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Petrographic analysis of Upper Paleozoic rocks in southern Luna County

by
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PETROGRAPHIC ANALYSIS OF UPPER PALEOZOIC ROCKS IN SOUTHERN LUNA COUNTY

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INTRODUCTION

Outcrops of upper Paleozoic rocks in southern Luna County are sparse. Relatively little has been published on their occurrences and there have been only three reports with some detailed petrographic data (Wilson, 1989, Buck and Clemons, 1991; Clemons, in press). Two 2-inch cores drilled during mineral exploration in the West Lime Hills (Figs. 1, 2) provide 684-ft and 1494-ft sample sections of upper Paleozoic rocks in that area. A small knoll (Fig.2) consists of about 75 ft of previously undescribed Lower Permian rocks. Two additional recently reported outcrops of Permian rocks in southern Luna County (Fig. 2) are at Eagle Nest (Seager and Mack, 1990) and "George" hill (N½ sec. 3, T29S, R5W), 7 mi south of Eagle Nest. The purpose of this report is to provide petrographic descriptions of these rocks and correlate them with other upper Paleozoic rocks in and near southern Luna County. Hopefully, data provided here will enhance the understanding of depositional conditions across the Florida-Moyotes Uplift, between the Orogrande and Pedregosa Basins (Fig. 3A), during Late Pennsylvanian and Early Permian times.

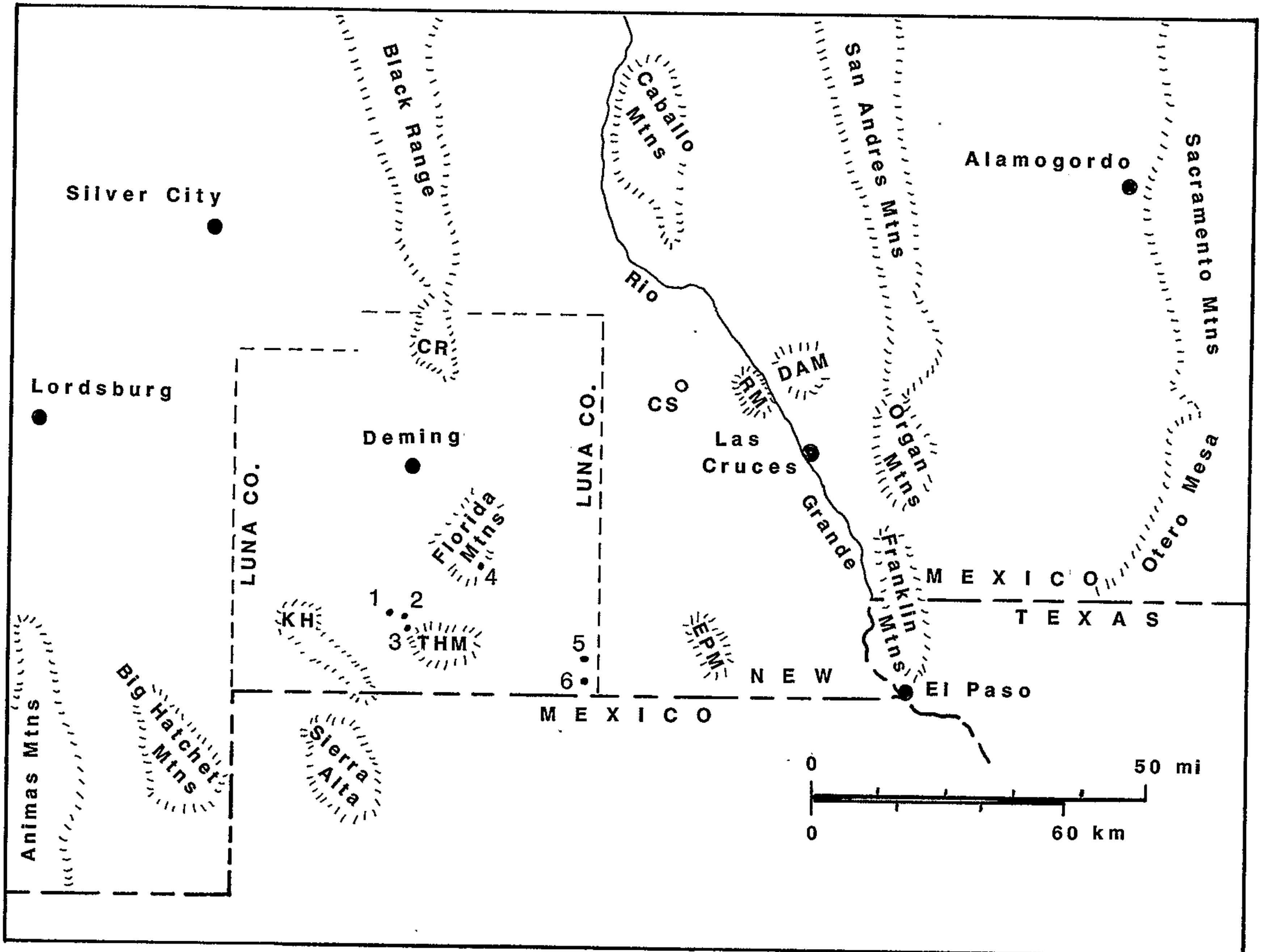

FIGURE 1—Localities of features between the Orogrande and Pedregosa Basins. 1, small knoll; 2, GWLH-1 core; 3, GWLH-3 core; 4, Gym Peak; 5, Eagle Nest; 6, George hill; CR, Cooke's Range; CS, Cities Service No. 1 Gov.–Corralitos A well; DAM, Doña Ana Mountains; EPM, East Potrillo Mountains; RM, Robledo Mountains; THM, Tres Hermanas Mountains.

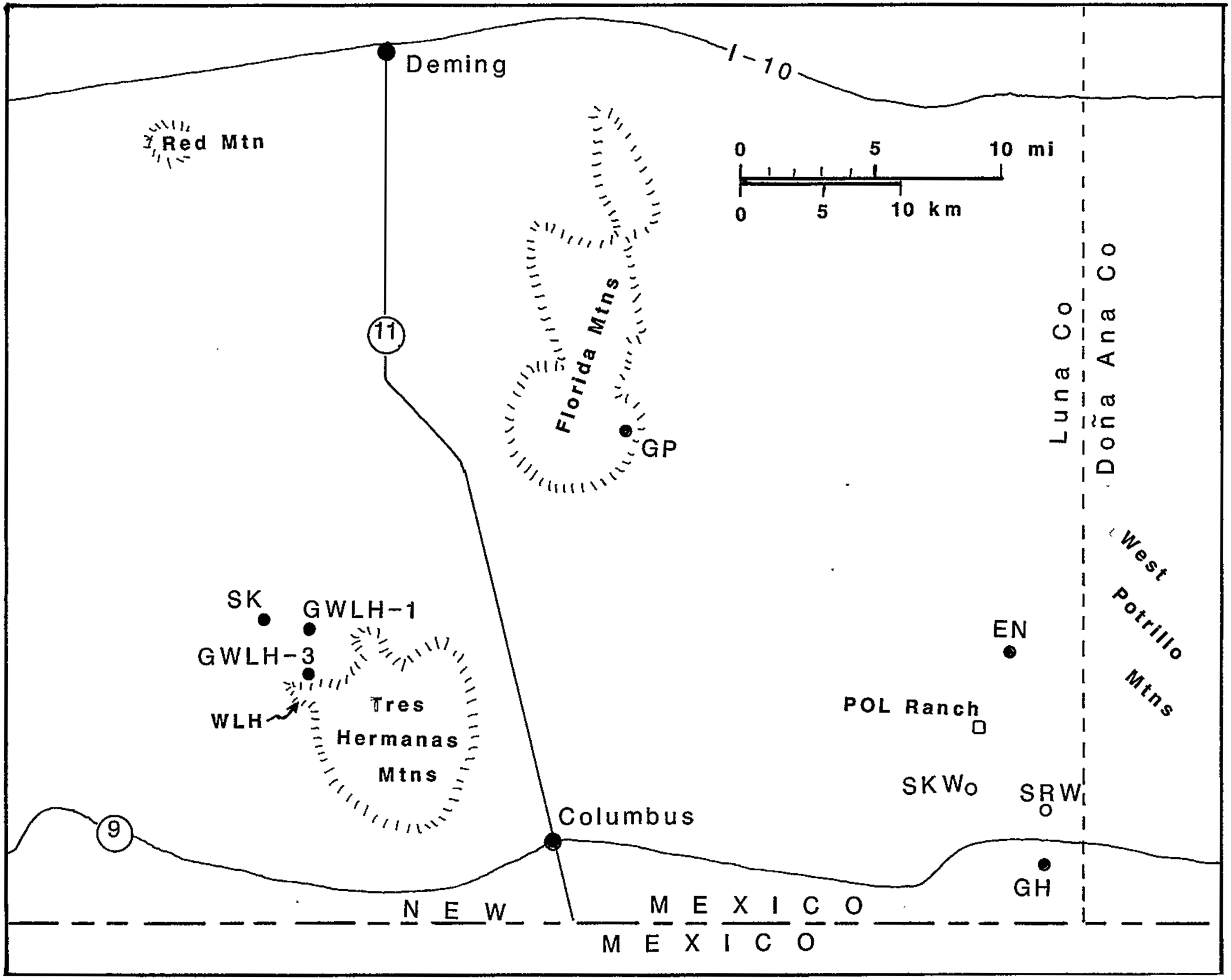

FIGURE 2—Localities of cores and sections included in this study. EN, Eagle Nest; GH, George hill; GP, Gym Peak; GWLH-1, GWLH-1 core; GWLH-3, GWLH-3 core; SK, small knoll; SKW, Skelly No. 1A New Mexico C well; SRW, SunRay Mid-Continent No. 1 New Mexico Fed. R well.

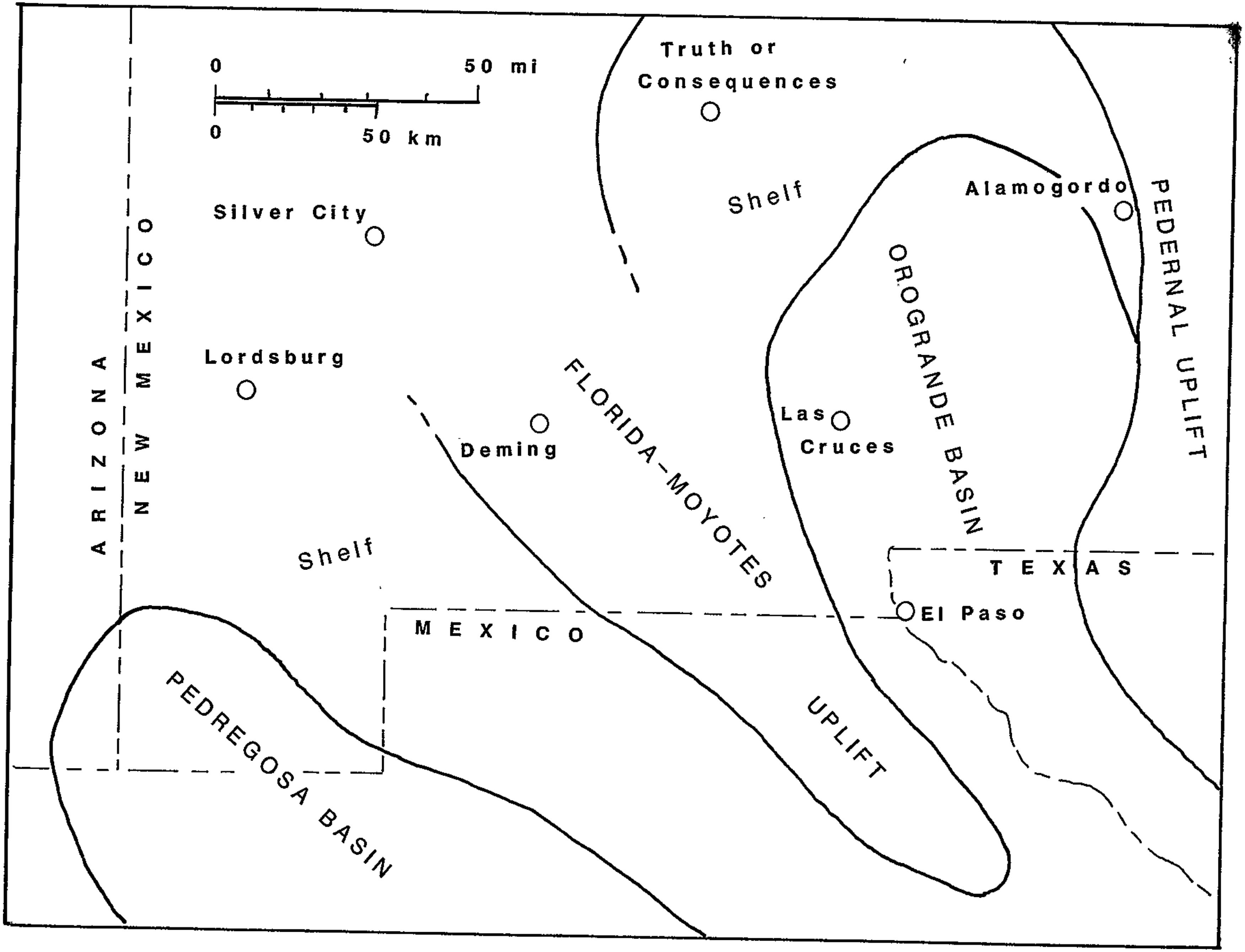

FIGURE 3A—Paleogeographic map of Orogrande and Pedregosa Basins.

Cores drilled in 1981-1982 by Gulf Mineral Resources from the GWLH-1(TD 2314 ft) and GWLH-3 (TD 2309 ft) holes were examined and a general description of each is in Appendix A. Samples were chosen from fossiliferous zones in the cores and at depths needed to represent all megascopically distinctive lithologies in the cores. Petrographic thin sections were prepared from 67 GWLH-1 core samples and 40 GWLH-3 core samples. Stratigraphic sections were measured and sampled at the small knoll 3.5 mi northwest of West Lime Hills (29 thin sections), southeast flank of Gym Peak in the southeastern Florida Mountains (29 thin sections), at Eagle Nest (17 thin sections), and "George" hill (8 thin sections). Permian strata in the northeastern Tres Hermanas Mountains were measured, sampled, and thin sectioned but contact metamorphism destroyed most of the original textures and prevents identification of bioclasts. Petrographic analyses were made on 190 thin sections.

REGIONAL GEOLOGY

Pennsylvanian and Permian rocks in south-central and southwestern New Mexico have received much attention due primarily to presence of oil and gas reservoirs in these age strata in southeastern New Mexico. Pennsylvanian strata range in age from Morrowan (?) to Virgilian and were deposited unconformably on Precambrian to Upper Mississippian rocks. The Pennsylvanian-Permian boundary is gradational in many areas; elsewhere Permian, Cretaceous and Tertiary rocks are erosionally unconformable on Pennsylvanian strata (Kottlowski, 1963, 1965). Pennnnsylvanian rocks (if ever present) apparently were eroded from the Florida

Mountains area during Early Permian. Erosion during early and middle Mesozoic time probably stripped Pennsylvanian and Permian rocks from the Burro Uplift in southwestern New Mexico (Kottlowski, 1960a, 1960b, 1963; Mack and Clemons, 1988).

Outcrops of Pennsylvanian-Permian strata are scattered in south-central and southwestern New Mexico and mapping units used by workers have varied greatly over the years. Ranges in south-central New Mexico contain exposures of Pennsylvanian beds deposited in the Orogrande Basin; ranges in southwestern part of the state have exposures of Pennsylvanian strata deposited in the Pedregosa Basin (Fig. 3A). Stratigraphic nomenclature for Permian and Pennsylvanian rocks in southwestern New Mexico has been adopted from southeastern Arizona whereas these age rocks in south-central New Mexico possess locally assigned names or named by correlation to rocks to the east and north (Fig. 4).

During the past several decades many workers have compiled data about Lower Permian-Pennsylvanian rocks in south-central and southwestern New Mexico. Zeller (1965) described about 8,000 ft of these strata in the Big Hatchet Mountains (Fig. 1, 4) that were deposited in the Pedregosa Basin. Additional studies of some of these rocks have been made by Ross (1973), Thompson and Jacka (1981) and Neely (1982). Diaz and Navarro (1964), Wilson and others (1969), and Holland (1980) measured and described 7,000 ft of similar Lower Permian-Pennsylvanian rocks exposed in Sierra Alta (previously named Sierra de Palomas) that were also deposited in the Pedregosa Basin (Fig. 1). Kottlowski and Foster (1962) reported 525 ft of Hueco Limestone and 560 ft of Pennsylvanian

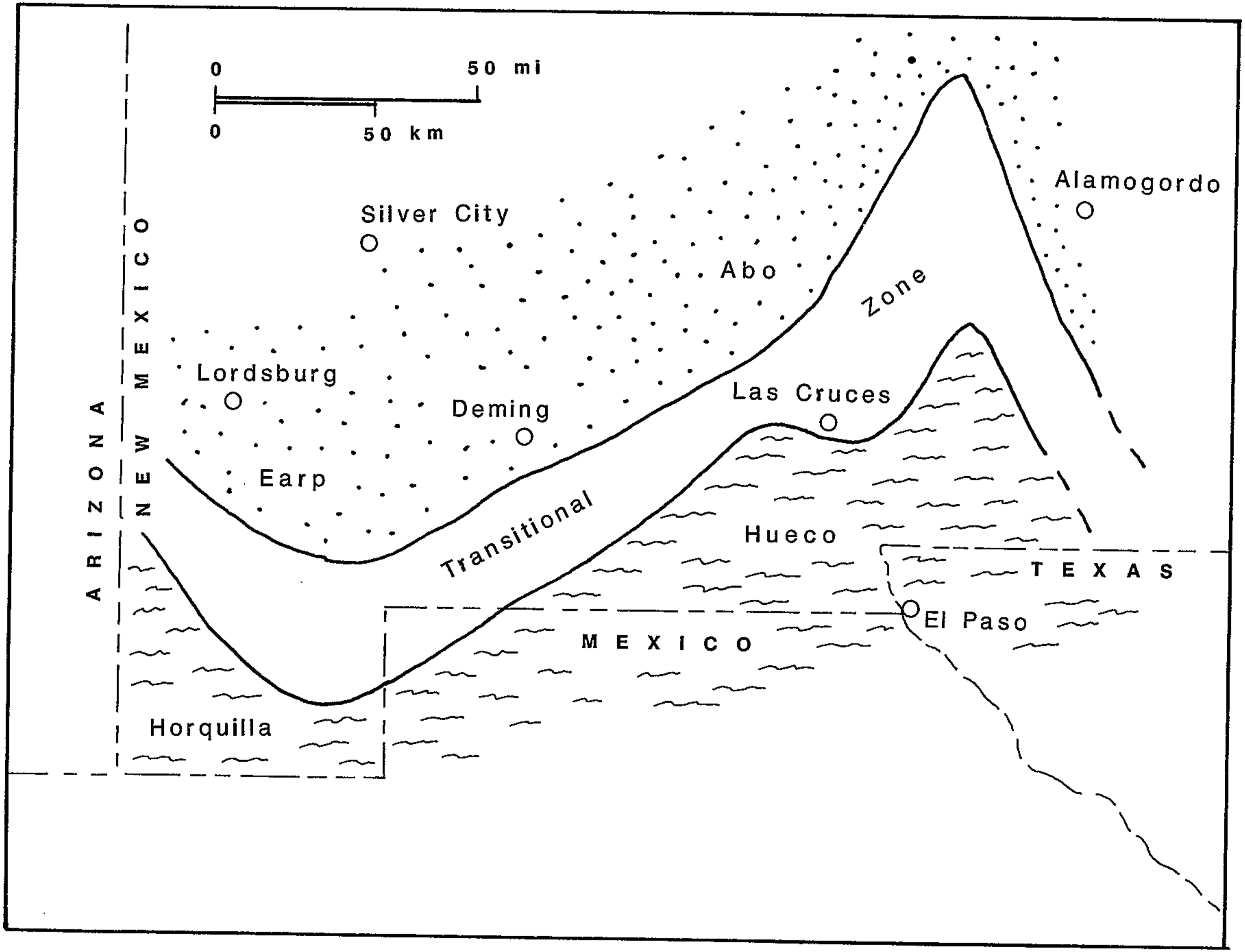

FIGURE 3B—Early Permian paleogeographic map of south-central and southwestern New Mexico (after Mack and James, 1986).

	Series	Big Hatchet Mountains	Sierra Alta	Cooke's Range	Robledo Mountains	Franklin Mountains	Caballo Mountains	Southern San Andres Mtns	Sacramento Mountains
PERMIAN	Ochoan								
	Guadalupian								
	Leonardian	Naco Group: Concha Ls Sherrer Ss Epitaph Dol Colina Ls Earp Fm	Concha Ls Epitaph Dol Colina Ls Earp Fm				San Andres Fm Yeso Fm	San Andres Fm Yeso Fm Hueco Ls/ Abo Fm	San Andres Fm Yeso Fm
	Wolfcampian			Abo Fm Bursum Fm	Hueco Ls/ Abo Fm Bursum Fm	Hueco Gp	Abo Fm Bursum Fm	Bursum Fm	Abo Fm/ Hueco Fm Bursum Fm
PENNSYLVANIAN	Virgilian	Horquilla Ls	Horquilla Ls	Magdalena Gp	Virgilian	Panther Seep Fm	Bar B Fm	Panther Seep Fm	Holder Fm
	Missourian				Missourian				Beeman Fm
	Desmoinesian				Desmoinesian	Bishop Cap Fm			Gobbler Fm
	Atokan				Atokan	Berino Fm	Nakaye Fm	Lead Camp Fm	
	Morrowan					La Tuna Fm	Red House Fm	Sandia Fm	

FIGURE 4—Stratigraphic chart of Permian–Pennsylvanian rocks in south-central and southwestern New Mexico.

limestone and sandstone in the Tres Hermanas Mountains, 14 mi northeast of Sierra Alta; a notably thinner section and one containing more clastic material deposited along the northeast margin of the Pedregosa Basin. Another 10 mi to the northeast, on the Florida-Moyotes Uplift, in the southeastern Florida Mountains, about 335 ft of Hueco Formation were deposited on Mississippian rocks (Clemons and Brown, 1983). Farther north, in the Cooke's Range, Jicha (1954) reported 183 ft of Upper Pennsylvanian limestone resting on Mississippian beds and overlain by a thin Lower Permian Abo section. Thirty miles northwest of Cooke's Peak, near Silver City, Jones and others (1967) described 810 ft of Lower Pennsylvanian limestone overlain by 165 ft of Lower Permian Abo redbeds.

