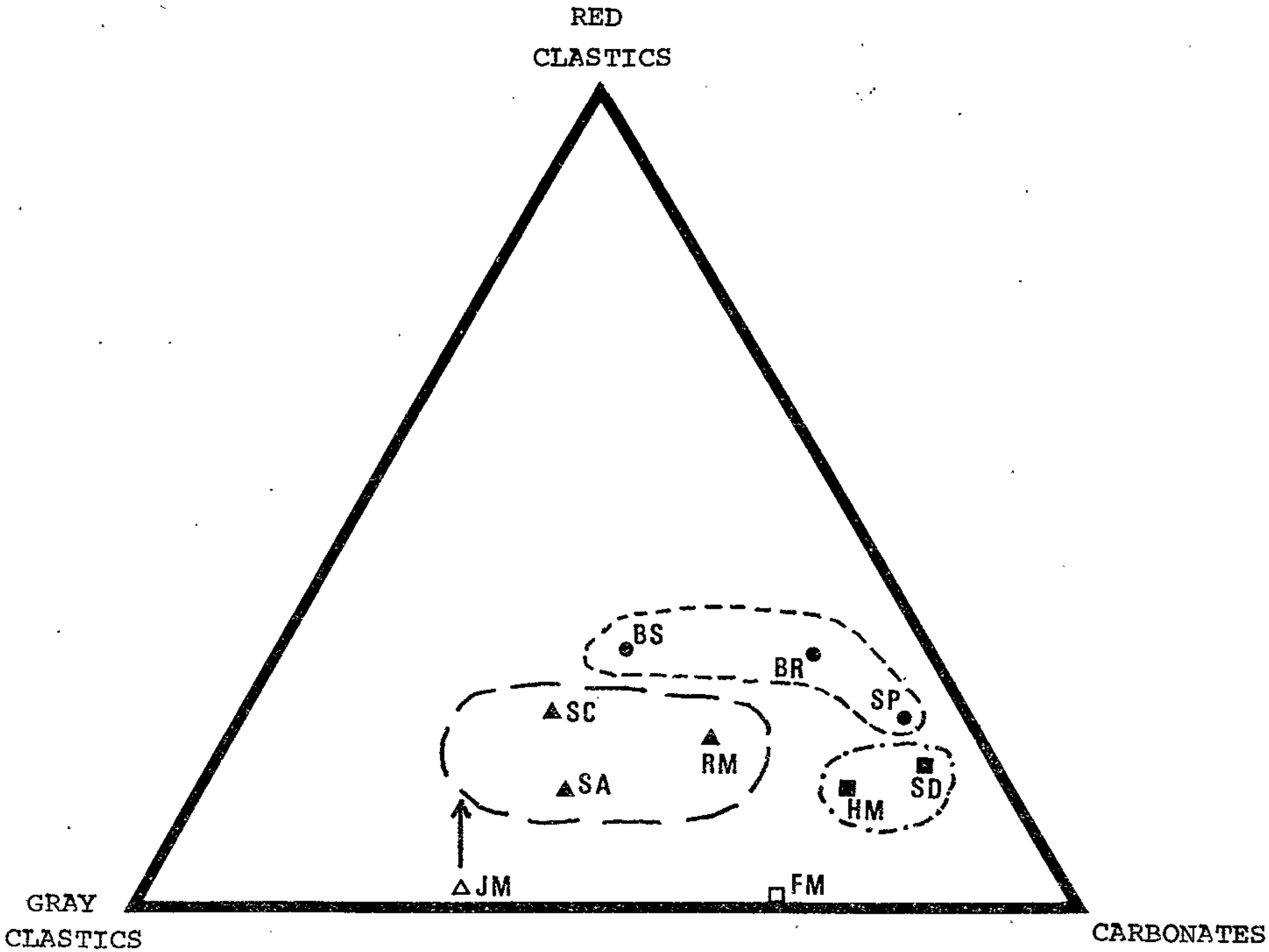
Letters refer to section titles.

● = sections encountering the Earp Formation

■ = sections encountering the Powwow Member

▲ = sections encountering the Abo Formation

It appears that the Abo Formation was assimilated by igneous intrusives at the top of the Jarilla Mountains section and that point JM on the diagram may belong to the field including Abo sections.



RED CLASTICS
BS
BR
SP
SC
RM
SA
HM
SD
JM
FM
GRAY CLASTICS
CARBONATES

limestone here include lagoonal and near-shore carbonates, evaporites and dolomites. Shoal facies with wornstone textures are best developed over the Diablo Platform. Similar facies occurring primarily on the western side of the Orogrande Basin contain more oolitic carbonates. Development of bioherms and platy algal beds is best on the shelf margin on the northeast side of the Pedregosa Basin and on the western edge of the Diablo Platform. To a lesser extent, these facies also occur on the western side and center of the Orogrande Basin. The presence of biohermal and shoal-water carbonates indicates shallow water conditions all across the Orogrande Basin during parts of Wolfcampian time. Restricted carbonates occur in lagoonal environments developed along the irregular front of the Pedernal Landmass and in lagoonal and near-shore conditions of post-Earp deposits on the northeast side of the Pedregosa Basin.

Age relationships and formation names and thicknesses are shown on Plate 11. Even with the assumption that the Yeso Formation and Epitaph Dolomite are entirely Leonardian, complete Wolfcampian sections (i.e. where Virgilian-Wolfcampian and Wolfcampian-Leonardian boundaries can be recognized) are seldom available. Delineation of the upper Wolfcampian-middle Wolfcampian boundary is difficult in New Mexico due to the absence of Monodiexodina, whose distribution is apparently controlled by a preference for sandy or clean calcarenite facies. Where possible, Schwagerina species were used to indicate the top of the middle Wolfcampian.

Correlations of carbonate and clastic facies, superimposed upon this biostratigraphic framework, are also illustrated on Plate 11. Detailed stratigraphic information is shown for all major tectonic elements of the study area except the Florida Islands, for which only general thicknesses and lithologies are know. As indicated by the fence diagram, several phases of sedimentation can be recognized during the Wolfcampian. These phases are asynchronous and generally become younger eastward and possibly southward. Phase 1 includes a great thickness and variety of rock types, but is characterized by pre-Abo sequences of interbedded shoal-water, biohermal, and shelf limestones. Generally, shallow water carbonates are best developed in lower parts of this phase and are overlain by shelf sequences that commonly contain facies transitional with the Abo. Typical examples of phase 1 sedimentation appear in lower sections of the Jarilla, southern San Andres, Robledo, Franklin, and Hueco Mountains, as shown in the fence diagram. Regional variations in this phase include early Wolfcampian erosion of the Pedernal Landmass and Diablo Platform, which resulted in nearshore deposition of the Laborcita clastics and Powwow conglomerates. To the southwest, in the Pedregosa Basin, carbonate sedimentation includes thick bioherms, but shoal facies are lacking.

Phase 2 consists basically of regressive fine-grained red-bed deposits. Its constituent lithic units to the west and north, the Earp and Abo Formations are correlated with the Cerro Alto Limestone on the Diablo Platform. This is based on general age relationships and the low-diversity fusulinid fauna of the Cerro Alto. Due to these correlations, red-beds above and below the Cerro Alto (i. e. the Deer Mountain Red Shale and the Powwow Member) on the Diablo Platform are excluded from phase 2. They were derived from different source areas than Abo clastics, consist of distinctly different rock types, and are of different ages. Further evidence of their exclusion from phase 2 is based on precise correlation of the Cerro Alto Limestone between the Franklin and Hueco Mountains, as determined by fusulinid subzones and carbonate facies. Bioherms in phase 2 are developed best in the Hueco Mountains, far from the clastic influence of Abo sediments.

Phase 3 represents post-Abo transgressive deposition of bioherm, shelf, and lagoonal carbonates. Correlation of upper biohermal units between the Robledo, Franklin, and Hueco Mountains further substantiates the equivalence of the Abo Formation and Cerro Alto Limestone. The Colina Limestone is included in phase 3 primarily due to its stratigraphic position above the Earp and general age relationships.

In summary, Wolfcampian strata of southern New Mexico and west Texas display three major phases of sedimentation that correspond to the threefold division recognized several years ago in the type Hueco Limestone. North to south interbeds of limestone and red-beds in the Orogrande Basin are correlated on the basis of the Cerro Alto-Abo equivalence. Powwow and Deer Mountain clastics on the Diablo Platform are local features and correlate northward across time lines with Abo clastics in the southern Sacramento Mountains. Wolfcampian strata of the Pedregosa Basin are correlated with the Orogrande Basin and Diablo Platform on the basis of fusulinid zonation and facies relationships. A similar threefold division is recognized here and the Horquilla Limestone correlates with the Hueco Canyon Formation, the Earp with the Abo and Cerro Alto, and the Colina with the Alacran Mountain Formation.

REFERENCES

Adams, J. E., et al., 1939, Standard Permian Section of North America, AAPG Bull., vol. 23, p. 1673-1681.

Bachman, George O. & Hayes, Philip T., 1958, Stratigraphy of Upper Permian Rocks in the Sand Canyon Area, Otero County, New Mexico, Geol. Soc. Am. Bull., p. 689-700.

Diaz G., Teodoro & Navarro G., Arsenio, 1964, Lithology and Stratigraphic Correlations of the Upper Paleozoic in the Region of Palomas, Chihuahua, West Texas Geol. Soc., Guidebook of Geology of Mina Plomosas-Placer de Guadalupe Area, p. 65-84.

Dirks, Thomas N., 1966, The Upper Paleozoic Stratigraphy of the Quimby Ranch Area, Southern Guadalupe Canyon Quadrangle, Cochise County, Arizona, Master's Thesis, University of Arizona, 70 pages.

Dunbar, C. O., 1953, A Zone of Pseudoschwagerina low in the Leonard Series in the Sierra Diablo, Trans-Pecos Texas, Am. Jour. Sci., vol. 251, p. 798-813.

Dunbar, C. O., 1960, Correlation of the Permian Formations of North America, Geol. Soc. Am. Bull, vol. 71, p. 1763-1806.

Dunbar, C. O., 1963, Trends of Evolution in American Fusulines in Evolutionary Trends in Foraminifera, Elsevier Publishing Co., New York.

Dunbar, C. O. & Skinner, J. W., 1931, New Fusulinid Genera from the Permian of West Texas, Am. Jour. Sci., 5th ser., vol. 22, p. 252-268.

Dunbar, C. O. & Skinner, J. W., 1937, Permian Fusulinidae of Texas in The Geology of Texas, Texas Univ. Bull. 3701, vol. 3.

