bed. Because sediment is thus transferred from dunes to underlying strata, bed forms must decrease in cross-sectional area or in number, or both, unless sediment lost from dunes during deposition is replaced with sediment transported from outside the depositional area.

Using equations that relate the amount of sediment lost by dunes to the amount gained by sets of cross-strata, we calculate that the dunes which deposited the De Chelly (Permian), Navajo (Triassic? and Jurassic), and Entrada (Jurassic) Sandstones had mean heights with lower and upper limits of 16 and 450 m, respectively. Although these calculated dune heights are surprisingly large, two kinds of field obsevations support the hypothesis that the dunes that deposited 10-m thick sets of cross-strata common in eolian sandstones may have been 100 m high or higher—comparable in size to large modern dunes or draas. First, many sets of eolian cross-strata are primarily bottomset beds; they rarely contain dune-crest deposits or convex-upward cross-strata deposited on lupper lee slopes, and some sets contain sand-flow toes that pinch out near the top of the set. Second, the sand-flow layers in these eolian sandstones are thicker and laterally more extensive than in modern 10-m high dunes. The hypothesis that large dunes deposit relatively thin sets of cross-strata explains the absence in the geologic record of sets of eolian cross-strata comparable in thickness to the height of large modern dunes.

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Model of Transgressive Barrier Island Stratigraphy

Cape Romain, South Carolina, is a large cuspate foreland, 50 km north of Charleston. Geomorphically, it is a barrier-marsh-lagoon complex in a state of rapid transgression. Historically, the shoreline has retreated more than a kilometer; the present retreat rate averages 10 m/year. A detailed coring program was undertaken to determine the Pleistocene-Holocene stratigraphy of the cape. The resulting depositional model has been correlated to the Cretaceous of Wyoming and the Carboniferous of Alabama.

Unconsolidated Pleistocene and Holocene sediments lie unconformably over Oligocene marls. These late Pleistocene facies consist of shallow embayment sand shoals. Silty highly protected lagoon fills and shell storm lags are found laterally. During the Wisconsin lowstand of sea level, the area was emergent, and a freshwater swamp developed forming a 1.8 m thick peat. The swamp existed for about 7,000 years, until the leading edge of the Holocene transgression overtopped it. Rapidly rising sea level exceeded sediment supply resulting in the deposition of laminated silts. A barrier island probably had already developed offshore, affording protection for the lagoon. As the rate of sea level rise slowed, the lagoon filled with a coarsening-upward sequence of flasered sands and silts, overlain by a silty sand tidal-flat facies. The lagoonal facies were capped by the barrier island and its associated marshes and tidal creeks. These barrier-related deposits consist of silty marshes and clean sand and shell washovers, inlet fills, and spit platforms. As the system moves landward, much of the lagoonal sequence is truncated at the shoreface, forming a ravinement surface overlain by an offshore sand; however, the Pleistocene deposits and the peat will be preserved below wave base.

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Mineralogic and Chemical Composition of Antrim Shale, Michigan

The Antrim Shale is the Michigan basin equivalent of Devonian-Mississippian black shales of the eastern United States. The Dow Chemical Co., with DOE funding, has investigated the possibility of in-situ gas production from the Antrim by underground combustion. This paper summarizes some results obtained in the shale characterization program that was a part of that study.

Antrim Shale is rather uniform in composition and contains about 30% Si, 8% Al, 4% Fe, 2% Mg, 3% Ca, 2% S, and 5% organic carbon. Mineralogically, Antrim Shale consists of 50 to 60% quartz, 20 to 35% illite, 5 to 10% kaolinite, 0 to 5% chlorite, and up to 5% pyrite. Calcite and dolomite, when present, occur as limestone nodules, lenses, and interbeds up to 5 ft (2 m) thick in the lower half of the Antrim. Bedford Shale, which overlies the Antrim in eastern Michigan, contains more total clays, illite and kaolinite, and less quartz. Ellsworth Shale, which interfingers with the upper part of the Antrim in western Michigan, contains up to 25% dolomite.

Antrim Shale contains up to 12.8% organic material, as measured by low-temperature ashing. Bitumen contents range from 0.2 to 0.8%. Average molecular weights of bitumen components are 360 to 370. Deeper drill holes have higher bitumen contents. Kerogen, which makes up the rest of organic material, is of low functionality, about 1 functional group per 25 carbon atoms. Hydroxyl (1 group/50 C atoms) and alkene double bonds (1 group/50 C atoms) are the most common groups present.

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Bridges to *What* Future?

The theme title of this annual meeting demands an answer to the question: what will be the principal energy source for mankind in 50 years? In 100 years? When our petroleum supplies are gone or so reduced as to be unimportant, what will be the alternatives? Geothermal and other minor sources will help, but the major possibilities are our other fossil fuels (oil shale, tar sands, and especially coal), nuclear energy, and solar energy. Because the other fossil fuels are also nonrenewable resources, they can only serve as a bridge to the ultimate major source: nuclear or solar. An examination of these in terms of adequacy, effects on man's environment, and the quality of human life, indicates that solar energy is the logical choice. It is not true that solar power is inadequate; recent studies indicate that solar energy could provide liquid and gaseous fuel and electricity, not only for the present world population of about 4 billion, but for the 10 billion forecast by the demographers by 2080, if adequate planning and development are started now. Present policies seem to be locking us into a nuclear future, with all of the major problems and dangers it entails. Rational, realistic decisions are needed, and we geologists can provide valuable advice to the policy makers.

