Carbonate Petrology and Paleoecology of Permo-Carboniferous Rocks, Southwestern Millard County, Utah*

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ABSTRACT.—Chesterian, Morrowan, Desmoinesian, and Wolfcampian strata of southwestern Millard County, Utah, consist of cyclic carbonate rocks belonging to the Mississippian and Pennsylvanian Ely Limestone and to the Riepe Spring Limestone of the Permian Arcturus Group. Many lateral and vertical changes in the stratigraphic section indicate a complex depositional history.

Petrologic analysis has permitted the recognization of nineteen distinct textural types, including three of dolomite, one of mudstone, five of wackestone, six of packstone, and four of grainstone.

Dolomite and mudstone units originated under the lowest-energy conditions and contain a limited biocoenosic fossil assemblage. Grainstone, packstone, and most wackestone units represent high to moderate depositional energy and originated in a shallow marine environment under conditions of normal marine salinities. These fossiliferous rocks contain a thanatocoenosic assemblage. Fusulinids are common in wackestone rocks and form the basis of age determination of the rocks. Distribution of these rock types has been linked to a conceptual model relating depositional energy and biotic distribution. With the aid of computer-applied statistics and graphics, variations of data derived from thin sections allowed for the recognization of hemicyclic and true cyclic events, along with nonpatterned variations in depositional energy.

INTRODUCTION

The conspicuous carbonate units of the Chesterian and Pennsylvanian Ely Limestone and the Wolfcampian Riepe Spring Limestone form much of the Mountain Home Range and adjacent Burbank Hills in southwestern Millard County, Utah (fig. 1). These cyclic carbonates form a 850-m-thick sequence of interbedded resistant limestones that form ledges, and less resistant dolomitic units that form covered slopes (figs. 2, 3). These rocks were deposited in repetitive series of shallow marine environments, as indicated by lithology, floral and faunal assemblages, and sedimentary structures.

The primary objective of this study is interpretation of the depositional histories of the carbonate rocks through the use of petrologic and paleontologic data. Energy cycles, which controlled the depositional history of the Ely Limestone and the Riepe Spring Limestone, are examined and described.

Location

Stratigraphic sections of upper Paleozoic rocks were measured in the Mountain Home Range and Burbank Hills, located in the east central portion of the Basin and Range Province, in southwestern Millard County, Utah (fig. 1). Figure 4 shows traverse locations for these sections. The sections are readily accessible via Utah 21 and maintained dirt roads.

Methods and Terminology

Field Methods

Three sections (fig. 4) of the Pennsylvanian Ely Limestone and the overlying Riepe Spring Limestone of the Permian Arcturus Group were measured with a Jacob's staff and meter stick. Section 2 was measured in detail, on a centimeter-by-centimeter basis. Each exposed unit of this section was described in detail and sampled for later thin sectioning. Several samples were collected from thick units and those units which are particularly fossiliferous. All samples were oriented to indicate "tops." Fusulinid-bearing horizons were sought, for they provide the best units for stratigraphic zonation and correlation.

The locations of the sections were selected on the basis of quality of exposure and accessibility. Each section shows minor effects of tectonism. Compensations for faults were made by offsetting along key beds. A few minor folds were also encountered. They were compensated for by closely monitoring the attitudes of beds and adjusting the traverse as necessary. Reconnaissance and measurement of sections 1 and 3 were accomplished during June and early July 1982. Section 2 was measured in detail during late July and August of 1982.

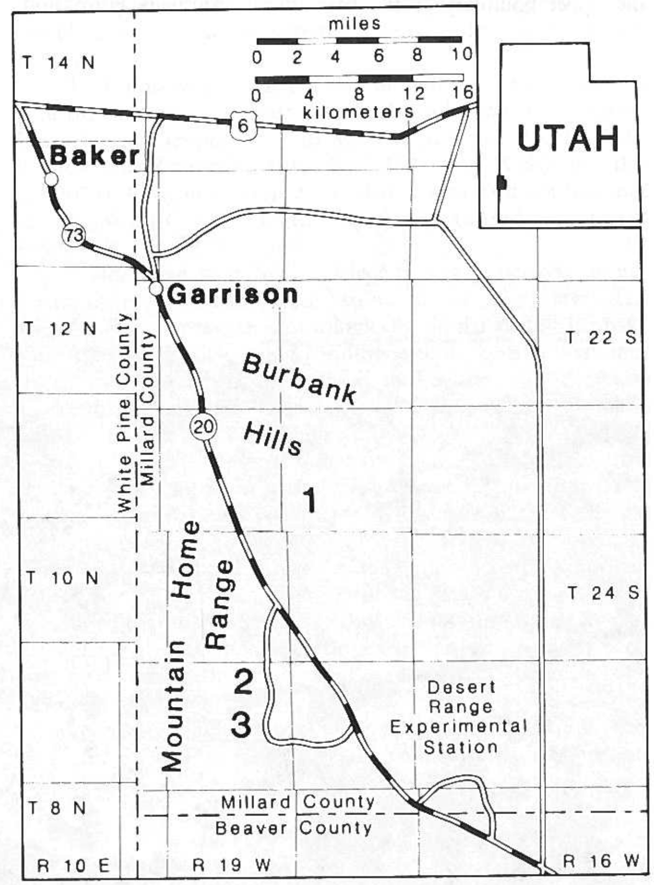

FIGURE 1.—Index map of Mountain Home Range area, near Utah–Nevada border, showing general locations of measured sections.

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Laboratory Methods

Altogether, 275 thin sections, along with several polished slabs, were made from samples collected from exposed units. They were then examined under a binocular microscope for microsedimentary structures, fossils, and clastic grains, and fabric and textural relationships. Samples were separated into nineteen textural groups based on these analyses. Relative depositional energies were determined from fabrics and textures. A petrographic microscope was also used for the analysis of selected mineral grains. Representative sections of each textural group were stained using ferrocyanide solution and Alizarin Red S (Friedman 1959) to determine relative amounts of calcite and dolomite.

The carbonate nomenclature of Dunham (1962), which classifies calcic carbonates on the basis of depositional textures, was used in this study. The depositional textures are obscured in dolomite of the Ely Limestone, which predominates as slope-forming rocks. Therefore, dolomitic rocks were classified on the basis of crystalline fabric. Both classifications are shown in figure 5.

Previous Work

The Ely Limestone was named by Lawson (1906) for a well-stratified, thick-bedded cherty limestone sequence in the Ely District of Nevada. Lawson placed the lower boundary of the Ely Limestone at the top of the Devonian carbonates, and the upper boundary at the base of the Arcturus Formation, which is middle Permian in age. Spencer (1917) redefined the Ely Limestone as the limestone unit between the underlying Chainman Shale and the overlying Arcturus Formation. Pennebaker (1932) redefined the upper Ely Limestone contact at the base of a thick sandstone and siltstone sequence formerly assigned to the Arcturus Formation, which he named the Rib Hill Formation. Dott (1955) elevated the Ely Limestone to group rank in the Elko and North Diamond Ranges of Nevada. He divided the Ely Group in that region into two formations, the Moleen and Tomera. The strata of these two formations represent western facies of the Ely Group.

Steele (1960) restricted the Ely Limestone to those rocks stratigraphically above the Chainman Shale or Scotty Wash Quartzite, whichever is present, and below the regional Desmoinesian-to-Missourian unconformity. He also proposed the name *Riepe Spring Limestone* for the upper 100 m of the former Ely Limestone. These units are massive, coralline- and fusulinid-bearing rocks of Wolfcampian age. Steele (1960) designated a reference section for the Ely Limestone in the Moorman Ranch area, T. 17 N, R. 59 E, White Pine County, Nevada.

Lane (1960) applied group rank nomenclature to the reference section of Steele (1960). Lane used "unnamed sequence" for the upper 300–330 m of silty limestone above the restricted Ely Limestone. Robinson (1961) proposed the Hogan Formation for Desmoinesian age rocks in the central Pequop Mountains of Nevada. Mollazal (1961) determined that the "unnamed sequence" of Lane (1960) is the Desmoinesian Hogan

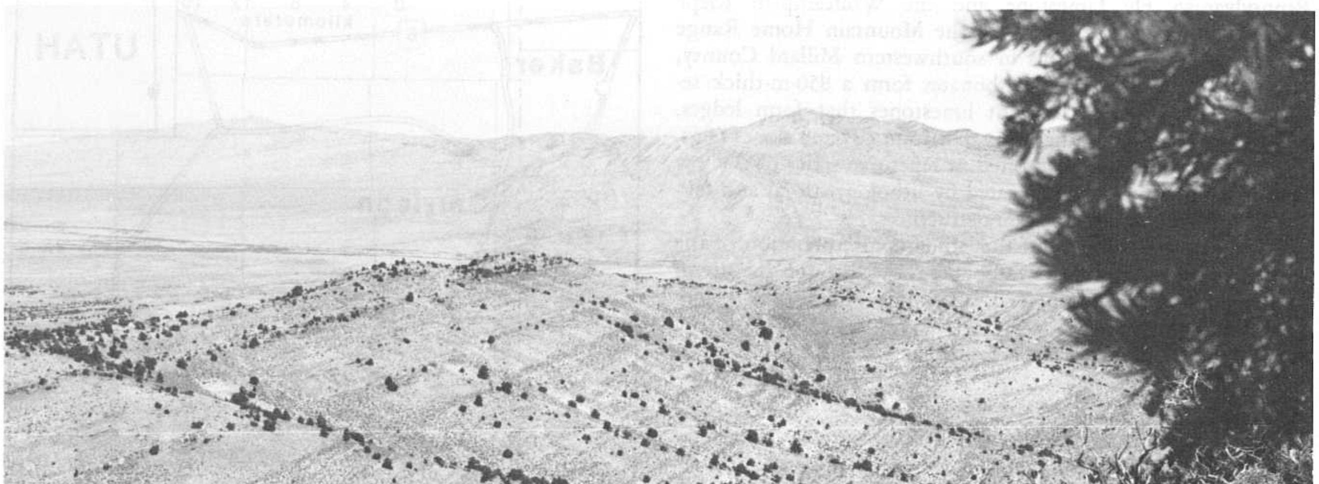

FIGURE 2.—Distant view of typical Riepe Spring Limestone and Ely Limestone outcrop in northern spur of Mountain Home Range, left center. Southern Burbank Hills in distance.

FIGURE 3.–Closeup view of Ely Limestone outcrop. Note limestone ledges protruding from covered slope.

Formation of Robinson (1961) and considered it to be part of the Ely Limestone.

Hose and Repenning (1959) designated the alternating, resistant, thick-bedded, and slope-forming slabby limestones in the Confusion Range of western Utah as Ely Limestone (of formation rank).

Several regional studies of the Pennsylvanian and Permian tectonics and strata have been published. Bissell (1964a) gave a regionally extensive description of Pennsylvanian and Permian strata of the Ely, Arcturus, and Park City Groups. Rich (1969, 1971) described the Middle Pennsylvanian rocks of the Great Basin and combined stratigraphic and petrologic data to define several general lithofacies of the region. Paleogeographic patterns of deposition during the Pennsylvanian were examined on an epoch-by-epoch basis in Utah by Welsh and Bissell (1979) and in the western United States by Rich (1977). The cyclic nature of the Ely Limestone has been noted, described, and illustrated in general terms by Bissell (1964b), Dott (1958), and Mollazal (1961).

PALEOTECTONIC FEATURES AND BASINAL HISTORY

Main paleotectonic features that influenced Pennsylvanian-Permian deposition in west central Utah and east central Nevada were the Antler orogenic belt, which developed in Late Devonian to Early Mississippian, and several basins and uplifts. The Ely Limestone and the Riepe Spring Limestone of the Arcturus Group were deposited on part of the unstable shelf of the Cordilleran region (fig. 6), variously referred to as the Butte-Deep Creek Trough (Steele 1960), the Hamilton Basin (Brill 1963), and the Ely Basin (Bissell 1964a, b; Coogan 1964; Mollazal 1961). The term *Ely Basin* is most commonly used in literature and therefore is used in this study.

Deposition in the Ely Basin of east central Nevada and west central Utah was greatly influenced by the Antler orogenic belt. That belt was a positive feature and an important source of clastics during the Pennsylvanian and Early Permian (Bissell 1964a, Dott 1955, Steele 1960). Harris (1959) proposed that an additional area, the Sevier Arch, came into existence in western Utah during Early Pennsylvanian and was intermittently a source of sediments until early Tertiary. Steele (1960) and Bissell (1964a) referred to this arch as the West-Central Utah Highlands. Steele also postulated another positive area in northeastern Nevada that influenced sedimentation in the Ely Basin.

The Ely Basin was one of a dynamic series of basins in the unstable region during the late Paleozoic. It was connected with the Oquirrh Basin to the east and northeast and with the Bird Spring Basin to the south (Bissell 1964a, b; Coogan 1964; and Steele 1960). Coogan (1964) noted marked thickening of strata within the Ely Basin during Morrowan time, with a depocenter near Ely, Nevada. He also noted a lack of basinward thickening of Atokan strata in the same area, suggesting that the Ely Basin was not persistently a negative feature in its early history.

The Pennsylvanian pattern of sedimentation was broken by a broad emergence in east central Nevada and west central Utah during Desmoinesian to Missourian time (Bissell 1964a, b; Hose and Repenning 1959; Rick 1977; and Welsh and Bissell 1979). Coogan (1964) stated that a westward continuance of the West-Central Utah Highlands caused the broad emergence.

Wolfcampian strata of the Riepe Spring Limestone lie unconformably on Desmoinesian strata in the study area. The Riepe Spring Limestone is lithologically similar to the Pennsylvanian Ely rocks, suggesting conditions of deposition were similar during the Pennsylvanian and Early Permian.

Pennsylvanian and Permian strata in the study area are exposed in several Basin and Range fault blocks. The original late Paleozoic patterns of deposition have been somewhat obscured by later structural deformation. The degree of modification of original facies patterns is difficult to estimate because the extent of Sevier-age thrust faults in the area is questionable. Gould (1959) mapped thrust faults in the northern Mountain Home Range; however, Baer (personal communication 1982) concluded that displacement on those faults is minimal. Preliminary maps by students in the Brigham Young University summer field camp (1982) suggested a thrust fault beneath overturned Pennsylvanian and Permian strata in the western Mountain Home Range, west of where the three sections were measured for this study. All sections studied for this project are on a single fault block and are considered to be autochthonous.

ACKNOWLEDGMENTS

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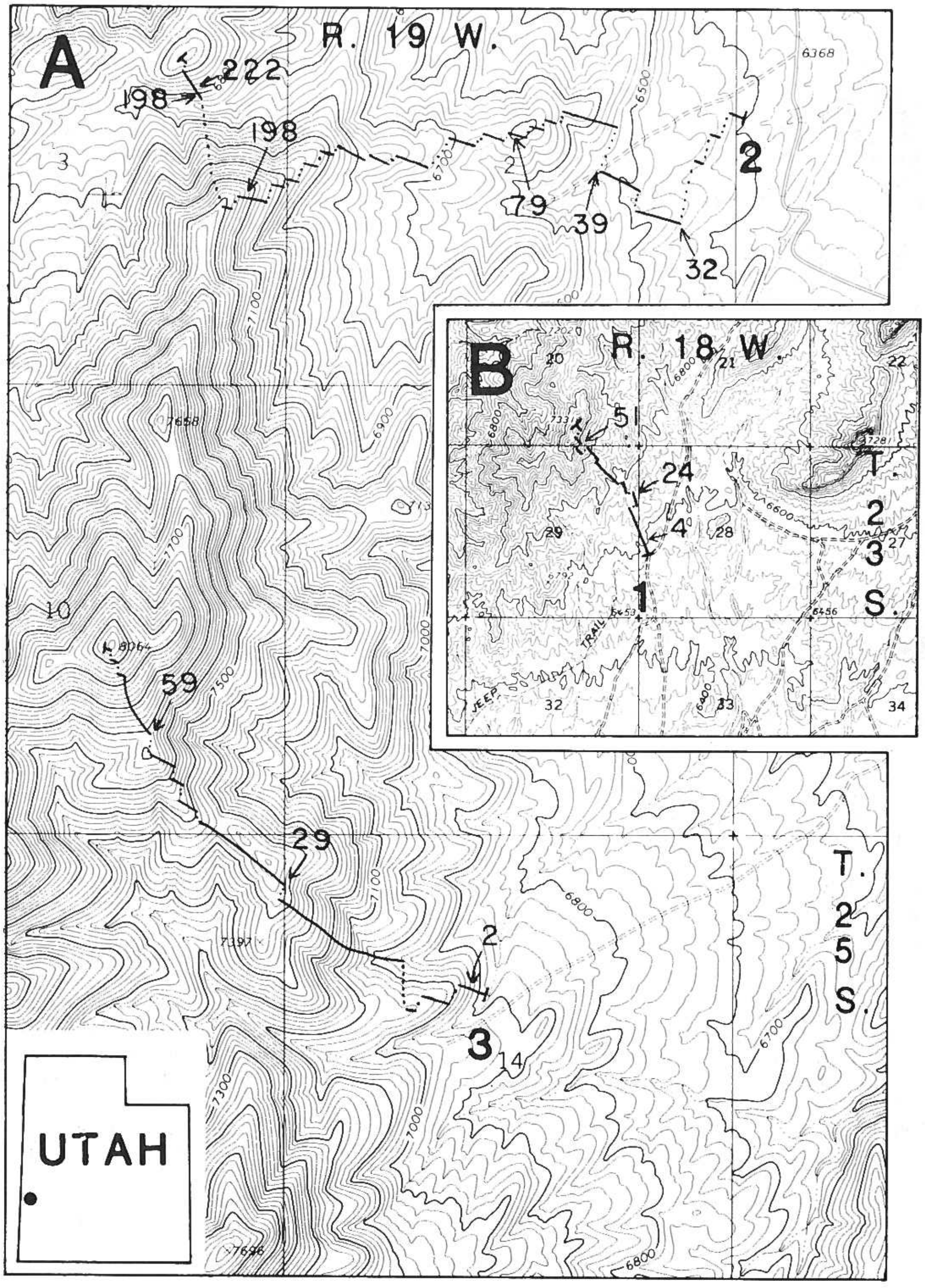

FIGURE 4.—Detailed locations of measured sections. A. Measured sections 2 and 3, Mormon Gap 7.5-Minute Quadrangle, Millard County, Utah. B. Measured section 1, Burbank Hills 15-Minute Quadrangle, Millard County, Utah. Arrows indicate approximate locations of several units.

LIMESTONES					DOLOMITES		
Original components not bound together during deposition				Original components bound together during deposition	Crystalline Fabric		
Contains mud (particles of clay and silt)			Lacks mud and is grain supported		up to 0.01 mm	0.01–0.05mm	more than 0.05 mm
Mud supported		Grain supported					
Less Than 10% grains	More Than 10% grains						
(M4)	(W5-9)	(P10-15)	(G16-19)		(D1)	(D2)	(D3)
MUDSTONE	WACKESTONE	PACKSTONE	GRAINSTONE	BOUNDSTONE	DOLOMICRITE	FINELY CRYSTALLINE DOLOMITE	MEDIUM CRYSTALLINE DOLOMITE

FIGURE 5.–Classification of carbonate rocks, modified after Dunham (1962) and Dean (1981), showing size parameters for crystalline dolomite.