East of the late Paleozoic Florida-Moyotes Uplift lay the north-trending Orogrande Basin between Las Cruces and Alamogordo (Fig. 3A). Excellent exposures of about 5,400 ft of Lower Permian and Pennsylvanian strata in the Sacramento Mountains have been extensively studied and interpreted as having been deposited along the eastern edge of the Orogrande Basin (Pray, 1961; Toomey and others, 1977; Wilson, 1967; Otte, 1959; Bachman and Myers, 1975; Benne, 1975; Van Wagoner, 1977; Schoderbek and Chafetz, 1988; Schoderbek, 1991), 5,300 ft in the San Andres Mountains (Kottlowski and others, 1956) and 4,800 ft in the Franklin Mountains (Harbour, 1972; Jordan, 1971; Jordan and Wilson, 1971) are interpreted to have been deposited in the Orogrande Basin. Permian-Pennsylvanian sections about 2,600 ft thick in the Doña Ana Mountains (Mack and others, 1988; Seager and others, 1976; Goerger, 1993) and Robledo

Mountains (Seager and others, in press; Roepke, 1984) and a Lower Permian section about 1,000 ft thick in the East Portillo Mountains (Seager and Mack, 1986, in press) represent deposits along the western edge of the Orogrande Basin.

Kottlowski (1958) described a "triangular area between the Robledo Mountains, Cooke's Peak and Tres Hermanas Mountains, and probably adjoining areas" as the late Paleozoic Florida islands. This area, covering southwestern Doña Ana County and eastern Luna County, overlies part of the Florida-Moyotes Uplift where Permian-Pennsylvanian strata are thin or absent. No exposures of these rocks are known between the Robledo Mountains and Cooke's Range, a distance of 47 mi. Only two small outcrops (Eagle Nest and "George" hill) occur in the 40 mi between the East Portillo and Tres Hermanas Mountains and it is another 43 mi to the Big Hatchet Mountains' section of Permian-Pennsylvanian rocks. Several oil and gas exploration wells have been drilled in this region but little data has been reported about late Paleozoic rocks penetrated. The Cities Service No. 1 Gov.-Corralitos A well, drilled about 10 mi west of the Robledo Mountains (Fig. 1) in 1971, penetrated 776 ft of Yeso-Abo section and 578 ft of Pennsylvanian strata (Thompson and Bieberman, 1975). The Sunray Mid-Continent No. 1 New Mexico Federal R well (Fig. 2) drilled 2 mi north of "George" hill in southeastern Luna County in 1962, penetrated about 3,000 ft of interbedded Paleozoic dolostone, limestone, silty limestone and dolostone, shale, and sandstone but no diagnostic ages were determined. The Skelly No. 1-A New Mexico C well (Fig. 2), drilled 3 mi west of the Sunray well in 1964, penetrated 500 ft of lower

Paleozoic rocks, overlain by Tertiary volcanic rocks (Kottlowski and others, 1969). Wilson (1987, 1989) (and Wilson and Jordan, 1988) have correlated Lower and Middle Pennsylvanian strata and depositional environments in the Orogrande and Pedregosa Basins. The Lower Permian siliciclastic-carbonate transitional zone (Fig. 3B) across south-central and southwestern New Mexico has been described by Mack and James (1986).

PETROGRAPHY

Small Knoll

A limestone knoll less than 20 ft high and 200 ft long parallel to strike of bedding is in SW¼. sec. 13, T27S, R10W, 3.5 mi northwest of West Lime Hills. The outcrop consists of 75 ft of medium - to dark-gray, medium-bedded, bioclastic, grain supported limestone. Megascopic fossils include gastropods, brachiopods, echinoderms and algae. Large dark-brown chert nodules are present in a few beds. Twenty nine samples were collected at a maximum of 5 ft intervals, and at any change in color or texture within that interval.

Petrographic analysis showed relatively little change in depositional environments throughout the section. Dominant bioclasts include tubular foraminifera, <u>Globivalvulina</u>, <u>Tuberitina</u>, gastropods, ostracods and phylloid and dasycladacian algae (Figs. 5, 6). Stromatolites (Fig. 6A) are common at the base of the exposed section. Red algae (Fig. 6J) is abundant in the boundstone and bafflestone at 40 and 65 ft. Minor bioclasts include echinoderms, bryozoa, brachiopods and fusulinids (Fig. 6D). Most bioclasts are encrusted by tubular foraminifera or less abundantly,

thickness (ft)	algae	brachiopod	bryozoa	coral	echinoderm	foraminifera	gastropod	intraclast	ostracod	peloid	silt	sponge spicule	trilobite	rock name	SMF
base	A					A	t		C					wackestone	20
2	A				t	s			t					boundstone	20
5	C			t		A	C		C	C				packstone	19
10	t				s	A	C		s					grainstone	18
15	s					A	C		s	s				packstone	19
20	s				s	A	A		t	C				rudstone	19
25					s	C	A		C	C				packstone	19
28					t	C	s		C	C				wackestone	19
30					C	A	s		s					packstone	19
34		t	t		s	A	s		s	s				grainstone	18
39	s	s	t		s	A	C		s					packstone	19
40	A	t	C		t	s			t	s				boundstone	19
43	t	s	s		t	C	A		t	C				rudstone	19
45	C	C	s		C	C	C		s	s				rudstone	9
47	s	t			s	s	C		s	A				floatstone	19
50	C				s	A	C		s	A				floatstone	19
53	t	t			t	A			s	s				grainstone	18
55	A	t			s	C	s		s	A				floatstone	19
57	A				A	C	s		C	s				packstone	9
58	s		s		C	A	s		s	C				packstone	9
60			s			A	s		s	C				boundstone	9
62	A	s			C	C	C		C					packstone	9
64	A	s			t	C	t		s	A				bafflestone	7
65	A		t		t	t	s		s					bafflestone	7

FIGURE 5—Allochem compositions of thin sections of small knoll samples. A, abundant; C, common; s, scarce; t, trace; SMF, standard microfacies from Wilson (1975).

FIGURE 5—(continued)

66	C	C	s		A	A	C	s	s	s				rudstone	9
68	t				A	A	C	s		t				grainstone	18
70	C	s	s	t	A	A	t		t	C				grainstone	9
72	t		t		A	A	s	A						grainstone	18
75	C	s			A	C	C		s	s				packstone	9

FIGURE 6—Photomicrographs of representative limestone samples of small knoll 3.5 mi northwest of West Lime Hills.

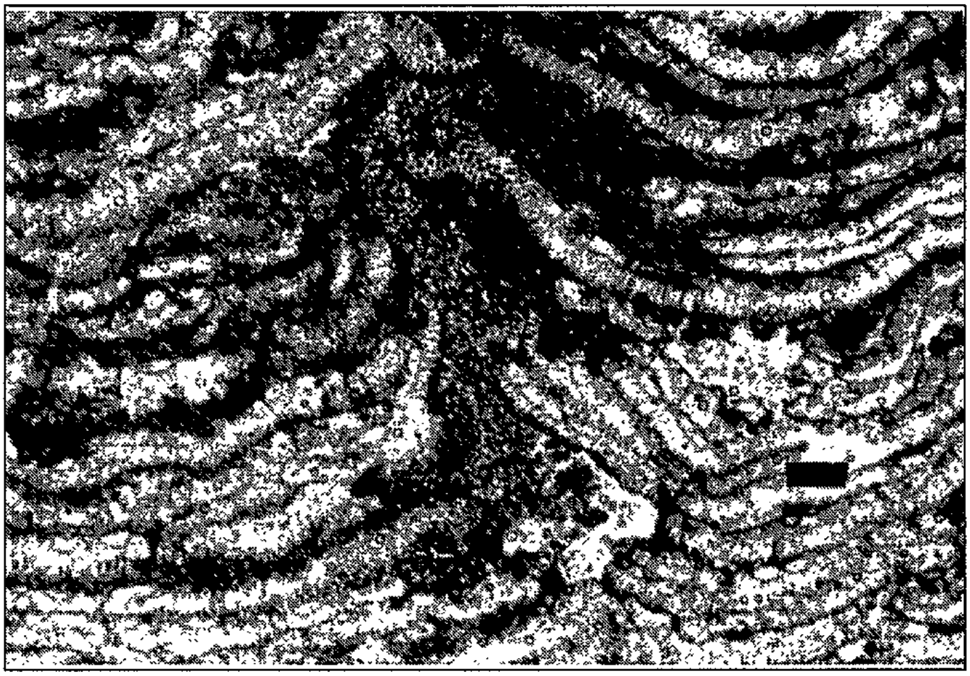

FIGURE 6A—Stromatolite at base of section; plane light, bar = 0.2 mm.

FIGURE 6B—Micritized and coated foraminifera in grainstone 10 ft above base; plane light, bar = 0.1 mm.

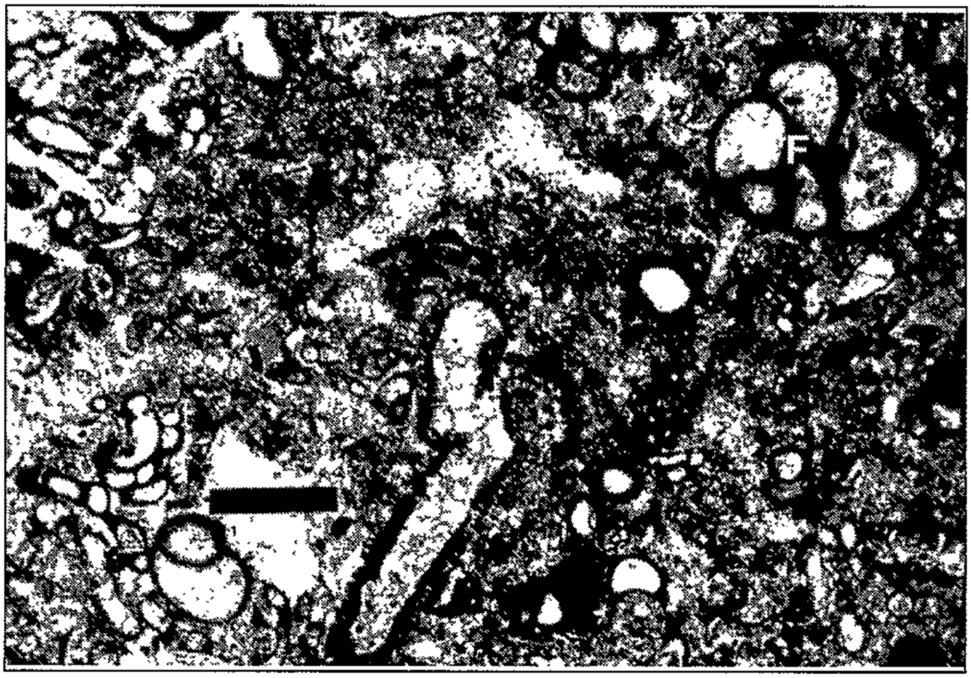

FIGURE 6C—Tubular and *Globivalvulina* foraminifera (F) and coated algal plate in packstone 34 ft above base; plane light, bar = 0.2 mm.

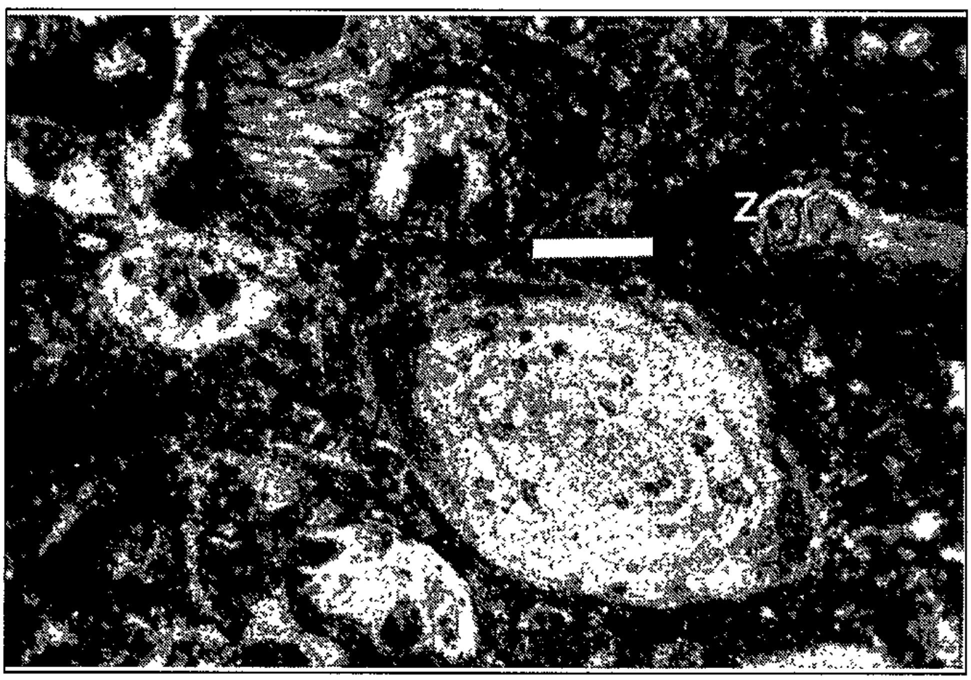

FIGURE 6D—Neomorphosed fusulinid and bryozoa (Z) fragments in packstone 45 ft above base; plane light, bar = 0.2 mm.

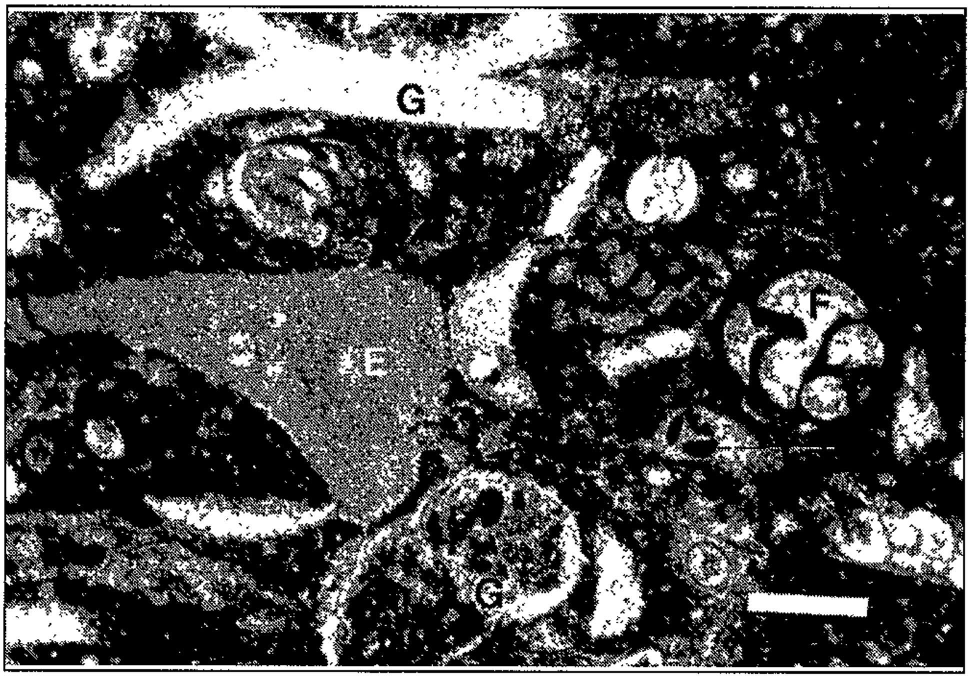

FIGURE 6E—*Globivalvulina* (F), echinoderm (E), gastropod (G) in packstone 45 ft above base; plane light, bar = 0.2 mm.

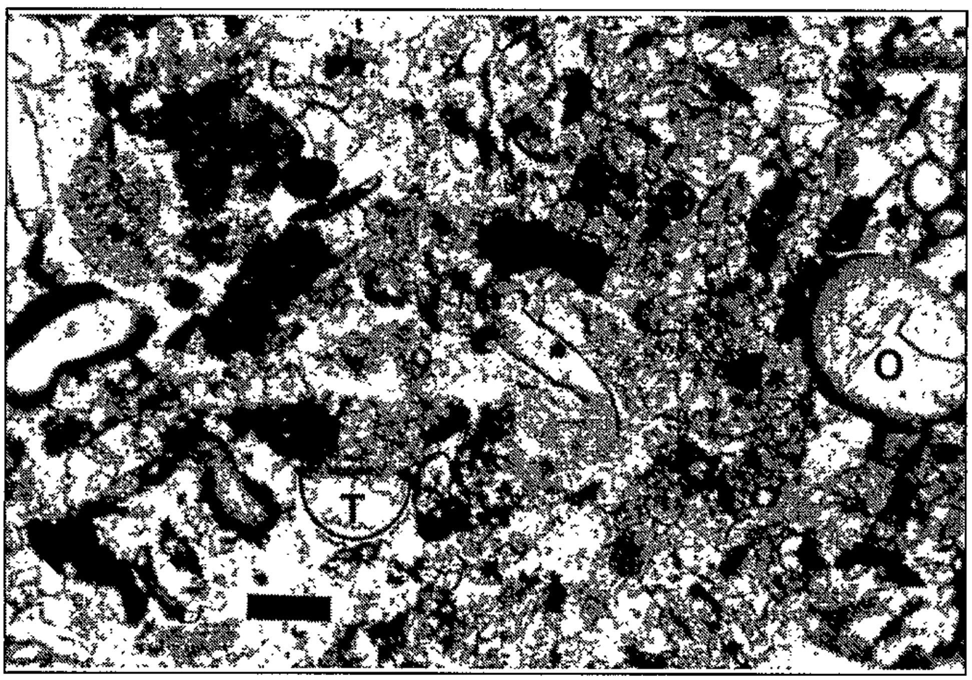

FIGURE 6F—*Tuberitina* (T) and ostracod (O) in grainstones 33 ft above base; plane light, bar = 0.1 mm.

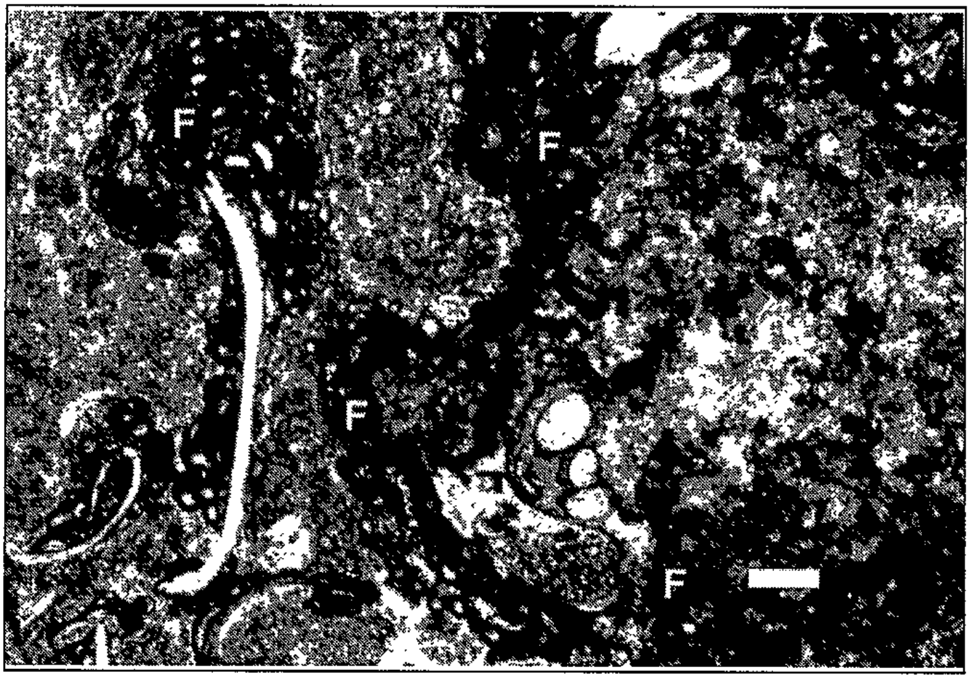

FIGURE 6G—Encrusting foraminifera (F) in packstone 57 ft above base; plane light, bar = 0.2 mm.

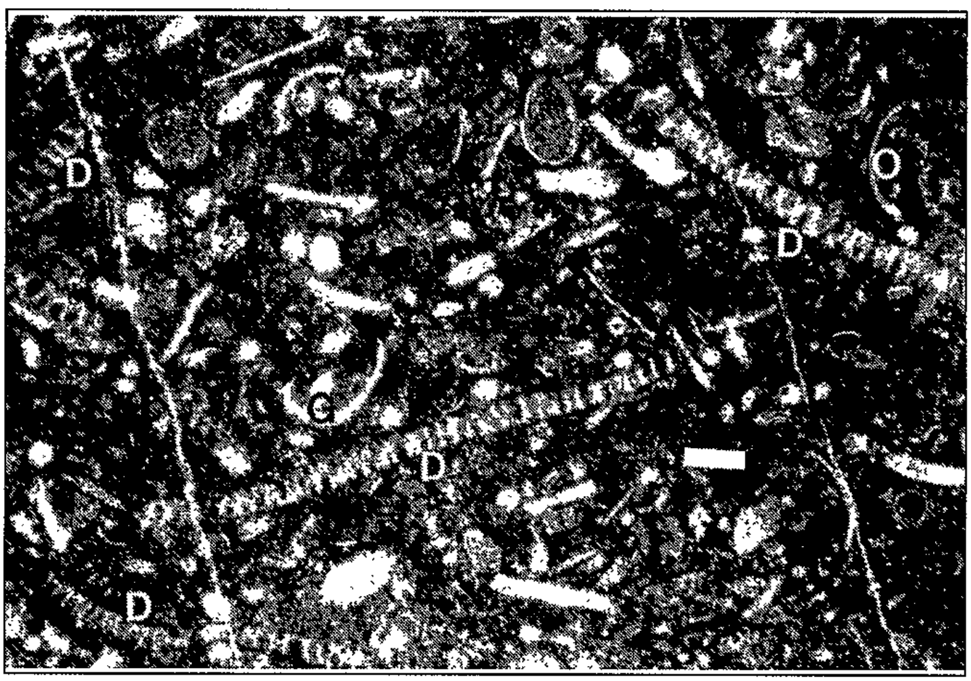

FIGURE 6H—Dasycladacian algae (D), gastropod (G), and ostracod (O) fragments in packstone 62 ft above base; plane light, bar = 0.2 mm.

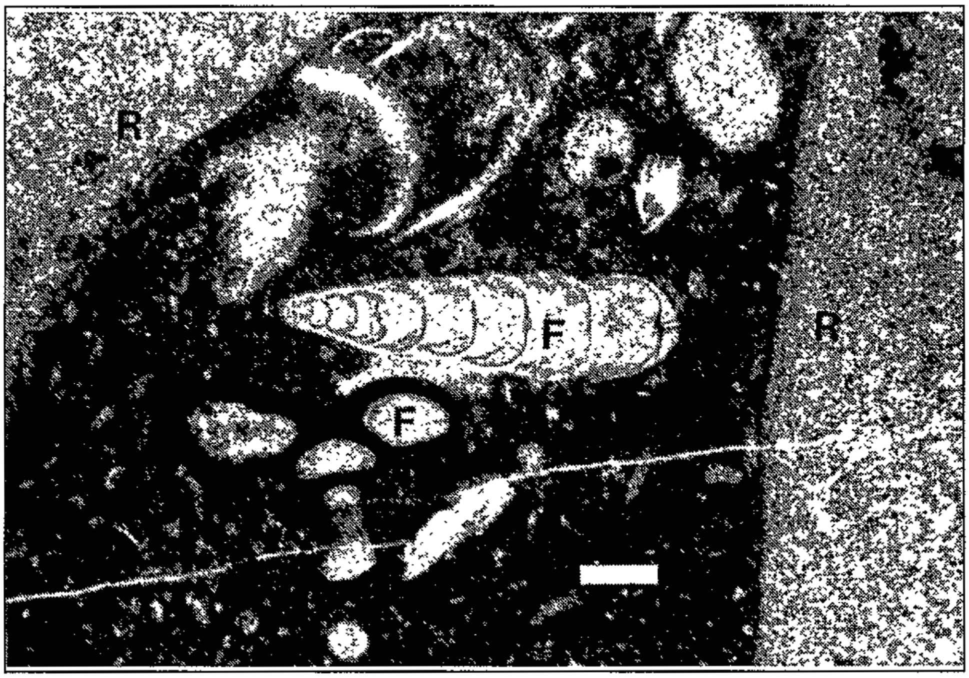

FIGURE 6I—Foraminifera (F) in micrite between red algae (R) fragments 64 ft above base; plane light, bar = 0.1 mm.

