reflect regional changes in paleogeography that caused progressive exposure of the platform. Rates of sea level rise were high and punctuated by periods of decreased rates or near stillstand as indicated by restricted-marine and clastic deposition with unconformities. The duration of these stable periods of relative sea level increased through time.

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Future Petroleum Exploration Trends in Arabian Gulf Area

The Arabian Gulf Province has more than half the world's discovered oil. The undiscovered potential is perhaps equal to the oil already discovered, and includes enormous quantities of gas. This mature basin is not thoroughly evaluated; it will be carefully reappraised for its full potential. Future exploration and drilling should concentrate on the following: (1) deep unexplored Paleozoic rocks (prolific gas play in Permian Khuff and Cambro-Ordovician rocks on known structures); (2) extension of present pay zones to adjacent areas, and exploration for non-giant structures associated with the giant fields; (3) exploration for stratigraphic and other subtle traps by analysis of geologic data and special seismic processing and interpretation; (4) enhanced recovery from producing fields and of shallow heavy oil and low-grade deposits; (5) development of Oligocene-Miocene reservoirs in northern Gulf and Zagros areas for the discovery of new giant fields; (6) development of new geologic-sedimentologic concepts to evaluate source rocks, migration mechanism, reservoirs, and traps; (7) exchange of geologic, geophysical, and geochemical data among Arab countries, and regional petroleum exploration; (8) exploration in the vast areas of the Arabian basin that are not sufficiently tested (Rub al Khali and southern Iraq); (9) better production schemes, based on reservoir and simulation studies and advanced well logs and their evaluation; (10) evaluation of all horizons in presently producing structures; (11) exploration for new oil and gas reserves offshore in the Arabian Gulf; (12) production from fields with high potential that are sealed for economic and market reasons (i.e., the reserves are not commercial by area standards); and (13) exploration in the offshore area of the Arabian Peninsula on the Indian Ocean, which has barely been explored.

Future exploration will necessarily involve extensive drilling programs, and the risk of drilling dry holes will be relatively higher.

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Improved Recognition of Sedimentary Fabrics using Fluorescence Microscopy—Implications for Interpreting Carbonate Facies and Diagenetic History

Blue-light fluorescence microscopy applied to carbonate petrography can result in more accurate recognition of depositional facies, diagenetic history, and porosity evolution in some pervasively dolomitized or recrystallized limestones previously uninterpretable using existing petrographic techniques. Fluorescence microscopy also has other useful applications for the study of less diagenetically altered carbonates.

Preliminary observations establish that fluorescence microscopy potentially can: (1) make depositional grain types and textures visible in thin sections of massively dolomitized or recrystallized limestones; (2) identify or clarify diagenetic fabrics; (3) more precisely relate porosity evolution to depositional fabric and diagenesis; (4) provide a clearer understanding of the relative timing of diagenetic events (dolomitization, pressure solution, cementation, neomorphism) and their relationship to porosity evolution; (5) aid in the differentiation of carbonate cement from neomorphic spar, both for calcite and dolomite; (6) permit more rapid evaluation of mineralogical stabilization and neomorphism in Holocene and Pleistocene carbonates; and (7) improve delineation of porosity and pore geometries.

Fluorescence microscopy is a rapid, easily-used and nondestructive technique that requires no special sample preparation. As with standard staining techniques or cathodoluminescence, this tool does not work for all samples. However, when fluorescence microscopy is successfully applied to the study of carbonates, it elicits important information from a thin section that, in many cases, other standard petrographic techniques fail to detect. Based on its potential usefulness, fluorescence microscopy should become a routine tool for the petrographic evaluation of carbonates.

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Radiometric Dating of Wolfcamp Ground Water Using $^4$He and $^{40}$Ar

Hydrologic investigations of the Wolfcamp aquifer, Palo Duro basin, Texas Panhandle, report slow flow rates and long travel paths, which lead to a prediction of very old ages for the ground water. Because the expected ages are about 10 million years, many methods of dating ground water are unsuitable. The U, Th $\rightarrow$ $^4$He and $^{40}$K $\rightarrow$ $^{40}$Ar clocks are suitable. All ground water samples have large amounts of radiogenic $^4$He and $^{40}$Ar. Using these $^4$He and $^{40}$Ar data and a mixture of estimated and measured values for K, U, and Th contents, water-rock ratios, and release factors, the initial age estimate for the ground water is about 100 million years at two wells, Stone and Webster 1 Sawyer in Donley County, Texas, and Stone and Webster 1 Zeeck in Swisher County, Texas. At a third well, Stone and Webster 1 Mansfield in Oldham County, Texas, the concentrations of $^4$He and $^{40}$Ar are much higher, and the apparent ages are about 250 million years. Other isotopic and chemical data ($\delta$D, $\delta^{18}$O, Br/Cl) for ground water from this third well indicate a different origin and/or history. The current working hypothesis is that ground water sampled in the 1 Mansfield well is a mixture of meteoric water and a deep-basin ground water.

