Kansas-type cyclothems and porosity development in the Middle Pennsylvanian Marmaton Group, Dirks field, Logan County, Kansas

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Abstract

Seven facies are recognized in core from the upper part of the Middle Pennsylvanian (Desmoinesian) Marmaton Group, Texaco Dirks # 2 well, Dirks field, Logan County, Kansas. These facies make up two Kansas-type cyclothems, the Altamont and Lenapah, and record deposition in response to fluctuating sea level and varying terrigenous influx on the broad, epeiric shelf that was the northern extension of the Hugoton embayment. The facies correspond to Heckel's (1977) basic, Kansas-type, cyclothem members, i.e., (transgressive) middle limestone, (transgressive) core shale, (regressive) upper limestone, and (regressive) outside shale. The Altamont cyclothem lacks the core shale and perhaps the middle limestone. The overlying Lenapah cyclothem contains all of the basic members of Heckel's Kansas-type cyclothem.

Porosity development in the Altamont and Lenapah cyclothems of the Dirks # 2 is restricted to the upper limestone members. The upper limestone of the Lenapah cyclothem, the Idenbro Limestone Member, contains intergranular and moldic (principally oomoldic) porosity. Portions of this regressive limestone are weakly oil stained, and porosity is poor to locally fair. The upper limestone member of the Altamont cyclothem, the Worland Limestone Member, is strongly oil stained and is a pay in this well and in the study area. The Worland Limestone displays intergranular, moldic, solution-enlarged moldic, vuggy, and fracture porosity. Porosity and permeability are fair to locally good and are thought to be primarily the result of meteoric diagenesis perhaps associated with a subtle topographic high on the seafloor during deposition of the Altamont Limestone. A cross section through the study area indicates a slight thinning of strata overlying the Altamont Limestone in wells where porosity in the Worland is well developed and the Worland Limestone is a producing oil reservoir. This thinning may indicate an ancient Altamont high.

Introduction

Core 4 of the Texaco Dirks # 2, Dirks field, Logan County, Kansas, is 45.5 ft (13.9 m) in length (subsurface depth 4,374–4,419.5 ft) and from the upper part of the Middle Pennsylvanian (Desmoinesian) Marmaton Group. The core primarily is composed of cyclically deposited limestone, shale, and dolomitic limestone of the Bandera Shale, Altamont Limestone, Nowata Shale, Lenapah Limestone, and Holdenville Shale (fig. 1). Detailed core study and subsurface mapping using wireline logs provide information about the depositional environments and porosity development in the Altamont Limestone, the reservoir in the Dirks and adjoining Miller fields. These fields are situated on a northern extension of the Hugoton embayment (fig. 2). The first production from these fields was in May 1981. Combined lifetime production from the five producing wells in the two fields was 35,085 bbls of oil as of May 1983, with production for May 1983 being 898 bbls of oil and 1,887 bbls of water (1,457 bbls of water were from a single well).

Pennsylvanian cyclic sedimentation of the Midcontinent

Much of the Pennsylvanian and Permian of Kansas is characterized by an alternation of laterally persistent shale, sandy shale, and limestone, reflecting cyclic sedimentation on a broad, epeiric shelf. Moore (1929, 1936, 1949) was one of the first to apply cyclical sedimentation patterns to understanding these sequences. He regarded couplets of successive shale and limestone members as cyclothems.

Heckel (1977) defined the basic, vertical, cyclic pattern which characterizes the Missourian part of the Upper Pennsylvanian in eastern Kansas. In ascending order it is: outside shale member, middle limestone member, core shale member, upper limestone member, and outside shale member (fig. 3). This basic sequence he termed a Kansas-type cyclothem. Moore's (1936, 1949) restricted usage of the term cyclothem to a shale-limestone couplet was abandoned by Heckel, as it is here. Watney (1980), in his study of the Upper Pennsylvanian Lansing–Kansas City Groups in northwestern Kansas and southwestern Nebraska, referred to these units respectively as: upper shale, lower carbonate, lower shale, upper carbonate, and upper shale (table 1).

The vertical pattern or sequence defined by Heckel and Watney is explained most simply, they suggested, by a single transgression and regression of the sea with deepest water (maximum transgression) during deposition of the core shale (fig. 3). The middle limestone was deposited during the transgressive phase. The upper limestone and most of the outside shale were deposited during the regressive phase. The upper part of the outside shale can be transgressive recording the initial stages of deposition of the overlying cyclothem. Heckel stated that the sedimentary record of the marine transgression is typically very thin

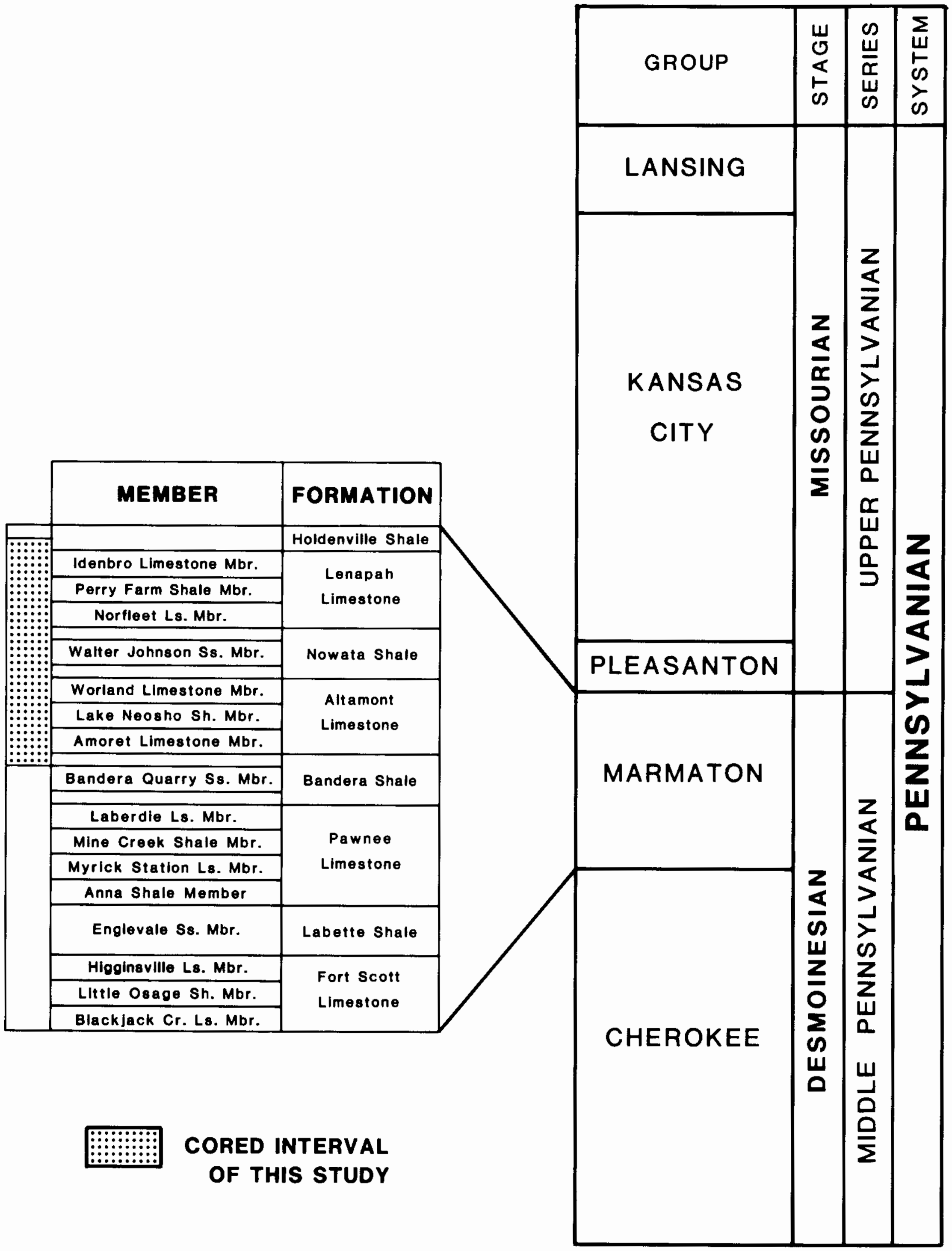

FIGURE 1—Pennsylvanian/Desmoinesian–Missourian stratigraphy of Kansas (from Zeller, 1968).

because of the progressive stranding of detrital influx farther away at the shoreline (in the case of northwestern Kansas to the north [Watney, 1980]) and the difficulty of generating carbonate material during rapidly deepening water.

