McElroy Field: Development Geology of a Dolostone Reservoir, Permian Basin, West Texas*

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Abstract and Contents

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McElroy field produces from shallow-water shelf dolomudstones and from shallow-water shelf-to-intertidal dolopackstones and dolograinstones. Continuity of production in the reservoir is well developed in the homogeneous bioturbated dolomudstones, where dolomitization has increased horizontal and vertical permeability. In contrast, the heterogeneous shallow-water shelf-to-intertidal deposits have interbedded porous and tight zones that subdivide the reservoir vertically. Porosity and permeability change significantly both laterally and vertically in the Grayburg, reflecting a combination of variations in depositional texture, dolomite crystal fabric, and evaporate plugging.

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Abstract

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Introduction

McElroy field, located in West Texas along the boundary between Crane and Upton Counties, is one of the larger San Andres/Grayburg fields in the Permian Basin. The field is part of a major productive trend lying along the eastern edge of the Central Basin Platform (fig. 1). Other significant fields lying along the same trend and producing from the Upper Permian Grayburg and San Andres Formations include Yates, Dune, Cowden, Foster, Goldsmith, and Means (Bebout and Harris, 1986). Total areal extent of McElroy field is in excess of 50 mi^2, of which a 35-mi^2 portion is entirely Chevron operated (fig. 2). The remainder, the North McElroy Unit, is operated by Texaco. The Chevron-operated portion of McElroy field is the subject of this paper.

In-place total reserves for the field are estimated to be 3,000 million barrels (MMbbl) of oil, of which approximately 601 MMbbl are recoverable (436 MMbbl from the Chevron-operated portion of the field). Cumulative production is 513 MMbbl from the entire field and 363 MMbbl from the Chevron-operated portion; current annual production from the Chevron-operated part of the field is 6 MMbbl of oil and 28 MMbbl of water, with a decline rate of 6 percent.

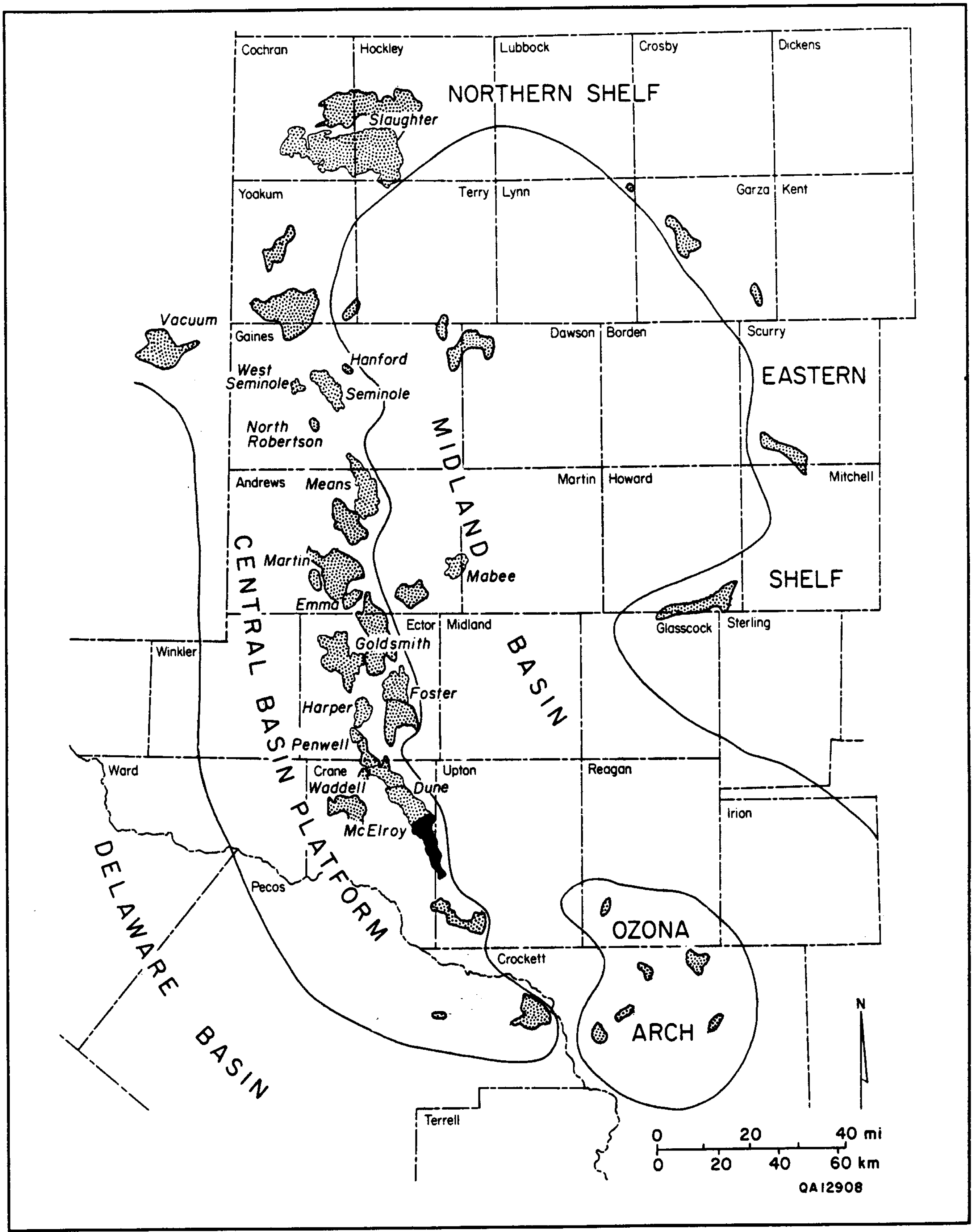


FIGURE 1. Regional map highlighting McElroy field and other important fields producing from the San Andres/ Grayburg Formations, Permian Basin.

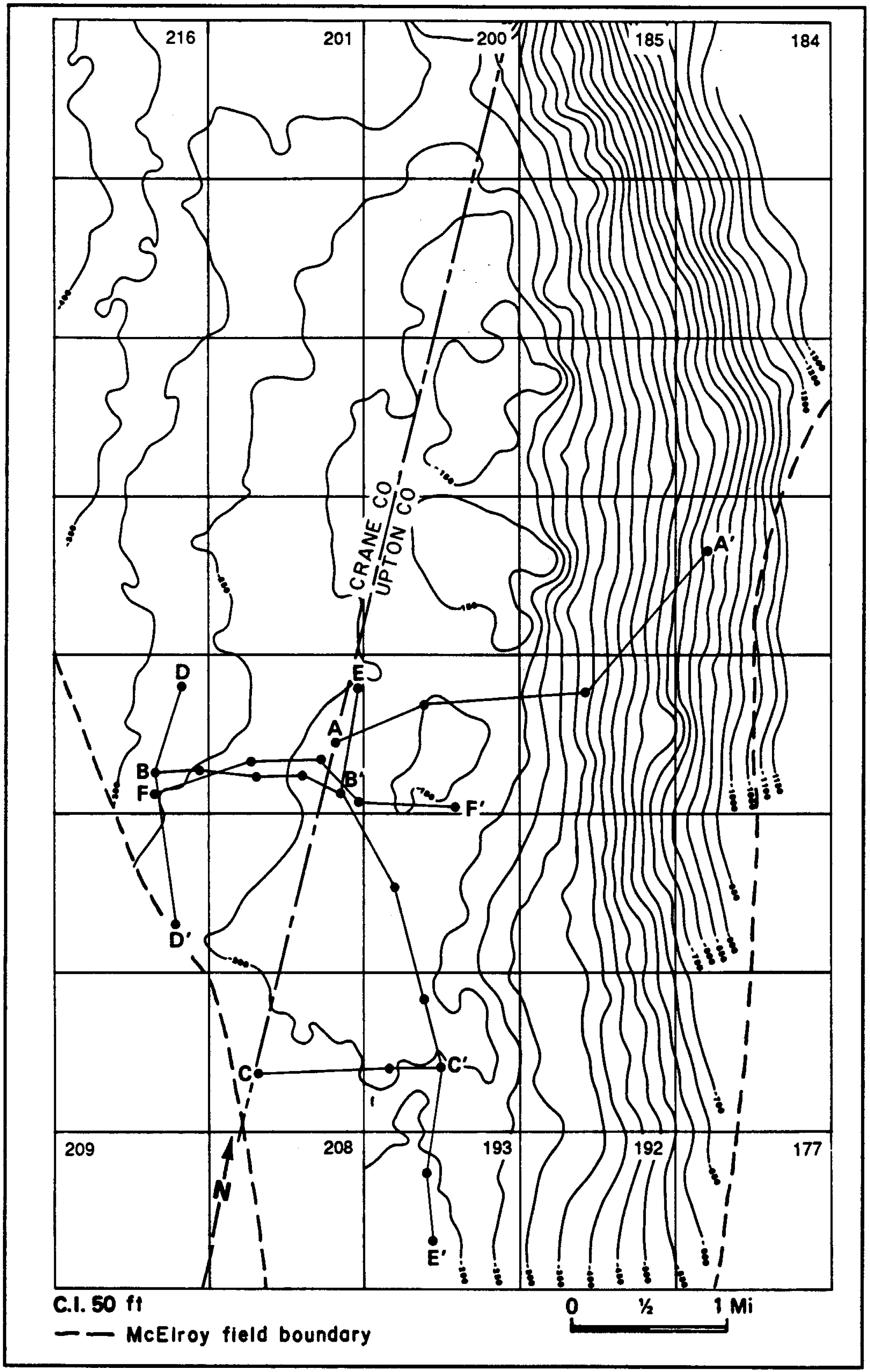


FIGURE 2. Structure map of a marker within the upper Grayburg Formation over the McElroy field illustrating the strongly asymmetrical nature of the anticline. Datum is sea level. Locations of cross sections A-A′ to F-F′ are shown.

Production History

McElroy field and the giant Yates field to the southeast were discovered in 1926 during initial exploration along the Central Basin Platform. Structure was mapped and inferred using surface geology, scant well data from elsewhere in the basin, and trend drilling. Gulf Oil completed the J. T. McElroy No. 1, the discovery well for the field (Section 203, Block F, C.C.S.D. & R.G.N.G. Railroad Survey), which had an initial production of approximately 500 bbl of oil per day. Production in McElroy field is predominantly from porosity zones within dolostones of the Grayburg Formation (Upper Permian, lower Guadalupian) (fig. 3). Other deeper zones with shows and/or production in the field are the Lower Permian (Wolfcamp), Pennsylvanian (Bend), and Devonian, Silurian, and Ordovician (Ellenburger).

Reservoir energy in McElroy field was initially provided by a solution-gas drive mechanism. Development was first concentrated in what is now the central portion of the field. Field expansion and subsequent development started in 1930 and proceeded in several stages. Expansion was the result of a series of step-out wells that were completed with the assistance of a hydraulic fracturing procedure. These step-out wells added thousands of productive acres to the McElroy properties. Drilling in most of the Chevron-operated portions of McElroy field, encompassing about 18,600 acres and containing some 1,800 wells, has been developed on 10-acre spacing (fig. 4).

Pilot waterfloods were initiated in McElroy field in 1959 and 1960 (Goolsby and Anderson, 1964), and a full-scale waterflood was installed in the early 1960's. There have been two phases of infill drilling, an initial phase from 1971 through 1973 and a later phase from 1975 to 1977. Infill wells changed the waterflood patterns from the previous 40-acre 5-spots to 40-acre inverted 9-spots. Oil production dropped sharply in late 1977, and a stabilized decline of approximately 8 percent per year began.

