by subscriptions from the energy industry and from time to time selected results have been published. We report palinspastic reconstructions for the present Arctic region through Phanerozoic time with a tectonic commentary.

HARRIS, DAVID C., Sohio Petroleum Co., San Francisco, CA, and WILLIAM J. MEYERS, State Univ. New York at Stony Brook, Stony Brook, NY

Carbonate-Cement Stratigraphy of Burlington Limestone (Osagean) of Iowa: Evidence for Eh Gradients in a Regional Mississippian Paleogroundwater System

Cathodoluminescent petrography of calcite overgrowth cements in crinoidal grainstones from the Burlington Limestone reveals compositional zoning, which suggests that a chemical gradient was effective during cementation. These syntaxial calcite cements have as many as 7 luminescent zones. On the basis of these zones, a regional cement stratigraphy has been established among 22 measured sections within a 5,000 mi^2 area in southeastern Iowa. Overgrowths are interpreted as freshwater phreatic-zone precipitates. Comparison of the characteristic luminescent signature of Burlington calcite cements with cements in underlying Kinderhookian and overlying Meramecian limestones suggest the Burlington formed during, or before, the regional mid-Meramecian (sub-St. Louis Limestone) hiatus.

Early nonferroan calcite cements show a pronounced basinward change in luminescent zoning. Updip cements consist of 4 distinct compositional zones. In contrast, downdip cements contain only a single luminescent zone. Zonal distribution may have formed when cementation occurred along an Eh gradient within a fresh or phreatic-water system during exposure in mid-Meramecian time. Updip recharge areas were characterized by alternating oxidizing and reducing conditions, resulting in a sequence of luminescent (low Eh) and nonluminescent (high Eh) cement zones. Downdip, away from recharge areas, contemporaneous cements have only a single luminescent zone, which formed under continuously reducing conditions. The recognition of Eh gradients that were effective during carbonate cementation enables paleoflow paths to be determined, and aids in the prediction of diagenetic trends.

HARRIS, W. BURLEIGH, Univ. North Carolina, Wilmington, NC, GERALD R. BAUM, Exxon Production Research Co., Houston, TX, and PAUL E. DREZ, Exxon Minerals Co., Houston, TX

Sodium Distribution in Eocene Dolomites from Castle Hayne Limestone, North Carolina

An 11-m section of the bryozoan biomicridite facies of the Castle Hayne Limestone in the Martin Marietta quarry, New Hanover County, North Carolina is locally dolomitized. About 6.5 m below the overlying unconformity, a 1.0-m zone consists entirely of sucrosic dolomite. The percentage of dolomite decreases fairly uniformly above and below this zone, and 3.6 m below the upper unconformity, the unit is undolomitized. The dolomite is nonferroan and occurs as fine anhedral to subhedral crystals. Above and below the zone of maximum dolomitization, the dolomite selectively replaces the micrite matrix. Where dolomitization increases toward a maximum, calcite allochems are replaced.

Acid-soluble sodium ranges from a low of 252 ppm in calcite to a high of 1,500 ppm in dolomite. Microprobe analysis revealed that sodium is concentrated in heulandite-group zeolite. The interlocking nature of the dolomite and zeolite crystals, the euhedral morphology of the zeolite, and the strong positive correlation between percentage of dolomite to sodium concentration suggest that both mineral phases are authigenic and formed penecontemporaneously from an open-system, stratified fluid (Dorag).

Unless the sodium distribution can be documented, these data suggest that whole-rock sodium concentrations in ancient dolomites may not be an accurate indicator for hyposaline versus hypersaline dolomitization. Dolomitization in proximity to the overlying subaerial unconformity has greatly enhanced postdepositional permeability in the micrite facies of the Castle Hayne Limestone. Dorag dolomitization caused by a lowering of eustatic sea level in conjunction with favorable hydrologic and lithologic conditions can have a profound effect on reservoir properties and permeability distribution in ancient carbonates.