Dunham, R. J., 1970, Stratigraphic Reefs versus Ecologic Reefs, AAPG Bull., vol. 54, p. 1931-33.

Epis, R. C., 1956, Geology of the Pedregosa Mountains, PhD Thesis, Univ. of Calif, 181 pp.

Foster, R. W., 1957, Stratigraphy of west-central New Mexico, Four Corners Geol. Soc. Guidebook of Southwestern San Juan Basin, p. 62-72.

Galley, J. E., 1958, Oil and Geology in the Permian Basin of Texas and New Mexico, in Habitat of Oil, Banta Publishing Co., Menasha, Wisconsin p. 395-446.

Gillerman, Elliot, 1958, Geology of the Central Peloncillo Mountains, Hidalgo County, New Mexico and Cochise County, Arizona, State Bureau of Mines and Mineral Resources, Bull. 57, 152 pp.

Gilluly, James, 1956, General Geology of Central Cochise County, Arizona, Geol. Survey Prof. Paper 281, 169 pp.

Gilluly, James, Cooper, J. R. and Williams J. S., 1954, Late Paleozoic Stratigraphy of Central Cochise County, Arizona, U. S. Geol. Surv., Prof. Paper 266, 49 pp.

Hardie, S. H., 1958, The Geology of a part of the Hueco Mountain, Otero Co., New Mexico, Master's Thesis, Univ. of Illinois, Urbana, Ill.

Hay-Roe, Hugh, 1957, Geology of Wylie Mountains and Vicinity, Culberson and Jeff Davis Counties, Texas, Geologic Quadrangle Map No. 21, Bur. of Economic Geology, Univ. of Texas.

Henbest, L. G., 1963, Biology, Mineralogy, and Diagenesis of Some Typical Late Paleozoic Sedentary Foraminifera and Algal-Foraminiferal Colonies, Cushman Foundation for Research, Spec. Pub. No. 6.

Jahns, R. H., 1955, Geology of the Sierra Cuchillo, New Mexico Geol. Soc., Guidebook, South-Central New Mexico, p. 158-174.

Jicha, H. L., 1954, Geology & Mineral Resources of the Lake Valley Quad. N. M. New Mexico Bur. of Mines & Mineral Resources., Bull. 37, 93 pp.

Johnson, J. H., 1963, Pennsylvanian and Permian Algae, Colo. School of Mines Quarterly, vol. 58, no. 3, 211 p., 81 plates.

Jordan, C. F. Jr. & Wilson, J. W., 1971, The Late Paleozoic Section of the Franklin Mountains (in press), SEPM-West Texas Geological Society Guidebook.

Kelley, V. C. & Silver, C., 1952, Geology of the Caballo Mountains, New Mexico Univ. Pub. Geol. Ser., no. 4, 286 pp.

King, P. B., 1965, Geology of the Sierra Diablo Region, Texas, USGS Prof. Paper 480, 185 pp.

King, P. B., King, R. E., & Knight, J. B., 1945, Geology of the Hueco Mountains, El Paso and Hudspeth Counties, Texas, USGS, Oil and Gas Inv. Prelim. Map 36.

Klement, K. W. & Toomey, Donald F., 1967, Role of the Blue-Green Algae Girvanella in Skeletal Grain Destruction and Lime-Mud Formation in the Lower Ordovician of West Texas, Jour. Sed. Pet., Vol. 37, no. 4, pp. 1045-1051.

Konishi, Kenji & Wray, J. L., 1961, Eugonophyllum, A New Pennsylvanian and Permian Algal Genus, Jour. Paleo., Vol. 35, no. 4, p. 659-667.

Kottlowski, F. E., 1958, Pennsylvanian and Permian Rocks Near the Late Paleozoic Florida Islands, Roswell Geol. Soc. Guidebook, Hatchet Mnts. and the Cooks Range—Florida Mnts. Area, p. 79-87.

Kottlowski, F. E., 1963, Paleozoic & Mesozoic Strata of Southwestern and South-Central New Mexico, N. M. Inst. Min. & Tech., St. Bur. of Mines & Mineral Resources, Bull. 79, 100pp.

Kottlowski, F. E., 1965, Sedimentary Basins of South-Central and Southwestern New Mexico, AAPG, p. 2120-2139.

Kottlowski, F. E., Thompson, M. L. & Foster, R. W., 1956, Stratigraphic Studies of the San Andres Mountains, New Mexico, New Mexico Instit. Min. & Tech., State Bureau of Mines & Mineral Resources, Mem. 1, 132 pp.

Kottlowski, F. E. & Foster, R. W, 1962, Pre-Tertiary Strata of Tres Hermanas Mountains, Luna County, New Mexico, AAPG Bull., vol. 46, p. 2090-2098.

Kottlowski, F. E., Foster, R. W., & Wengerd, S. A., 1969, Key Oil Tests and Stratigraphic Sections in Southwestern New Mexico, New Mexico Geol. Soc., Guidebook, p. 186-196.

Kottlowski, F. E., & Stewart, W. J., 1970, The Wolfcampian Joyita Uplift in Central New Mexico, New Mexico Instit. Min. Tech., State Bureau Mines and Mineral Resources., Memoir 23, Part I, p. 1-31.

Kuellmen. F. J., 1954, Geologic Section of the Black Range at Kingston, New Mexico, New Mexico Instit. Min. & Tech., State Bur. Mines & Mineral Resources, Bull. 33, 100 pp.

Lodewick, R. B., 1970, The Petrology & Stratigraphy of the Earp Formation, Pima & Cochise Counties, Arizona, PhD Thesis, Univ. of Arizona.

Majewske, O. P., 1969, Recognition of Invertebrate Fossil Fragments in Rocks and Thin Sections, Brill Pub., Netherlands.

Malek-Aslani, M., 1970, Lower Wolfcampian Reef in Kemnitz Field, New Mexico, AAPG Bull., vol. 54, p. 2317-2335.

Meyer, R. F., 1966, Geology of Pennsylvanian and Wolfcampian rocks in Southeast New Mexico, New Mexico Instit. Min. Tech., State Bureau Mines and Mineral Resources, Mem. 17, 123 pp.

Needham, Claude Erwin, 1937, Some New Mexico Fusulinidae, New Mexico Bureau of Mines and Mineral Resources, Bull. no. 14.

Needham, C. E. & Bates, R. L., 1943, Permian Type Sections in Central New Mexico, Geol. Soc. Amer., Bull., vol. 54, p. 1653-1667.

Newell, N. D. et al., 1953, The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico, Freeman and Co., San Francisco.

Oppel, T. W., 1959, The Pennsylvanian-Permian contact in Lower Fresnal Canyon, Sacramento Mountains, New Mexico, Roswell Geol. Soc. Guidebook of Sacramento Mountains, p. 186-195.

Otte, C., Jr., 1954, Wolfcampian reefs of the Northern Sacramento Mountains, Otero County, New Mexico, Geol. Soc. Am. Bull., vol. 65, pt. 2.

Otte, C., 1959, Late Pennsylvanian and Early Permian Stratigraphy of the N. Sacramento Mountains, New Mexico Bureau of Mines Bull. 50.

Otte, C., Jr. & Parks, J. M., Jr., 1963, Fabric Studies of Virgil and Wolfcamp Bioherms, New Mexico, Jour. of Geol., vol. 71, no. 3, p. 380-396.

Plummer, H. J., 1948, Morphology of Globivalvulina, Amer. Midland Nat., vol. 39, p. 169-173.

Pray, L. C., 1961, Geology of the Sacramento Mountains Escarpment, Otero County, New Mexico, New Mexico Instit. Min. Tech., State Bureau Mines and Mineral Resources, Bull. 35, 144 pp.

Rauser-Chernoussova, D. M., 1948, Contributions to the foraminiferal Fauna of the Carboniferous deposits of Central Kazakhstan, Geol. Instit. Nauk, Trudy, Akad. Nauk, S.S.S.R., 66 pp.

Read, C. B., 1957, Paleobotonical Zones in the Upper Paleozoic Rocks, (abs.) New Mexico Geol. Soc., Guidebook, Southwestern San Juan Mountains, p. 257-258.

Rich, Mark, 1970, The Genus Tuberitina (Foraminiferida) in Lower and Middle Pennsylvanian Rocks from the Eastern Great Basin, Jour. of Paleontology, Vol. 44, p. 1060-1066.

Rigby, J. K., 1958, Two New Upper Paleozoic Hydrozoans, Jour. of Paleontology, vol. 32, p. 583-586.

Ross, C. A., 1962, Evolution and Dispersal of the Permian Fusulinid Genera Pseudoschwagerina and Parashcwagerina, Evolution, vol. 16, p. 306-315.

Ross, Charles A., 1963, Standard Wolfcampian Series (Permian), Glass Mountains, Texas Geol. Soc. Memoir 88.

Ross, C. A., & Tyrell, Willis W., Jr., 1965, Pennsylvanian and Permian Fusulinids from the Whetstone Mountains, Southeast Arizona, Jour. of Paleontology, vol. 39, p. 615-635.

Sabins, F. F., Jr., 1967, Stratigraphic Relations in Chiricahua and Dos Cabezas Mountains, Arizona, AAPG Bull., vol. 41, p. 466-510.

Sabins, F. F., Jr., & Ross, C. A., 1963, Stratigraphy and Fusulinids of the Naco Group in Chiricahua and Dos Cabezas Mountains, Arizona, New Mexico Geol. Soc., Guidebook for the Sixteenth Field Conference, p. 148-157.

Sanderson, G. A. & Verville, G. J., 1970, Morphologic Variability of the Genus Schwagerina in the Lower Permian Wreford Limestone of Kansas, Paleontology, vol. 13, p. 175-183.

Schmidt, Paul G. & Craddock, Campbell, 1964, The Geology of the Jarilla Mountains, Otero County, New Mexico, New Mexico Instit. of Mines & Tech., State Bureau of Mines and Mineral Resources, Bull. 82, 55 pp.

Steiner, Maureen B. & Williams, T. E., 1968, Fusulinidae of the Laborcita Formation (Lower Permian), Sacramento Mountains, New Mexico, Jour. of Paleontology, vol. 42, p. 51-60.

Stewart, W. J., 1968, Schubertellinae from the Wolfcamp, Lower Permian, Franklin Mountains, Texas, Jour. Paleontology, vol. 42, p. 322-328.

Skinner, J. W. & Wilde, G. L., 1954, The Fusulinid Subfamily Boultoniinae, Jour. of Paleontology, vol. 28, p. 434-444.

Skinner, J. W. & Wilde, G. L., 1965, Lower Permian (Wolfcampian) Fusulinids from the Big Hatchet Mountains, Southwestern New Mexico, Contrib. from the Cushman Found. for Foram. Research, vol. XVI. 95-105.