Depositional facies of the Dirks # 2 core

Twenty-one lithologic units, organized into seven depositional facies, have been recognized in core from the Dirks

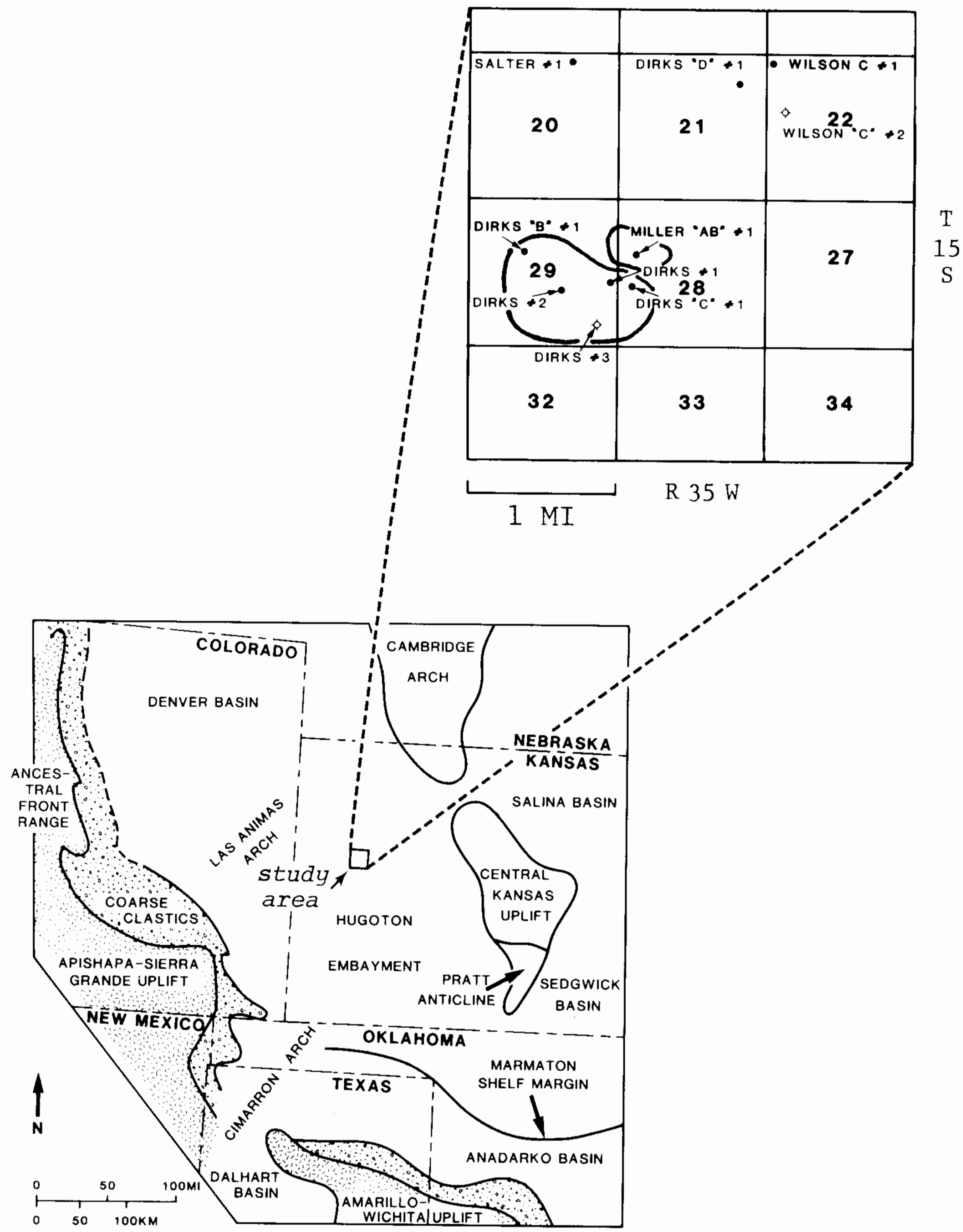

FIGURE 2—Desmoinesian–Missourian paleogeographic map of western Kansas and adjacent areas (after Watney, 1980) and detailed inset of study area (Dirks and Miller fields outlined). Marmaton shelf margin, defining the northern limit of the Anadarko Basin, is based on a gross change in lithology from a shelf limestone facies (> ⅔ limestone) to a basin shale facies (< ⅓ limestone) as mapped by Rascoe (1962).

2 (fig. 4; on sheet 3 in back pocket). Each of these facies corresponds to a member of Heckel's basic Kansas-type cyclothem. Description of these facies is given below, followed by a discussion of the position of each facies in the cyclothem model. Unless specified, Heckel's terminology will be used in this report.

Facies I

Facies I (units 1–3) includes greenish-gray, unfossiliferous siltstone (units 1 and 2) and olive-gray, sparsely fossiliferous shale (unit 3). The massive to mottled nature of the siltstone may indicate burrowing or plant-root action (plate 1A). The siltstone, with local carbonate nodules, suggests deposition in a shallow nearshore/marginal-marine or terrestrial (e.g., brackish marsh) environment. The shale records deposition in quieter, slightly deeper, marine waters. Olive-gray shale of the upper 0.5 ft (0.15 m) of this facies grades upward into interbedded shale and limestone of facies II.

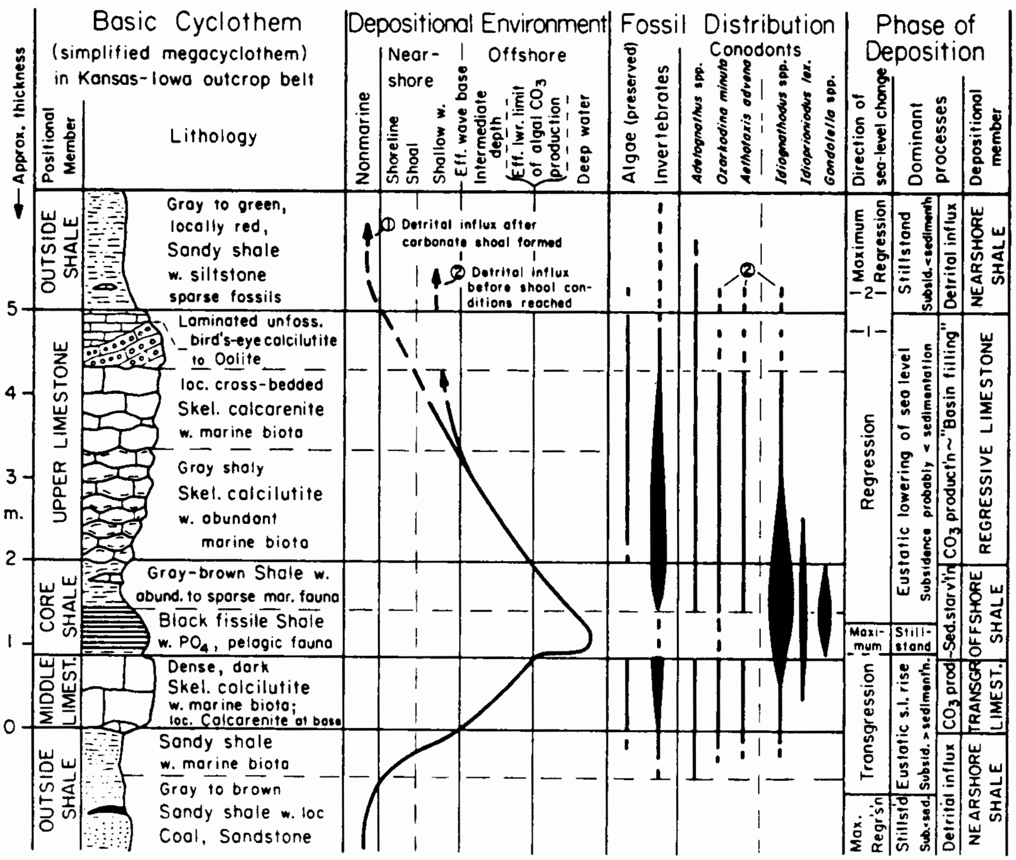

FIGURE 3—Basic Upper Pennsylvanian Kansas-type cyclothem sequence (from Heckel, 1977).

TABLE 1—Lithologies, diagenesis, and depositional environments of Kansas-type cyclothem facies, Lansing and Kansas City Groups, northwest Kansas (from Watney, 1980). S—sharp contact G—gradational contact

Heckel's members	Watney's facies	Thickness (ft)	Lithology	Diagenetic alternation	Facies contacts	Genetic facies	Depositional environment
outside shale	upper shale	<5–30	red-brown, unbedded silty shale	intense		regressive shale	oxidized, continental clastics
					S		
upper limestone	upper carbonate	<1–15 (upper)	lime-mudstone to grainstone common; occasionally dolomitic; sparse to very fossiliferous	moderate to intense		regressive carbonate	shallow, clear-water carbonate; tidal flat, lagoon, and open marine; high and low energy
		(lower)	lime-mudstone or wackestone, argillaceous at bottom; fossiliferous				subtidal, low energy, clear-water, open-marine carbonate grading downward to mixed turbid argillaceous carbonate
					G		
core shale	lower shale	2–20	fossiliferous, gray-green; occasionally black	minimal		marine shale	subtidal, low energy, marine; restricted, anoxic conditions prevalent to south and to north locally shallow water
					G		
middle limestone	lower carbonate	0–15 (upper)	lime-mudstone to wackestone, fossiliferous	minimal to locally moderate		transgressive carbonate	subtidal, low energy, open marine; clear to turbid water conditions
		0–8 (lower)	silty grainstone to packstone; occasionally base rich in quartz sand or silt				sandy or silty reworked shoal water, intermittent restricted to open marine
					S		

Facies II

Facies II contains four units: interbedded olive-gray shale and crinoid-brachiopod wackestone characterized by undulose bedding (unit 4; plate 1B), bioclast wackestone and minor *Tubiphytes* boundstone (unit 5; plate 1C, D, and E), *Chaetetid* bafflestone (unit 6; plate 2B, C, D, and E), and limy dolomite and dolomite (unit 7; plate 3). *Chaetetid* bafflestone and the underlying wackestone of unit 5 are heavily oil stained.

Unit 4 and the lower and middle parts of unit 5 record subtidal deposition in quiet, marine waters which decreased in turbidity with time. Deposition was below wave base but in the photic zone in water probably a few meters to a few tens of meters deep. Relatively diverse biota of unit 4 and the lower and middle parts of unit 5 (fig. 4) are interpreted to represent normal-marine conditions with phylloid algae recording clear, relatively shallow water deposition. A sharp decline in fossil diversity and abundance in the upper part of unit 5 (fig. 4), indicates a shift to more restricted conditions related to decreasing water depths. Bioclasts in the uppermost 0.5 ft (0.15 m) of this unit are restricted essentially to brachiopods. The contact of units 5 and 6 is abrupt and irregular (plate 2A), and the upper 1 ft (0.3 m) of unit 5 is strongly dolomitized. These features suggest that the upper surface of unit 5 may record subaerial or very shallow marine erosion.

