calcite–aragonite sand sequence to temporal variations in rates of CO_2 production and loss. The model can be used to help predict the spatial distribution of zones of dissolution and cementation is various coastal marine carbonate sediments.

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Lateral Seals of Small Stratigraphic Traps in Cretaceous Rocks, Western Nebraska

The lateral seals of straigraphic traps located on monoclines offer some interesting perspectives on problems of hydrocarbon entrapment. On the eastern flank of the Denver basin, oil reservoirs in Cretaceous valley-fill sandstone bodies afford a particularly instructive example. There the updip seal is provided by sandy, silty, and clayey marine facies into which were cut the slightly younger valleys. A subsequent marine transgression covered the entire sequence with clay shale, providing a top seal.

The lateral seal can be visualized as a maze of pipes and capillaries through which the oil phase finds its way, until blocked at each potential escape route by entry pressures that exceed that generated by the buoyancy of the oil column. Cores of the sealing facies show that burrowed silty sandstone is a small-scale maze, where silty laminae shortly block oil invasion. Wave-rippled shallow-shelf sandstone beds offer more continuous conduits, but are lenticular on a scale of a few hundred meters and are separated by shale beds that ultimately baffle oil escape. Cross-stratified shoreline sandstone is also a sealing facies by diagenetic kaolin; stained sets of cross-laminae are enclosed in unstained rock, a testimony to slightly different capillary pressure characteristics.

Careful examination of cores of rock facies can give vital information on the geometric nature of a seal; on how to convert laboratory measurements of capillary pressure using mercury and air to natural oil-brine systems; on critical oil saturation levels that distinguish seal and non-seal rocks; and on the height of hydrocarbon column than may be trapped by a seal.

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Upper Jurassic Evaporites and Carbonates of Gulf Coast

Shallow-water carbonate rocks of the Upper Jurassic Smackover Formation contain some of the most promising exploration targets of the Gulf Coast. Evaporites of the Louann, the Buckner, and within the Smackover have been important factors in forming the reservoirs.

The Louann, a thick salt lying stratigraphically below the Smackover, localized production and influenced facies patterns and diagenesis. The updip limit of the Louann coincides with peripheral basin faults, so fault traps in the Smackover arr to some degree related to salt movement. Salt flowage created highs on the sea floor that localized high-energy oolite bars and, in some places, reef development. Some Smackover porosity was created secondarily during early freshwater diagenesis in association with the highs. Late-stage burial diagenesis in the Smackover, which is also important in forming reservoir porosity, may have been caused by interstitial fluids that were expelled from the Louann during salt compaction.

Anhydrite occurs in the Buckner and Smackover in several forms: (1) nodules, (2) microcrystalline replacement, (3) laminations of blocky crystals, (4) poikilitic cement, (5) poikilitic replacement, (6) fracture fill of blocky or lath-shaped crystals, (7) lath-shaped replacement crystals, and (8) plugging of oomoldic porosity. The Buckner anhydrites and shales are important seals for Smackover reservoirs. Commonly the Buckner interfingers with the reservoir at the updip limit of a field and as a result of basinward progradation forms an impermeable cap. The Buckner may have influenced early diagenesis of the uppermost Smackover by introducing brines into the lime sands. Thickness maps of the Buckner serve as a valuable exploration tool for the Smackover, because porous facies are associated with Smackover highs underlying the Buckner thins. Anhydrite within Smackover grainstones can locally reduce porosity to form internal seals. The presence of minor amounts of anhydrite in Smackover carbonate rocks can confuse log interpretations on neutron and density log crossplots by causing overestimates of the dolomite percentage and underestimating of porosity.

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Subaerial Exposure Surfaces: Variations on a Theme

Carbonate sediments are commonly subjected to subaerial exposure and surficial alteration relatively early in their history through real or relative changes in sea level. The resultant diagenetic overprint may be superficial or pervasive, subtle or profound, depending upon the interplay between a number of controlling variables. It is particularly important to realize that, to a first approximation, the nature and extent of near-surface subaerial diagenesis is not exclusively a time-dependent function, but rather commonly reflects the prevailing subaerial (climatic) regime. Because of this, the course of such diagenetic modification is highly variable.

