Vitrinite reflectance readings are significantly higher in wells that penetrated thin intrusions, and this increase in vitrinite reflectance to values of around 1% is evident in one well at least 500 m above a 156-m thick doleritic dike where fission tracks have also been reset. The intrusions have thus heated a considerable volume of regionally immature rocks to temperatures equating to the oil window for a short period of time. Whether this relatively short-lived temperature increase has led to significant generation of hydrocarbons is unknown; however, oil recovered from one well that penetrated a doleritic dike had a sterane:aromatic sterane ratio suggestive of generation during a rapidly cooling heat pulse.

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Chin Coulee Field—a Stratigraphic Trap in Lower Cretaceous Fluvial Valley-Fill Sandstones

Hydrocarbons, stratigraphically trapped in fluvial valley-fill sandstones, constitute some of the more important oil fields in North America. The Chin Coulee field in southeastern Alberta, Canada, has produced over 4.4 million bbl of oil since its discovery in 1960, with an estimated 1 million bbl still to be produced via secondary recovery. The field covers approximately 80 km^2 with an average net pay thickness of 3 m. The hydrocarbons are stratigraphically trapped in the fluvial Sunburst Sandstone, which records the Early Cretaceous transgression of the Boreal Sea.

These lower Mannville aggradational sequences accumulated in an incised drainage system in Jurassic marine shales, which provide the bottom seal for the reservoir sandstones. Following deposition of the Sunburst Sandstone, an accelerated rise in base level led to the accumulation of argillaceous limestones and calcareous shales commonly referred to as the "ostracod zone." These fine-grained strata provide an effective seal above the porous sandstones.

Postdepositional tilting of the strata to the west, due to subsidence in the foreland basin east of a rising orogene (Nelson uplift), resulted in migration of hydrocarbons in an easterly updip direction. Stratigraphic trapping of these hydrocarbons occurred in sandstones pinching out in the upper reaches of tributary valleys to the east of the main drainage system (Chin Coulee and Taber Southeast fields).

Regional paleoenvironmental reconstructions suggest that the Sunburst Sandstone is equivalent to the Cut Bank Sandstone of the Cut Bank field area in northwestern Montana. The Cut Bank field lies along the same Late Jurassic drainage system (Fox Creek escarpment), and similar tributary valleys situated east of the escarpment may exist between these two producing field areas. This suggests the presence of additional untested hydrocarbon reservoirs exhibiting stratigraphic characteristics similar to those described in the Chin Coulee field.

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Processes of Sedimentation Associated with Fault-Controlled Trough Across a Shelf

Western North America was a rapidly subsiding, passive continental margin during the Cambrian. During the Middle Cambrian, a belt of carbonate deposition dominated the central shelf. It was bounded by fine-grained terrigenous sediments that accumulated in deep water to the west and in shallow water to the east. Movement along a high-angle fault that extended across the shelf produced a conspicuous embayment into the carbonate belt in Nevada and Utah during the middle Middle Cambrian. This fault movement controlled basin geometry and distribution of carbonate and shale lithofacies on the shelf for at least the next 40 m.y.

The embayment was an asymmetrical trough that deepened and widened as it extended some 400 km westward toward the edge of the continent. South of its abrupt southern margin, which marked the position of the fault, shallow subtidal and peritidal sediments accumulated throughout the Middle Cambrian. The northern flank of the embayment was a drowned platform that sloped gently southward into the trough axis. On this ramp, a carbonate platform was rapidly reestablished through vertical accretion and progradation. In the trough axis, which lay near the faulted margin, sediments representing anoxic and deep-water environments accumulated throughout the middle and late Middle Cambrian. Sedimentation rates in this axial region were inadequate to reestablish a shallow-water depositional setting because of reactivation of faulting and because the trough acted as a sediment bypass zone.

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Gas Compositions in a Well Column

An onsite mud-logging system was developed to avoid possible alterations in gas samples during shipment to laboratories. Compensation was made for the large gas contribution of the drilling mud entering the hole, for the rate of drilling, and for lag time of the drilling mud. Location of gas anomalies is more apparent with the modified system.

Several wells in the DJ basin were compared to establish a pattern of sediment gas vs. lithology or geologic formation. Gas content of the drilling mud throughout the hole showed that large changes occur in the absolute concentrations of methane through butanes and also showed an erratic pattern of the component ratios. These compositional changes should be taken into account in surface exploration for gas.

Other gases in the well column were also monitored. Hydrogen and helium were found in most wells. Their concentrations varied widely from well to well and in a single well. Carbon dioxide also showed large variations. Carbon isotope ratios of carbon dioxide did not correlate with the carbon isotope ratios of carbonate cements in the same samples.

