a now-eroded, oblong reef rim probably existed. Within the reefs, 7 forereef, 2 reef-core, and 12 backreef subtypes can be distinguished. Transgressions and regressions of the sea resulted in cyclic sedimentation on the flat, widespread shelf-lagoon. Locally the transgressive cycles start with black marls, whereas the regressive cycles terminate with laminites and erosion features. The topmost parts of the subsiding reefs are built of convex limestone caps (Iberg facies), tens of meters thick; there is no backreef lagoon facies. Two facies subtypes can be recognized within these very fossiliferous limestone caps—biodetrital limestones with a high original interframe porosity, and micritic limestones with "stromatactis" (so-called still-water bioherms).

The interreef basins between the isolated reef complexes are characterized by black bituminous shale (so-called "Flinz" facies). Also in the geosynclinal trough, dark, pelagic shales are present. Limestone turbidites are continuous from the outer forereef flanks into the adjacent deeper basins.

Dolomitization occurs mainly in the fine-grained bank types and the micritic backreef subtypes, whereas the reef-core and the sparry-cemented, forereef subtypes are less dolomitized. The dolomitization is preponderantly epigenetic (bound to joints, faults, bedding planes, or schistosity planes). No economic discoveries of oil or gas have been made in the Devonian carbonate complexes in central Europe. Origin and source of asphaltite in the isolated small Iberg-Winterberg reef, Harz Mountains, are still unresolved.

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WIDTH-THICKNESS RELATIONS FOR FLUVIAL AND SHORELINE SAND BODIES

The relation between the width and thickness measurements of 2 different types of sand bodies were studied. The measurements were gathered from more than 100 literature sources.

The reduced regression line through the width-thickness data for shoreline sand bodies is significantly different from a similar line determined for fluvial sand bodies. The lines are almost parallel with the shoreline sand line, a fact which shows that shoreline sands have a greater width than fluvial sands for any stated thickness. Both populations may be fit by bivariate log-normal distributions and both result in nearly linear relations between the mean, median, and modal widths and the thickness.

Equations are presented for determining the relative frequency function of the width for any thickness of sand found in a well. Therefore, the probability that the width is greater or less than a stated value, or the probability that the width lies within a particular range, can be determined if one knows only the maximum thickness of the cross section being studied and the type of sand body. The possible error resulting from using a thickness other than the maximum is small when the thickness used is 80 ft or more for a fluvial sand body and 50 ft or more for a shoreline sand body.

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REMOTE SENSING FOR PETROLEUM

Remote sensing techniques in the exploration for petroleum have not moved from the small-scale, limited-study-area, experimental state to full-scale, large-area, operational status. Remote sensing techniques will have come to maturity when total basin surveys for known and potential hydrocarbon anomalies are commonplace. As with much of petroleum exploration, remote sensing is primarily an indirect technique limited to the development of drillable petroleum prospects. Remote sensing techniques include spectroscopic analysis, which offers the potential for airborne geochemical surveys. Research toward the latter objective is still in early phases.

The most commonly used wavelengths are the visible part of the spectrum (0.3–0.7μ), infrared film emulsions (0.3–1.1μ), and thermal infrared (8–14μ). Equipment and materials covering these spectral bands are the best developed and the most widely available.

Exploration in areas of consistently poor illumination because of meteorologic conditions will bring about increased use of the longer wavelength (microwave) equipment. Cloud penetration is a function of wavelength; passive microwave radiometers, side-looking radar, and scatterometers possess this capability. Currently, airborne microwave instrumentation is not widely available, but indications are that it will come into wider use.

Educational opportunities to orient exploration personnel to the uses and limitations of this new tool appear adequate. In addition to the proliferation of short courses on remote sensing at numerous universities, industry-sponsored seminars have been conducted.

Service companies prepared to perform multisensor data collecting on a global scale are now operational. They offer, on a contract basis, sophisticated equipment in advanced aircraft, with or without interpretation packages. In addition to petroleum companies, their clientele includes mining companies, widely diversified agricultural interests, and domestic and foreign government agencies.

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APPLICATION OF STABLE OXYGEN AND CARBON ISOTOPE TECHNIQUES TO STUDIES OF DIAGENESIS

Oxygen and carbon-isotope techniques are well established in classical paleotemperature work, in the fields of igneous and metamorphic petrology, and in certain phases of organic geochemistry. However, there is a wealth of fundamental data on the isotopic behavior of sedimentary rock-forming mineral systems (carbonates, silicates, sulfates, and their interaction with various fluids) that await systematic exploitation by geochemists interested in low-temperature diagenesis of sedimentary rocks. One example of specific isotopic studies involves early dolomitization.

