

rich record of Pleistocene-Holocene events of both sub-aerial 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.

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#### 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 Paleocologic Analyses and Application to Petroleum Exploration

Several computer programs used in the oil industry help provide rapid, reliable, and consistent paleocologic 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 paleocologic 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).

Two types of paleoecologic products are particularly useful, namely (1) paleobathymetric well logs, and (2) occurrence charts on which fossils found in a well are arranged in sequence and groups according to their paleoecologic significance.

The ultimate objective is to utilize all the interpreted paleontologic data in the most effective manner for maximum contribution to the exploration program. The logs are synthesized to produce paleobathymetric maps, cross sections, and other displays, which support the exploration effort in numerous ways, such as (1) reconstructing geologic history, (2) recognizing eustatic sea-level changes and evaluating their influence on reservoir sand distribution patterns, (3) enhancing well correlations, and (4) defining depositional trends which are favorable for hydrocarbon accumulation.

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#### Sedimentary Aspects of Organic Material in Green River Shale

Characteristics of the organic material in Green River Formation shale suggest that this material was derived mainly from algae that grew in Eocene lakes. The basin depressions were formed by the uplifting of the Rocky Mountains. Large quantities of soluble salts flowed into these basins from the mountain streams, increasing the salinity of the lakes until they became chemically stratified. In the upper, relatively freshwater section of the lakes, abundant quantities of microscopic algae and other biota grew. The lower section of the lakes became highly reducing and stagnant because of lack of seasonal oxidative turnovers, thus providing ideal conditions for the accumulation and preservation of the organic debris.

Precipitation of mineral carbonates and silicates from the highly saline waters provided most of the minerals that were co-deposited with the organic matter. The characteristics of the lake water varied considerably and significantly effected the composition of both the inorganic and organic constituents of the Green River shale.

Sixty to seventy-five samples from each of three basins of the Green River Formation were analyzed for changes in the organic constituents. Considerable variations in the organic components of the soluble bitumens and of the insoluble kerogens were evident. Some of these variations appeared to be related to depth of burial and some to source material or the environment of the lake water. Compositional differences were related to lithologic differences in the sediments of the three basins.

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#### Castillo Gas Field, Spain

Spain's first hydrocarbon discovery, the No. 1 Castillo drilled by CIEPSA near the northern city of Vitoria, was completed as a gas well in 1961 and continues to produce a small but locally important amount of gas from a thick fractured marl. The field is not significant

economically but does provide nearby industry with needed fuel and gives information on the behavior of a type of reservoir which will become more important in the future as demand and prices increase.

Located on the south flank of the Cantabrian trough, the reservoir section of Turonian and Cenomanian age is between 2,000 and 3,000 m deep on a large anticlinal structure formed during Alpine orogenic events. More critical than structural closure are the various fracture systems which create both reservoir volume and permeability in the 1,000-m column of marls, thin limestones, and minor quartzitic sandstones. Effective primary porosity is negligible.

The field has produced over 1.2 Bcf since 1963 out of an estimated ultimate reserve of 2 Bcf. A variety of drilling, completion, and stimulation techniques have been used in attempting to extend production without marked success; however, higher prices for gas may result in a reevaluation of these methods. It is anticipated that modest reserves such as these will be needed in the future.

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#### Central Mediterranean Thrust Belts

The Alps and Apennines contain major thrust-associated hydrocarbon reserves and unexplored deep prospects in Mesozoic platform carbonate rocks and in Tertiary foredeep fill. The belts contain an S-curved, originally west-facing plate stack composed of the European craton, a sandwiched ophiolite belt, and the Africa-derived Adria plate, in turn overridden by the Tethyan Dinarides. The Vienna basin and the Calc-Alpine contain hydrocarbon reserves and prospects in upper-plate carbonate rocks, in overridden foredeep fill (Molasse) and shelf (Helveticum). Swiss and French lower-plate prospects depend on depth to foreland basement and on structure of allochthonous massifs. On the back side of the orogene, thrusts antithetic to collision loop around the Po basin (with its major oil and gas deposits), involving reworked arc-trench sediments and shelf carbonate rocks. In the southern and central Apennines, the detached shelf unit is exposed. In the northern Apennines, it is thrustured and covered beneath resediments. Refraction seismic data indicate the limits of the thrust configuration. In Calabria and Sicily, antithetic thrusting becomes predominant, outlining a subduction flip with a deep Benioff zone, a volcanic-island arc, and prospects on south-facing shelf carbonate thrust sheets beneath chaotic trench fill. In the Dinarides, surface structure, dimensions, some reflection seismic data, and crustal data suggest a classic thrust belt involving similarly prospective sediments.

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#### Appalachian Thrust Belt Between Trenton, Georgia, and Tuscaloosa, Alabama

Of the 260 km of late Paleozoic westward transport inferred for the Blue Ridge thrust mass, 70 to 100 km affect the Valley and Ridge thrust belt. Transport is