REVETT, LOWELL W., Welex, Lafayette, LA, and BRIAN E. LOCK, Univ. Southwestern Louisiana, Lafayette, LA

Resistivity Curves from Complex Reservoirs: Under-Utilized Tools for Exploration and Production Geologists

Most geologists regard resistivity curves simply as sources of information concerning lithology and degree of water saturation of subsurface strata; however, other important geologic information can also be obtained. For example, water saturation is related both to pore characteristics and to the buoyancy pressures that lead to water expulsion from those pores by a hydrocarbon column. Thus, resistivity response is indirectly modified by a complex of factors including pore size, pore geometry, and grain-surface characteristics (including presence of clays). The combined effect of these pore characteristics is revealed most directly by capillary pressure curves. Because these same factors also determine permeability, resistivity itself can be regarded as responding to permeability.

This approach to resistivity interpretation has several important consequences. For example, true oil-water contacts encountered in the well bore display transitional resistivity values as upwardly increasing buoyancy pressures approach those necessary to produce irreducible water saturation. Complex reservoirs with inclined permeability barriers (such as shale drapes along lateral accretion cross-bedding in point-bar sands or shale interbeds in tilted turbidite sand sequences) may include false water levels where vertically adjacent but separated beds may have different fluid contents and may lack transition zones. Recognition of the distinction between these two types of oil-water contact may profoundly affect reserve calculations and help avoid passing over of viable reservoirs.

Correctly interpreted resistivity curves may also permit recognition of water production resulting from leading permeability barriers, may aid in distinguishing different types of oil show (leading, trailing, and residual) and may aid in explaining and predicting early water production, etc. Proper use of this readily available tool can have an important impact on successful exploration and production.

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Thermal Transformation of Smectite to Illite

The diagenetic transformation of smectite to illite, with an intermediate series of mixed-layered compositions, has been documented by numerous studies of surface and subsurface rocks. Shales from typical Gulf Coast wells show compositions greater than 50% illite at approximately 100°C; the composition stabilizes at about 80% illite at the greatest depths sampled where the temperature is or has been as high as 130°C.

These findings are difficult to reconcile with data from oil (lower Paleozoic) rocks if it is assumed that illite-smectite compositions are equilibrium phases at specific temperatures. Potash bentonites (Ordovician) associated with thin cratonic sediments contain 80% illite in the mixed-layered species, and these rocks were probably never heated over 60°C. In addition, many shales and limestones of Devonian age and older contain almost pure illite despite histories of only moderate burial depths.

Studies of shales near contacts with basaltic dikes show that compositions near 80% illite are associated with peak temperatures (calculated) of approximately 300°C, though the duration of the heating event was short ($\approx$ 1,000 yr).

A synthesis of available information suggests that the smectite to illite transformation is kinetically controlled, and that a high-order rate law is required, despite laboratory synthesis results which fit a first-order kinetic scheme. These conclusions are not accepted by all investigators, and the details of the reaction stoichiometry, kinetic mechanisms, and the possible occurrence of equilibrium intermediate compositions have yet to be convincingly demonstrated.

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Character and Origin of Natural Gases from Wattenberg Area, Denver Basin, Colorado

Hydrocarbons are being produced at depths ranging from 4,000 to 8,500 ft along the axis of the Denver basin. On the basis of chemical and isotopic composition, gases from the three main reservoirs of Cretaceous age are interpreted to be of thermogenic origin. Gases from the Terry and Hygiene Sandstone Members of the Pierre Shale, the youngest reservoir, are the isotopically lightest ($\delta^{13}C_1$ values range from -55.7 to -49.2 ‰) and chemically wettest ($C_1/C_{1\text{-}5}$ values range from 0.67 to 0.83), and are associated. Gases from the Codell Sandstone Member of the Carlile Shale generally become isotopically heavier ($\delta^{13}C_1$ values range from -47.8 to -43.9 ‰) as they become chemically drier ($C_1/C_{1\text{-}5}$ values range from 0.76 to 0.8). During the main part of mature stage, oil and associated gas (isotopically lightest and chemically wettest) were generated from type II kerogen. During the hotter, later part of the stage, wet gas (isotopically heaviest and chemically driest) and condensate were generated from residual kerogen and from heavier hydrocarbons previously generated. Variations in character of the gases from the "J" sandstone, the oldest reservoir, are similar to those of the Codell; they become isotopically heavier ($\delta^{13}C_1$ values range from -47.9 to -43.1 ‰) as they become chemically drier ($C_1/C_{1\text{-}5}$ values range from 0.84 to 0.87). Gases from "J" are interpreted to have been generated at similar levels of maturity as those of the Codell, but from type III kerogen. These gases are nonassociated and are isotopically heavier and chemically drier at similar levels of maturity than are those generated from type II kerogen.

