a combination of kriging and simulated correlated variables. The statistical models of geologic variables so produced are in conformity with the histogram, variogram, and actual data values, and most important, they mimic spatial variability between sampled locations.

The key factor in geologic applications of geostatistics is the translation of geologic reality into mathematical abstraction. Each random statistical function is a function of the physical processes that produced the deposit, which processes in turn varied in both space and time. The deposit under study has been divided into seven domains based on the best available geologic model, and different random functions established for each variable in each domain.

Three-dimensional models describing the spatial fluctuation of elevations and bitumen saturations were produced and stored as grids having 25 m (82 ft) vertical and 1 m (3 ft) horizontal resolution. These models will be used to develop strategies for mine planning.

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C^{13}-Rich Diagenetic Carbonates Associated with Heavy-Oil Deposits

The isotopic composition of secondary calcites in 120 samples from biodegraded heavy-oil deposits of the Lower Cretaceous Mannville Group of Alberta ranged in $\delta^{13}C$ from -1.3 to $+14.1$ ‰ PDB. The calcites postdate oil emplacement and are anomalously enriched in C^{13} in comparison with common sedimentary and diagenetic carbonates associated with conventional oil pools and authigenic carbonates of other shallow Cretaceous sediments of Alberta. In contrast to previously reported occurrences of heavy carbonates (Moneray Formation, Kimeridge Clay of Dorset, Caspian syncline), the heavy-oil calcites are not related to organic-rich clayey sediments and no coexisting low ^{13}C-carbonates were found. The API gravities of the biodegraded oil correlate with the $\delta^{13}C$ values of the carbonate, suggesting a relationship between the biodegradation process and C^{13}- enriched cements. Different isotopic systematics were observed in 25 samples from other heavy-oil deposits (Indonesia, Malagasy, Brazil, Sicily, Zaire, California, Kentucky, Utah) whose $\delta^{13}C$ ratios ranged from -21.6 ‰ to $+1.1$ ‰ PDB.

An explanation may involve oxidation of the paraffinic oil components by microorganisms producing alcohols, organic acids, and ketones. A change to anoxic conditions causes fermentation of these biodegradation products, leading to the formation of ^{13}C-rich CO_2, which precipitates as heavy carbonate. If anoxic conditions are not achieved, oxidation will persist and lead to the formation of light carbonate cements.

The detection and understanding of the formation mechanism of anomalously heavy carbonates can be useful in both future exploration strategy and exploitation of heavy oil deposits, particularly to enhanced recovery schemes based on CO_2 flooding.

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Regional Aquifers and Petroleum in Williston Basin Region of United States

At least five major aquifers underlie the northern Great Plains of the United States, which includes parts of the Williston basin in Montana and North Dakota. These aquifers form a hydrologic system that extends more than 960 km from recharge areas in the Rocky Mountains to discharge areas in eastern North Dakota and the Canadian Provinces of Manitoba and Saskatchewan. The regional flow system in the aquifers has had a major effect on the chemical composition of ground water within the Williston basin. Hydrodynamic forces may contribute to the accumulation of petroleum within the basin.

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Application of Principal Axis Ordination (Q-Mode Analysis) in Classification of Depositional Environments of Morrow (Upper Carboniferous) Strata in Southeastern Colorado

A variation of Q-mode analysis, termed "principal axis ordination," is evaluated as a tool for classifying depositional environments from well log data. The stratigraphic interval investigated is in the upper Morrow (Upper Carboniferous) of the Las Animas arch region in southeastern Colorado. Variables derived from digital induction and gamma-ray log data are used for classification based on principal axis ordination (PAO). The resulting classes closely match a set of inferred sedimentary environments in wells from a densely drilled area. These results allow the PAO classification technique to be extended to wells in sparsely drilled areas as a reliable aid in predicting reservior trends.

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Geologic Analysis System—Oil and Gas Exploration and Research Applications

The Geologic Analysis System is an applications software package designed to integrate and display geologic data used in petroleum exploration and research. The Geologic Analysis System contains two components: (1) a file management system (TECH/SYS) that builds, edits, merges, and extracts data for geologic applications, and (2) applications programs including a geologic mapping and contouring system (PICS), cross section and fence diagram programs, a time-temperature index (TTI) model, a stratigraphic report graphic (SRG), paleontological and geochemical displays, a sample data-display module (SDS), and a variety of multivariate statistical routines.

The Geologic Analysis System has been under development since 1977 when the U.S. Geological Survey assumed responsibility for the National Petroleum Reserve (NPR) exploration program in Alaska. The Geologic Analysis System represents the application of techniques developed during the NPR program for use with data collected by geologists throughout the United States. In cooperation with Petroleum Information Corporation, files of well data, base maps, lithology, petroleum geochemistry, and paleontology have been constructed and analyzed using applications software.

Geologic Analysis System utility is demonstrated using the following examples: (1) a contoured well-data map, cross section, and fence diagram from the Paradox basin, (2) SRG summaries from the San Juan basin, (3) SDS-generated ternary diagrams and downhole plots of petrographic data, (4) C_1-C_7 hydrocarbon and headspace-gas displays from Alaska, and (5) species abundance versus depth plots.

System benefits to the geologist include (1) publication- or report-ready graphic displays, (2) file manipulation to optimize data analysis, and (3) graphically and statistically displayed data from cores, measured sections, and well cuttings that objectively characterize the exploration potential of a stratigraphic sequence.

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Mechanism for Enhanced Reservoir Porosity Generation in Tripolitic Chert

Tripolitic chert is present in many Rocky Mountain basins. In the Green River basin, enhanced porosity in tripolitic chert comprises a significant portion of the porosity in the Ericson Sandstone. Prediction of enhanced reservoir porosity within tripolitic chert is dependent on understanding the mechanism for creation of this porosity. Dissolution experiments were performed on selected chert samples to determine the causal mechanism.

Chert samples used in the dissolution experiments were from the Phosphoria Formation in the Overthrust belt. Paleocurrent directions and the presence of sponge spicules and apatite in the Ericson cherts all indicate a Phosphoria source within the thrust belt for much of the Ericson chert. Both acid-treated and untreated chert fragments were placed in organic acid solutions. Results of the experiments show it is the 25-30% carbonate fraction within the chert that dissolves to create tripolitic chert. Silica solubility was not affected by the organic acids.

The opportunity to dissolve calcite and dolomite within detrital chert fragments exists at several times during progressive burial. Depending on the fluid chemistry, carbonate could be dissolved by an early pulse of organic acids generated prior to hydrocarbon migration. This would be