Studies on Pleistocene deposits from localities such as Barbados and Florida demonstrate a tremendous range in exposure-surface fabric. These fabrics encompass lithified but otherwise little-altered horizons, thin but texturally variable calcrete crusts, thick complex caliche profiles, in-situ psuedobreccias, and solution karst with pits and channels of high relief. It is common to find sharply contrasting fabrics developed in close proximity on the same exposure surface.

To recognize such breaks in outcrop or core, it is necessary to maintain a critical appreciation that variability is the rule rather than the exception. There is no question about the importance of such breaks, for they serve as major time-stratigraphic datums, provide insight into basin history, and may either locally enhance porosity or act as substantial vertical permeability barriers, commonly within stratigraphic sequences that otherwise appear to be lithologically uniform.

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Geologic Studies of Steam Drives Pay Off in Kern River Field, California

The Kern River field in California currently produces over 100,000 bbl of heavy crude oil per day from several steam-drive projects. Conservatively, recoverable reserves of 600 million bbl remain as the prize of enhanced oil recovery techniques. Operating costs for steam-drive projects are high because for every three barrels of crude produced, one barrel is burned to generate the steam. To effectively operate such projects, geologic conditions of the reservoir must be thoroughly understood. Close coordination between the geologist and the engineer is needed to evaluate and follow steam-drive performance on a pattern-by-pattern basis. Detailed cross sections and isopach maps of the reservoir sands and their overlying heat capping shales are prepared by the geologist. Then, working with the engineer, correlations of reservoir heat patterns are made by matching actual temperature response and production trends within their geologic constraints. These geologic-engineering evaluations of existing projects have often pointed out the need for significant changes in steam-injection profiles, steam rates, and other operating conditions. The geologist has an important role to play not only in forward planning for steam-drive projects, but also in formulating operational plans and decisions throughout the life of the project.

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Weathering-Induced Chemical Changes in Surface Coals from Paleocene Fort Union Formation, Red Rim Area, Sweetwater and Carbon Counties, Wyoming

Statistically significant differences in chemical composition between 20 outcrop and 22 stratigraphically equivalent core coal samples were demonstrated by proximate and ultimate analyses, heat-of-combustion and forms-of-sulfur determinations, and chemical analyses for 37 elements. The outcrop samples were collected from depths of 30 to 72 in. (75 to 180 cm) on very steep (> 45°) slopes. Core samples were from depths of 31 to 190 ft (9 to 58 m) at distances between 300 and 1,500 ft (91 and 457 m) from the outcrop. Mean annual precipitation in the Red Rim area is ~11 in. (28 cm); mean monthly temperatures range from 22°F (−5.5°C) in January to 68°F (20°C) in July. Apparent rank of unweathered coal is subbituminous C coal. Compared with the core samples (moisture and Btu/lb, as-received basis, all others moisture-free basis) the outcrop samples have significantly higher mean moisture (37.4 vs 23.8%), volatile matter (43.8 vs 35.1%), oxygen (24.9 vs 15.6%), and nitrogen (1.0 vs 0.8%); lower ash (13.3 vs 18.2%), hydrogen (3.0 vs 4.7%), sulfur (0.6 vs 1.1%) and heat of combustion (5,330 vs 7,690 Btu/lb); similar fixed carbon (42.5 vs 46.6%) and carbon contents (56.7 vs 60.3%). The sulfate part of the total sulfur increased from 5% in core to 18% in outcrop samples; pyritic sulfur decreased from 14 to 10%, and organic sulfur decreased from 84 to 71%. As indicated by differences in element/Al ratios between core and outcrop samples, the relative rates of removal of Si, K, B, Cr, Ga, La, Li, and V from coal during weathering are significantly greater than Al; Cd, Co, F, Ni, Se, and Zn are significantly greater than Al; Cd, Co, F, Ni, Se, and Zn are significantly less than Al; and Ca, Mg, Na, Fe, Ti, As, Ba, Be, Cu, Mg, Mn, Mo, Nb, Pb, Sb, Se, Sr, Th, U, Y, Yb, and Zr are similar to Al. Additional significant chemical changes in outcrop samples should be expected in areas of warmer, more humid climates, where coal is of lower rank, or in samples collected on less-steep slopes or at shallower depths.