HARRISON, WILLIAM B., III, and KAYLEEN JALKUT, Western Michigan Univ., Kalamazoo, MI

Petrology, Stratigraphy, and Depositional Environments of Burnt Bluff Group in Michigan

Recent discoveries of sizable natural gas deposits (production at least 1 MMCFGD/well) in 3 widely separated areas of Michigan have touched off exploration interest in the lower Middle Silurian Burnt Bluff Group. The Burnt Bluff and Manistique Groups are stratigraphically equivalent to the better known Clinton Group.

Analyses of core samples, outcrop samples, and wireline logs allow for a preliminary reconstruction of facies relationships and depositional environments. Where thickest, in northeastern Michigan, the Burnt Bluff Group can be divided into 3 formations: Lime Island Dolomite, Bryon Dolomite and Hendricks Dolomite. To the southwest the group thins dramatically to a single lithologic unit. The Lime Island and the Hendricks Dolomites represent shallow subtidal facies with abundant large, whole bioclasts of corals, stromatoporoids, and brachiopods. The Bryon Dolomite is a thinly laminated intertidal and supratidal carbonate with desiccation cracks, algal laminae, and anhydrite nodules.

Presently, natural gas production is found only in slightly dolomitized portions of the subtidal bioclastic facies in the Burnt Bluff. Porosity development is the key to production and is primarily solution-enlarged interparticle porosity restricted to the Hendricks and Lime Island Dolomites.

HARRISON, T. MARK, State Univ. New York at Albany, Albany, NY

Sedimentary Basin Thermal Histories Through $^{40}Ar/^{39}Ar$ Analysis of Detrital Microcline

The $^{40}Ar/^{39}Ar$ age spectrum technique has the demonstrated ability to resolve gradients of $^{40}Ar^*$ within crystals resulting from geologic heatings. A practical application of this observation is the analysis of detrital microcline from sedimentary beds to assess the source age of the feldspar, the time of basin heating, and the thermal intensity of the heating event. This intensity of the heating event is available through knowledge of the amount of $^{40}Ar^*$ lost from the sample and the temperature-dependent rate of argon transport within microcline. Both of these parameters are obtained as a by-product of the age spectrum experiment.

Results from a variety of sedimentary basins are encouraging and demonstrate the quality of information available from this technique. $^{40}Ar^*$ gradients in samples from the Basin block of the southern San Joaquin Valley, California, indicate a heating duration of 500,000-1 m.y., which is consistent with the stratigraphy. In conjunction with the present heat-flow data, these results suggest an equilibrium thermal gradient ~7°C/km higher than that presently observed—a consequence of rapid burial. K-spar separates from deep drill holes in the Albuquerque basin, New Mexico, reveal age spectra characteristic of substantial $^{40}Ar^*$ loss. Thermal calculations based on these data indicate a simple conductive history for samples above a present depth of about 6 km, although hydrothermal activity is evident in deeper material. Microcline separates have been obtained from a Kimmeridgian Sandstone (Tartan field, North Sea basin) that has been displaced about 1 km by a normal fault. Age spectra from these samples reveal minor $^{40}Ar^*$ losses of 4 and 6% from the samples in the upthrown and downthrown blocks, respectively. These loss profiles correspond to temperature histories that agree well with the formation temperatures and burial histories estimated for these wells. The subtle contrast in argon loss between these 2 samples suggests that this structure is relatively recent.

HARWOOD, GILL M., Univ. Newcastle upon Tyne, Newcastle upon Tyne, England

Porosity Evolution and Diagenesis of Smackover Grainstones, Bryan's Mill Area, East Texas

Reservoir carbonates in the Bryan's Mill area of east Texas are ooid-dominated grainstones that occur toward the top of stacked coarsening-upward sequences. Individual grains were coated by isopachous circumgranular cements producing early lithification of the grainstones with retention of a modified intergranular porosity. This was patchily

occluded by later equant intergranular cements. Grainstones in each sequence were subject to at least 2 phases of facies-selective dolomitization. The earliest phase mimicked the preexisting texture, whereas the later phase was texture-destructive with rhombic dolomite crystals.