RICHARDSON, RANDALL W., and CHRISTOPHER J. SCHENK, U.S. Geol. Survey, Denver, CO

Recognition of Anhydrite Dissolution—A Cause of Secondary Porosity in Two Petroleum Reservoirs

Rectangular and "stair-step" pore reentrants in carbonate mudstones have been recognized previously as indirect evidence for anhydrite dissolution. In this study, direct evidence for dissolution of interstitial anhydrite in subsurface rocks includes: (1) cleavage-related dissolution fringe on anhydrite crystal surfaces and (2) isolated remnants of optically continuous (formerly poikilotopic) anhydrite. Influenced by the prominent cleavages, the dissolution fringe on the surfaces of the anhydrite crystals consists of a series of sharp, right-angled projections and reentrants. Experimentally etched anhydrite surfaces exhibit features that directly compare to the dissolution fringe, whereas experimentally grown anhydrite does not.

Anhydrite in both the dolomite grainstones of the Permian San Andres Limestone in the Vacuum field, Lea County, New Mexico, and the sandstones of the upper (Permian) part of the Minnelusa Formation in the West Mellot Ranch field, Crook County, Wyoming, exhibited these direct evidences, demonstrating the presence of secondary porosity after anhydrite.

We deduced the following sequence of anhydrite dissolution within these rocks. Slow incipient dissolution began along the boundaries between anhydrite and adjacent minerals. From these intercrystalline boundaries, solutions penetrated anhydrite cleavages, leading to more rapid preferential dissolution perpendicular to the more prominent cleavage planes. The widened cleavage planes, together with intercrystalline boundaries, acted as conduits for removal of dissolved ions. In the final stage, as dissolving anhydrite borders retreated toward pore throats, dissolution slowed and was, again, restricted to intercrystalline boundaries. This process was repeated in adjacent interstices.

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Mixed Siliciclastic and Carbonate Sedimentation Within Spar Mountain Member of Ste. Genevieve Limestone, Hamilton County, Illinois

The Spar Mountain Member of the Ste. Genevieve Limestone (middle Mississippian) in Hamilton County, Illinois, consists of 40-60 ft (12-18 m) of interbedded limestones, shales, and sandstones. Five cores and 1,400 electric logs were used to delineate two shallowing-upward carbonate cycles and 2 major clastic pulses within the Spar Mountain. Eight lithofacies representing 6 depositional environments were identified. They are: (A) echinoderm-brachiopod dolomicstone to packstone (outer ramp), (B) ooid-peloidal grainstone (intermediate ramp), (C) skeletal grainstone (intermediate ramp), (D) ooid-molluscan-intraclastic wackestone to grainstone (inner ramp), (E) pelletal-skeletal wackestone (inner ramp), (F) quartzarenite (channelized nearshore), (G) quartz-sublithic arenite to wacke (delta platform), and (H) quartz mudstone (prodelta, delta platform).

Deposition occurred on a southwest-dipping carbonate ramp, with siliciclastic sediments originating from the northeast. The sequence of facies and their inferred depositional environments record 2 major progradational episodes. Oolitic facies are interpreted to be of tidal-bar belt origin and quartzarenite facies are interpreted to be of delta–distributary channel origin. Their distribution is partially controlled by antecedent and syndepositional topography. Many of these paleotopographic highs are positive features today and yield pinch-out stratigraphic relationships. Paleogeographic reconstructions demonstrate that the primary control on facies distribution was the position of the delta proper along strike. However, depositional topography also influenced sedimentation, particularly in the sand-sized fraction. Using this concept, better prediction of underlying porous buildups (ooid shoals) is possible if thickness of the overlying siliciclastic is known. Within buildups, a complex diagenetic history complicates the distribution of porosity.

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Trenton Formation in New York, a Computer-Aided Study

The Trenton Formation is an Upper Ordovician sequence of interbedded limestones and limy shales that extends from the Hudson River valley in the east throughout the western part of New York state. It was one of the first gas-producing reservoirs in the area with most of the more than 300 test wells producing or indicating natural gas.

Subsurface information on the Trenton includes century-old reports, operators tops, sample logs, and geophysical logs. The logs, run over more than a 40-yr span, vary widely in type, lithology response, and depth scale. To aid interpretation, all available data were added to the New York state computer data base for map processing, and the geophysical logs were digitized for uniform evaluation and presentation. Individual log curves were corrected to a standard lithology response, combined, and played out as a series of standard control cross sections. Computer posted and contoured maps were constructed and compared to log sections for correction of errors. Finally, geologic interpretation was added to the maps and cross sections to produce a new evaluation of the Trenton Formation.

The Trenton in the subsurface can be divided into three distinct members with a disconformity between the lower two. Depositional centers shifted from central New York for the lower member to the northern part of the state for the upper member. The formation is a fractured porosity reservoir with the main fracture zones located along basement-controlled tectonic structures. The main features trend northeast-southwest in the northern part of the state, whereas orthogonal, northwest-southeast trends dominate in the south.