FIGURE 6J—Red algae bafflestone 65 ft above base; plane light, bar = 0.2 mm.

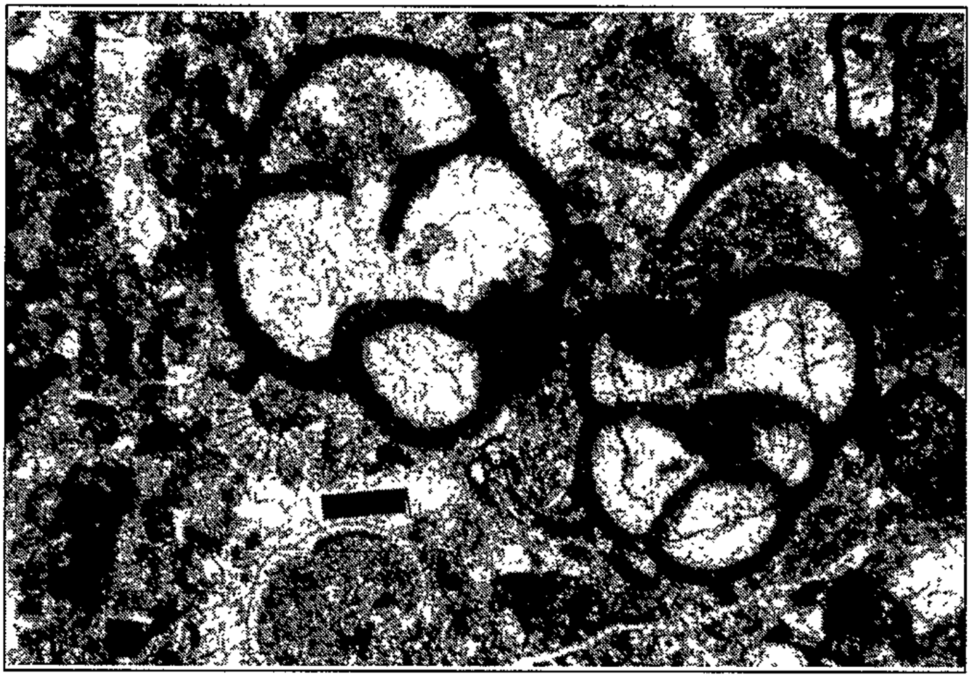

FIGURE 6K—Two *Globivalvulina* in grainstone 66 ft above base; plane light, bar = 0.1 mm.

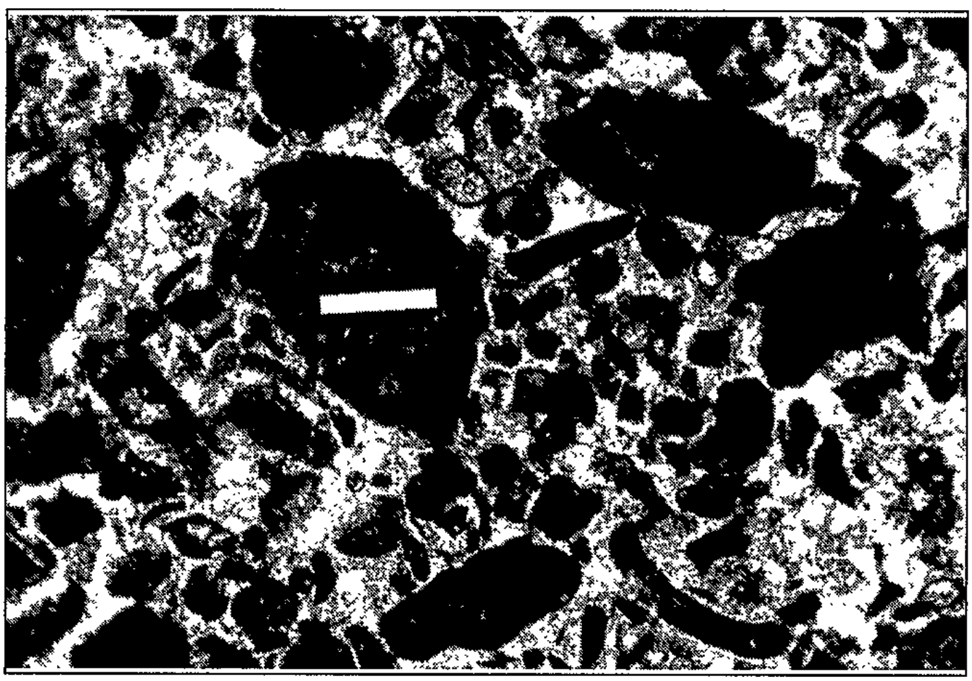

FIGURE 6L—Intraclast grainstone 72 ft above base; plane light, bar = 0.2 mm.

coated by algae (Fig. 6G). The small knoll section is composed primarily of grainstones and packstones.

Depositional environments varied between shallow, restricted circulation on a marine platform to a shallow, open marine lagoonal facies (Mark Brown, written commun., 1984; Buck and Clemons, 1991). The abundant tubular foraminifera can occur in bioherms, normal marine and lagoonal environments. They can tolerate variations in salinity and oxygen levels and thus are seen through the section. Stromatolite boundstone (Fig. 6A) present at the base and near the top of this section indicate a shallow, restricted environment. This facies grades upward into a restricted lagoonal environment dominated by gastropods, tubular foraminifera and ostracods. The open marine lagoonal facies is recognized by the greatest diversity of bioclasts, containing echinoderms, bryozoans and phylloid and dasycladacian algae. The dasycladacian algae (Epimastopora?) indicate low energy, and very shallow depths, between 3.3 and 5 m (Buck and Clemons, 1991). The abundance of gastropods in this section is similar to the lagoonal facies of the Leonardian Colina Formation. The abundant tubular foraminifera are also typical of the Wolfcampian Hueco Formation. The fauna, as well as similarity to Colina lagoonal facies, indicates this small knoll section to be Wolfcampian or Leonardian and probably equivalent to part of the Colina Formation.

GWLH-1 Core

The GWLH-1 core was drilled in SW¼ sec. 19. T27S, R9W 1.7 mi southeast of the small knoll. there is another small hill, 50 ft high, about midway between the two sites that consists of medium-bedded dolostone resting (depositionaly or in fault contact) upon massive black limestone. Neither of these two rock units have been correlated to known stratigraphic units but may be Epitaph-Colina equivalents. Megascopic fossils in the GWLH-1 core include gastropods, brachiopods, echinoderms, bryozoa, fusulinids and rugose corals(?). Generalized lithology of the core section is in Appendix A-1. Lower Permian rocks were intersected at a depth of 820 ft and the 1,494 ft of core to TD 2,314 ft is interpreted to be Permian-Pennsylvanian strata. Breccia zones at 1,585 and 1,800 ft may indicate presence of small faults; laminations and bedding appear to be near horizontal except near these breccia zones. The core between 820 and 1,000 ft is interbedded shale and laminated lime mudstone; a few wackestones and packstones occur below 940 ft.

Petrographic analysis of the thin sections show the rock is mostly bioturbated with only a couple of thin, undisturbed laminated zones. Dominant bioclasts between 1,000 and 1,500 ft are brachiopods, echinoderms, foraminifera, gastropods and ostracods (Fig. 7). Echinoderms appear to be chiefly echinoids. Fusulinids are common in 5 thin zones between 1,198-1,300 ft. Charles Ross (Written commun, 1994); identified a species of Parafusulina (Skinnerella) at 1,198 ft depth and a species of Chalaroschwagerina at 1,224 ft depth. Algae is common at several horizons (Fig. 8) and bryozoa are common between 950-1,090 and 1,415-1,430 ft. Bioclasts are generally small, abraded fragments and many have micritized rims. The 305 ft section between 1,500-1,805 ft is dominantly finely laminated lime mudstone with minor interbedded shale and siltstone. Oncoids (Fig. 9B) are abundant at 1,714 ft.

FIGURE 7—Photomicrographs of GWLH-1 core thin sections.

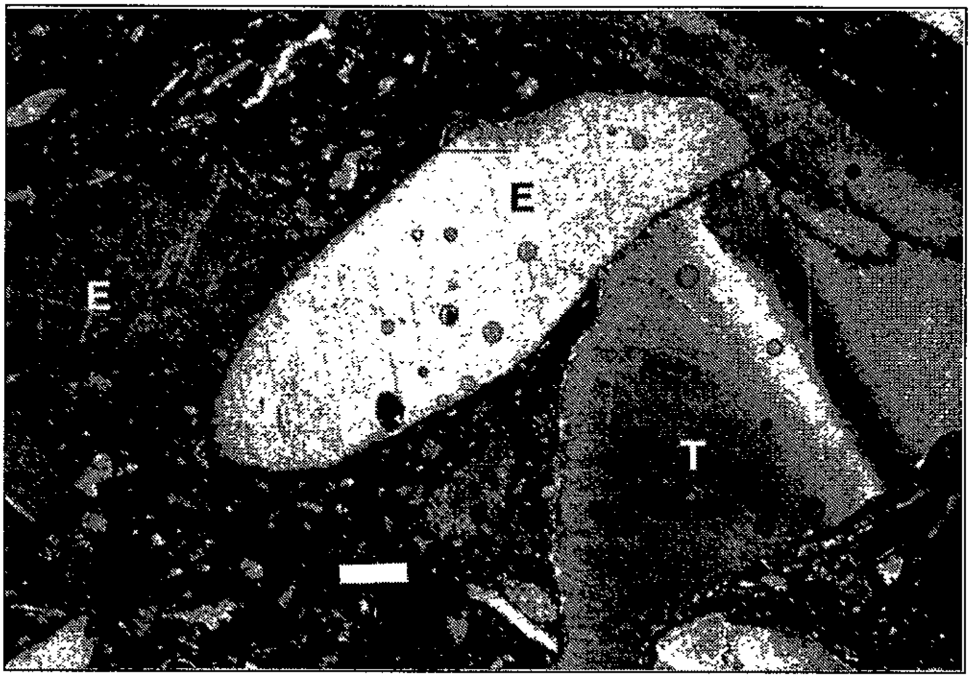

FIGURE 7A—Echinoderm (E) and trilobite (T) fragments in floatstone at 944 ft; crossed nicols, bar = 0.2 mm.

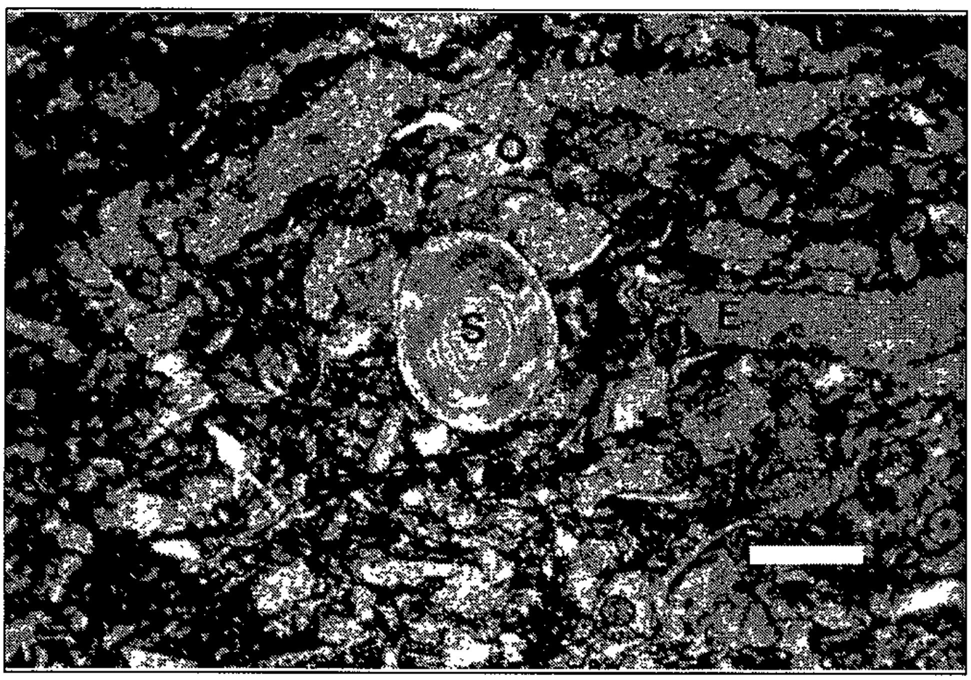

FIGURE 7B—Brachiopod spine (S), echinoderm (E), and abundant unidentified neomorphosed bioclasts at 983 ft; plane light, bar = 0.2 mm.

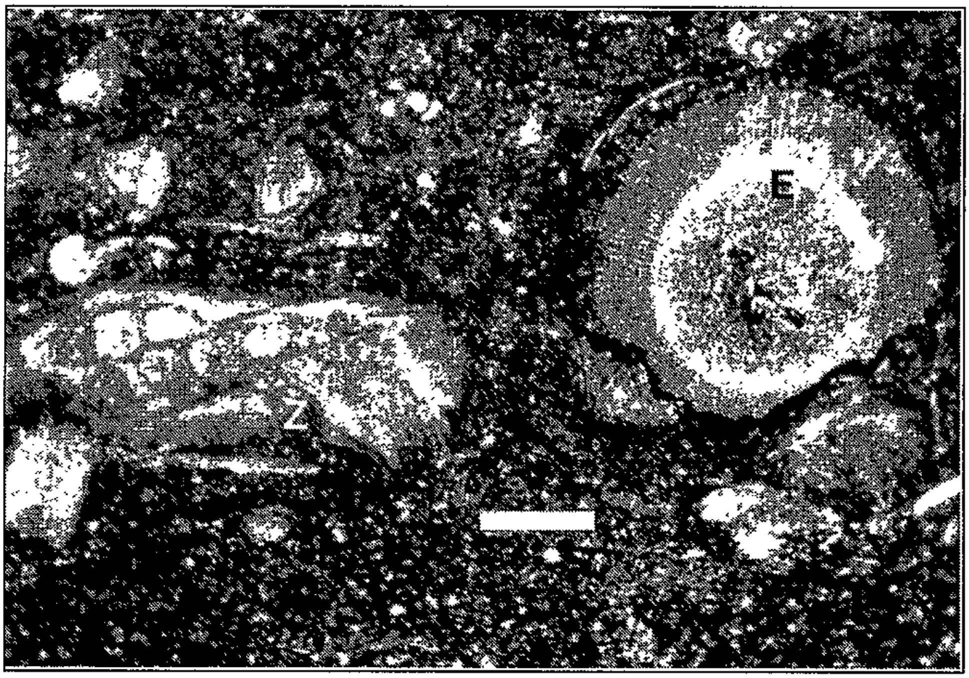

FIGURE 7C—Echinoderm (E) and bryozoa (Z) in silty lime mudstone at 1,065 ft; plane light, bar = 0.2 mm.

FIGURE 7D—Brachiopod spines (S) and valves (V) in wackestone at 1,086 ft; plane light, bar = 0.2 mm.

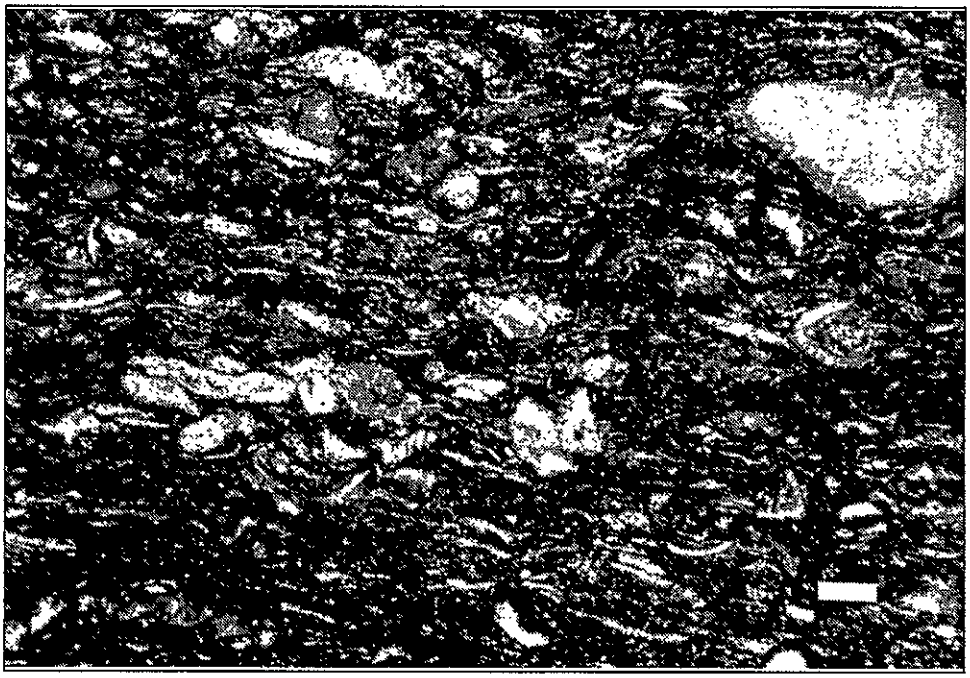

FIGURE 7E—Laminated packstone with echinoderm and ostracod valves at 1,088 ft; plane light, bar = 0.2 mm.

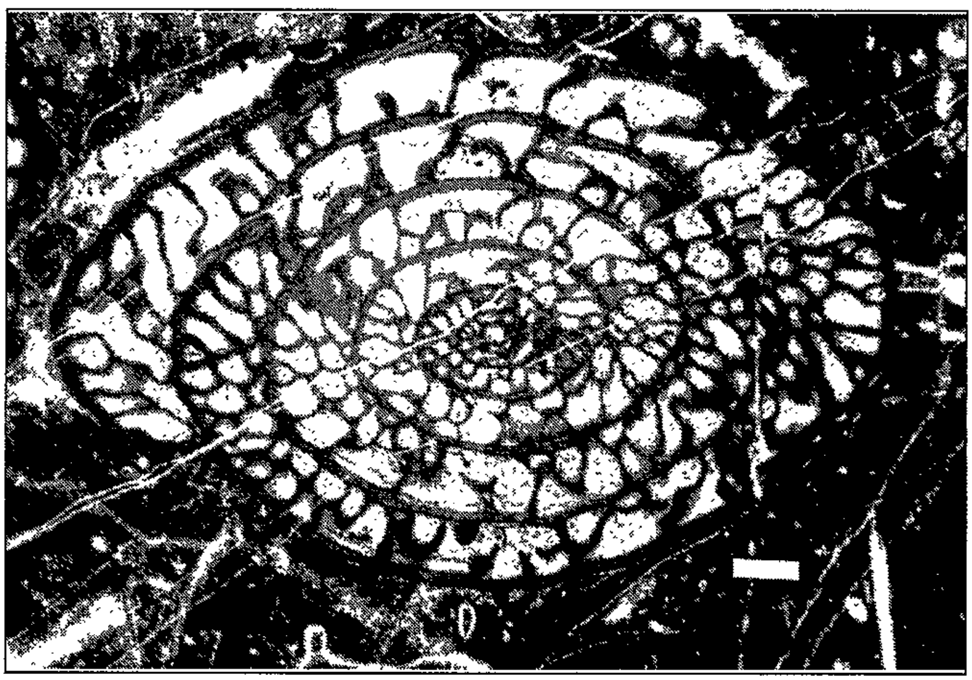

FIGURE 7F—Fusulinid in rudstone at 1,224 ft; plane light, bar = 0.2 mm.

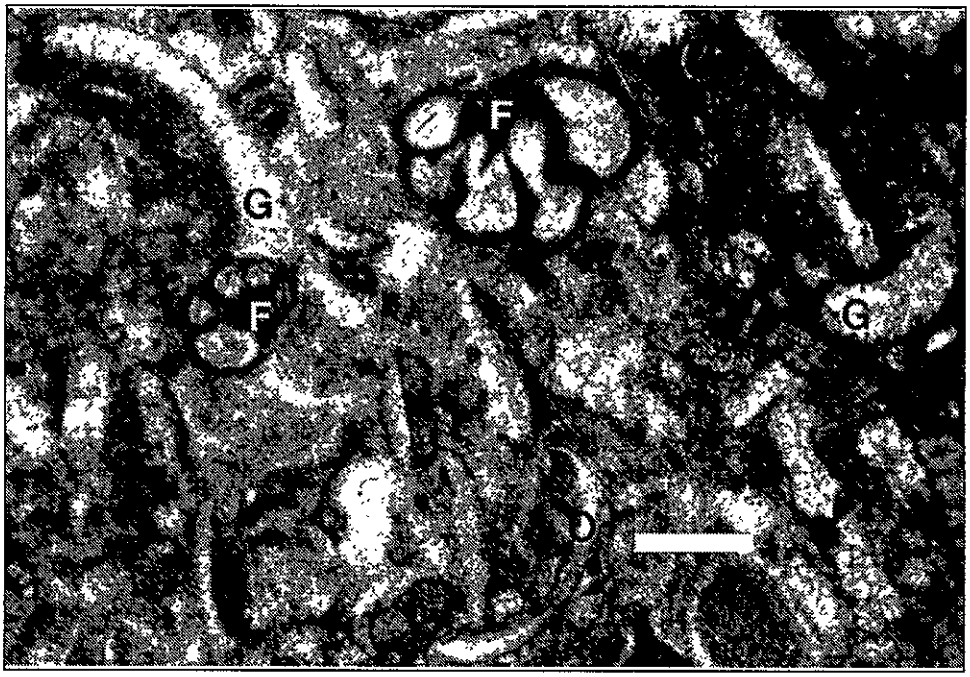

FIGURE 7G—Globular foraminifera (F), ostracod (O), and gastropod (G) fragments in packstone at 1,216 ft; plane light, bar = 0.2 mm.

