which may not be accompanied by measurable earthquakes, also causes some failures. These tectonic factors appear to be important in triggering repeated failures in the thick sedimentary unit that is forming offshore of the Eel River.

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Mineralogic Analysis and Uranium Distribution of Sedimentary-Type Uranium Ores

Nine cores from a sedimentary-type uranium orebody of the upper Jackson Formation, Karnes County, Texas, were studied to determine the stratigraphy and the mineralogy in relation to the uranium distribution, and to provide guidelines for further exploration and/or exploitation. The uranium concentration ranges from 1.4 to 6,000 ppm in approximately 200 samples, as determined by delay neutron counting.

The orebody is generally a fine-grained, gray, well-sorted, arkosic sandstone that is enclosed in finer grained, poorly sorted lagoonal or paludal mudstone or lignite. The depositional environment of the orebody is presumably a beach-barrier-bar sequence with its northeastern end delineated by a downward-cutting fluvial system.

The bulk mineralogy of the ores consists primarily of quartz and feldspar with minor amounts of biotite, muscovite, augite, clinoptilolite, and very minor amounts of hematite, pyrite, and coffinite. The clay analysis of the less than 2 $\mu m$ fractions reveals a preponderance of smectite with very minor amounts of kaolinite and illite.

The high concentration of uranium in the cores is generally associated with a high concentration of clays, zeolites, and/or carbonaceous material. Additionally, uranium concentration usually increases with a decrease in size fraction. Since smectite dominates the clay mineral assemblage in the ore, the expandable and absorptive smectite could be a significant factor in uranium mineralization.

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Athabasca Oil Sands—Facies Characteristics and Distribution

The Athabasca oil sands represent one of the world's great untapped energy resources, with in-place bitumen reserves estimated at $146 \times 10^9$ m$^3$ ($922 \times 10^9$ bbl). About 10% of the reserves lie close enough to the surface to be mined in open-pit operations, but the vast majority (~90%) must be developed by as yet unproved in-situ means. A geologic understanding of the facies is crucial in applying in-situ techniques.

Most of the rich oil sand bodies are channel deposits in the Middle Member of the Lower Cretaceous McMurray Formation. This member, averaging 35 m in thickness, is dominated by upward-fining sequences interpreted as meandering river deposits. Earlier detailed work on epsilon cross-strata in outcrop confirms the interpretation of single channels 20 to 30 m deep. The channel sequence is dominated by trough cross-bedded sands at the base, grading upward into thinner bedded rippled sand units with increasingly abundant clay drapes toward the top. Burrowing is common in the upper parts but palynology indicates a basically freshwater setting. The channels are part of a complex fluvial-deltaic system associated with standing bodies of fresh to brackish water.

The fluvial Lower Member fills lows in the underlying Devonian limestone. The sands are commonly very argillaceous or water-bearing, but in places, form good reservoirs.

The Upper Member is a 20-m-thick sequence of shoreline deposits. This member is generally very argillaceous, but extensive upward-coarsening marine sands near the top commonly make good reservoirs.

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Induced Spectroscopy: A Mineralogy-Lithology Well Log

Nuclear spectroscopy logging, specifically with the induced gamma-ray tool (GST), measures the relative yields of gamma rays resulting from interactions of neutrons with different elements (isotopes) present in downhole formations.

The data are interpreted by associating the spectra of certain elements with sedimentary rocks which are typically dominated by the element (e.g., silicon = sandstone). The measured elemental yields are proportional to the volume fractions present in the rock formations. The yields are also proportional to some unknown values: effective neutron flux, concentration of selected elements in other sedimentary rocks, microscopic thermal neutron capture cross sections, and gamma-ray production and detection efficiencies. The effects of these unknowns can be minimized by laboratory calibration of yields in known formations or by comparison with whole or sidewall core data.

With the above and some additional information (SARABAND, NGT), the well-site analysis or a more sophisticated computerized presentation yield volume fractions of effective porosity, sandstone, limestone, feldspar, and the total clay ("shale") volume which may be further divided into volumes of clay porosity, illite, and chlorite. The resulting visual representation of these data becomes an invaluable aid to stratigraphic analysis.

In a field study of tight gas shaly sandstones in the Cotton Valley Group (Upper Jurassic) in east Texas, the analysis not only described the clay mineralogy and lithology but also highlighted several important geologic features which are important in designing an efficient hydraulic fracturing program: genetic units of sedimentation, laminated and thick-bedded shales, hydrated shale beds, and zones of well-developed intergranular pore-filling (quartz or calcite) cements—all of which may be fracture-containment boundaries.

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Surface Wall Texture and Evolutionary Classification of Cenozoic Planktonic Foraminifera

The classification most widely applied to Cenozoic planktonic Foraminifera employs relatively simple morphologic criteria, such as chamber shape and apertural position, to sort test forms into genera. Because the criteria are few and distinct, this traditional approach is easy to apply and has been generally accepted by stratigraphic paleontologists. Most morphologic features, however, evolved several times during the Cenozoic. Peripheral keels appeared independently at least eleven times. Form-genera based solely on such features are unavoidably polyphyletic.

Surface wall texture, in contrast, has been evolutionarily conservative during the Tertiary. Once developed, the few basic wall-textural types persisted within lineages. A classification based primarily on surface wall textures and secondarily on gross morphology most accurately reflects patterns of descent recognized from species-by-species evaluation of ancestor-descendant relations and conveys important stratigraphic and paleoecologic information.