Coated-grain packstone, making up the lowermost few inches of unit 6, abruptly overlies unit 5 (plate 2A). Overlying this is *Chaetetid* bafflestone. The environmental significance of *Chaetetes* was reviewed by Wilson (1975, p. 209) in his discussion of Pennsylvanian–Early Permian microfacies of the Midcontinent. Wilson stated that the *Caninia–Chaetetes* microfacies is characterized by massive, micritic limestone beds with corals, not necessarily in growth position nor attached to each other, forming a bafflestone. This microfacies, Wilson suggested, represents coral-rich banks and shoals in clear, very shallow, relatively quiet, open-marine waters. A similar environment is visualized for *Chaetetid* bafflestone of unit 6.

Unit 7 is characterized by features suggesting subaerial exposure and meteoric diagenesis. Planar algal stromatolites in the lower part of unit 7 (plate 3A) and a low-diversity fossil assemblage, composed predominantly of ostracods, brachiopods, and gastropods, represent intertidal to supratidal deposition. Desiccation and dissolution features include clay-filled fractures and fissures, hardened clasts, and irregular-shaped vugs (plate 3). The contact between units 7 (facies II) and 8 (facies III) is sharp, and the upper surface of unit 7 is irregular with relief of approximately 1 inch (2.5 cm; plate 3B). This surface was probably subaerially exposed and perhaps eroded. The rock immediately underlying the contact may be a caliche. Dolomitization of unit 7 is pervasive below this contact as it was below the irregular contact between units 5 and 6 (fig. 4).

Thus, facies II is an upward-shoaling carbonate sequence terminating in subaerial exposure and erosion. The environment changed from shallow-marine shelf to supratidal.

Facies III

Olive-gray shale of unit 8 (facies III) abruptly overlies facies II. The lower 0.5 ft (0.15 m) of shale (plate 4A) is unfossiliferous, contains minor carbonaceous material, and is generally lighter in color and less fissile than the remainder of the facies. Bryozoans and crinoids are rare and brachiopods are locally common in the middle and upper parts of facies III. The fossiliferous shale was deposited in a quiet-water, subtidal, marine environment perhaps a few meters to a few tens of meters deep. Unfossiliferous shale of the lower part of the facies records nearshore, perhaps slightly shallower, marine deposition. The relatively sparse, low-diversity fauna of this facies is attributed to detrital influx.

Facies IV

Olive-gray shale of facies III grades upward into olive-gray, locally bioturbated, bioclast wackestone of facies IV (plate 4B, C). Limestone of facies IV becomes less argillaceous upward. The relatively diverse fauna (e.g., brachiopods, encrusting forams, fusulinids, green algae, bryozoans, and crinoids), micrite matrix, and lack of current structures suggest deposition generally below wave base in normal-marine waters a few meters to perhaps a few tens of meters deep. *Osagia* (blue-green algae and encrusting foram)-coated bioclasts (plate 4B), possibly analogous to modern oncolites (Crowley, 1969), suggest occasional, moderate wave or current energies.

Facies V

Facies V is composed of calcareous, olive-gray to olive-black, fissile shale. Thin-shelled brachiopods are locally common and crinoids are present in the upper part of the facies (plate 4D). Phosphorite (?) nodules are rare. This shale displays a gradational contact with overlying limestone of facies VI. Deposition of this shale probably was below wave base in quiet, marine waters.

Facies VI

The lower part of facies VI (unit 11) is lime mudstone and argillaceous, crinoid wackestone and packstone (plate 5A). These rocks grade upward into locally oil-stained and cross-stratified bioclast grainstone and packstone (plate 5B, C, and D) which make up the middle part of this facies (units 12-14). In places, the matrix of these rocks was selectively dolomitized. Elsewhere, medium-crystalline dolomite cement fills intergranular areas. Crinoids and bryozoans generally are the most common bioclasts in these rocks with calcispheres (?) common in unit 13 (plate 5C). A relatively thin interval of interbedded limestone, shale, and conglomerate (unit 15; plate 5F) overlies the bioclast grainstone and packstone. The conglomerate contains lime mudstone and pale-green siltstone clasts. Overlying this and comprising the upper part of facies VI (unit 16) is burrowed, bioclast wackestone and packstone grading upward into cross-stratified ooid grainstone (plate 6A).

Facies VI contains two shoaling-upward sequences, units 11–15 and unit 16. Both begin with subtidal, marine wackestone and packstone and grade upward into high-energy, shallow-water grainstone.

Facies VII

Greenish-gray, unfossiliferous shale and nodular, unfossiliferous lime mudstone of facies VII, units 17–19 (plate 6B and C), record tidal-flat or perhaps shallow-

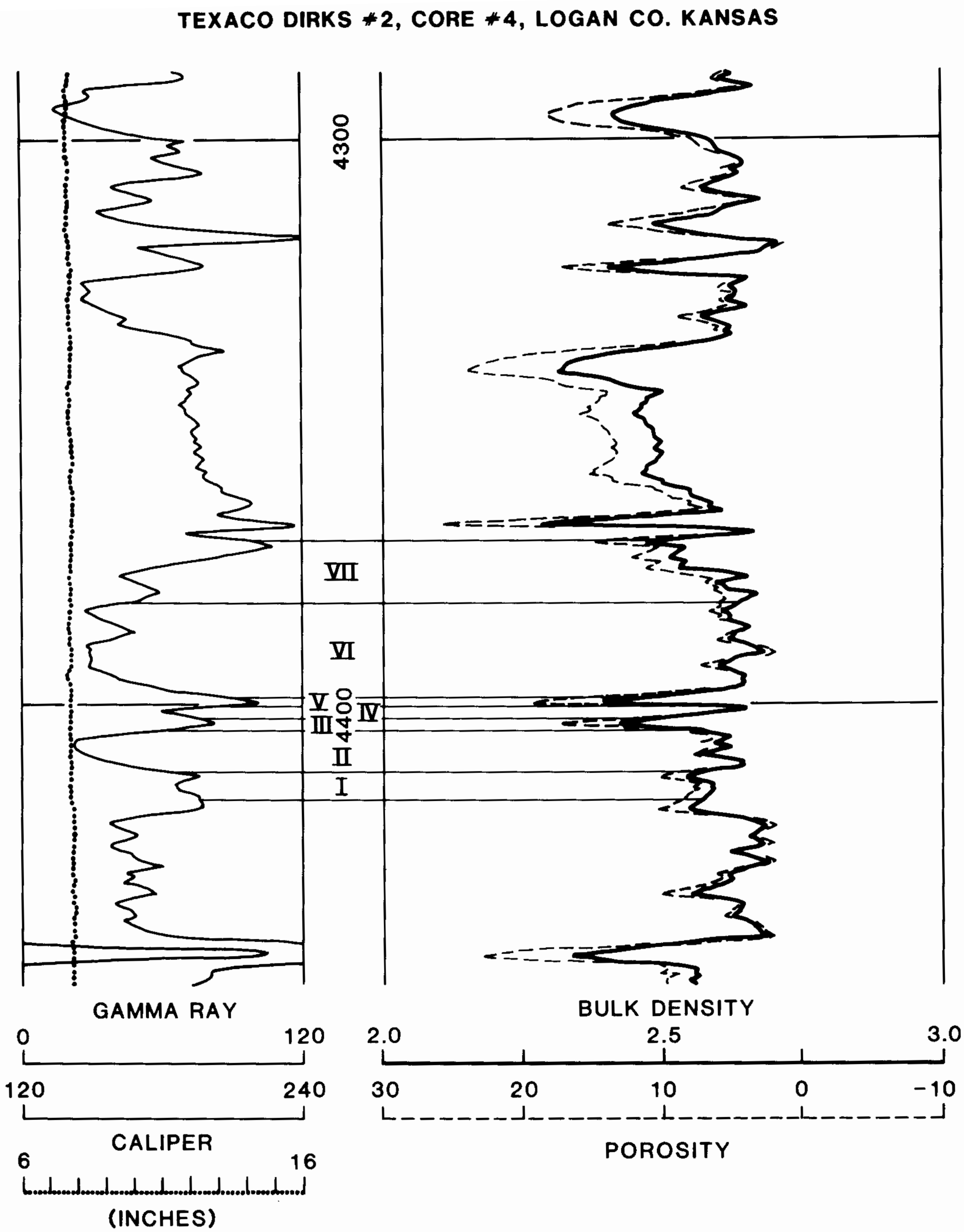

FIGURE 5—Gamma ray/neutron-density well log signatures of the depositional facies of the Dirks #2 core.

lagoon to nonmarine deposition. Irregular-shaped limestone nodules residing in greenish-gray shale in the lower part of unit 19 may be due in part to early solution of carbonate mud by waters undersaturated with respect to calcium carbonate (plate 6B). Limestone nodules in the middle and upper parts of unit 19 may have precipitated from meteoric waters in the soil zone and may be caliche. Calcite-filled fractures in some nodules (plate 6C) indicate desiccation or perhaps dissolution. Brownish-gray and grayish-brown, unfossiliferous mudstone (plate 6D) of the upper part of facies VII (unit 20) may reflect nonmarine deposition, with a possible return to marine conditions recorded by olive-gray shale which makes up the uppermost 0.5 ft (0.15 m) of the facies.

