depths of 500 ft (152 m) or less. The gas-bearing aquifer is underlain by gas-bearing, low-permeability sandstones of Early Cretaceous age that form the Wattenberg field. It contains reserves of natural gas at depths of 7,500 to 8,500 ft (2,285 to 2,590 m) but requires massive hydraulic stimulation to provide economic flow rates.

Gases from the water wells are generally dry ($C_1/C_{1-5} > 0.99$) and enriched in the light isotope ^{12}C ($\delta^{13}C_1$ values range from -73 to -70 ppt). These gases are interpreted to be of biogenic origin that are being or have been generated in an anoxic, sulfate-free environment within the aquifer system. The probable source of carbon is the organic matter originally deposited with the Upper Cretaceous sediments.

In an area north of Milton Lake, coinciding with a region containing higher amounts of dissolved sulfate in ground water, methane is generally not detected in ground water. Water from wells in this region has a putrid odor and probably contains hydrogen sulfide resulting from microbial sulfate reduction. The absence of methane is probably explained by the fact that methanogenesis generally is not concurrent with the process of sulfate reduction and usually begins after dissolved sulfate is removed from ground water.

Gases from the Wattenberg field, coming from considerably greater depths than those from the water wells, are distinctly different from most of the water-well gas in both chemical and isotopic composition. They contain significant amounts of heavier hydrocarbons (C_1/C_{1-5} values range from 0.83 to 0.87) and are isotopically heavier ($\delta^{13}C_1$ values range from -49 to -43 ppt). The chemical and isotopic composition of the gases indicate that they are thermogenic in origin and were generated by thermal cracking processes during intermediate stages of thermal maturity in the deeper part of the Denver basin. This interpretation is consistent with the level of maturation determined by source rock studies.

Occasionally, gases from water wells are almost identical in both chemical and isotopic composition to gases produced from the underlying Wattenberg field in the immediate area. These gases are also interpreted to be of thermogenic origin and probably migrated from deeper reservoirs.

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Porosity Types in Limestones

A suite of selected oolitic limestones ranging in age from Devonian to Pleistocene was studied petrographically with light microscopy and SEM observation of resin pore casts, and petrophysically with measurements of porosity, gas and liquid permeability, and with mercury injection capillary pressure curves. A new genetic classification of porosity types and related processes in oolitic limestones is presented which is based on the chronological order of their occurrence in the natural history of the rock, following the terminology and concepts of Choquette and Pray.

The 11 subdivisions of the proposed classification are: *Primary Porosity*: pre-deposition, deposition; *Secondary Porosity*: eogenetic dissolution, eogenetic drusy cementation, eogenetic compaction, mesogenetic cementation, mesogenetic dissolution, mesogenetic compaction, late mesogenetic cementation, telogenetic recrystallization and telogenetic dissolution. Furthermore, it is possible to subdivide the investigated samples into five evolutionary stages showing the gradual reduction of primary porosity mainly through cementation, and into six stages showing the modification of secondary porosity mainly through dissolution.

Concurrently, 11 laboratory experiments were performed in which samples of a tightly cemented Mississippian oolitic calcarenite were submitted to simulated burial conditions, and undersaturated carbonic acid solution was forced to pass through them. The result was selective dissolution of the ooid cortical layers, with the sparite cement preserved undissolved. It is concluded that oomoldic porosity can result from textural variation between components and does not necessarily imply that the ooids had an unstable mineralogy.

The understanding of the complex time and space relationships between the different types of porosity in oolitic limestones is critical for reconstructing their depositional-diagenetic history and for evaluating their economic importance as potential hydrocarbon reservoirs.

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Lithologic Comparison of Two Linear Sand Ridges from Nearshore and Middle Portions of New Jersey Continental Shelf, U.S.A.

Two linear sand ridges from the nearshore and middle portions of the New Jersey continental shelf were sampled using a vibracore system and box corer. Lithologic descriptions were made of the cores based on epoxy peels, X-ray radiographs, and impregnated core slabs. The cores were sampled for grain-size analysis. Box cores sampled lithologies and relative abundance of physical and biogenic structures found in the upper 25 to 46 cm (9.8 to 18.1 in.) of the sediment. Bottom topographies were established using 3.5 kHz data.

