preting the bathymetry of ancient depositional environments. With the advent of geohistory methods that require quantitative paleodepth data, greater importance has been placed on benthic foraminifera as paleodepth indicators. The purpose of this symposium is to review some of the problems and prospects offered by our current state-of-knowledge.

Widely used foraminiferal paleodepth indicators include faunal trends (species abundance, species diversity, test composition, planktonic to benthic ratios) and species depth limit (e.g., UDL) based upon distributional studies of modern benthic microfaunas. The application of such ecologic approaches in the interpretation of fossil data relies on three assumptions that have received little attention: that modern distributional patterns are analogous to those of the past; that homeomorphs of modern taxa had similar ecological adaptation; and that the depth habitats of modern species were the same in the past. The first appears sounds, but growing evidence suggests that the latter two require revision.

From the study of foraminiferal ecology it is clear that species distribution is unrelated to bathymetry per se but coincides with water-mass, sediment, and nutrient boundaries in the ocean. Because such boundaries vary within the oceans, few, if any, modern species are actually isobathyal (same upper depth limit) outside of limited regions. Paleobathymetric models calibrated in terms of modern species are probably less precise than originally presumed. During the Cenozoic, climatic fluctuations produced major changes in water-mass distribution, sediment patterns and oceanic productivity that, in turn, caused shifts in the depth distribution of many deep sea species. How bathyal assemblages in continental margins responded to these environmental changes remains an unanswered question in foraminiferal paleobathymetry. Also unclear is the paleobathymetry of fossil assemblages, for which there are no direct modern analogs such as the agglutinated assemblages found in Cretaceous and early Tertiary time.

Despite current problems, benthic foraminiferal paleobathymetric approaches are basically sound and as benthic faunal responses to climatic-oceanographic changes are better understood, benthic foraminifera will be even more useful indicators of environment.

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Significance of Carbonate-Clastic Shoaling Cycles in Mississippian of Northern Arkansas

Shoaling-upward carbonate shelf cycles are known to occur in many parts of the world and throughout the geologic record. A typical shoaling carbonate cycle begins with deep-shelf, interbedded, lime mudstones and shale. These are succeeded by open-shelf bioclastic packstones and grainstones, and finally in many places by oolite, the latter representing the culmination of the shoaling process. Subsequent cycles repeat this basic pattern. When correlated across a shelf, the cycles are thought to represent the episodic progradation of a carbonate sand platform that built up to wave base, subsided, and built up again.

Upper Mississippian (Chesterian) strata in northern Arkansas consist of alternating limestones and shales that include a set of shoaling-upward cycles. These cycles, occurring within the dominantly carbonate Pitkin Formation, differ from the pattern described above in that they contain a significant terrigenous component. This material exists both as fissile black shale within lower-cycle lime mudstone, and as quartz sand admixed within upper-cycle oolite grainstones. This dual occurrence is thought to be related to movement of the shoreline that accompanied the repeated outbuilding of a carbonate platform. At the beginning of a cycle, the shoreline was distinct from the deeply submerged shelf and lime and terrigenous mud accumulated in a quiet-water setting. Thickness and facies analysis of the Pitkin indicate an east-west trending shelf with a shoreline located in southern Missouri, perhaps curving south around the Ozark uplift. Eastward increase in shale percentage in the Pitkin suggests transport of fine clastics around the southeast flank of this uplift. The Illinois basin was an active Chesterian depocenter and during periods of maximum transgression fine clastics may have passed through a seaway southwest into northern Arkansas. As shoaling proceeded, the shoreline regressed south with the advancing carbonate sand sheet, cutting off the avenue of fine clastics. Quartz sand, probably derived from a thick sequence of lower Paleozoic sandstones exposed along the uplift by the retreating sea, became admixed with oolite across the newly built platform. These shoaling cycles are the product of slow, steady, subsidence along a northern Arkansas shelf punctuated by episodes of relatively rapid carbonate sand sedimentation and clastic influx. A similar tectonic and depositional setting must have given rise to other such deposits that occur in the geologic record.