Depositional Setting

The transition from the Central Basin Platform to the Midland Basin forms the depositional setting of the Grayburg Formation in McElroy field. An understanding of the structural configuration and depositional components of this platform-basin transition is derived from considering local stratigraphic evidence. Core and log studies from both McElroy field and North McElroy Unit (Longacre, 1980, 1983, 1986; Harris and others, 1984; Walker and Harris, 1986) have established the depositional facies in the area at Grayburg time (fig. 5). A broad spectrum of deposits, ranging from shoreline and inner-shelf (or inner-ramp) sediments on the west to slightly deeper-water marine-shelf (or outer-ramp) environments toward the east, accumulated along the eastern portion of the Central Basin Platform fronting the Midland Basin. The depositional slope across the portion of the shelf that now composes the field was gradual, possibly interrupted only by bars of carbonate sand or local reefs. Longacre (1983) has shown that a thick shelf-margin reef section, equivalent to the Grayburg Formation, is present along

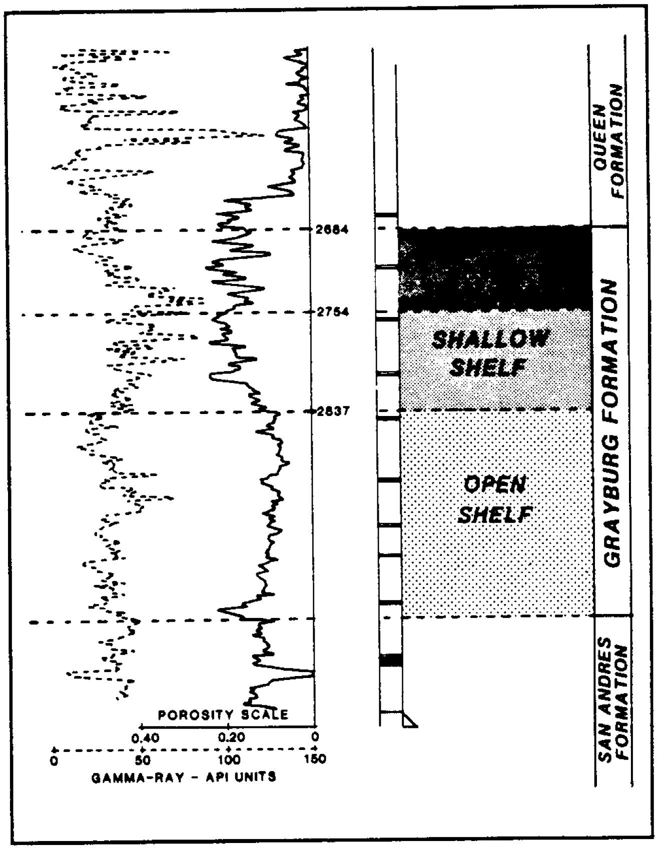


FIGURE 3. Type log of J. T. McElroy 1026 well, central McElroy field, with typical gamma-ray and neutron log responses. Porosity values were corrected to core-equivalent values over the reservoir interval using a core-to-log transform established for that portion of the field. Grayburg facies were defined by study of both conventional core and wireline logs. Wellbore diagram next to depth track indicates perforated intervals.

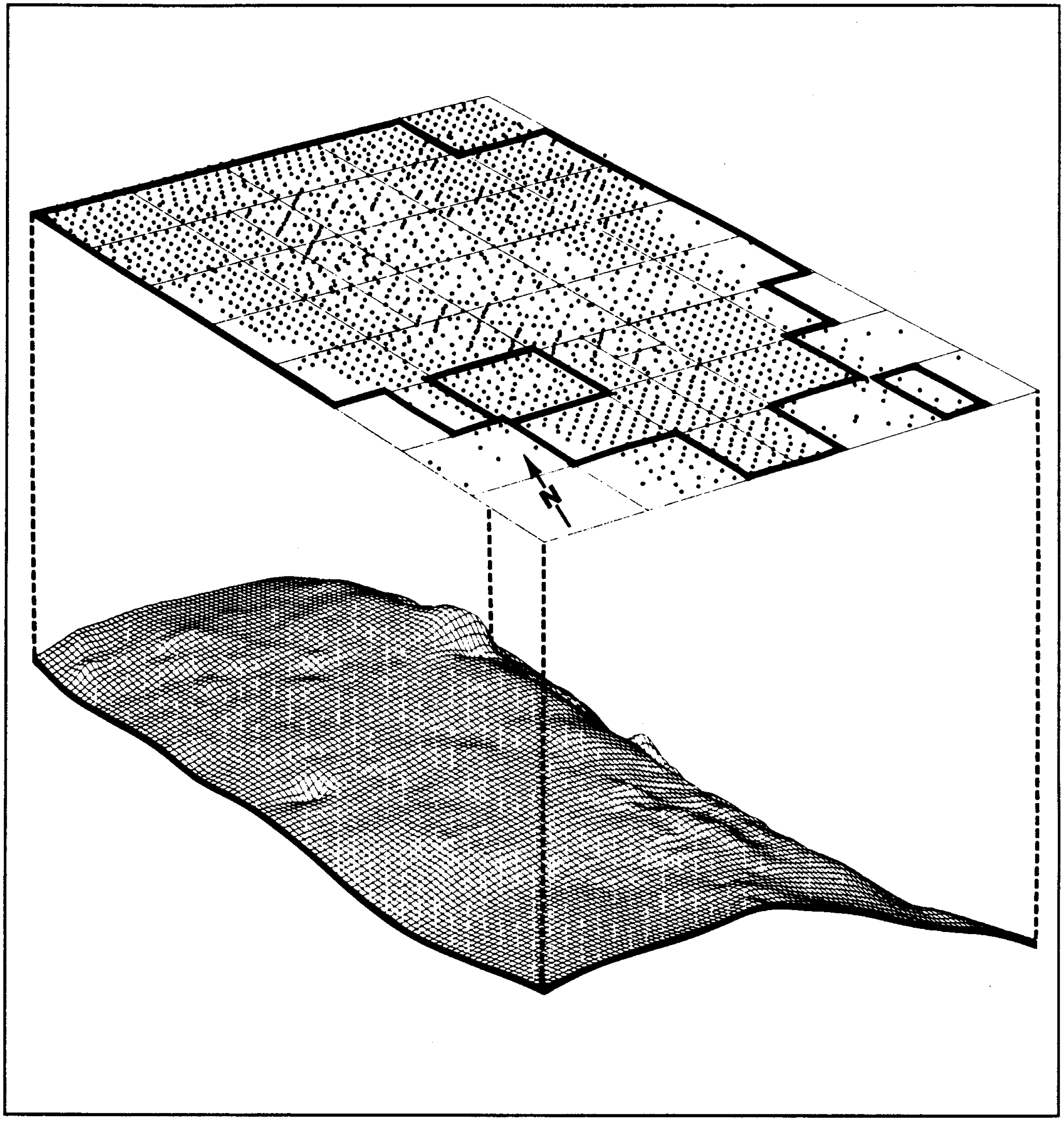


FIGURE 4. Mesh perspective structure map of an upper Grayburg marker, overlain by a map of well locations in McElroy field. Since 1926, more than 1,800 wells have been drilled in the field. Development of the reservoir has been through patterned drilling to improve the success of waterflooding. Different patterns have been used to exploit varying reservoir quality—sunflower patterns in the central portion of the field and 9-spot patterns on both the eastern and western flanks. Approximately 1,350 producing wells are supported by 450 water-injection wells. Section boundaries (1-mi^2) are shown on map view.

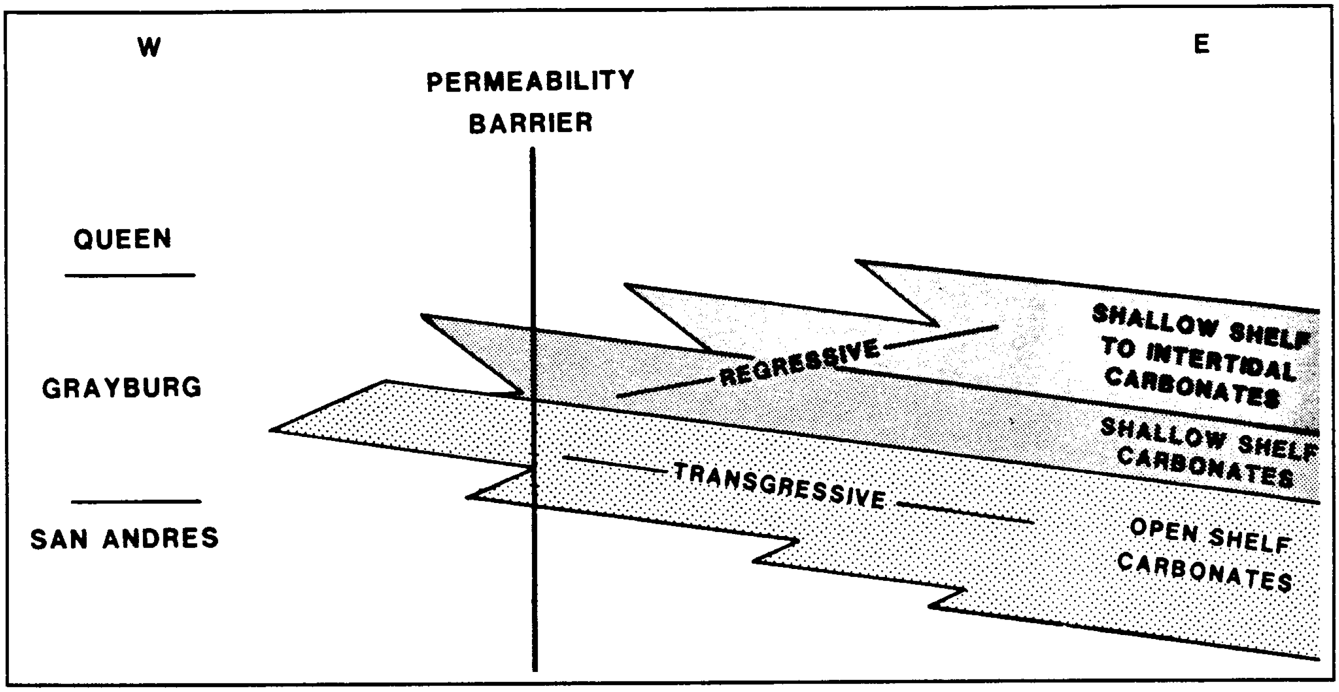


FIGURE 5. Schematic stratigraphic cross section through McElroy field emphasizing depositional facies of the Grayburg Formation. Dolostones of the Grayburg include open-shelf deposits formed during a transgression of the previously exposed San Andres shelf and overlying shallow shelf and intertidal regressive deposits. Continued regression resulted in evaporitic deposits forming both updip and overlying seals. The updip permeability barrier that defines the western edge of the field is due to evaporite plugging of porosity in dolostones as well as to bedded evaporites.

a portion of the easternmost boundary of the North McElroy Unit. But the continuity of the reef elsewhere along the margin of the Central Basin Platform has yet to be proven, and the reef interval does not contribute to the reservoir in North McElroy field.

McElroy field is a combination stratigraphic-structural trap. The field is now positioned along a north-trending asymmetrical anticline with a steeply dipping eastern limb and a more gently dipping western limb (fig. 2). Relief on the top of the Grayburg Formation, exceeding 1,000 ft on the east flank and 200 ft on the west, was not present at the time of deposition, as shown by lithofacies distribution and stratigraphic reconstruction. Regional isopach maps of the Grayburg and overlying strata show the timing of folding for the asymmetric structure to be post-Grayburg but still Permian in age (during deposition of the upper part of the Queen Formation and of the Seven Rivers Formation).