Skinner, J. W. & Wilde, G. L., 1965, Permian Biostratigraphy and Fusulinid Faunas of the Shasta Lake Area, Northern California, Univ. of Kansas Paleontological Contributions, Protozoa, Article 6, 98 pp.

Skinner, J. W., & Wilde, G. L., 1966, Type Species of Pseudofusulina Dunbar & Skinner, Univ. of Kansas Paleont. Contrib., Paper 13, 8 pp.

Thompson, M. L., 1934, The Fusulinid Genus Staffella in America, Jour. Paleo., vol. 9, p. 111-120.

Thompson, M. L., 1948, Studies of American Fusulinids, Univ. Kans. Paleontological Contrib., Protozoa, Article 1, p. 1-184.

Thompson, M. L., 1954, American Wolfcampian fusulinids, Kansas Univ. Paleontological Contrib., no. 14, Protozoa, article 5, 226 pp., 52 pls.

Thompson, M. L., 1964, in Treatise on Invertebrate Paleontology, R. C. Moore, editor, p. C358-C432.

Thompson, M. L. & Kottlowski, F. E., 1955, Pennsylvanian & Lower Marine Permian Stratigraphy of South-Central New Mexico, Guidebook of South-Central New Mexico, New Mexico Geol. Soc., Sixth Field Conference, pp. 71-76.

Toomey, D. F., 1962, Note on a supposed "Algal-Foraminiferal Consortium" from the Permian of West Texas, Cushman Foundation, vol. XIII. part 2, p. 52-55.

Tovar, Jorge, 1969, Stratigraphic Study of the Sierra Santa Rita, New Mexico Geol. Soc., Guidebook of the Border Region, Twentieth Field Conference, p. 165-170.

White, M. P., 1932, Some Texas Fusulinidae, Univ. Texas Bull. no. 3211;

Williams, T. E. 1963, Fusulinidae of the Hueco Group (Lower Permian), Hueco Mountains, Texas, Peabody Museum of Natural History, Yale Univ., Bull. 18, 123 pp.

Williams, T. E., 1966, Permian Fusulinidae of the Franklin Mountains, New Mexico-Texas, Jour. of Paleontology, vol. 40, p. 1142-1156.

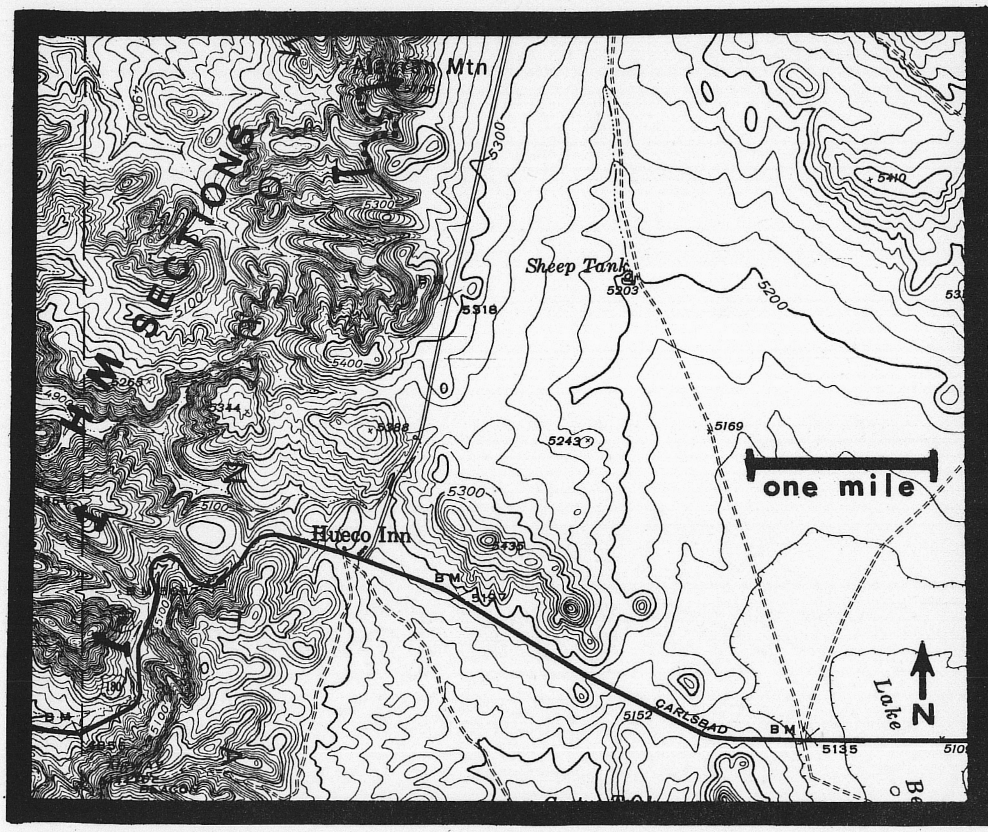
Wilpolt, R. H., Macalpin, A. J., Bates, R. L., & Vorbe, G., 1946, Geology of La Joya Area, Los Pinos Mountains and Northern Chupadera Mesa, USGS Oil & Gas Inv., Prelim. Map 61.

Wilson, James L., 1967, Cyclic and Reciprocal Sedimentation in Virgilian Strata of Southern New Mexico, Geol. Soc. Am. Bull., vol. 78, p. 805-818.

Wilson, James L., 1970, Depositional Facies Across Carbonate Shelf Margins, Transactions--Gulf Coast Assn. of Geol. Soc., vol. XX, p. 229-233.

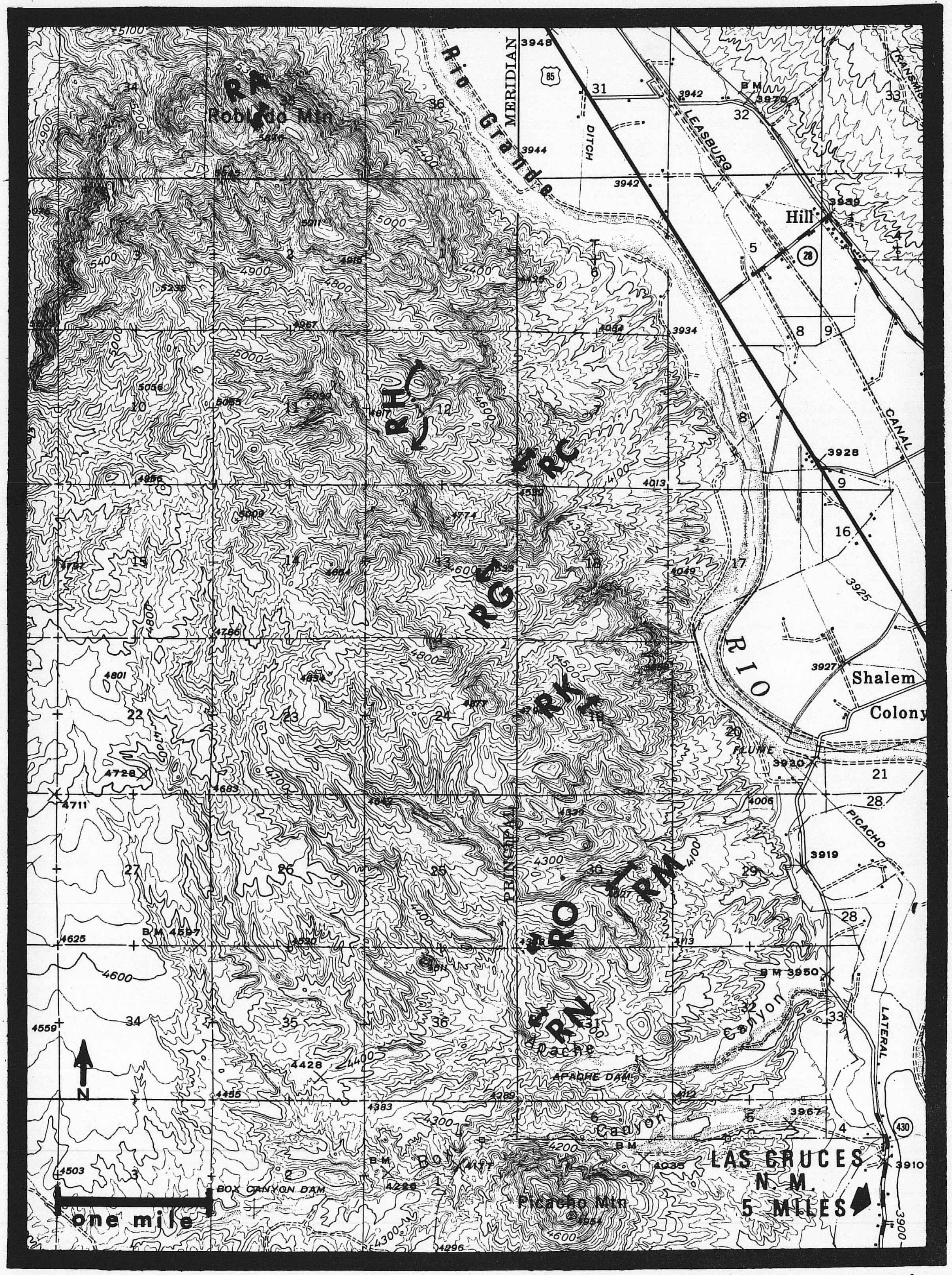
Wilson, James L., Madrid-Solis, A., & Malpica-Cruz, R., 1969, Microfacies of Pennsylvanian and Wolfcampian Strata in the Southwestern U.S.A. and Chihuahua, Mexico, New Mexico Geol. Soc., Guidebook of the Border Region, Twentieth Field Conference, p. 85-95.

Zeller, Robert A., Jr. 1965, Stratigraphy of the Big Hatchet Mountains Area, New Mexico, New Mexico Instit. Min. & Tech., State Bureau of Mines & Mineral Resources, Mem. 16, 128 pp.

