sional surface, and the top is gradational with the overlying shale. The dominant sedimentary structures are parallel lamination and low-angle cross-lamination filling broad, shallow troughs. Wave-ripple cross-lamination and wave ripples are commonly developed in the upper parts of the cycles. Trace fossils are generally restricted to the rippled surfaces and consist of horizontal *Ophiomorpha* and *Thalassinoides, Diplocraterion*, and *Chondrites*. Shells, including gastropods, bivalves, and ammonites, occur as lenses near the base of the cycles and as concretions laterally where the sandstones are not developed.

The thin sandstone cycles occur as elongate bodies that are a few tens of miles across and several tens of miles long. The bodies collectively occur in a southward-projecting lobe that covers an area of 40,000 sq mi (64,372 sq km) in central Montana. The sediments were transported as much as 700 mi (1,127 km) in a southeastward direction from the Dunvegan delta in northwestern Alberta. The sandstone cycles are interpreted to have been deposited by storm events on a broad shallow shelf. The sand was probably transported by intense wave action and storm-generated currents and deposited after erosion during the waning stages of the storm.

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Development of Biogenic Gas from Shallow, Low-Permeability Reservoirs—Examples from Southeastern Alberta and Bowdoin Dome Area, North-Central Montana

Prior to 1970, shallow gas production was established in "sweet spots" where the reservoirs are best developed in the northern Great Plains. Recent advances in completion technology coupled with higher gas prices have led to the expansion of these areas through the development of submarginal, low-permeability reservoirs. The development is concentrated in two main areas which cover more than 22,000 sq km. The gas occurs at depths less than 600 m, and recoverable reserves average 2 Bcf of gas per section.

The reservoirs are of Late Cretaceous age and generally consist of siltstone and sandstone laminae, a few millimeters or less in thickness, enclosed in organic-rich silty shale that serves as a seal and was the source for the biogenic gas. The laminae are discontinuous because of depositional processes and/or biologic activity. Coarsening-upward sandstone cycles are locally developed. Although these cycles display the best reservoir properties, they are volumetrically minor. Porosity is confined to small passageways within the laminae, among randomly oriented allogenic clay platelets, and to well-sorted sandstone near the top of coarsening-upward cycles. Diagenesis has reduced permeability and resulted in the formation of fluid-sensitive clays and carbonate cement. However, dissolution has enhanced porosity and permeability in well-sorted lithologies.

The reservoirs are stimulated with sand proppant, carbon dioxide, and water to provide economic flow rates. Typical wells have initial potentials of 300 Mcf of gas per day. Production declines rapidly the first year, but levels off to about 100 Mcf of gas per day. Wells are difficult to evaluate because conventional logs cannot distinguish pay zones in sequences of thin, discontinuous, low-permeability reservoirs.

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Low-Cost Microprocessor System for Paleontologic Information, Including Images

A major problem with paleontologic information is that the names by which fossils are recorded tend to change in meaning over the years, and to be applied differently by different authors. This prevents the growth of an enduring, reliable data base for biostratigraphic and paleoenvironmental interpretations. We are using the storage and sorting capabilities of a microcomputer to supplement Linnaean names with a searchable system of morphologic descriptors. A problem with systems of descriptors is that they can convey only a very limited fraction of the information about the shape of a fossil. Our microcomputer system, therefore, has the capability of storing a low-resolution image together with the set of verbal and numeric descriptors of each form.

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Location of Littoral Energy Fence and Resolution of Relict Features on Atlantic Shelf, United States—Fourier Grain Shape Analysis

Even though, in any given area, shelf sands deposited during the Holocene-Pleistocene may have a common provenance, sands deposited during the latest transgression can be distinguished from sands delivered earlier, by using Fourier Grain Shape Analysis. Sands with longer residence times on the Long Island shelf have smooth abraded grain profiles whereas the youngest sand tends to be much more irregularly shaped. In the nearshore zone, the percentage of irregular grains grades rapidly from approximately 100% at the beachface to 70% at the 10 m depth. Seaward of the 10-m isobath, the proportion of irregular sand decreases at a much slower rate. This change in gradient defines a boundary between nearshore sands and more abraded sands of the middle and outer shelves where little onshore-offshore mixing of sediments occurs. This boundary, the littoral energy fence, also has been seen on the South Carolina shelf.

Sands on the Long Island middle and outer shelf are characterized by relatively high percentages of highly abraded sand. Samples from this zone show areas with slightly higher (80 to 100%) or lower (50 to 80%) proportions of abraded quartz. This pattern appears to be related to morphologic elements on the shelf. In contrast, the South Carolina middle and outer shelf contains broad, coast-perpendicular stripes of abraded sand alternating with stripes from 10 to 30 km wide that are strongly dominated by first-generation irregular sand. Stripes containing high proportions (over 75%) of irregular sands are interpreted to be understories of alluvial valleys of the ancestral Cooper, Santee, and Waccamaw Rivers.