The top of the pay zone occurs at 2,620 ft in the central portion of the field, deepens to 3,000 ft toward the west, and increases to 3,800 ft to the east. Gross thickness of the producing interval is 400 ft, and total thickness of producing zones varies across the field from 80 to 250 ft. A stratigraphic permeability barrier caused by a facies change and an increase in the amount of porosity-plugging evaporites defines the western edge of the field, whereas the eastern boundary of the reservoir is limited by a gradual reduction of permeability coupled with an increase in water saturation.

Oil produced from McElroy field is naphthenic (fig. 6), has 32° API gravity, and has 2 weight-percent sulfur and 6 to 7 percent H_2S. Shales and shaly siltstones of the Lower Permian (Wolfcamp Formation) beneath the Midland Basin are suspected to be the primary source, on the basis of their organic contents and maturity. However, the oil-source correlation has not yet been established by organic geochemical data. Thus far, the organic geochemical data can only prove a source that is younger than the Mississippian Woodford Formation.

Average total organic carbon (TOC) for the Wolfcamp, an interval more than 1,000 ft thick, is 1.0 to 1.5 percent; maximum TOC is 2.0 percent. The kerogen type is undetermined and structureless;

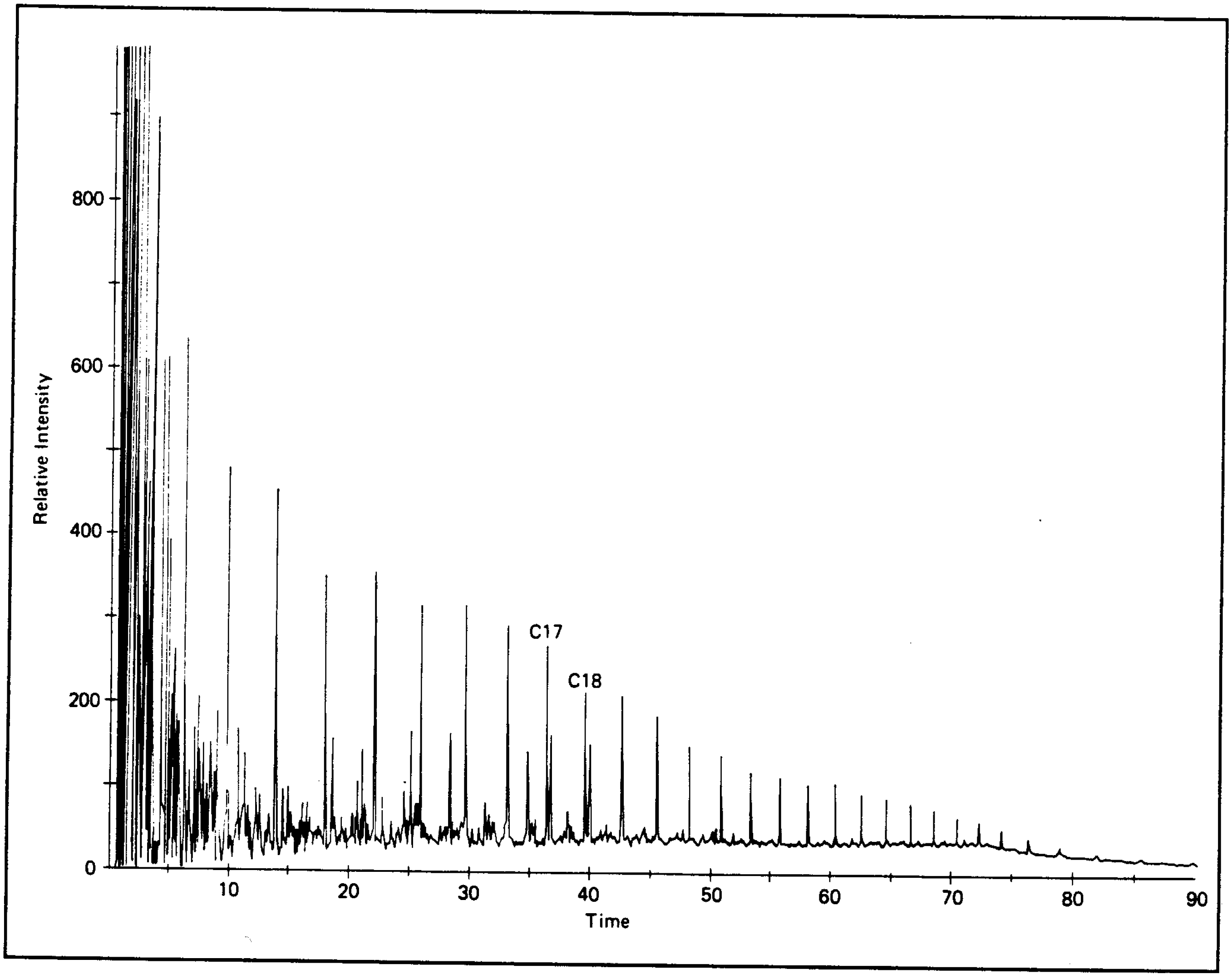


FIGURE 6. Representative gas chromatogram of oil sample, Grayburg reservoir, McElroy field.

vitrinite reflectance has an R_0 of 1.0 to 1.4. Depth to the top of the Wolfcamp is approximately 7,000 ft beneath McElroy field, with maximum burial perhaps 1,500 ft deeper reached at the end of the Mesozoic (fig. 7). The Wolfcamp Formation is thicker and 1,000 ft or more deeper to the east in the Midland Basin.

Stratigraphy and Facies

Stratigraphic relations within McElroy field have been discussed by Longacre (1980, 1983, 1986), Harris and others (1984), and Walker and Harris (1986). Longacre (1980) divided the Grayburg/San Andres and lower Queên sections into 11 depositional facies based on detailed core studies of the North McElroy Unit. In contrast, Harris and others (1984) proposed a more generalized facies subdivision of the McElroy field. We use this more generalized facies scheme of open-shelf, shallow-water shelf, and shallow shelf-to-intertidal facies (figs. 5 and 8) because the scale of the units is such that they are correlatable by both core and log methods and are probably more apt to be used by engineers during reservoir modeling.

The Grayburg carbonate shelf deposits are anhydritic dolostones that become increasingly evaporitic and silty toward the top of a upward-shoaling sequence. Dolostones are commonly finely crystalline, anhedral to subhedral, interlocking crystal mosaics. Well-formed dolomite rhombs are found only in small patches. Clay is rare, consisting of only trace amounts of poorly developed illite and kaolinite.

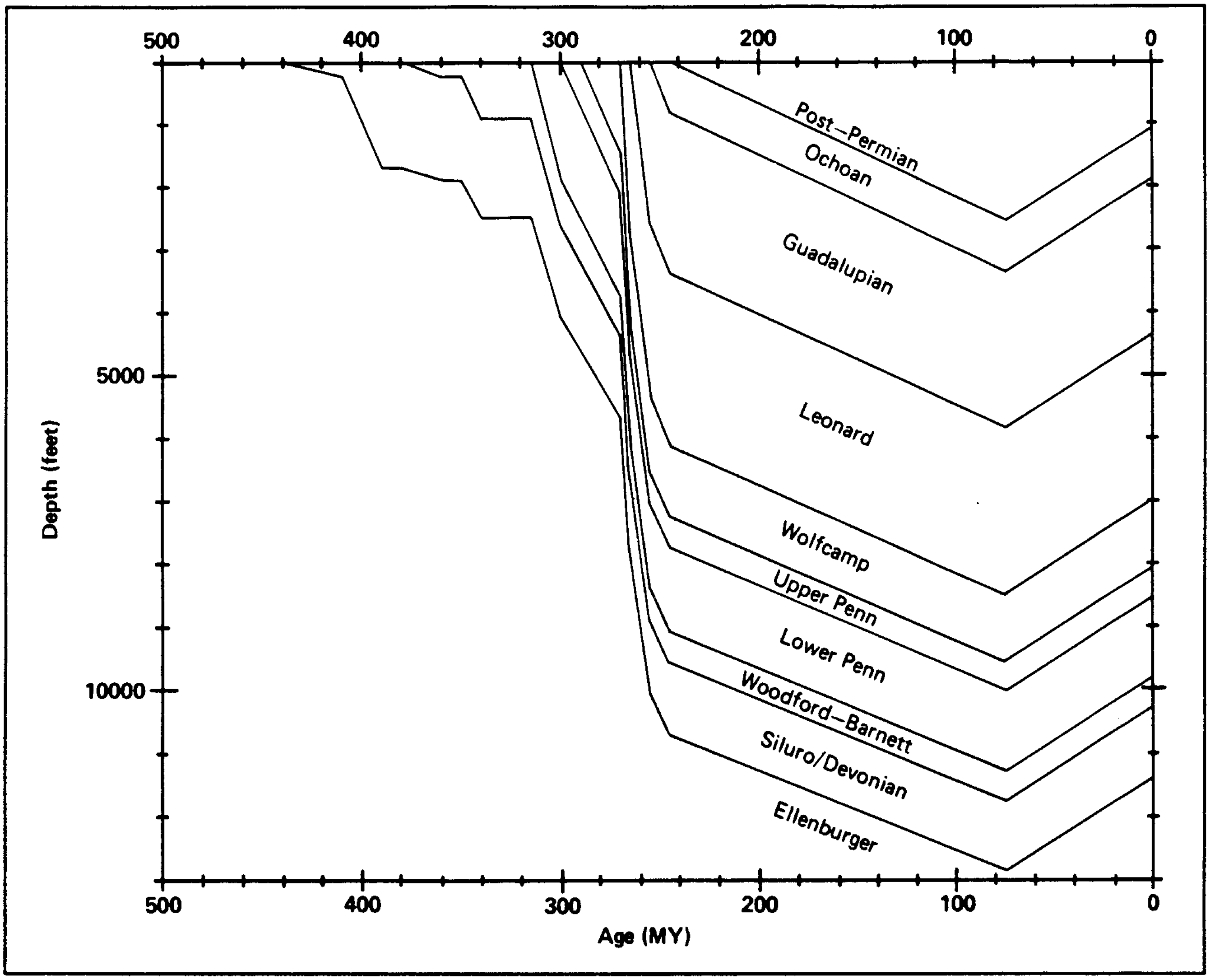


FIGURE 7. Geohistory plot, McElroy field. Various formation tops encountered in a well from the center of the field are plotted along the right vertical axis. Time of deposition, using the Decade of North American Geology geologic time scale (Palmer, 1983), and burial path through time for each of the formations are shown.

Coarsely crystalline anhydrite is ubiquitous, occludes moldic, vugular, and intercrystalline pores, and also occurs as nodules. Gypsum, bassanite (an unstable, hemihydrated phase of calcium sulfate), and authigenic quartz are also present in the dolostone in minor amounts.

Evaporitic Tidal Flat and Clastic Facies

The uppermost Grayburg and lower Queen Formations include tight, low-porosity tidal-flat and terrigenous clastic deposits that form the seal over the Grayburg shelf deposits (fig. 9A). Anhydrite occurs with mosaic texture or as isolated nodules that have displaced the surrounding sediment. Quartz siltstone and fine-grained sandstones, which are sometimes reddish, are tightly cemented by anhydrite and dolomite. The siltstones, along with gray-green silty dolomudstones, contain argillaceous material and finely dispersed pyrite. Dolostones are variable in texture and grain composition but are characterized by pisolites, intraclasts, desiccation cracks, collapse breccia, algal laminae, and fenestral porosity. Hairline fractures in dolopackstones/dolograinstones are commonly healed by anhydrite; nonetheless, minor microfracture and fenestral porosity remain.