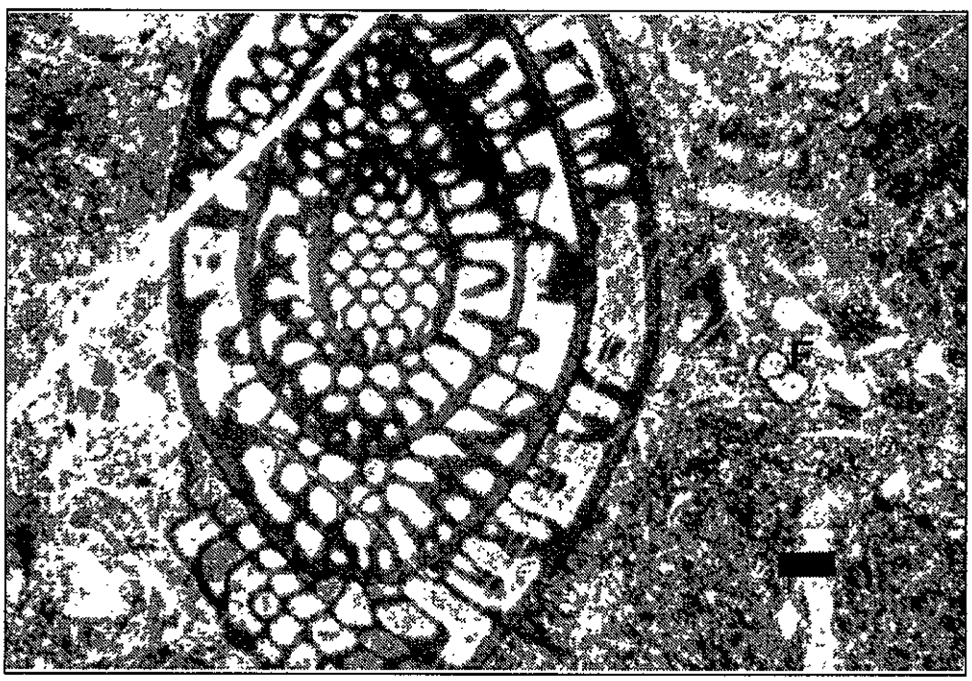

FIGURE 7H—Fusulinid and globular foraminifera (F) in packstone at 1,293 ft; plane light, bar = 0.2 mm.

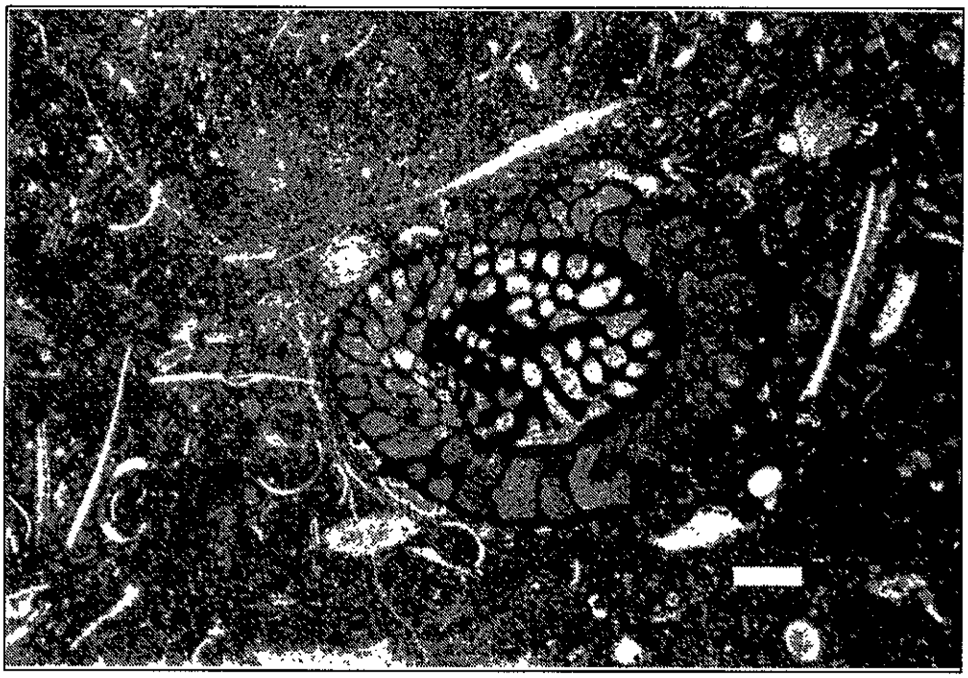

FIGURE 7I—Fusulinid in packstone at 1,300 ft; plane light, bar = 0.2 mm.

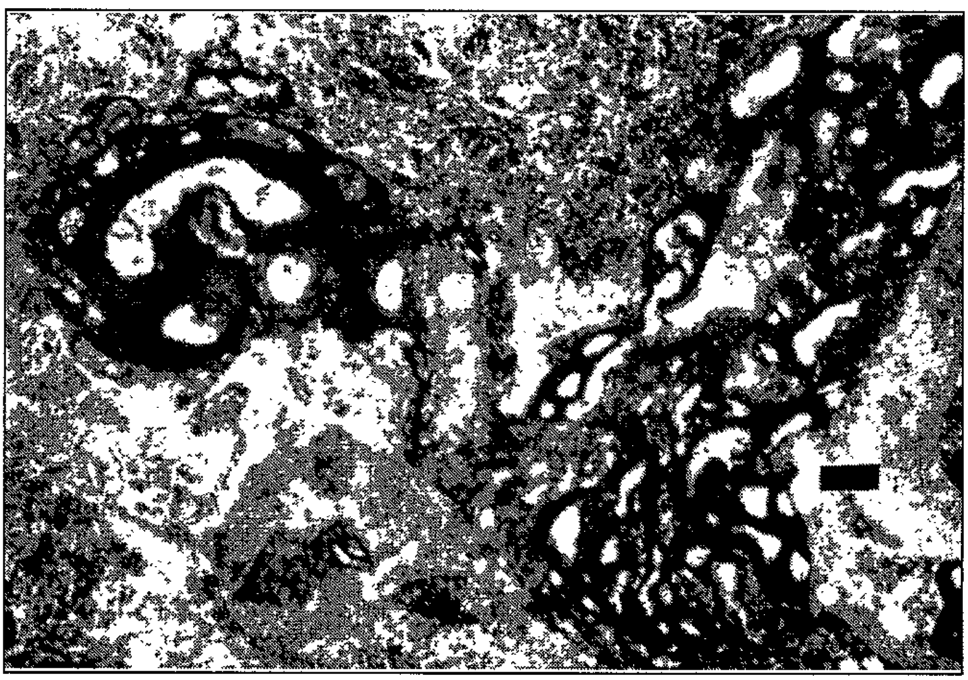

FIGURE 7J—Encrusting foraminifera in bindstone at 1,362 ft; plane light, bar = 0.2 mm.

FIGURE 7K—Dasycladacian algae in packstone at 1,412 ft; plane light, bar = 0.2 mm.

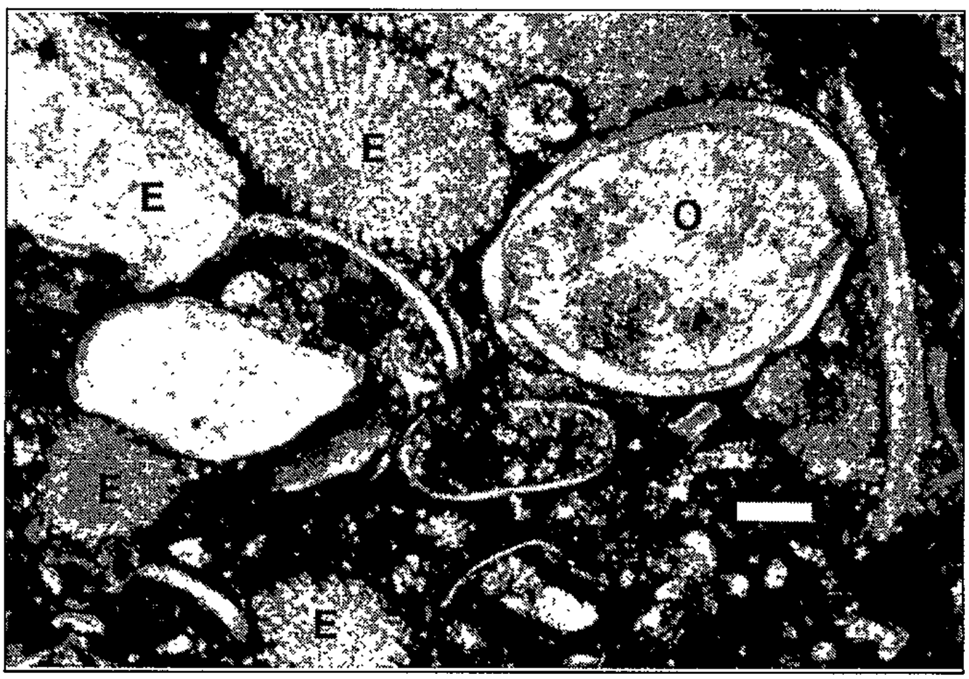

FIGURE 7L—Echinoderm (E) and ostracod (O) in packstone at 1,421 ft; plane light, bar = 0.2 mm.

core depth (ft)	algae	brachiopod	bryozoa	coral	echinoderm	foraminifera	gastropod	intraclast	ostracod	peloid	silt	sponge spicule	trilobite	rock name	SMF
944		s			A								s	floatstone	19
950		C	s		s	s			s					wackestone	19
954		s	C		C	s			C					wackestone	9
983		s			A	t		s	s					packstone	9
1003	C	C	C		C	s	C							rudstone	9
1005	C	C	s		C		C		t		s			floatstone	9
1021	t	C	s			C			s					packstone	19
1060		t	C		t	t	t		t					lime mudstone	19
1065			s		s				t		s			lime mudstone	19
1086		A	C		C	t	s		C					wackestone	9
1088		C	s		A				A		s		s	packstone	9
1198		s				A			A					wackestone	19
1199		C	t			A			A					rudstone	9
1216	C	t			s	A	A		C					packstone	19
1224	s	s			C		t		t	A				wackestone	9
1229	s	s			C	t	A		t	A				floatstone	9
1232	s	C			C	A	t		t			s		wackestone	9
1236	s	t			C	A	s		t	C				packstone	9
1237	C	C	s		s	A			s					rudstone	9
1241		C		t	s	s	C		t	C				packstone	9
1293	s	s			t	A	C		s					packstone	9
1300		C			A	s	A		C				s	packstone	9
1362	C	s	s		s	A	s		s	C			t	bindstone	7
1396		t			C	C	C		t					packstone	9

FIGURE 8—Allochem compositions of GWLH-1 core thin sections. A, abundant; C, common; s, scarce; t, trace; SMF, standard microfacies from Wilson (1975).

FIGURE 8—(continued)

1412	A				C	C	A		s	s				packstone	9
1414		t			A	C	A							rudstone	19
1418	s	s	C		C	A	A		C					packstone	9
1419		A	s		s	A	s		t					rudstone	9
1420	t				s	A	C		C	s				packstone	9
1421	A	s	s		s	s	A	C	t	C				packstone	9
1422	C	C	C		t	s	C		t	s				wackestone	9
1427		A	C		C	C	t		s					rudstone	9
1428		C	A		A	s			s					packstone	9
1448			s		s	A	C		s					packstone	9
1500						A			s					packstone	19
1551														lime mudstone	19
1601											t			lime mudstone	19
1700											s			lime mudstone	19
1714	A										C			lime mudstone	22
1750											A			siltstone	--
1790														lime mudstone	19
1802														lime mudstone	19
1807		C	A	t	C	t	t		t		t			packstone	9
1808		C	A		C	t	t				t			packstone	9
1824		C	s		A		s		t					packstone	9
1852											C			lime mudstone	19
1862		s	A		C						s			wackestone	19
1865		C	A		C		s						t	packstone	9
1868		s	A		A		t							packstone	9
1872		s	C		t						C			wackestone	19
1875		t	A		t						C			wackestone	19
1876		s	A		t						s			wackestone	19

FIGURE 8—(continued)

1878		A	A		A									wackestone	9
1882		s	A		s						A			wackestone	19
1883		s	A		s						A			wackestone	19
1886		A	A		A									rudstone	12
1888		C	A		A									rudstone	12
1890		C	A		A						A			packstone	10
1900		t			t									lime mudstone	8
1927		s	A		A								s	lime mudstone	12
1948											C			lime mudstone	9
2013		s	t		A		t	t						grainstone	12
2073					A									grainstone	12
2100					A									grainstone	12
2150					A									grainstone	12
2190		t	t		C									lime mudstone	9

FIGURE 9—Photomicrographs of GWLH–1 core thin sections.

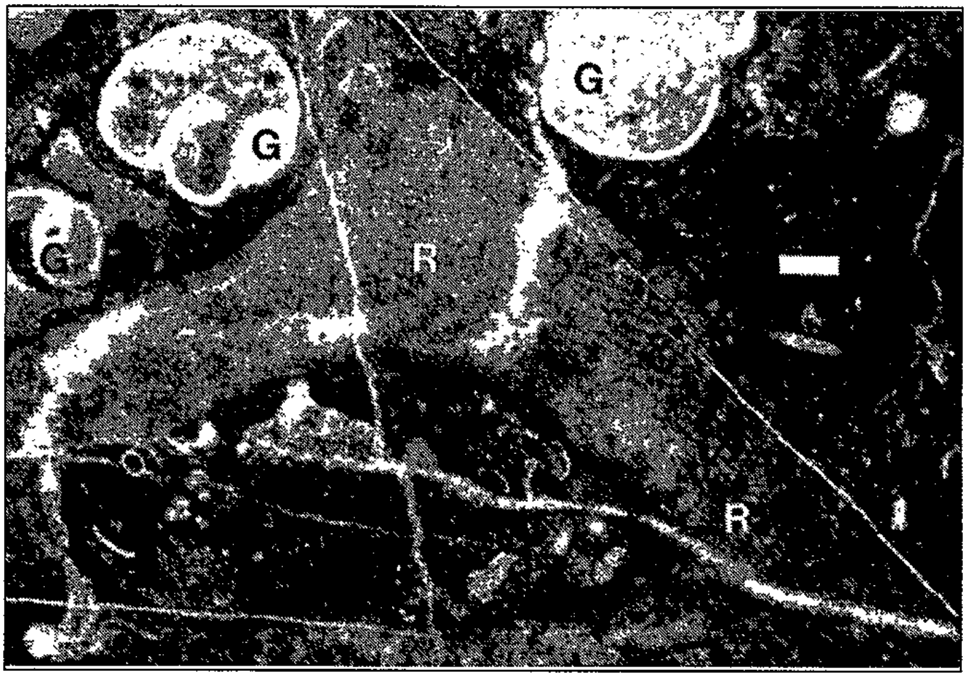

FIGURE 9A—Red algae (R) and gastropod (G) bioclasts in packstone at 1,421 ft; plane light, bar = 0.2 mm.

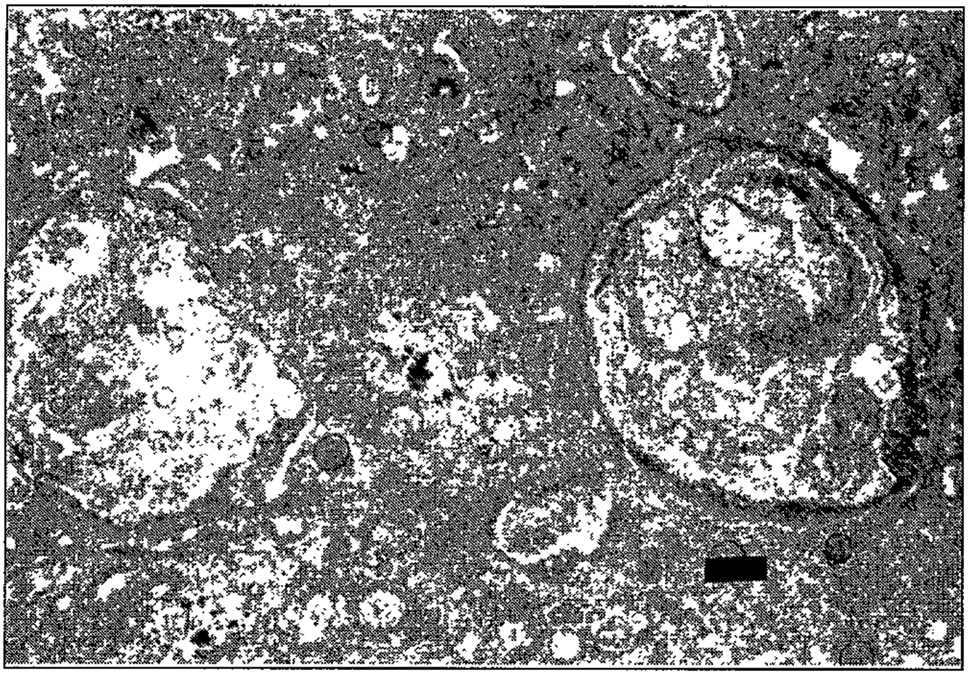

FIGURE 9B—Oncoids in lime mudstone at 1,714 ft; plane light, bar = 0.2 mm.

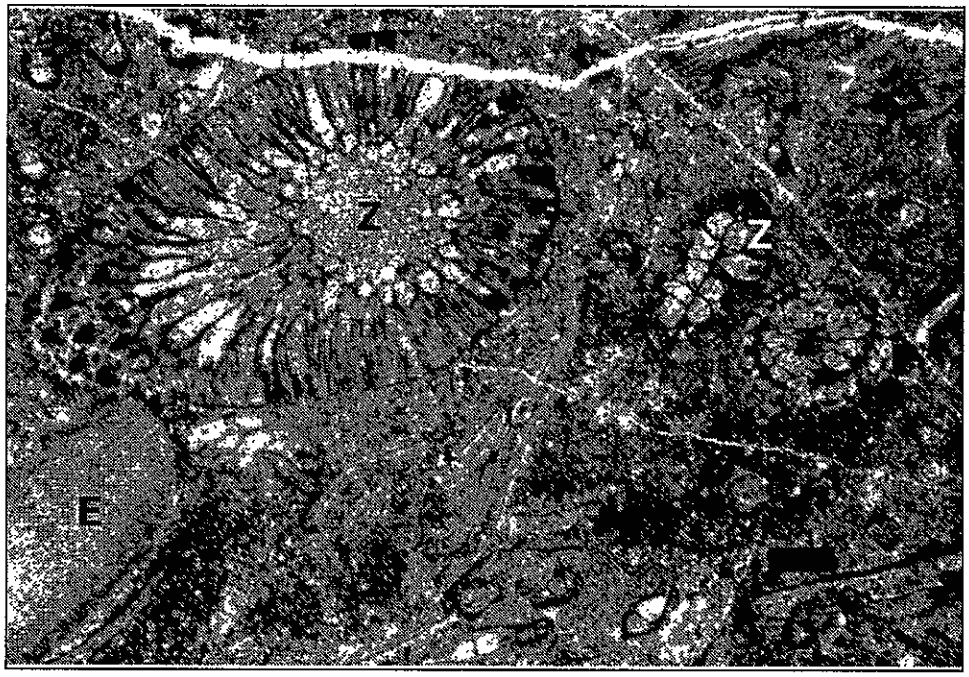

FIGURE 9C—Bryozoa (Z) and echinoderm (E) bioclasts in packstone at 1,807 ft; plane light, bar = 0.2 mm.

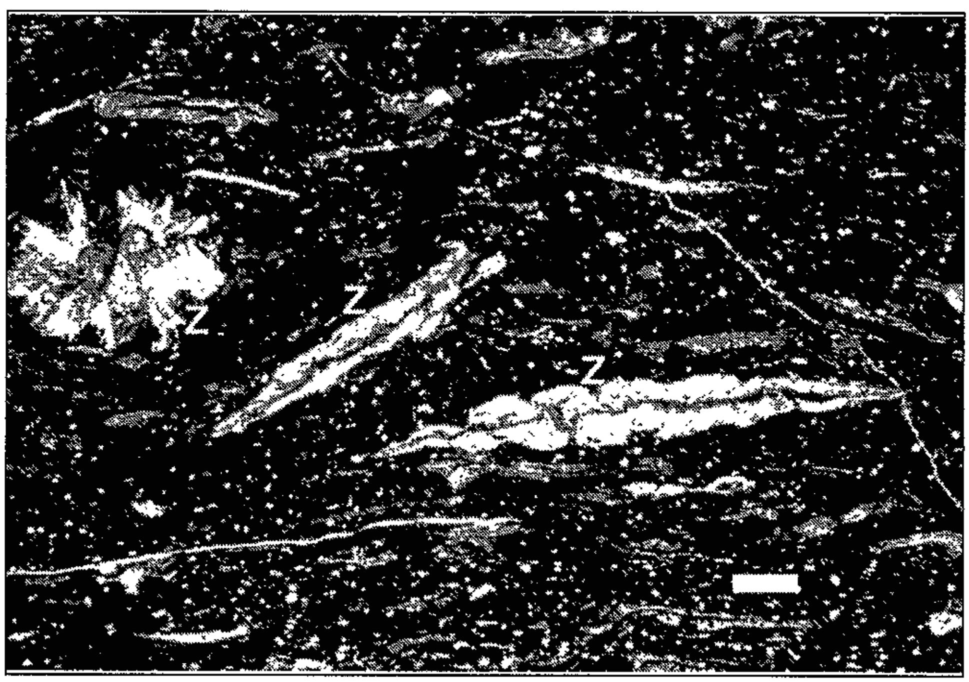

FIGURE 9D—Bryozoa (Z) in laminated silty wackestone at 1,872 ft; plane light, bar = 0.2 mm.

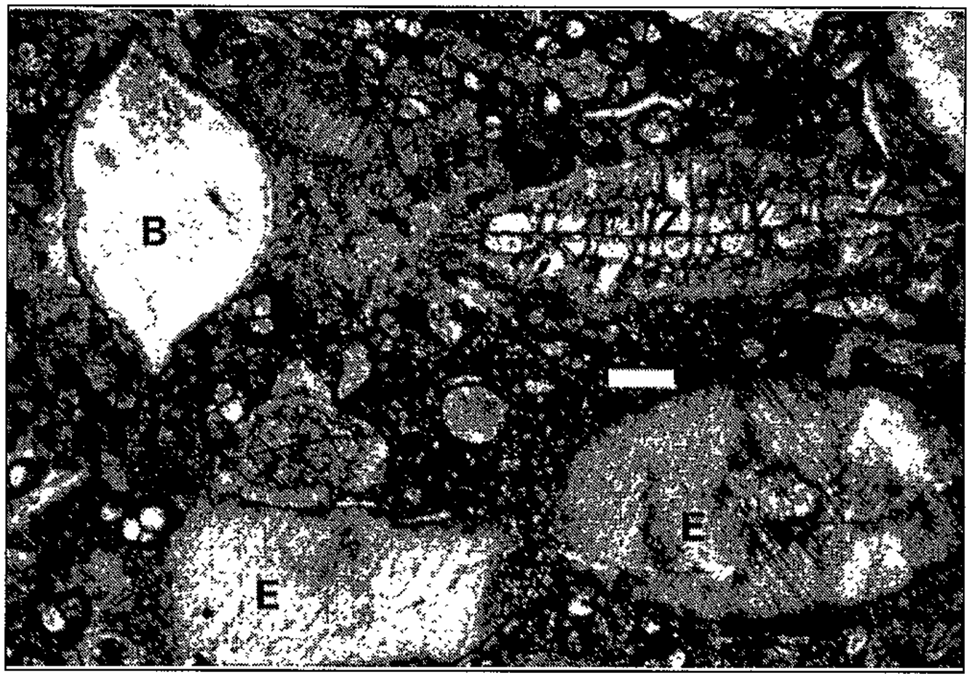

FIGURE 9E—Brachiopod (B), echinoderm (E), and bryozoa (Z) bioclasts in packstone; plane light, bar = 0.2 mm.