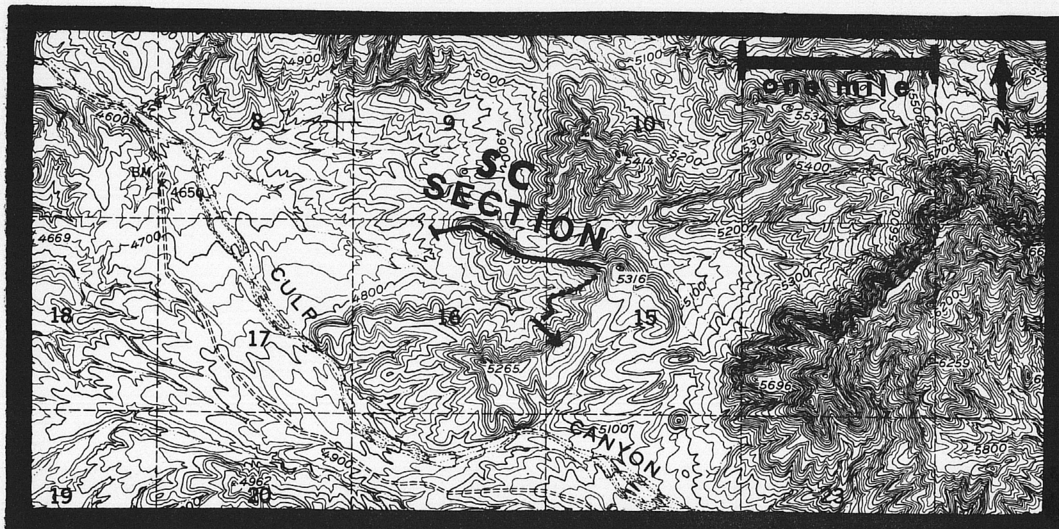


<u>Map I</u>: Hueco Mountains of West Texas. Composite Wolfcampian section measured in three HM sections in which strata become younger northward; map base from NW¼SE¼ of 15' Hueco Mountains Quadrangle (1941).

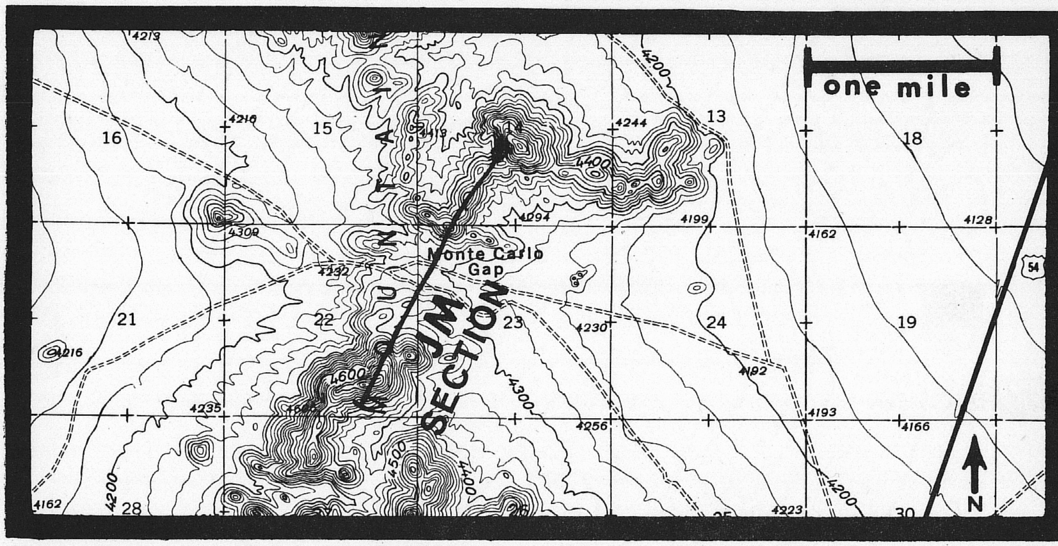
<u>Map II</u>: Franklin Mountains of West Texas. Wolfcampian section measured in the FM section; map base from S½NE¼ of 15' Canutillo Quadrangle (1917).



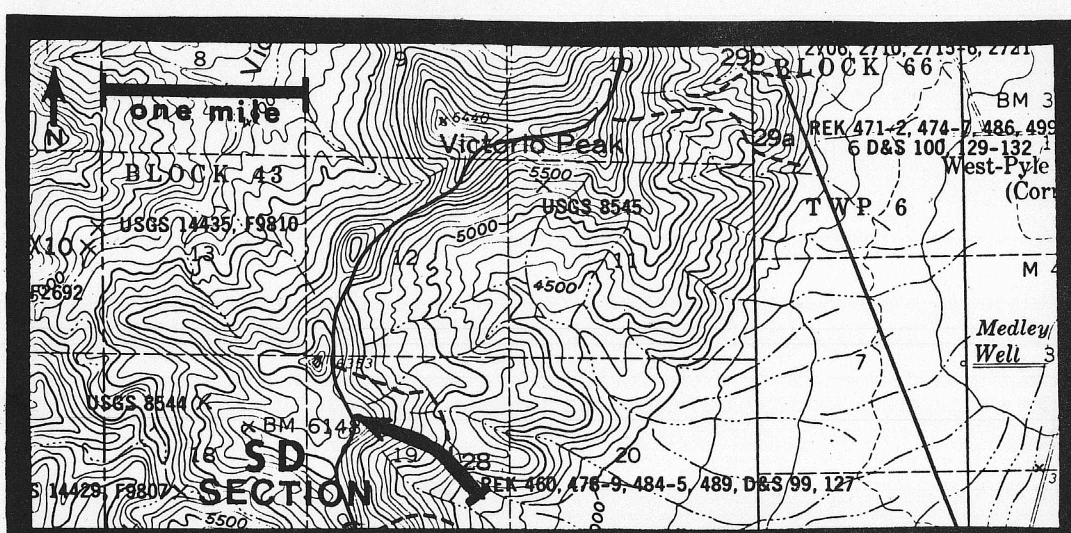
Map III: Robledo Mountains of southern New Mexico. Composite Wolfcampian section measured in eight components--from oldest to youngest, the RA, RC, RH, RG, RK, RM, RO, and RN sections; map base from center of 15' Las Cruces Quadrangle (1941).



Map IV: Sacramento Mountains (N. M.), SC section; map base from N½SE¼ of 15' Escondido Canyon Quadrangle (1950).

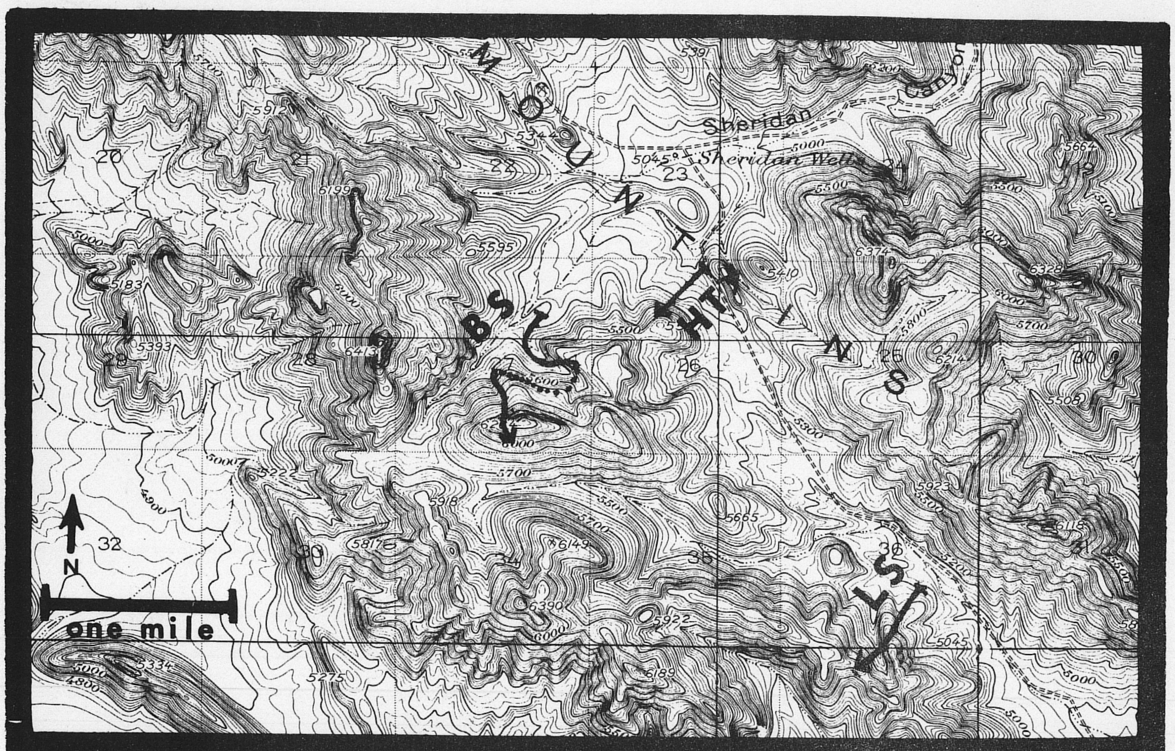


Map V: Jarilla Mountains (N.M.), JM section; map base from NW¼NE¼ of 15' Orogrande Quadrangle (1940).



Map VI: Sierra Diablo Mtns. (W. Texas), SD section; map base from USGS Professional Paper 480, P. B. King, 1965.

Map VII: San Andres Mountains of southern New Mexico. Composite Wolfcampian section measured in two components, upper and lower stratigraphic SA sections; based on S½SE¼ of 15' Bear Peak Quadrangle (1948).



Map VIII: Big Hatchet Mountains of extreme southwestern New Mexico. Composite Wolfcampian section measured in three components--from oldest to youngest, BS, HT, and LS sections which are abbreviations for Zeller's (1965) Borrego, Hale Tank, and Lower Sheridan Tank sections. Map base is from N½S½ of 15' Big Hatchet Peak Quadrangle (1937).