Similar rocks have been described by Watney (1980) from the Upper Pennsylvanian (Missourian) of northwestern Kansas and southwestern Nebraska. Watney stated that nodular carbonates (some with shrinkage fractures), the absence of fossils, and the oxidized appearance of sediment, including a typical red-brown color, reflect continental deposition and in some cases development of a paleosol.

Log signature

Fig. 5 shows the gamma ray/neutron-density log signatures of the depositional facies of the Dirks # 2 core. Log responses of Kansas-type cyclothems were discussed in detail by Watney (1980) and will not be reviewed here. A figure from Watney's study is, however, included to show the typical responses of several cyclothems in the Kansas City Group (fig. 6). Note the similarities with cyclothems of the cored interval of this study.

Depositional cycles

The vertical sequence of the Dirks # 2 core fits, with some irregularities, Heckel's Kansas-type cyclothem model. The core contains two cyclothems represented by facies I-III, a partial cyclothem, and III-VII, a complete Kansas-type cyclothem.

Siltstone and shale of facies I suggest continental (?) and shallow-marine deposition and correspond to Heckel's outside shale. Olive-gray shale of the upper part of this facies signals the initiation of a marine transgression. The overlying, upward-shoaling carbonates of facies II record an overall marine regression culminating in subaerial exposure. This facies corresponds to Heckel's upper limestone. Completing the partial cyclothem is olive-gray shale of facies III, equivalent to Heckel's outside shale. The core shale member is absent in this sequence and in the equivalent interval in nearby wells. The transgressive, middle limestone member, likewise, seems to be absent. This member may, however, be represented by the lowermost 2–3 ft (0.6–0.9 m) of facies II. In any case, this sequence (facies I–III) suggests that only a relatively minor transgression occurred in the area during deposition of the lower cyclothem.

The overlying cyclothem begins with olive-gray shale of the upper part of facies III (outside shale) recording a marine transgression. Facies IV is Heckel's middle limestone, i.e. a relatively thin, bioclast wackestone and packstone that contains a diverse and relatively abundant marine biota recording deposition in an open-marine environment generally below effective wave base but in the photic zone. Facies V corresponds to the core shale. Absence of a black shale in facies V suggests water depths were too shallow for the establishment of a thermocline which would inhibit good bottom oxygenation (Heckel, 1977). This relatively thin shale is, however, darker and less silty than those interpreted as outside shales (e.g., facies I, III, and VII). Facies VI is the upper limestone. Like Heckel's upper limestone member, facies VI consists of shale-parted, bioclast wackestone and packstone which grade upward into bioclast packstone and grainstone and finally into cross-stratified, ooid grainstone. Facies VII, representing tidal flat and nonmarine deposition, is an outside shale.

Diagenesis

Pennsylvanian cyclothems of the Midcontinent display diagenetic patterns which can be related to the cyclic depositional model described earlier in this report (fig. 3). These patterns, discussed by Watney (1980; table 1, this report) and summarized by Heckel (1982, 1983), are reviewed here with respect to the Dirks # 2 core. A generalized model showing shallow-subsurface, diagenetic environments is presented in fig. 7.

Heckel stated that the middle limestone and core shale were deposited during continued transgression and pass directly from the marine phreatic diagenetic environment into the low-oxygen, connate environment with little or no evidence of meteoric diagenesis. Core shales may show some discoloration (mottled yellow red), dissolution of fossils, and occasional fracturing due to percolating meteoric waters. This shale acted as a seal, however, above the middle limestone, and mineralogically unstable grains in the middle limestone were not leached but, instead, underwent slow neomorphism. The result is good preservation of original depositional textures. Cements generally are ferroan calcite and dolomite in the middle limestone and may postdate considerable compaction. Calcarenites when present in the core shale also display ferroan-carbonate cements and overpacking of grains.

In the Dirks # 2 core no discoloration or fracturing of the core shale (facies V) is present. The middle limestone (facies IV) shows good preservation of original depositional textures with no secondary meteoric or primary porosity. These rocks are muddy, and overcompaction is not present.

Generally, diagenetic alteration of the upper limestone and outside shale is more striking and displays a greater variety of features. Heckel stated that the upper limestone displays features indicative of its passage through a number of diagenetic environments beginning with the marine phreatic and passing through the meteoric, mixing zone, and deeper connate. Mineralogically unstable grains are leached and blocky calcite cement precipitated in the meteoric environment under conditions that become increasingly oxygen depleted as mixing zone and deeper connate water move into the rock during and after the succeeding transgression.

Upper limestone members of the Dirks # 2 core (facies II and VI) show a variety of porosity and cement types. Fracture, moldic (primarily leached bioclasts), solution-enlarged moldic, and vuggy porosity in facies II record freshwater diagenesis in the meteoric environment (plates 1D, and E; 3B, C, and E). In addition, *Chaetetid* corals display intragranular porosity in this facies (plate 2D). Porosity in the lower part of facies VI (units 12 and 13) generally is primary and includes intergranular and intragranular. In ooid grainstone of the upper part of facies VI (unit 16), bladed, isopachous, calcite cement records early, marine phreatic cementation. This stage of cementation was arrested prior to complete filling of intergranular areas, resulting in the retention of some primary intergranular porosity (plate 5E). In places, this intergranular porosity is filled by poikilitic, echinoderm overgrowths and/or a finely crystalline, equant calcite cement. Moldic and oomoldic porosities in unit 16 developed due to dissolution of mineralogically unstable grains in the meteoric environment (plate 5E).

Microcrystalline replacement dolomite and medium-crystalline dolomite cement of facies II, concentrated immediately beneath two irregular surfaces thought to record subaerial exposure (fig. 4), may have formed soon after deposition. This dolomite may have resulted from mixing of marine pore fluids with freshwater during subaerial

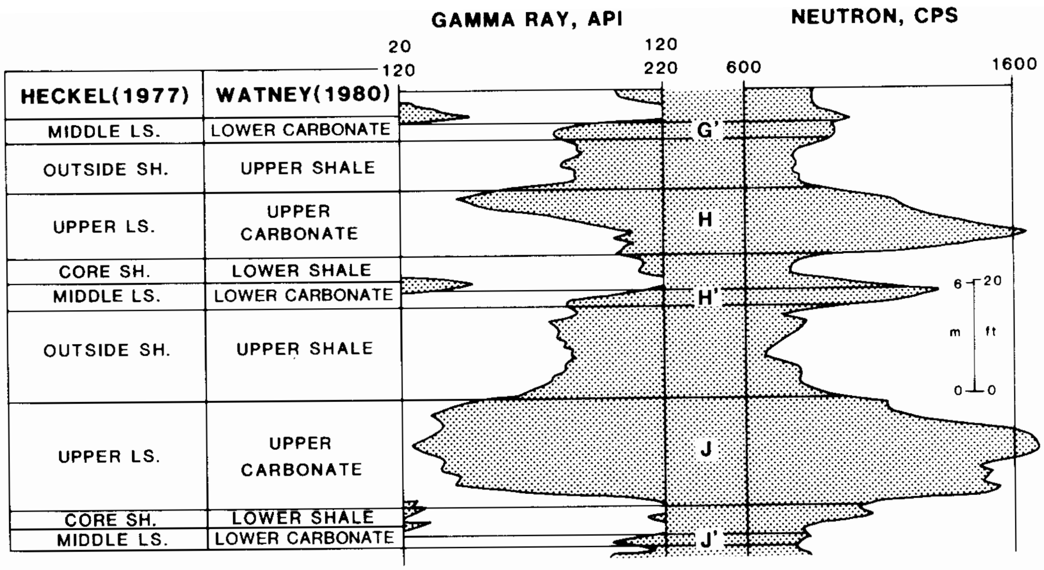

FIGURE 6—Typical gamma ray/neutron well log signatures of Kansas-type cyclothems from an interval in the Kansas City Group, northwestern Kansas (from Watney,1980).

CORE FACIES	POSITION IN KANSAS-TYPE CYCLOTHEM (Heckel, 1977)	STRATIGRAPHIC UNITS: Member	STRATIGRAPHIC UNITS: Formation	CYCLOTHEM
VII	OUTSIDE SHALE		Holdenville Shale	LENAPAH CYCLOTHEM
VI	UPPER LIMESTONE	Idenbro Limestone	Lenapah Limestone	
V	CORE SHALE	Perry Farm Shale		
IV	MIDDLE LIMESTONE	Norfleet Limestone		
III	OUTSIDE SHALE		Nowata Shale	
II	UPPER LIMESTONE CORE SHALE(ABSENT) MIDDLE LIMESTONE(?)	Worland Limestone Lake Neosho Shale Amoret Limestone	Altamont Limestone	ALTAMONT CYCLOTHEM
I	OUTSIDE SHALE		Bandera Shale	

FIGURE 7—Correlation of core facies with formations and members of the Altamont and Lenapah cyclothems.

exposure. Microcrystalline replacement dolomite and dolomite cement in units 12 and 13 of facies VI may have precipitated at shallow burial depths in a hydrologic system of mixed meteoric and marine waters.

Heckel stated that diagenetic processes that affected the outside shale member were closely related to the depositional environment of the shale and were an extension of those that affected the underlying upper limestone member. These processes often were associated with subaerial exposure and included soil formation and freshwater phreatic and vadose diagenesis. Watney (1980) suggested that carbonate nodules, closely resembling caliche, and tubule structures, interpreted as recording plant-root action, attest to the presence of soil-forming processes in the outside shale.

