The C zone dolomite of the Red River is the major oil-producing zone in Richland County. This dolomite occurs immediately beneath the "C" zone anhydrite as concentrated lenses of: (1) tight cryptocrystalline anhydritic dolomite, (2) porous fine to very fine-grained dolomite, and (3) relatively tight partly dolomitized limestone. The dolomitized lenses are typically one to two km in diameter and up to 50 m thick. They apparently formed beneath "holes" in the C anhydrite through which dense Mg-rich brines (formed during precipitation of the subtidal anhydrite) seeped. These "holes" formed almost randomly, probably by hydraulic fracturing as interstitial waters from compacting sediments beneath the anhydrite escaped upward, but minor faulting may have created more linear "holes" locally.

The D zone dolomite along the eastern edge of Richland County also formed by gravitational seepage, but the absence of a D zone anhydrite allowed for relatively laterally persistent dolomitization. Distribution of D zone dolomite was controlled mainly by paleo-topography of the basin floor; the brines filled in lows whereas dolomitization was minor or nonexistent over paleo-highs.

LONGSTAFFE, FRED J., Univ. Alberta, Edmonton, Alberta, Canada

Low-^{18}O Authigenic Clays and Calcite in Shallow Cretaceous Sandstones of Alberta

$\delta^{18}O$ values of authigenic minerals in shallow (<1,500 m) Cretaceous rocks from Alberta suggest that ground water exerts an important control upon the diagenesis of sandstones. In Alberta, ground waters are significantly depleted in ^{18}O relative to seawater.

Minerals precipitated in equilibrium with ground water should have $\delta^{18}O$ values predictably lower than similar phases formed from more ^{18}O-rich fluids. The $\delta^{18}O$ values of 150 clay samples from the Milk River, Belly River, and Viking formations range from 6 to 20‰ (SMOW). An equally large variation in $\delta^{18}O$ (+11 to +28‰, SMOW) and $\delta^{13}C$ (−10 to +2‰, PDB) is shown by over 125 carbonate samples. Detrital clays from the Milk River have $\delta^{18}O$ values of +16 to +20‰ (SMOW). The $\delta^{18}O$ (+24 to +28‰, SMOW) and $\delta^{13}C$ (−3 to +1‰, PDB) values of dolomite clasts are typical of platform carbonates. The much lower $\delta^{18}O$ values of the authigenic kaolinite, smectite (+10 to +15‰, SMOW), and calcite (+15 to +19‰, SMOW) in the sandstone aquifer reflect neoformation from low-^{18}O ground waters at temperatures as low as 5°C. Involvement of organically derived CO_2 during calcite formation is indicated by low $\delta^{13}C$ values (−10 to −3‰, PDB). In sandstone of the Belly River Formation, early pore-lining chlorite and later pore-filling kaolinite and calcite have quite low average $\delta^{18}O$ values of 6.3, 12.0, and 13.1‰ (SMOW) respectively. The kaolinite and calcite approach oxygen isotope equilibrium at a temperature of 55±10°C with ground waters of about −8 to −10‰(SMOW). The chlorite is out of isotopic equilibrium and formed either at lower temperatures and(or) from more ^{18}O-rich fluids. The $\delta^{18}O$ values of <2μm clays from the Viking Formation (18-20‰ SMOW) may reflect a detrital origin. Illite-smectite, however, which is concentrated in the <0.2μm fraction, has lower $\delta^{18}O$ values (+12 to 16‰), perhaps suggesting ground-water involvement in its genesis.

LORSONG, J. A., Saskatchewan Geol. Survey, Regina, Saskatchewan, Canada

Channels and Chimeras: Coastal vs. Fluvial Deposition of Mannville Group, Lloydminster Area, Saskatchewan