PLATE 1

HM SECTION

HUECO MOUNTAINS

WEST TEXAS

See Figure 25 for legend and
Appendix Map I for line of section

C F JORDAN JR 1971

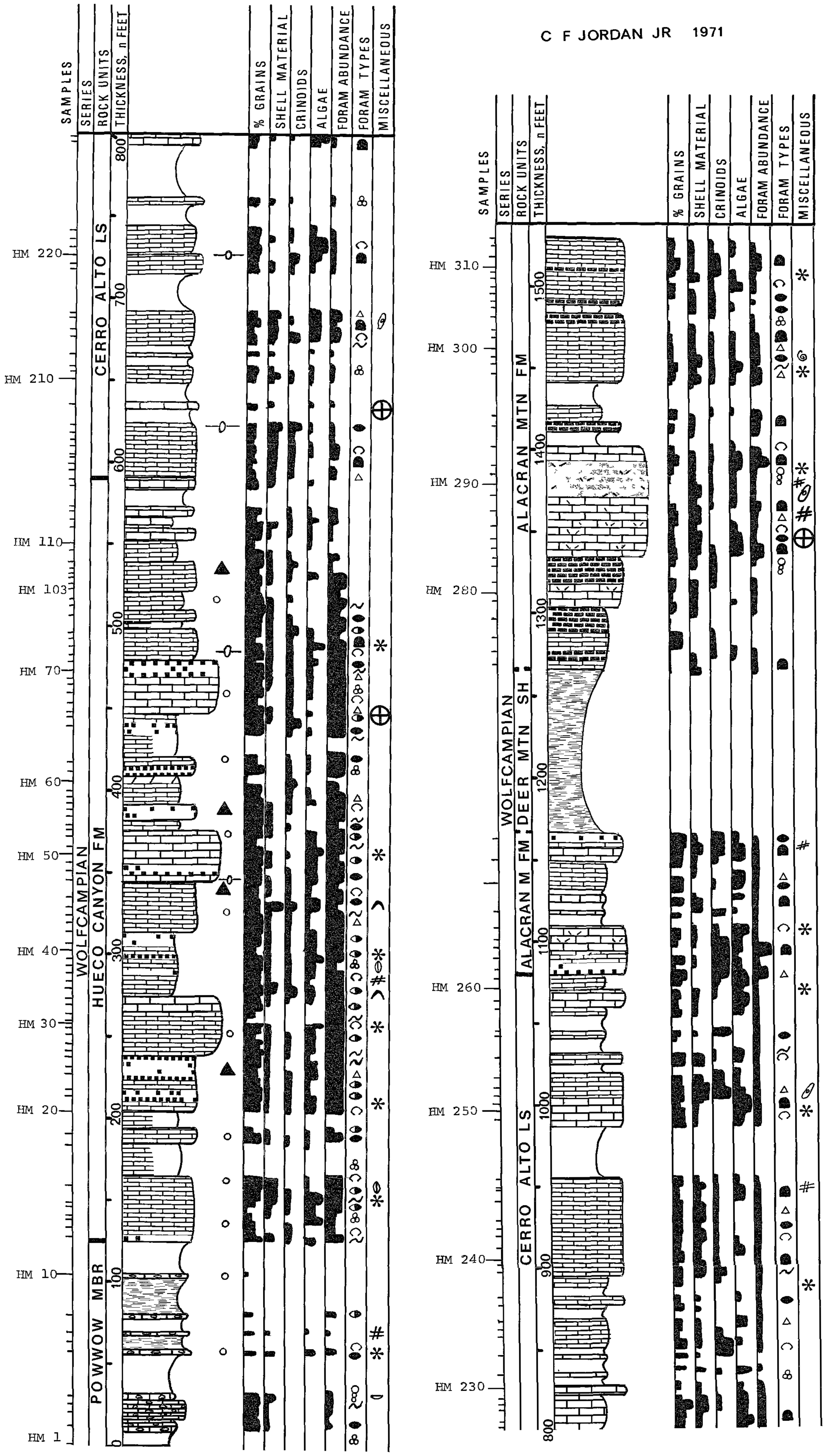


PLATE 2

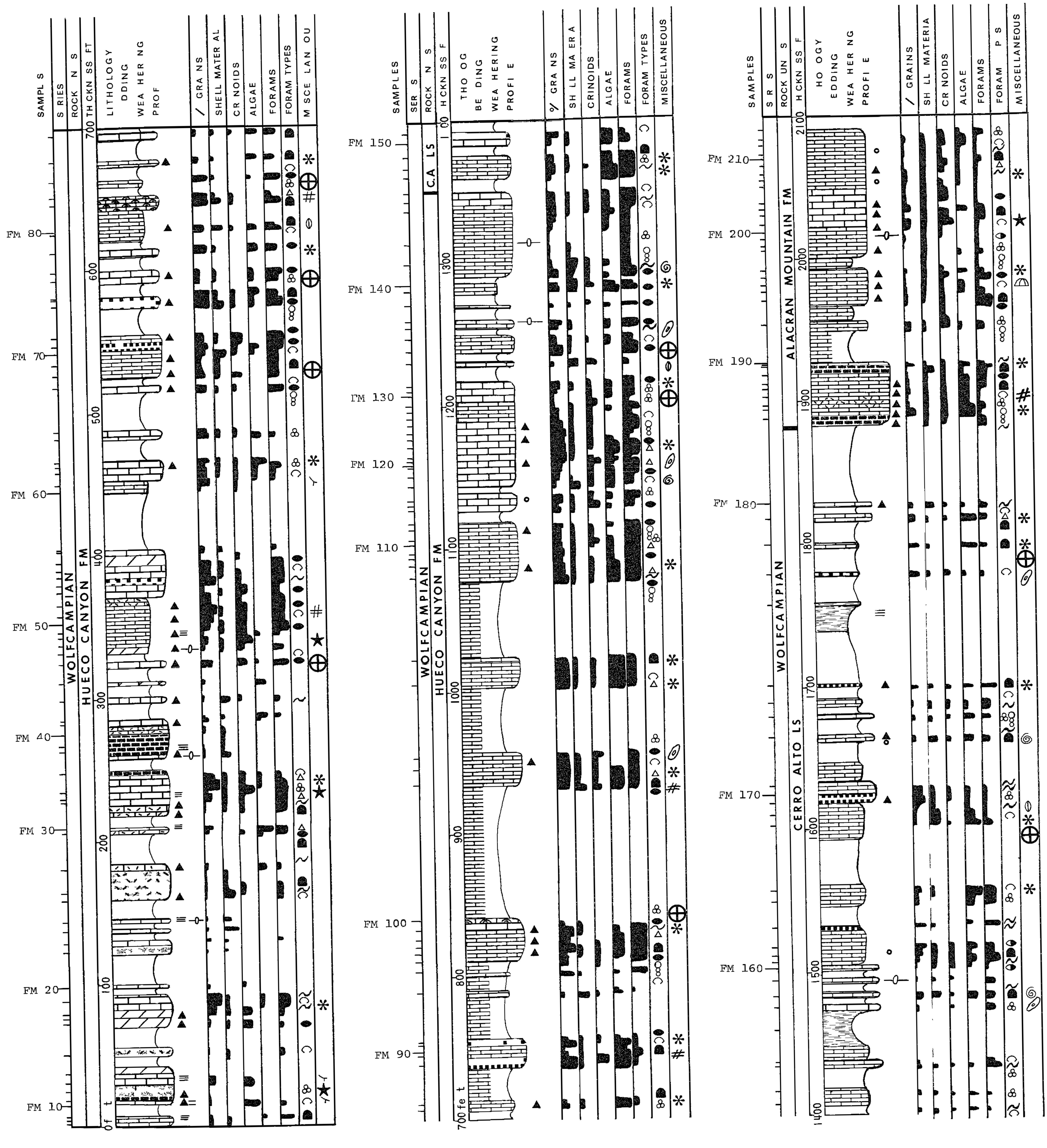
See Figure 25 for legend and
Appendix Map II for line of section