The Queen Formation normally exhibits a pronounced gamma-ray variation. It is not unusual to have streaks of greater than 120 API units, and the jagged nature of the gamma-ray curve reflects the interbedded nature of the Queen (fig. 10). A natural gamma-ray spectroscopy log shows that high gamma-ray peaks result from elevated potassium and thorium values, and log-to-core correlations show that these peaks correlate with silty layers in the Queen. In contrast, dolostones in this part of the section have low levels of radioactivity. Gamma-ray response in the Grayburg is largely due to elevated uranium values in the dolostones, and less so to thin siltstones in the upper portion of the interval. Core studies in McElroy field indicate that the thin siltstones of the Grayburg are not laterally continuous. However, their continuity and therefore their value as correlation markers apparently increases along trend to the north where, in Dune field, some of the major siltstones are recognizable in wells 10 mi apart (Bebout, 1986; Bebout and others, 1987).

Shallow Shelf-to-Intertidal Facies

The shallow shelf-to-intertidal unit is heterogeneous in depositional textures and contains intraclast, fusulinid, and ooid dolograinstones interbedded with dolomudstones, burrowed dolowackestones, and minor quartz siltstone (fig. 9B). These deposits pinch out toward the west end of the field into tidal-flat and terrigenous clastic facies. Along the crest of the present-day structure, the best porosity and permeability observed in any lithofacies throughout the field occur in ooid and peloid dolograinstones of shallow shelf-to-intertidal origin. The porosity is predominantly interparticle; similar dolograinstones are cemented with anhydrite off the crest of the structure in the field, suggesting that solution of evaporites and enlargement of interparticle pores may have contributed to the porosity in the dolograinstones along the crest.

The electric-log character of the shallow shelf-to-intertidal deposits is as variable as the lithology (fig. 8). Lateral facies changes and interfingering with the overlying siltier sediments make correlation of the unit difficult without core. Both upper and lower contacts are gradational; however the upper contact with low-porosity sands and anhydrite is easier to pick than the lower change to porous shallow-water shelf dolostones.

Shallow (Water) Shelf Facies

The shallow shelf is characterized by burrowed dolowackestones and dolopackstones containing pelecypods and peloids (fig. 9C, 9D). On the basis of depositional textures, grain types, and sedimentary structures observed in cores, shallow shelf lithofacies are interpreted to have formed in a slightly more agitated environment relative to the underlying open-shelf facies. Gradual changes in shallow shelf lithologies occur across the field. From west to east, homogeneous dolomudstones with scattered pelecypods and echinoid fragments become more fossiliferous with the addition of bryozoans and green algae. These sediments are still mud-supported, suggesting little current activity. However, on the structural crest and east flank of the field, local grain-supported intervals suggest an increase in bottom agitation. Porosity types are intercrystalline, vuggy, and moldic after pelecypod shells; porosities decrease toward the western edge of the field owing to evaporite plugging.

Smaller patch reefs or mounds described by Longacre (1983) and Harris and others (1984) contribute only locally to the reservoir interval in McElroy field in both the shallow shelf and underlying open-shelf portions of the Grayburg section. Sponges, algae, bryozoans, *Tubiphytes*, and fibrous marine cements form the framework for the small patch reefs or mounds. The original porosity within this framework has subsequently been occluded by evaporites. The carbonate sands associated with the reef are commonly peloidal dolograinstones and dolopackstones. Only minor porosity remains in the sands as anhydrite, and, less commonly, gypsum fills most interparticle, fracture, and vuggy porosities.

Open-Shelf Facies

Open-shelf deposits of the basal Grayburg Formation include dolowackestones and dolopackstones and, less commonly, doloboundstones (patch reefs with associated carbonate sands). Dolowackestones and dolopackstones of the open shelf are burrowed mixtures of peloids and fusulinids (fig. 9E, 9F). Fusulinid molds sometimes contribute to porosity but more typically are filled with anhydrite. Reservoir zones within the open-shelf facies occur in dolomitized muds; these may occur as dolomudstones, dolowackestones, or even matrix in dolopackstones. Porosity types include interparticle between peloids,

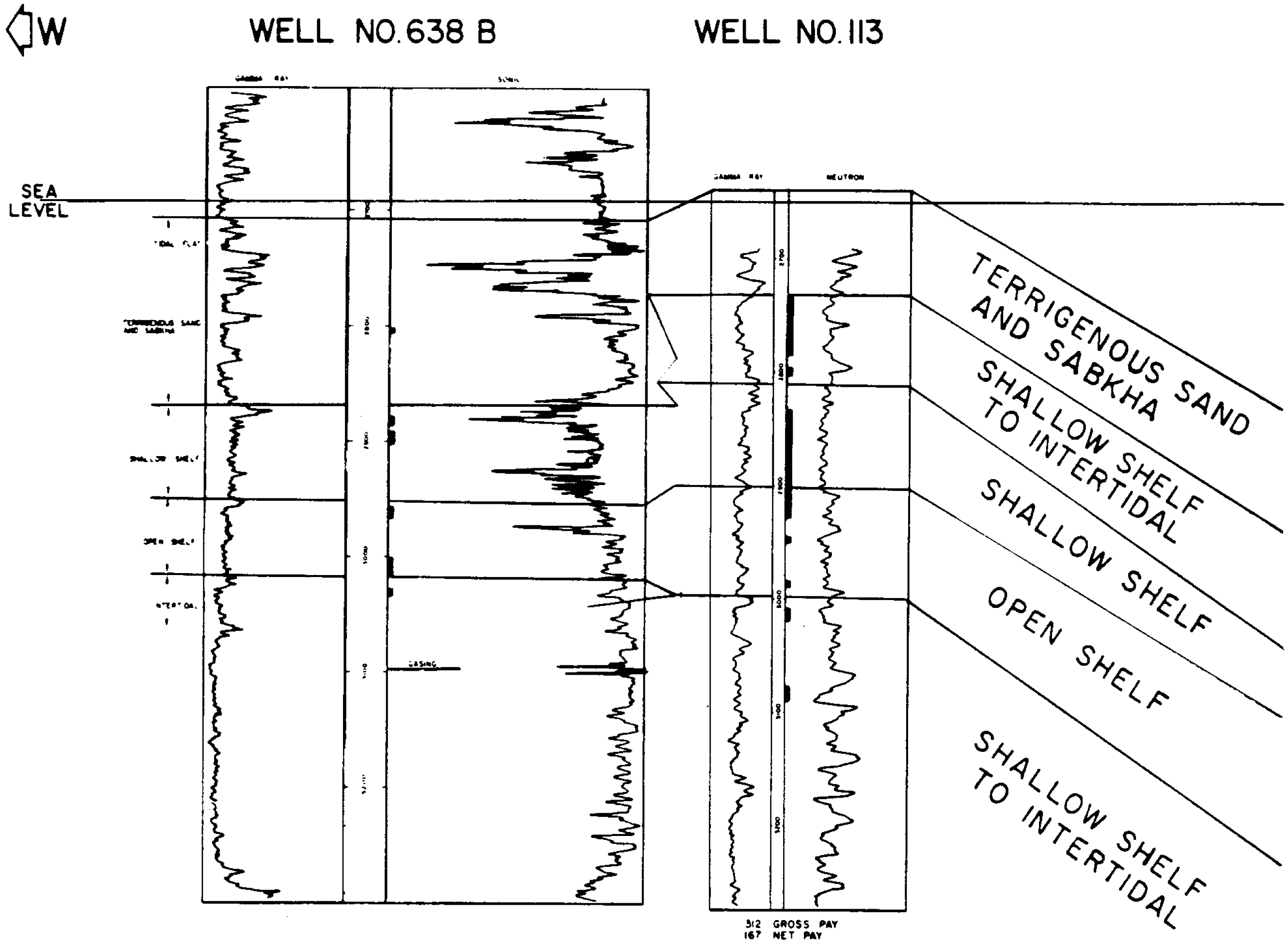
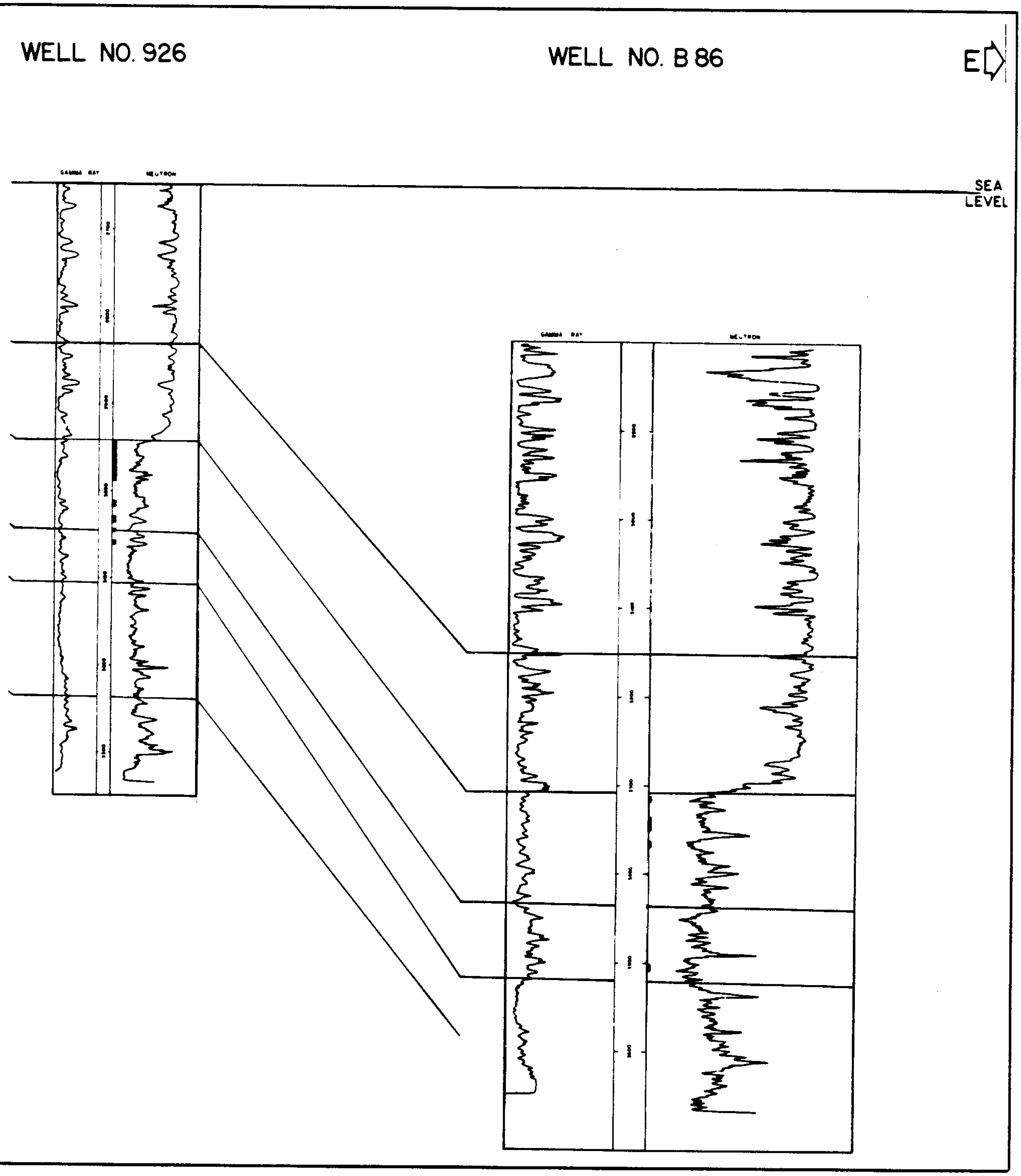


FIGURE 8. Cross section A-A′, McElroy field. See figure 2 for well locations and line of section. Lithofacies interpretations are based on continuous conventional cores; correlations are adjusted to wireline log picks. Shallow shelf-to-intertidal deposits extend to the east but are missing in wells to the west such as well 638B. The tidal-flat to terrigenous clastic facies that cap the Grayburg sequence and form the Queen Formation are



much thicker in more westerly wells where the shallow shelf-to-intertidal deposits are missing. Log variation between wells reflects lithological changes that control porosity development within depositional facies. Vertical black bars indicate reservoir zones with permeability greater than 1 md.

intercrystalline, and microvuggy. Intraparticle porosity is also present where fusulinids are preserved. Dolomudstones in the open-shelf facies appear to have fine intercrystalline porosity in thin section, but core analysis indicates that the associated permeability varies greatly.