The nearshore sand ridge sampled (74°22′W, 39°19′N) exceeded 5 km (3 mi) in length and ranged up to 2 km (1.2 mi) in width and had a relief of 6 to 10 m (20 to 33 ft). A mid-shelf ridge (74°08′W, 39°09′N), nearly 4 km (2.5 mi) long and up to 1 km (0.6 mi) wide, with a relief of 10 to 11 m (33 to 36 ft) was also studied.

The vibracores averaged 6 m (20 ft) of penetration and in excess of 95% recovery, and although partially deformed as a result of the coring procedure, revealed three general lithologic units which may be common to both ridges.

At the base of many of the cores, nonskeletal mud and poorly sorted sand are present; some of the interlayered sands and muds contain laminations and abundant pebbles. Overlying this unit in the nearshore ridge is a shell-rich mud and sand interval that is for the most part massive (bioturbated). This lithology was also recovered in one core from the middle shelf ridge. C-14 dates taken from the shell-rich units indicate that the middle and nearshore ridges are of different ages.

The top unit in all the cores is a fine to medium-grained sand, here termed the upper ridge sand. This unit, similar in both ridges, consists of stacked beds ranging from 3 to 71 cm (1.2 to 28 in.) in thickness, and generally coarsens upward. This unit in the nearshore ridge system has a slightly coarser mean grain-size range (150 to 400 μ) than the mid-shelf ridge (130 to 350 μ). Both ridges contain some alternating laminated and nonlaminated bed sequences. C-14 dates from the upper ridge sand units are indecisive in establishing whether the upper units in the nearshore and middle shelf are time equivalent. Nearshore box cores which only penetrate the upper ridge sand from 25 to 46 cm (9.8 to 18.1 in.) contain well-developed ripples and cross-bedding; physical structures dominate. The middle shelf box cores are dominantly burrowed sand and are muddier than nearshore box cores.

Major observations from this study are: (1) what is interpreted as the base of the nearshore ridge directly overlies skeletal rich sediments, whereas what is interpreted as the base of the middle shelf ridge directly overlies sediments without skeletal remains; (2) skeletal rich and nonskeletal lithologies are present in the relief-forming portions of the ridges; and (3) the upper unit, the "upper ridge sand," is generally similar in character on both ridges.

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Gulfs of Northern Red Sea: Depositional Settings of Distinct Siliciclastic-Carbonate Interfaces

The two narrow gulfs of the northern Red Sea, Gulf of Suez and Gulf of Eilat (Aqaba), have had different tectonic histories, but both display active interfingering of siliciclastic and carbonate facies. In an early stage of rifting, these embryonic seas are flanked by rugged mountains (about 2,000 m, 6,500 ft) and narrow coastal plains built of fans composed of poorly sorted terrigenous debris. An arid setting promotes aperiodic transport of siliciclastic sediments as well as deposition of evaporites (coastal sabkhas) and carbonates (reefs and associated sediments). Gulf margins prograde by a combination of rapid fan deposition during flash floods and subsequent carbonate stabilization of terrigenous fans and cones during intervening periods. High-resolution seismic and side-scan sonar data suggest that narrow pathways for sediment transport are continually active on these features and probably accommodate much of the sediment transport to deep water during small discharge events. Large flash floods may completely overwash carbonates at the distal ends of fans, requiring renewed reef development. Rapid siliciclastic deposition, coupled with biological and chemical binding of carbonates as well as their tendency toward vertical buildups, results in steep slopes along the gulf margins.