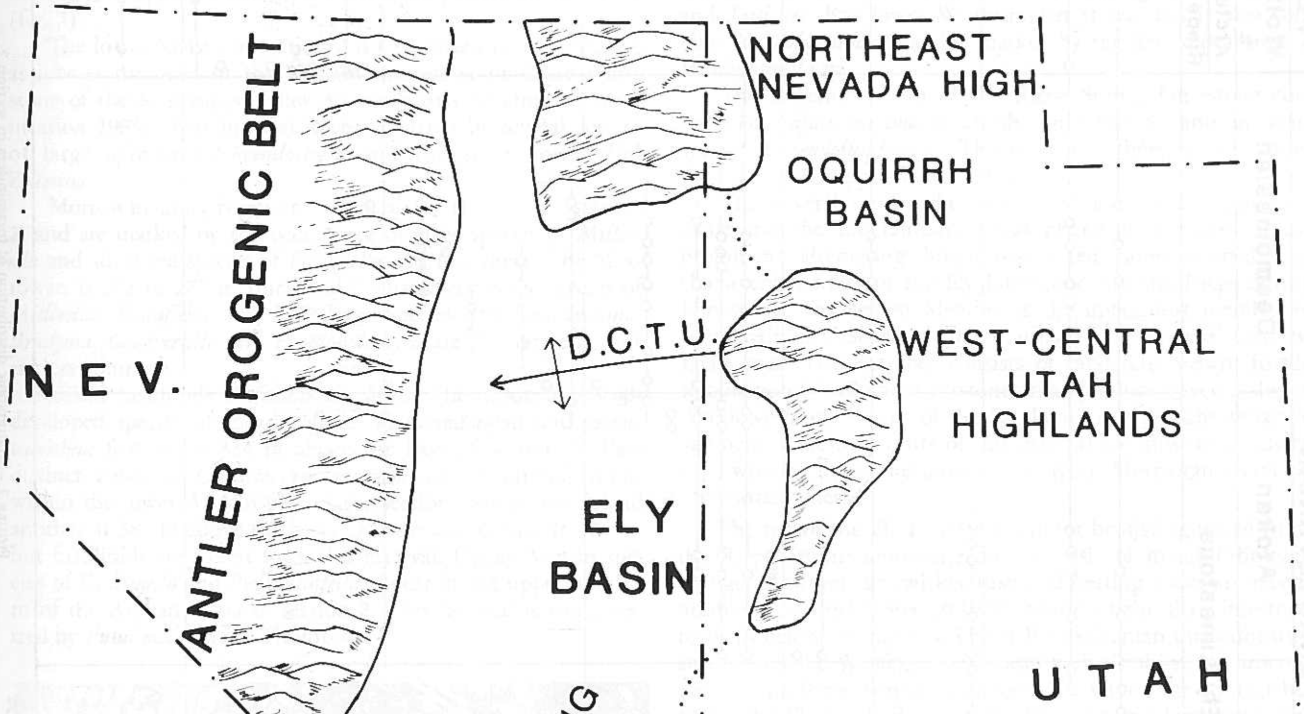

FIGURE 6.–Paleotectonic features affecting deposition in western Utah and eastern Nevada during late Paleozoic times. Deep Creek-Tintic Uplift (D.C.-T.U.) was a positive feature during the Wolfcampian. Modified after Rich (1977), Bissell (1964b), Coogan (1964), Brill (1963), Steele (1960), Welsh and Bissell (1979), and Steele (1979).

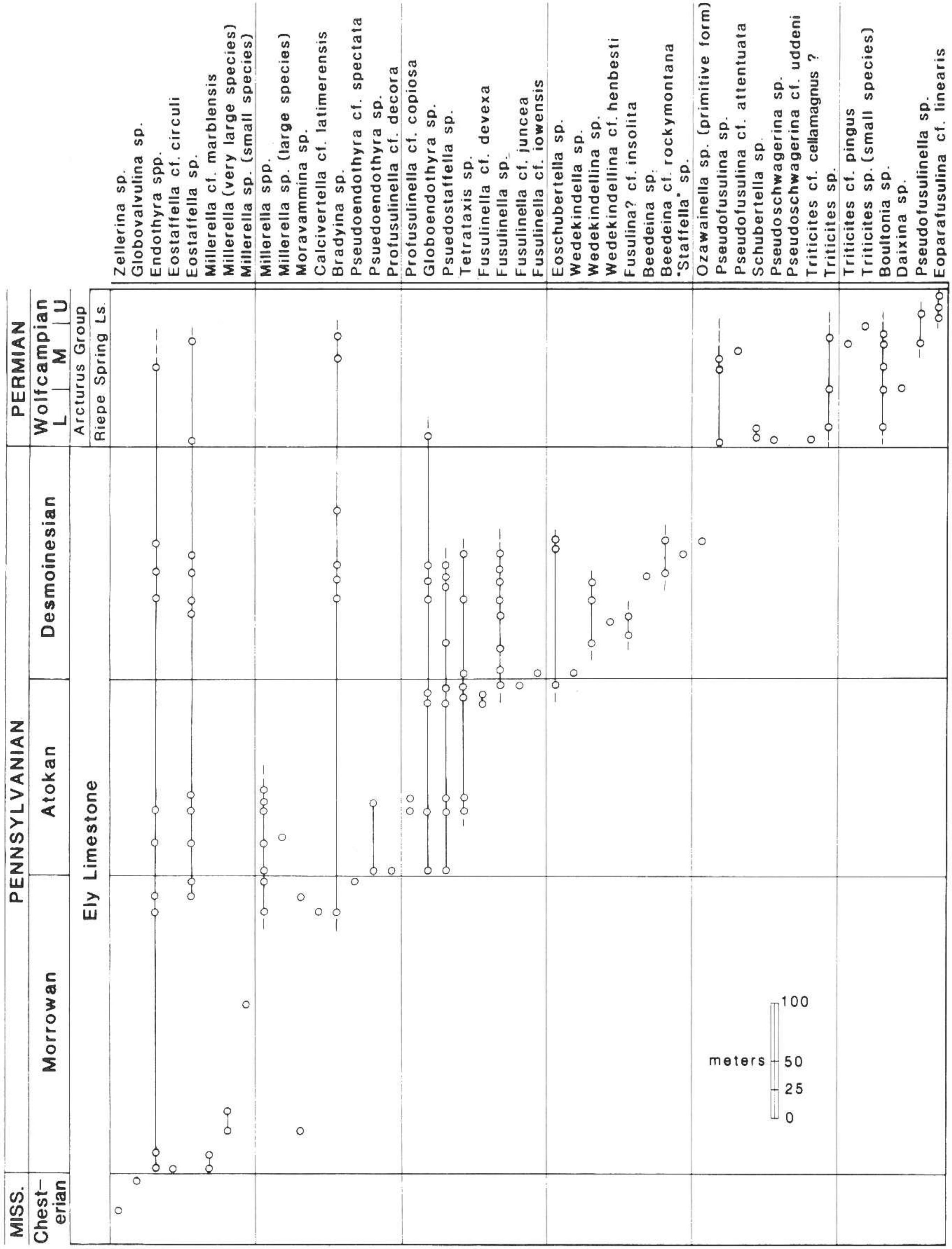

FIGURE 7.—Stratigraphic distribution of foraminifera in section 2.

Texas, aided in the identification of the fusulinids, and Dr. John L. Wray of Marathon Oil Company, Littleton, Colorado, verified algae identifications. Joel G. St. Aubin and Jeffrey R. Hietpas served as field and laboratory assistants. Thanks are also extended to John and Cathy Kinney for their hospitality during our stay at the Desert Range Experimental Station. Expenses of this thesis were defrayed by grants from Husky Oil Company of Cody, Wyoming; May Petroleum Incorporated of Salt Lake City, Utah; and by a grant-in-aid from the American Association of Petroleum Geologists of Tulsa, Oklahoma.

AGE AND FORMATIONAL DIVISIONS

Age assignment of Pennsylvanian and Permian strata in the Great Basin is based on fusulinid zonation. Identifications by Dr. Charles Ross of foraminifera from section 2 indicate the presence of at least 26 genera of fusulinid and endothyrid foraminifera, many of which are useful in dating these rocks. His identifications indicate that Upper Mississippian (Chesterian); Morrowan, Atokan, lower to middle Desmoinesian; and lower, middle, and upper Wolfcampian strata are present in section 2 (fig. 7).

The lower 59.4 m of section 2 is Chesterian in age, perhaps as low as the level of the Menard Limestone or Clore Limestone of the Mississippi Valley Section (Ross personal communication 1983). This interval is characterized by several species of large spinose *Globoendothyra* and the small millerellid *Zellerina.*

Morrowan units begin at 59.4 m above the base of section 2, and are marked by the occurrence of large species of *Millerella* and advanced species of *Eostaffella* and *Endothrya.* The Morrowan is 262 to 272 m thick and is characterized by species of *Millerella, Eostaffella* and *Endothyra.* Species of *Moravammina, Bradyina, Calcivertella* and *Pseudoendothyra* are also present, but are less common.

Atokan fusulinids *Profusulinella decora* Thompson and well-developed species of *Pseudostaffella, Pseudoendothyra* and *Globovalvulina* first occur 334 m above the base of section 2. Two distinct zones of *Chaetetes* and *Profusulinella* fusulinids occur within the lower Atokan part of the section, one at 334 m and another at 387 m above the base. *Chaetetes* also occurs at 471 m, but fusulinids are absent from this interval. Upper Atokan species of *Fusulinella* and *Pseudostaffella* appear in the uppermost 15 m of the Atokan strata of section 2. This interval is characterized by *Fusulinella devexa* Thompson.

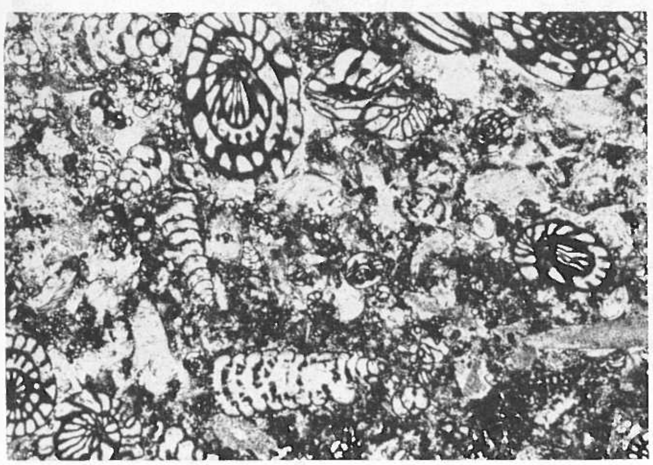

FIGURE 8.–Photomicrograph of foraminifera packstone. Unit 134, 559.0 m above base of section 2, X9.

Desmoinesian units (fig. 8) are marked by the occurrence of *Fusulinella? iowenesis* at 495 m above the base of the section. *Beedeina rockymontana, Wedekindella* spp., *Fusulinella* spp. and *Pseudostaffella* sp. are common in this interval.

The lower Permian fusulinid, *Pseudofusulina* sp., first occurs in the section 710 m above the base. The stratigraphic base of the Permian may be lower, however, for the section approximately 100 m below the first occurrence of *Pseudofusulina* sp. lacks fusulinids or contains nondiagnostic forms. Unit 198 (figs. 9, 10) is a key unit, easily recognizable in the field as Lower Permian, and consists of a fusulinid packstone of *Pseudoschwagerina* sp., *Triticites* cf. *cellamagnus,* and other forms. Lower Wolfcampian strata are about 49 m thick in the section and contain species of *Triticites, Pseudoschwagerina, Schubertella, Boultonia?, Daixina?,* and other genera whose ranges extend upward from the Pennsylvanian. The top of the lower Wolfcampian is about 758 m above the base of the section.

Middle Wolfcampian strata are approximately 61 m thick, and extend to 827 m above the base of the section. This interval contains different species of *Pseudoschwagerina, Boultonia,* and *Triticites* than lower Wolfcampian strata, and it also contains *Pseudofusulina* sp. and is marked by the first appearance of *Pseudofusinella* sp.

The uppermost 9 m of the Riepe Spring Limestone contains *Eoparafusulina linearis* Dunbar and Skinner and an ovate species of *Pseudofusulinella?.* This interval is therefore just above the base of the upper Wolfcampian.

The lower boundary between the Mississippian Chainman Shale and the Ely Limestone was placed at the base of the prominent alternating limestone-covered slope interval that characterizes strata of the Ely Limestone and the Riepe Spring Limestone. The Jensen Member is the uppermost member of the Chainman Shale in the southwestern Millard County, Utah, area. This member consists of moderate brown, fossiliferous, poorly indurated siltstones that produce covered slopes. The lowermost 59.4 m of the Ely Limestone are Chesterian in age here. Limestone units of this interval are most often chert-free, whereas limestone units of overlying Morrowan strata often contain chert.

The top of the Ely Limestone cannot be distinguished from the Riepe Spring Limestone on the basis of major lithologic change. However, several key fusulinid-bearing rocks are recognizable in the field. Steele (1960) restricted the Ely Limestone to rocks below the regional Upper Pennsylvanian unconformity and named the Wolfcampian limestone beds above the unconformity the Riepe Spring Limestone. Therefore, the contact between the Ely Limestone and the Riepe Spring Limestone was placed in this study at the first occurrence of Permian strata, 710 m above the base of section 2.

The regional unconformity between the Pennsylvanian and Permian strata is not always clearly expressed in the field. Several workers, including Hose and Repenning (1959), have found it necessary from a mapping viewpoint, to include the Riepe Spring Limestone as part of the Ely Limestone. However, the writer feels that from an earth history viewpoint, the Ely Limestone and the Riepe Spring Limestone represent two distinct events, even though they are of similar lithologic character. For the present detailed stratigraphic and paleoecologic analysis, these two sequences are separated. Attempts at systematic mapping by others have shown the contact to be laterally ambiguous because of abrupt facies changes at the blended unconformity.

The top of the Riepe Spring Limestone is represented in the field by a distinct lithologic change from the cyclic carbonates of the Riepe Spring Limestone to the distinctive sandy dolomites of the Riepetown Formation(?) of the Arcturus Group. The top of the Riepe Spring Limestone is located 832 m above the base of section 2, and the formation there is 130 m thick.

PETROLOGY OF THE CARBONATE GROUPS

Except for minor siltstone, all rocks exposed in section 2 of the Ely Limestone and the Riepe Spring Limestone are carbonates. Each carbonate unit was thin-sectioned and classified as one of nineteen major textural groups on the basis of fabric and texture. The groups are designated by a letter-and-number system. The first component of the designation, D, M, W, P, or G, indicates the main textural characteristics: dolomite (D), mudstone (M), wackestone (W), packstone (P), and grainstone (G). The second part of the group designation is a number from 1 to 19. These numbers represent general relative energy of deposition; 1 is lowest and 19 is highest. Dolomite and mudstone are assigned values 1 through 4 only for means of differentiation, but probably were all deposited under similar energy conditions, although later experiencing different diagenetic histories. Except for groups D1, D2, D3, and M4, all numbers represent relative levels of energy. Tables 1 and 2 define the parameters and list the petrographic details of each textural group. The frequency distribution of the textural types is shown in figure 11.

Dolomite

Approximately 7 percent of the exposed units and probably a large portion of the concealed units of section 2 are dolomite. These rocks weather to ledgy slope-forming units, which commonly exhibit irregular and undulatory silty laminations (fig. 12). The majority of concealed units are dolomitic and produce soil- to flaggy-rubble-covered slopes.

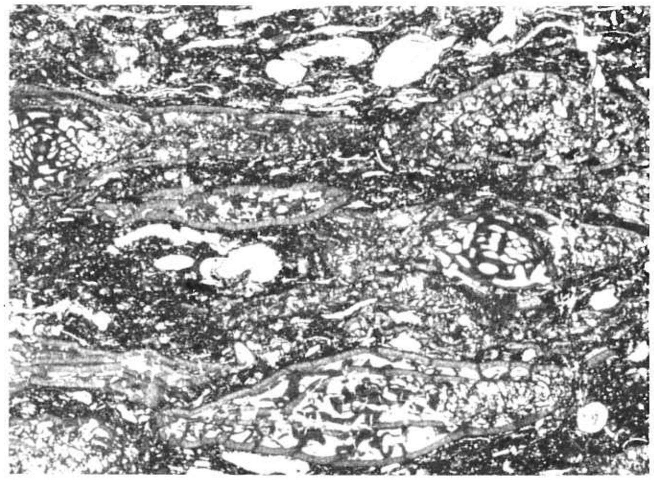

FIGURE 10.–Photomicrograph of fusulinid packstone, type P14, containing crushed tests of *Pseudoschwagerina* sp., *Triticites* cf. *cellamagnus*?, and other forms. Unit 198, 711.4 m above base of section 2, X4.5.

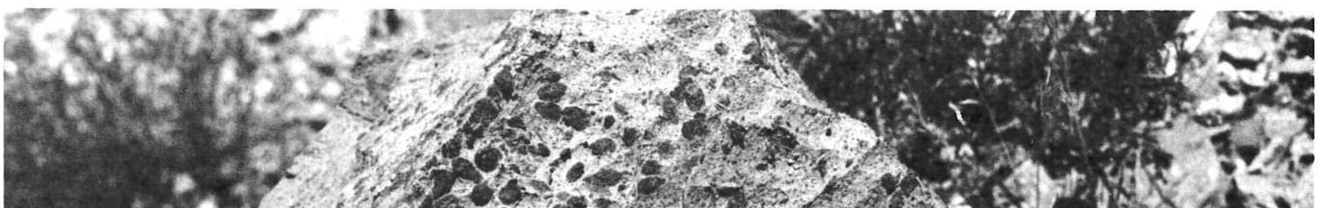

FIGURE 9.–Bedding plane exposure of unit 198, 712.0 m above base of section 2, exhibiting several species of fusulinids, including *Pseudoschwagerina* and *Triticites* cf. *cellamagnus*?

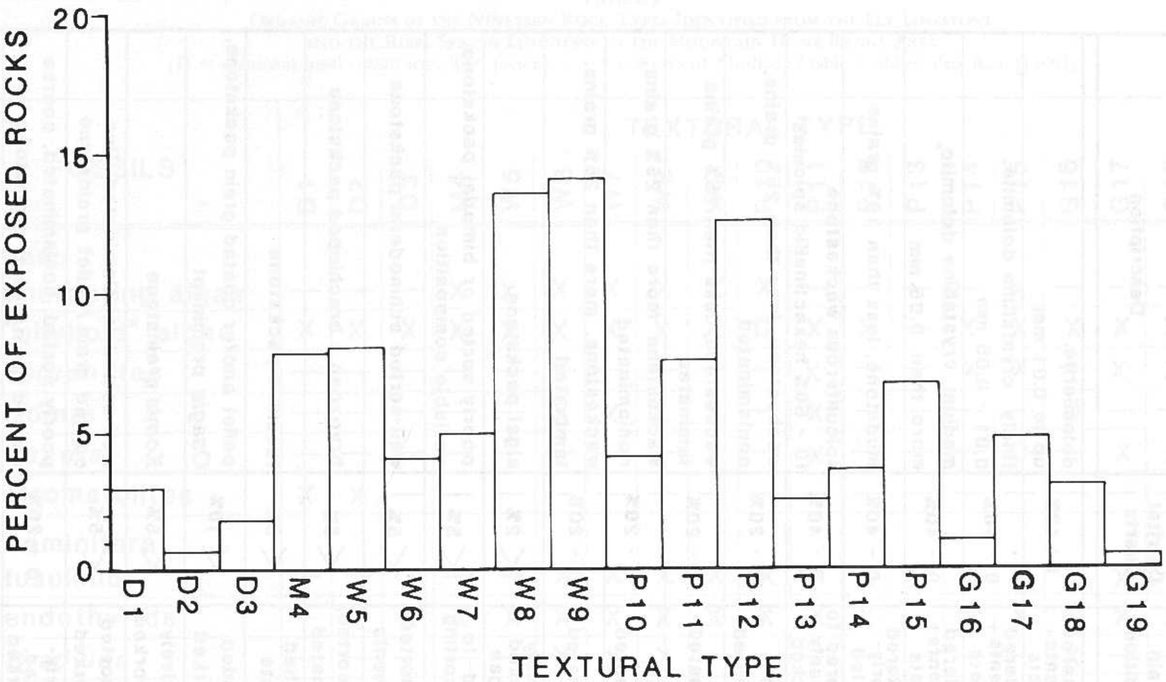

FIGURE 11.–Frequency distribution of nineteen rock types identified in section 2 of Ely Limestone and Riepe Spring Limestone. D = dolomite, M = mudstone, W = wackestone, P = packstone, and G = grainstone.