The open-shelf facies thickens slightly on the east flank of the field where it is in gradational contact with the overlying shallow shelf (fig. 8). The contact is difficult to pick on wireline logs. In contrast, the same contact is more abrupt in the western portions of the field and can be identified easily on gamma-ray logs. Log identification is possible because the open shelf is cleaner and has a lower gamma count than the overlying shallow shelf (figs. 3 and 10). The neutron porosity logs indicate that porosities are higher in the shallow shelf than in the open shelf, and a gradual reduction of porosity occurs with depth.

Facies Interpretation

The depositional sequence recognized in cores from McElroy field formed in a shallow shelf (inner ramp) and related tidal-flat and evaporitic (sabkha) setting (fig. 11). The facies developed during easterly progradation across a deeper-water open shelf (outer ramp). Core data and depositional models of other fields along the trend (Yates field by Adams, 1930, Donoghue and Gupton, 1957, and Craig and others, 1986; Foster field by Young and Vaughn, 1957; Dune field by Bebout, 1986, and Bebout and others, 1987; Means field by George and Stiles, 1978, 1986) suggest that major portions of the eastern margin of the Central Basin Platform were dominated by similar depositional facies systems in which carbonate sand-shoal and updip tidal-flat facies belts were important.

Toward the end of Grayburg deposition, carbonate production was gradually terminated by the rapid advance from the west of silts and evaporites of the uppermost Grayburg and Queen Formations. A gradational change occurs in cores from McElroy field from carbonates to siliciclastics and evaporites updip and upsection. The upper Grayburg is typically a silty, anhydritic dolostone marking the upper portions of an upward-shoaling depositional sequence that is recognized in McElroy and other fields along the trend (Garber and Harris, 1986). Bartel and Broomhall (1986) described a similar progradational situation in the San Andres Formation in Means

FIGURE 9. Core photographs of various lithofacies, McElroy 109 well. ►

A. Evaporitic tidal-flat and terrigenous clastic facies, Queen Formation. Bedded dolopackstone/grainstone with root tubules(?), clasts, and microfractures. Core slab, 2,671 ft.

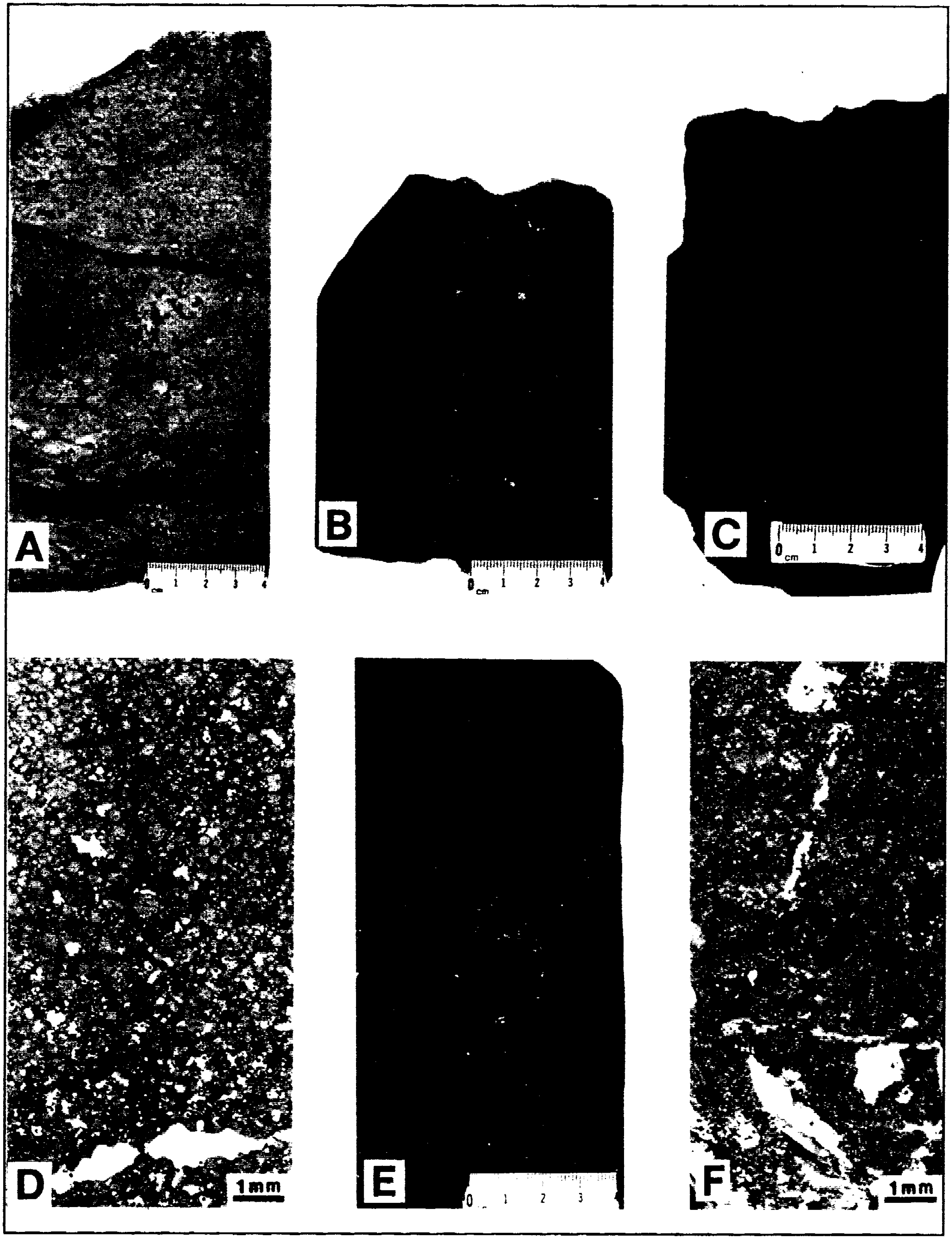
B. Shallow shelf-to-intertidal facies, Grayburg Formation. Silty dolowackestone/packstone. Core slab, 2,743 ft.

C. Shallow shelf facies, Grayburg Formation. Burrowed peloid and ooid dolograinstone. Core slab, 2,755 ft.

D. Shallow shelf facies, Grayburg Formation. Photomicrograph of thin section in plane-polarized light, 2,746 ft. Sample similar to core slab of figure 9C, showing porous peloidal dolograinstone. A few of the grains are ooids or composite grains. Porosity shown in white; note solution-enlargement of pores.

E. Open-shelf facies, Grayburg Formation. Burrowed fusulinid dolopackstone/wackestone. Note the spotty development of moldic porosity after fusulinids. Core slab, 2,853 ft.

F. Open-shelf facies, Grayburg Formation. Photomicrograph of thin section in cross-polarized light, 2,840 ft. Sample shows anhydrite-filled fusulinid molds and microfracture in dolowackestone. Microvuggy porosity shown in black.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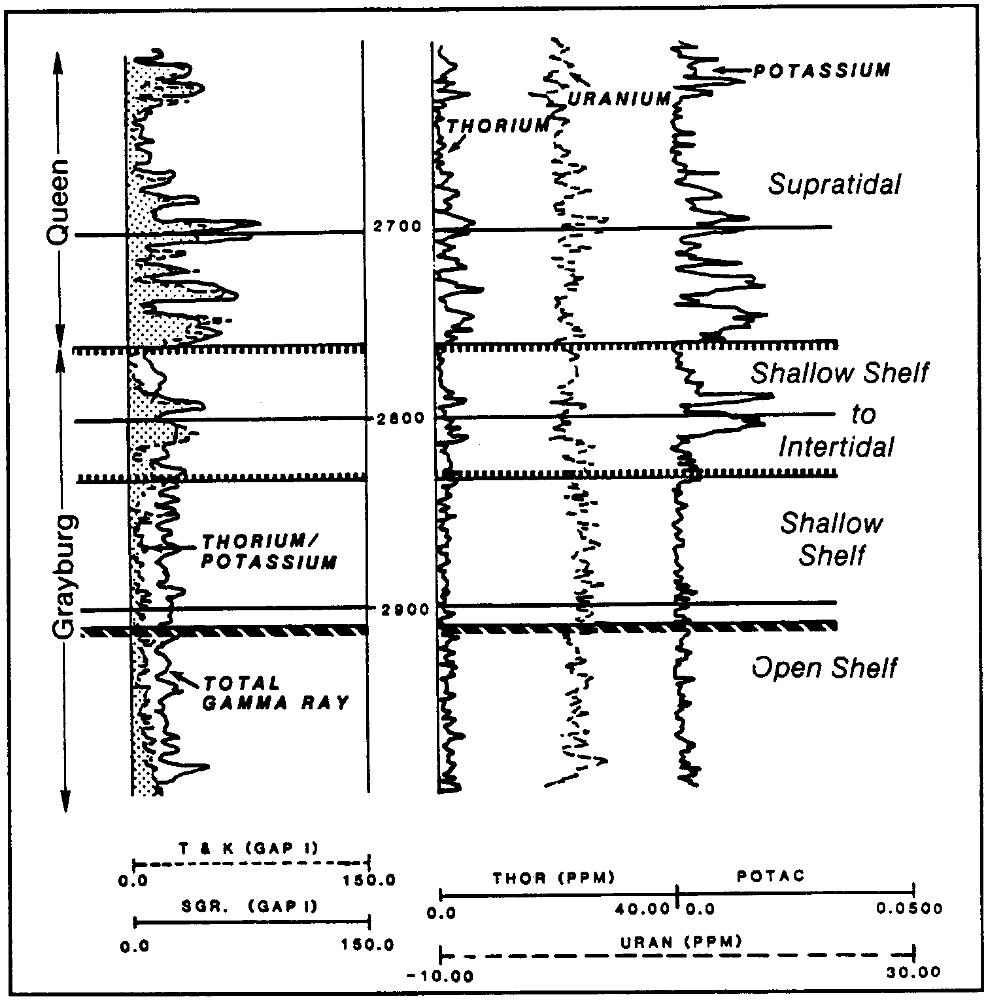


FIGURE 10. Natural gamma-ray spectroscopy log, McElroy 1030 well, showing the variation of the total gamma ray and its components with regard to lithofacies.