Dolomitized grainstones have highest porosities and permeabilities resulting from calcite dissolution and physical compaction. Calcite dissolution within ooids occurred after the second dolomitization phase; thus, oomoldic porosities are not related to meteoric leaching during or after Smackover deposition. Subsequent physical compaction enhanced permeability. Later, partial porosity occlusion was by anhydrite calcite.

Dolomitization was caused by refluxing brines during deposition of the overlying Buckner evaporites. Dolomite $\delta^{13}C$ values are compatible with Smackover/Buckner seawater; $\delta^{18}O$ values become lighter with time, a probable function of dolomitization during progressive burial. A change to coarse clastic sedimentation coupled with syn-Buckner faulting modified the hydraulic regime of the area. This may have been the stimulus for calcite dissolution and hence porosity development within the Smackover grainstones.

HASTINGS, JOHN O., JR., Texas A&M Univ., College Station, TX

Structural Characteristics and Evolution of Vicksburg Formation: Javelina and East McCook Fields, Hidalgo County, Texas

The major structure at Javelina and East McCook fields is a decollement surface on the Jackson Formation. Movement along this glide plane was contemporaneous with sedimentation and has resulted in extreme rollover (up to 50°) and great vertical and horizontal displacement of overlying Vicksburg sediments. Changing rollover trends observed in dip logs of lower Vicksburg strata, and structure of this glide plane surface demonstrate its listric nature both updip and along strike.

Structure within the Vicksburg Formation is dominated by 3 major listric, normal growth faults. The faults penetrate the entire Vicksburg section, which is over 8,000 ft (2,438 m) thick. These faults have significantly affected Vicksburg deposition, as the entire section expands more than 40% or 2,500 ft (762 m) across the field. Expansion ratios for individual units are higher. Structural displacement and complexity of the section increase with depth, with stratigraphic throws greater than 2,000 ft (610 m) in deeper Vicksburg beds. Fault drag is commonly observed in dip logs. Antithetic faulting is conspicuously absent.

Structural evolution of the Vicksburg was controlled by formation of a diapiric shale ridge updip early in Vicksburg deposition. Diapiric uplift resulted in evolution of a major growth fault on the basinward shoulder of the ridge. Once initiated, the fault maintained itself throughout Vicksburg deposition and resulted in decollement on, or within, Jackson shales. Development of this fault aided in formation of the other 2 growth faults. Formation of these faults was also related to movement along the glide plane, shale diapirism, and sediment-loading stresses.

HEASLER, HENRY P., and RONALD C. SURDAM, Univ. Wyoming, Laramie, WY

Thermal and Hydrocarbon Maturation Models for Coastal California

Hydrocarbon maturation models for coastal California must consider thermal and geochemical constraints imposed by plate tectonics, diagenetic reactions, and the sedimentation history of the region.

Plate tectonism drastically effects the thermal history of California basins in many ways. Initially, temperatures in the crust of coastal California are suppressed during subduction of the Farallon plate. With the passage of the Mendocino triple junction, subduction ceases and a void is created into which asthenosphere moves. This elevates temperatures in the basins in a complex manner depending on the time of passage of the Mendocino triple junction and the location of a specific basin. Finite-difference numerical models were developed to approximate the thermal effects of subduction and lithospheric upwelling.

Diagenetic reactions and sedimentation history affect both the maturation model and thermal history of a basin. Diagenetic reactions through time in the Miocene Monterey Formation may change thermal conductivity values by 70%. Facies changes also have an important effect on sediment thermal conductivity and hence sediment temperatures.