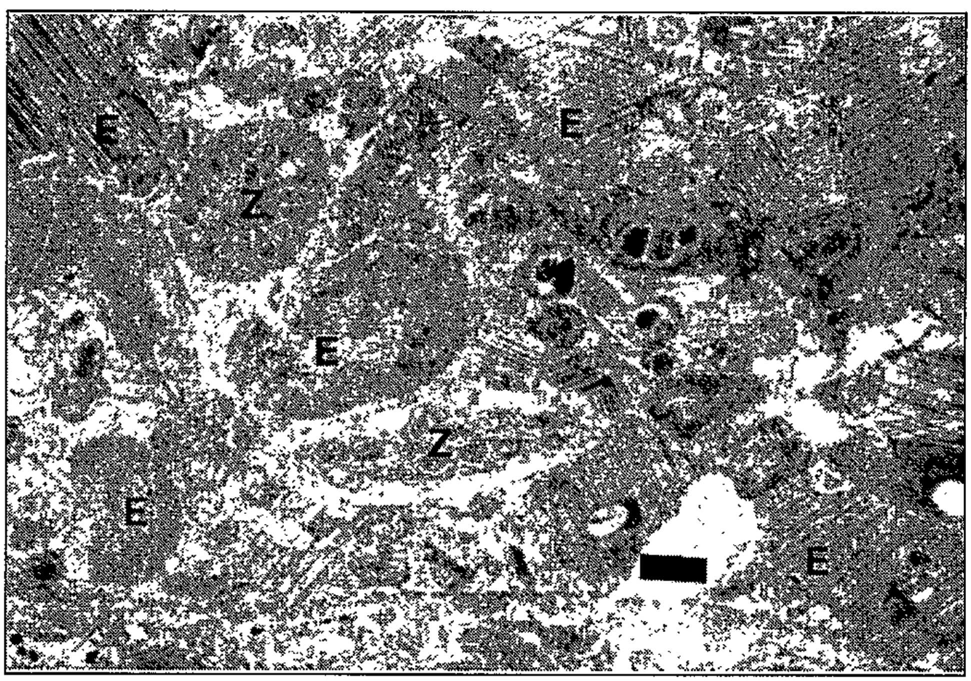

FIGURE 9F—Echinoderm (E) and bryozoa (Z) bioclasts in grainstone at 1,927 ft; plane light, bar = 0.2 mm.

Dominant bioclasts in the packstones and wackestones between 1,805-1,900 ft are small, abraded fragments of brachiopods, bryozoa and echinoderms (Fig. 9). Quartz silt is intermittently common throughout this 95 ft of section. Echinoderm-bryozoa grainstones (Fig. 9E) and two thin lime mudstones comprise the section between 1,900-2,190 ft. The lower 124 ft of core is massive white marble to TD of 2,314 ft.

Depositional environments were predominantly shelf-edge shoal with constant winnowing for the lower 400 ft in the core. Upward, the core section represents shallow, open-circulation shelf facies with intermittent protected or restricted shelf lagoons and minor influxes of siliciclastic sediments. The fusulinids (Fig. 7F, H, I) at 1,199, 1,224, 1,293 and 1,300 ft are Early Permian forms so this part of the section is probably Colina or possibly Earp Formation equivalents. The lower part of the core may be Wolfcampian Horquilla Formation.

GWLH-3 Core

The GWLH-3 core was drilled in SW¼, sec. 30, T27S, R9W 1 mi south of GWLH-1 and 1.5 mi north of West Lime Hills. Apparently there is a northwest-trending fault between GWLH-1 and GWLH-3 with the southwest block downthrown because the Tertiary/Permian contact is about 800 ft lower in GWLH-3. Lower Permian rocks were intersected at a depth of 1,625 ft in GWLH-3 and the 684 ft of core to TD of 2,309 ft is interpreted to be Lower Permian strata based upon lithologic and faunal similarities and proximity to GWLH-1. Megascopic fossils include gastropods, brachiopods and echinoderms. Breccia zones at 1,712-1,726, 2,159-2,176, 2,272-2,279 and 2,281-

2,283 ft intervals may be faults. Laminations and bedding are nearly horizontal except near the breccia zones. A general lithologic description of the core is in Appendix A-2. From 1,625-1,805 ft the core is mostly lime mudstone, sandy mudstone and siltstone. Packstones and wackestones dominate the rest of the core with interbedded dolostone and siltstone common between 1,885-2,000 ft and siltstone below 2,160 ft.

Dominant bioclasts are echinoderms and gastropods (Fig. 10B, C, G) with foraminifera (globular, tubular, encrusting, uniserial and Tuberitina) common between 1,800-2,000 ft (Fig. 10C, D, 11). Ostracods are scarce, but present throughout the section. Brachiopods (Fig. 10B, E) and bryozoa (Fig. 10H) are intermittently present below 1,790 ft. A sponge fragment (Fig. 10F) occurs with peloids, gastropods, echinoderms and trace amounts of trilobites, foraminifera, bryozoa and brachipods at 2,133 ft and sponge spicules (Fig. 10I) are abundant at 2,305 ft.

Depositional environments were predominantly restricted marine shelf lagoons and bays, indicated by the gastropod-foraminifera-echinoid-ostracod fauna in the lime mudstones and wackestones. Intermittently there was some open circulation on the shelf during which the few grainstones and bioturbated packstones were deposited. Minor influxes of silt and sand at the base, upper middle, and upper parts of the core (Fig. 11) probably indicate the depositional site was relatively near the shoreline.

Gym Peak

About 430 ft of Lower Permian rocks are well exposed in the southeastern Florida Mountains, 16 mi northeast of the West Lime

FIGURE 10—Photomicrographs of GWLH-3 core thin sections.

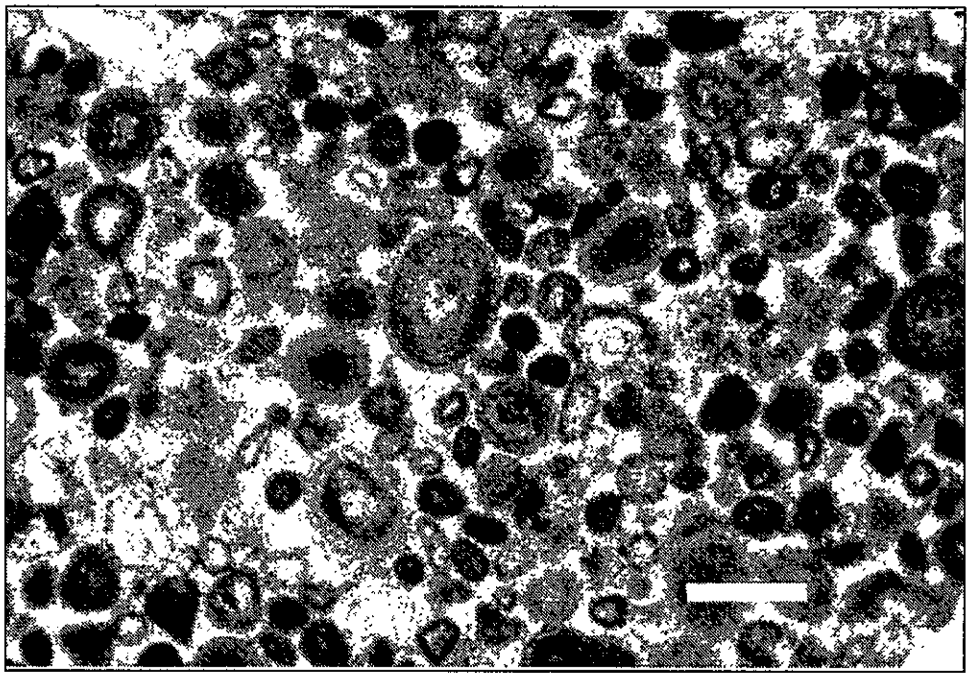

FIGURE 10A—Ooid grainstone at 1,635 ft; plane light, bar = 0.2 mm.

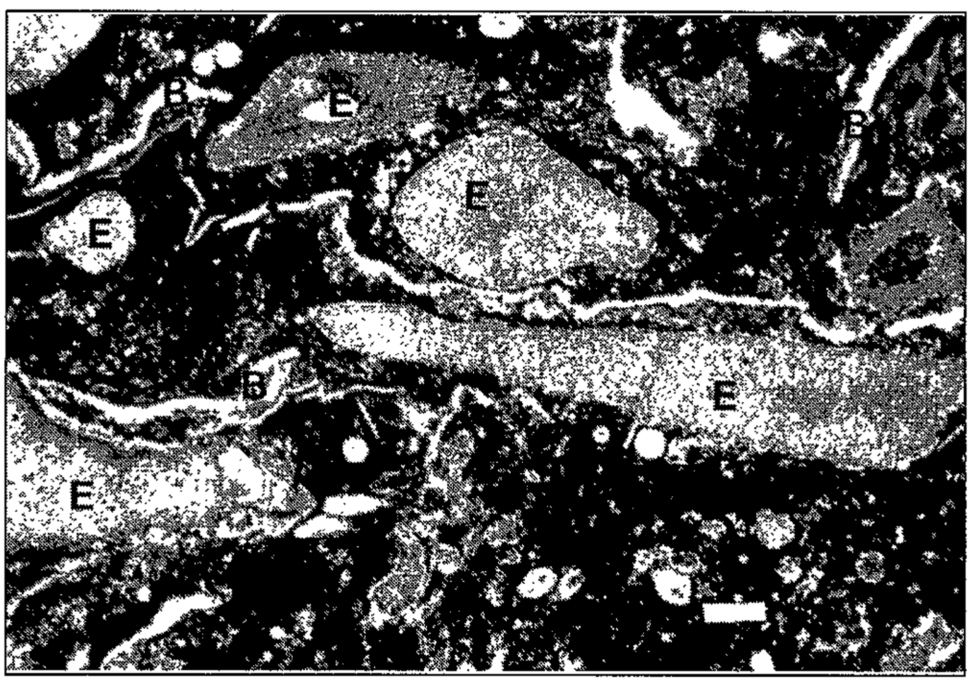

FIGURE 10B—Echinoderm (E) and brachiopod (B) bioclasts in packstone at 1,792 ft; plane light, bar = 0.2 mm.

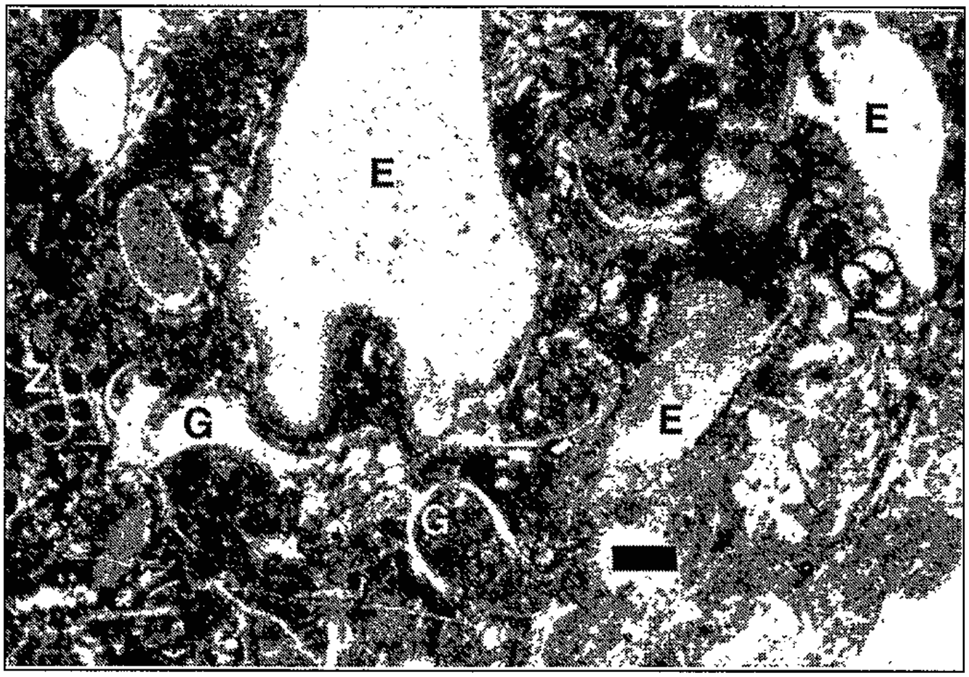

FIGURE 10C—Echinoderm (E), foraminifera (F), bryozoa (Z), and gastropod (G) bioclasts in rudstone at 1,830 ft; plane light, bar = 0.2 mm.

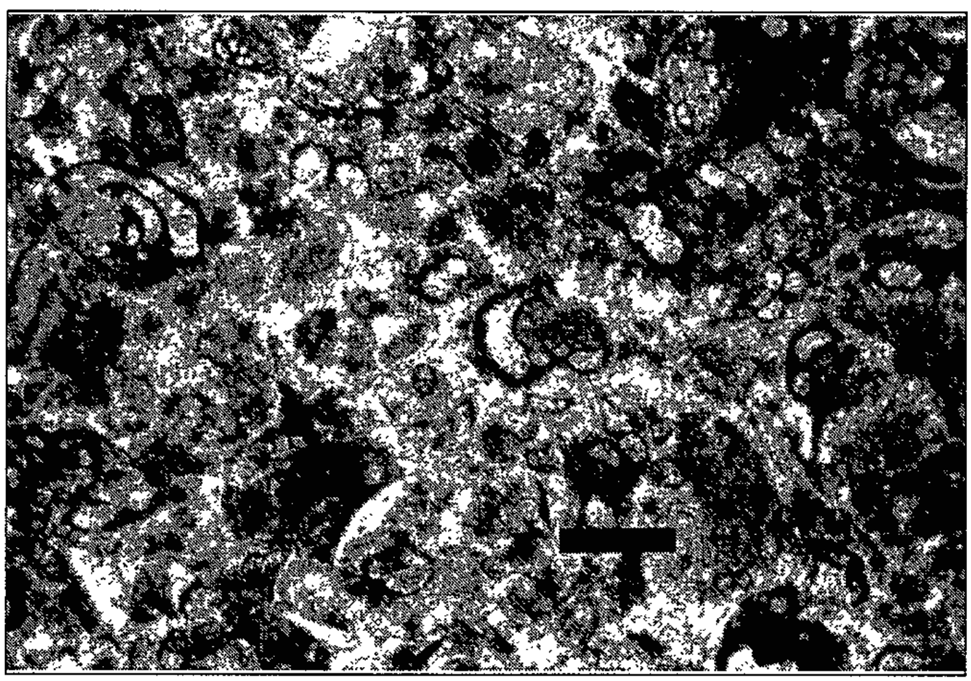

FIGURE 10D—Foraminifera in grainstone at 2,002 ft; plane light, bar = 0.2 mm.

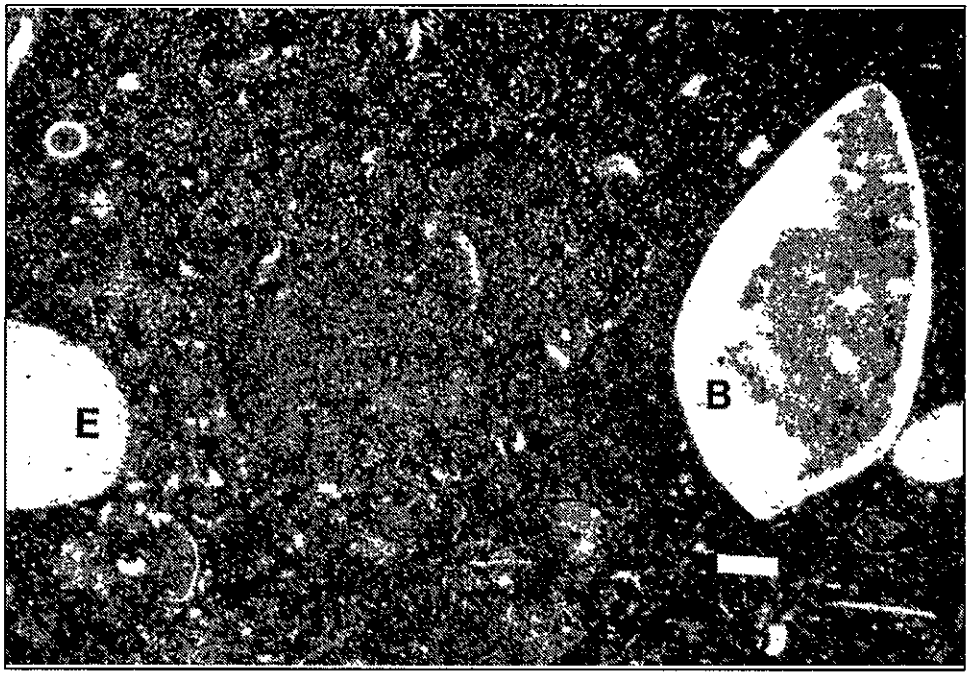

FIGURE 10E—Whole brachiopod (B) and echinoderm (E) columnal in wackestone at 2,039 ft; plane light, bar = 0.2 mm.

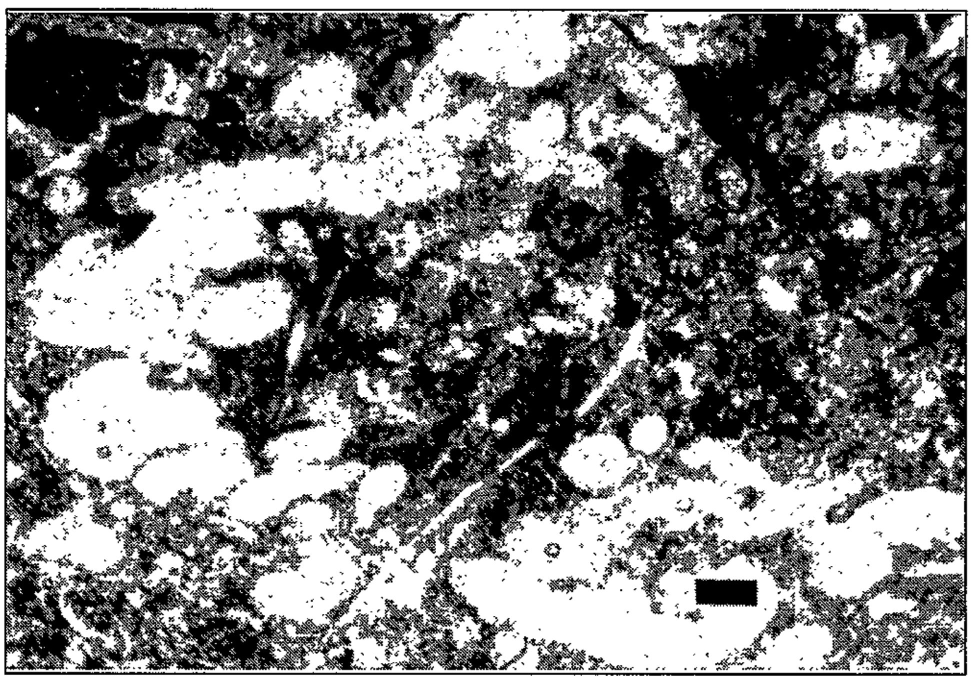

FIGURE 10F—Sponge fragment in rudstone at 2,135 ft; plane light, bar = 0.2 mm.

FIGURE 10G—Peloids and gastropod fragments in rudstone at 2,133 ft; plane light, bar = 0.2 mm.

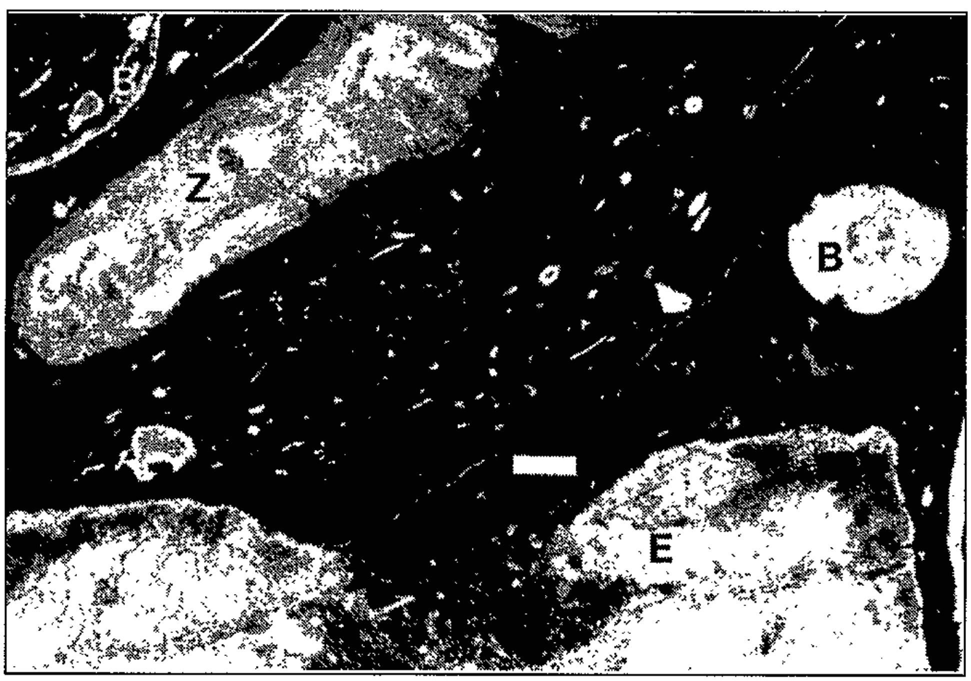

FIGURE 10H—Echinoderm (E), bryozoa (Z), and brachiopod (B) bioclasts in wackestone at 2,255 ft; plane light, bar = 0.2 mm.

