feldspathic, chaotic conglomerate/slate mixtures associated with graded-stratified conglomerates, dispersed and massive pebbly sandstones, and sandstone turbidites. Paleocurrents are toward the north-northwest. Conformably overlying these beds are quartzose cross-stratified sandstones (possibly Gog Group) consisting of facies: (1) trough cross-stratified conglomerate and sandstone; (2) graded swaley-or-hummocky cross-stratified conglomerate; and (3) isolated trough cross-stratified sandstone sets in shale. Paleocurrents are toward the east-southeast. Miette beds were deposited on a slope, possibly within a submarine canyon. These beds record deposition near a shelf break, possibly with storm influence.

In the western Kicking Horse Pass, quartzose Gog sediments belong to Facies 1-3, and (4) small-scale trough cross-stratified quartzite; (5) planar cross-stratified quartzite; (6) very low angle to horizontally stratified quartzite; and (7) shale. Absence of desiccation features and abundance of horizontal trace fossils suggest a shallow, sublittoral marine setting.

Overall cyclicity consists of the following units upsection: (a) Facies 1, 3, 4, and 7 with unidirectional west-southwesterly paleoflows; (b) Facies 5 with bimodal paleoflows; (c) Facies 1, 4, and 3 with unidirectional westerly paleoflows; (d) large scale epsilon cross-stratified quartzites; and (e) Facies 6 with bimodal to random paleoflows. This sequence may represent shoaling-up from offshore dune and bar complexes with alternating oceanic current (sequences a and c) or tidal (sequence b) influence. Above are lateral accretion deposits due to migration of a spit or ridge (sequence d), topped by high energy nearshore deposits (sequence e).

Paleoflow patterns are complex, suggesting that sediment dispersal was not simply a westerly prograding clastic wedge.

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Discriminant and Cluster Analysis as Statistical Aids in Stratigraphic Correlation

Stratigraphic interpretation has largely been done by geological, geophysical, and well-logging techniques. Statistical analysis of geophysical and well-logging data has been rather well accepted during the past 10 to 20 years. Analysis of geochemical data has only been recently accepted as a technique that aids in correlation and interpretation of other stratigraphic problems.

Two statistical techniques which have proven useful in stratigraphic or other types of geological interpretation have been cluster and discriminant analysis. These techniques are generally regarded as investigative tools. However, they can also be used in a predictive sense. This is particularly true of discriminant analysis. In both techniques, one allows the observed data to describe the similarity of formations, produced fluids, or some other measure of interest. These statistical methods have been applied using oil or water chemistry, well-logging data, and various reservoir parameters to solve stratigraphic problems or support a hypothesis. These techniques have been used successfully to recognize bypassed oil, sedimentary environments of deposition, miscorrelated horizons, and erroneous data.

In this paper, several case studies are presented that involve cluster and discriminant analysis to establish or substantiate hypotheses about reservoir continuity. These include one North Sea field, one Middle East field, and one domestic reservoir. A model which was previously proposed is further extended; this model will distinguish whether a produced water has been in contact with either oil or gas.

These techniques can be advantageous in planning future exploration strategy.

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Upper Mannville "Glauconitic" Channels, Little Bow Area, Alberta: Geologic Models for Seismic Exploration

Large channels in the Glauconitic interval of southern Alberta have proved to be elusive exploration targets owing to the discontinuous nature of reservoir sands. In the Little Bow area, a 20 m deep channel has been cut through sandstones and shales of the Glauconitic interval and limestones and shales of the underlying Ostracod Zone. Mineralogy, texture, and geometry of the channel sands are distinctly different from those adjacent to the channels.

The montmorillonitic Bantry Shale of the Ostracod Zone is an excellent regional marker and is absent only where it has been cut out by a channel. Sediments of the Glauconitic interval, which conformably overlie the Bantry Shale, were deposited in a broad, shallow subtidal marine bar system. The marine bars are tabular sand bodies only a few meters thick, and are composed of low porosity fine to medium-grained, calcite and clay cemented chertarenites.

