of development of clay structures bear remarkable similarities to the structures of China. A few examples are intensely deformed clay analogous to the central China foldbelt, undeformed clay analogous to the Tarim, Ala Shan, Ordos, and other stable areas, and intensely deformed and elevated clay analogous to the upthrusts surrounding the stable areas of China.

GALLOWAY, WILLIAM E., CHRISTOPHER D. HENRY, and GARY E. SMITH, Bur. Econ. Geol., Univ. Texas, Austin, TX

Hydrostratigraphic Framework and Flow Dynamics of Uraniferous Aquifer–Oakville Sandstone of South Texas Coastal Plain

Synthesis of geologic, hydrochemical, and hydrologic data for the Oakville Sandstone provides a framework for effective hydrochemical exploration, leach mine planning, and evaluation of mining impact.

Quantitative lithofacies maps were combined with structural and well-pump test data to produce a regional Oakville transmissivity map. Interpreted groundwater flux patterns within the resultant three-dimensional transmissivity framework were mapped, and quantitatively illustrate several hydrodynamic principles.

(1) The complete groundwater system includes meteoric, elisian (compactional), and thermobaric connate zones. Boundaries separating zones are dynamic and evolve through time.

(2) Recharge of meteoric systems occurs directly at outcrop by seepage through overlying confining units, and by seepage from underlying aquifers.

(3) Flow occurs within a hierarchy of cells, ranging from unconfined local ($n \times 10$ sq mi) to intermediate confined ($n \times 10^3$ sq mi) to regional confined ($n \times 10^4$ sq mi) flow cells. Shallow groundwater may move in any direction with respect to dip.

(4) Discharge occurs by direct groundwater flow upward to the water table and by vertical seepage, commonly localized by fault zones, into adjacent aquifers.

(5) Topography and the three-dimensional permeability framework localize recharge and discharge zones and control flow direction. Recharge occurs in topographically high areas; discharge in lowest areas.

Groundwater flux in the Oakville is highly complex. Major uranium deposits occur within the realm of local (Ray Point district), intermediate (George West district), and regional (Duval County) flow cells. Extant flow direction commonly does not agree with geochemically-inferred mineralization-front polarity.

GARDNER, G. H. F., Gulf Research and Development Co., Pittsburgh, PA

New Dimensions in Seismic Exploration

The current price of crude oil makes it practical to explore for smaller reservoirs using more expensive techniques. Several techniques are discussed in this lecture which would not have been possible ten years ago for both economic and technical reasons.

Three-dimensional seismic methods add new dimensions to the amount of data collected, processed, and interpreted. Examples are given of 3-D field data and interpretations.

Signbit data recording adds a new dimension to the number of seismic traces that can be recorded, with a loss of amplitude information. Examples of field and model data are used to illustrate some of the advantages and disadvantages of this technique.

Color displays add a new dimension to the information content of a seismic cross section. Examples are shown of some conventional and unconventional displays.

Attributes other than amplitude and phase are shown to have promise in locating hydrocarbons.

GARDNER, J. V., U.S. Geol. Survey, Menlo Park, CA, et al

Hydraulic Piston Coring in Equatorial Pacific—Preliminary Results from DSDP Site 503 (Leg 68) Indicate Continuous Section of Undisturbed Late Noegene and Quaternary Sediment

Deep Sea Drilling Project Site 503 was cored, using the Hydraulic Piston Corer, at the location of Site 83 on the north flank of the Galapagos Rise. Two holes were cored to a total depth of 235 m and a section was recovered which represents approximately the past 8 m.y. The upper 100 m (Holocene through mid-early Pliocene) is virtually complete whereas below 100 m (to late Miocene) about 70% of the section was recovered. The sediment is a uniformly siliceous calcareous ooze with carbonate and color cycles throughout. These cycles have periodicities from 20,000 to 40,000 years per cycle. Clay content remains fairly constant at low percentages to 226 m but then abruptly increases to greater than 25%. This increase is thought to be the result of hydrothermal activity or weathering of the igneous basement or both. The section is highly undercompacted, which is thought to result from a significant percentage of diatoms.

Aboard ship we were able to identify most magnetostratigraphic boundaries above the Gauss-Gilbert. Sedimentation rates are about 4 cm/k.y. from lower Pliocene through mid-Pliocene but decrease to 1.5 to 2.5 cm/k.y. for the mid-Pliocene through Quaternary. Calculated bulk accumulation rates steadily decrease from late Miocene to late Quaternary with a distinct event of low accumulation rates in mid-Pliocene. This event may be a reflection of the emergence of the Isthmus of Panama.

The high accumulation rate and high quality of these cores provide the most detailed stratigraphic record of the past 8 m.y. available from the equatorial Pacific.

GAUTIER, DONALD L., U.S. Geol. Survey, Denver, CO

Physical Characteristics of Shallow Methane Reservoirs of Northern Great Plains

Sedimentary rocks deposited during the Upper Cretaceous Eagle-Telegraph Creek regression provide an excellent opportunity to examine shallow biogenic gas reservoirs in the northern Great Plains.

In central Montana, coastal sandstones of the Eagle Sandstone are highly porous (25%) and permeable (200 to 300 md) conventional reservoirs. Reservoir quality is adversely affected by the formation of authigenic min-

erals and enhanced by the development of dissolution porosity in silicate grains and carbonate cement.