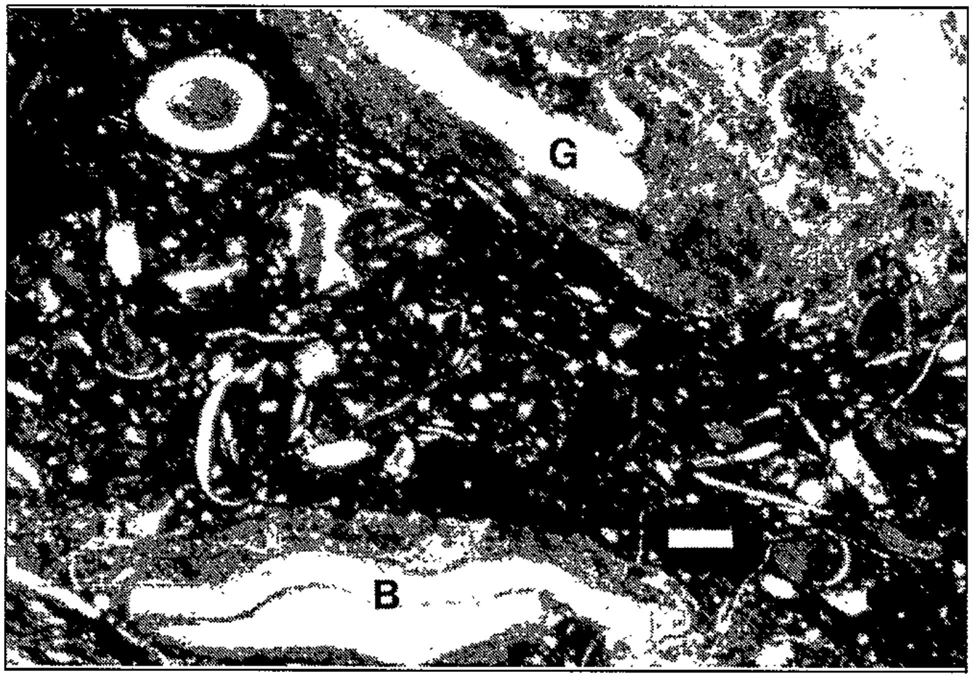

FIGURE 10I—Encrusting algae on gastropod (G) and brachiopod (B) fragments; small white fragments are sponge spicules in packstone at 2,305 ft; plane light, bar = 0.2 mm.

core depth (ft)	algae	brachiopod	bryozoa	coral	echinoderm	foraminifera	gastropod	intraclast	ostracod	peloid	silt	sponge spicule	trilobite	rock name	SMF
1635							s	A*						grainstone	15
1680						t			t					lime mudstone	19
1750							t		t					lime mudstone	19
1791						t			t					lime mudstone	19
1792		A	s		A	t	A		s					packstone	9
1798														lime mudstone	19
1801					t		s					t		lime mudstone	19
1807						A	C	C		C				grainstone	18
1830		t	s		A	s	A		s	t			t	rudstone	9
1864	t	A	t		s		C		C	s				packstone	9
1952	t				s	A	C		s					wackestone	19
1999		s			C		A							packstone	19
2002		t			s	A	C		s					grainstone	18
2006		s			s								t	wackestone	19
2025		t	t		A		A							packstone	9
2027	C	t	t		s	A	C		t					floatstone	19
2029		s			C		s							wackestone	19
2030		s			s		s							wackestone	19
2033					s		s		t					wackestone	19
2038		s			s		A							wackestone	9
2039		s	t		s		s		s					wackestone	9
2043														lime mudstone	19
2091					A		s							wackestone	19
2133		t	t		C	t	A			A		s	t	rudstone	19

FIGURE 11—Allochem compositions of GWLH-3 core thin sections. A, abundant; C, common; s, scarce; t, trace; SMF, standard microfacies from Wilson (1975).

FIGURE 11—(continued)

2154		t			s	s	C			A				wackestone	19
2190	A				s	t	C			C				grainstone	12
2254		s			C		C		s					packstone	9
2255	s	C	C		A		s		s					packstone	9
2263	s	C	C		C		s		s					packstone	9
2305	C	t			A		A		C			A		packstone	19

Hills. Darton (1916, 1917) included this Permian limestone south of Gym Peak in his Gym Limestone. Bogart (1953) assigned the name Hueco to these rocks based on lithologic similarity and a study of gastropod fauna that he thought to be very similar to the Wolfcampian Hueco Limestone, but Jordan (1971) stated that the Permian-age strata resembled more closely Colina Limestone in Sierra Alta and Big Hatchet Mountains. Clemons and Brown (1983) referred to these strata as Hueco Limestone. Total thickness of the Hueco here is difficult to determine due to fault complications. A thickness of 430 ft is considered a minimum.

The southeastern Florida Mountains' Permian strata disconformably overlie Mississippian Rancheria Formation 1 mi southeast of Gym Peak and are angularly overlain by the early Tertiary Lobo Formation., The Hueco (Colina) Formation consists of thin-, medium- and massive-bedded, dark-gray wackestones, packstones, and minor grainstones. Chert development is restricted to a few scattered brown nodules. Abundant large (up to 8 cm) bellerophonid gastropods are common. Scattered high-spired gastropods, solitary corals, brachiopods, and echinoid fragments are also common throughout. Thin section examination reveals bioturbated material (Fig. 12) with abundant fragments of gastropods, echinoderms, (probably echinoids), ostracods, peloids, and foraminifera (<u>Globivalvulina</u>, <u>Tuberitina</u>, paleotextularids, tubular and fusulinids). The fusulinids (Fig. 12E, G) are severely neomorphosed and occur 30 and 250 ft above the base. Dasycladacian algae (Fig. 12B, C, F, H) are abundant in some zones. Minor amounts of trilobite, brachiopod, sponge (Fig. 12D, I) and bryozoa

FIGURE 12—Photomicrographs of Lower Permian rocks in the southeastern Florida Mountains.

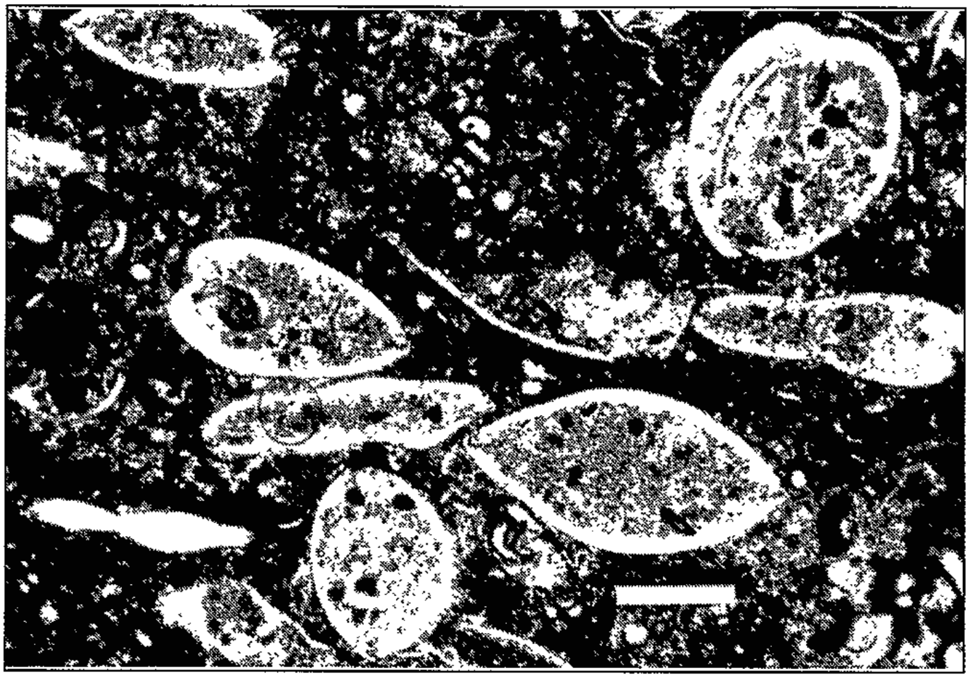

FIGURE 12A—Whole and collapsed ostracods in wackestone at 25 ft; plane light, bar = 0.2 mm.

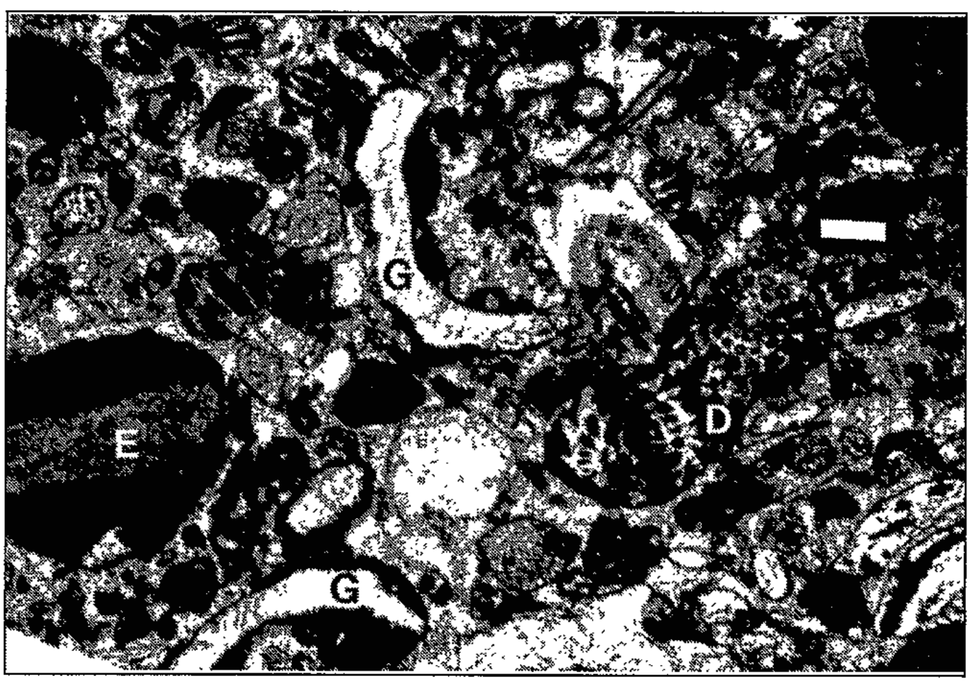

FIGURE 12B—Dasycladacian algae (D) and encrusted echinoderm (E) and gastropod (G) bioclasts in grainstone at 39 ft; plane light, bar = 0.2 mm.

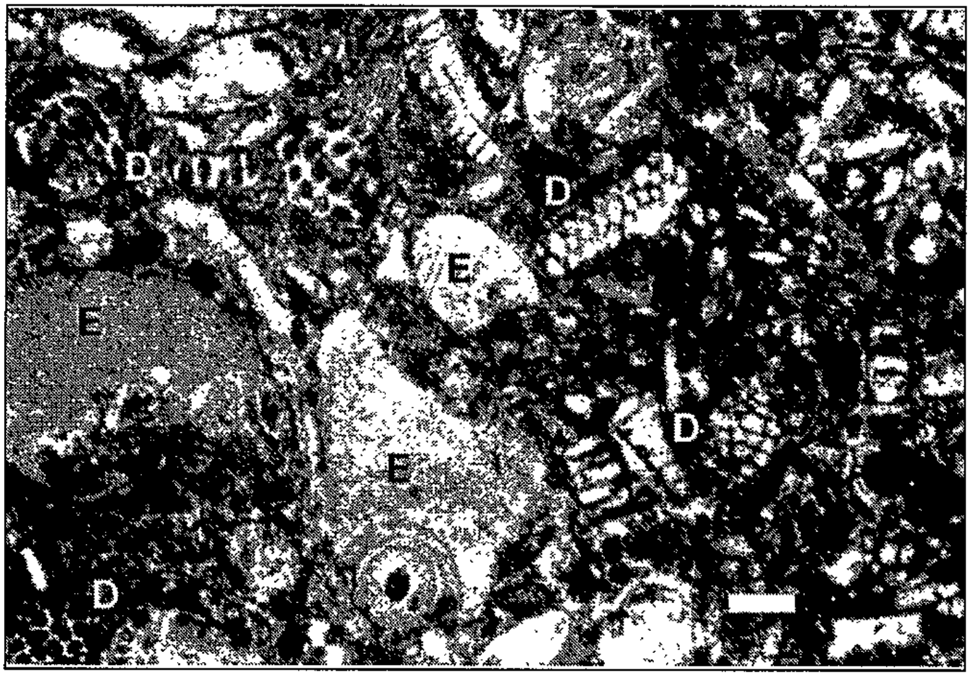

FIGURE 12C—Dasycladacian algae (D) and echinoderm (E) bioclasts in packstone at 154 ft; plane light, bar = 0.2 mm.

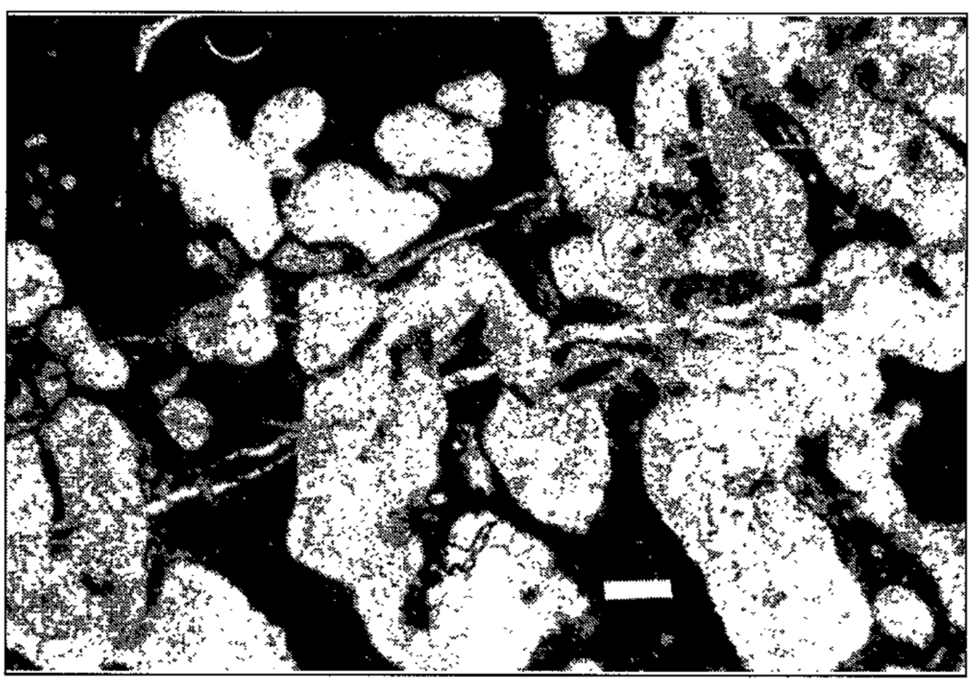

FIGURE 12D—Sponge fragment in wackestone at 164 ft; plane light, bar = 0.2 mm.

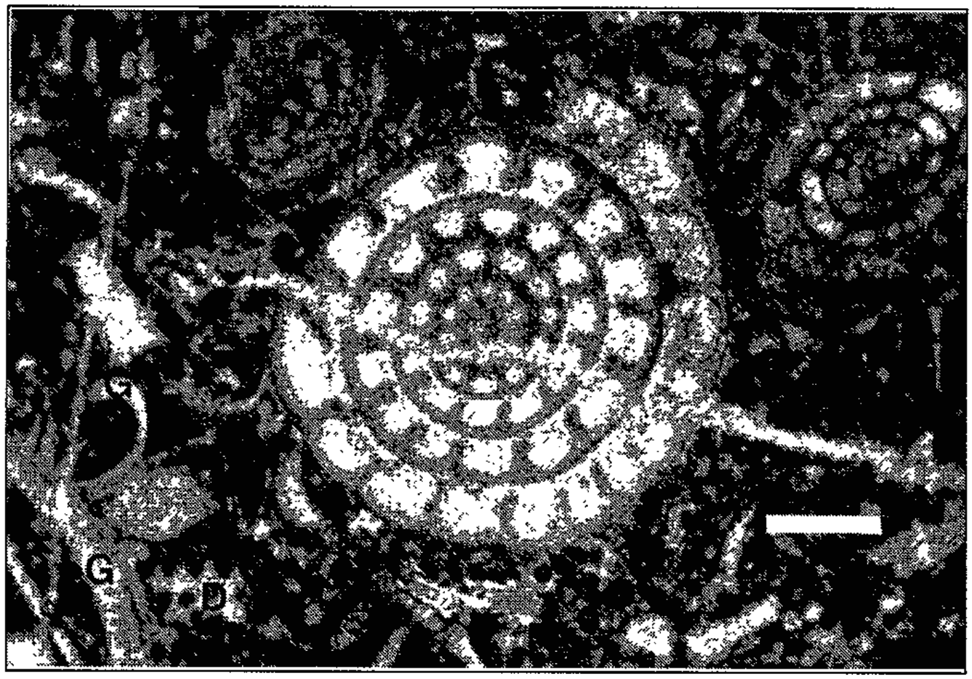

FIGURE 12E—Fusulinid, dasycladacian algae (D) and gastropod (G) bioclasts in packstone at 231 ft; plane light, bar = 0.2 mm.

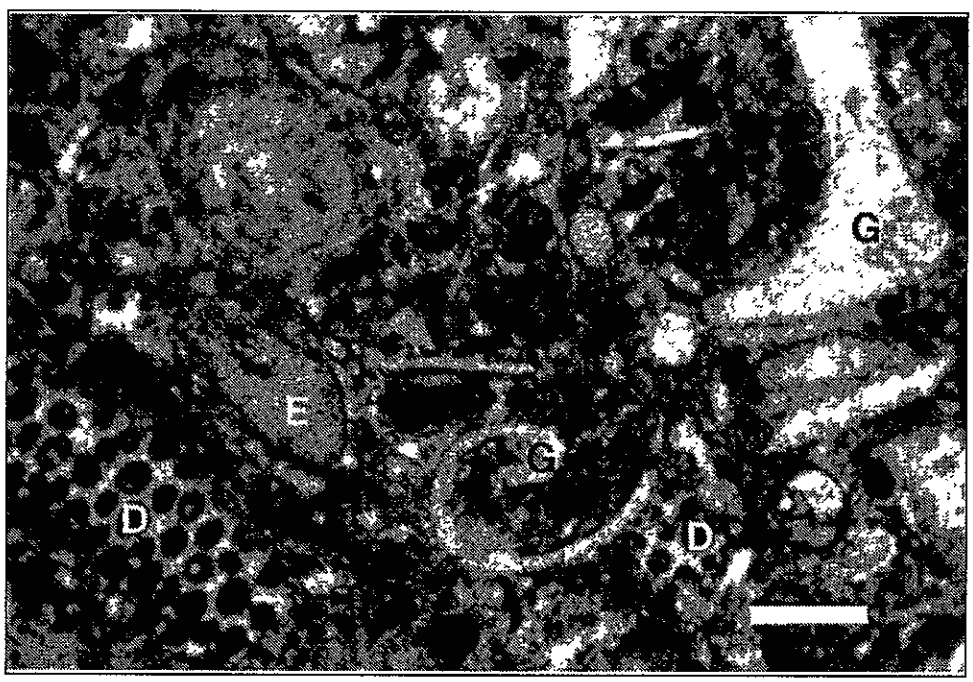

FIGURE 12F—Dasycladacian algae (D), gastropod (G), and echinoderm (E) bioclasts in packstone at 231 ft; plane light, bar = 0.2 mm.

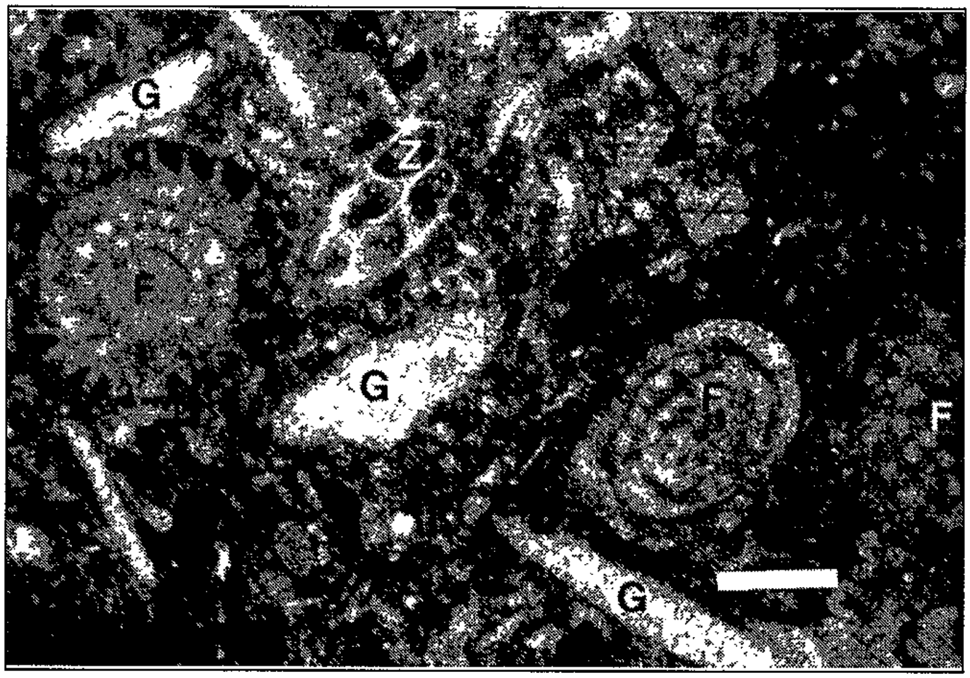

FIGURE 12G—Fusulinid (F), bryozoa (Z), and gastropod (G) bioclasts in packstone at 250 ft; plane light, bar = 0.2 mm.

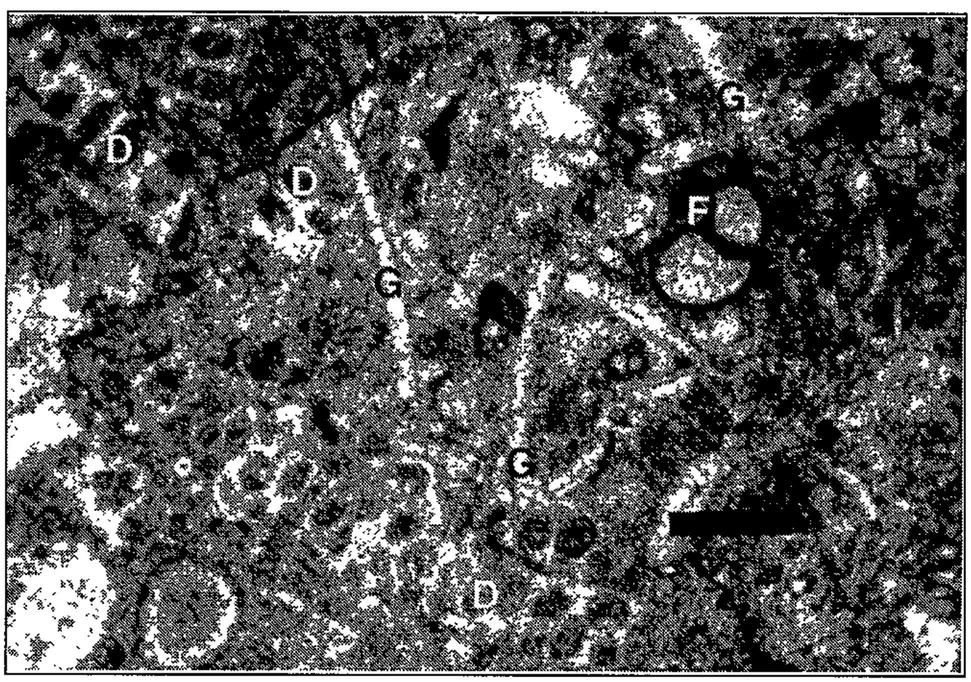

FIGURE 12H—Dasycladacian algae (D), globular foraminifera (F), and gastropod (G) bioclasts in packstone at 278 ft; plane light, bar = 0.2 mm.