Maturation models indicate varying levels of maturity depending on the method used. Models using the Time Temperature Index of Lopatin indicate the lowest level of maturity. Tissot and Espitalie's method, which uses multiple activation energies and varying constants for the kerogen types, results in an intermediate level of maturity. The highest level of maturity results from the use of the Tissot and Espitalie method modified by using a single activation energy of 178.69 kJ $mole^{-1}$ and a constant of 4.92×10^{13} $hour^{-1}$ as reported by M. D. Lewan for shale from the Phosphoria Formation.

HELMOLD, K. P., Cities Service Oil & Gas Corp., Tulsa, OK, and R. G. LOUCKS*, ARCO Oil & Gas Co., Plano, TX

Origin of High-Permeability Reservoirs in Upper Minnelusa Sandstone (Permian) Powder River Basin, Wyoming and Montana

Petrographic analysis of samples from 8 Minnelusa cores from Campbell County, Wyoming, and Powder River County, Montana, reveals that high-permeability reservoirs (up to 3,200 md) are the result of extensive dissolution of early precipitated gypsum or anhydrite cement. The Minnelusa reservoirs are in eolian sandstones (dune and interdune facies) that are very fine to coarse-grained, moderately to bimodally sorted quartz-arenites, subarkoses, and sublitharenites. Dune and interdune sandstones exhibit differences in detrital mineralogy that are the result of postdepositional dissolution of labile grains.

The most common cements in the sandstone are anhydrite (0-30%), quartz overgrowths (0-10%), dolomite (0-10%), kaolinite (< 5%), and illite (< 1%). Most cementation occurred during the pre-Jurassic when the sandstones were buried less than 1,500 ft. The porosity network within the sandstone is a combination of primary and secondary porosity created by the dissolution of anhydrite cement. Burial history curves suggest that anhydrite dissolution occurred during the Late Jurassic to Early Cretaceous, when the top of the sandstones was still near the surface. During this time, 3 periods of uplift and erosion occurred in which meteoric waters undersaturated in calcium sulfate may have flowed through the sandstones. The distribution of the reservoirs is probably controlled by the regional structure during the periods of flushing.

Dune sandstones are the most productive facies in the high-permeability reservoirs. Porosity in the dune facies averages 21% compared with an average of 9% in the interdune facies. This difference is the result of both lower depositional porosity and greater quartz and dolomite cementation in the interdune sandstones. Porosity loss due to mechanical compaction is similar for both facies.

HENDERSON, F. B., Geosat Committee, Inc., San Francisco, CA

Joint Geosat-NASA/JPL Test Case Program: Field Evaluation of Future Geological Satellite Remote-Sensing Systems

The principal industrial users of land-observation satellite systems are several hundred oil and gas, mining, and engineering or environmental companies worldwide. The primary system used is Landsat/MSS (Multispectral Scanner), the data from which are now used operationally as an improved geologic mapping tool to help direct more expensive geophysical surveying and drilling, thus assisting exploration decision making. Use is also made of SKYLAB photography, SEASAT and SIR-A (Shuttle Imaging Radar) radar, and the new Landsat/TM (Thematic Mapper) data. Industrial use will soon be made of data from France's SPOT (1985), India's IRS (1986), the European Space Agency's ERS (1987), Canada's RADARSAT (1990), and Japan's JERS (1991) remote-sensing satellites.

Data representing these systems were evaluated during the 7-yr, $10-million joint Geosat Committee-NASA/JPL Test Case Program. Begun in 1977, the objective of this program was to assess, in known geologic areas, the value of existing and potential satellite remote-sensing methods for petroleum exploration, mineral exploration, and engineering geology applications. The published study includes an evaluation of sensors, data-processing techniques, and interpretation methods.

Some conclusions include the following. The Landsat/TM combines the visible and very near Infrared (IR) spectral bands of the MSS, with the shortwave IR 1.6-2.2 μm band region, which can indicate the presence of clays, carbonates, and sulfates. This system allows greater rock and soil discrimination than the MSS alone. Similarly, the TM bands demonstrate numerous, as yet little understood, geobotanical anomalies clearly related to leaking gas over oil and gas deposits. Landsat data, as well as that