These results indicate that shelf sediments preserve a rich record of Pleistocene-Holocene events of both subaerial and subaqueous nature. In addition to clarifying the history of modern shelves, aerial patterns of quartz grain shape variation can be carried into the stratigraphic record, thereby allowing a more detailed paleogeographic-paleoenvironmental reconstruction.

RIGHTMIRE, C. T., and H. H. RIEKE, TRW, Inc., and W. H. FERTL, Dresser Atlas, Houston, TX

Resource Evaluation of Gas-Bearing Coal Beds

Bituminous and subbituminous coal deposits in the United States are a significant fossil fuel resource. Furthermore, a large methane gas resource is trapped in these coal beds and associated strata.

Distribution and resource assessment of these potential gas reserves in 380,000 sq mi (988,000 sq km) of coal-bearing strata is currently under investigation. Diagnostic techniques include regional and local geologic studies, mud log evaluations, geophysical wireline logging with associated digital interpretation in both open and cased boreholes, conventional and sidewall core analyses, drill-stem and production testing, and coal bed stimulation techniques.

Integration and analysis of the resultant data provide valuable information as to coal bed thickness, coal rank, ash and moisture content, coal permeability, face and butt-cleat orientation, gas content, pressure, and flow potential. Overburden characteristics and the elastic rock properties of the floor and roof rocks, such as Young's modulus, bulk modulus, shear modulus and Poisson's ratio, are determined from logging techniques and provide information important to mine design, mining operation, stimulation of gas-bearing coal beds, and in-situ coal gasification projects.

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Migration and Entrapment of Petroleum—Examples from Utah Oil-Impregnated Sandstone Deposits

Utah contains more than 50 deposits of oil-impregnated rock ranging in size from tiny patches to areas covering hundreds of square miles. These deposits are estimated to contain a total of 22.9 to 29.3 billion bbl of oil.

The following deposits are discussed, with illustrations and samples displayed. (1) South margin of the Uinta basin (P. R. Spring, Hill Creek, and Sunnyside deposits)—complex of deltaic sands impregnated with oil which is migrating out of the Uinta basin. Entrapment is controlled by thickness, volume and permeability changes in the reservoir; buoyancy of oil; regional structure; and jointing. (2) Central Uinta basin (Chapita Wells and Pariette deposits)—oil migrating up vertical gilsonite veins and outward into adjacent porous fluvial channel sandstones. (3) North flank of Uinta basin (Tabiona deposit)—pale yellow, live oil seeping up vertical sandstone beds in a structurally complex area, migrating across an unconformity, and accumulating as a black "tar sand" in basal sandstone above the unconformity. (4) Central southeast region (Tar Sand Triangle and Circle Cliffs deposits)—giant "fossil" oil fields on flanks of major uplifts exposed by erosion. The Tar Sand Triangle with 12.5 to 16.0 billion bbl in place in the Permian White Rim Sandstone is the largest tar sand deposit in the United States. The Circle Cliffs deposit contains 1.3 billion bbl of oil in the middle (Torrey sandstone) member of the Moenkopi Formation (Triassic).

At their present location, Utah's oil-impregnated rock deposits may still be migrating toward a trap or to seepage and dissipation. Some deposits are active seeps indicating untapped oil reservoirs at an unknown vertical and horizontal distance.

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Common Factors Among Atypical Fields

Several common factors are functionally relevant to the occurrence of typical as well as atypical oil and gas fields. Attention is focused on the more clearly atypical fields.

We may observe an apparent relation between the presence of oil or gas and certain geologic or geochemical factors without determining the true causality of that relation (which could involve other vital factors unperceived). Thus, our conclusions can be founded on mere coincidence and, once reached, those conclusions may carry a lot of momentum.

Some pertinent criteria of effective entrapment which can be examined in both typical and atypical fields are: upward reservoir convergence; differential compaction; stratigraphic shunting; deep-water discharge; structural coherence; minimum potential energy; local cover weakness; hydrothermal chimneys; near-vertical faulting; and hydrochemical plumes.

At this stage in our knowledge about petroleum occurrence we can probably learn more from the "atypical" than from the "typical," because some of our tacit assumptions are challenged. The atypical situation forces us to answer new questions. The new answers then may enable us to fine-tune the search for more dependable oil and gas prospects—typical or otherwise.

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Computer Assisted Paleoecologic Analyses and Application to Petroleum Exploration

Several computer programs used in the oil industry help provide rapid, reliable, and consistent paleoecological interpretations of paleontologic and lithologic data from wells drilled in the silico-clastic regime. Some of the more significant programs are described and their value to the exploration program is demonstrated.

The basic input is the coded description of the fossil and lithologic constituents of washed well samples described by paleontologists. The output is a basic, detailed paleontologic well log, plus several additional products, including paleoecologic logs and displays.

The basic paleontologic log consists of a sample-by-sample, coded, quantitative listing of fossil identifications and lithologic content of the entire well plotted to a vertical scale, usually 1 in. = 100 ft (1 cm = 76 m).