Uranium Exploration Systems Case Study—Copper Mountain, Wyoming

Regional surveys, including studies of rock chips and aerial radiometrics and magnetics, focused within an area of 400 sq km on the Canning stock, found enrichment in U, Th, and K. Stream-sediment data indicated an anomalous block adjacent to and including the North Canning and Fuller deposits. A subregional soil survey noted overlapping anomalies of eU, xU, Pb, Cu, and Ba in the vicinity of the North Canning deposit. This was confirmed by overlapping anomalies of eU, xU, Pb, Cu, and Ba in the rock-chip survey. Integrated radon and soil helium data were ineffective in delineating drilling targets at the subregional scale. The subregional magnetic, VLF-EM, and resistivity data confirmed the presence of a fractured and crushed zone within the host granite of the North Canning deposit. This interpretation is based on the presence of an overlapping low resistivity zone and a magnetic depression of about 40 gammas. Core holes were sited within an area of 25 sq km that included the North Canning deposit, the leachable-uranium-in-rock-chip anomaly, the aerial radiometric anomaly, and overlapping geochemical (xU, eU, Ba, He, Rn, As, Ni, and Pb) anomalies in the detailed soil survey. These holes, logged with a multispectral (K-U-Th) probe, show zonation of K, eU, and eTh in the monzonite and granitic host rock and indicate both directional and genetic information related to the origin of the uranium deposit.

BRANDT, DANITA S., Univ. Cincinnati, Cincinnati, OH

Biogenic Structures as Indicators of Depositional Rate

Distinctive blue-gray shales characterized by a homogeneous texture, blocky weathering, and an abundant trilobite fauna (*Flexicalymene, Isotelus*) are found at various stratigraphic positions in the Upper Ordovician near Cincinnati, Ohio. Whole and fragmentary trilobite body fossils are randomly oriented within the shale, bivalves are common, and biogenic structures (*Chondrites*) are locally abundant. Limestones and siltstones above and below the shales are more extensively burrowed and contain at least two ichnogenera, *Chondrites* and *Diplocraterion*.

The absence or relatively low density of biogenic structures in shale traditionally has been interpreted as (a) an inhospitable environment for burrowing organisms during shale deposition or (b) rapid deposition of the shale, which prevented disruption of the original fabric by burrowers. The abundance of trace fossils in lithologies below and above the "trilobite shales" implies favorable conditions for burrowers before and after shale deposition. The abundant pelecypod fauna and low organic content of these shales suggest the muds were well-oxygenated. The relatively low density and localized occurrence of biogenic structures in these shales, then, reflect rapid deposition of the shales. Paleontologic criteria, including the excellent preservation and random orientation of trilobites, support the interpretation of rapid deposition for the shales.

The "trilobite shales" represent events in which a turbid layer of silt and clay swept over the shelf, killing and rapidly burying the trilobites. Burrowers, also disturbed during the event, reestablished themselves and exploited the new substrate after it had stablized. Rapid, recurrent influxes prevented extensive disturbance by burrowers.

BREDEHOEFT, JOHN D., U.S. Geol. Survey, Reston, VA

Permeability of Clay and Shale

Permeability is a critical factor in the maintenance of abnormal fluid pressures. The permeability of "tight" geologic materials is difficult to measure, particularly in situ. Both the laboratory and in-situ methods require special techniques when the permeabilities are less than 10^{-10} cm/sec (10^{-7} darcys).

Permeability can be measured: (1) on rock samples in the laboratory; (2) in situ, using well-test procedures; and (3) on a regional scale, using a hydrodynamic analysis of the entire system.

Special techniques have been used to measure permeabilities in the Cretaceous Pierre Shale in South Dakota. Comparison indicates that the regional permeability exceeds the local permeability by two to three orders of magnitude. This suggests that secondary features, probably fractures, control the regional permeability.

BRICE, SUZAN E., Gulf Oil Exploration and Production Co., Houston, TX, KERRY R. KELTS, Geological Inst., Zurich, Switzerland, and MICHAEL A. ARTHUR, U.S. Geol. Survey, Denver, CO

Lower Cretaceous Lacustrine Source Beds from Early Rifting Phases of South Atlantic

Significant amounts of oil are produced from Lower Cretaceous pre-evaporite, nonmarine sequences of these west African marginal basins: Gabon, Cabinda, Congo Brazzaville, and Angola. Organic-rich lacustrine source beds attain thicknesses up to 900 m. Their geometry and sediment similarities among several basins indicate a small number of large Early Cretaceous lakes extending along the South Atlantic rift with dimensions and conditions similar to Lake Tanganyika. The organic-rich facies is underlain by a sandy facies deposited during initial rifting. The lacustrine phases deposited green clays and fluviolacustrine-deltaic sands, which were abruptly terminated by marine incursions in the Aptian.

Our study of conventional whole cores from the Melania Formation of Gabon provides further evidence that these source beds were deposited in brackish to freshwater environments in a deep lake. Logs show characteristic low bulk densities and high resistivity which allow correlations over 80 km. Large-scale cyclic preservation of organic matter in a stable, low energy environment with anoxic bottom conditions is interpreted. There is little clay in the organic-rich "shales" which typically comprise finely laminated, carbonaceous and dolomite-rich rhythmic couplets. Bulk organic carbon concentrations up to 20% are not uncommon. Palynomorphs, ostracods, and algae also indicate temperate conditions around a low salinity environment. The slope sequences are richest in uniform laminates with

some intercalated thin turbidites and enterolithic slump folds, whereas coarse turbidites were funneled into the deep basin plain. These hydrocarbon-saturated turbidite sandstones are derived from fluvial systems draining crystalline hinterland.