The typical red-brown color of mudstone in the upper part of facies VII may be post-depositional in part, and, in places, irregular-shaped, lime-mudstone nodules in this facies may have resulted from early solution of lime mud by percolating meteoric waters (plate 6B). Tubular structures and carbonate nodules in the upper part of unit 19 (plate 6C) resemble those described by Watney, which he suggested were associated with soil-forming processes of the outside shale.

Stratigraphy

Four Kansas-type cyclothems make up the Marmaton Group. In ascending order, they are the Fort Scott, Pawnee, Altamont, and Lenapah. These cyclothems, previously termed megacyclothems, were described by Jewett (1945) and Moore (1949). Two of these cyclothems, the Altamont (facies I–III) and the Lenapah (facies III–VII), occur in core 4 from the Dirks # 2. Correlation of the seven core facies of the Dirks # 2 with formations and members of these cyclothems is shown in fig. 8.

Schenk (1967) described the Altamont Limestone, of the cyclothem of the same name, where it crops out along a northeast-southwest trend stretching from Iowa to northeastern Oklahoma. In outcrop the Altamont Limestone is divided into three members, the older Amoret and younger Worland Limestones and the intervening Lake Neosho Shale. Schenk stated that the Amoret and Worland Limestones are transgressive and regressive, marine carbonates, respectively, and the Lake Neosho Shale is a black, phosphoritic shale recording maximum marine transgression. He further stated that the Bandera Shale and Nowata Shale which underlie and overlie the Altamont Limestone, respectively, contain variegated, terrigenous detritus, often with coal, and record deltaic deposition. These units make up Schenk's Altamont megacyclothem and correspond to the members of Heckel's Kansas-type cyclothem. Core study of the Altamont cyclothem in the Dirks # 2 and subsequent log correlations indicate that the Lake Neosho Shale (core shale member) and possibly the Amoret Limestone (middle limestone member), described in outcrop, are absent in the study area (fig. 8). In contrast, all of the formations and members of the Lenapah cyclothem are present in the core.

Exploration methods

Watney (1980) detailed exploration techniques for the Lansing–Kansas City Groups in northwestern Kansas and southwestern Nebraska. Depositional environment and diagenesis were critical to reservoir development in this region. The regressive, upper limestone members afforded the best opportunity for hydrocarbon accumulation. Upper limestone reservoirs include grainstones and mud-supported rocks. Critical to reservoir development in the upper limestones was the creation of secondary porosity by brackish or freshwater dissolution of carbonate. In general, the effects of meteoric diagenesis become increasingly pronounced northward (landward) and over local topographic highs (Watney, 1980). In the Dirks # 2 core, porous intervals are likewise restricted to the regressive, upper limestone members (fig. 9), occur in grainstones (facies VI) and mud-supported rocks (facies II), and are characterized by secondary porosity produced by meteoric diagenesis.

Mapping by Watney showed that structure alone can not account for all Lansing–Kansas City production in this area. In fact, a major problem in the exploration for Pennsylvanian hydrocarbon accumulations in this region has been the lack of correspondence between present-day structure and distribution of reservoir facies. Production is on structure in some areas, but elsewhere it occurs on the flanks of structural highs or in lows. This lack of correspondence seems to be the case in the study area, where the producing interval is the Altamont Limestone (Worland Limestone Member). Here, the Texaco Dirks # 1 and # 2 are producing from a structural closure as mapped on the top of the Altamont Limestone, while the Texaco Dirks "B" # 1 production is from the flanks of that structure (fig. 10; on sheet 3 in back pocket). Thus, additional maps, e.g., lithofacies, isopachs, and porosity, are needed to define the play.

In Watney's work, porosity development is not necessarily related to present structure but may be controlled by lithofacies distribution or paleotopography. As seen in fig. 10, Altamont porosity shows a general correlation with present structure. In detail, however, this relationship does not hold (e.g., compare Dirks "B" # 1 and Dirks # 3 in sec. 29).

Lansing–Kansas City production in this region is commonly associated with subtle highs on the Pennsylvanian seafloor that were favorable to the development of reservoir-quality porosity. Higher energy conditions associated with these topographic highs may have resulted in the deposition of carbonate sands with good, primary intergranular porosity. In addition, these elevated areas would more likely undergo meteoric diagenesis and the formation of secondary porosity. An east-west cross section through Dirks and Miller fields (fig. 11) shows that the stratigraphic interval immediately overlying the Altamont Limestone is relatively thick in the Dirks # 2 dry hole, the southernmost well on the cross section. This thickening suggests a position just off a subtle Altamont high. The lack of porosity in the Altamont in the Dirks # 2 (fig. 10) may indicate the absence of significant meteoric diagenesis in this setting. Thus, porosity and permeability development in the Worland Limestone Member of the Altamont Limestone (facies II), the reservoir in the Dirks and Miller fields, seems to have depended primarily on meteoric diagenesis associated with a local Altamont high on the seafloor.

Conclusions

Core 4 of the Texaco Dirks # 2, Logan County, Kansas, records deposition of a broad, epeiric shelf, a northern extension of the Hugoton embayment, in response to fluctuating sea level and varying terrigenous influx. The core includes two Kansas-type cyclothems (facies I–III and III–VII), Marmaton in age. Regressive carbonate units in the cyclothems, termed upper limestone members in Heckel's (1977) model, afford the best opportunities for hydrocarbon reservoirs. The regressive carbonate of the upper part of the core, facies VI (Idenbro Limestone Member of the Lenapah Limestone), displays primary intergranular and secondary moldic, primarily oomoldic, porosity. Porosity is poor to locally fair. The regressive carbonate which makes up facies II (Worland Limestone Member of the Altamont Limestone) is heavily oil-stained and is the pay in the study area. Primary intragranular and secondary porosities, including moldic, solution-enlarged moldic, vuggy, and fracture, characterize this carbonate. Porosity here is fair to locally good and permeability in the fractured portion of the facies is good. Porosity development in facies II was primarily the result of meteoric

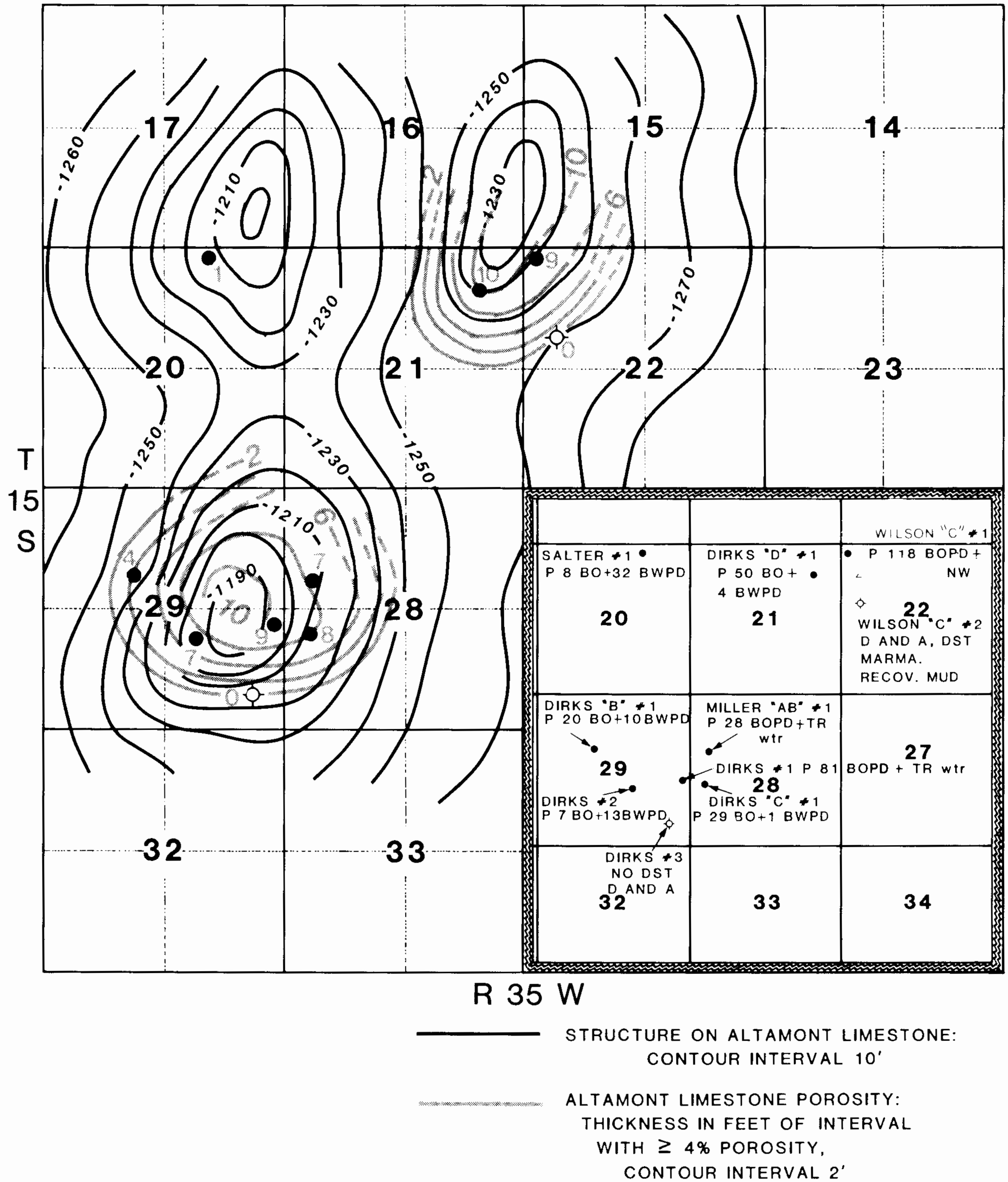

FIGURE 8—Map showing relationship of Altamont porosity, determined from compensated neutron-formation density log, to present-day structure mapped on the Altamont, T. 15 S., R. 35 W., Logan County, Kansas. Inset shows well names and initial productions.