FIGURE 12.–Outcrop of dolomite showing undulatory silty laminations. Unit 193, 686.7 m above base of section 2.

TABLE 1
PETROLOGIC ASPECTS OF THE NINETEEN ROCK TYPES IDENTIFIED FROM THE ELY LIMESTONE AND THE RIEPE SPRING LIMESTONE IN THE MOUNTAIN HOME RANGE AREA
(Outline of table modified after Rich [1969])

Rock Type	Total Grains	Coated + Pelloidal Grains	Fossil Grains	Fossil Assemblage	Grain Size	Support	Grain Condition	Detrital Quartz	Description
D1	< 10%	up to 5%	up to 5%	euryhaline	up to 1 cm	mud	scattered fragments+ pellets	0 -40%	dolomicrite, up to 0.01 mm
D2	< 10%	up to 5%	up to 5%	euryhaline	up to 1 cm	mud	scattered fragments + pellets	0 - 40%	finely crystalline dolomite, 0.01 - 0.05 mm
D3	< 10%	up to 5%	up to 5%	euryhaline	up to 1 cm	mud	scattered fragments+ pellets	0 - 40%	medium crystalline dolomite, more than 0.05 mm
M4	< 10%	fossil + coated grains + pellets = < 10%		euryhaline	up to 1cm	mud	scattered poorly-sorted	0 - 40%	mudstone, less than 10% grains
W5	10-60%	< 5%	10-60% spicules	euryhaline stenohaline	1 to 2 mm in length	mud	scattered to closely packed	0 - 40%	spiculiferous wackestone, 10 - 60% hexactinellid spicules
W6	10-25%	fossil+coated grains+ pellets = < 25%		stenohaline	variable < 0.5 mm	mud	non-laminated	0 - 20%	wackestone less than 25% grains, nonlaminated
W7	10-25%			stenohaline	variable < 0.5 mm	mud	laminated	0 - 20%	wackestone, less than 25% grains laminated
W8	> 25%	fossil+coated grains+ pellets = > 25%		stenohaline	variable < 0.5 mm	mud	non-laminated	0 - 20%	wackestone more than 25% grains, nonlaminated
W9	> 25%			stenohaline	variable < 0.5 mm	mud	laminated	0 - 20%	wackestone, more than 25% grains, laminated
P10	> 60%	absent	20-80% algae	stenohaline	variable < 0.5 mm	grain	closely packed algae	< 2%	algal packstone
P11	> 75%	≈35%	> 40%	stenohaline	variable < 2 mm	grain	good- to fair- sorting	< 5%	poorly sorted or bimodal packstone, variable composition
P12	> 75%	absent	> 75%	stenohaline	bimodal	grain	well-sorted fragments	< 5%	well-sorted echinoderm packstone
P13	> 75%	absent	> 75%	stenohaline	up to several cm in length	grain	fairly-sorted, laminated	< 5%	bryozoan - brachiopod packstone
P14	> 75%	absent	> 75%	stenohaline	up to several cm in length	grain	crushed tests	< 5%	fusulinid packstone
P15	> 75%	> 50%	10-25%	stenohaline	up to 2 mm in diameter	grain	rounded reworked	< 10%	pellet and/or coated grain packstone, *Osagia* prominent
G16	> 60%	absent	> 60% *Komia*	stenohaline	up to several cm in length	grain	relatively unreworked	< 5%	*Komia* grainstone
G17	> 75%	> 75%	absent	stenohaline	0.01 - 0.03 mm in diameter	grain	well-sorted reworked	< 5%	well-sorted, nonlaminated, fine coated grain /pellet grainstone
G18	> 75%	> 75%	absent	stenohaline	up to several mm in diameter	grain	poorly-sorted, reworked	0 - 20%	poorly sorted, nonlaminated, coarse coated grain/pellet grainstone
G19	> 50%	> 75%	absent	stenohaline	≲ 1 mm in diameter	grain	reworked, well-sorted	up to 50%	well-sorted, cross-bedded, laminated, coarse coated grain, grainstone

TABLE 2

ORGANIC GRAINS OF THE NINETEEN ROCK TYPES IDENTIFIED FROM THE ELY LIMESTONE AND THE RIEPE SPRING LIMESTONE IN THE MOUNTAIN HOME RANGE AREA

(D = dominant fossil constituent, X = present, — = not present. Outline of table modified after Rich [1969])

FOSSILS	TEXTURAL TYPE																		
	D1	D2	D3	M4	W5	W6	W7	W8	W9	P10	P11	P12	P13	P14	P15	G16	G17	G18	G19
Algae																			
encrusting algae	—	—	—	X	X	X	X	X	X	X	—	—	—	—	X	—	—	—	—
"phylloid" algae	X	X	X	X	X	X	X	X	X	D	X	X	—	X	X	X	X	X	X
Tubiphytes	—	—	—	—	—	—	—	—	—	—	X	—	—	X	X	—	X	X	X
Komia	—	—	—	—	—	X	X	X	X	—	X	—	—	—	—	D	—	—	—
Osagia	—	—	—	—	—	—	—	—	X	—	X	—	—	—	D	—	X	X	X
stromatolites	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Foraminifera																			
fusulinids	—	—	—	—	—	X	X	X	X	X	X	X	—	D	X	X	X	—	—
endothyrids	—	—	X	X	X	X	X	X	X	X	X	X	—	X	X	X	X	X	X
Bradyina	—	—	—	—	—	X	X	X	—	—	—	—	—	—	—	X	—	—	—
Tetrataxis	—	—	—	—	—	X	X	X	X	—	X	—	X	X	—	X	—	—	—
other forms	—	—	X	X	—	X	X	X	X	—	X	—	—	X	X	X	X	X	X
Porifera																			
Chaetetes	—	—	—	—	—	X	X	X	X	—	—	—	—	—	—	—	X	—	—
spicules	X	X	X	X	D	X	X	X	X	X	X	X	—	—	—	—	—	—	—
Brachiopods																			
punctate	—	—	—	—	—	X	X	X	X	—	X	—	X	X	—	—	X	X	X
impunctate	—	—	—	—	—	X	X	X	X	—	X	X	D	X	X	—	X	X	X
psuedopunctate	—	—	—	—	—	X	X	X	X	—	X	X	D	X	X	—	X	X	X
spines	—	—	—	—	—	X	X	X	X	—	X	X	X	X	X	—	X	X	X
Corals	—	—	—	—	—	X	X	X	X	—	X	—	X	X	X	—	X	X	X
Bryozoans																			
twiggy	—	—	—	—	—	X	X	X	X	X	X	X	D	X	—	X	X	X	X
encrusting twiggy	—	—	—	—	—	X	X	X	X	X	X	X	D	X	—	X	X	X	X
fenestrate	—	—	—	—	—	X	X	X	—	—	—	—	X	—	—	—	—	—	—
Mollusks																			
gastropods	X	X	X	X	X	X	X	X	—	X	—	—	—	—	—	—	—	—	—
bivalves	—	—	—	—	—	X	X	X	—	—	X	—	X	—	—	X	—	—	—
other mollusks	—	—	—	—	X	X	X	X	X	—	X	—	—	—	—	X	X	X	X
Arthropods																			
trilobites	—	—	—	—	—	X	X	X	X	X	X	—	—	—	—	—	X	X	X
ostracodes	X	X	X	X	X	X	X	X	X	X	X	—	—	—	—	X	—	—	—
Echinoderm																			
plates	—	—	X	X	X	X	X	X	X	X	X	D	X	X	X	X	X	X	X
spines	—	—	X	X	X	X	X	X	X	X	X	X	X	X	—	—	X	X	X

Dolomites have been divided into three types–D1, D2, and D3–based on crystalline fabrics (figs. 13, 14). Types D1, D2, and D3 are microcrystalline dolomicrites with crystalline fabrics less than 0.01 mm, 0.01 to 0.05 mm, and greater than 0.05 mm, respectively. Rocks classed as D1 and D2 contain unimodal crystal size and less than 10 percent calcite, whereas the rocks of group D3 exhibit wide variation in crystalline texture within individual samples and contain up to 25 percent calcite.

All three dolomite types have several common characteristics. All contain less than 10 percent combined total of fossil and peloidal grains and exhibit the most restricted floral and faunal assemblages. Phylloid algae, peloids, and ostracodes are the most common grains in thin section, although they constitute less than 10 percent of the rocks. Other fossils seen in thin section include fusulinids, hexactinellid sponge spicules, echinoderm plates, and gastropods. Many of the gastropods, peloids, probable phylloid algae and ostracodes are not abraded, indicating they probably were not transported far, if at all. These fossils are most common and probably represent an assemblage of organisms living in the area of deposition. The fossils present in this assemblage are especially tolerant of high marine salinities judging from distributions elsewhere (Flügel 1982, p. 472).

Whole fossils recovered from these rock types include *Amphiscapha* sp. (fig. 15), a high-spired gastropod (fig. 16), and one scaphapod. A portion of a poorly preserved stromatolite was recovered from a type D2 sample in unit 176 of section 2 (fig. 13). Evidence of bioturbation is scarce but does occur in all three types of dolomite. Activity is generally expressed as small (1–2 mm in diameter) collapsed burrows and disrupted laminations. Horizontal burrows are common in Wolfcampian dolomitic units between 744 and 757 m from the base of the section. Flügel (1982) indicated that horizontal burrows are dominant in subtidal zones in the geologic record.

All three types of dolomite were probably deposited as high magnesium calcite, with primarily penecontemporaneous dolomitization altering types D1 and D2. Types D1 and D2 both contain very fine unimodal crystalline fabrics (fig. 13), suggesting one period of very early diagenesis. Examples of penecontemporaneous dolomite in the geologic record have a grain-size range of a few microns up to 30 or 40 microns (Chilingar

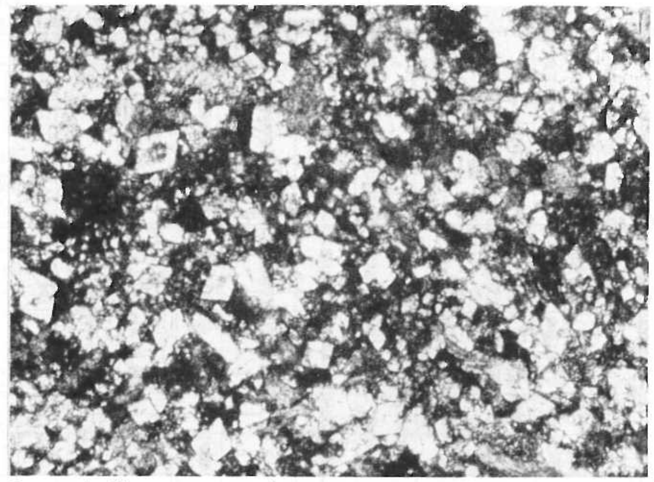

FIGURE 14.–Photomicrograph of type D3 texture showing heterogeneous fabric, variations in crystal size, and rhombs indicating at least two generations of growth. Unit 141, 579.1 m above base of section 2, X100.

FIGURE 15.–*Amphiscapha* sp. from unit 169, 629.7 m above base of section 2.

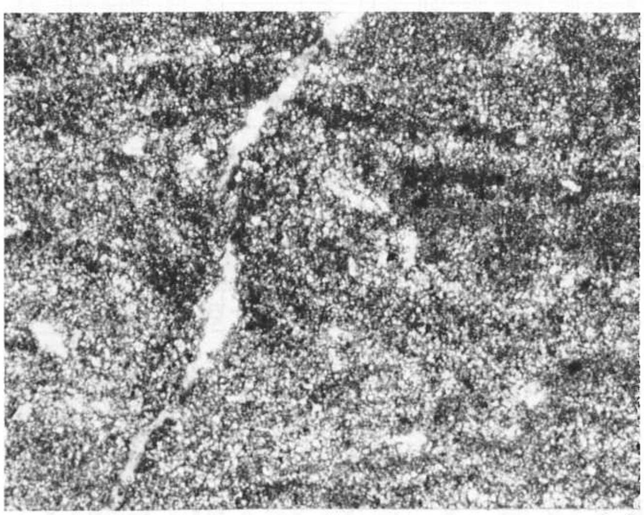

FIGURE 13.–Photomicrograph of type D2 texture, showing remnant cryptoalgal laminations and homogeneous nature of fabric. Unit 176, 637.3 m above base of section 2, X100.

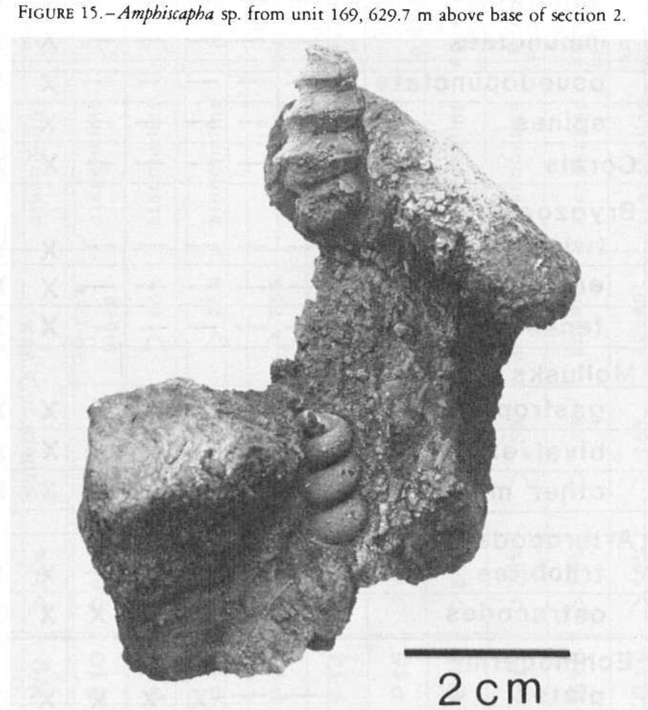

FIGURE 16.–High-spired gastropod test and steinkern from unit 190, 676.6 m above base of section 2.

and others 1979, p. 498). All type D1 rocks and the majority of the D2 rocks fall within these constraints. Individual samples within the D3 group contain a wide variety of crystalline fabrics with some dolomite rhombohedra up to 0.4 mm in diameter. Many larger crystals exhibit two periods of growth (fig. 14). Variations in crystal sizes, presence of more calcite, and evidence for at least two periods of diagenesis suggest that diagenetic history of D3 dolomite units differs substantially from that of D1 and D2 dolomites. However, because crystal-size distribution is not bimodal within the D3 group, diagenesis probably began early but was not as rapid or as complete as in types D1 and D2. Penecontemporaneous dolomites that show essentially complete, unimodal, extremely fine grain crystal sizes were probably deposited under higher-salinity conditions than those which show incomplete crystallization, poorly sorted crystal sizes, and several periods of alteration. Probably higher-than-normal salinities resulted in deposition of type D3 dolomite, but probably also salinities were highest during the deposition of types D1 and D2.

Masses of anhydrite and euhedral gypsum are present in amounts of less than 1 percent in thin sections of D1 and D2 rocks, which generally contain anhydrite as matrix material around a few dolomite rhombohedra. The extremely fine crystalline nature of these rocks makes differentiation difficult. Euhedral gypsum crystals are present in some D3 rocks in amounts up to 4 percent and are much easier to differentiate because of coarser fabrics. D3 rocks also contain minor amounts of anhydrite.

Detrital quartz grains and secondary chert are also common in dolomite of the Ely Limestone and the Riepe Spring Limestone. The quartz grains are predominantly angular silt-size particles. Silt concentrations range up to 40 percent but are generally less than 10 percent. Laminations, when present in dolomite (fig. 12), are related to silt concentrations. Silt-free dolomites of all types show minor textural laminations only on a microscopic scale. These microlaminations are related to small collapsed burrows and minor variations in crystal size.

Chert comprises up to 30 percent of the exposed dolomites and is most common in type D3. Case-hardened chert is also present in all varieties but is most common in silt-rich units. Chert is extremely irregular and forms wide shapes, sizes, and varieties of blebs and nodules, where it has replaced grains and matrix. A few units contain chert that appears to have replaced burrows up to 3 cm in diameter.

Types D1 and D2 are considered to have been deposited in a shallow restricted sea with higher-than-normal-marine salinity because of the following evidence:

1. Peloids occur, along with euryhaline organisms such as probable phylloid algae, ostracodes, and gastropods.
2. Nonabraded algae are present, indicating deposition within the photic zone.
3. Essentially penecontemporaneous dolomitic recrystallization of micritic sediments occurs with evaporite minerals which formed from high magnesium calcite.
4. Dolomites are very thin bedded and silt laminated.

Type D3 is considered to have been deposited under elevated but slightly lower salinity conditions than those of D1 and D2 types because of the lack of a dominant fabric of penecontemporaneous dolomite, even though minor evaporitic minerals are present. This lack of very early diagenetic dolomite is suggested by the presence of large variations in crystal sizes in single samples and evidence of at least two periods of recrystallization. D3 rocks contain more calcic matrix and are less completely altered than are D1 and D2 rocks.

Mudstones

Mudstones exposed in section 2 are all designated as type M4 rocks. These rocks constitute 8 percent of the exposed units and probably a large portion of the dolomitic concealed units. In the field, these rocks appear as very thin-bedded, brownish gray, dolomitic micrite, with up to 20 percent irregular chert. Units are commonly intralaminated with silt and/or silty dolomite. Exposures are fair to very poor.

Type M4 rocks are transitional to dolomite and wackestone of the section. Alteration to dolomite is common, and many samples are nearly 50 percent dolomite. Rhombohedra range up to 0.4 mm in diameter and dominantly replace matrix. Anhydrite patches are present and, in some cases, exhibit pseudocubic cleavage. This secondary mineralization replaces fossil fragments and fills voids. Floral and faunal assemblages are more diverse than in dolomite units, but are considerably more restricted than in the wackestones.

Grains constitute less than 10 percent of the volume of these rocks, as in the dolomites. Hexactinellid sponge spicules, ostracodes, peloids, and probable phylloid algae are the most abundant grains present. These fossils represent the same biocoenosic assemblage that is present in the dolomites. However, type M4 rocks also contain bivalves and bryozoans, and more echinoderm fragments than the dolomites. Occurrence of these few stenohaline forms suggests that salinity conditions were still higher than normal, but not so severe as during deposition of the dolomites. Grains are poorly sorted and vary in degree of abrasion. Bioturbation is present in type M4 rocks and is more common than in the dolomite units, although similar in nature.

Detrital quartz and secondary chert are common and evident in outcrops. Detrital quartz consists of angular silt-size grains and accounts for up to 20 percent of the rocks. As in the dolomite units, laminated varieties are generally rich in silt. Irregular chert ranges up to 30 percent of rock volumes but is absent in many M4 units.