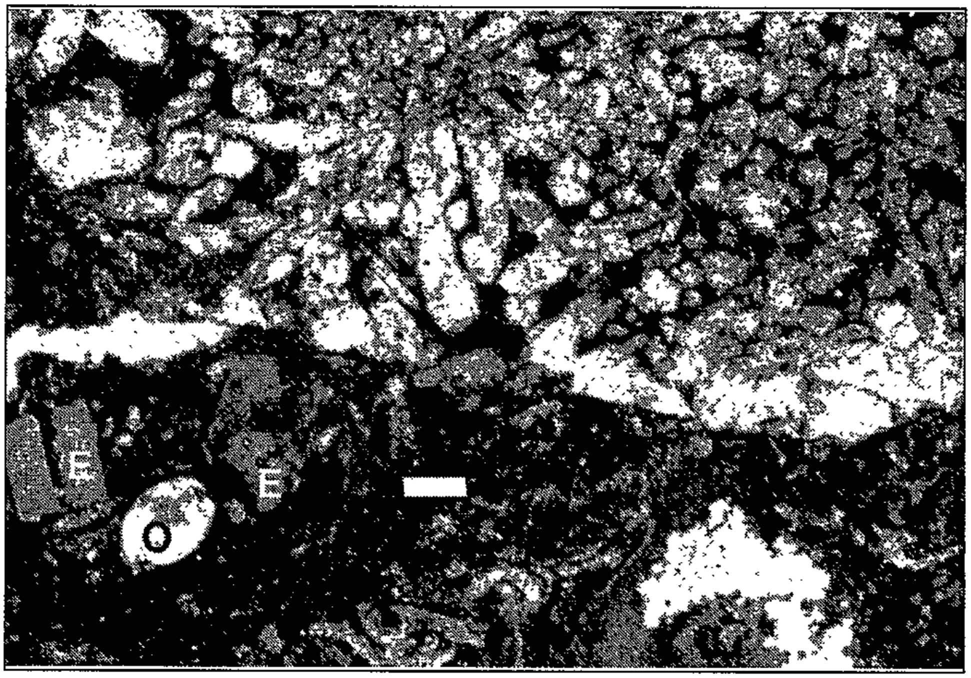

FIGURE 12I—Large sponge fragment (top half of photo), echinoderm (E) and ostracod (O) bioclasts in packstone at 308 ft; plane light, bar = 0.2 mm.

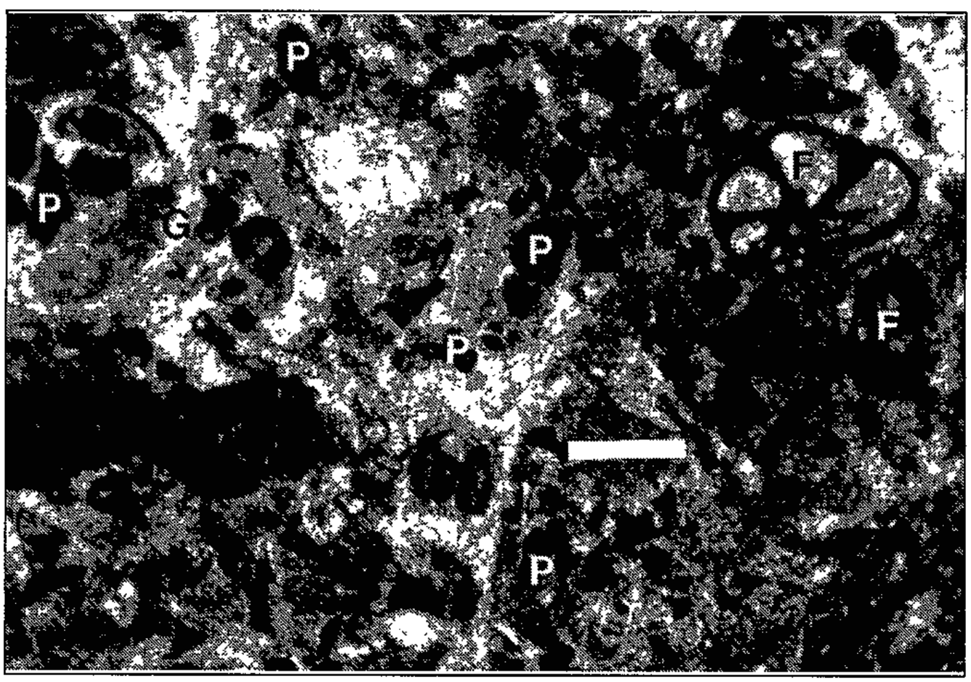

FIGURE 12J—Peloids (P), globular foraminifera (F), and gastropod (G) bioclasts in packstone at 308 ft; plane light, bar = 0.2 mm.

(Fig. 12G) fragments occur intermittently. Reddish-brown siltstone interfingers with limestone near the top of the faulted section.

Bioturbated foraminiferal wackestones, packstones and grainstones (Fig. 13) characteristic of the Hueco (Colina) Limestone southeast of Gym Peak are considered typical shallow-shelf facies. Presence of abundant gastropods, echinoderms (probably echinoids), ostracods, and peloids (Fig. 12, 13) in some dark-gray beds indicates possible lagoonal conditions at times. Dasycladacian algae indicate very shallow marine water. The strata probably represent shallow-subtidal deposits. Influx of silt and fine sand probably indicates near-shore marine conditions and possibly represents regression of the shoreline during times of deposition (Clemons, in press). No new evidence on the age of the Hueco (Colina) strata at Gym Peak was discovered during this study.

Eagle Nest

Eagle Nest is in southeastern Luna County about 17 mi southeast of the Florida Mountains. The crest of Eagle Nest ridge and the small hills northwest of the ridge are composed of about 820 ft of Lower Permian strata thrust over Lower Cretaceous rocks (Seager and Mack, 1990; Schuster, 1991). The lower part of the Permian section consists of 325 ft of thick-bedded, dark-gray limestones. Abundant chert nodules occur in several horizons. Megascopic fossils include large planispiral gastropods, solitary rugose corals, branching corals (75 ft above base), coild and orthoconic nautiloids. Seventeen samples for petrographic study were collected at 20-50 ft intervals to represent any variations that might be present in the apparently uniform lithologic section.

thickness (ft)	algae	brachiopod	bryozoa	coral	echinoderm	foraminifera	gastropod	intraclast	ostracod	peloid	silt	sponge spicule	trilobite	rock name	SMF
base	t	s			A	C			C	C				wackestone	19
5	t	t	s		A	C	A		C	C			t	grainstone	19
10	A	s			C	s	s		s	s				rudstone	9
25		t				C	C		A	A				wackestone	19
30	s	t			C	C	s		s	A			t	grainstone	19
33	t		t	t		A	s		A	C				packstone	19
39	A	t		t	s	A	s		t					grainstone	18
46	A	t			s	C			C	C				grainstone	18
59	C	s	t	t	C	A	s		s	C				packstone	19
79	C		t		C	C	s	C	t	C				grainstone	18
85	C	t			s	C	s	C	s	C				grainstone	18
98		t	t		C	C			C	A				grainstone	18
105	C	t			C	C	A		s	A			t	packstone	19
116		t			s	A			s	A				grainstone	19
128	s	s	C		C	C			C	s		C		wackestone	9
138	s				C	s	C		s	C		s		wackestone	9
154	A	C		t	C	s	C		s					packstone	9
164	A	t			s	C	A		C			s	t	wackestone	9
190	C	s			C	s	A		t	C				rudstone	19
213		t			s	s	A		C			C		wackestone	19
231	A			t	C	A	C		t	C			t	packstone	19
241	A	t			s	A	C		s	s		C		packstone	19
250	s	t	t		C	s	A			C			t	packstone	19
254	C	t			s	s	C		s	A				grainstone	18
278	A	s			s	s	A		s	s			t	packstone	19

FIGURE 13—Allochem compositions of Lower Permian thin sections from southeastern Florida Mountains. A, abundant; C, common; s, scarce; t, trace; SMF, standard microfacies from Wilson (1975).

FIGURE 13—(continued)

288	A	t			s	s	A		s	A			t	packstone	19
308	s	s	s		C	C	C		C	C		C	t	packstone	19
326	A			t	s	C	C		C	s		s		packstone	19
335					t	t	t		s	A				wackestone	19

Seager and Mack (1990) described the upper part of the Permian section, exposed in small hills north of Eagle Nest, as consisting of 328 ft of light - to medium-gray, thin - to medium-bedded, cherty, dolomitic limestone. They correlated the lower limestone section to the Colina or upper Hueco Formations. No petrography was done on the upper dolomitic section in this study.

A brief petrographic analysis showed no change in depositional environments throughout the section. Small, abraded echinoderm bioclasts (Fig. 14E, H, I) are dominant, followed by Climacammina (Fig. 14A, F), Globivalvulina (Fig. 14B), Tuberitina, uniserial and globular foraminifera, brachiopods (Fig. 14E,I), ostracods (Fig. F, I, K) and bryozoa (Fig. 14G). Trace amounts of small trilobite fragments (Fig. 14H, J) are present in most thin sections (Fig. 15). Even though megascopic corals and gastropods are present throughout the 525 ft section, coral bioclasts were only seen in thin sections of the lower 75 ft and gastropod bioclasts in the upper 200 ft (Fig. 15).

The basal silty lime mudstone probably represents a restricted shelf lagoon or bay. Depositional environment of the overlying 500 ft of strata was shallow, open circulation, marine shelf as evidenced by the consistent bioturbated bioclastic wackestones and packstones. Diversity of organisms, relatively few peloids, and absence of algae or micritized rims support the open circulation environment interpretation. Megascopic and microscopic lithology of this section is unlike any of the other sections in this study. I believe the Eagle Nest limestone section is best correlated with the Colina Formation and agree with Seager and Mack (1990) that the

FIGURE 14—Photomicrographs of Lower Permian rocks at Eagle Nest.

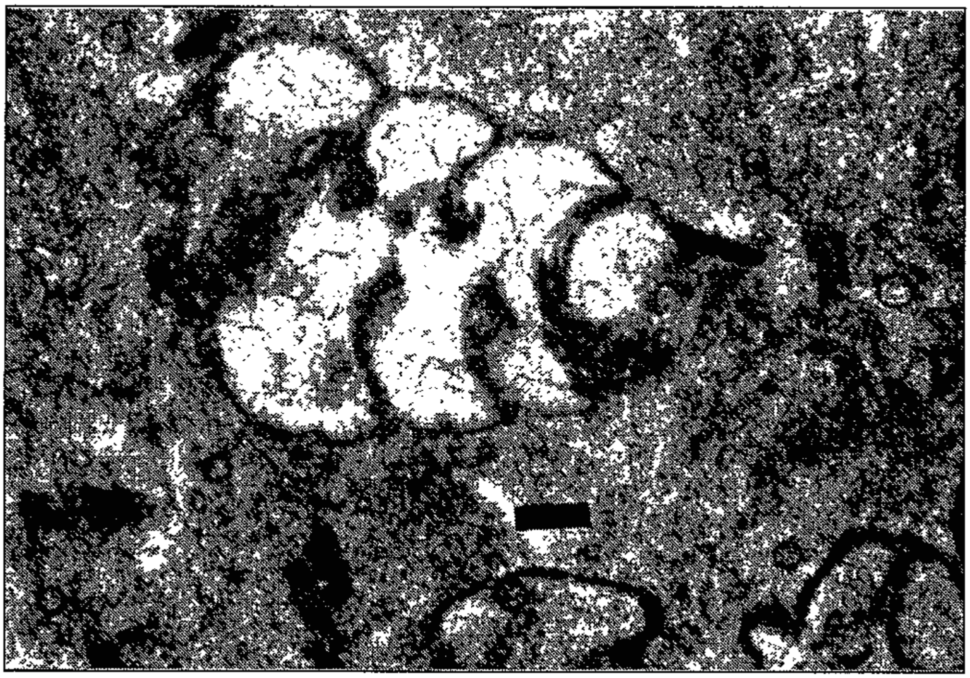

FIGURE 14A—*Climacammina*? in wackestone at 20 ft; plane light, bar = 0.1 mm.

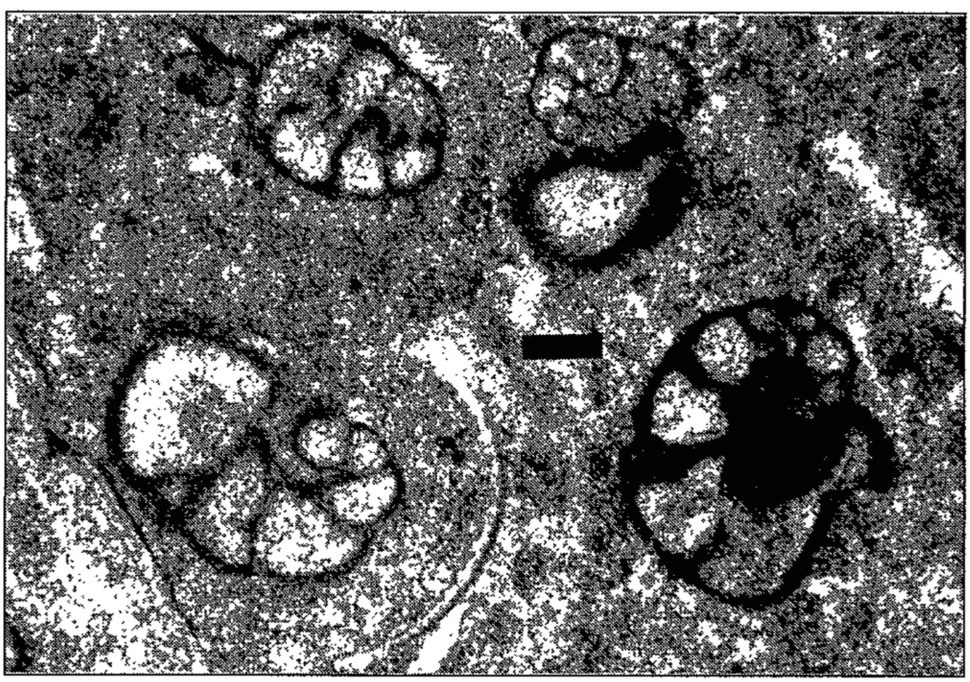

FIGURE 14B—*Globivalvulina*? in wackestone at 20 ft; plane light, bar = 0.1 mm.

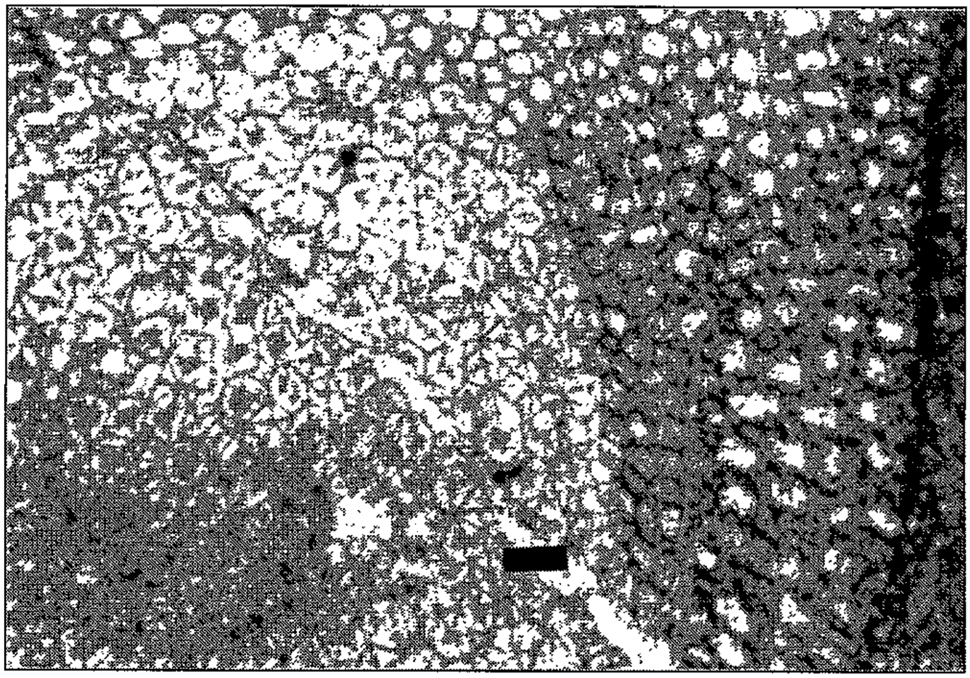

FIGURE 14C—Transverse section of branching coral in wackestone at 75 ft; plane light, bar = 0.2 mm.

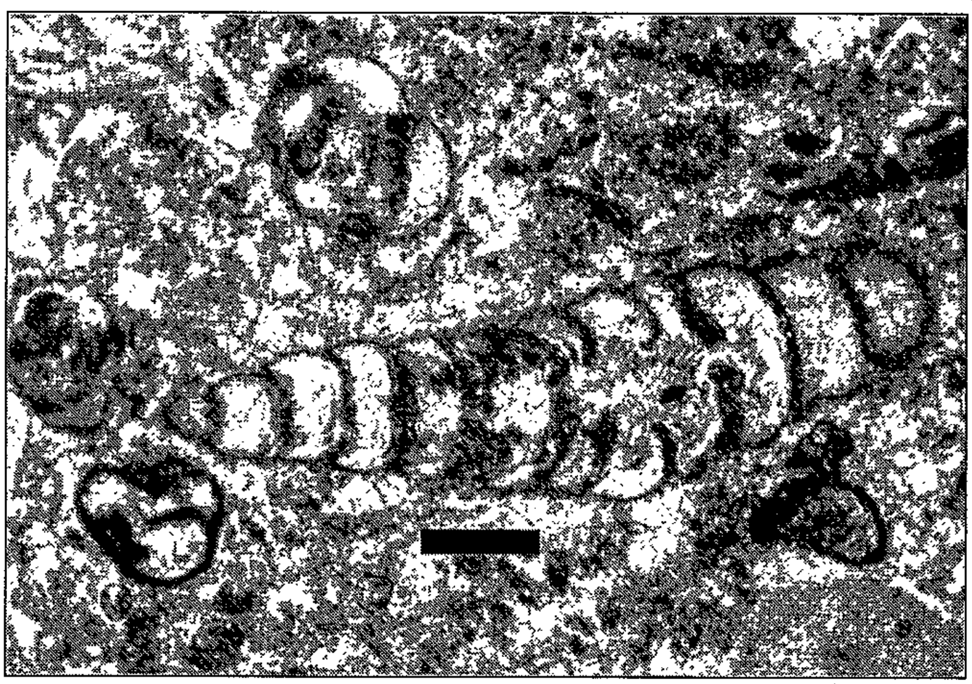

FIGURE 14D—Paleotextularid and globular foraminifera in wackestone at 75 ft; plane light, bar = 0.2 mm.

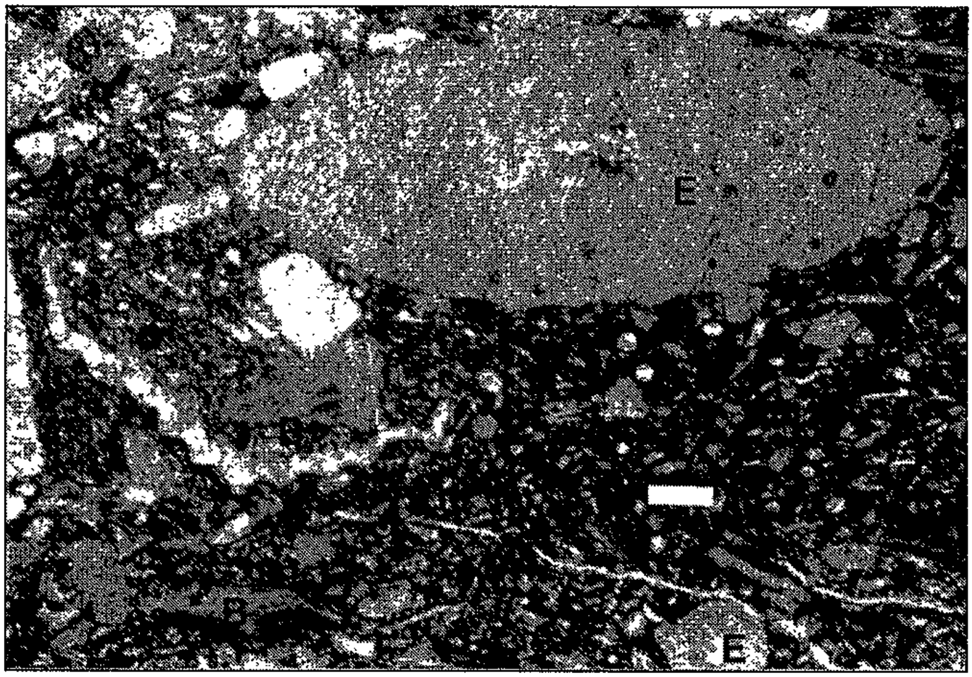

FIGURE 14E—Echinoderm (E) and brachiopod (B) bioclasts in packstone at 110 ft; plane light, bar = 0.2 mm.

FIGURE 14F—*Climacammina*?, globular foraminifera (F) , and ostracod (O) valve in wackestone at 285 ft; plane light, bar = 0.2 mm.

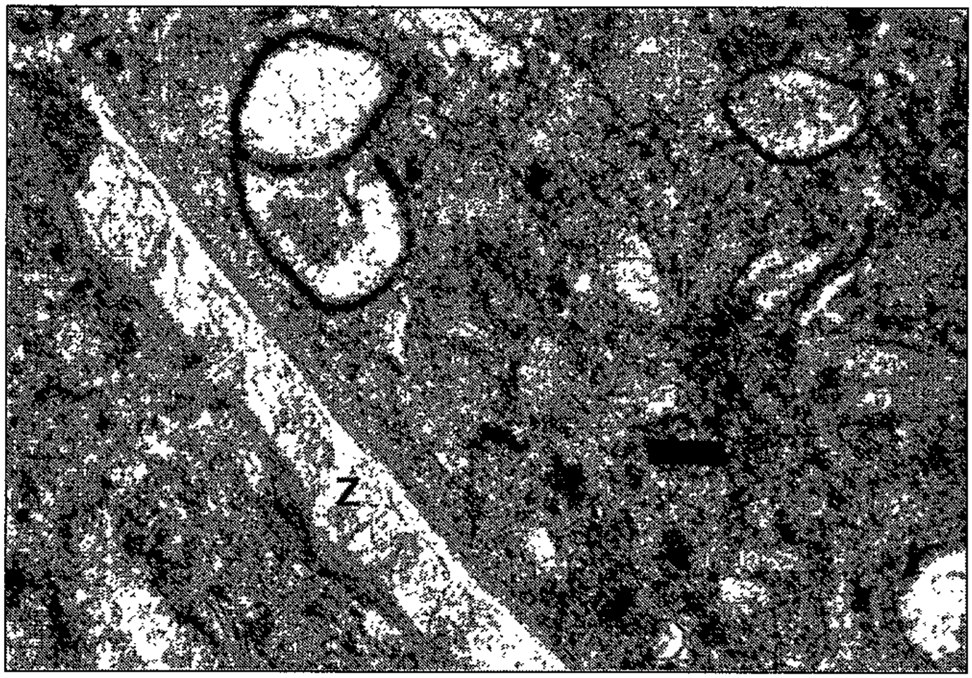

FIGURE 14G—Bryozoa (Z) and foraminifera in wackestone at 340 ft; plane light, bar = 0.2 mm.