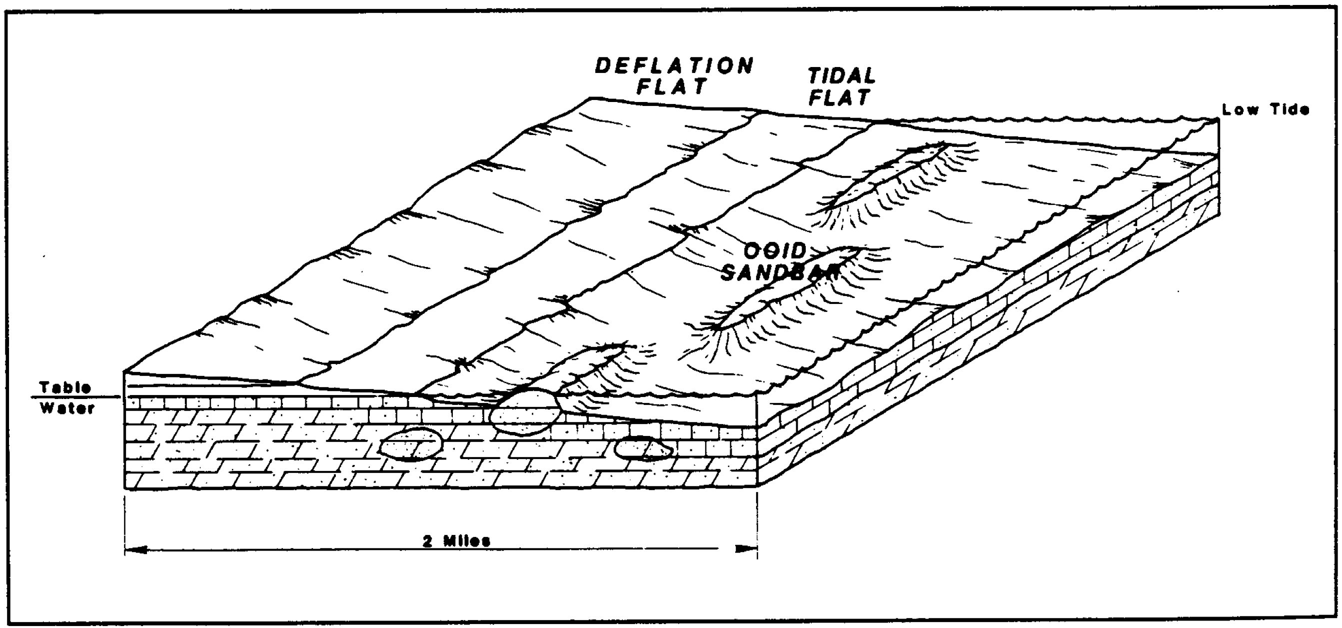


FIGURE 11. Schematic block diagram illustrating the various depositional environments present in McElroy field during deposition of the shallow shelf-to-intertidal sediments. Discontinuous carbonate sands are some of the most porous portions of the shallow shelf-to-intertidal facies. These are interpreted to have formed as sand bars on a shallow-water marine shelf or inner ramp.

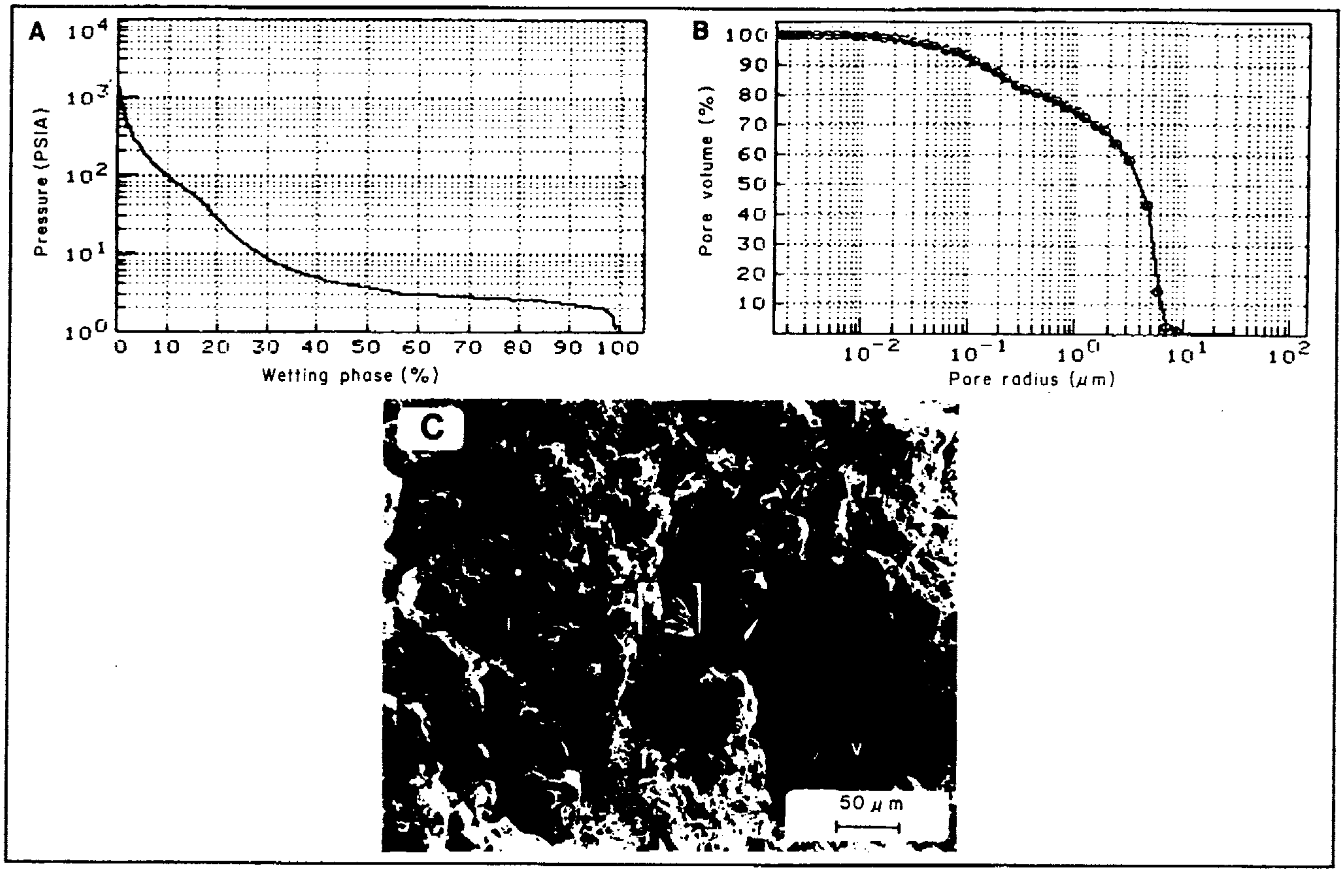


FIGURE 12. Capillary pressure curve and SEM photomicrograph of a finely crystalline dolomite with 15 percent porosity and 53 md permeability. The capillary pressure curve (A) is converted to a curve of pore throat radius versus percentage of pore space (B). SEM photomicrograph (C) shows intercrystalline pores (I) and large pores that may be either solution-enlarged moldic pores or vugs (V). Small box highlights an area containing kaolinite. Seventy percent of the pores are between 1 and 10 μm radius.

field (Andrews County, Texas), further to the north along the same edge of the Central Basin Platform. Their interpretation of seismic lines suggested that discrete depositional intervals were present in successively younger stratigraphic position on the east flank of the structure at Means field, and farther to the west in the field, the stratigraphic section is interrupted by sequence boundaries. Cores from McElroy field show apparent gradational changes between major facies, however, suggesting that abrupt basinward shifts of the facies tracts did not occur there as in Means field.

Development Aspects

Approximately 75 percent of the reservoir of McElroy field lies within dolostones of shallow shelf and intertidal origin that contain intercrystalline porosity. Other porosity types are also important to production where they occur in conjunction with the intercrystalline porosity (figs. 12 and 13); moldic porosity is common in dolowackestones and packstones, and vugular and fracture porosity are present in portions of the field. Although quite variable, the average porosity is 9 percent and the average permeability is 2.5 md. Capillary pressure measurements indicate that porosity observed in thin sections alone is a poor indicator of reservoir potential because of variations in permeability and pore-throat size. Permeability variation is related to depositional texture, crystal size of dolomite crystals, and porosity occlusion by evaporites. Because clays are rare, they have little effect on permeability.

Intercrystalline pores vary in size and position relative to dolomitized carbonate grains. The most abundant intercrystalline pore type is very fine in size (approximately 1 to 2 μm pore throat diameters) and

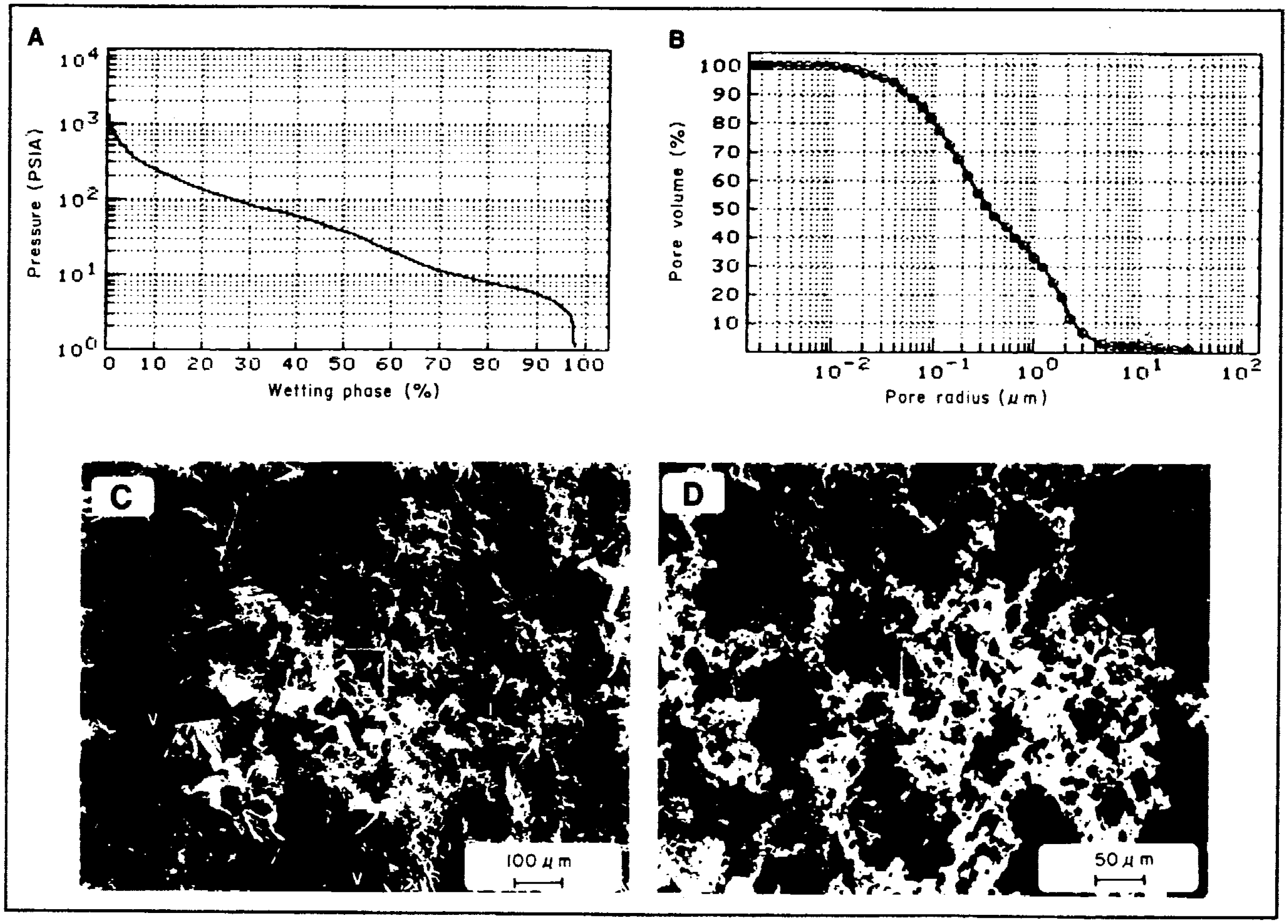


FIGURE 13. Capillary pressure curve (A), curve of pore throat radius versus percentage of pore space (B), and SEM photomicrographs of a finely crystalline dolomite with 9 percent porosity and 0.3 md permeability. SEM photomicrograph (C) shows minor intercrystalline porosity (I and boxed area) and scattered, large, vugular or moldic porosity (V). Epoxy pore cast (D) shows moldic and intercrystalline pores; most intercrystalline pores are irregularly shaped, smaller than 10 μm in diameter with pore throat diameters less than 1 μm, and dead-ended. The pore cast was made by injecting plastic resin into the oil-extracted sample at 1,500 psi and dissolving away the carbonate rock.

is located in matrix areas away from carbonate grains. Epoxy pore casts show that these small, intercrystalline pores are highly irregular in shape and moderately well connected. Less common are intercrystalline pores with minimum pore throat diameters of approximately 5 μm. These intercrystalline pores are located immediately adjacent to carbonate grains (peloids and ooids), are more regular in shape, and are moderately well interconnected. A peloidal texture was sometimes apparent in pore cast but not in a thin section of the same sample. A third minor type of intercrystalline pore occurs only in the nuclei of ooids. This microporosity is less than 1 μm in diameter and is surrounded by a much less porous rim consisting of dense interlocking dolomite crystals.