Wackestones

Wackestones are the dominant lithology in exposed units of section 2 and account for 41 percent of the total thickness. Wackestones are divided here into five lithologic groups. Spiculiferous wackestones, W5, are composed of 10 to 60 percent sponge spicules (fig. 17). Nonlaminated wackestones, W6, and laminated wackestones, W7, contain less than 25 percent grains. Nonlaminated wackestones, W8, and laminated wackestones, W9, contain more than 25 percent grains. Examples of type W6 and W8 textures are illustrated in figures 18 and 19.

In the field, these rocks appear as light to medium gray silty limestones, with varying amounts of fossil debris. Silt-size quartz grains are present in quantities up to 30 percent, but generally constitute less than 10 percent of the volume. Very thin silt laminations are present, but are not as common as in dolomite and mudstone units. Many wackestone units also contain rounded sand-size quartz grains in amounts up to 1 percent of the volume. Silicification of fossil material is common and does not occur in any one variety more than another. Chert occurs in many shapes and forms, and is of two basic varieties, case-hardened and solid silica. Chert ranges from light moderate brown to brownish black and comprises up to 45 percent, by volume, of some rocks. Wackestone units weather to blocky rubble and produce small ledges, which are commonly laterally discontinuous.

The most diverse fossil assemblages in rocks of the Ely Limestone and the Riepe Spring Limestone in the Mountain

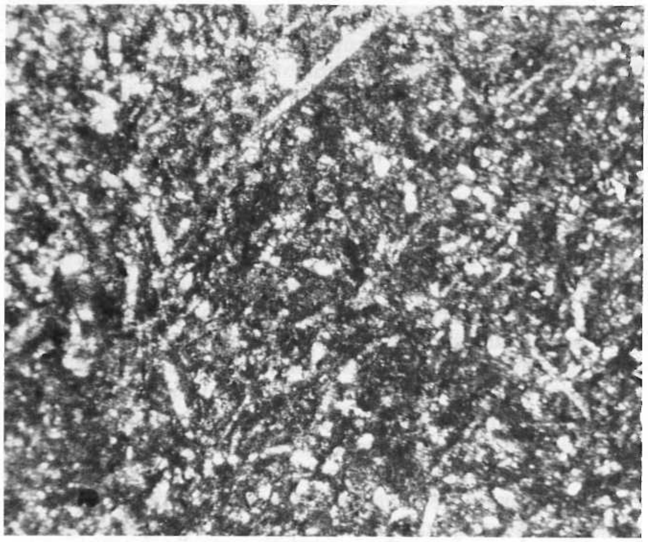

FIGURE 17.–Photomicrograph of spiculiferous wackestone, type W5, containing scattered hexactinellid sponge spicules in a silty micritic matrix. Unit 224, 757.1 m above base of section 2, X10.

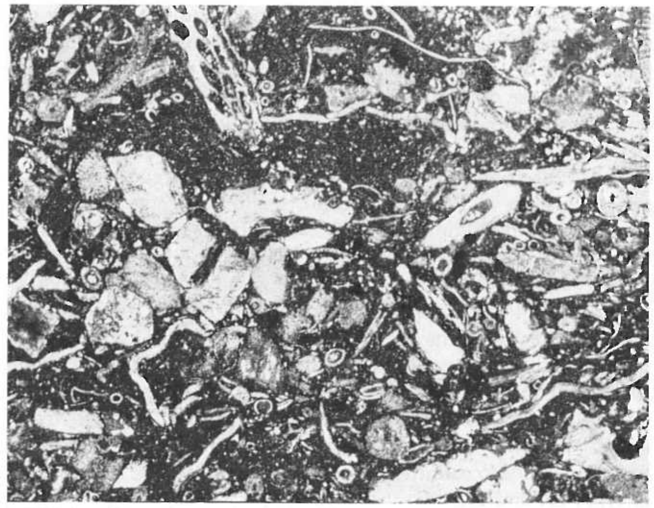

FIGURE 19.–Photomicrograph of nonlaminated wackestone with more than 25 percent grains, type W8. Note wide biologic diversity of grains. Included are fragments of brachiopods, bryozoans, echinoderms, trilobites, and others. Unit 35, 119.8 m above base of section 2, X10.

Home Range area are contained in wackestone units. Common fossil grains include fragments of ostracodes, trilobites, corals, bryozoans, brachiopods, echinoderm plates, probable phylloid algae plates, and foraminifera such as *Tetrataxis* and various fusulinid genera. Brachiopod grains include shell fragments of punctate, pseudopunctate, and impunctate genera, with impunctate and pseudopunctate types dominant. Twiggy, encrusting twiggy, and fenestrate bryozoans are also present in wackestone units. Fenestrate varieties are most common in nonlaminated W6 and W8 units but are not restricted to them. Individual beds show great diversity of fossil grains, except for W5 rocks that contain predominantly hexactinellid sponge spicules. The occurrence of stenohaline floral and faunal assemblages in most of the wackestone units indicates normal marine salinities.

Bioclastic grains show fair to poor sorting and are angular. Grain size is extremely variable but generally is greater than 0.25 mm. Some wackestone units of each lithology except W5 contain *Syringopora,* a caninid coral, and several varieties of rugose corals.

Type W5 units may contain up to 60 percent hexactinellid sponge spicules, but most commonly spicules comprise less than 25 percent of the rocks. Spicules are most often lineated and concentrated in fine laminations, although in some rocks they are scattered (fig. 17). There is no apparent correlation between volume of spicules and orientation. Other fossil grains are considerably less common in W5 units. Subordinate fossil grains suggest an euryhaline assemblage and include ostracodes, probable phylloid algae, and peloids.

The W5 rocks are the most diagenetically altered of the various wackestones. Dolomitization has replaced up to 25 percent, by volume, of the rocks. Euhedral gypsum crystals, partially replaced by anhydrite, are present in amounts up to 10 percent (fig. 20). These crystals are irregularly oriented, suggesting that they replaced soft sediments.

Sponges are generally considered to be stenohaline organ-

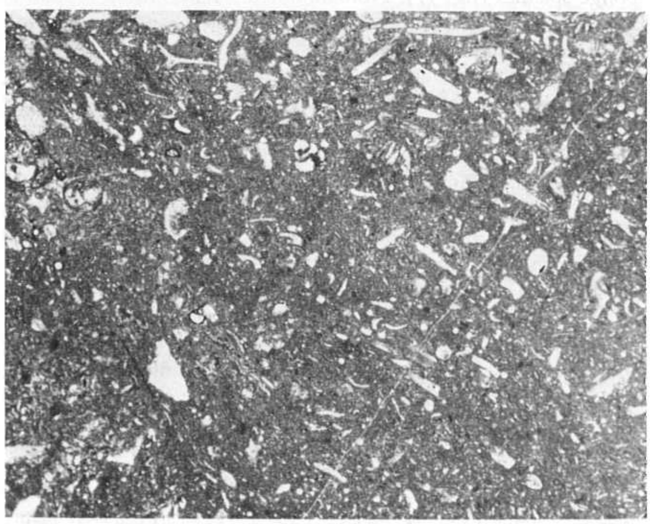

FIGURE 18.–Photomicrograph of nonlaminated wackestone with less than 25 percent grains, type W6. Unit 5, 28.3 m above base of section 2, X10.

FIGURE 20.–Photomicrograph of gypsum crystals in a spiculiferous wackestone, type W5 rock. Unit 13, 47.4 m above base of section 2, X100.

isms, although a few forms are euryhaline. Spicules often show evidence of transportation, but subordinate grains do not. This relationship, seen in rocks where early diagenetic euhedral gypsum crystals also occur, suggests that the spicules were transported into a more saline environment than that in which the sponges lived, or that these sponges were euryhaline forms that lived in the environment of deposition. It seems unlikely that large concentrations of spicules would be transported into a restricted shoreward environment from an open marine environment. Sponges were probably growing in small communities, and, as they died, their spicules disarticulated and accumulated in the high magnesium carbonate mud along with skeletal debris from more euryhaline organisms living in the environment. No whole hexactinellid sponge specimens were found.

Rocks of type W5 probably represent a somewhat more restricted environment than do other wackestone types. Other wackestone units contain diverse fossil assemblages indicative of more nearly normal open marine conditions and lack gypsum, anhydrite, and dolomite.

Wackestone types W6 to W9 contain a similar assemblage of stenohaline organisms. Increase in lamination and grain content probably indicates increase in depositional energy. It is possible that winnowing played a role in concentrating fossils, but it is unlikely, especially in the nonlaminated wackestone which shows no disruptions of fabrics and textures, or minor ones.

Types W8 and W9 are the most abundant wackestones, accounting for 14 percent and 13.5 percent, respectively, of the exposed ledges. Types W6 and W7 are represented in the field by 4 percent and 5 percent of the ledges, respectively.

Packstones

Packstones have been divided into six textural types as follows: P10, algae packstones; P11, poorly sorted packstones of variable grain composition; P12, well-sorted echinoderm packstone; P13, brachiopod-bryozoan packstone; P14, fusulinid packstone; and P15, peloid and/or coated-grain packstone. Figures 21 through 26 illustrate these six different packstone types. Packstone units account for 33 percent of the thickness of exposed units of section 2.

In the field, these units appear as medium to dark gray fossiliferous limestones. In general, they lack silty laminations like those present in dolomite, mudstone, and wackestone facies. Angular silt-size quartz grains comprise less than 10 percent of the rocks by volume. Secondary silicification of fossil material is common and particularly affects P12 units. Many P12 units have been almost totally silicified. Chert comprises up to 30 percent of the units by volume, but most units contain less than 5 percent chert. Packstone units weather to blocky rubble and form ledges that are laterally discontinuous along strike. Hydrocarbon odors are emitted from freshly fractured surfaces of many units. Type P12 rocks emit strong fetid odors from encrinal debris. Dead oil is common in type P11, P13, and P14 rocks.

All packstone rocks are grain supported and contain a mud matrix. Some units also contain a cloudy microspar cement which has recrystallized from micrite. In general P10, P12, P13, and P14 varieties show the best sorting.

Type P10 units exhibit a diverse assemblage of fossils, including fragments of algal plates, sponge spicules, foraminifera such as *Tetrataxis* and fusulinids, ostracodes, trilobites, gastropods, bryozoans, and echinoderms. Fossil grains, other than algal plates, are numerically limited, but they do represent a stenohaline assemblage. Fossil fragments are subrounded and sometimes micritized. However, grains in P10 rocks are less abraded than those in other packstone varieties. Unit 200 of section 2 contains an alga of uncertain affinity, which shows no evidence of transport (fig. 21). Bioclastic grains exhibit fair to good sorting.

P10 units are generally silt free; however, as subordinate grains increase in quantity, so do quartz silt grains. This suggests that units with more silt contain grains that have been transported farthest.

Light requirements of algae in P10 units and presence of euryhaline subordinate forms suggest that P10 rocks were deposited in shallow seas within the photic zone, in or near to normal marine salinity.

Type P11 rocks (fig. 22), contain a great variety of grains, including both skeletal fragments and peloids. Rocks of this group are generally nonlaminated, with grain diameters ranging from 0.01 to 2.0 mm. A few P11 rocks show a bimodal grain-size distribution, suggesting two sources of grains. Most grains are partly worn and subrounded, and many have been

FIGURE 21.–Photomicrograph of "algal" packstone, type P10. Unit 200, 712.9 m above base of section 2, X10.

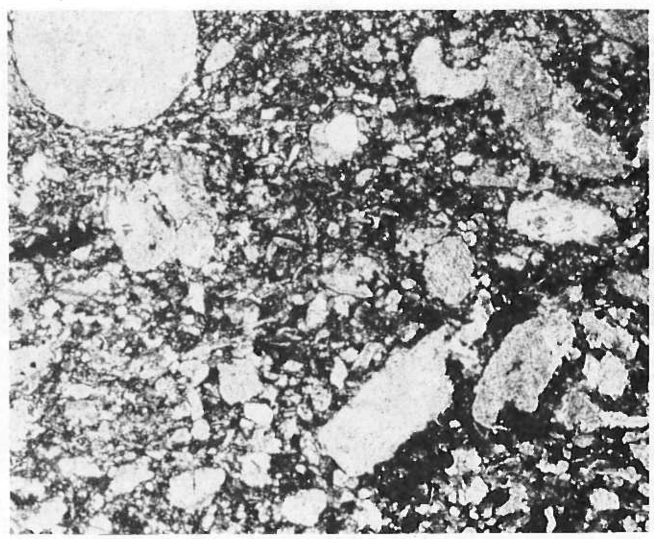

FIGURE 22.–Photomicrograph of poorly sorted packstone, type P11, containing mostly echinoderm fragments. Unit 128, 543.8 m above base of section 2, X10.

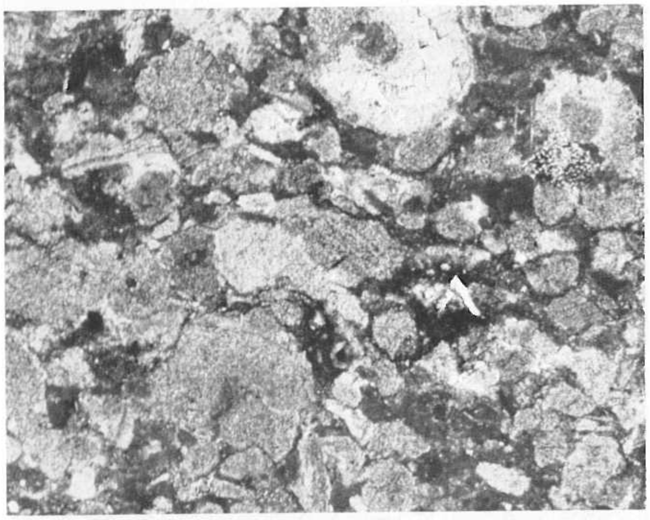

FIGURE 23.–Photomicrograph of echinoderm packstone, type P12. Note sutured grain contacts and partial silicification of a few crinoid ossicles. Unit 238, 807.7 m above base of section 2, X10.

micritized, all indications of movement of grains in water before burial. Type P11 rocks were probably deposited in an environment of normal marine salinity, generally below storm wave base, where lime mud was winnowed away and grains were effectively concentrated. These rocks are similar to W8 and W9 units, but contain more peloidal and skeletal grains that show slightly more abrasion.

Type P12 units (fig. 23) are well-sorted packstones and show a bimodal grain-size distribution. Individual units fall into one of two categories: those with a grain size of approximately 0.5 mm and those with a grain size of 0.1 mm. Each type contains grains that are well sorted with respect to size and that are predominately crinoidal. Many grains exhibit sutured contacts, evidence of microstylolitization during compaction. Large Mississippian Waulsortian mounds in New Mexico (Cotter 1965) and Montana (Laudon and Bowsher 1941) are commonly flanked by steeply dipping beds of coarse echinoderm packstones very similar to P12 units of this study.

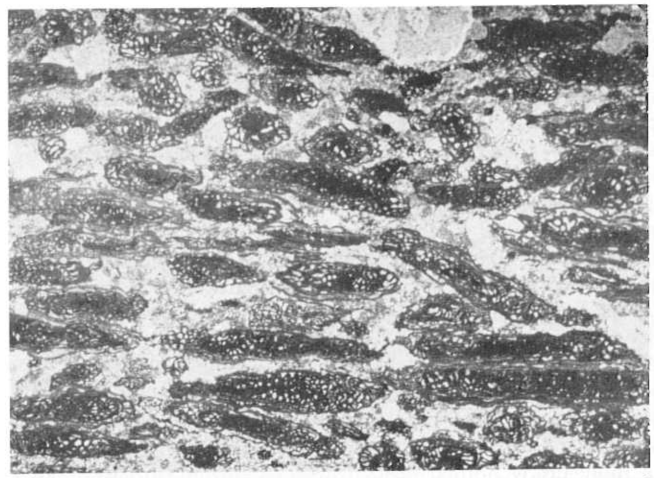

FIGURE 25.–Photomicrograph of fusulinid packstone, type P14. Crushed tests of *Eoparafusulina* cf. *linearis* indicate rapid burial. Unit 239, 823.0 m above base of section 2, X5.

Wilson (1975, p. 164) stated that disarticulated echinoderm plates probably floated after death of the organism, because of their porous nature, until their infilling with calcite and the inversion of the plate to Mg calcite. Because of this great potential for dispersion, an abundant and relatively close source of echinoderm debris must have been present.

Type P13 rocks (fig. 24) contain fragments of ramose bryozoans and several genera of brachiopods. A diverse brachiopod population is shown by the presence of punctate, impunctate, and pseudopunctate shell fragments. Impunctate varieties dominate the brachiopod population, and *Rhombopora* dominates the bryozoan population. These units are well laminated and contain fractured and slightly abraded bioclasts that range up to several centimeters long. The P13 units make up 12.5 percent of the exposed units in section 2. Wilson (1982) studied similar limestone deposits that contain brachiopods and ramose bryozoans in the Permian Bird Spring Group of southern Nevada. He postulated three mechanisms for their deposition:

1. When bryozoans died or became unattached, their branches were swept along the sea floor and trapped by living

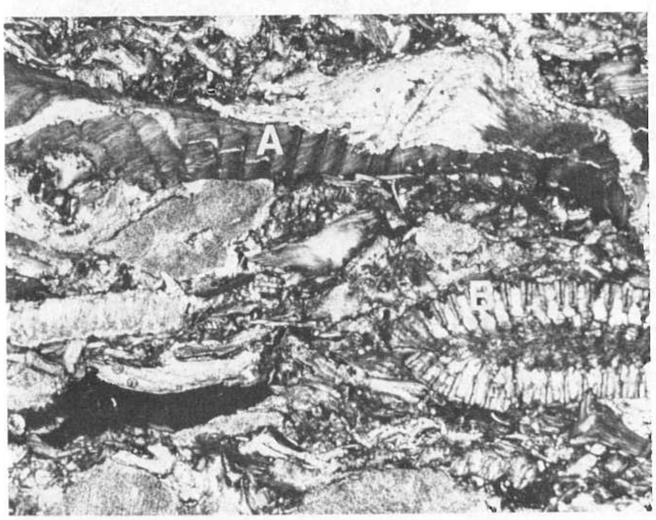

FIGURE 24.–Photomicrograph of brachiopod-bryozoan packstone, type P13. A, pseudopunctate brachiopod fragment; B, cryptostome bryozoan fragment. Unit 149, 589.9 m above base of section 2, X10.

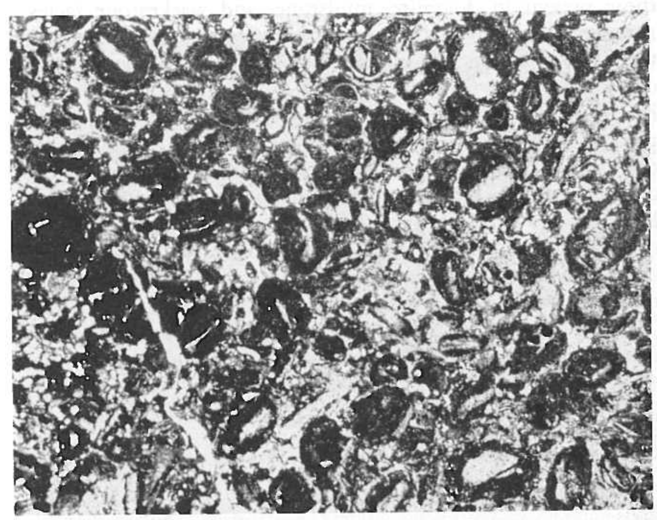

FIGURE 26.–Photomicrograph of coated-grain packstone, type P15. Most grains are *Osagia*-encrusted fragments of brachiopods, corals, bryozoans, and Tubiphytes. Unit 81, 362.1 m above base of section 2, X10.

bryozoan colonies attached to large shells. These large living fragments and associated dead fragments formed traps which caught and accumulated other fragments that were being moved.