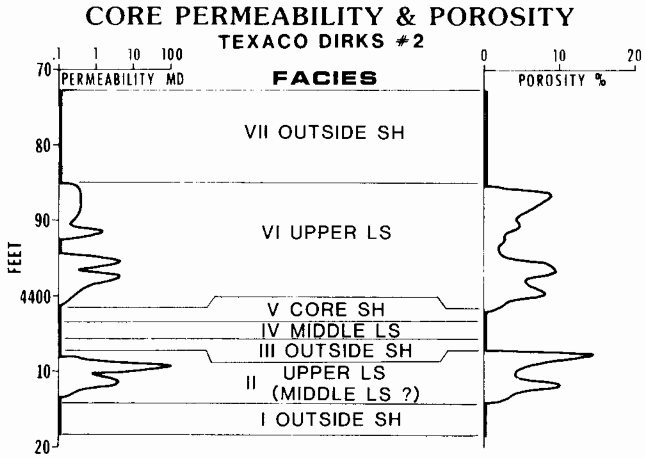

FIGURE 10—Core permeability and porosity of Texaco Dirks #2.

diagenesis which was related to subaerial exposure on an Altamont high on the seafloor.

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Plates 1–6 follow

PLATE 1—Facies I and II.

A) Mottled, greenish-gray siltstone of facies I (units 1 and 2). Mottling is due to plant-root action (p) or perhaps burrowing.

B) Interbedded shale and crinoid wackestone of the lower part of facies II (unit 4).

C) Bioclast wackestone facies II (unit 5) showing green algae plates (a) and *Tubiphytes* (T).

D and E) Secondary porosity in bioclast wackestone of facies II (unit 5). Photomicrograph E (crossed nicols) shows moldic (leached bioclasts) porosity (m). Photo D shows moldic (m) and solution-enlarged moldic (?) porosity in dolomitized wackestone. Some bioclasts (green algae plates) have been leached and the resulting pore space infilled by medium-crystalline, dolomite cement (dc).

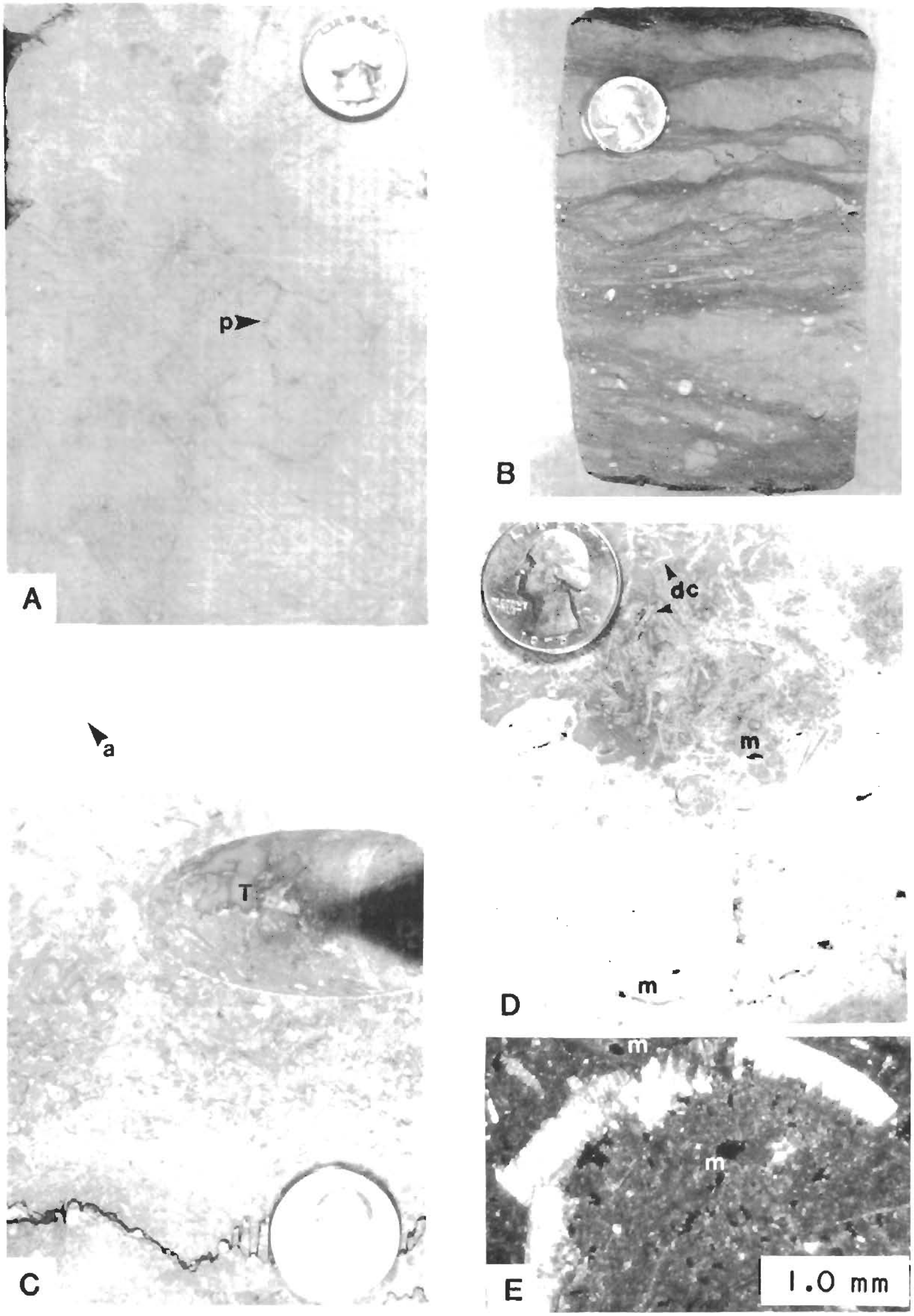

p
A
B
dc
m
D
T
a
C
m
E
1.0 mm

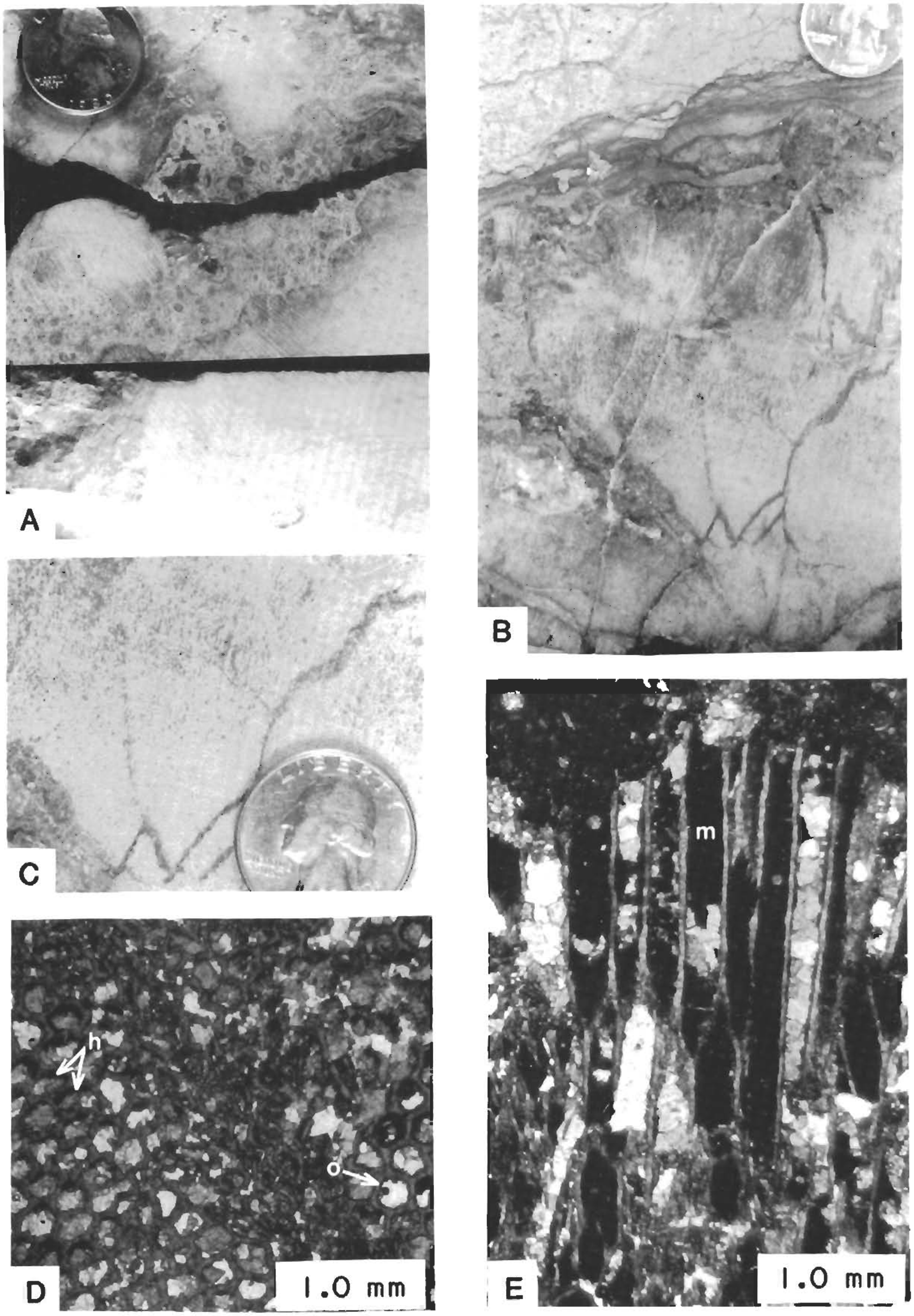
PLATE 2—Facies II.

