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Geologic History of a Basin Depicted by Computer Mapping

Reconstructions of detailed geologic histories of basins have become an increasingly important part of the exploration process. However, a history that includes numerous stratigraphic horizons and several periods of orogeny and erosion usually involves handling such a great volume of data that use of a computer becomes necessary. A complete depiction of the geological history of a basin must include the geometric relationships between the various horizons (onlap, offlap, truncation, etc), the depths and thicknesses of the formations, and the effects of orogeny and erosion throughout the basin.

Most computer mapping programs generate interpolated grids that are used for drawing contour maps. These grids and maps can show configurations of horizons at various stages of basin development, and can also show pre-erosional and pre-orogenic forms. The procedures are: (1) Interpret major geologic events. (2) Capture data at each selected control point (elevations of each mappable horizon and unconformity, estimates of loss in thickness due to erosion, estimate tectonic tilts and structures). (3) Construct grids (prepare data, construct grids of present stratigraphy, construct grids of pre-erosional forms). The resultant grids are used to depict present structure, paleostructure, map isopach units, and draw stratigraphic cross sections.

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Prospective Evaluation Techniques in Less Explored Basins of World

Prospect evaluation in some of the less explored basins, such as offshore China and several southeast Asian and south Asian basins, is hampered by lack of data. Exploration ventures in such areas are generally labeled high risk, resulting in short-term, usually abortive, investment. Examples from Pakistan and China are presented, showing that condemnation of large areas on the basis of analogies with highly explored basins is generally due to limited availability of data and not due to lack of petroleum potential. In less explored basin areas, a more imaginative and conceptual approach is required to assimilate and synthesize limited exploration data.

Generalization with respect to gravity distribution of crudes in the Potwar basin, northern Pakistan, is also misleading. Detailed investigations indicate that gravity differentiation is a result of biodegradation, or is related to the type of source material and time and depth of burial. Nonmarine sediments in Pakistan have not been fully evaluated for their petroleum potential, however, the fact that almost all the interior basins in China produce oil from nonmarine reservoirs derived from nonmarine sources indicates that nonmarine sediments in Pakistan deserve greater attention.

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Porosity Styles of the Midale Field in Williston Basin of Southeastern Saskatchewan

The Midale oil field, southeastern Saskatchewan, lies on the northeastern flank of the Williston basin. The reservoir is in limestones, dolomites, and evaporites (mainly anhydrite) of the Midale Beds (Mississippian), that were deposited during a predominantly regressive episode on a shallow shelf.

The Midale Beds are divided into a lower, middle, and upper zone. Many of the characteristic pore types in these zones, as observed in thin section and under SEM, can be related to both original depositional environment and postdepositional diagenetic modifications.

The dominant styles of porosity in the fine-grained argillaceous limestones of the lower zone are secondary intraparticle, moldic, or microvuggy. These fabrics result from the preferential dissolution of cement or very fine shell debris. A lack of pore interconnections precludes these sediments from being effective reservoir rocks.

The most significant pore type in the middle zone is secondary intercrystalline porosity within fine-grained dolomite. This fabric is the result of solution of calcite or aragonite from between rhombs after incomplete dolomitization. A crinoidal grainstone with pervasive early diagenetic syntaxial rim cement forms a tight trap in the middle zone.

The upper zone consists of fractured calcareous microcrystalline dolomite. The main pore type is a non-fabric selective system of oblique to vertical microfractures, which may be associated with regional uplift or local salt solution. The presence of dolomite rhombs on fracture surfaces indicates that dolomitization was relatively late, postdating fracturing. The microfractures in the upper zone counteract the porosity-occluding effects of stylolitization and secondary anhydritization.

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Evidence for Migration Along Fractures Within a Fine-Grained Carbonate Rock

A detailed geochemical investigation was undertaken to characterize both the soluble (bitumen) and insoluble (kerogen) organic components of DSDP Site 535. This work reveals an organically rich carbonate section of Valanginian to Hauterivian age. This stratigraphic interval contains as much as 11% organic carbon. The kerogen component is dominated by material with elevated atomic H/C ratios, and thus is oil-prone. However, the entire section is thermally immature and has not reached the principal stage of petroleum generation and expulsion. The bitumen component is dominated by nonhydrocarbons (asphaltenes and NSOs) typical of thermally immature sediments. Gas chromatograms of the saturate fraction are also characteristic of thermally immature sediments, revealing a bimodal distribution of components and an abundance of steranes and triterpanes.

Within this limestone section, numerous fractures are filled with a "tar-like" material. Preliminary chromatographic analyses suggest that the "tar-like" character of this material may be the result of post-migration alteration. Also within this interval, chromatographic evidence suggests the presence of thermally mature, unaltered hydrocarbons. Computer modeling of maturity indicates that these mature hydrocarbons seemingly have migrated several tens, if not hundreds, of kilometers updip. The uniformity of physical properties throughout the Cretaceous limestone sequence and the association of these hydrocarbons and "tars" with the fractured and brecciated horizons suggest that the migration occurred along the fracture system.

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Miocene Paleo-Oceanography and Paleo-Productivity

Deep Sea hiatuses in pelagic sequences are largely determined by surface productivity and the rate of sediment removal by bottom currents and corrosiveness of deep waters with respect to calcite and silica. In regions of high biotic productivity, sedimen-

tary sequences are typically free of hiatuses or contain very short hiatuses. Hence, hiatus distribution maps can outline regions of high paleo-productivity. Analyses of Miocene deep-sea cores reveal eight intervals of widespread hiatuses and four distinct sediment distribution changes in the world's oceans. These maps reveal major paleo-oceanographic changes affecting the biotic productivity in the Miocene ocean. Four main episodes in the evolution of oceanic circulation and paleo-productivity are apparent leading to the establishment of present-day high productivity regions.