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Massive Siliciclastic Deposits Juxtaposed Against Massive Carbonate Bodies: Paradox of Eastern Gulf of Mexico

The eastern Gulf of Mexico is the location of a major and dramatic transition from siliciclastic to carbonate deposits and deposition. The massive lutites that make up the Mississippi Cone are juxtaposed against the equally massive carbonates intercalated with evaporites that make up the western portion of the Florida Platform. The region now occupied by the continental margin of the eastern Gulf has been cut off from clastic sedimentation since Late Jurassic or Early Cretaceous time, and over 5,000 m (16,404 ft) of predominantly carbonate sediments have built up.

Surficial sediments of the carbonate portion of the transition zone are called the West Florida Lime Mud Facies. A foraminifera-coccolith ooze is still being deposited in water depths as shallow as 200 m (656 ft); this facies covers over 40,000 km^2 (15,444 mi^2) and in many respects resembles a deep-sea ooze. However, in some places shelf carbonate debris, including whole valves of mid-shelf oysters, have cascaded over the shelf-slope break and are incorporated into the slope ooze. Composition, rates of accumulation, and relatively shallow deposition suggest that this sedimentary body may be an analog of some of the chalk deposits of northwestern Europe.

It has long been considered axiomatic that planktonic foraminifera and coccolith oozes are deep-sea deposits that accumulate at rates of a few tens of millimeters per thousand years. However, radiocarbon dates show that the eastern Gulf margin ooze has accumulated rapidly. Prior to the last rise in sea level, deposition rates were as high as 65 cm/1,000 years (25 in./1,000 years); and ever since sea level began to rise sedimentation rates have still been as high as 20 cm/1,000 years (8 in./1,000 years). Such a rapid buildup of the carbonate sediments has led to widespread mass wasting and all forms, from creep to massive multiple slide deposits containing thousands of cubic kilometers of material, are represented in our set of high resolution seismic profiles.

The actual contact between carbonates and siliciclastics occurs in a variety of styles. Carbonate rubble is found in a terrigenous lutite matrix at the base of the West Florida Escarpment. Farther west on the Mississippi Cone the brown and yellow-brown siliceous lutites contain carbonate turbidites with provenance the West Florida slope. Another type of contact is shown in some piston cores with carbonate ooze in normal and alternating depositional contact with Mississippi siliceous lutite.

The position and timing of alternating carbonate and fine terrigenous deposition, as well as the loci of carbonate buildups on the slope, must be affected and perhaps even controlled by the positioning of the Loop Current, a major precursor to the Gulf Stream which, depending upon factors as yet not totally understood, irregularly advances into or retreats from the eastern Gulf. When the loop is "up" and sweeps from north to south along the West Florida slope, it blocks or deflects Mississippi sedimentation. When the loop is restricted to the area of the Florida Straits, fines derived from the Mississippi River can be deposited at the base of the escarpment and even up on the slope.

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Palo Duro Basin, An Exploration Frontier in the Texas Panhandle

Recent oil discoveries in the northwestern and central Palo Duro basin have renewed interest in this sparsely drilled area. Production in the northwest, in Oldham and Potter Counties, is from Pennsylvanian granite wash and carbonates. These fields are located in a highly faulted area south of the Amarillo uplift, and traps are structural. Discovery wells here produce oil at rates that range from 150 to 650 bbl per day. Oil production in the central basin, in Briscoe County, is from Pennsylvanian carbonate. The reservoir is probably a Strawn shelf-margin buildup or a debris flow into the basin from a younger Pennsylvanian shelf margin.

The Palo Duro basin seems to contain potential reservoirs, traps, and source rocks; thermal maturity is probably the limiting factor for hydrocarbon production in the basin. The current geothermal gradient is relatively low, 1.1°F/100 ft (20°C/km), and it apparently has not been significantly different in the past. Vitrinite reflectance (R_o) measured in cores increases linearly with depth (temperature) by the relation: $R_o = 0.00003 \times$ depth (ft) + 0.36. R_o values seem to be in equilibrium with current depths and temperatures of the vitrinite. This suggests that (1) rocks in the basin are at or near their maximum burial depth, and (2) the geothermal gradient was not higher in the past. Shales of different ages that are at approximately the same depth have similar vitrinite reflectance values, an indication that increased time did not cause increased maturity in these Paleozoic samples.