Moldic pore space is the second most common pore type. Although these pores are larger than the intercrystalline pores (diameters of approximately 100 μm), they add to the effective pore volume only if connected by intercrystalline pore space. Most of the moldic pores are elongate to round and represent leached fossils and peloids. Where moldic pores are truly isolated, measured permeabilities are low and pore casts are difficult to make.

Two types of vugular pores are recognized: (1) large, irregularly shaped pores located between dolomite crystals (greater than 50 μm diameters) and (2) small, irregularly shaped pores located within dolomite crystals (1 to 2 μm diameters). The smaller vugular pores formed by the partial dissolution of dolomite crystals. The larger vugular pores, on the other hand, may represent solution enlargement of moldic pores and dissolution of evaporite nodules.

Distribution of absolute permeability in individually measured samples ranges from 0.01 md to 2 darcys. Microscopic heterogeneity of permeability distribution reflects dolomite crystal size and sorting, dissolution of carbonate grains and sulfates, and the varying pore types discussed previously, whereas macroscopic heterogeneity across the field results from facies changes and the accompanying variation of depositional texture. Porosity occlusion by evaporites is apparently more extensive on the flanks of the structure than along the crest; the development of vugular porosity, conversely, is more common along the crest of the structure. As a result of these variations, the trend is for the more permeable interval to thicken toward the center of the field. Recovery efficiency under both primary and secondary operations improves in the center of the field, as does the pay quality. Cumulative-production data indicate that maximum production has been from wells in the center of the field that are situated along the crest of the structure (fig. 14).

Reservoir performance of any stratigraphic interval varies throughout the field as the quality of the pay interval changes. Reservoir zones thin toward the eastern side of the field and pinch out to the west. Interbedded nonporous zones separate the reservoir vertically throughout the entire field and make correlation of pay zones and prediction of continuity between wells difficult (figs. 15 and 16). Shallow shelf deposits are relatively homogeneous and unstratified, and vertical continuity within this zone is good, despite localized nonporous zones due to evaporite cementation. The overlying shallow shelf-to-intertidal deposits are stratified and show abrupt lithological variation vertically and horizontally.

The importance of evaporite facies as updip seals in reservoirs like McElroy cannot be overstated. Oil discovered in Guadalupian strata throughout the Permian Basin is found primarily at the boundary between updip evaporites and associated shelf dolostones or siliciclastics (Ward and others, 1986). At McElroy field, the reservoir is overlain and passes updip into an impermeable anhydrite, halite, siltstone,

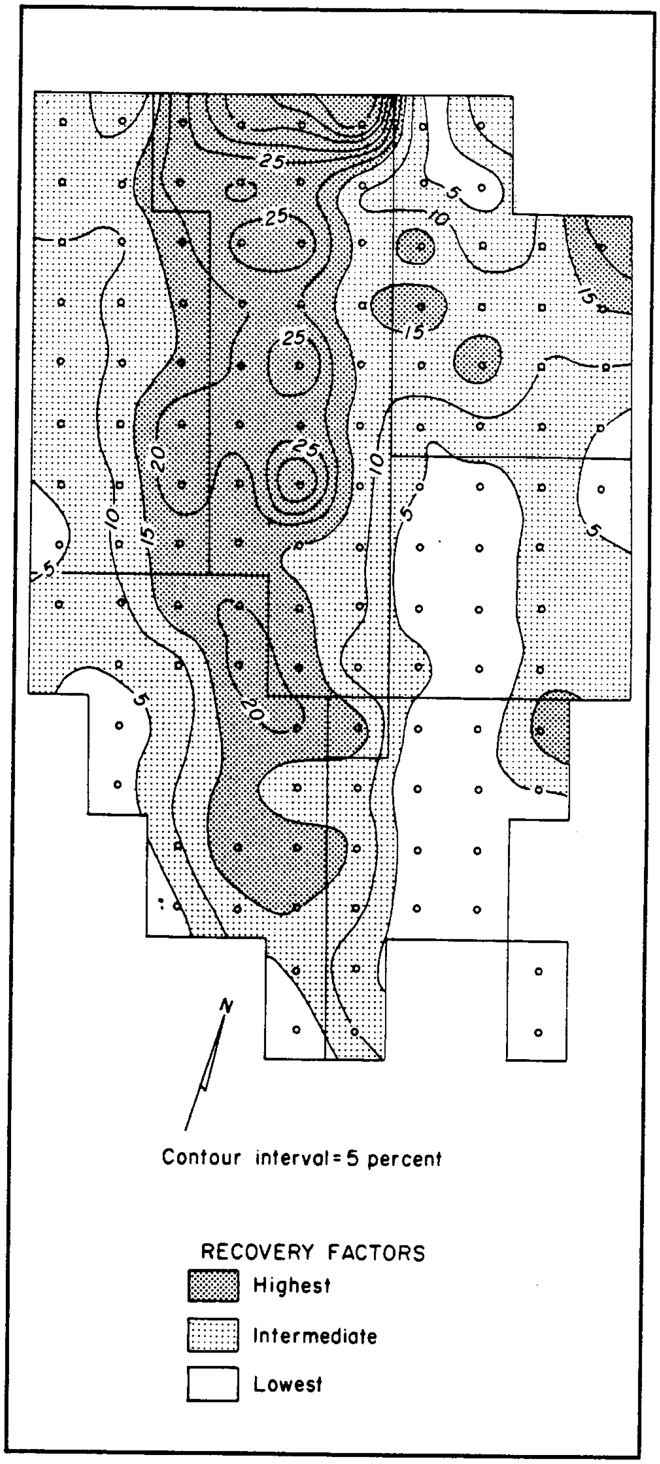
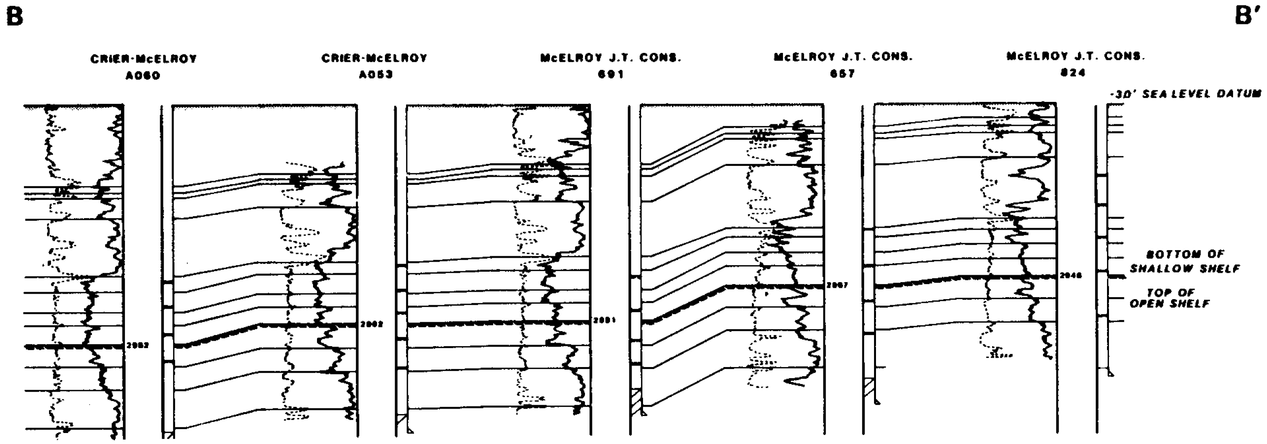


FIGURE 14. Recovery-factor map of McElroy field illustrating varying recovery between central and flanking areas. Highest recoveries are from central field areas; poor reservoir performance, in the flanking areas of the field, is related to decreased reservoir quality.


B
B′
CRIER-McELROY
A060
CRIER-McELROY
A053
McELROY J.T. CONS.
691
McELROY J.T. CONS.
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McELROY J.T. CONS.
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-30′ SEA LEVEL DATUM
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2982
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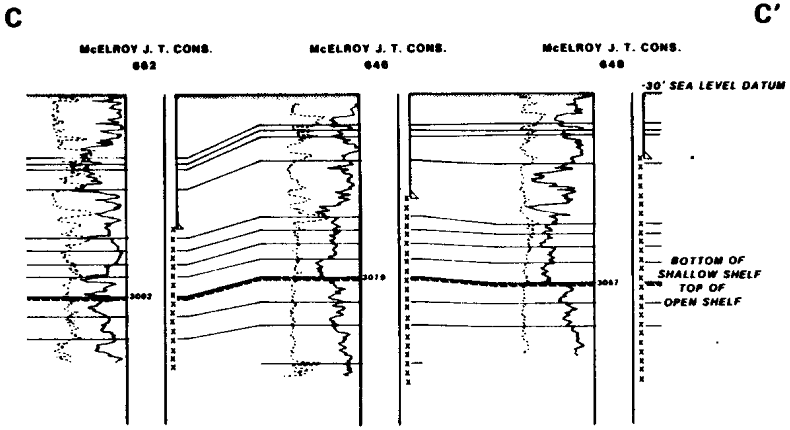
BOTTOM OF
SHALLOW SHELF
TOP OF
OPEN SHELF


C
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McELROY J. T. CONS.
662
McELROY J. T. CONS.
646
McELROY J. T. CONS.
648
-30′ SEA LEVEL DATUM
3002
3019
3067
BOTTOM OF
SHALLOW SHELF
TOP OF
OPEN SHELF