BRICE, SUZAN E., and GEORGES PARDO, Gulf Oil Exploration and Production Co., Houston, TX

Hydrocarbon Occurrences in Nonmarine, Pre-Salt Sequence of Cabinda, Angola

The nonmarine, pre-salt sequence of offshore Cabinda, Angola, is a prolific hydrocarbon producer. Thick, organic-rich, lacustrine shale was the source of the oil trapped in four distinct, nonmarine, reservoir rocks.

Subsidence followed by the formation of deep grabens introduced the Early Cretaceous rifting of the South Atlantic. The resultant basins of west Africa were filled with up to 2,500 m of nonmarine deposits. Aptian salt overlies the nonmarine deposits. Pre-rift and syn-rift strata are distinguishable in the pre-salt sequence and are separated by major unconformities. Hydrocarbons occur in both the pre-rift and the syn-rift strata.

The mostly clastic, pre-rift strata rest unconformably on metamorphic basement and were deposited in fluvial-lacustrine environments prior to active rift faulting. Today, the pre-rift strata are in tilted fault blocks dipping 20° or more. The Lucula Formation, a fine-grained sandstone in the pre-rift strata within these blocks, is one of the major productive reservoirs of West Africa.

The syn-rift strata, which unconformably overlie the pre-rift rocks, gradually filled the deep graben lakes produced by initial rift faulting. Organic-rich dolomitic shale, the source rock for both pre- and syn-rift reservoirs, grades upward into shallow-lacustrine green shale and carbonate rocks. The shallow-water, nonmarine carbonate rocks are important reservoirs. Final rifting caused gradual westward tilting and erosion of the syn-rift topography. Nonmarine carbonate rock and sand unconformably filled the resultant surface. Along the eastern margin of this basin fill, carbonate reservoirs produce oil.

BRIGGS, S. R., Massachusetts Inst. Technology, Cambridge, MA, and Woods Hole Oceanog. Inst., Woods Hole, MA, and J. B. SOUTHARD, Massachusetts Inst. Technology, Cambridge, MA

Tidal-Current Sand Waves in Vineyard Sound, Massachusetts

Response of bed forms to tides and storms was studied for 8 months on Middle Ground Shoal, Vineyard Sound, Massachusetts, which has a nearly bi-directional tidal ellipse parallel with the shoal axis. Bed forms are on three scales: sand waves (H, one to several m; λ, 20 to 200 m), megaripples (H, up to 1 m; λ, 1 to 20 m) and ripples ($H < 10$ cm; $\lambda < 1$ m). Ripples are superimposed on both sand waves and megaripples; megaripples are commonly superimpsed on large sand waves. Four transponder-navigated surveys with $\pm$ 1 m accuracy were made with 200-kHz narrow-beam echo sounding and side-scan sonar. Successive charts of sand-wave crest positions were inter-compared to measure sand-wave migration. One wave at the edge of the sand-wave field was studied during several deployments of a tetrapod instrumented with four acoustic-travel-time velocity sensors at 30, 50, 100, and 300 cm from the bed, a bottom camera, and a 4-mHz sonic profiler to record bed heights. Sand waves show a slight upslope component of migration. Flood and ebb waves are separated by a 100 to 200-m belt of symmetrical waves at the shoal axis; some crests are continuous across the entire shoal. Flood or ebb migration ranged from 2 to 28 m during the 8-month period, but certain segments of waves migrated much more than other segments. Superimposed megaripples, which migrate too rapidly for survey-to-survey correlation, were monitored by divers using a staked and measured line over a sand wave; these forms, with H up to 1 m and λ up to 20 m, migrated a full wavelength in up to several weeks.

BROOKINS, D. G., R. S. DELLA VALLE, and J. K. REGISTER, Univ. New Mexico, Albuquerque, NM

Rb-Sr Dating of Diagenesis—Epigenesis in Mesozoic Rocks, San Juan Basin, New Mexico

The Rb-Sr radiometric age determination method has been applied to problems of dating diagenesis-epigenesis in the southern San Juan basin, New Mexico. Nonmarine and marine units of the Morrison Formation (Late Jurassic) and Dakota and Mancos formations (Cretaceous) have been examined. Clay minerals from the $-2\ \mu$ fraction, when carefully characterized by X-ray and SEM techniques, are especially useful if maintained at low oxidation potential conditions since the time of the last diagenetic or epigenetic effect on the rocks. Montmorillonites, illites, and mixed layer montmorillonite-illite from the Westwater Canyon and Brushy Basin Members of the Morrison Formation yield a composite date of $130-140\pm15$ m.y.B.P., although the errors for individual units are larger. Chlorite-rich fractions penecontemporaneous with uranium mineralization in the Grants Mineral Belt yield dates of 139 ± 10 m.y.B.P. for early epigenesis and, where remobilization has occurred, dates commonly cluster about $110-120$ m.y.B.P. Dates on the Dakota Formation (93 ± 8 m.y.B.P.) and Mancos Formation (83 ± 7 m.y.B.P.) are consistent with K-Ar dates reported for these units. In general, low CEC clay minerals formed during or slightly later than sedimentation yield the most useful information; an exception is kaolinite-rich material which may prove to be more useful in determining the age of source area material.

BROOKINS, D. G., Univ. New Mexico, Albuquerque, NM

Geochronologic Evidence for Paleozoic Plutonic Activity in Florida Mountains, New Mexico

Plutonic rocks of the Florida Mountains, New Mexico, have been mapped both as Precambrian and as Mesozoic. Corbitt and Woodward demonstrated that the Floridas are bisected by the southern Cordilleran thrust belt, and Brookins reported Precambrian Rb-Sr dates from south of the thrust for granitic rocks while alkali granites-syenites from north of the thrust yielded scat-