tional 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.

Modified Lopatin diagrams were used for detailed maturation modeling of four of the Phosphoria sampling sites. This detailed modeling clearly demonstrates that the thermal effects of overthrusting do significantly influence the maturation history of organic material incorporated in overthrust sediments. Briefly, the result of thrusting is to cool the overriding sheet and warm the sediments being overridden. A unit in the hanging wall of a thrust will not be subjected to high temperatures for nearly as long a time as the equivalent unit in the footwall of the thrust. Comparison between observed reflectance values for the four sampling sites with vitrinite reflectance values calculated from Lopatin diagrams indicates that better agreement between observed and calculated values is obtained when thermal modifications due to thrusting are incorporated within the Lopatin diagrams.

Finally, in the absence of actual geochemical information such as R_o or T.A.I., the models here described appear to be accurate enough to give a reasonable estimate of the thermal maturity of a potential source bed. Such a predictive technique can be of great value in planning an exploration program in previously untested overthrust terrains.

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Depositional Environments of Ranger Limestone (Pennsylvanian), North-Central Texas

The Ranger Limestone was deposited on the broad shallow Eastern shelf of the Midland basin during Missourian time. The sequence of alternating carbonate and terrigenous sediments comprising the Ranger Limestone is reflective of the overall cyclicity exhibited by the Canyon Group. An analysis of the interrelationships of the facies produced a framework for reconstructing the depositional history. Earliest carbonate deposition in the Ranger appears to have been initiated on local topographic highs of probable minor relief. Phylloid algae are abundant biotic constituents in the Ranger Limestone and probably played a key roll in the carbonate buildup. The Ranger Limestone is composed primarily of sediments that represent four major depositional environments. The carbonate environments recognized include an inner shelf, a transitional inner shelf, and a restricted inner shelf. These carbonate accumulations are laterally restricted by distal delta-front deposits of the Perrin delta complex.

A multivariate statistical analysis based on point-count data of lithologic and biologic constituents was utilized in the delineation of facies within the Ranger Limestone. On the basis of the detailed petrographic study four facies were defined. These facies are: (1) algal-echinoid-bryozoan wackestone, (2) algal wackestone, (3) lime mudstone, and (4) calcareous shale.

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Evolution of Oil-Generative Window (OGW) in Niger Delta Basin

Assuming a simple model of delta development involving progradation and uniform subsidence to present depths (rate, 500 m/m.y.; 1,640 ft/m.y.), oil-genesis nomographs derived from the TTI method were constructed for various geothermal gradients of the Niger delta (2.2., 2.5., 2.9, 3.2, 3.6, 4.0, 4.4, and 4.7°C/100 m) and utilized in mapping the positions (depth, temperature) of the top of the oil-generative window (OGW) at arbitrarily selected times (40 m.y.B.P., 30 m.y.B.P., 15 m.y.B.P., and the present). About 200 data points were evaluated.

During the active subsidence phase, oil generation within any megastructure was initiated at a temperature of 140 to 146°C (284 to 294°F) and depth of 3,000 to 5,200 m (9,842 to 17,060 ft) within 7 to 11 m.y. after deposition of the potential source rocks. After cessation of subsidence, upward movement of the OGW by 800 to 1,600 m (2,624 to 5,249 ft) was accompanied by a temperature lowering of 23 to 54°C (73 to 129°F). Lower temperatures produced correspondingly heavier crudes.

In some parts of the delta oil generation and expulsion from the lower part of the Agbada Formation predates the cessation of subsidence and structural deformation, while in others it postdates those events. In most parts of the Niger delta, the upper and normally compacted part of the Akata Formation appears to constitute the major source rock.

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Biogenic Structures in Pelagic Carbonates: An Ichnofacies Comparison of Deep-Sea and Shelf-Sea Chalks

As a general rule, pelagic sediment is totally bioturbated, and primary sedimentary structures are rarely preserved. The fabric and internal structure of the sediment are modified post-depositionally by the burrowing activities of the infaunal benthos. However, various aspects of the original depositional environment, such as water depth, sediment type, and substrate stability, may be reflected in the ichnofacies. The ichnotaxa apparently differ in their environmental requirements and tolerances; thus, ichnofacies transitions exist even within the pelagic depositional regime.

Today fine-grained, calcitic nannofossil ooze is deposited beyond the reach of terrigenous sources in water depths of about 2,000 and 4,500 m (6,562 to 14,764 ft). At certain times in the past, however, such as during the Late Cretaceous in northern Europe, fine-grained calcareous ooze was deposited in much shallower depths as well, perhaps as little as a few hundred meters.

Trace fossils aid our understanding of the paleobathymetry and substrate conditions in ancient chalky sea bottoms. Deep-sea chalks differ from their shallow-water counterparts in northwest Europe in their typical lack of abundant shelled megafossils and flint horizons. The European chalks commonly contain a *Thalassinoides*-dominated ichnofacies, which very directly influenced such early diagenetic processes as hardground formation and silica reprecipitation. A deeper water ichnofacies in the European chalks, dominated by *Zoophycos*, is less commonly associated with hardgrounds and flint horizons. In truly deep-sea chalks, *Thalassinoides*, bored hardgrounds, and well-developed burrow flints are very rare; a *Zoophycos-Chondrites-Planolites* association is characteristic.

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Depositional Environment of Pittsburgh No. 8 Coal Seam

The Pittsburgh No. 8 coal, the basal member of the Monongahela Formation, is considered one of the most important coal seams in Ohio. Maceral analyses and reflectance studies were conducted on four seams to determine its depositional environment. Petrographic analyses of coal from Guernsey, Belmont,