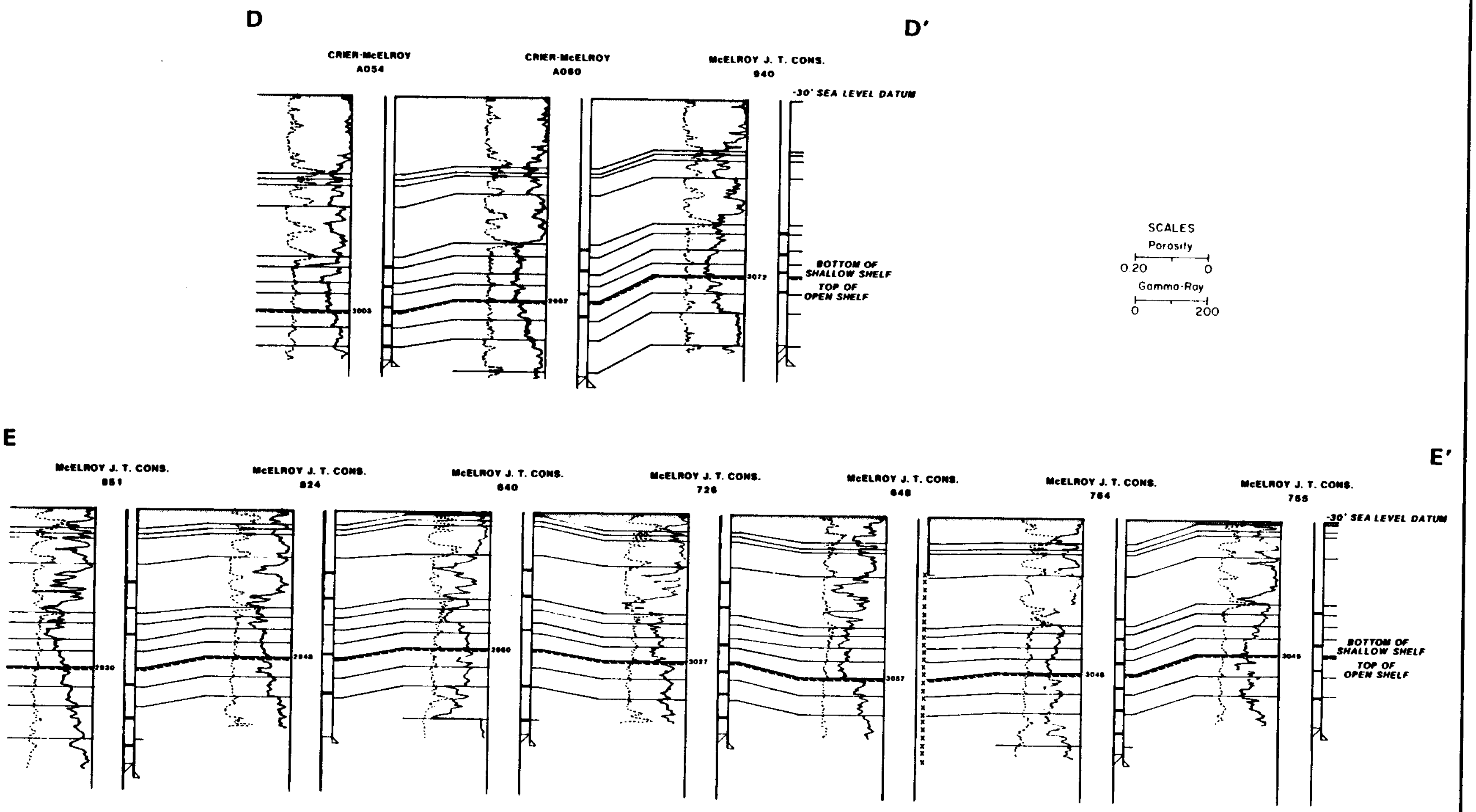

FIGURE 15. Stratigraphic cross sections B-B', C-C', D-D', and E-E' based on gamma-ray log correlations, which highlight porosity variation in closely spaced wells from the southwestern portion of McElroy field. Porosity is higher in the shallow-water shelf than in the open-shelf interval in each well, but it varies between wells at all stratigraphic intervals. Well locations and lines of section are shown in figure 2.

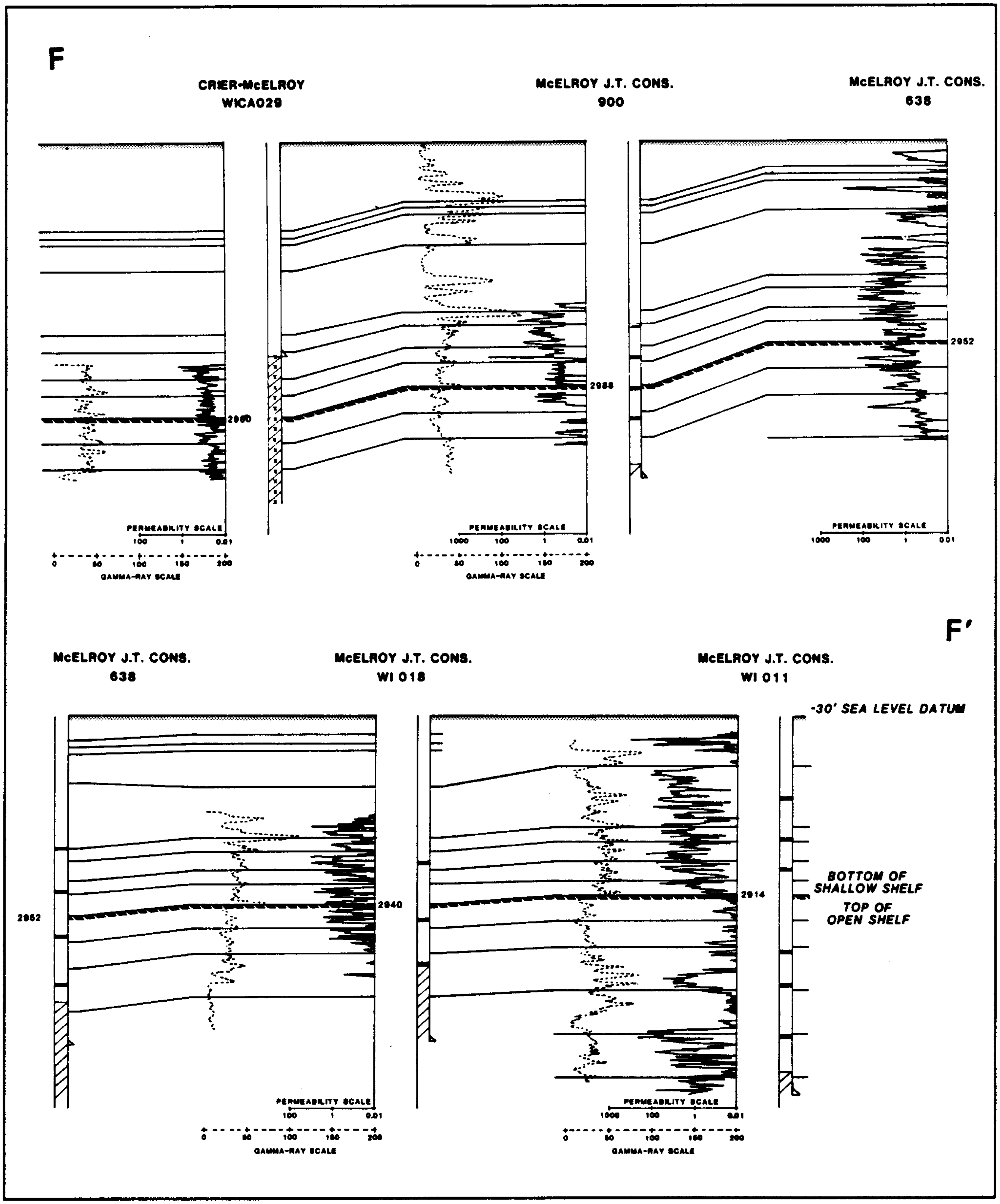

FIGURE 16. Stratigraphic cross section F-F′ based on gamma-ray log correlations and showing permeability variation between closely spaced cored wells from southwestern McElroy field. Well locations and line of section shown in figure 2.

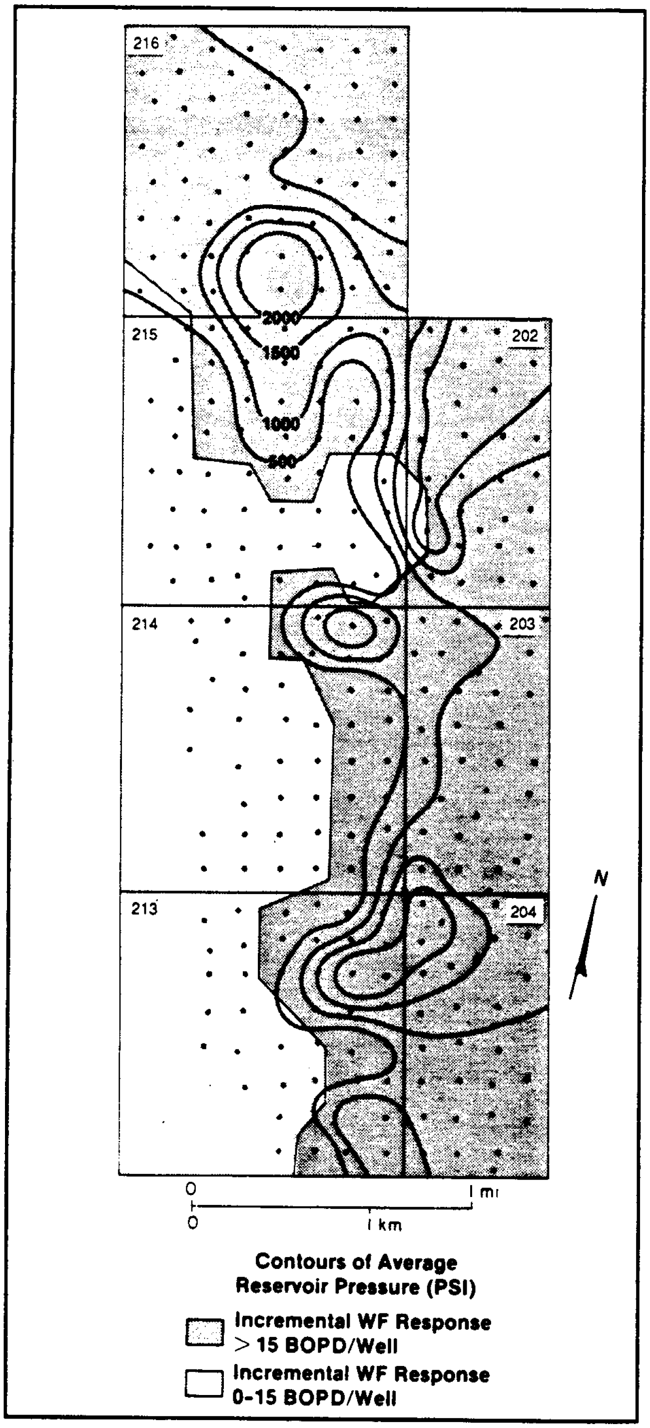

FIGURE 17. Map of part of the western edge of McElroy field showing both average reservoir pressure and incremental waterflood response. Shading highlights the decrease of reservoir quality that parallels a facies change to more evaporitic and siliciclastic lithologies.

and dolostone section. Waterflood response, as shown for part of the field (fig. 17), reflects these facies changes. Incremental waterflood response and average reservoir pressure are greater immediately downdip of this evaporite boundary in the field. Anhydrites and locally impermeable dolomites of the underlying San Andres Formation similarly restrict the lower extent of the productive oil column.

Production in McElroy field is complicated locally by larger-scale permeability patterns. After the beginning of the waterflood, abnormally high water production could be traced to direct communication between injection and producing wells. Log and core studies have confirmed that fractures are present in McElroy field, and engineering data suggest that the fractures cause the high production in certain wells. These fractures are both natural and induced, the latter having formed during overinjection or by treatments to stimulate production.

Recovering the most oil possible from large reservoirs like McElroy field by using better enhanced-recovery techniques is vital. Plans for continued development of the reservoir focus on improving the current waterflood by more careful evaluation of reservoir continuity using geological models and reservoir engineering data. Further study of the orientation and magnitude of permeability "channeling" is necessary to aid remedial work intended to direct more injected water into unswept zones. Fluid-injection profiles are being modified on certain water injection wells through polymer treatments, and an increase in the volume of injected water into "tighter" zones is intended to provide waterflood support in portions of the field where poor vertical sweep efficiency has made the flood ineffective. A CO_2 pilot program has been proposed and is currently under study.

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