2. Skeletal fragments could have formed current-stable deposits as they accumulated on the sea floor.

3. Skeletal elements accumulated in shallow depressions or current shadows in the lee of small elevations on the substrate.

Wilson (1982) concluded that all three mechanisms contributed to deposition of rocks in the Bird Spring Trough that are similar to ones studied in the Mountain Home Range area. However, other evidences–such as the probable presence of small elevated bioherms, together with rapid lateral and vertical changes in lithologies–point to an uneven sea floor in the Ely Basin. Whole specimens in growth position are lacking. Therefore, it seems likely that skeletal accumulation in shallow depressions was the major mechanism for deposition of P13 units in the Ely Basin.

Several units of type P14 are exposed in section 2, including unit 198, which contains abundant tests of a very primitive form of *Pseudoschwagerina* and *Triticites* cf. *cellamagnus?* (figs. 9, 10); unit 222, which contains tests of *Boultonia?* sp., *Triticites?* sp., or *Daixina?* sp.; and unit 239, which contains tests of *Eoparafusulina* cf. *linearis* Dunbar and Skinner (fig. 25). These units account for 3.5 percent of the exposed part of the stratigraphic section. Subordinate skeletal grains include fragments of *Tubiphytes,* probable phylloid algae, brachiopods, bryozoans, echinoderm plates, along with *Tetrataxis* and other foraminifera. These units generally show bimodal sorting, with fusulinids being the larger grains. All grains were probably brought in by the same currents, but the fusulinids were probably less dense than the subordinate skeletal grains. Many P14 units contain crushed fusulinids, indicating rapid influx of sediment and compaction before tests could fill with meteoric water or sediment. Fusulinids often show marked orientations. These packstone units probably represent storm deposits of grains derived essentially from the same source area. They are among the most easily recognized beds in the field and appear to extend several miles laterally, even though they vary in thickness and exposure quality.

Type P15 rocks (fig. 26) are composed of grain-supported, coated grains that are mainly *Osagia*-encrusted and peloids that are probably fecal in origin. Subordinate grains of well-abraded and coated foraminifera, *Tubiphytes,* and probable algae are present. The latter grains are found between coated grains within the matrix, but also act as nuclei for the *Osagia*-coated grains. Grains range up to several millimeters in diameter. Subordinate fossil grains are fragmented, evidently transported, and therefore not indigenous to sites of deposition. Material between grains is predominantly micrite, although up to 40 percent microcrystalline cloudy calcite occurs, making these units transitional between packstone and grainstone textures.

In Lower Permian units of the southern Alps, rocks of the same textural and fossil assemblage are limited to protected shelf lagoons and turbulent environments on the margins of open shelf platforms (Flügel 1982, p. 490). Rich (1969) also noted similar units in Atokan rocks of the central and southern Great Basin. He interpreted these rocks as forming under shallow-water, high-energy conditions on top of elevated features in the unstable Ely Basin.

Grainstones

Grainstone rocks of section 2 have been divided into four textural types (figs. 27–30): G16, *Komia* grainstone; G17, well-sorted, nonlaminated coated-grain or peloid grainstone; G18, poorly sorted, coarse, nonlaminated, coated-grain grainstone; and G19, well-sorted, coarse, coated-grain grainstone. These units appear as thin- to medium-bedded, medium gray, coarse-grained limestones in the field. Individual beds are generally laterally discontinuous. They account for 9.2 percent of the exposed units. Grainstones were deposited under the highest energy conditions of any of the rocks exposed in section 2. Minor amounts of other clastic grains also occur in G16 rocks, including fragments of prismatic mollusk shells, algal plates, trilobites, echinoderm plates, foraminifera, and bryozoans. They contain both micrite and microcrystalline cement, but crystalline calcite is most abundant; they probably represent deposits of shoal-water environments. Similar rocks are common in the Middle Pennsylvanian strata of the southwestern United States. For example, *Komia* is reported to form porous grainstones on

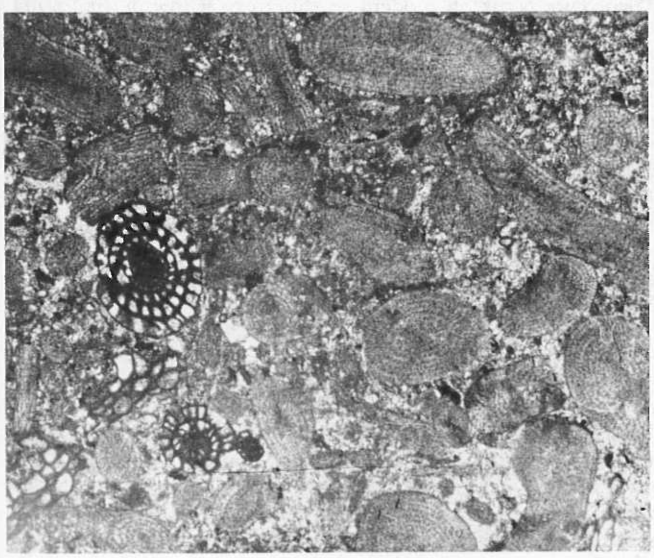

FIGURE 27.–Photomicrograph of *Komia* grainstone, type G16. Unit 138, 571.2 m above base of section 2, X10.

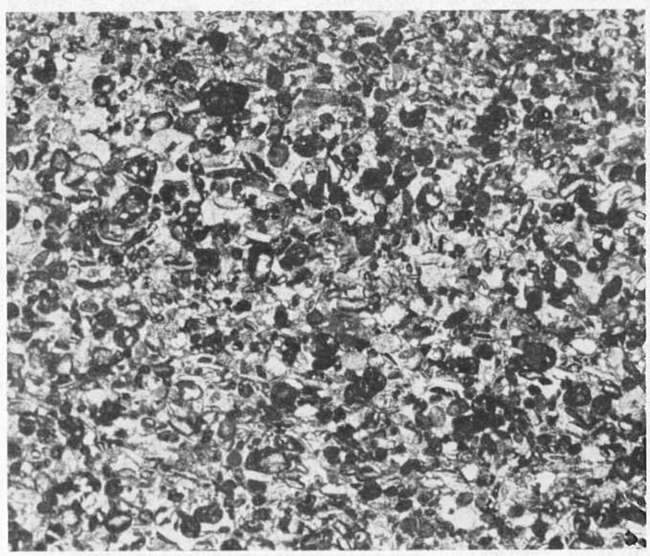

FIGURE 28.–Photomicrograph of well-sorted, fine, nonlaminated coated-grain grainstone, type G17. Unit 51, 221.6 m above base of section 2, X10.

the tops and seaward sides of buildups along shelf margins in the Middle Pennsylvanian strata of western Texas (Toomey and Winland 1973). Rich (1969) reported *Komia* grainstones from Atokan rocks of the central and southern Great Basin. *Komia* grainstones make up 1 percent of the exposed units in section 2.

Type G17, G18, and G19 rocks all contain similar grain assemblages. They all contain fecal pellets, *Osagia*-coated grains, and micritized skeletal grains. Skeletal grains include fragments of echinoderm plates, algae, trilobites, brachiopods, mollusks, bryozoans, and many others that are unidentifiable. All have been transported and considerably abraded and therefore are not indigenous to the environment in which they accumulated. They vary mainly in grain size, sorting, and degree of orientation of grains. Type G17 rocks are nonlaminated to sublaminated and consist of well-sorted grains with an average diameter of 0.3 mm. Type G18 rocks are nonlaminated and consist of poorly sorted grains 0.1 to 1.5 mm in diameter. Type G19 rocks are composed of alternating laminations of silt-size quartz grains and bioclastic grains with diameters of approximately 0.5 mm. The laminations were probably a result of minor variations in energy of currents during deposition. Type G19 rocks are cross-bedded silty limestones where seen in the field (fig. 31). Grainstone rocks have not undergone extensive dolomitization and, except for type G19 rocks, are devoid of detrital quartz. Type G17, G18, and G19 are represented in section 2 by 4.7, 3.0, and 0.5 percent of the exposed units, respectively. These grainstone units are transitional to type P15 units and were also deposited in shoal-water environments, under slightly higher-energy conditions.

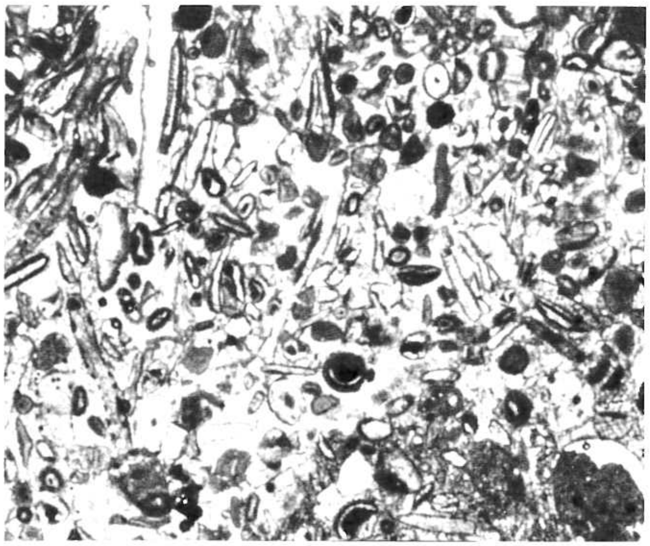

FIGURE 29.–Photomicrograph of poorly sorted, coarse, nonlaminated coated-grain grainstone, type G18. Grains consist of micritized algal, bryozoan, brachiopod, and coral fragments. Unit 3, 20.4 m above base of section 2, X10.

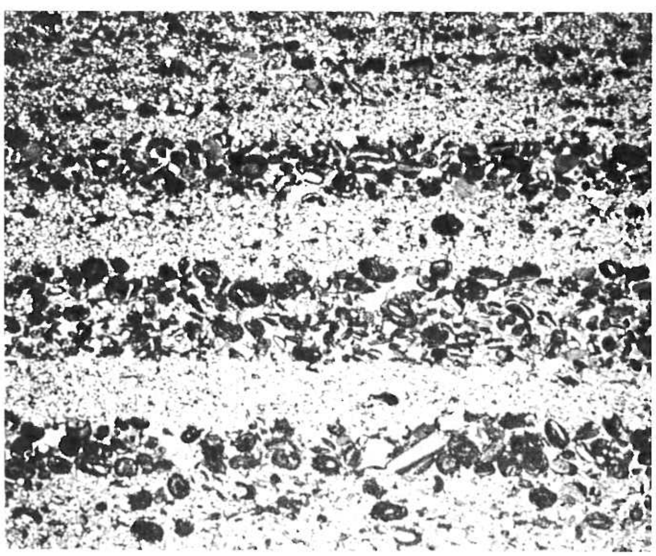

FIGURE 30.–Photomicrograph of coated-grain, silt-laminated grainstone, type G19. Note alternating laminae of silt and well-sorted, coated grains. Unit 45, 191.7 m above base of section 2, X5.

In summary, rocks of the Ely Limestone and the Riepe Spring Limestone exhibit diverse characteristics, but the following general trends are well expressed in the progression from dolomite to grainstone units:

1. Fossil content and diversity increase.
2. There is a progression from euryhaline to stenohaline fossil assemblages.
3. There is a progression from poorly sorted angular skeletal grains to well-sorted rounded grains.
4. There is a progression from very silty units to silt-free units.
5. There is a decrease in dolomitization and evaporitic minerals.
6. There is a progression from mud-supported fabrics to grain-supported fabrics.
7. There is an increase in bedding thickness.

Glauconite

Rounded glauconite grains occur in rocks between 746 and 753 m above the base of section 2. Strata in this interval are Wolfcampian in age. Glauconite is present in a wide variety of lithologies in quantities up to 1 percent, by volume. All glauconite-bearing rocks also contain large volumes of silt-size quartz grains and are generally laminated.

Glauconite is strictly a marine mineral, forming by several possible processes such as direct precipitation from seawater and alteration of detrital phyllosilicate minerals, but mainly from alteration of organic matter such as fecal pellets (Burst 1958). Glauconite occurs in modern seas in areas of low detrital sedimentation and is most common at depths ranging from 30 to 700 m where temperatures are between 10 and 15°C (Porrenga 1969).

Glauconite-bearing rocks of the Riepe Spring Limestone contain large quantities of detrital material, were deposited in warm shallow seas, and contain very minor amounts of glauconite. Glauconite grains may have originated in a deeper portion of the Ely Basin (in an environment more suitable for formation) and then been transported shoreward during storms and deposited in the restricted portion of the basin.

Detrital Quartz

Evaluation of measured sections and thin sections indicates that deposition in the Mountain Home Range area was dominated by carbonate sediments during the Chesterian part of the Mississippian, during Pennsylvanian, and during Wolfcampian times. However, angular detrital silt-size quartz is present in almost all the nineteen textural types. Quartz volumes are related to lithology rather than to stratigraphic position. Dolomite, mudstone, and wackestone units contain the greatest amounts of silt, up to 50 percent by volume. A few rounded sand-size grains were also noted in units of each of these rock types.

These rounded grains are very subordinate in numbers and may indicate the presence of a source area separate from that from which angular silt-size grains were derived, or the larger grains may have been wind transported. Silt grains are angular, most likely because of the protection from abrasion by water held by surface tension.

The Antler orogenic belt was a known source of clastic debris to the west side of the Ely Basin during the Pennsylvanian and Permian (Bissell 1964b). Rocks in the studied stratigraphic sections were deposited on the eastern margin of the Ely Basin. This area appears to have been restricted from normal marine circulation and contains large quantities of quartzose silt throughout. These factors strongly suggest that the West-Central Utah Highlands were a prominent source of debris in the rocks studied.

Chert

The Ely Limestone and the Riepe Spring Limestone contain chert-rich and chert-free units. Many distinctive chert-bearing units produce key beds in the field. Chert ranges up to 40 percent, by volume, in some beds. Two main varieties of chert are recognizable in the field, case-hardened and actual. Neither is more abundant than the other; however, any one particular cherty unit generally contains only one variety.

Case-hardened chert appears as a silica shell that varies in thickness from 1 to 4 mm and generally surrounds a limestone core. Bissell (1959) referred to this type of chert as "burnt chert" because of its distinctive moderate brown to black color. Case-hardened chert affects the silt-rich units more than those that are silt free. It commonly appears as spherical nodules that often have centers of actual chert that is liesegang banded. Such spheres range in diameter from a few centimeters to more than 1 m (fig. 32). These chert spheres often characterize distinctive key beds within the section. Dott (1958) studied the Ely Limestone in east central and southern Nevada and also noted similar concentric liesegang banding within case-hardened spheres. He concluded that the concentric bands represent either replaced algal remains, contraction spheroids resulting from rhythmic shrinkage during dehydration of silica gel, or minor alterations in mineralogy. These spheroidal masses are probably early diagenetic features, for they are too symmetric to have resulted from recent weathering.

Not all rocks that exhibit case-hardened chert contain spheroidal masses. Several very silty units are covered with a silica crust on their weathered surfaces; for example, such surfaces are prominent on G19 rocks. These case-hardened crusts are evidently a recent weathering phenomenon controlled, at least in part, by primary silica content of the rocks.

Actual chert varies greatly both in abundance and in shape of the masses. In general, individual units contain actual chert masses of only one shape. Chert has replaced grains and matrix. Residual fabric and structures within chert nodules appear to be the same as fabrics and structures within the unaltered host, at least rocks of all chert nodules examined in thin section in this study. Many chert nodules have aureoles that contain euhedral dolomite rhombohedra (fig. 33). Interiors of these chert

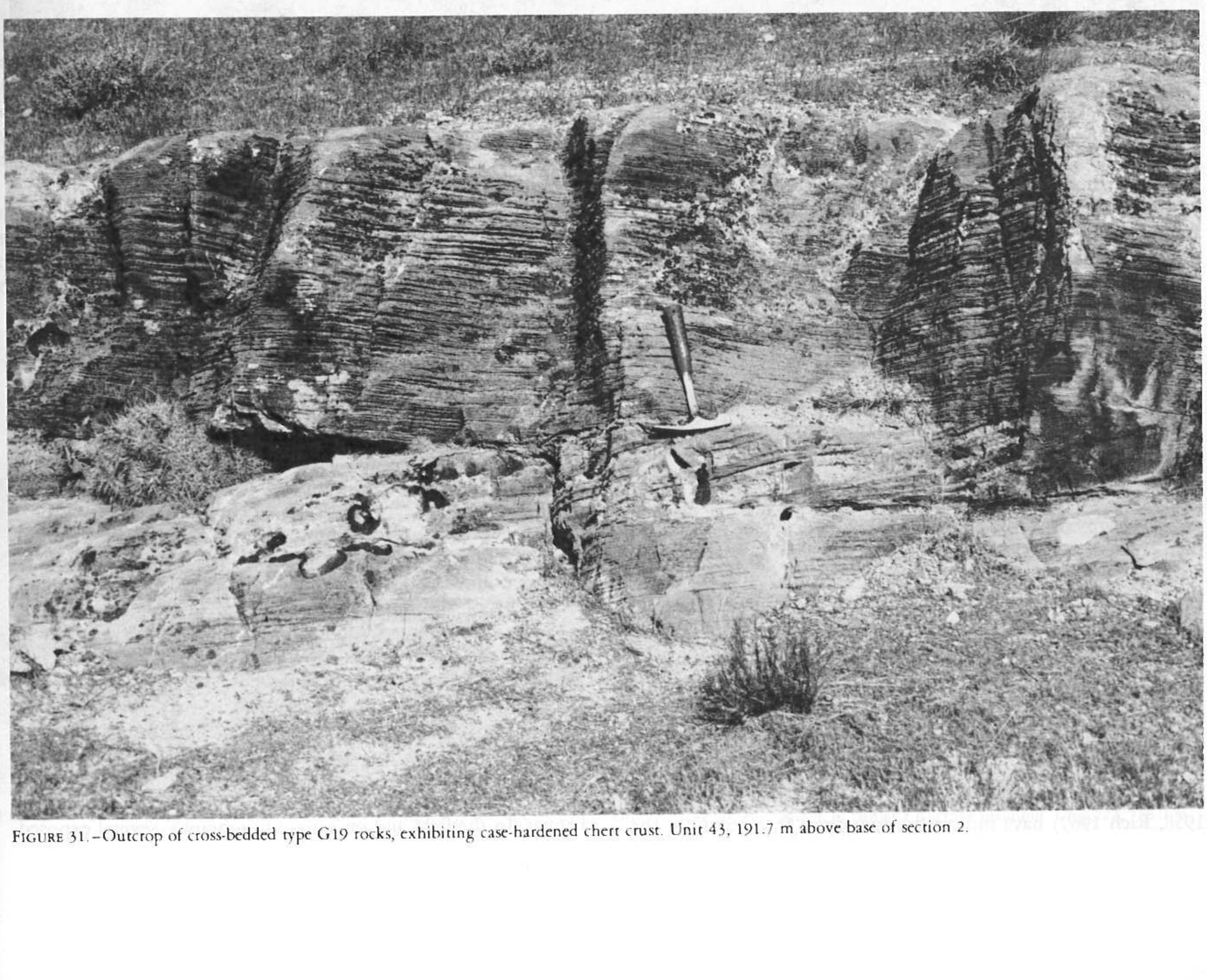

FIGURE 31.–Outcrop of cross-bedded type G19 rocks, exhibiting case-hardened chert crust. Unit 43, 191.7 m above base of section 2.