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Influence of Pore Geometry on Future Enhanced Recovery in Ordovician (Red River) Carbonate Reservoirs at Cabin Creek Field, Montana

This study related the distribution of pore geometry to enhanced recovery within the Upper Ordovician Red River

Formation, Cabin Creek field, Montana. The field is located on the Cedar Creek anticline in southeast Montana. The Red River Formation is a sequence of alternating limestones and dolostones. Lateral and vertical variations of dolomitization are mostly responsible for reservoir heterogeneity. Production is from the U2, U4, and U6 dolostones, whereas the interstratified U1, U3, and U5 limestone units are nonproductive. Cumulative Ordovician and Silurian production was 61,574,000 bbl of oil as of September 1979, with reserves of 13,426,000 bbl. Waterflood began in 1964, and the field is a good candidate for tertiary recovery by the carbon dixoide miscible process.

Studies of thin sections, mercury capillary pressure curves, and resin pore casts have shown that several different types of pore systems occur, each associated with a particular depositional environment and diagenetic regime. Pore-system geometry is a function of the size and shape of the dolomite crystals composing the reservoir rock matrix. The size, sorting, and shape of pore throats determine the reservoir characteristics of each pore system. In addition to dolomitization, post-depositional leaching of calcite and evaporitc sulfate minerals was important in reservoir porosity development.

Mean pore-throat size, a statistical measure of pore geometry, was found to increase as porosity increased. Using this relation and electric log porosity values, it is possible to predict pore geometry and, as a consequence, recovery efficiency, if lithofacies distribution, porosity type, and diagenetic history are known. Since residual oil saturation is strongly dependent on the pore-system characteristics of the reservoir rock, it is possible to identify parts of the reservoir which have potentially high residual oil saturation, thus establishing targets for enhanced recovery.

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Lithofacies and Depositional Environments of Coaledo Formation, Coos County, Oregon

The middle to upper Eocene (Narizian) Coaledo Formation, well exposed along the southwestern Oregon coast, includes seven basic lithofacies types which constitute a complex marine-deltaic sedimentary sequence. The lithofacies are defined by lithology, fossils, bedding characteristics and sedimentary structures.

Petrographic examination of Coaledo sandstones indicates a dominantly andesitic volcanic source with subordinate plutonic, metamorphic, and sedimentary sources. Paleocurrent indicators suggest that these source areas were located to the southeast, from the initial calc-alkaline vents in the southern ancestral Cascades and from the northern Klamath Mountains. Regional paleocurrent analysis also suggests open-ocean conditions to the west, offshore from a wide, swampy coastal plain.

The pre-Coaledo units exposed in the Cape Arago area are interpreted to be delta foreset deposits. Coarsening-upward sequences recognized within the lower Coaledo member are interpreted as delta topset deposits, including subaqueous distributary channel, interdistributary tidal flat, lagoonal, and barrier-bar facies. The lower part of the middle member is characterized by deeper marine facies. The upper part of the middle Coaledo member represents prodelta deposition during a second progradational phase. Coarsening-upward sequences are recognized in the upper Coaledo member, again representing delta topset deposits. Uppermost Coaledo sands and overlying units show a gradual return to deeper marine conditions.

Coaledo sediments unconformably ovelrie gently folded fore-arc sediments of the Tyee basin. Deposition of coal-bearing deltaic sediments far to the west of the axis of the basin suggests regional tectonic uplift along the flank of the basin, or progradational filling of the continental flank of the basin.

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Eustatic Control of Distribution of Lower Upper Cretaceous Coal Beds in Utah: Application in Coal Exploration

Upper Cretaceous rocks in the Western Interior of North America record a series of transgressions and regressions that reflect shifts in the balance between rates of tectonic subsidence and sediment input and rates of eustatic sea level fluctuation. One of the transgressive-regressive cycles spans latest Albian through middle Turonian time and appears to have been primarily controlled by the rise and fall of worldwide sea level. The distribution of coal-bearing strata in this part of the Upper Cretaceous section in Utah reflects, and is probably a direct function of, this eustatic cycle. Rocks deposited during the transgressive phase of the cycle generally contain only thin beds of high-ash and high-sulfur coal that are of little or no economic value. Likewise, rocks of the regressive phase contain little coal. The accumulation of thick deposits of peat was restricted to the transgressive and regressive maxima of the eustatic cycle. These peats formed the coals of the Alton, Harmony and Kolob, and the Emery and Vernal coalfields, respectively. The delicate balance between subsidence, sediment input, and eustatic sea level change that existed at times of maximum transgression and maximum regression allowed for the stacking of deltaic sequences, which then resulted in the accumulation of thick bodies of peat. This situation invites the development of a predictive model relating the distribution of economic deposits of coal to the various phases of the eustatic cycle. This model is applied to predict the areas most likely to contain thick beds of coal in the deep subsurface between the northern limit of the Emery coalfield and the southern edge of the Uinta basin in central Utah.

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Seismic Interpretation of Statvik Field, Norway—3-Dimensional Study of Subunconformity Trap

The Statvik field is located in Norwegian North Sea block 34/10. Initial exploration was based on the interpretation of a one-kilometer 2-D migrated seismic grid. In 1979, at a relatively early stage in the exploration phase, it was decided that better quality data were needed to adequately map the structurally complex, highly faulted area, and to guide further delineation drilling. A 3-D seismic survey was therefore shot, covering the whole structure.

It is obvious from a comparison of individual lines that the 3-D data is of significantly higher quality than the 2-D data. Furthermore, the extremely dense grid of lines makes it possible to develop a more accurate and complete structural and stratigraphic interpretation.

Specifically, the 3-D data made it possible to map more accurately the dip and the subcrop of the subunconformity strata. The early geologic model had the Jurassic reservoir sands dipping steeply westward over the whole of the structure. This implied extensive erosion of the main reservoir sands toward the east. With the 3-D seismic data, however, we were