The $^4$He ages for the 1 Sawyer well and 1 Zeeck well samples appear to be valid and are presently assigned errors of about a factor of two, determined almost entirely by uncertainties in U and Th concentrations and water-rock ratios. The $^{40}$Ar ages remain suspect because data are currently too few to confirm or negate the possibility that a significant fraction of the $^{40}$Ar is inherited from detrital minerals.

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Gamma-Ray Spectrometry of Marine Shales in Outcrop—A Tool for Petroleum Exploration and Basin Analysis

Gamma-ray spectrometry was conducted on outcrops of marine shale and chalk deposited in the Cretaceous Western Interior seaway. Study of the Cenomanian-Turonian Greenhorn cyclothem of Colorado, New Mexico, and Utah showed that profiles of gamma-ray spectra are useful in evaluating organic carbon content, interpreting paleoenvironments, and correlating otherwise homogenous sequences of marine shale. Gamma-ray spectra provide estimates of total gamma radiation and K, U, and Th contents. Th/U and K/U ratios can be used to estimate relative abundances of detrital minerals and organic matter, whereas the Th/K ratio is an indicator of clay mineralogy. Variations in these ratios reflect both local depositional processes and widespread events that can be correlated for hundreds of kilometers across lithofacies boundaries. Profiles of total gamma radiation can be used to help map shale facies. Spectrometer surveys can be used to show directions of sediment transport, to indicate proximities of paleoshorelines, and to aid in estimation of lateral and temporal variations in paleosalinity. Outcrop profiles can be compared directly with well logs of gamma-ray spectra.

Gamma-ray spectrometry of shale outcrops is a versatile technique. Results can be interpreted in the field, the sampling program can be modified as it progresses, and the effects of event deposits such as bentonites and bone beds can be characterized. If lead shielding is used to keep sample mass and geometry constant, reproducible results can be obtained even from shales that contain below-average concentrations of K ($<2\%$), U ($<2$ ppm), and Th ($<10$ ppm).

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Dolomitization Patterns in Subtidal Bighorn Dolomite (Upper Ordovician), Southeastern Wind River Range, Wyoming

The Bighorn Dolomite, which is 38–53 m (125–174 ft) thick, lies disconformably between the Cambrian Gallatin Limestone and Mississippian Madison Limestone. It is approximately equivalent to the productive Red River Formation in the Williston basin. Above the basal Lander Sandstone, the unit is massive to slabby (toward top), fretted-weathering, locally vuggy to cavernous, low-insoluble, finely crystalline dolomite. An abundant marine fauna and pervasive, bedding-controlled *Thalassinoides*-type burrow patterns indicate a subtidal environment of normal salinity for the original carbonates prior to dolomitization.

The positive elements of the fretted-weathering pattern represent burrow fillings, and consist of xenotopic, decimicron-size dolomite; the recessed areas, or "matrix," are composed of xenotopic to idiotopic dolomite. Whereas the matrix is also chiefly decimicron size, the inclusion of more skeletal debris (particularly pelmatozoan fragments) than in the burrow fillings contributes to the coarses texture of the matrix. However, the significantly greater intercrystalline to mesovuggy (mesomoldic?) porosity in the matrix results in its lesser resistance. Where weathered tubes are even with or recessed below the matrix, pores in the matrix are filled with chalcedonic quartz. Well-preserved fossils, relatively fine crystallinity, conodont color-alteration index (1), and oxygen-isotope data ($\bar{x} = -4.7‰$ PDB) strongly suggest early diagenetic dolomitization of both burrow fillings and matrix at relatively shallow burial depths. Isotope values and pseudomorphically replaced pelmatozoan fragments suggest mixing-zone effects. The widespread Bighorn has generally similar characteristics throughout much of its extent in the northern Rocky Mountain area.

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