Most Cenozoic species, for example, are usually assigned to either *Globorotalia* or *Globigerina.* Used in this way, these taxa are over-inclusive and provide no information beyond a mnemonic clue to apertural position. As appropriately modified, *Globorotalia* is exclusively a Neogene genus, and Paleogene species are assigned to *Acarinina, Morozovella,* and *Planorotalites. Globigerina* is largely a middle Tertiary taxon, containing only a few cool-water modern species; most late Neogene globigeriniforms belong in *Neogloboquadrina* or *Globoturborotalita.* An emphasis on phyletic species-grups is requisite for the development of multiple-phyletic zonations.

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Bioclastic Carbonate Facies of Great Barrier Reef, Australia

The variations which can be observed in the component compositions of the reefal sediments result from differences in the percentage contributions made by five dominant skeletal types, namely: coral, coralline algae, "Halimeda," foraminiferids, and mollusks. The distribution within the reef top environment is controlled partly by the nature of the reefal communities and partly by the production of specific skeletal size modes which are preferentially transported to different depositional environments under a variety of high-energy and/or low-energy hydraulic regimes.

The changing nature of the skeletal component composition of the reefal sediments associated with reefs at varying stages of their morphologic evolution is clearly discernible. This allows relations which exist between reef morphology, depositional environments, sediment types, sedimentary facies, and depositional processes to be qualitatively and quantitatively assessed, thereby, providing insight into the behavior of reefal sediments in both a temporal and a spatial context.

The commonly occurring sedimentary facies are illustrated and described. They provide an extremely useful basis for paleoenvironmental reconstructions of pre-Holocene reefs or ancient analogs, especially considering the Great Barrier Reef is one of the few modern carbonate terranes which has exact counterparts in the rock record (e.g., the Devonian "Great Barrier Reef" of the Canning basin; the Permian Texas reef; the Jurassic-Cretaceous buried reef off the Atlantic Coast; Devonian reef complexes of Canada).

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Fluvial Facies Associations—Guide to Tertiary Coal Development and Exploration in Powder River Basin, Wyoming and Montana

The Paleocene Tongue River Member of the Fort Union Formation supports widespread coal-mining activity and contains most of the recoverable coals in the Powder River basin. Coals are well-developed in eastern and northern Powder River basin, but the best exposures are in the northern part. Most mining is from the very thick (as much as 125 ft or 38 m) coals; however, as these coal reserves are depleted, future exploration will focus on moderately thick coals. Exploration guides for the moderately thick coals may be their facies associations. In the northern Powder River basin, 175 mi (280 km) of cross sections, constructed from closely spaced outcrop sections and drill holes, provide detailed facies associations of the coals.

One facies association is dominated by thick fluvial-channel sandstones and coals as much as 40 ft (12 m) thick and 12 mi (19 km) in extent. The coals formed in poorly drained backswamps in which uniformly thick peat bogs accumulated, subparallel to meandering channels and opposite their migration and avulsion directions. A second facies association is characterized by abundant crevasse sandstones, subordinate thin channel sandstones, and lacustrine limestones, shales, and siltstones. Facies-associated coals, as much as 8.5 ft (17 m) thick and 5 mi (8 km) in extent, formed in well-drained backswamps frequently interrupted by crevasse splays that debouched into flood-plain lakes. The best development of economic coals of the fluvial-channel dominated facies is in the lower part of the Tongue River Member, and that of the flood-plain-lacustrine coal-facies association is in the upper part.

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Depositional Environments and Reservoir Properties of Sandstones of Lower Cretaceous Nanushuk and Upper Cretaceous Colville Groups, Umiat Test Well 11, National Petroleum Reserve, Alaska

Delta-front sandstones of the Grandstand Formation, Killik Tongue of the Chandler Formation, and the Ninuluk Formation (Nanushuk Group) are moderately well to well-sorted, very fine to fine-grained, angular to subangular chert-arenite and phyllarenite. A source terrane of low-grade metamorphic rocks, sandstones, and cherty limestone was southwest of Umiat and the delta prograded northeasterly. Weighted average porosity and permeability of cored sandstones are 15.6% and 167 md for the Grandstand Formation, 16.4% and 96.2 md for the Killik Tongue of the Chandler Formation, and 12.6% and 10.7 md for the Ninuluk Formation.

The Seabee Formation (Colville Group) is predominantly marine shale, interbedded with several sandstone units. These marine sandstones are moderately well to well-sorted, very fine to medium-grained, angular to subangular phyllarenite, metarenite, and volcanic litharenite. Volcanic rock fragments and volcanic plagioclase feldspar are abundant. Abundant chlorite and smectite reduce permeability; weighted average permeability is 3.1 md and weighted average porosity is 11.5%.

The Tuluvak Tongue of the Prince Creek Formation (Colville Group) is composed of interbedded delta-plain and delta-front facies of a northeasterly prograding delta. Sandstones from the Tuluvak Tongue are moderately well to well-sorted, very fine to medium-grained, angular to subangular phyllarenite, feldspathin phyllarenite, and volcanic litharenite. Abundant authigenic smectite reduces permeability; weighted average permeability is 3.9 md and weighted average porosity is 14.6%.

Composition of the sandstones has a major effect on porosity and permeability. Sandstones that have a higher content of compressible grains (mainly phyllite), and sandstones that have greater matrix and cement content generally have lower porosity and permeability. Expandable clay matrix is essentially absent in the Nanushuk Group sandstones. Porous and permeable Nanushuk Group sandstones should exist in those depositional areas that received only sparse amounts of metamorphic rock debris and in areas where energy conditions at the site of deposition facilitated sorting and winnowing of the sediment.