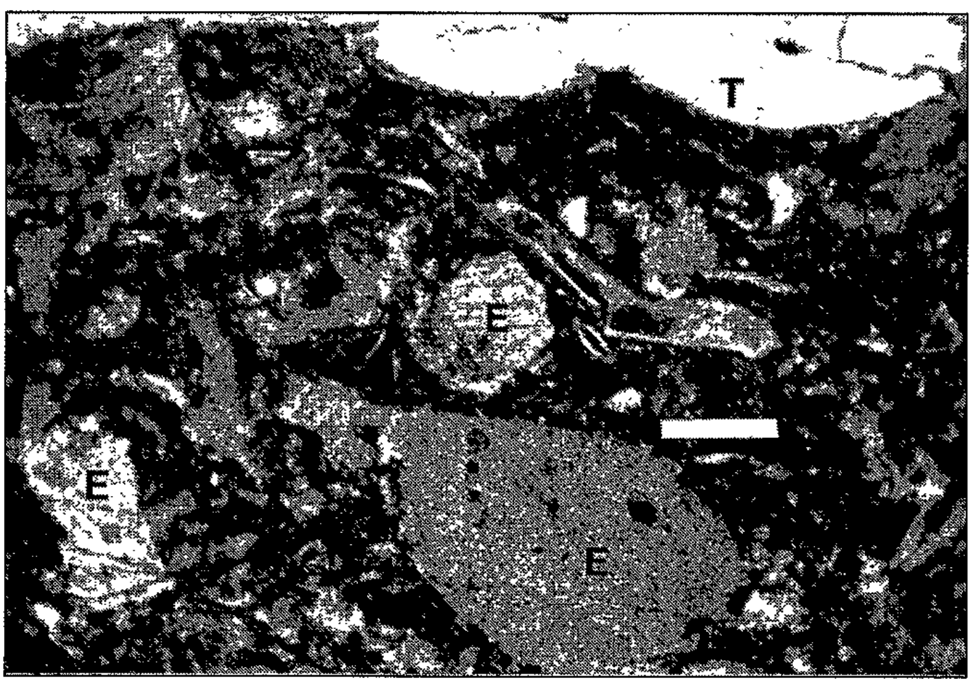

FIGURE 14H—Echinoderm (E) and trilobite (T) bioclasts in packstone at 380 ft; plane light, bar = 0.2 mm.

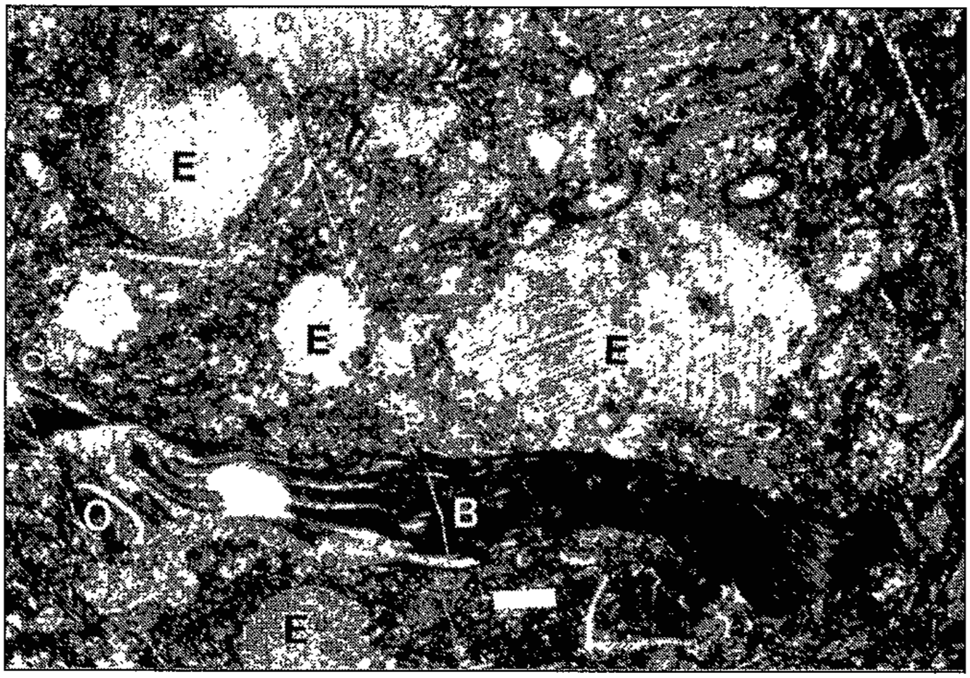

FIGURE 14I—Echinoderm (E), brachiopod (B), and ostracod (O) bioclasts in packstone at 410 ft; plane light, bar = 0.2 mm.

FIGURE 14J—Trilobite (T), echinoderm (E), and foraminifera (F) in laminated packstone at 460 ft; plane light, bar = 0.2 mm.

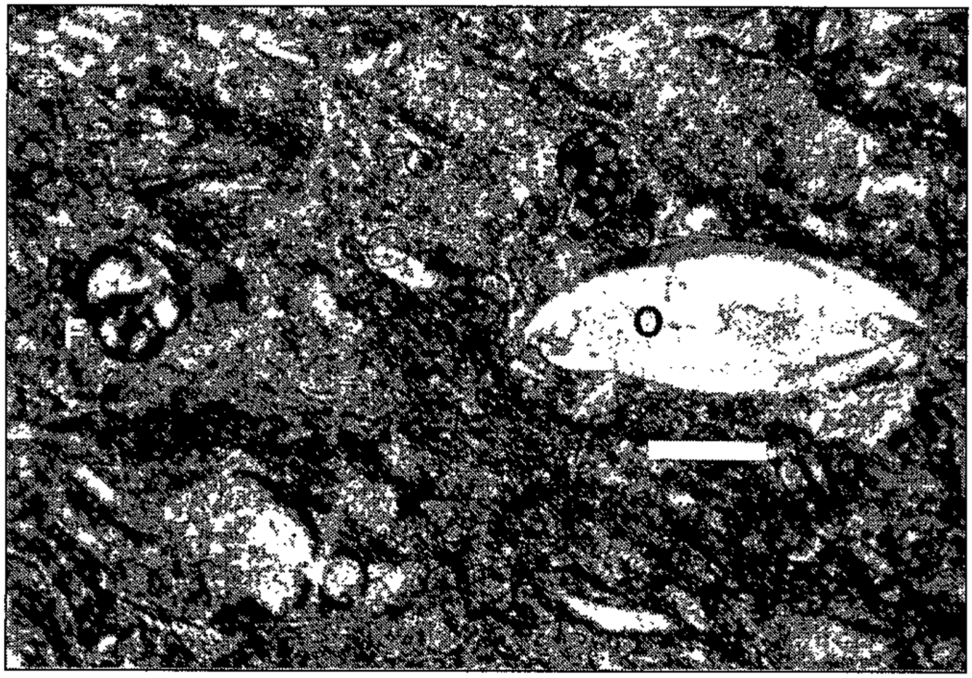

FIGURE 14K—Ostracod (O) and foraminifera (F) in laminated packstone at 460 ft; plane light, bar = 0.2 mm.

thickness (ft)	algae	brachiopod	bryozoa	coral	echinoderm	foraminifera	gastropod	intraclast	ostracod	peloid	silt	sponge spicule	trilobite	rock name	SMF
base										A	t			lime mudstone	19
20		s		t	s	A			C					wackestone	9
35		C	C	t	s	s			C				t	wackestone	9
75		s		C	C	C			C					wackestone	9
100		s			A	s			s				t	packstone	9
110		A			A				s					packstone	9
145		C			A	t			t				t	packstone	9
195		A	s		A	t			s	s			t	packstone	9
230		s	t		A	s			s				t	packstone	9
255		t			A	C			s				t	packstone	9
285		s	s		C	A			C				t	wackestone	9
340		s	s		A	s	s		C	A			t	wackestone	9
380		s	C		A	t	t		s				t	packstone	9
410		C	s		A	t			s				t	packstone	9
460		C	s		C	C			s				t	packstone	9
510		s	C		A	t			s	C			s	wackestone	9
525			C		C	s	C		s				t	packstone	9

FIGURE 15—Allochem compositions of thin sections from Eagle Nest. A, abundant; C, common; s, scarce; t, trace; SMF, standard microfacies from Wilson (1975).

overlying, dolomitic rocks are probably Epitaph equivalents.

"George" Hill

An unnamed hill 7 mi south of Eagle Nest, in N½, sec. 3, T29S, R5W, is composed mostly of fossiliferous Hueco Limestone overlain by clastic Cretaceous beds (Kottlowski and others, 1969). The U. S. Geological Survey topographic map shows a signal station named George on top of this hill so I refer to this section as "George" hill. About 100 ft of dark-gray, medium - to massive-bedded limestone is exposed in the north slope of the hill. Megascopic fossils include large planispiral gastropods, solitary corals, and cephalopods. Abundant large, dark-gray chert nodules occur at several horizons. Seven samples were collected from 95 ft of section at 10-20 ft intervals in order to include all possible representative lithologies.

Petrographic analysis showed a rather uniform depositional environment for the 95 ft of strata. Dominant bioclasts include echinoderms, Tuberitina, paleotexularid, globular and tubular foraminifera, gastropods and ostracods. Dasycladacian algae (Fig. 16A) is common in the upper half of the section. Small fragments of brachiopods, corals, and trilobites are scarce and a few fragments of poorly preserved fusulinids (Fig. 16B) occur only in one thin section. Six of the samples are grainstones and a sample from the top of the exposed section is a slightly silty packstone (Fig. 17).

Depositional environment appears to be shallow shelf with mostly restricted marine shoals. Dasycladacian algae throughout the section indicates nearby, low energy, very shallow water

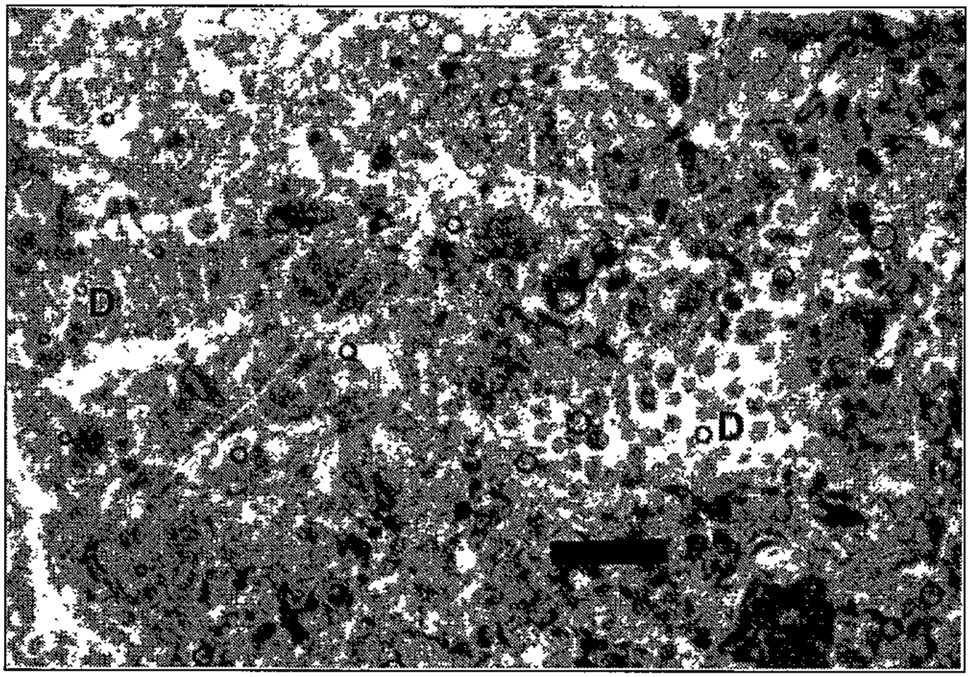

FIGURE 16A—Photomicrograph of Dasycladacian algae (D) and peloids in grainstone at 80 ft; plane light, bar = 0.2 mm.

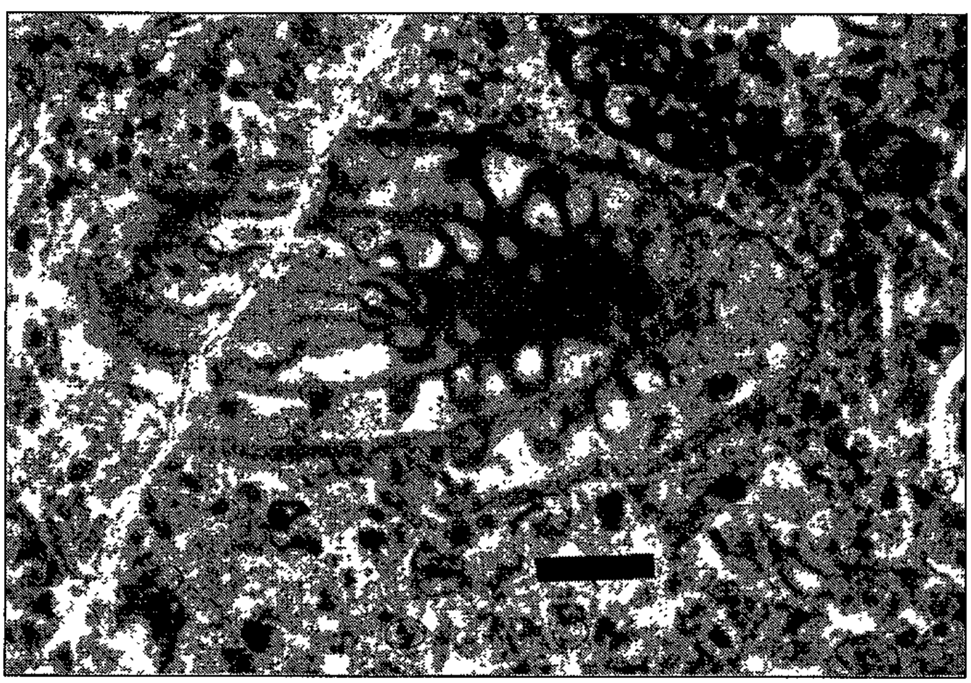

FIGURE 16B—Photomicrograph of fusulinid fragments and peloids in grainstone at 80 ft in "George" hill section; plane light, bar = 0.2 mm.

thickness (ft)	algae	brachiopod	bryozoa	coral	echinoderm	foraminifera	gastropod	intraclast	ostracod	peloid	silt	sponge spicule	trilobite	rock name	SMF
base	s	s		t	C	C	s		C	A				grainstone	16
35		t		t	s	C	s		s	A			t	grainstone	16
50					s	C	A	s	s	A				grainstone	16
60	s				s	s	s		s	A				grainstone	16
70	s	s			C	C	C	A	t	C				grainstone	16
80	A				s	A	s		s	A			t	grainstone	16
95	C			t	s	t	A		C	A	t			packstone	16

FIGURE 17—Allochem compositions of thin sections from "George" hill. A, abundant; C, common; s, scarce; t, trace; SMF, standard microfacies from Wilson (1975).

depths. Essentially all the bioclasts are small, abraded fragments and many have micritized rims. The echinoderms are probably mostly echinoids which along with the gastropods and peloids typify a lagoonal facies.

SUMMARY

Fauna represented by bioclasts is typical of Lower Permian-Upper Pennsylvanian rocks to the east and west. GWLH-1 core contains five zones of fusulinids (Fig. 18) between 1,198-,1300 ft depths that include *Parafusulina* *(Skinnerella)* and *Chalaroschwagerina* that are early Leonardian. Sparse fusulinids in the small knoll, Gym Peak and "George" hill sections are poorly preserved but also are probably early Leonardian or Wolfcampian. Early Leonardian conodonts have been reported from dolostones (probably Epitaph) capping the ridge in West Lime Hills (Thompson, 1982).

All sections, except "George" hill, contain a generally diverse fauna. However, GWLH-1 core has about 300 ft (1,500-1,800 ft depth) of unfossiliferous section and below 1,800 ft the section is more silty and bioclasts limited to brachiopods, bryozoa and echinoderms.

Peloids are abundant in the small knoll, Gym Peak and "George" hill sections and at 1,200-1,400 ft depths in GWLH-1 core. They are sparse in Eagle Nest and GWLH-3 sections.

Silty limestones are common in the GWLH-1 and GWLH-3 cores; interbedded siltstones and a few sandstones are interbedded in the cores. No silt was recognized in the other four studied sections, but siltstones overlie the limestone section in the southeast Florida Mountains.

Algae is abundant in the small knoll and Gym Peak sections; sparse in the GWLH-1 and GWLH-3 cores and not observed in the Eagle Nest section.

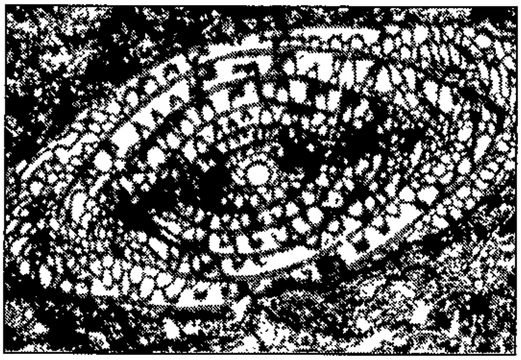

FIGURE 18A—*Parafusulina (Skinnerella)* at 1,198 ft depth in GWLH–1 core; ×10 (photo provided by W. E. King).

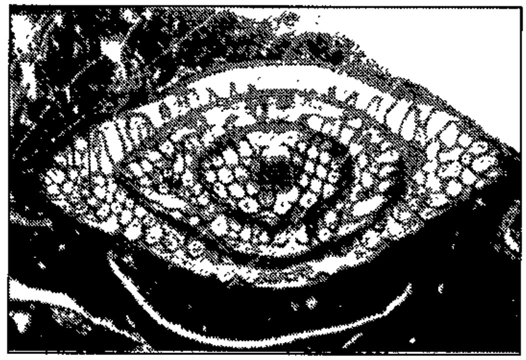

FIGURE 18B—*Chalaroschwagerina* at 1,224 ft depth in GWLH–1 core; ×10 (photo provided by W. E. King).

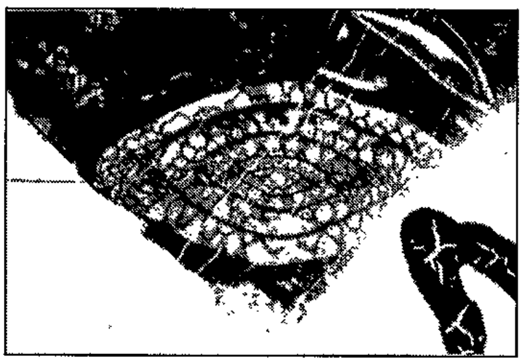

FIGURE 18C—*Chalaroschwagerina* at 1,224 ft depth in GWLH–1 core; ×10 (photo provided by W. E. King).

Southeast Luna County lies on the northeastern shelf of the Pedregosa Basin (Figs. 1, 3A) so I recommend using the stratigraphic nomenclature developed in the Pedregosa Basin. Thus the following tentative correlations are suggested:

1. Small knoll section (75 ft) is Colina Limestone.
2. Upper part of Paleozoic section (1,494 ft) in GWLH-1 core is probably Colina Formation; lower part is probably Horquilla or possibly Earp Formation.
3. Paleozoic section (684 ft) in GWLH-3 core is probably Colina or Earp Formation.
4. Gym Peak section (335 ft) may be Horquilla (with overlying Earp siltstones) or Colina Limestone.
5. Eagle Nest section (525 ft) is probably Colina Limestone.
6. "George" hill section (95 ft) is probably Colina Limestone.

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APPENDIX A-1

General Description of GWLH-1 Core

		unit thick (ft)	total depth (ft)
1.	Alluvium, no core.	110	
			110
2.	Interbedded pale grayish-red, silty, sandy, and conglomeratic volcaniclastic rocks with andesite-latite clasts.	438	
			548
3.	Interbedded light-grayish-red and pale red, calcareous siltstones and very fine to fine sandstones.	122	
			670
4.	Interbedded limestone-chert pebble-cobble conglomerates with reddish and orange-gray silty and sandy matrices, coarse siltstones and medium sandstones. Abundant mudstone and shale as well as very angular to subrounded limestone clasts in basal conglomerates.	150	
			820

- - - probable top of Lower Permian - - -

5.	Interbedded light - to medium-gray limestone and shale; mostly laminated; some mottled medium-dark gray shale; laminated light-gray siltstone at 910-912 ft.	110	
			930
6.	Interbedded dark-gray shale, laminated limestone, and limestone with light - to medium-gray shale at 1,173-1,185 ft.	255	
			1,185
7.	Medium - to dark-gray limestone (fusulinids at 1,198, 1,224, 1,241, 1,293 and 1,300 ft; poorly cemented, coarse sandstone at 1,208-1,213 and 1,220-1,223 ft; 2-ft medium-gray siltstone bed at 1,377 ft; 2-ft breccia zone at 1,583-1,585 ft.	420	
			1,605
8.	Medium - to dark-gray limestone; mostly thin bedded to laminated, few thick-bedded zones, some mottled medium-to dark-gray shale zones at 1,615-1,620, 1,757-1,762 and 1,916-1,920 ft, limestone pebble conglomerate at 1,690-1,692 ft, breccia zone with white spar cement 1,799-1,801 ft.	315	
			1,920

9. Medium - to dark-gray limestone; thin - to medium-bedded with some dark-gray, thin bedded limestone.	129	
		2,049
10. White marble; some recognizable crinoid fragments; dark-gray, thin-bedded limestone/marble at 2,190 ft.	265	
		2,314

APPENDIX A-2

General Description of GWLH-3 Core

		unit thick (ft)	total depth (ft)
1.	Alluvium, no core.	91	
			91
2.	Interbedded, fine-grained and conglomeratic volcaniclastic rocks.	109	
			200
3.	Pale-red, calcareous siltstone.	221	
			421
4.	Grayish-red-purple, biotite-hornblende latite.	22	
			443
5.	Pale-red, porous, muddy very-fine sandstone and siltstone with minor limestone-chert pebble conglomerate.	70	
			513
6.	Light-gray chert pebble-cobble conglomerate with siliceous, grayish-orange-pink, muddy matrix.	339	
			852
7.	Interbedded medium-gray chert pebble conglomerate with calcareous, muddy matrix; limestone clasts 1,400-1,405; sandstone and siltstone clasts 1,435-1,440 ft; light-brownish-gray and dark-grayish-red		

calceous siltstone, and light - to medium-gray and grayish-red, calcareous granular medium sandstone. 588

1,440

8. Interbedded light-gray calcareous siltstone and medium-gray limestone and siltstone breccia with 75 ft of coarse sandy limestone pebble conglomerate at base. 185

1,625

- - - probable top of Lower Permian - - -

9. Medium-gray lime mudstone and ooid grainstone. 11

1,636

10. Interbedded, pinkish-gray, conglomeratic sandy mudstone (1,636-1,655 ft), medium- to dark-gray brecciated lime mudstone (1,655-1,697 ft), light-gray marble and breccia (1,712-1,726 ft), dark-gray lime mudstone (1,726-1,744 ft), and light-gray, calcareous siltstone (1,744-1,749 ft). 113

1,749

11. Interbedded dark-gray lime mudstone (1,749-1,823 ft), olive-green shale (1,823-1,828 ft), laminated, mottled dark-gray/black limestone (1,828-1,884 ft) with shaly zone at (1,836-1,856 ft). 135

1,884

12.	Mottled light/medium-gray, laminated dolostone.	42	
			1,926
13.	Medium - to dark-gray, limestone.	38	
			1,964
14.	Interbedded olive-green siltstone and very-fine sandstone, laminated grayish-yellow-green mudstone and greenish-gray dolostone.	41	
			2,005
15.	Mottled dark-gray/black limestone.	154	
			2,159
16.	Limestone breccia with coarse white spar filling pores.	17	
			2,176
17.	Interbedded dark-gray limestone and light - to medium-gray, calcareous silt-stone with breccia zones at 2,272-2,279 and 2,281-2,283 ft.	133	
			2,309