A) Sharp, irregular contact between sparsely fossiliferous, light-gray dolomite of the upper part of unit 5, facies II, and coated-grain packstone of the lowermost part of unit 6, facies II.

B) Fractured, *Chaetetes* bafflestone (unit 6) and abruptly overlying dolomite (unit 7).

C) *Chaetetes* coral chambers filled by dolomite (light-colored) and minor calcite cements (unit 6).

D and E) Photomicrographs showing chambers of the tabulate coral *Chaetetes* (unit 6). Chambers are open (o) or are filled or partially filled with micrite (m), calcite cement, dolomite cement, or residual hydrocarbons (h). Note diagonal band of collapsed chambers in photo D. Both photos under plane light.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B
C
D
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m
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o
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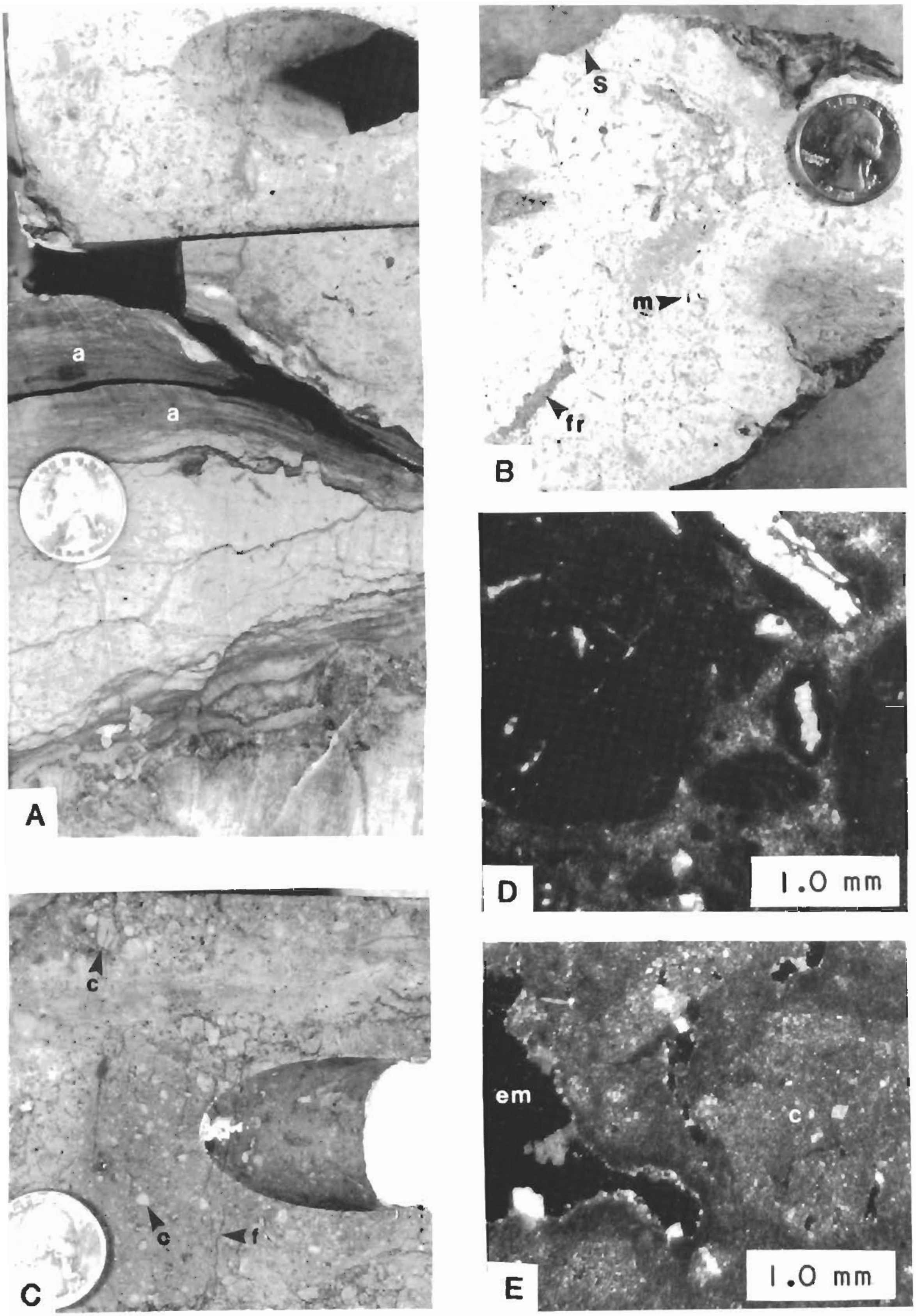
PLATE 3—Facies II.

A, B, and C) Dolomite and dolomitic limestone of facies II (unit 7). Photos show planar algal stromatolites (a), clasts (c), moldic (m) and fracture (f) porosity, clay-filled fractures or fissures (fr), and the irregular upper surface of facies II (S). Dolomite at top of unit may be a caliche (photo B).

D) Photomicrograph of clasts in dolomitic limestone of facies II (unit 7).

E) Solution-enlarged moldic (em) and moldic porosity in finely crystalline dolomite of facies II (unit 7), light-colored clasts (c). Photo taken under crossed nicols.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c
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D
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E
em
c
1.0 mm

PLATE 4—Facies III, IV, and V.

A) Olive-gray shale of the lower part of facies III (unit 8).

B and C) Bioclast wackestone of facies IV (unit 9). Note *Osagia* grains (o) and crinoids (c) in photo B and burrow mottled character of limestone in photo C.

D) Olive-black, fissile shale of facies V (unit 10). Band of thin-shelled brachiopods and phosphorite (?) nodules (pn) in middle part of photo.

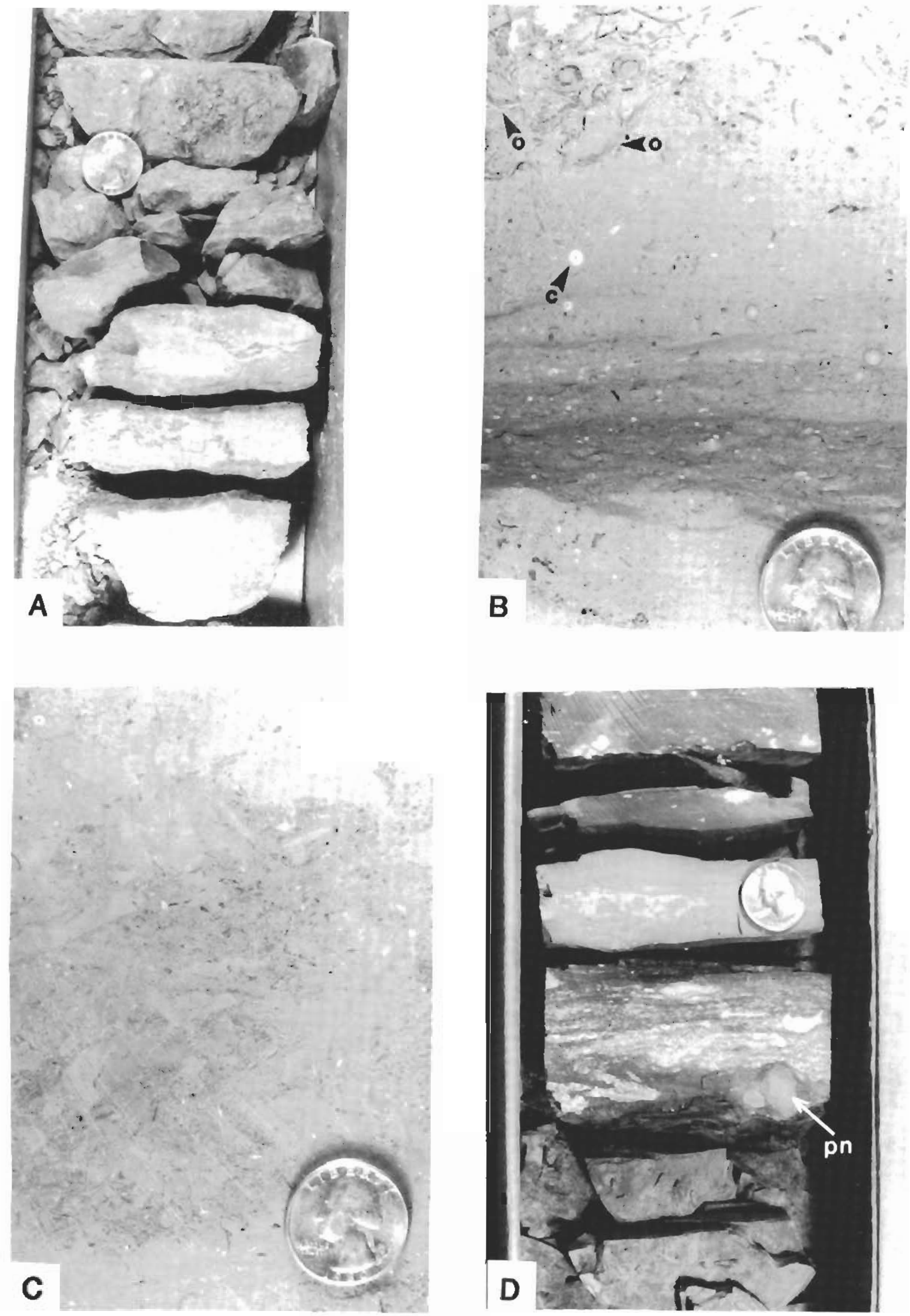

A
o
o
c
B
C
pn
D

PLATE 5—Facies VI.