C F JORDAN JR 1971

FM SECTION

FRANKLIN MOUNTAINS

WEST TEXAS



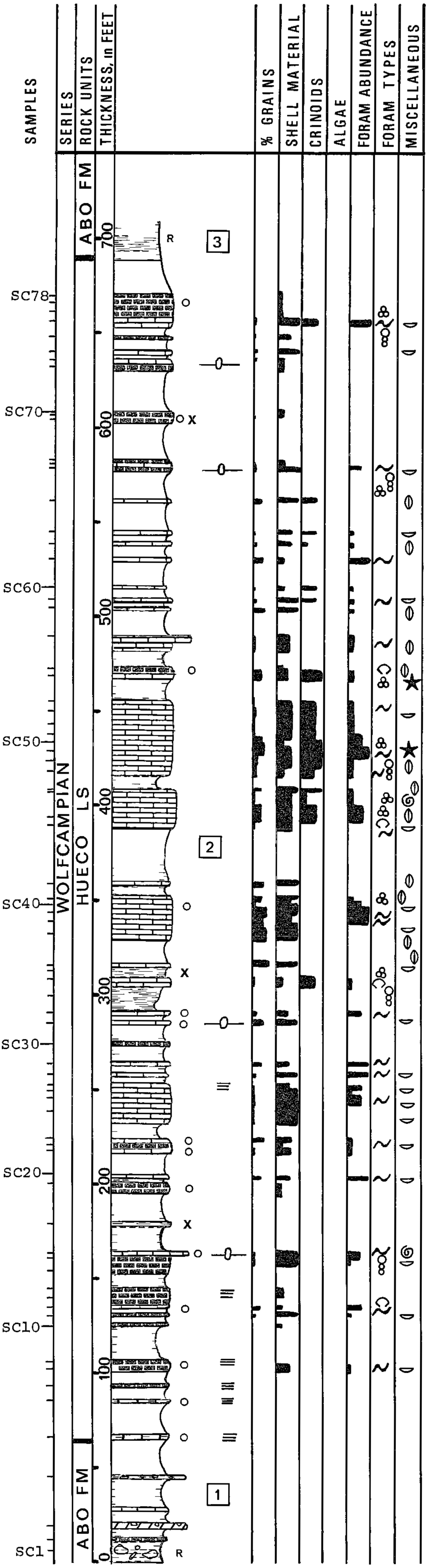


PLATE 3

SC SECTION
S SACRAMENTO MOUNTAINS
NEW MEXICO

See Figure 25 for l gend and
Appendix Map IV for line f s ction

C F JORDAN JR 1971

3 LEE RANCH TONGUE of ABO FM

2 PENDEJO TONGUE of HUECO LS

1 DANLEY RANCH TONGUE of ABO FM

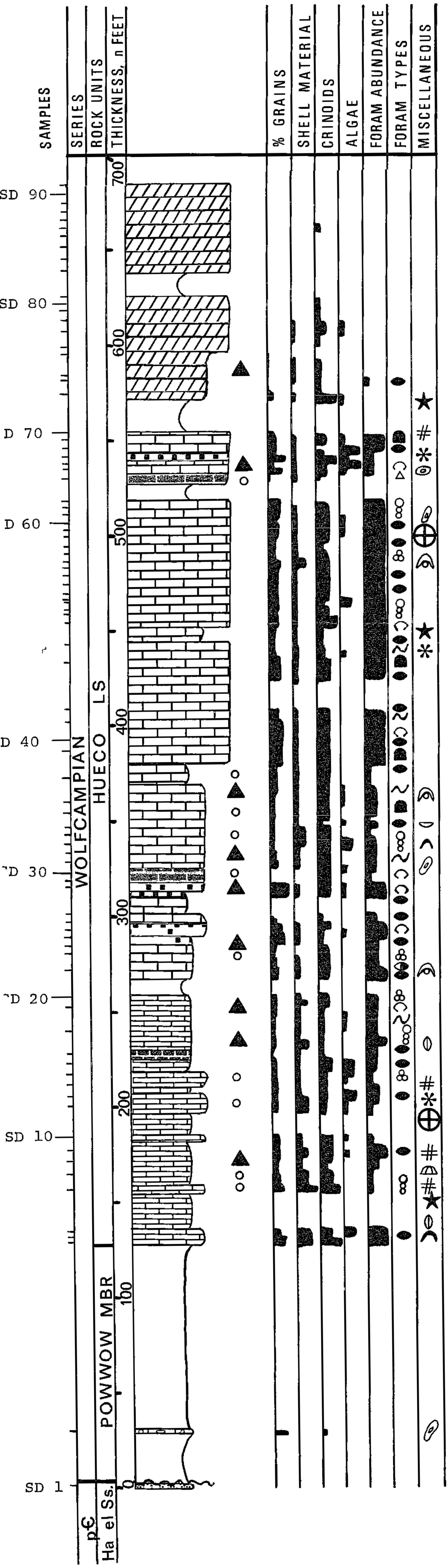


PLATE 4

SD SECTION

SIERRA DIABLO MOUNTAINS

WEST TEXAS

See Figure 25 for lengend and Appendix Map VI for line of section

C F JORDAN JR 1971

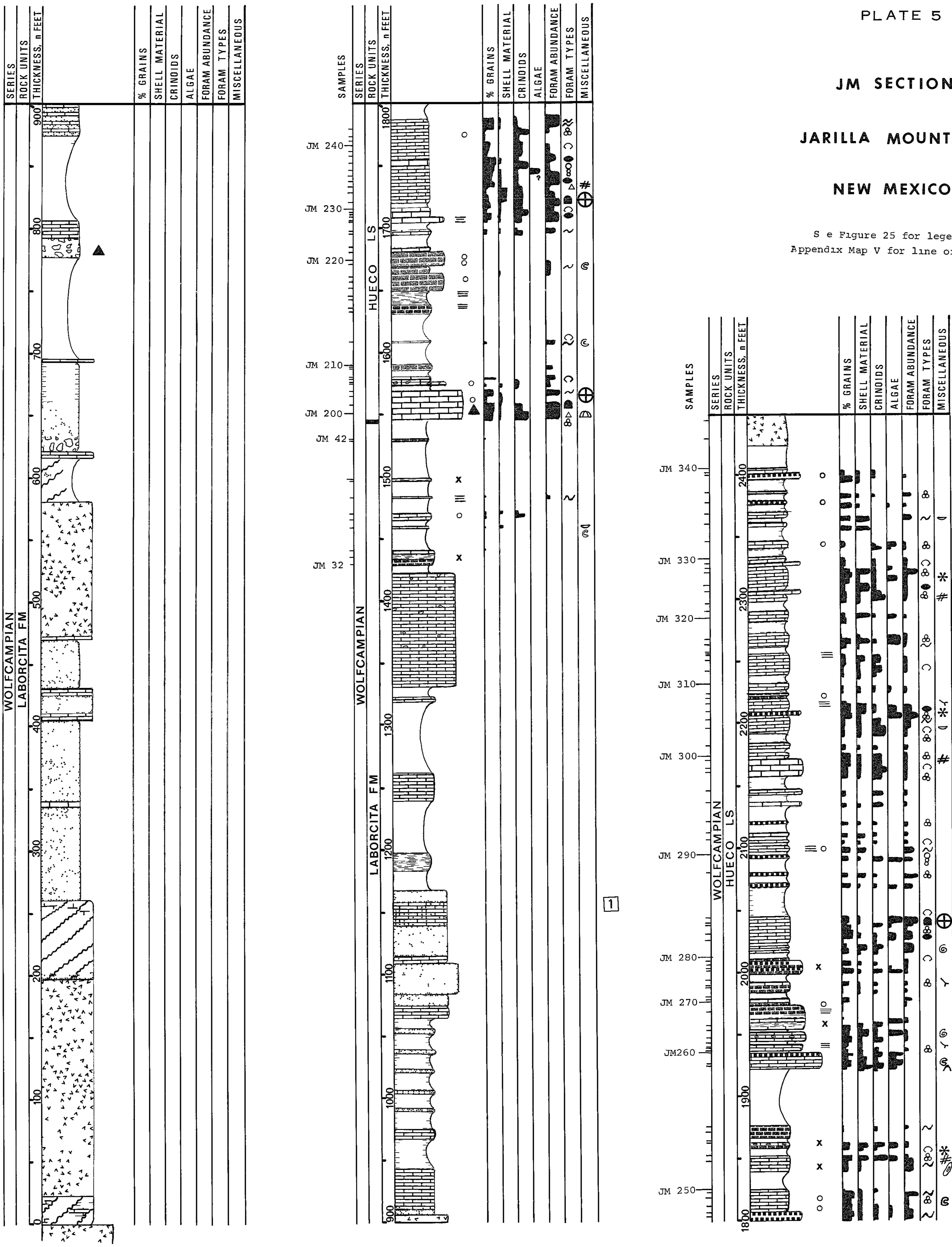
PLATE 5

JM SECTION

JARILLA MOUNTAINS

NEW MEXICO

See Figure 25 for legend and Appendix Map V for line of section



1 METASEDIMENTS
LABORCITA SECTION
BASED ON SCHMIDT
& CRADDOCK 1964

PLATE 7

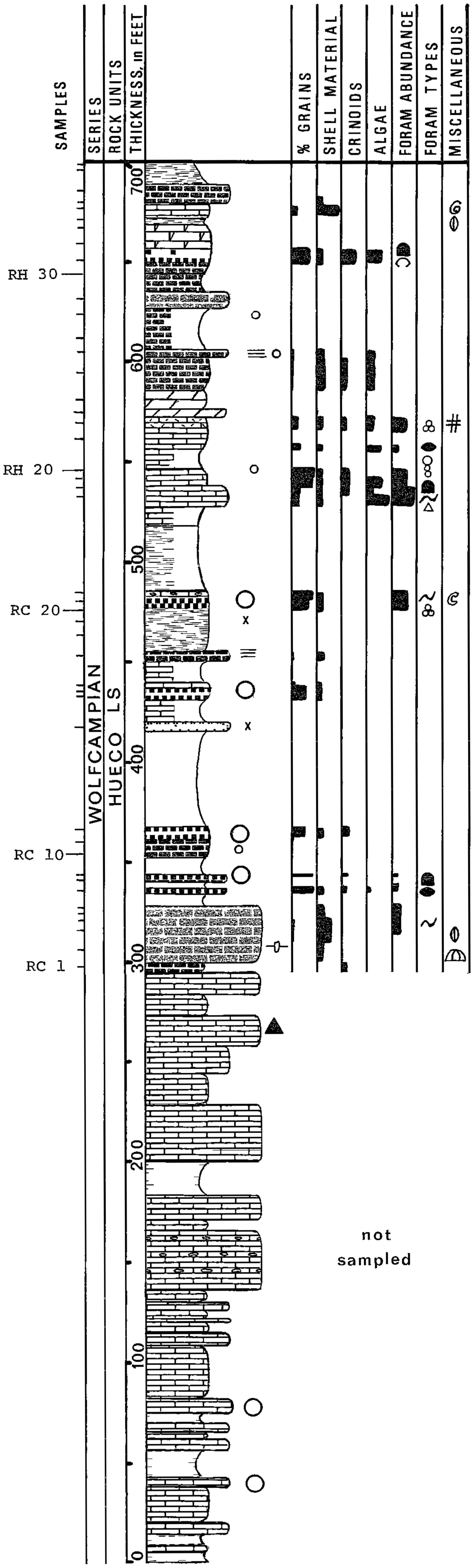
R SECTIONS

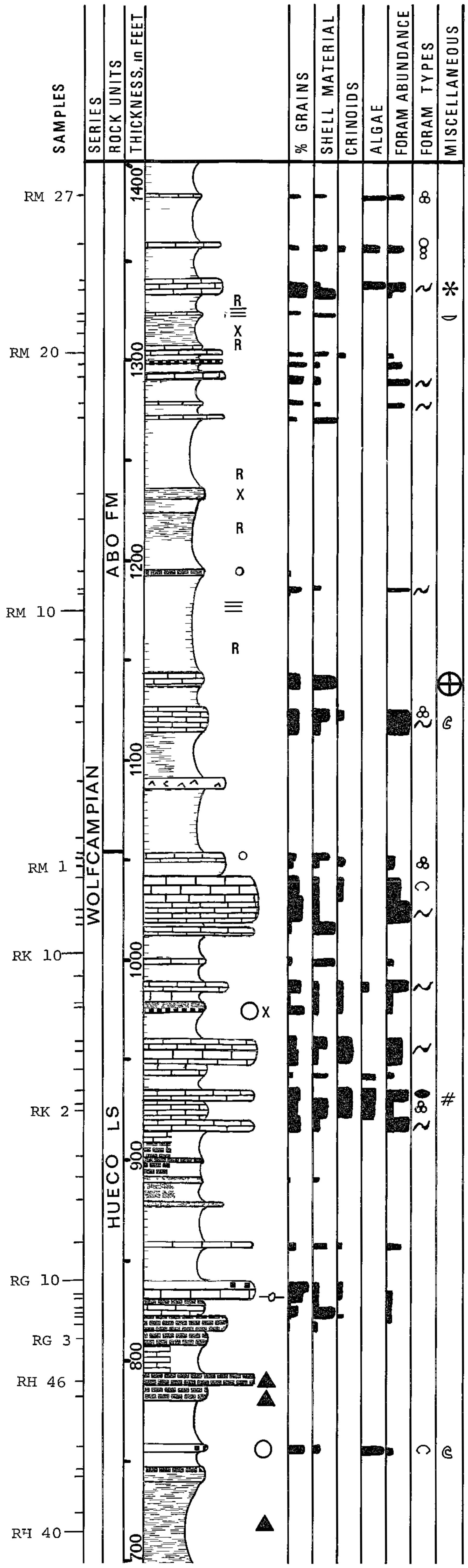