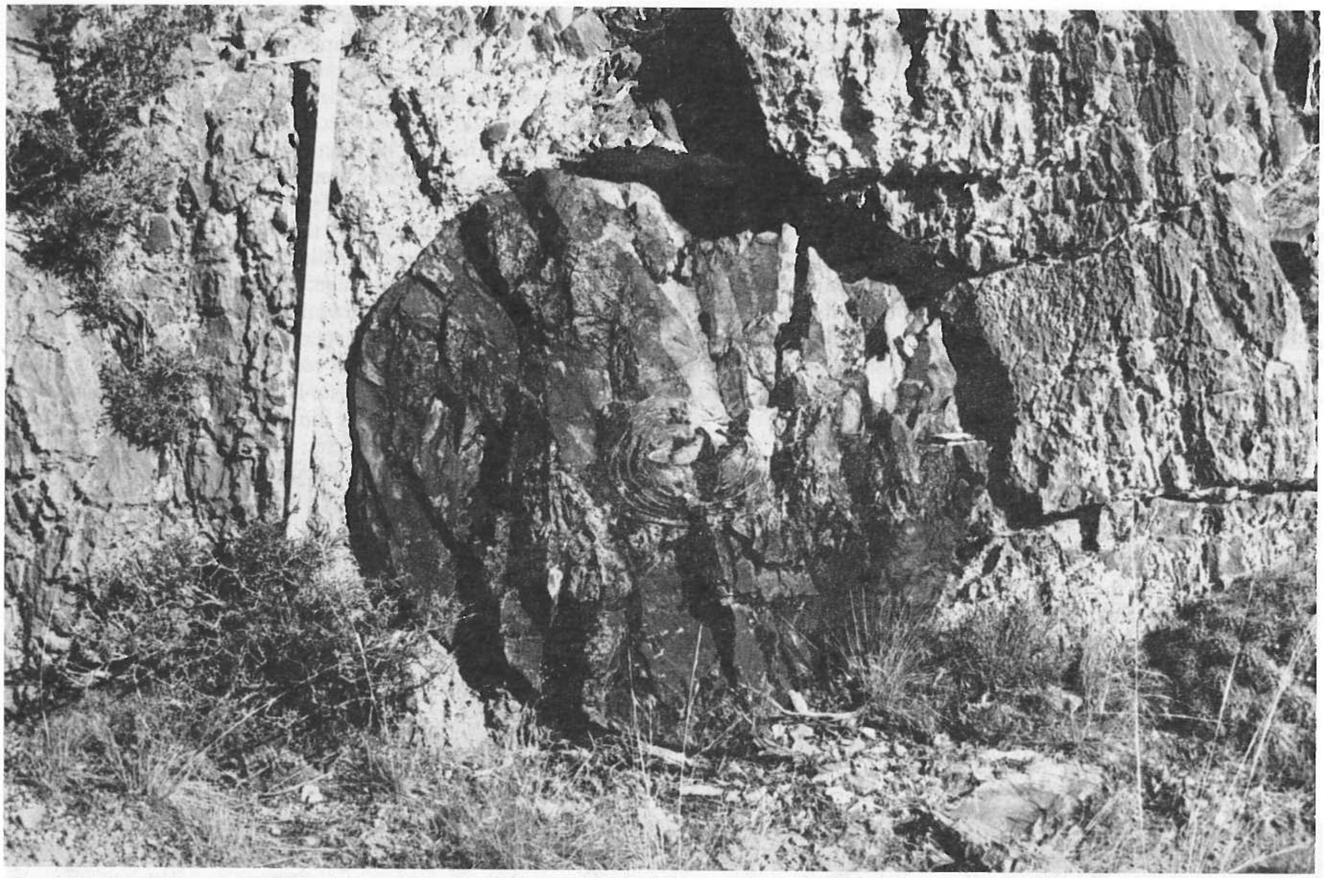

FIGURE 32.–Case-hardened chert ball with liesegang-banded interior. Unit 89, 386.8 m above base of section 2. Meterstick at left shows scale.

nodules also contain euhedral dolomite, but less abundantly than at the nodule–host rock interface.

In the field one can also see that dolomite is concentrated around many chert nodules. This relationship was also noted by Rich (1969) in the Atokan rocks of the central and southern Great Basin, although he gave no explanation for this phenomenon. Dolomitization is known to increase porosity; therefore, it is probable that dolomitization also increased permeability and allowed silica-rich solutions to migrate into dolomitized areas. This relationship is also noted in the field, for those rocks that have been altered by dolomitization also show the most chert. Although actual chert is probably secondary in origin, sources of silica are conjectural. Part of the silica was likely derived from siliceous animal remains and perhaps part from siliceous detrital minerals.

Several methods of chertification of carbonate rocks have been discussed and postulated by Newell and others (1953), Taliaferro (1934), Chilingar (1956), and Krumbein and Garrels (1952). None of their theories seems to account for all the varieties of chert in the Ely Limestone and the Riepe Spring Limestone.

Silicification of Fossils

Fossil types vary in susceptibility to silicification. Brachiopod shells and spines, along with corals, are most commonly silicified. Echinoderm packstones (P12) are also commonly silicified, although studies of the Ely Group in other areas (Dott 1958, Rich 1969) have indicated echinoderm fragments are the least-replaced fossil debris. Other fossils are also silicified, but generally only on weathered surfaces. Although fusulinids are seldom reported to show silicification, unit 222 of section 2 contains tests of *Boultonia?* sp., *Triticites?* sp., or *Daixina?* sp. that have been partially replaced by chalcedony (fig. 34). Permeability and exposed surface area of skeletal material seem to be most important factors in selective silicification of fossil material (Dott 1958).

DISTRIBUTION AND GEOMETRY OF CARBONATE TYPES

The Ely Limestone and the Riepe Spring Limestone were deposited under fluctuating energy conditions. These fluctuations are expressed in outcrop as rocks that weather to alternating covered slopes and ledges. All exposed units were assigned to one of the nineteen carbonate types. Stratigraphic position versus group number was plotted to visually express cycles and to aid in understanding the depositional system of the Ely Limestone and the Riepe Spring Limestone. With the aid of computer-applied statistics and graphics, several variations of basic data derived from thin-section analysis were also plotted. Several of these plots are illustrated in figures 35, 36, and 37. Deposition of rock types and inherent energy of the system were cyclic. Hemicyclic and truly cyclic events, together with apparent nonsymmetric patterns of depositions, are apparent in plotted data.

Vertical and lateral distribution and associations of the nineteen rock types indicate many multidirectional facies changes. In the field and on aerial photographs, several exposed units, especially in the upper units of the Riepe Spring Limestone, are laterally continuous for several tens of meters. However, the great majority of exposed units are laterally discontinuous and disappear into covered slopes along strike. Many units sampled are exposed for less than a meter along strike. These rapid vertical and lateral changes, along with paleontologic evidences, indicate an uneven seafloor was present in the Ely Basin.

Frequency Distribution of Rock Types

Total meters of exposed dolomites, mudstones, wackestones, packstones, and grainstones were plotted on a frequency histogram (fig. 38). From this figure, it is apparent that exposed rocks exhibit a nearly normal distribution, with mean and mode being almost coincident. The average exposed unit is texturally a W9 type unit. The dashed curve on the histogram (fig. 38) is an estimation of the frequency distribution of actual lithologies present in the Ely Limestone and the Riepe Spring Limestone, taking into account probable lithologies of covered areas. The dashed curve indicates that the most common lithologies present are dolomite and mudstone. It is evident that exposed units of the Ely Limestone and the Riepe Spring Limestone represent relatively uncommon depositional events, whereas covered intervals of poorly indurated, silty, laminated mudstones and dolomites represent the common depositional environments of the system.

That part of the Ely Basin represented by this study probably was partially isolated from normal marine conditions that most of the Ely Basin experienced during the Pennsylvanian and the Wolfcampian. Dott (1955, 1958), Hose and Repenning (1959), and Lane (1960) studied the Ely Limestone to the north and east of the Mountain Home Range area and noted far less dolomite in those sections, along with an abundance of deposits normally considered to be basin accumulations, such as shale and thinly laminated mudstone, which are lacking in sections analyzed here.

Although most of the nineteen rock types appear to be irregularly distributed vertically, on an individual basis a few show distinct vertical distribution patterns that are part of a complex series of cycles. The maximum number of successive exposed units that are of the same textural type is two. In general, transitional forms are stratigraphically associated with each other.

All the exposed dolomite units of D1, D2, and D3 types are present, with one exception, between 623 to 756 m above the base of the section. This interval overlaps the Pennsylvanian-Permian boundary and is distinctive in the field (fig. 39). As determined from the three sections measured for this study, this interval thickens southward. The northern section contains 91.5 m, the central section 127 m, and the southern section 153 m. Little or no dolomite was reported from equivalent Ely Limestone and overlying Wolfcampian strata in nearby ranges to the northwest and north (Bissell 1964a; Dott 1955, 1958; Hose and Repenning 1959). The increase in thickness to the south in the Mountain Home Range agrees with the paleoreconstruction of Stevens (1979), who postulated that during the Lower Permian, an east-west-trending land mass, which he called the Deep Creek-Tintic Uplift, was exposed approximately 60 km north of the Mountain Home Range. He indicated that the area south of this positive feature was a shallow shelf that deepened gradually southward.

Wackestone rocks are commonly associated with each other vertically and laterally. All W5 units occur within the lowest 365 m of section 2. Packstone units are also commonly associated with wackestone units.

P12 and P14 rocks are most common in the Wolfcampian part of the sequence. P12 units occur ten times in the vertical sequence between 683 and 829 m above the base of section 2, but only three times in the entire sequence below 683 m.

Grainstones are most common below 488 m above the base of section 2, with G19 rocks occurring in only one 2-m interval between 191 and 193 m above the base. *Komia* grainstones, G16, are the exception, for they occur in a narrow vertical position between 570 and 573 m above the base. *Komia* fragments occur in wackestone units directly above and below this interval. Both G19- and G16-appearing rocks have been described from the Pennsylvanian-Permian strata of other parts of the Great Basin (Rich 1969).

Correlation of sections measured for this study is difficult because of rapid vertical and lateral facies changes (fig. 39). For example, *Chaetetes* occurs in one unit of section 1, and in three units of section 2. Sections 1 and 3 are also faulted, and total displacement of the rocks is not known.

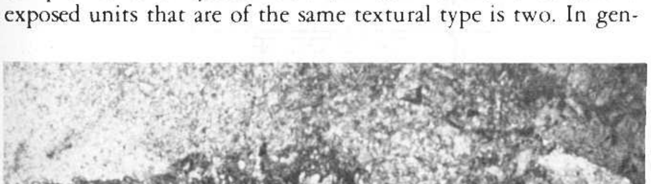

FIGURE 33.—Photomicrograph of limestone (L), dolomite (D), and chert (C) interface. Unit 48, 213.9 m above base of section 2, X5.

FIGURE 34.—Photomicrograph of partially silicified fusulinid. Unit 222, 758.0 m above base of section 2, X10.

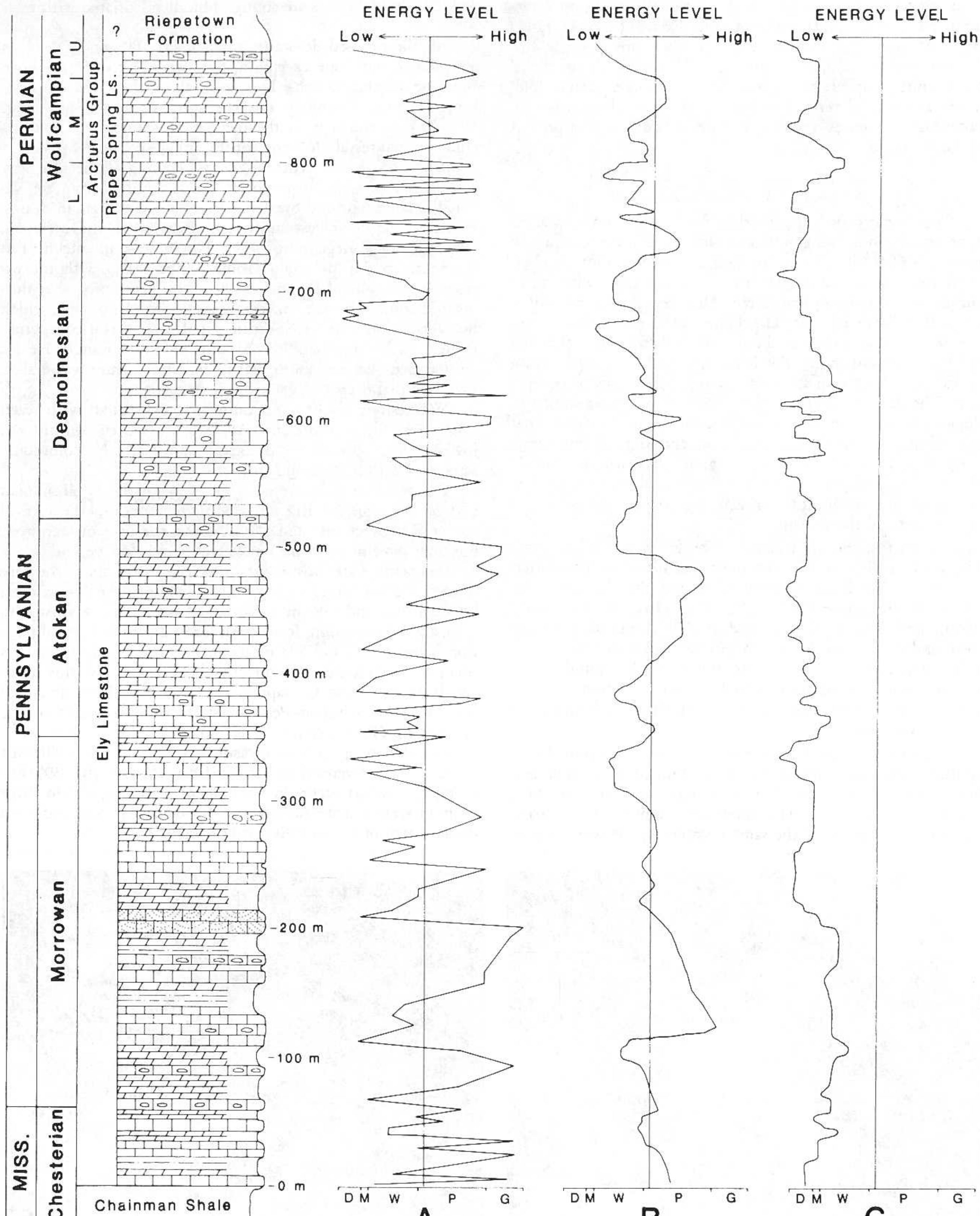

FIGURE 35.–Stratigraphic section of measured section 2, Ely Limestone and Riepe Spring Limestone, and energy plots. Curve A, plot of energy level of exposed units versus stratigraphic position. Curve B, moving average with period of 5 of curve A. Curve C, moving average with period of 10 of curve A, plus a synthetic low-energy data point for each covered interval. D = dolomite, M = mudstone, W = wackestone, P = packstone, G = grainstone.

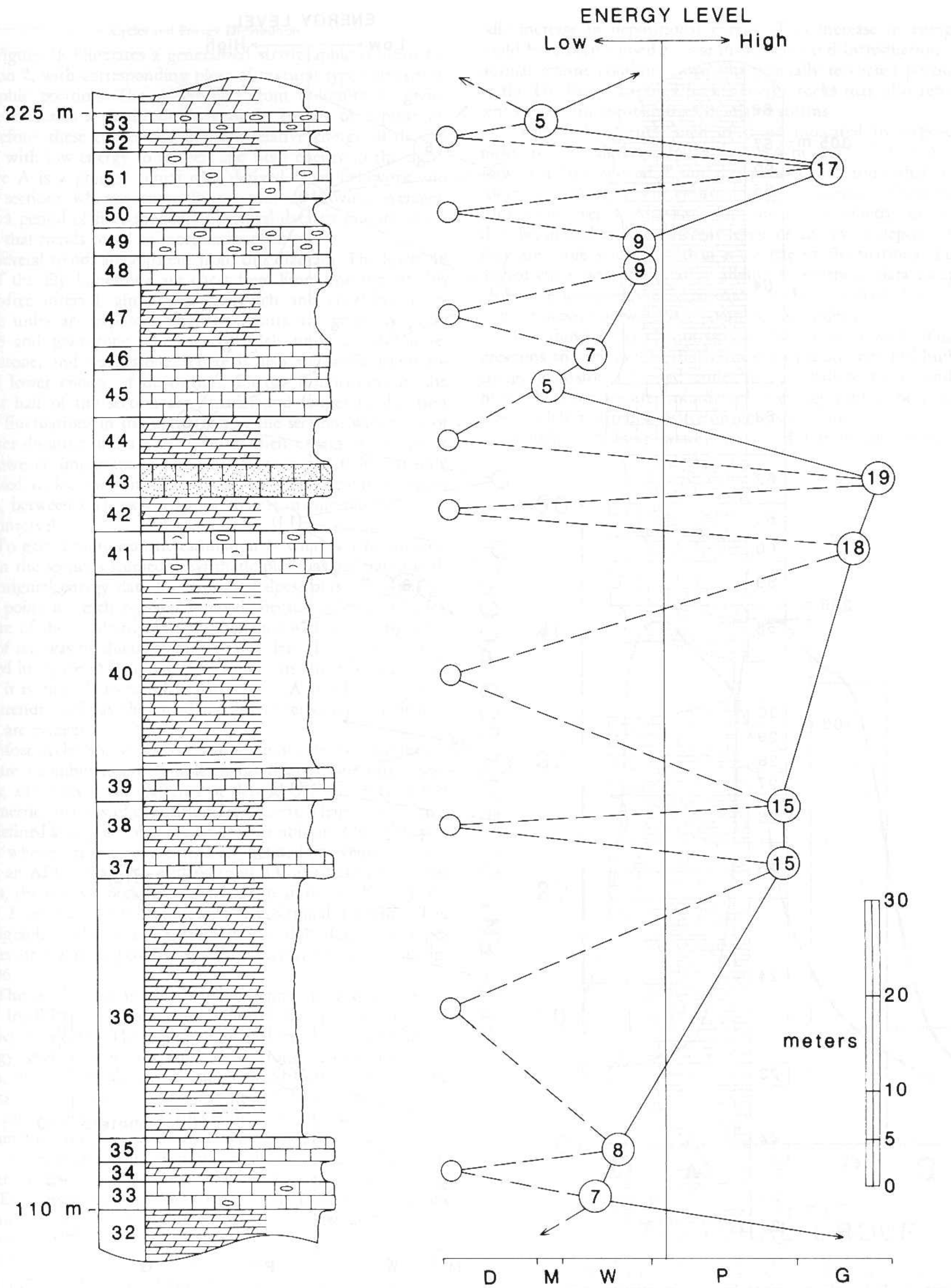

FIGURE 36.–Hemicyclic patterns of deposition as expressed in part of measured section 2, Ely Limestone. Solid line connects actual data from exposed ledges; dashed line illustrates pattern with a synthetic low-energy point added for each covered interval. D = dolomite, M = mudstone, W = wackestone, P = packstone, and G = grainstone.