Deeply buried shales, 7,000 to 9,000 ft (213 to 2,743 m), from Pennsylvanian and Wolfcampian basin facies theoretically should have reached temperatures sufficient to generate hydrocarbons. Recent discoveries provide evidence that oil actually was generated in the Palo Duro basin.

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Research in Geology Applied to Enhanced Oil Recovery

Geologists, working in close cooperation with engineers, have an important role to play in maximizing the recovery of oil and gas from producing fields and especially in implementing enhanced oil recovery (E.O.R.) projects. In order for this contribution by geologists to be useful, however, geologic descriptions of reservoir rocks must be quantified for inclusion in numerical models of fluid flow within the porous interval. In particular, research is needed in characterizing both large and small scale heterogeneities within porous reservoir rocks. In addition, research is needed in geophysical monitoring of E.O.R. processes in heterogeneous reservoirs.

At one scale are heterogeneities in the stratification of porous sedimentary facies. Thin shale beds, evaporite layers, cemented zones, and other features that affect the movement of fluids within a formation should be noted and made as important a part of reservoir description as is the nature of the porous rock itself. Numerical models for forecasting production commonly lack this kind of geologic input until development drilling is completed; so models of discontinuities in various clastic and carbonate facies are essential for accurately predicting reservoir heterogeneity with only a minimum of well control.

At a different scale are heterogeneities within the pore systems of reservoir rocks. Recent work by a few investigators has shown the importance of geometry of the pore system to entrapment and retention of nonwetting fluids. Observations by engineers and petrophysicists of differences in the capability of certain rock types to produce the fluids they contain have long been a basis for subdividing reservoir intervals for numerical modeling, but only recently has an understanding of the causes of these differences been gained through work with models and casts of actual pore networks. Further research is needed in this microscopic realm to link the description of rocks and their pores quantitatively with anticipated reservoir behavior.

Yet another field for future research is the chemical interaction of reservoir rocks with various non-native fluids to which they are exposed. Most petrographic studies stop with simple descriptions of pore-lining components of rocks, and only a few published studies provide empirical data on potential chemical reactions between these components and various acidic, caustic, and organic solutions in the subsurface environment.

Finally, another area of development that would be highly beneficial to E.O.R. projects is in our ability to monitor indirectly the progress of various fluids through the reservoir. Remote sensing of fluids of different compositions, through surface or borehole geophysics, without the need for numerous monitor wells between injectors and producers, would be desirable for control of the progress of an E.O.R. project and for reducing the cost of evaluating studies of pilot-areas.

Research of the kind mentioned is, of necessity, a multidisciplinary effort. Geologists or geophysicists working alone tend to stop short of seeing that the reservoir analysis they provide is adequate for answering the questions at hand; and engineers, without geologic guidance, tend to have an oversimplified concept of a reservoir. Either extreme is less than the desired result of which we are capable as a team, if all of the kinds of pertinent information are integrated and maximum use is made of them.

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Influence of Overthrusting on Maturation of Hydrocarbons in Phosphoria Formation, Idaho-Wyoming Overthrust Belt

The regional maturation history of the Phosphoria Formation in the Idaho-Wyoming Overthrust belt was determined from a suite of Phosphoria samples collected throughout the region. Samples were collected from both the footwall and hanging wall of as many thrust sheets as possible. The results of this study indicate that inclusion of the thermal effects of thrust faulting on the temperature history of the region is critical to a thorough explanation of the variations in maturity levels observed in the Phosphoria. A simple evaluation based only on the thickness of the overburden will not be sufficient to accurately interpret the maturation data. Instead, maturation models incorporating the thermal effects of thrust faulting with techniques developed by Lopatin are used to explain the geochemical maturation data.