Examination of nearly 4,000 m of core from more than 180 wells clearly demonstrates that fluvial processes were insignificant in deposition of the Mannville Group (Lloydminster member and above) in the Lloydminster area of Saskatchewan (R18W3-28W3, T44-54). Previous fluvial models are based primarily on the presence and geometry of channels interpreted from geophysical well logs. With rare exceptions, however, well spacing and core data are inadequate to prove a fluvial origin of such features, if they exist at all. A notable exception is an unequivocal channel deposit in the Waseca Formation in the Pikes Peak–Lashburn area. However, the nature of adjacent strata, the presence of numerous clay drapes within the deposit and its dimensions (≤40 m thick, 1.6 to 2.7 km wide, but only 30 km long) are inconsistent with fluvial deposition in a terrestrial setting. The most compelling argument against a fluvial origin of the Mannville is the presence in every core studied of numerous sedimentary structures that are extremely difficult to reconcile with fluvial deposition and the paucity of possible fluvial structures or sequences of structures. The former include swash-zone cross lamination; oscillation ripples; and hummocky cross-stratification; and flaser, wavy, lenticular, and pin-stripe bedding. Cored intervals of strata which can be equivocally interpreted to represent fluvial or other channels (such as massive or ripple cross-laminated sands) are nearly everywhere less than 5 m thick. Even if such an interpretation is applied in every example, channel deposits are volumetrically insignificant. Finally, many undoubtedly marine or brackish assemblages of foraminifera and dinoflagellates have been recovered in the study area. Ubiquitous wave-generated sedimentary structures, essentially tabular geometries of sand bodies, and microfossils in the Mannville Group clearly demonstrate deposition in a coastal, rather than fluvial, setting.

LOUCKS, R. G., Cities Service Exploration and Production Research, Tulsa, OK, and D. A. BUDD, Univ. Texas at Austin, Austin, TX

Subsurface-Derived Secondary Oomoldic Porosity, Smackover Formation (Upper Jurassic), South Texas

Subsurface-derived secondary oomoldic porosity is an important factor in reservoir development in the south Texas Smackover Formation. Much of the section penetrated is impermeable; however, reservoirs as thick as 33 ft (10 m), with porosity ranging from 4 to 26% and permeabilities ranging from 0.1 to 6.5 md, have been cored at depths below 18,000 ft (9,486 m).

In the grainstone facies, four general stages of diagenesis affected porosity: Stage 1 (marine-phreatic environment), precipitation of an isopachous carbonate cement and extensive grain micritization; Stage 2 (shallow-meteoric environment), precipitation of very coarse-crystalline syntaxial calcite and fine-crystalline equant calcite, dissolution of aragonitic skeletal grains, and incipient solution-compaction; Stage 3 (regional fluid-mixing environment), intrapore precipitation of and grain/matrix replacement by fine to medium-crystalline rhombic dolomite; and Stage 4 (subsurface environment associated with basinal fluid expulsion), dissolution of ooids and dolomite resulting from decarboxylation of kerogen, microstylolitization by solution compaction, and precipitation of coarse-crystalline calcite and baroque dolomite. The magnitude of each general diagenetic stage varies regionally.

Oomoldic porosity is present only in the updip, highly dolomitized grainstone facies. The dolomite formed a chemically rigid matrix that allowed the calcite ooids to be dissolved without solution compaction between grains. In the downdip, poorly dolomitized facies there was no chemically rigid framework, and dissolution proceeded by solution compaction resulting in loss of porosity.

Exploration in the deep south Texas Smackover Formation cannot depend upon finding reservoirs consisting of preserved, early types of porosity, but must depend upon defining areas where late subsurface-derived oomoldic porosity formed reservoirs.

LOWENSTEIN, TIM K., Johns Hopkins Univ., Baltimore, MD

Petrographic Approach for Study of Ancient Potash Evaporites, Salado Formation (Permian), New Mexico

Petrographic analysis of a potash evaporite, the Salado Formation (Permian) of New Mexico and Texas, has allowed distinction of primary sedimentary features, from metamorphic alteration "overprints." Primary sedimentary textures in laminated anhydrite, thin-bedded halite, and muddy halite include vertical growth structures (gypsum "swallowtails" and "chevron" halite), incorporative and displacive intrasediment growth of gypsum, halite, and glauberite, carbonate-gypsum and gypsum-halite couplets, and gypsum wave ripples. The Salado primary chemical and depositional environment, interpreted by comparison with similar features from modern evaporite environments, is a salt pan up to halite saturation alternating with a perennial brine body stage at gypsum and sometimes halite saturation.

A complex diagenetic-metamorphic history has imparted a secondary alteration overprint on the Salado salts. Halite has recrystallized; gypsum has dehydrated to anhydrite, reacted with brine to form polyhalite, or dissolved, leaving a void now occupied by halite or sylvite. Formation of new minerals, the most important being sylvite, carnallite, langbeinite, and kieserite, has occurred as displacive or incorporative intrasediment growth (langbeinite), or as void filling cement (sylvite, carnallite). Further alteration is recorded as reaction of brine with langbeinite to form kieserite, kainite, leonite, and bloedite. From their observed distribution, texture, and mineralogy, and by comparison with experimental data, secondary features in the Salado are interpreted to have resulted from the subsurface migration of alien, non-seawater composition brines at elevated temperatures.