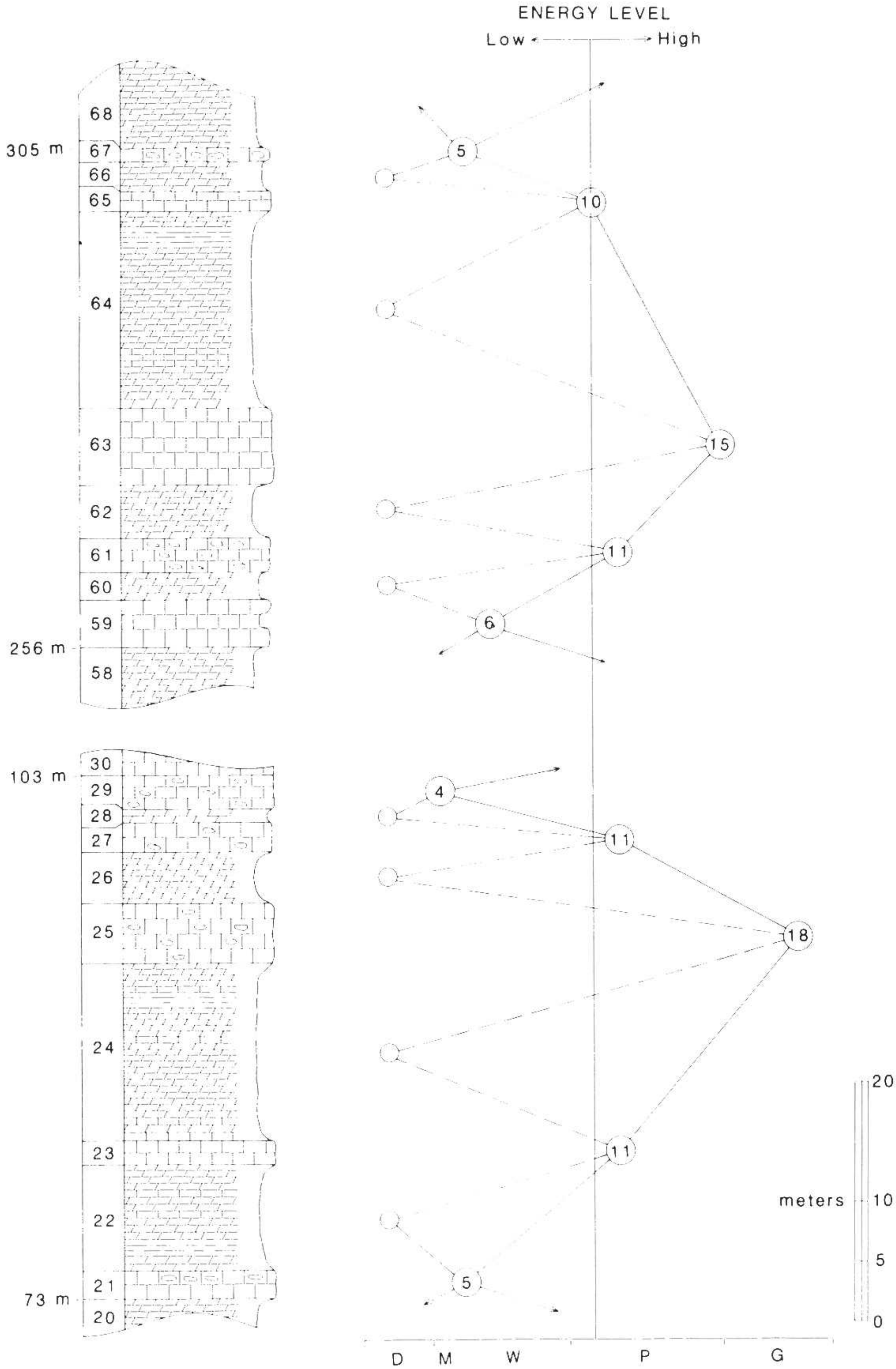

FIGURE 37.–Truly cyclic patterns of deposition as expressed in part of measured section 2, Ely Limestone. Solid line connects actual data from exposed ledges; dashed line illustrates pattern with a synthetic low energy point added for each covered interval. D = dolomite, M = mudstone, W = wackestone, P = packstone, G = grainstone.

Cycles and Energy Distribution

Figure 35 illustrates a generalized stratigraphic column for section 2, with corresponding plots of textural type versus stratigraphic position. The progression from dolomite to grainstone indicates a significant increase in energy of deposition. Therefore, these curves also indicate relative energy of deposition, with low energy to the left and high energy to the right. Curve A is a plot of actual data derived from fieldwork and thin sections whereas curve B is a plot of moving averages, with a period of five, applied to textural data to smooth curve A so that trends could be more easily seen.

Several trends are apparent from this diagram. The lower 48 m of the Ely Limestone are chert free. From the top of this chert-free interval, alternating chert-rich and chert-free limestone units are exposed. Chert-free units are generally packstone and grainstone whereas chert-rich units are dolomite, mudstone, and wackestone. There is also a distinct trend toward lower energy of deposition. Energy fluctuations in the lower half of the section are broader and longer in duration than fluctuations in the upper half of the section, which are of shorter duration and are narrower in their energy spectrum. It is, however, important to note that these curves represent only exposed rocks, and that there is a low-energy event, in most cases, between each exposed unit that is manifested by a covered interval.

To gain a more realistic estimation of what is actually present in the sections studied, a synthetic plot was generated with the original energy data for exposed ledges, plus a low-energy data point for each covered interval. Because of the complex nature of the resultant plot, another plot with a moving average of ten was produced from the same data. This plot is represented in figure 35 by curve C. Because this curve is so generalized, it is difficult to correlate it to curves A and B; however, a few trends, such as the trend toward lower energy of deposition, are evident.

Most cycles shown by the various plots are not symmetric and are a combination of simple energy fluctuations with hemicyclic and truly cyclic patterns of deposition. However, a few symmetric patterns of deposition are present. Hemicyclic events are defined as depositional events that exhibit an ABCABC pattern, whereas truly cyclic events are defined as events that exhibit an ABCBA pattern of deposition. On the basis of exposed rocks, the interval between 110 to 225 m above the base of section 2 represents two hemicyclic depositional patterns. The stratigraphic column and corresponding plot of textural types versus stratigraphic position for this interval are shown in figure 36.

The solid curve in this diagram represents actual textural data from exposed units and indicates the presence of two hemicyclic events. The first is indicated by the progression in energy level from wackestone to packstone to grainstone textures, then a sharp decline in energy of deposition. This decline marks the beginning of the next hemicyclic pattern. The second pattern begins with a wackestone texture and proceeds to a grainstone texture. Both events were produced by a relatively slow increase and rapid decrease in depositional energy. This pattern is also present in most other hemicyclic events within the Ely Limestone and the Riepe Spring Limestone. The remaining hemicyclic patterns of deposition are not as well defined.

The dashed line is an estimation of energy fluctuations with a postulated low-energy unit for covered intervals. This dashed curve indicates a low-energy environment of mainly dolomite deposition with a hemicyclic overprint caused by periodic increase in depositional energy. This increase in energy could have been caused by rise in sea level and introduction of normal marine condition into this generally restricted portion of the Ely Basin. Exposed higher-energy rocks may also represent short-term events caused by major storms.

Truly cyclic events, such as those indicated by exposed rocks in intervals between 73 to 103.6 m and 256 to 305 m above the base section 2, are also present, but somewhat less common than hemicyclic events. Figure 37 illustrates these two truly cyclic events. Although they are not symmetric in that they begin and end at different levels of energy of deposition, they are more symmetric than most energy fluctuations. The dashed curve was produced by adding in synthetic data to approximate low-energy covered intervals. It is evident that patterns of deposition were very complex, but ordered.

The above cycles cannot be directly correlated with transgressions and regressions. Both low-energy dolomites and high-energy grainstones formed under similar shallow-water conditions, therefore a shift toward higher energy cannot be interpreted solely as a transgressive or regressive event.

Widely correlative cyclothems could not be identified in

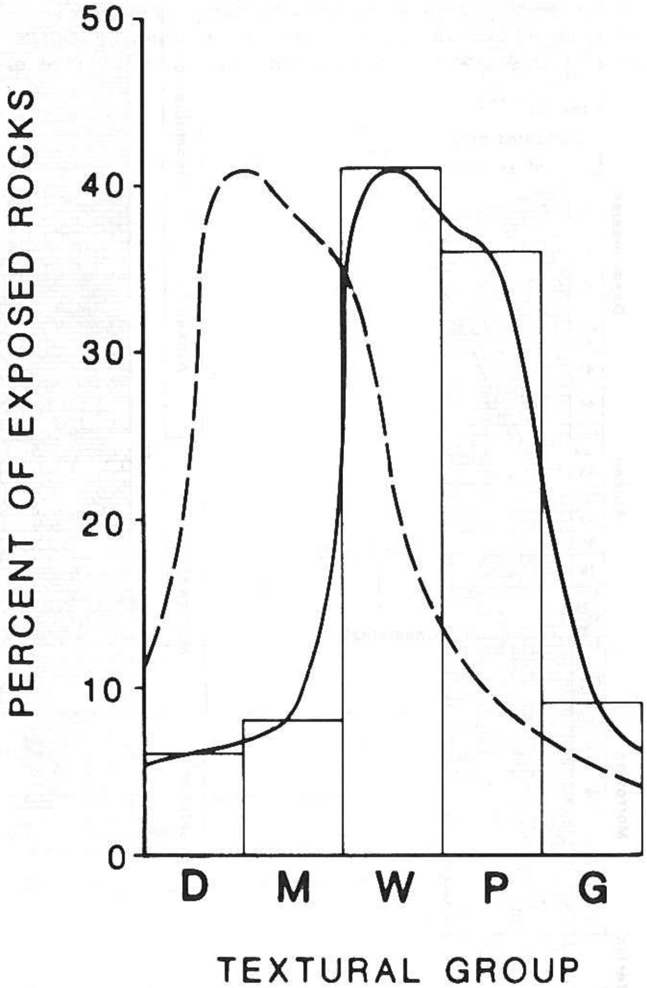

FIGURE 38.–Frequency histogram of textural groups, D = dolomite, M = mudstone, W = wackestone, P = packstone, and G = grainstone. Solid line represents distribution of exposed ledges; dashed line is an estimate of exposed plus covered intervals. D = dolomite, M = mudstone, W = wackestone, P = packstone, G = grainstone.

rocks of the Ely Limestone and the Riepe Spring Limestone, in contrast to Pennsylvanian rocks of the midcontinent region. Cycles present in the Ely Limestone and the Riepe Spring Limestone in southwestern Utah are more subtle, occur on a smaller scale, and are more variable laterally than true cyclothems. Dott (1958) came to similar conclusions about the Ely Limestone in east central Nevada although lithologically the Ely Limestone is very different in that area.

DEPOSITIONAL SUMMARY

Sections studied in the southwestern Millard County, Utah, area represent accumulations in a restricted portion of the Ely Basin that was partially isolated from normal marine conditions (fig. 40). Dolomite, mudstone, and spiculiferous wackestone rocks of the Ely Limestone and the Riepe Spring Limestone were deposited in a restricted near-shore environment. This environment of deposition is indicated by the presence of a limited euryhaline fossil assemblage, minor evaporite minerals, and abundant detrital quartzose silt in these rocks. In addition, many of the dolomite units exhibit crystalline textures that suggest penecontemporaneous alteration of high magnesium carbonate to dolomite. Rocks of these textural types are by far the most abundant types present in the sections studied. They are commonly represented in the field as covered slopes, from

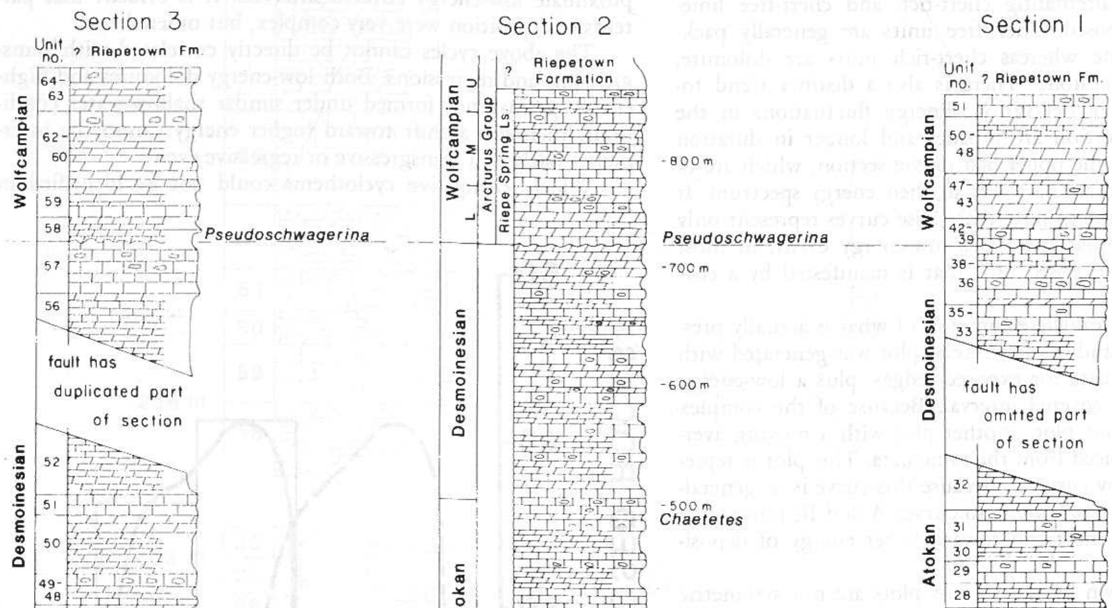

FIGURE 39.–Correlation of Ely Limestone and Riepe Spring Limestone, southwestern Millard County, Utah. Detailed location of stratigraphic sections shown in figure 4.

which ledges of wackestone, packstone, and grainstone protrude.

Packstone, grainstone, and the majority of the wackestone rocks were deposited under normal marine conditions. This conclusion is supported by the textures and fabrics these rocks exhibit, along with the presence of diverse stenohaline marine fossil assemblages. These rocks represent normal carbonate shelf to shoal water accumulations.

Grainstone rocks, which were formed under the highest energy of deposition, probably accumulated near the tops of small linear carbonate shoals oriented parallel to the shore (fig. 40). Sorting, rounding, and lamination of grains would decrease in the rocks formed in deeper waters along the sides of the shoals; however, they would still be subject to rather high energy of deposition. A progression from grainstone to packstone textures would prevail under these conditions. As depth increased along the sides of the shoals, energy would decrease, and the resultant rocks would contain wackestone textures. Wackestone rocks were probably deposited along the base of the shoals and basinward from them. Grain content would decrease as depth, and therefore energy, decreased. The maximum depth of deposition represented by the rocks studied here probably was still relatively shallow, however, for algal material in all facies indicates deposition in shallow, clear waters.

Cyclic changes dominated deposition of the Ely Limestone and the Riepe Spring Limestone in the Mountain Home Range area. Cyclic increases, followed by rapid decreases in depositional energy, produced an overprint of normal marine carbonate wackestone, packstone, and grainstone textures in the dominately restricted environment of dolomites and mudstones (fig. 40). A few cycles are patterned but most represent simple energy fluctuations. These cycles could have been controlled by several factors, including short-term major storms or fluctuating sea levels.

PALEONTOLOGY

Very few whole body-fossils were found in the Ely Limestone and the Riepe Spring Limestone of the Mountain Home Range area. The bulk of fossil material in the rocks is preserved as fragments, except for several small relatively rare forms which were identified in thin section. With minor exceptions, all recognizable whole-body megafossils recovered were found in the dolomite, mudstone, and wackestone units, with the latter containing the most diverse and abundant varieties.

Algae are ubiquitous in all facies, but are especially numerous in *Komia* grainstone (G16) and algal packstone (P10) rocks (figs. 21, 27). Recognizable algae include *Tubiphytes, Osagia,* and *Komia.* Of these three genera, both *Tubiphytes* and *Komia* are of uncertain biologic affinity.

Tubiphytes is considered a blue-green algae by most authors, including Croneis and Toomey (1965, p. 10) and Flügel (1982, p. 351). *Tubiphytes* fragments occur in great abundance in some

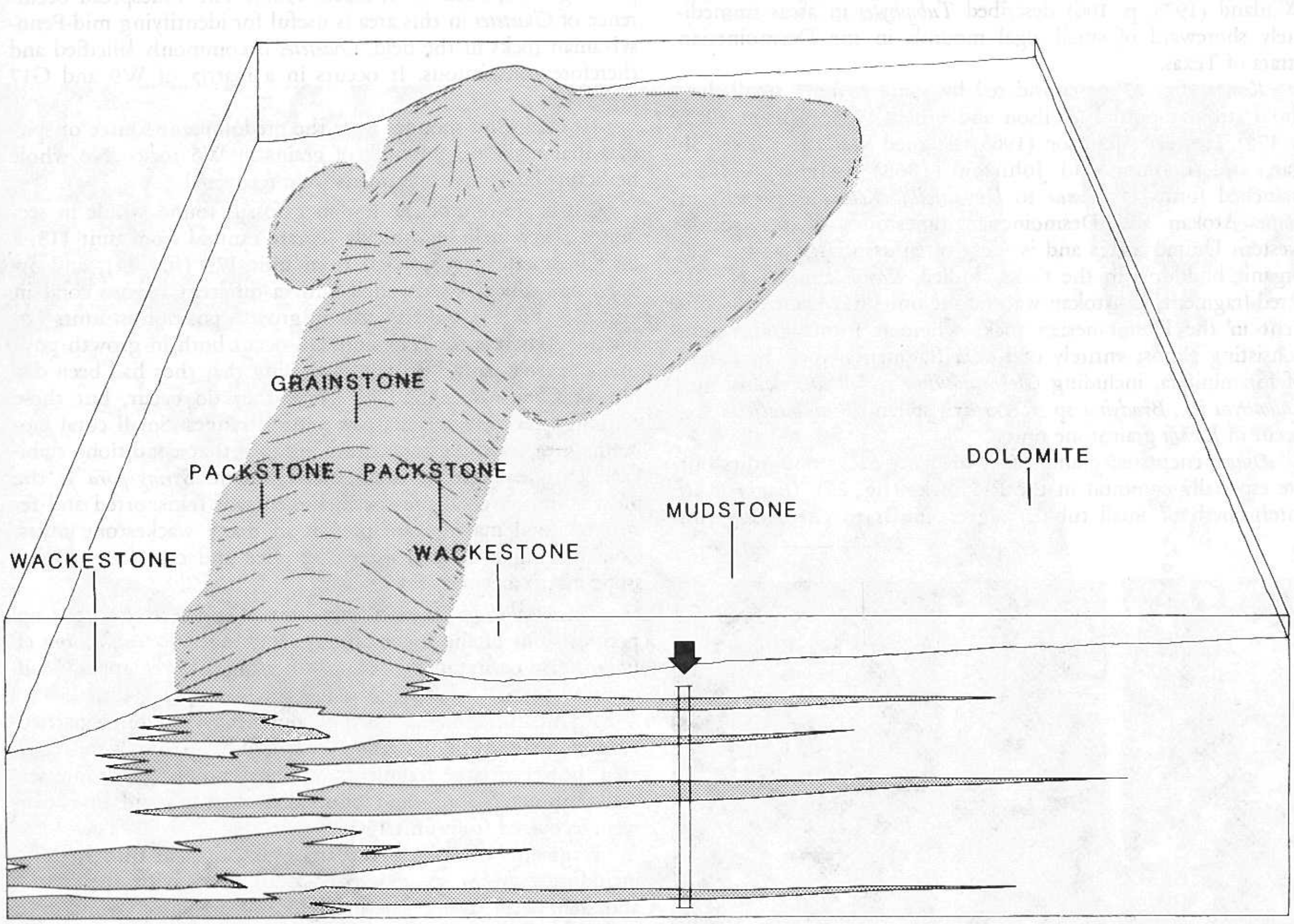

FIGURE 40.–Depositional model of the Ely Limestone and the Riepe Spring Limestone in the Mountain Home area. Shaded area represents high-energy environments of deposition; other areas are regions of low energy. Arrow points to a diagrammatic representation of approximately 30 m of a typical measured section reported here. Great vertical exaggeration; diagram not to scale.