ROBLEDO MOUNTAINS

NEW MEXICO

Se Figure 25 for legend and Appendix Map III for line of section

C F JORDAN JR 1971





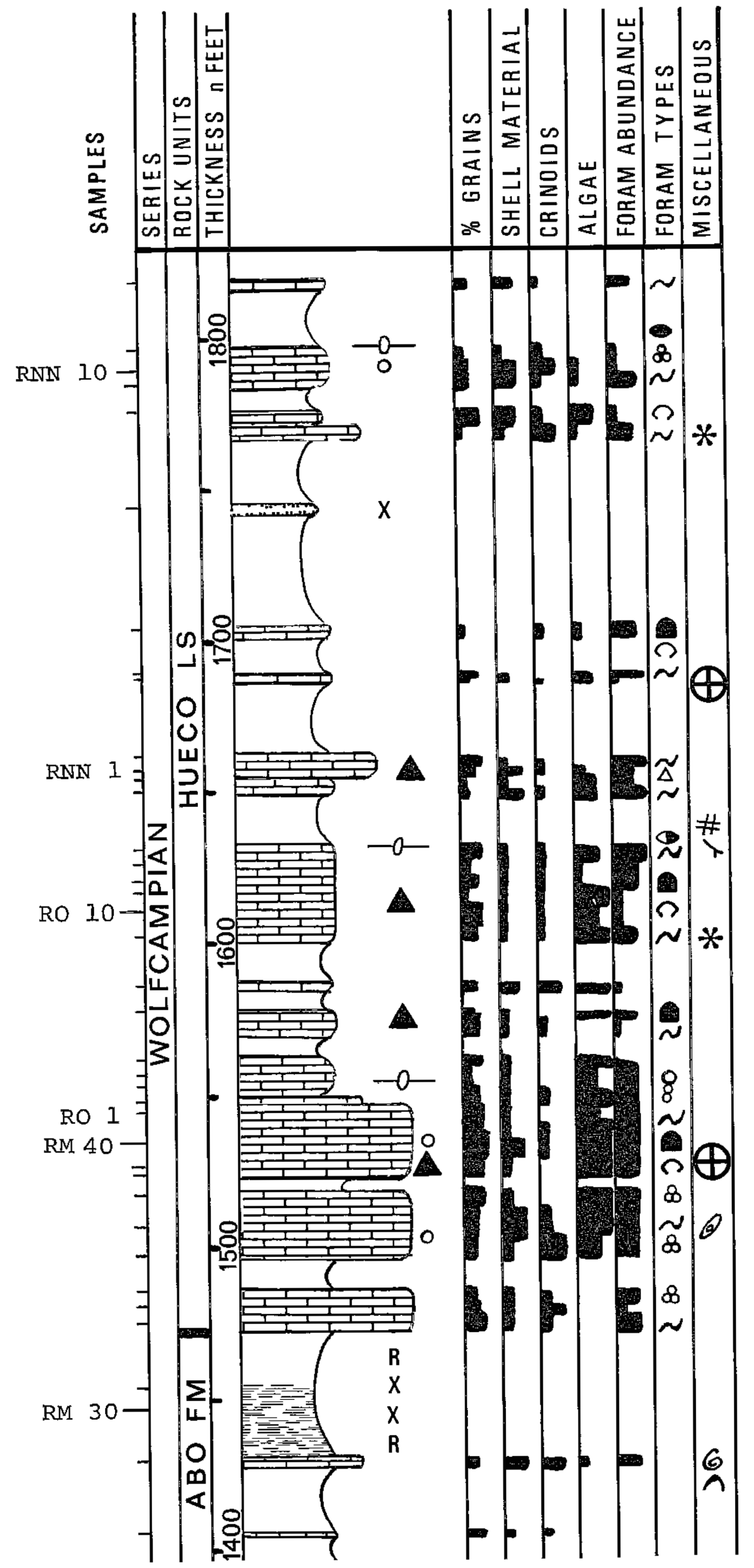


PLATE 8

C F JORDAN JR 1971

S Fıgur 25 for leg nd and
Appendıx Map VIII for lın of ectıon

BS, HT & LS SECTIONS

BIG HATCHET MOUNTAINS

NEW MEXICO

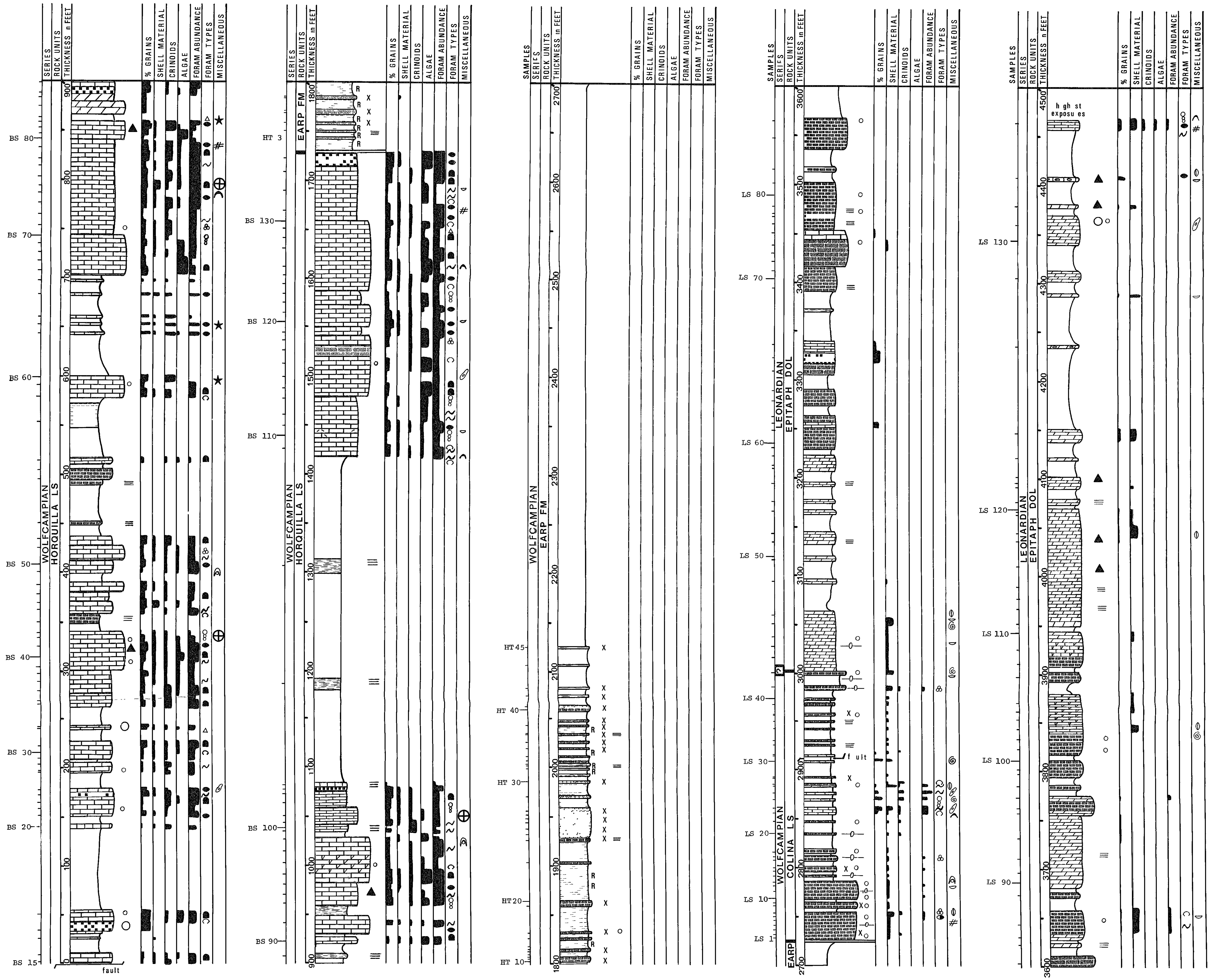


PLATE 9

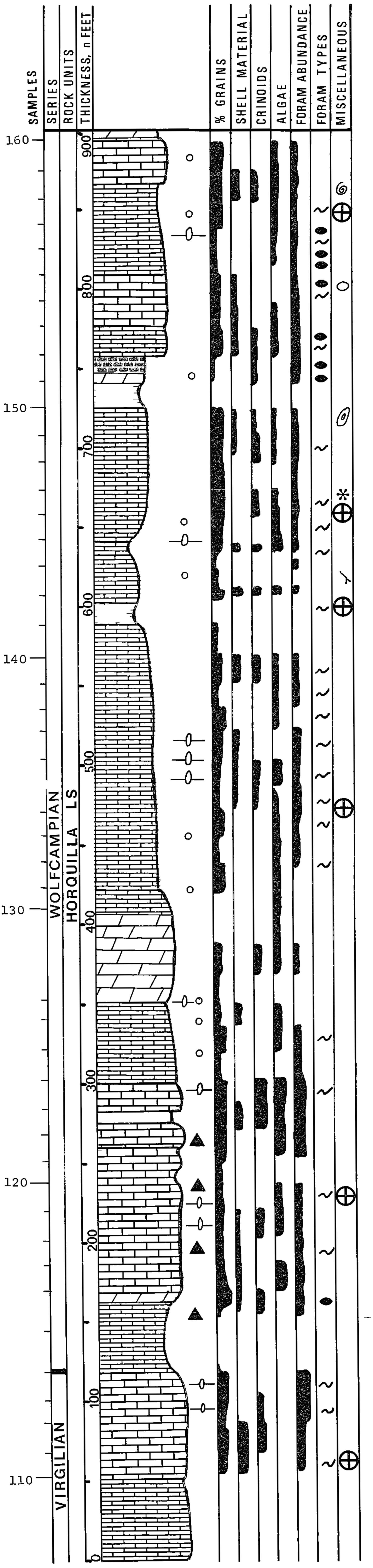
BUGLE RIDGE SECTION

BIG HATCHET MOUNTAINS

NEW MEXICO

See Figure 25 for legend

C F JORDAN JR 1971



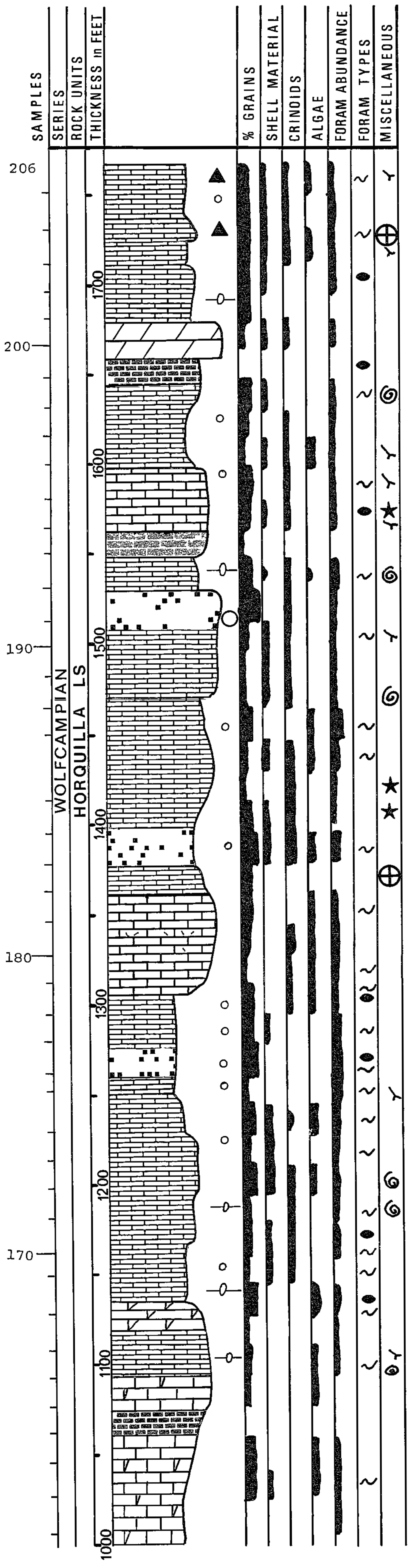


PLATE 10

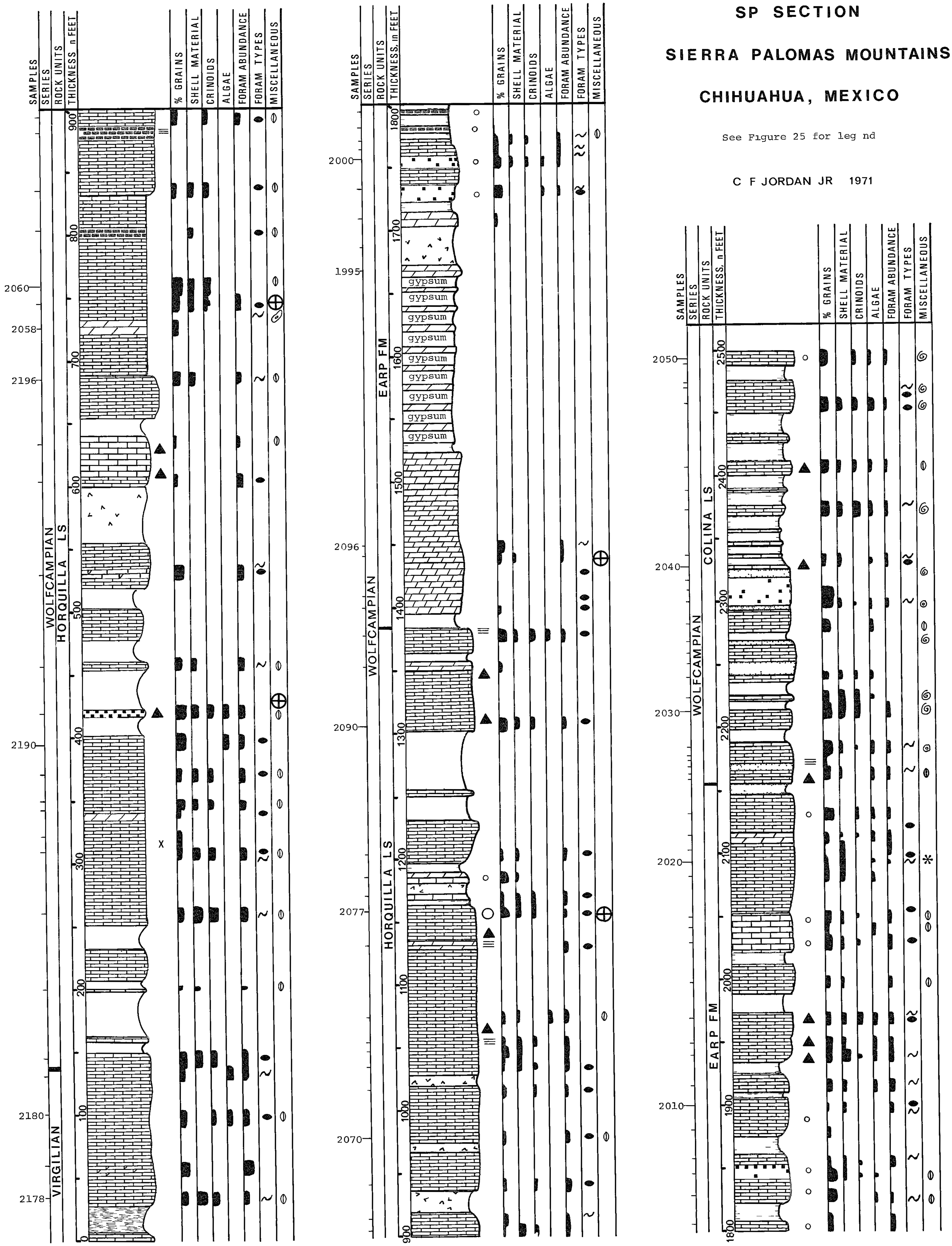
SP SECTION

SIERRA PALOMAS MOUNTAINS

CHIHUAHUA, MEXICO

See Figure 25 for legend

C F JORDAN JR 1971



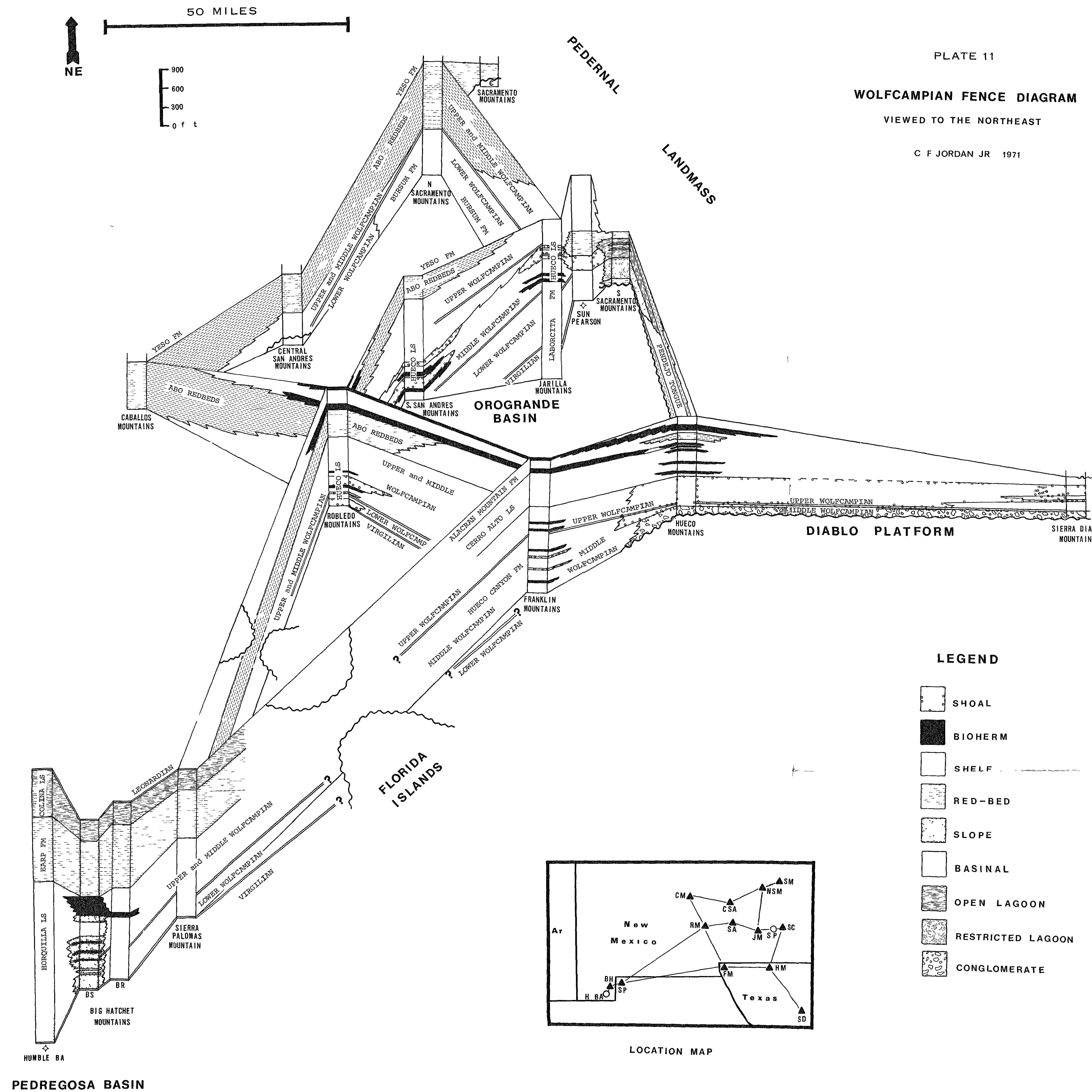


PLATE 11
WOLFCAMPIAN FENCE DIAGRAM
VIEWED TO THE NORTHEAST
C F JORDAN JR 1971
50 MILES
NE
900
