around it resulting in independent Canadian and American schemes of stratigraphic nomenclature being proposed.

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The Colony Shale Oil Project

For many years, the oil shale "boom" in western Colorado has been just around the corner. Now, the Colony Shale Oil Project, a joint development of The Oil Shale Corp. and Exxon Corp., is under full construction and will be the nation's first full-sized commercial shale oil project. The Colony operation, located in Garfield County in northwestern Colorado, is targeted for production at a rate of 47,000 bbl/day of synthetic oil in early 1986. To support the plant, it will be necessary to produce 66,000 tons/day of oil shale from a conventional room-and-pillar mine.

The shale will be hauled from the mine in 85-ton trucks and crushed to -9 in. (229 mm) in a 72×109 in. (1.8×2.8 m) gyratory crusher. The coarse ore will then be transported by a 72 in. (1.8 m) conveyor belt 5,000 ft (1,525 m) to the secondary crushing station where it will be further reduced to $-\frac{1}{2}$ in. (13 mm) by eleven impactor crushers. The finely crushed shale will enter six Tosco II retorts, each capable of processing 11,000 tons/day. When heated to 900°F (482°C) in the pyrolysis drum, the kerogen vaporizes and is separated from the spent shale. The oil shale vapors are then condensed, fractionated, and upgraded by hydrotreating before entering a pipeline to be transported to a conventional refinery. By-products ammonia, sulfur, and coke will be recovered from the upgrading process.

To mitigate the impact of a large work force on the sparsely populated Western Slope, Colony is developing the Battlement Mesa community on the Colorado River 15 mi (24 km) south of the project site. When completed, the community will house approximately 25,000 residents in a variety of housing types, and will be the second largest town in western Colorado. Colony is providing the equivalent of interest-free loans to local organizations for the establishment of schools, a fire station, and other needed facilities.

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Variation in Depositional Systems Along Shoreline Embayments—Modern and Ancient Examples

The stratigraphic record of strandline depositional environments shows a systematic change along shoreline embayments in response to changes in the ratio of wave-energy flux to tidal-energy flux. Waves diminish in size and tidal ranges increase from the entrances to the heads of such embayments.

A depositional model for shoreline embayments emphasizing sand bodies shows the following: *embayment entrance*—wave-dominated deltas, microtidal barriers, abundant washover fans, and flood-tidal deltas in lagoons; *mid-zone*—mixed-energy deltas, mesotidal barriers, numerous inlets, back-barrier tidal-channel sands; and *embayment head*—tide-dominated deltas, offshore tidal sand ridges, no barriers, extensive marsh/tidal flat systems.

Two ancient shoreline embayments, along the Carboniferous shoreline of the southern Appalachians and the Late Cretaceous shoreline of Wyoming and Colorado, illustrate the model. Both examples illustrate a change in sand-body geometry from microtidal, wave-dominated barriers at the entrances to mesotidal, inlet-dominated barriers farther inside the embayments.

Thus, subsurface exploration for sand bodies containing economic deposits should focus on strandline-parallel sands with lagoonward building washovers and flood-tidal deltas at embayment entrances, and strand-perpendicular tidal sands at embayment heads. Exploration in the mid-zones of the embayments would be the most difficult, because of the complexity brought about by the migration of tidal inlets at the shoreline and tidal channels in the back-barrier area.

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Diagenetic Model for Carbonate Rocks in Mid-Continent Pennsylvanian Eustatic Cyclothems

Diagenetic patterns in cyclic Mid-Continent Pennsylvanian carbonates are readily explained in terms of a predictive diagenetic model derived logically from the eustatic depositional model for widespread Pennsylvanian cyclothems. Transgressive shoal-water calcarenites are characterized by overpacking of grains, discernible neomorphism (with excellent preservation of structure) of originally aragonitic grains (ooids, green algae, mollusks), and ferroan calcite and dolomite cement, which indicate movement from the marine phreatic environment of deposition and diagenesis into the low-oxygen deeper burial connate zone, with substantial compaction before any cementation. Offshore invertebrate calcarenites associated with offshore ("core") shales also are characterized by overpacking of grains and ferroan carbonate cements, which indicate a similar diagenetic history. Regressive shoal-water calcarenites show a much greater variety of diagenetic features, including early marine cement rims and large-scale leaching of originally aragonitic grains, commonly with subsequent collapse of micrite envelopes, grain fragments, and overlying material in samples insufficiently stabilized by early cement rims. This was followed by pervasive cementation by blocky calcite before much further compaction, then by ferroan calcite, and finally ferroan dolomite in remaining voids. This pattern indicates replacement of depositional marine phreatic water by meteoric water, which dissolved unstable carbonate grains and then deposited stable carbonate cements in environments that eventually became increasingly oxygen-depleted and otherwise chemically changed, probably as mixing-zone and deeper connate water moved back into the rock and replaced the meteoric water during and after the succeeding transgression. Trends in calcilutites are essentially similar to those in calcarenites of equivalent phase of deposition, with evidence of subaerial exposure and meteoric vadose soil formation in strata at the top of many regressive limestones. It is apparent that with the regression of the sea and emergence that terminated deposition of a cyclothem, meteoric water penetrated the permeable parts of the regressive carbonate and left its distinctive diagenetic patterns of early leaching and cementation before much compaction occurred, but rarely did meteoric water penetrate the impermeable offshore shale, which acted as a seal and allowed associated deep-water and underlying transgressive carbonates to become more deeply buried and substantially compacted before cementation, with unstable grains undergoing slow neomorphism in the absence of leaching.

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Facies Associations in Slope-to-Shelf Transition: Precambrian Miette to Lower Cambrian Gog Group, Kicking Horse Pass, Southern Canadian Rocky Mountains

In the eastern Kicking Horse Pass, Miette sediments consist of 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