LU, KEZHENG, Stanford Univ., Stanford, CA

Tectonic Setting and Eastward Migration of Mesozoic-Cenozoic Sedimentary Basins, Eastern China

Basins of eastern China are characterized by thin crust and alternately arranged NE or NNE-trending regions of subsidence and uplift. During the Indosinian (Late Triassic), the western part of eastern China was depressed relative to eastern areas. Upper Triassic and Jurassic formations comprise the major basin fill of the Sichuan and Eerduos basins, while only minor Upper Triassic-Jurassic rifts and related basins are superimposed on earlier swells in eastern regions. In the Early Cretaceous, the depocenters of the Sichuan and Eerduos (Ordos) basins shifted westward or southward, and soon afterward were uplifted as a whole. In contrast, the most extensive and intensive subsidence in the Songliao basin occurred during the Quantou-Nenjiang stage (middle Cretaceous). To the south, the Huabei basin had a multicyclic, rifted history, but the most intensive subsidence occurred during the Eocene-Oligocene. Still farther east, the present-day marginal seas formed mainly during the Late Cretaceous-early Neogene. Thus, the history of these basins clearly shows the eastwardly migratory nature of the timing of basin formation in eastern China. The development of these basins was influenced not only by subduction of the Pacific plate in the formation of initial stage shearo-compressional swells and depressions, but also by the motion of Tethys-Indian plate northeastward. The latter movements resulted in an eastward component which led to the progressive elevation of the west. Back-arc spreading also played an important role in this process.

Basins of eastern China can be classified into two groups, one formed in compressive or shearo-compressive settings, the other in tensile or shearo-tensile settings. Basins of the former type formed as structural depressions or flexures due to lithosphere deformation. These display foreland fold-thrust belts on their western borders. The tensile group of basins includes: (1) complex rift-depression types (monocyclic or polycyclic); (2) simple rift valleys or minor block-fault depressions; (3) coastal delta-shelf basins on the rifted continental margin; and (4) back-arc spreading basins.

LUNDIN, ROBERT F., Arizona State Univ., Tempe, AZ, and LEE E. PETERSEN, Anadarko Production Co., Denver, CO

Succession of "Nonpaleocope" Ostracods Related to Graptolite Biozones, Type Wenlock Series

Analysis of the stratigraphic occurrences of 23 species of podocope, metacope, and platycope ostracods in Wenlockian strata of the type Wenlock area of the Welsh Borderland demonstrates the following. (1) Five species are restricted to the lower Wenlockian; four of these range from the *centrifugus* Biozone through the *rigidus* Biozone, and one ranges from the *centrifugus* Biozone through the *ellesae* Biozone. (2) Five species range throughout or nearly throughout the Wenlockian sequence. (3) Thirteen species are restricted to the upper Wenlockian; eleven of these range from the *lundgreni* Biozone through the *lundensis* Biozone, one ranges from the *nassa* Biozone through the *lundensis* Biozone, and one ranges from the *lundgreni* Biozone through the *nassa* Biozone.

These observations, which are based on the identification of more than 11,000 ostracods, indicate a significant change in the ostracod fauna in the middle of the Coalbrookdale Formation, i.e., in the middle of the type Wenlock Series or near the Sheinwoodian-Homerian boundary. A similar change occurs in the brachiopod succession in the same interval. Because the change in the ostracod fauna is relatively abrupt (i.e., within two graptolite biozones), we believe that it was induced by an environmental change which did not significantly affect the lithology of the stratigraphic interval involved. We conclude that the interval near the Sheinwoodian-Homerian boundary in the type Wenlock area represents the time of maximum Wenlockian transgression, after which regression and shallowing occurred.

LYNCH, VANCE M., Union Oil Co. of California, Los Angeles, CA

Erawan Field, Gulf of Thailand: A History of Applying Evolving Geophysical Technology to a Complex Geologic Structure

The Erawan gas field, with estimated recoverable reserves of 1.5 tcf of natural gas, was discovered in 1972. The drilling locations have all been selected on the basis of complicated reflection seismograph results. The productive section is a Tertiary sand-shale sequence of fluvial to shallow-marine origin, and individual sand units rarely exceed 50 ft (15 m) in thickness. The Erawan structure is a complexly faulted graben, with fault block rotation producing an anticlinal attitude. High fault density (200 to 500 m separation) and thin productive beds result in many separate hydrocarbon traps. Commercially productive sands occur at depths between 5,000 and 9,000 ft (1,525 to 2,740 m) subsea.

Union Oil Co. of California acquired the acreage in 1968 and