600
300
0 ft
PEDERNAL
LANDMASS
OROGRANDE BASIN
DIABLO PLATFORM
FLORIDA ISLANDS
PEDREGOSA BASIN
SACRAMENTO MOUNTAINS
N SACRAMENTO MOUNTAINS
CENTRAL SAN ANDRES MOUNTAINS
CABALLOS MOUNTAINS
S. SAN ANDRES MOUNTAINS
JARILLA MOUNTAINS
SUN PEARSON
S SACRAMENTO MOUNTAINS
ROBLEDO MOUNTAINS
FRANKLIN MOUNTAINS
HUECO MOUNTAINS
SIERRA DIABLO MOUNTAINS
SIERRA PALOMAS MOUNTAIN
BIG HATCHET MOUNTAINS
HUMBLE BA
BS
BR
YESO FM
ABO REDBEDS
BURSUM FM
UPPER and MIDDLE WOLFCAMPIAN
LOWER WOLFCAMPIAN
UPPER WOLFCAMPIAN
MIDDLE WOLFCAMPIAN
VIRGILIAN
HUECO LS
LABORCITA FM
PENDEJO TONGUE
ALACRAN MOUNTAIN FM
CERRO ALTO LS
HUECO CANYON FM
LOWER WOLFCAMP
POWWOW MBR
LEONARDIAN
COLINA LS
EARP FM
HORQUILLA LS
LEGEND
SHOAL
BIOHERM
SHELF
RED-BED
SLOPE
BASINAL
OPEN LAGOON
RESTRICTED LAGOON
CONGLOMERATE
Ar
New Mexico
Texas
CM
CSA
NSM
SM
RM
SA
JM
SP
SC
BH
H BA
FM
HM
SD
LOCATION MAP