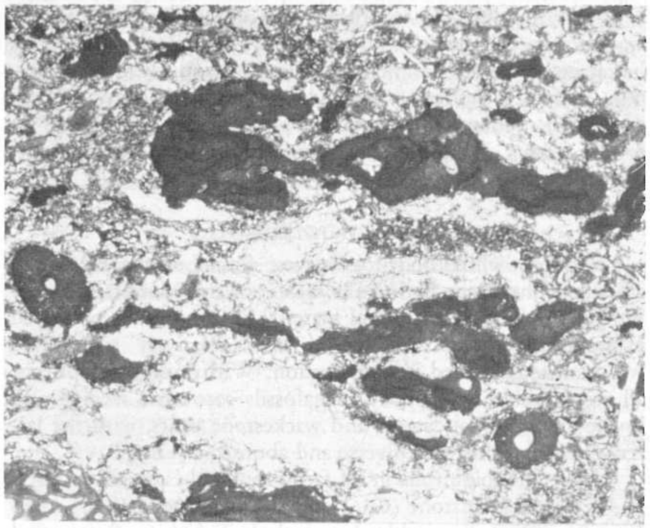

FIGURE 41.–Photomicrograph of dark *Tubiphytes* sp. from unit 205, 731.5 m above base of section 2, X10.

packstone units (fig. 41) and act as nuclei for the encrusting *Osagia* organisms. *Tubiphytes* is most often reported in upper Paleozoic reefoidal and mound environments. Toomey and Winland (1973, p. 106) described *Tubiphytes* in areas immediately shoreward of small algal mounds in the Desmoinesian strata of Texas.

Komia (fig. 27) is considered by some to be a small dendroid stromatoporoid (Wilson and others 1963; Wilson 1975, p. 173). However, Johnson (1963) assigned *Komia* to the red algae, and Toomey and Johnson (1968) assigned certain branched forms of *Komia* to *Ungdarella*. *Komia* is present in some Atokan and Desmoinesian limestones of the southwestern United States and is most often associated with small organic buildups. In the rocks studied, *Komia* appears as scattered fragments in Atokan wackestone units but is most prominent in the Desmoinesian rocks where it forms grainstones consisting almost entirely of *Komia* fragments. A wide variety of foraminifera, including *Globovalvulina* sp., *Wedekinellina* sp., *Endothyra* sp., *Bradyina* sp., *Tetrataxis* sp. and *Pseudostaffella* sp., occur in *Komia* grainstone units.

Osagia-encrusted grains occur in many packstone units but are especially common in the P15 rocks (fig. 26). *Osagia* is an intergrowth of small tubular algae, similar to *Girvanella*, and

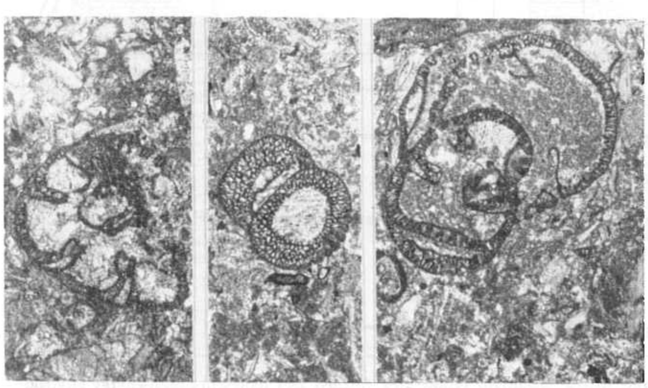

FIGURE 42.–Photomicrographs of several views of *Bradyina* sp. from unit 57, 254.2 m above base of section 2, X10.

the encrusting foraminifer *Nubecularia* (Johnson 1963, p. 134). The nuclei of these grains are skeletal fragments of mollusks, *Tubiphytes*, and other organic grains, although quartz grains are also centers of encrustation.

With the exception of the above forms, algae are very poorly preserved and in most cases of uncertain affinity. Algae which fall into this category include several encrusting forms and probable phylloid algal plates.

Foraminifera are abundant in wackestone rocks of the Ely Limestone and the Riepe Spring Limestone. Several mobile foraminifera, including large, inflated species of *Bradyina* (fig. 42) and *Globovalvulina*, are common. The encrusting foraminifer *Tetrataxis* is also present in many thin sections. Toomey and Winland (1973) listed all these forms as important foraminifera associated with Desmoinesian algal buildups in Texas. Many other unidentified calcareous foraminifera are also present. Fusulinid and endothyrid forms are abundant in wackestone and some packstone units (fig. 25). Figure 7 lists identified foraminifera and their stratigraphic distributions in section 2. Several new fusulinids were recognized by Dr. Charles Ross in thin sections of these rocks.

Chaetetes, the "hair coral" which may be a sclerosponge, is common in Atokan strata of the southwestern Millard County area (fig. 43), where it commonly occurs with several species of *Profusulinella*. *Chaetetes* is characteristic of Atokan rocks in the eastern Great Basin (Bissell 1964, Coogan 1964, Hose and Repenning 1954, Rich 1960, Steele 1960). The widespread occurrence of *Chaetetes* in this area is useful for identifying mid-Pennsylvanian rocks in the field. *Chaetetes* is commonly silicified and therefore conspicuous. It occurs in a matrix of W9 and G17 type rocks.

Hexactinellid sponges were the predominant source of spicules that make up the bulk of grains in W5 rocks. No whole hexactinellid sponge specimens were recovered.

Corals are one of the few megafossils found whole in section 2. They include a thickly septate caninid from unit 113, a thickly septate rugose coral from unit 179 (fig. 44), and *Syringopora*, which is associated with a different rugose coral in unit 183 (fig. 45). Corals occur in growth position in units 179 and 183, whereas those in unit 113 occur both in growth position and irregularly oriented, indicating that they had been disturbed. Corals are abundant where they do occur, but these communities have very narrow vertical ranges. Small coral bioherms in a few limestone units indicate that conditions stabilized long enough to allow their growth. *Syringopora* is the most common coral present. Fragments of transported and reworked coral material are present in many wackestone units. Coral-bearing units are often chert free and contain a wackestone matrix between fossils.

Thysanophyllum sp. occurs in unit 242 of section 2, the uppermost unit of the Riepe Spring Limestone. *Eoparafusulina* cf. *linearis* also occurs in this unit, indicating a lower upper Wolfcampian age.

Bryozoan fragments are very common in section 2, particularly in Desmoinesian strata. No whole bryozoans were recovered; however, large fragments of a stenoporid trepostome several centimeters long, and of smaller rhomboporid bryozoans were recovered from unit 150.

Fragments of many bryozoans were noted in thin sections, including *Polypora* sp., *Fenestrellina* sp. along with fistuliporid and stenoporid forms. Encrusting forms are most common in rocks formed in higher-energy environments, where they encrust fragments of organic grains.

Brachiopods are most abundant as shell fragments and spine material, with punctate, impunctate, and pseudopunctate forms represented. Several whole or large partial fragments of spiriferid, productid (fig. 46), and derbyid shells were recovered. *Composita* sp. and *Derbya?* sp. were also recovered. Larger specimens were occasionally found scattered in wackestone units. However, brachiopod hash is an important constituent of wackestone units and of some packstone and grainstone units as well. Lack of whole-body specimens and abundance of fragments indicate relatively few brachiopods inhabited the area during deposition of the rocks.

Whole gastropods were recovered from several dolomite units of section 2, including *Amphiscapha* sp. from unit 169 (fig. 15) and a high-spired gastropod from unit 141 (fig. 16). Dolomite units often contain impressions of large gastropods now filled with calcite crystals. Other fragments of mollusks, including bivalves, are rare, even in thin section. A piece of a scaphopod was recovered from unit 158.

Echinoderm fragments are abundant in thin section and are especially plentiful in wackestone and some packstone and grainstone rocks. Type P12 rocks are composed almost entirely of echinoderm fragments, which are generally badly abraded and cannot be classified further, although echinoid spines are present in many rocks. No whole echinoderm fossils were recovered.

Trilobite fragments are common in wackestone rocks, and ostracodes are important in dolomite, mudstone, and some wackestone units. No whole arthropods were recovered.

Ichnology

Two basic types of trace fossils are present in the Ely Limestone and the Riepe Spring Limestone, and are locally abundant. Horizontal burrows are common in lower Wolfcampian dolomite units, in the interval from 744 m to 757 m above the base of section 2. These burrows are small, 1 to 2 mm in diameter and represent pascichnid grazing traces of unknown organ-

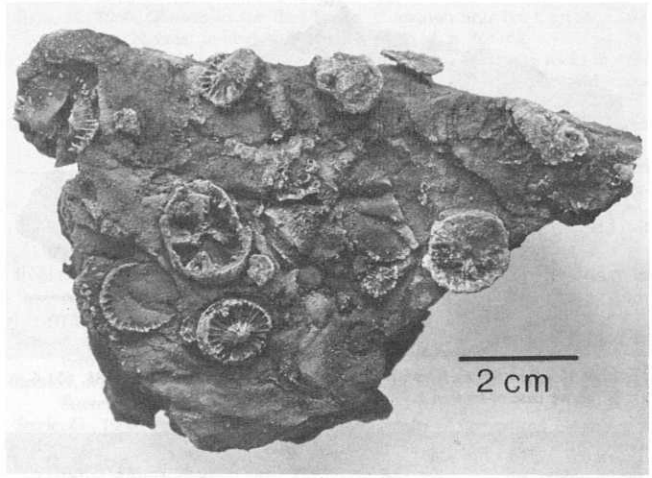

FIGURE 44.—Rugose corals from unit 179, mostly in growth position, 642.8 m above base of section 2.

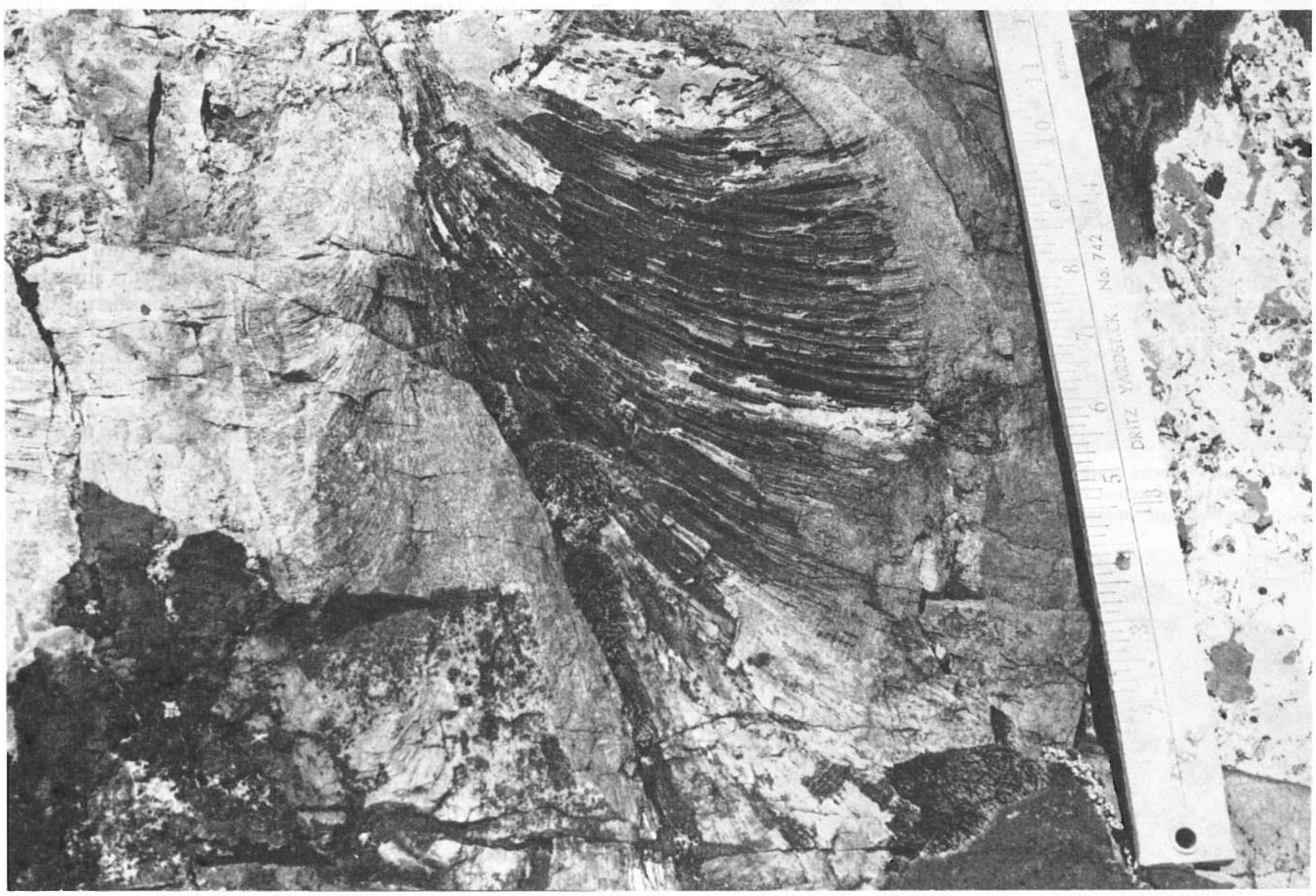

FIGURE 43.—*Chaetetes* as seen in outcrop in unit 72, 331.6 m above the base of section 2.

isms. Burrows are also common in thin sections from this interval, where they are collapsed and are infilled with micritic material.

Modern trace fossils from littorial and sublittorial carbonates (Kennedy 1975, p. 388) are predominantly small horizontal burrows like these and suggest that these Permo-Carboniferous rocks fall within the *Cruziana* facies (Kennedy 1975, p. 338).

The second variety of trace fossil present is a repichnid trace, which is 1 to 2 cm in diameter (fig. 47). This trace was probably made by a gastropod or arthropod and was located on the top bedding surface of unit 198, a lower Wolfcampian fusulinid packstone.

Chert often appears as though it has replaced larger, vertical burrows. The mottled nature of some limestone units may be the result of bioturbation. Thin sections occasionally show evidences of bioturbation. The limited number of trace fossils does indicate that the responsible organisms were relatively restricted.

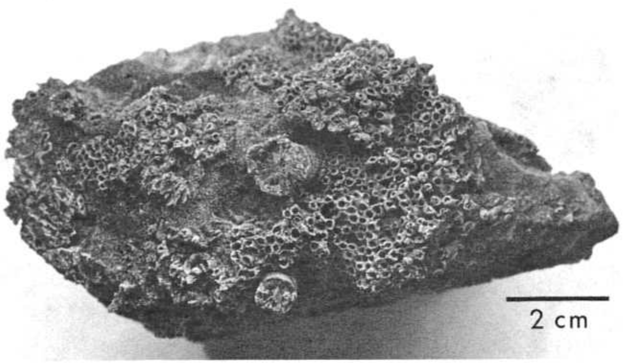

FIGURE 45.–*Syringopora* sp. with attached rugose corals from unit 183, 651.6 m above base of section 2.

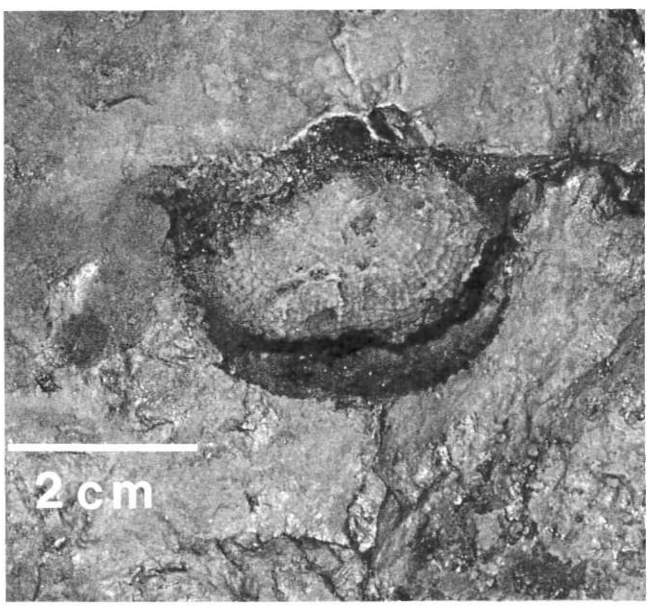

FIGURE 46.–Productid brachiopod from float of concealed unit 98, 420.0 m above base of section 2. Pseudopunctate brachiopod fragments are a common occurrence in many wackestone, packstone, and grainstone rocks.

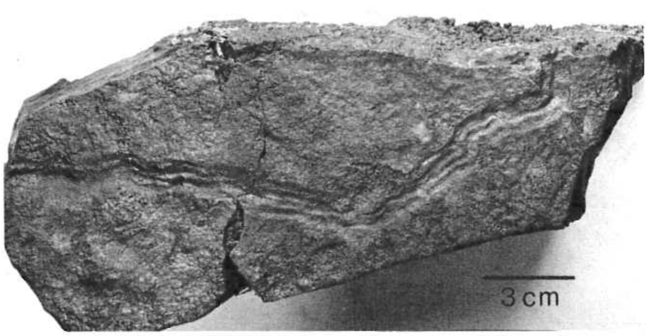

FIGURE 47.–Repichnid trace fossil from the top of unit 198, 712 m above base of section 2.

PALEOECOLOGY

Two basic fossil assemblages are preserved in the rocks of the Ely Limestone and the Riepe Spring Limestone in this area. The relatively nontransported, biocoenosic assemblage of ostracodes, algae, and gastropods is found in dolomite and mudstone units. Judging from distributions elsewhere (Flügel 1982, p. 472), this assemblage represents a group of organisms especially tolerant of high marine salinities, and therefore they probably accumulated in restricted environments.

The second assemblage is a transported thanatocoenosic group of echinoderms, bryozoans, algae, foraminifera, brachiopods, mollusks, and corals. These organisms thrived under conditions of normal marine salinity. This assemblage is found only in the limestone units.

Algal material is present in rocks of all textural groups and is an important constituent of both fossil assemblages. The presence of algae indicates deposition in clear, shallow seas within the photic zone. Their ubiquitous nature indicates that Chesterian, Morrowan, Desmoinesian, and Wolfcampian rocks of the area studied were deposited in a very shallow part of the Ely Basin, most likely on the eastern margin.

A few units do contain biocoenosic assemblages of corals. These colonies did not produce large topographic features in the Ely Basin, for populations extend only a few decimeters vertically and were relatively short lived. Of these, unit 183 of section 2 is particularly interesting. Unit 183 contains abundant *Syringopora* and rugose corals which lived in a commensualistic relationship (fig. 45). The rugose corals are attached to the *Syringopora* colonies and probably relied on them to provide a firm substrate upon which to grow. Several units of Atokan strata contain *Chaetetes* in growth position.

The paleoecologic aspects of other interesting units, such as the brachiopod-bryozoan packstone rocks, are discussed in the description of carbonate textural types.

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