A) Argillaceous, crinoid wackestone of the lowermost part of facies VI (unit 11).

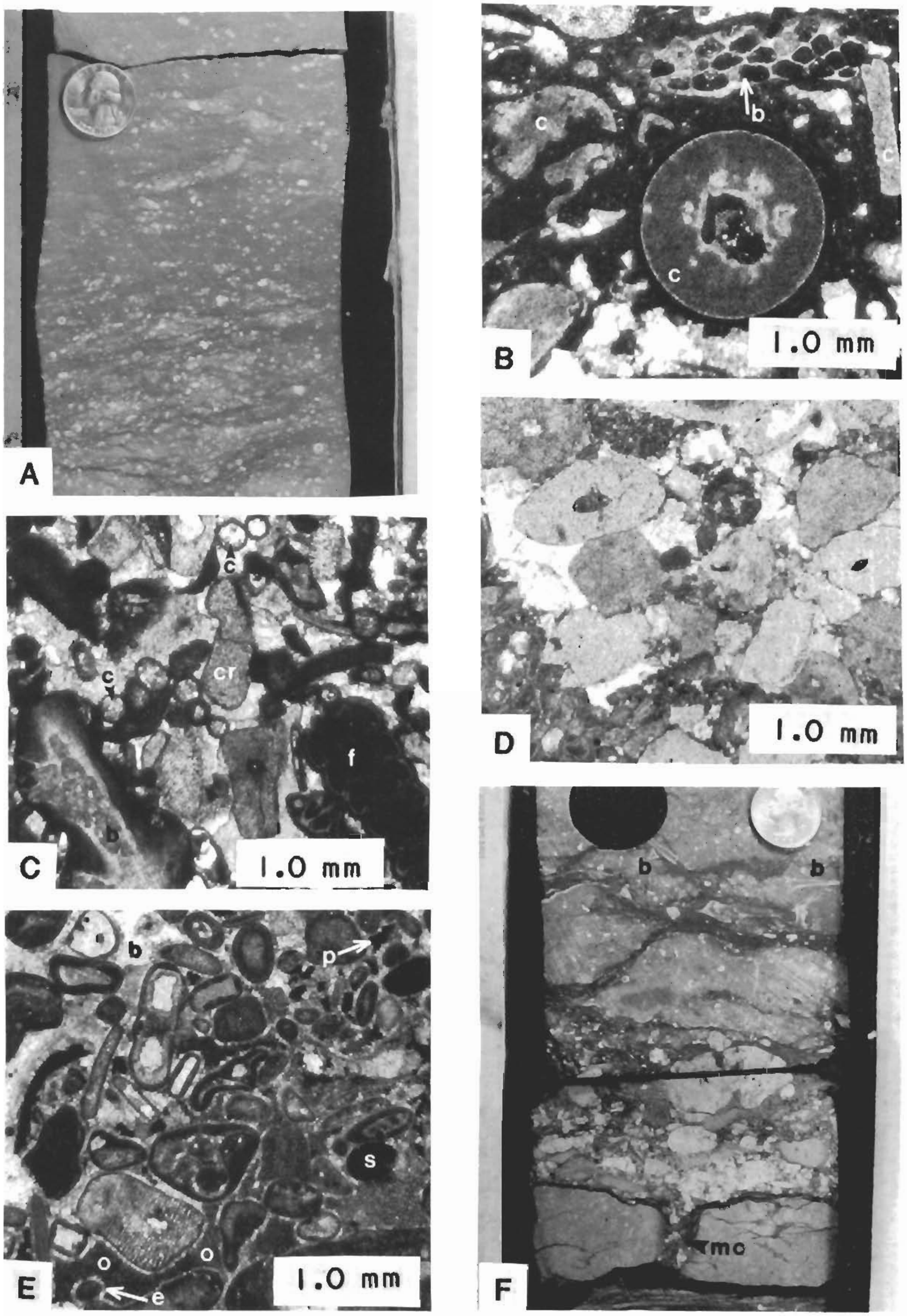
B) Bioclast packstone of the lower part of facies VI (unit 12); crinoid (c) and bryozoan (b).

C) Bioclast grainstone, facies VI (unit 13) containing crinoids (cr), calcispheres (?) (c), bryozoans (b), and small mobile forams (f). Plane light.

D) Overcompacted crinoid grainstone/packstone, crinoid fragments commonly with syntaxial, calcite overgrowths (unit 12).

E) Ooid-bioclast grainstone of facies VI (unit 16) showing early, marine isopachous cement (e), a later, finely crystalline, equant calcite cement (b), poikilitic, echinoderm overgrowths (o), primary intergranular porosity (p), and secondary oomoldic porosity (s). Photo under crossed nicols.

F) Peloidal limestone, facies VI (unit 15), displaying mudcracks (?) (mc) and overlain by siltstone-lime mudstone conglomerate and above that interbedded shale and crinoid-bryozoan wackestone (b = bryozoans).


A
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b
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B
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c
cr
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p
s
o
o
e
1.0 mm
E
b
b
mc
F

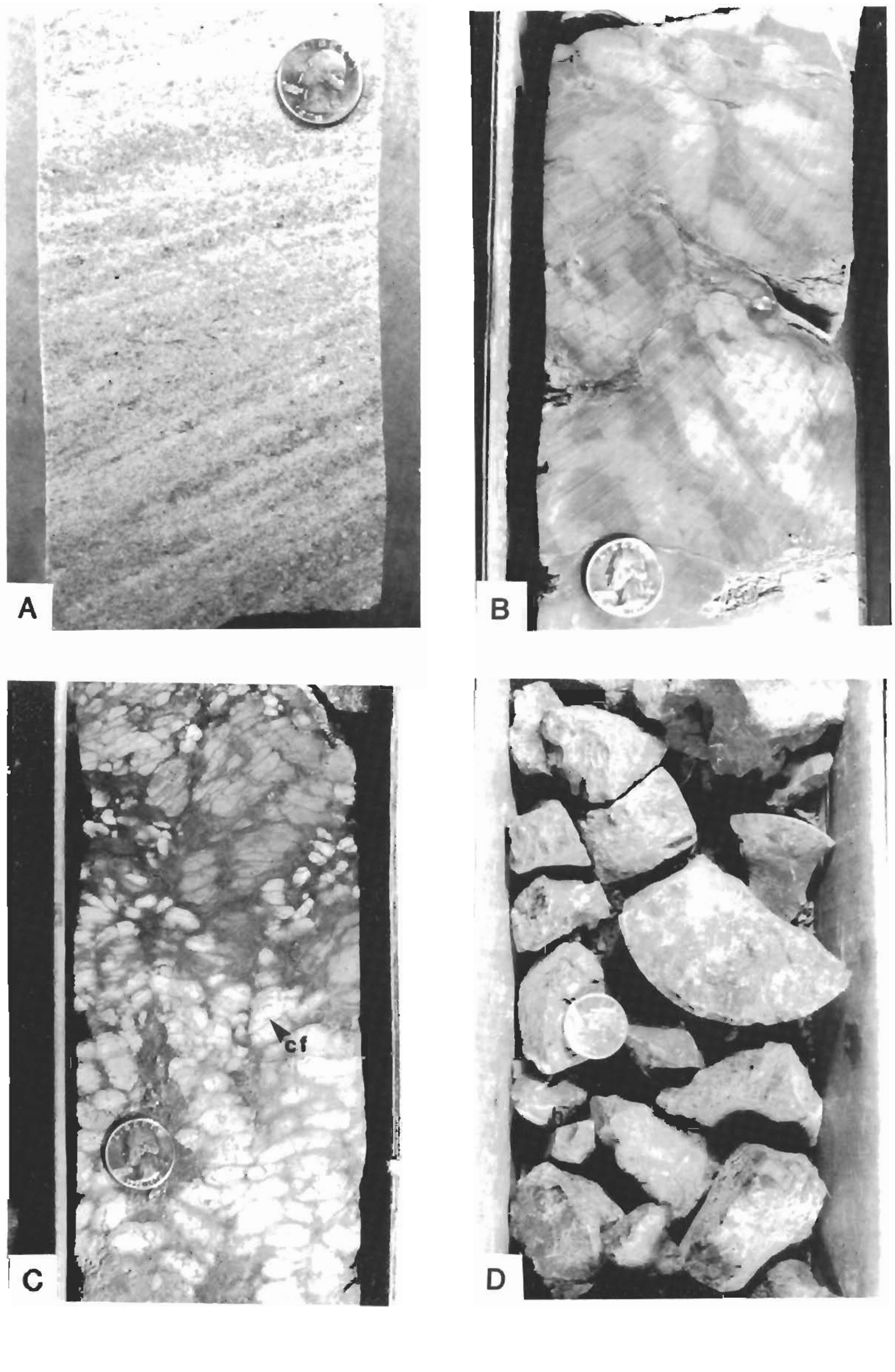
PLATE 6—Facies VI and VII.

A) Cross stratified, ooid grainstone of the uppermost part of facies VI (unit 16).

B) Nodular, lime mudstone and shale of facies VII (unit 19).

C) Shale and nodular limestone with calcite-filled fractures (cf) resembling caliche, facies VII (unit 19).

D) Brownish-gray, unfossiliferous mudstone, facies VII (unit 20).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D