The Gulf of Suez is shallow (< 100 m, 330 ft), and a relatively broad (> 12 km, 7.5 mi) and geometrically complicated strait separates it from the northern Red Sea. In contrast, the Gulf of Eilat is deep (< 1,800 m, 5,900 ft) and has a very narrow strait. Although both basins result from rifting associated with opening of the Red Sea, the Gulf of Suez is dominated by normal faults and tilted blocks, whereas the Gulf of Eilat formed primarily by strike-slip displacements with minor movements perpendicular to its extension. Seismic and borehole data confirm that the Gulf of Suez is a graben-like structure that has filled with nearly 6 km (20,000 ft) of dominantly siliciclastic sediment since Miocene times. An evaporite unit over 1-km (3,300-ft) thick and numerous thin carbonate horizons as well as local reef buildups interfinger with the noncarbonates. Over 3 km (9,800 ft) of sediment fill has been confirmed from the Gulf of Eilat, but a base for the sequence has not been identified. Turbidites and pelagic deposits fill the deepest basins.

The Gulf of Suez contains numerous carbonate platforms seated on subtle gulf-parallel structures. Some of these carbonate build-ups suggest that they are the initial stages of much larger carbonate platforms that will develop as rifting continues. Modern physical processes—strong axial winds (< 30 m/sec, 100 ft/sec), an energetic gulf-parallel wave field, and vigorous tidal currents (> 50 cm/sec, 20 in./sec)—tend to streamline reefs and sediment bodies, creating spindle-shaped carbonate platforms. The Gulf of Eilat has no mid-gulf platforms, but a complex of reef-dominated carbonates exists on gulf-normal structural blocks at the Strait of Tiran. A cross section reduction of this already narrow strait by lowering of sea level, reef growth, and/or sedimentation could drastically change the basin-filling process through restricted flow by eliminating reef growth and initiating salt deposition.

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A Three-Dimensional Seismic Survey Applied to Field Development in Williston Basin

The Medicine Lake field of Sheridan County, Montana, was discovered in March 1979. In October 1981, a mini-3-D seismic survey covering 2.5 mi^2 (6.2 km^2) was acquired over this field in order to facilitate development drilling by delineating the field's reservoirs and obtaining a more accurate image of the subsurface structure.

A multiline system, consisting of 240 geophone groups distributed on 8 lines, was used. The energy source was shothole dynamite using 5 lbs (2.3 kg) charges at 250 ft (46 m). The shotpoints were arranged in a cross pattern with extra shotpoints included to provide necessary control on the weathered zone. The average subsurface coverage was 600%, with CDP bins 165 ft (50 m) square. Prior to the actual shooting, a computer simulation of the resulting fold was performed to verify the field geometry. The entire survey was recorded in one day with no movement of the geophones, thus minimizing costs.

The data volume was processed in preserved amplitude through 3-D migration and 1-D inversion. The subsurface image was substantially improved by the 3-D migration process. The advantages of this enhanced focusing ability are particularly important when attempting to delineate the lateral extent of reservoirs and detect lithologic variations.

The Medicine Lake field is located on a structural high, although there are stratigraphic implications for several of the producing zones. The interpretation of the data therefore focused on both structural and stratigraphic features.

The Medicine Lake structure is prominently displayed on the Winnipeg event, showing a closure in excess of 180 ft (55 m). Several reflectors near the base of the Red River interval terminated against the Winnipeg event, indicating that this structure was a high in Red River time. Discontinuities in the Cambrian and Precambrian reflectors suggest that the Medicine Lake structure is a result of basement faulting.

The objective of the stratigraphic interpretation was to outline zones of possible porosity, particularly in the Madison and Red River intervals. The horizontal and vertical inverted sections were particularly useful for ascertaining the location and lateral extent of those anomalous zones. The results correlate well with known production, and should aid in the location of future development wells.

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Computer Analysis of Early Well Logs

Geophysical well logs have been recorded in wells drilled for petroleum and natural gas since the early 1930s. These, largely hard-copy records, comprise the greatest pool of factual subsurface information on producing reservoirs and on new prospects that were either not economic or overlooked when the wells were drilled originally. As such, they are a valuable exploration tool but are difficult to use because of the incompatibility of recorded information both within and between wells.

Early well logs display a wide range of curve types with a