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Geochemistry of Organic-Rich Shales and Coals from Middle Pennsylvanian Cherokee Group and Lower Part of Marmaton Group, Oklahoma, Kansas, Missouri, and Iowa

Middle Pennsylvanian rocks have produced substantial quantities of oil in eastern Oklahoma and southeastern Kansas. Initial results (Table 1) of a study of possible petroleum source rocks in these units show that organic-rich shales (> 1% organic C) can be divided into four groups. Group I shales are nonfossiliferous to fossiliferous marine, and commonly pyritic. Groups II, III, and IV shales are laminated, phosphatic, and nonfossiliferous to slightly fossiliferous. Groups III and IV shales are most common in the northern part of the area, which would be closer to the paleo-shoreline. Bulk organic geochemical properties of groups II and III shales are similar to coals, suggesting that most of the organic matter was derived from peat swamps. Reworking of organic matter, particularly in shale groups I and IV, was considerable, as indicated by low inferred hydrogen contents (H index) and relatively high inferred oxygen contents (O index). For types II and III shales and coals, average H and O indices decrease, and T_{max} (S_2 peak − Rock-Eval) increases from north to south, indicating an increasing maturity of organic matter to the south. This increasing maturity is consistent with changes in coal rank, which increases from high-volatile C bituminous coal in Iowa to high-volatile A and medium-volatile bituminous coal in Oklahoma. Total sulfur-organic carbon plots for the four shale groups do not intercept the sulfur axis, which suggests a lack of H_2S-containing bottom waters; different slopes of these plots suggest variability of sulfate availability, possibly due to salinity differences or rates of sedimentation.

Table 1.--*Summary data for rock samples from the Cherokee and Marmaton Groups*

	Shale class				
	.	II	III	IV	Coal
Number of samples-------------	37	35	15	11	70
Organic Carbon % [1]	3.3	10.5	21.3	8.4	55.8
Hydrogen index [1,2]	45	180	325	26	227
Oxygen index [1,2]	26	9	9	13	7
C vs S slope----------	.7	.24	.19	.14	--[3]
C vs S intercept % C----------	.8	1.5	14.4	3.9	--
C vs S correlation (r)	.9	.9	.8	.9	--

[1] mean values; [2] determined by Rock-Eval; [3]--, no data.

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Regional Upper Devonian Wabamun Lithofacies Computer Maps, Alberta

Regional distribution of lithology, fossils, and porosity within the Upper Devonian Wabamun Formation is summarized on ten maps covering Alberta and northeast British Columbia. The 2,600 data points on each map were derived from the Constrat digital lithology file and were contoured using Union Oil's Calgary 370/138 computer. The maps were made to outline regional lithofacies and biofacies environments and to pinpoint porosity pinch-out plays.

Maps displayed include: Wabamun isopach, net-feet dolomite, ratio of net dolomite to limestone, net anhydrite, porosity isopach, good oil shows, bioclast isopach, pellet isopach, crinoid isopach, and average particle size.

Interpretation of these maps defines four distinct depositional environments within the Wabamun: (1) a shallow shelf in southern Alberta that has interbedded dolomite and anhydrite with negligible porosity development; (2) a north-trending porous dolomite funnel or channel running up the 5th meridian; (3) a shallow-water basinal environment in central Alberta, characterized by abundant porous dolomite pods