Upward-coarsening sandstone sequences, 3 to 30 m thick, contained in the Eagle-Telegraph Creek-equivalent Gammon Shale, accumulated tens to hundreds of kilometers seaward (eastward) of the strand. These sandstones are transitional between conventional reservoirs and low-permeability reservoirs. Near the bottom of each sequence, porosity averages 15% and permeability averages 1 md. Upward through each sand accumulation, loss of allogenic clay and increasing sand content and grain size enhance reservoir properties. Porosity and permeability attain 25% and 150 md near the top of each sequence. Reservoir quality is controlled by allogenic clay content, intensity of bioturbation, precipitation of authigenic minerals, and the dissolution of cements and detrital grains.

The greatest volume of natural gas occurs in low-permeability mudstones of the Gammon Shale, which are identical to offshore equivalents of the Milk River Formation in southeastern Alberta. The reservoirs are silty shales containing discontinuous lenses and laminae of silt or very fine sand, a few millimeters or less in thickness. Effective porosity is confined to passageways within the laminae or to spaces among loosely packed clay platelets between clastic grains. Porosities range between 10 and 20%, permeabilities are commonly less than 0.1 md, and pore-entrance diameters are normally 0.1 μ or less. Because of the amount and composition of allogenic clay, the reservoirs are highly water sensitive and display very high water-saturation values. Although economic flow rates are only achieved through fracturing, subsequent production has been predictable and profitable.

GAUTIER, DONALD L., U.S. Geol. Survey, Denver, CO

Diagenesis in Shallow Conventional and Low-Permeability Biogenic Methane Reservoirs of Eagle Sandstone, Montana

The Upper Cretaceous Eagle Sandstone and equivalent rocks in north-central and eastern Montana provide an excellent opportunity to investigate postdepositional effects in gas reservoirs that have never attained thermal conditions sufficient for the generation of petroleum.

Investigations reveal that these reservoirs display inorganic diagenetic features similar to those of rocks having a burial history suitable for the formation of oil or thermogenic gas. These features are observed in both high-permeability and low-permeability reservoirs. Complex paragenetic sequences such as the following are common: (1) authigenic clay formation, (2) quartz overgrowth, (3) calcite cement and replacement, (4) carbonate dissolution, and (5) additional authigenic clay formation. Exotic phases, such as authigenic tourmaline, are observed locally. More importantly, there is widespread evidence of former calcite cementation and replacement, especially of plagioclase, followed by carbonate dissolution. The distribution of these features suggests that calcite has at various times occupied virtually every pore in many of the Eagle reservoirs. However, several lines of evidence, including the timing of gas generation and entrapment and the distribution of calcite in the Eagle Sandstone, suggest that the reservoirs have never been completely sealed by carbonate rock.

Thermal maturation of organic matter is not a prerequisite for the development of secondary porosity, nor for the development of minerals potentially hazardous to well-completion and treatment procedures. In addition, unequivocal evidence demonstrates that dissolution porosity can be produced without a previous period of total destruction of reservoir quality.

GEESAMAN, RICHARD C., Exxon Minerals, U.S.A., Albuquerque, NM and BRENT J. VOORHEES, Texaco Inc., Denver, CO

Facies and Depositional Tectonics of Middle Jurassic Carmel Formation, Southern Utah

The Middle Jurassic Carmel Formation of southern Utah is divided into two informal members deposited during a major transgressive-regressive cycle. The relatively thin lower member was deposited in a shallow, subtidal, marine to coastal, sabkha environment that advanced southeastward, onlapping and reworking coastal dunes of the Navajo and Page sandstones. Lithofacies of the lower Carmel include calcareous mudstone, bivalve micrite, oolitic grainstone and packstone, ostracod pelletal micrite, dolomicrite, algal stromatolites, aphanitic dolomite, and minor nodular gypsum and sandstone.

The sporadic northwest retreat of the Carmel Sea and progradation of coastal sabkha and continental sabkha and dune sediments is recorded in the thick upper member of the Carmel. Lithofacies include algal stromatolites, aphanitic dolomite, calcareous mudstone, nodular gypsum, horizontal to gnarly-bedded sandstone, and cross-bedded sandstone.

The lower Carmel undergoes rapid west to east thinning and facies changes, indicating that during the early Middle Jurassic (late Bajocian) the Hurricane fault was a tectonic hinge line that separated a westward tilting unstable shelf slope to the west from an unstable shelf to the east. Furthermore, lower Carmel facies, isopach anomalies, and regional stratigraphic and structural correlations indicate that anomalous subsidence and sedimentation in the present Sevier-Paunsagunt fault zone were contemporaneous and genetically related to initial deformation of the Middle Jurassic San Pete-Sevier rift of the hinge-line region of central Utah.

GHOSH, SANTOSH KUMAR, Ministerio de Energía y Minas, Mérida, Venezuela

Carbonate Facies of Peñas Altas Formation, Venezuela—Case Study of Cretaceous Shallow-Marine Shelf

The Peñas Altas Formation, deposited in a shallow-marine shelf environment, forms the lower part of a Cretaceous transgressive sequence. Starting with a basal conglomeratic clastic wedge, the formation passes upward into a shelf facies and culminates in the basinal Luna Formation. The important carbonate lithofacies include (1) algal wackestones with trace fossils of *Pla-*