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

very easy to use. In addition, several separate models for each well were generated and the results compared statistically in a very short span of time.

Results from several formations, including the Mancos "B" in western Colorado, are presented in detail to illustrate the advantage of the use of interactive graphics software.

The degree of success achieved in solving these problems indicates that the use of an interactive computer system in this manner is not only valid, but merits more widespread application.

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Ordovician Red River Formation, Eastern Montana and Western North Dakota: Relationships Between Lithofacies and Production

Ordovician Red River cores were examined from 16 wells across western North Dakota and eastern Montana plus core from 8 wells in Brush Lake field area, Sheridan County, Montana. Several distinctive basinwide carbonate lithofacies record at least three cycles of upward shoaling or restricted conditions. The oldest and best developed of these cycles consists of a fossiliferous burrowed carbonate mudstone member overlain by a nonfossiliferous, finely laminated micro- or crypto-crystalline dolomite member. The cycle is completed by an anhydrite of regional extent. The thickest development of porous dolomite is in the lowest cycle of the Red River. This cycle contains most of the Red River oil reserves of the study area.

Porosity distribution is directly related to patterns of dolomitization in the carbonate members of each cycle. In northeast Richland County, Montana, an area of dense well control, net porosity isopach maps of each member of the lowest cycle show alternating bands of porous and nonporous carbonates. These bands are oriented northeast-southwest. Bands of good porosity development in the burrowed member occur between bands of good porosity in the overlying laminated member. A classification system based upon these patterns of dolomitization is used to analyze statistically the occurrence of porosity in the lowest cycle.

Regional anhydrites, nonporous carbonate rocks and kerogenites within these cycles have formed adequate seals for the trapping of Red River oil.

Fifty percent of Red River structural growth occurred during upper Interlake time in northeast Montana. Rejuvenation of this growth occurred through Cretaceous time.

Black kerogenous limestones in the burrowed member of the lowest cycle may be the source of Red River oil.

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Seismic Stratigraphy and Sedimentation, Magdalena Fan, Southern Caribbean Sea

Multi- and single-channel seismic records from the Magdalena Fan reveal six seismic sequences in the entire sediment column (with thickness from >5.5 to 2.5 secs two-way traveltime). Although sediments were deposited in the Magdalena Fan since about the Late Cretaceous, terrigenous sedimentation became important only in later Cenozoic time during the deposition of the upper three units following the Andean uplifts. However, the uppermost seismic sequence is the fan unit, most influenced by influx of terrigenous sediments and deposited subsequent to the major uplift of Andes in Pliocene time. The morphologic and shallow acoustic (3.5 kHz) characteristics of this fan unit are: (1) upper fan, 1/50 to 1/100 gradients, with channels having well-developed levees and with several subbottom reflectors; (2) middle fan, 1/100 to 1/200 gradients, occurrence of numerous channels with very subdued levees and several subbottom reflectors; and (3) lower fan, <1/200 gradients having small channels and relatively smooth sea floor with few or no subbottom reflectors. Large irregular to regular hyperbolic echoes and sediment waves are very common in the upper, middle, and to some extent the lower fan, and have resulted from slumping and other downslope mass movements. On multichannel seismic records, the upper fan exhibits conspicuous channel-levee migration and onlapping and coalescing wedge-shaped reflection patterns (from levee deposits). The middle fan is characterized by the presence of chaotic and discontinuous reflection patterns which resulted from the presence of numerous channels and the hyperbolae and sediment waves of the type recorded on 3.5 kHz records. The lower fan region has continuous and smooth reflection patterns. Within the topmost seismic unit, several episodes of increased terrigenous sediment influx have resulted in a seaward progradation of different fan regions in Pliocene-Pleistocene times.

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Terrigenous and Carbonate Clastic Facies in a Transgressive Sequence Over Volcanic Terrain

The Kawainui marsh in Hawaii and its adjacent broad barrier accretion plain has been deposited over a former coralline algal-coral reef embayment surrounded by high slope volcanic hills. In late Holocene time, littoral transport formed a beach accretion plain which cut off the former marine embayment leading to deposition of lagoonal and deltaic facies which were eventually covered by a dense salt marsh formed of *Scirpus* sp. and "California" grass. A core program was used to obtain data for a three dimensional analysis of the resultant transgressive coastal environmental lithosomes. By use of a large number of radiocarbon dates and three relatively important archeological sites surrounding the marsh, the late Holocene settings and times of deposition of the various sedimentary environmental units were determined. This transgressive sequence began at least 5,000 years before present and continues to build landward and upward. The vertical stratigraphic sequence from top to bottom includes salt marsh peats, lagoonal marine muds or terrigenous deltaic deposits, in some areas a basal marsh peat, and a coralline algal-coral reef tract, underlain by basalts. The adjacent barrier accretion sands overlie a coralline algal-coral reef tract underlain by basalts. Preservation potential of such a sequence in a volcanic terrain appears to be fairly high as deposits of many previous high sea stands have been identified in the Hawaiian Island chain. Final burial under deep marine muds or oozes will eventually occur as the islands subside as evidenced by the previous history of the Hawaii-Midway Island chain. Buried similar sequences of transgressive coastal sedimentary facies should be anticipated along other volcanic terrains such as the Kelvin chain (Mytilus seamount) off the eastern Atlantic coast of North America, the Jordan Knoll in the southeast Gulf of Mexico, the Tonga-Fiji volcanic arc, and other similar geologic settings.

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Grand Rapids Formation, North-Central Alberta: An Example of Nearshore Sedimentation in a High Energy, Shallow, Inland Sea