The incised channel system contains 20-m thick point bar accretion sets and shale plugs. Point bar sands are porous medium to coarse-grained sublitharenites with high angle cross-stratification. Sand bodies are discontinuous along the length of the channel, and the channel margins are abrupt.

Geologic exploration for these discontinuous channel sands is difficult and high resolution seismic data integrated with sound geologic modeling is critical for successful prospect delineation.

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Hydrodynamic Control of the Present and Mid-Tertiary Regional and Local Geothermal Gradients, Alberta, Canada

The Upper Devonian Woodbend Group and Beaverhill Lake Formation of Alberta contain numerous crude oil and natural gas occurrences in several carbonate reef chains, which are hydraulically distinct with small but subtle differences in present reservoir temperature. Regionally, these hydrocarbon occurrences exhibit typical trends from immature gases in the shallower pools, sometimes associated with biodegraded crude oils, to deeper mature crude oils. Examination of the composition of the natural gases and the broad general characteristics of the crude oils suggests that there is imposed on these typical maturation trends differences in the fluid compositions and reservoir temperatures which are related to the different hydraulic systems and the position of each system within the low fluid-potential drain which essentially channels flow within the thick sequence of highly permeable Upper Devonian and Carboniferous carbonate rocks in the medium-depth part of the Alberta basin.

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Estimation of Organic Maturation from Seismic and Heat-Flow Data

A technique using seismic and heat-flow data was developed to estimate organic maturation level and timing of oil generation.

This technique of linking geochemistry and geophysics is especially valuable in pre-drilling evaluation of hydrocarbon potential in frontier or difficult areas where well data are not available owing to economic, environmental, or political reasons. Also it is a useful technique for a realistic assessment of hydrocarbon potential in a drilled area for two reasons. First, the proposed method is applicable to the evaluation of hydrocarbon potential in an off-structure area where most of the hydrocarbon generation occurred but where the conventional geochemical methods are useless because of lack of samples. Second, the technique incorporates subtle lateral changes in geothermal gradients—hence maturation level—due to variation in thickness and lithology of sediments.

The proposed method involves three major steps. (1) The thermal conductivity of a formation in a basin is determined from the seismic interval velocity. Then the subsurface temperature is calculated from heat flow (measured or estimated) and the thermal conductivity. (2) The calculated temperature is combined with geologic age derived from seismic stratigraphic or related data to calculate maturation level in terms of vitrinite reflectance (R_o) using our modified Lopatin's method. (3) The calculated R_o value is incorporated with burial history curve to reconstruct organic maturation history diagram. This diagram forms the basis for determining the timing of oil generation and depth interval of the oil window.

We have tested the modeling technique in several sedimentary basins using measured vitrinite reflectance value, DST temperature, and fluid inclusion as checks.

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Pyrolysis-Gas Chromatography as an Exploration Tool for Geochemical Evaluation of Source-Rock Potential

A pyrolysis system was developed to identify the possible production type (oil, condensate, and gas) and the presence of contamination (by migrated oil or drilling additives) in rock samples. This is accomplished by incorporating gas chromatography (GC) in the pyrolysis system so that a direct analysis can be made of the hydrocarbons in the pyrolysis products from sediments samples. This analytical capability of making a positive identification of pyrolysis products is one of the important advantages of this system. Because of this additional feature, this pyrolysis system can overcome problems related to the interpretation of indirect production type indicators such as the oxygen and hydrogen indices used by the commercially available ROCK-EVAL system.