(1) Circum-equatorial flow persisted to about 18 Ma with calcareous sedimentation in low and middle latitudes and predominantly siliceous sedimentation in the North Atlantic and Antarctic south of 60°S.

(2) Closing of the deep-water connection across Central America by 16 to 15 Ma initiated the "proto" Gulf Stream by diverting Atlantic deep and intermediate waters northward. Siliceous sedimentation increased in the Indian and Pacific Oceans at this time particularly in the eastern equatorial and marginal North Pacific. Coincident with the establishment of these high siliceous productivity regions is a decrease and eventual disappearance of biologic silica in the middle latitude North Atlantic presumably owing to the introduction of Norwegian Overflow Water.

(3) The main aspects of the present circulation and sediment distribution pattern were established by 12 Ma when major production of Norwegian Overflow Water displaced Antarctic deep water from the North and South Atlantic basins and enhanced siliceous sedimentation in the North Pacific.

(4) An essentially modern oceanic circulation system and high biotic productivity pattern were established by 6.5 Ma, possibly as a result of major production of Antarctic Bottom Water associated with the establishment of the West Antarctic ice sheet.

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Oligocene/Miocene Boundary: Correlation, Biostratigraphy, and Foraminiferal Evolution

Qualitative and quantitative planktonic foraminiferal trends have been examined across the Oligocene/Miocene transition in three DSDP sites in the South Pacific ranging from the equator to temperate regions. The evolutionary appearance of *Globoquadrina dehiscens* represents one of the most reliable datums for interregional correlation of the Oligocene/Miocene boundary. This datum occurs within the biostratigraphic range of *Globorotalia (Fohsella) kugleri* and marks the boundary between Zones N4A and N4B. *Globigerinoides* first evolved during the late Oligocene and is not coincident with the Oligocene/Miocene boundary.

Unlike the Eocene/Oligocene boundary, the Oligocene/Miocene boundary is not marked by a crisis in the Oligocene planktonic foraminiferal assemblages. Most Oligocene forms continue their range upward into the early Miocene where most are replaced by typical Neogene forms.

The evolution of *Globoquadrina dehiscens* effectively heralds the beginning of the major Neogene evolutionary radiations in planktonic foraminifera including: (1) the evolutionary radiation of *Globigerinoides* into a number of species; (2) the initial evolution of *Globorotalia (Globoconella) incognita,* which forms the earliest ancestral form of *Globoconella;* (3) the evolution of the *Globigerina (Zeaglobigerina) woodi* group; (4) the evolution of *Sphaeroidinellopsis disjuncta,* which is the ancestral stock of the *Sphaeroidinellopsis-Sphaeroidinella* lineage; and (5) the evolution of *Globorotalia (Fohsella) peripheroronda* from *Globorotalia (Fohsella) kugleri.* These evolutionary radiations are reflected by a general increase in simple species diversity through the early Miocene. In all sites, species diversity is lowest in the interval near the Oligocene/Miocene boundary. Amongst the sites examined, diversity is highest, not in the tropical site, but in warm-subtropical Site 208, because at this latitude the faunas include both tropical and temperate forms.

The earliest Miocene, immediately following the boundary, is marked by high frequencies of *Globorotalia (Fohsella) kugleri* in tropical areas and *Globoquadrina dehiscens* in warm subtropical to temperate areas.

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Chemical Geothermometers Applied to Formation Waters, Gulf of Mexico and California Basins

Twelve chemical geothermometers based on the concentrations of silica and proportions of Na, K, Ca, and Mg in water from hot springs and geothermal wells are used successfully to estimate the subsurface temperatures of the reservoir rocks. These 12 geothermometers together with a new geothermometer based on the concentrations of Li and Na were used to estimate the subsurface temperatures of more than 200 formation-water samples from about 40 oil and gas fields in coastal Texas and Louisiana and the Central Valley, California. The samples were obtained from reservoir rocks ranging in depth from less than 1,000 m to about 5,600 m.

Quartz, Na-K-Ca-Mg, and Na-Li geothermometers give concordant subsurface temperatures that are within 10°C of the measured values for reservoir temperatures higher than about 75°C. Na-Li, chalcedony, and a modified Na-K geothermometers give the best results for reservoir temperatures from 40°C to 75°C. Subsurface temperatures higher than about 75°C calculated by chemical geothermometers are at least as reliable as those obtained by conventional methods. Chemical and conventional methods should be used where reliable temperature data are required.

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Utilization of Interactive Computer Graphics to Solve Complex Geological Problems—A Case Study

The exact role of the computer in the fields of geology and well log analysis has been the subject of some controversy and confusion. The computer, when properly implemented and programmed, can assume a different role—that of an analysis partner. In this approach, the user must be able to communicate both freely and naturally with the computer—and vice versa; i.e., the system must be truly interactive. Another key element is graphics, as the geologist's world is usually described using maps, graphs, diagrams, charts, logs, etc. An interactive graphics system has been used to analyze several formations in various parts of the world. The main portion of this paper uses some of these analyses in a "case study" approach to help describe the techniques.

Most of the analyses involve interactive log analysis. The logs were first subjected to a conventional analysis using the computer to help speed up the mathematical computations. The computer also generated all data listings, graphs, plotbacks, and crossplots during this phase.

The next phase was to perform an in-depth, detailed analysis to discover more about the key characteristics of the formation. Most of these algorithims are beyond the capability of a hand held calculator, but the interactive nature of the system makes them