The productive type is recognized either qualitatively by GC fingerprint traces or quantitatively by hydrocarbon composition (C_1-C_4, C_5-C_{14}, and C_{15+}) from the kerogen (Peak II) pyrolysate. Oil-prone sediments are recognized by GC traces with a full spectrum of C_1 to C_{28} hydrocarbons, or by high amounts of C_{15+} hydrocarbons. In contrast, gas-prone sediments are characterized by the predominance of light hydrocarbons from C_1 to C_7 in the GC trace, or by low amounts of C_5-C_{14} and C_{15+} hydrocarbons. Condensate or mixed type production is intermediate in character between the two.

Migrated oil or liquid contaminants are detected by a stepwise heating of the rock samples and GC analysis or Peak I (solvent extractables) and Peak II (kerogen decomposition) products.

The application of this pyrolysis system over the past four years as a rapid method for evaluation of organic richness, maturation, and production type using well or outcrop samples along with the limitations of the techniques will also be discussed.

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Surficial Sediments, Chesapeake Bay, Virginia

Surficial sediments, Chesapeake Bay, Virginia, are significantly sandier than previously reported. Sixty-five percent of the area as determined from 2,000 grab samples are sands when plotted on the ternary sand:silt:clay diagram. The mean graphic-mean is 3.17ϕ. Distribution of sediments is, in large part, a function of geomorphology with an apparently good correlation between depth and sediment type. Finer grained sediments are usually confined to the deeper channels. The exceptions to the depth-size relationship are the presence of fines in the shallow, marginal embayments such as Mobjack Bay and the absence of fines in the deep channel in the southeastern section of the bay. The occurrence of sands here is a function of infilling with sands from the area of the bay mouth and, perhaps, of scour into older (Pliocene?) materials. Sediment distribution also reflects the local source with the shallow-water marginal sands derived from erosion of the banks and relict features.

Several large geomorphic features are distinguishable on the maps of sediment characteristics. These features include the deep channels, a large sand shield near Tangier Island, relict spits, the zone of influence of the bay mouth, and the possible existence of an ancient channel extending from Mobjack Bay. The number of samples in this study is an order of magnitude greater (2,000 versus 200) than previous studies, allowing a significantly better delineation of sediment types.

900 samples, biased away from the coarser sands, were analyzed for total carbon, organic carbon, and sulfur contents. There are strong correlations between these characteristics and sediment type, especially weight percent clay. Additionally, there is a good relationship between the organic carbon and sulfur content. Total carbon content reached 10% in some samples, however, the average was 1.5%. Average organic carbon and sulfur contents were 1.0 and 0.34%, respectively.

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Three-Dimensional Study of a Modern Flood-Tidal Delta in South Carolina

A three-dimensional study of a modern flood-tidal delta in South Carolina was conducted using historical charts and photographs, geomorphic and sedimentologic process measurements, and shallow seismic profiling. Results suggest that the flood-tidal delta developed in response to shoreline erosion of the Santee River delta since the river was dammed and diverted in the first half of this century. The Santee flood-tidal delta complex consists of a transgressive sequence topped with tidal delta deposits 1 to 1.5 m thick. The clean, coarse to medium-grained sand of the flood-tidal delta is underlain by tidal flat, tidal channel fill, and bay-fill sediments. Beneath that lies estuarine-lower delta plain deposits.

The relationship of peak ebb and flood currents to the depth of flow and the degree of shielding by topographic highs exerts control over bed-form orientation and distribution. Ebb-oriented bed forms dominate the tidal delta surface, but preferential preservation favors flood-oriented bed forms owing to higher hydraulic energy on the ebb shield and flood ramp, and by protection from ebb currents provided in the lee of the ebb shield. Textural and mineralogic evidence indicates that littoral-derived sediments are being deposited in the North Santee channel. Seismic and stratigraphic data indicate the maximum volume of clean sand in the flood-tidal delta is between 387,000 and 500,000 m^3.

Surface mapping suggests that the North Santee flood-tidal delta will continue to transgress the adjacent tidal flat, weld onto nearby Cane Island, and be capped by salt marsh if undisturbed by rediversion of the Santee. The flood-tidal delta would apper in