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MARKOV CHAIN ANALYSIS OF CARBONATE ROCKS: APPLICATIONS, LIMITATIONS, AND IMPLICATIONS AS EXEMPLIFIED BY PENNSYLVANIAN CARBONATES IN SOUTHERN NEVADA

Markov chain analysis is a simple, powerful, mathematical tool for testing the presence, absence, and length of "memory" in a sequence of events. Use of this method on the Pennsylvanian carbonates of southern Nevada revealed the presence of a "memory" ($X^2 = 32.55$ with 15 df) in the thick basinal interval of the Bird Spring Group of the Arrow Canyon Mountains and a relative lack of memory ($X^2 = 20.5$ with 15 df) in the thinner, age-equivalent, shelf deposits of the Callville Limestone on Frenchman Mountain.

Covered intervals have little effect in situations

where the number of intervals is less than 20% of the total number of identified units. Best results are obtained if coincident layers of identical lithology are treated as a unit facies rather than as multistory facies. The effect of varied identification of lithologies is critical. For example, grouping clay and shale gives markedly different results from cases in which they are distinguished. It can be concluded that (1) Markov tests support current beliefs in that they indicate relative lack of memory in shelf sediments indicating many breaks in sedimentation, and (2) consistent evaluation of facies is critical, as different labels for the same lithology cause large-scale variation in numerical results.

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DIAGENESIS OF SHALY ROCKS

Argillaceous rocks show major chemical and mineralogic trends as a function of geologic age. If the trends are compared by eras, they are of global significance. The ratios of the various metal oxides to Al_2O_3 plotted against geologic age form 3 distinct behavioral groups and oxide–Al_2O_3 ratios, except those of K_2O and FeO, diminish with increasing rock age.

The first group, water ($-H_2O$), CaO, and CO_2, decreases with rock age from high to very low values. The covariance of H_2O with CaO and CO_2 is consistent with a gentle water leach of shale and loss of original calcium carbonate through time. MgO, Na_2O, and SiO_2 form a second group, but change with geologic age much less than the first group. The chemical trends of these second group oxides, along with K_2O, reflect the differences in shale mineralogy as a function of age. The increase in illite percentage in older rocks results in a slight "relative" enrichment in K_2O whereas the abundance of expanded clays in younger shales gives rise to Mesozoic-Cenozoic shales of higher Na_2O, MgO, and SiO_2 content. This interpretation requires that reactions of the following type obtain within shales in the first few hundred million years after burial: (low silica) kaolinite + (high silica) expanded clay + potassium = (intermediate silica) illite + MgO, Na_2O, and SiO_2 (lost from shale).

The third group includes FeO and Fe_2O_3. There is a reciprocal relation between these oxides; young rocks are high in oxidized iron, old rocks low, but the total iron oxide concentration in shale is almost constant with geologic age. This trend partly reflects the postdepositional oxidation of organic matter and attendant reduction of iron in shales as they progressively age.

These time-dependent chemical and mineralogic trends are in harmony with the general concepts of differential sedimentary cycling and chemical uniformitarianism; concepts that predict approximately the kinds of long-term, postdepositional, selective changes expected in argillaceous rocks as a function of geologic age, and that help to discriminate between primary and secondary chemical and mineralogic features.

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SABLE ISLAND DEEP TEST OF SCOTIAN SHELF

Mobil Oil No. 1 Sable Island was drilled to a total depth of 15,106 ft on the Scotian shelf of the Canadian Atlantic offshore. It was the first deep test in the region. The well, on the outer shelf, 190 mi east of Halifax, Nova Scotia, used historic Sable Island as a drilling platform.

The exploratory test was drilled into the Lower Cretaceous; thus, it not only documented the extension of the submerged Atlantic coastal plain south of Nova Scotia, but also indicated the presence of a thick Cretaceous sedimentary succession in the region.

The well section is predominantly marine clastic rock composed of 4,050 ft of Tertiary and Quaternary, and 11,056 ft of Cretaceous strata. These sequences can be subdivided into 11 units on the basis of sandstone percentage, paleontologic data, and other lithologic criteria. These units indicate the occurrence on this part of the Scotian shelf of fluctuating, mainly marine Cretaceous and Tertiary deposition in littoral to bathyal water depths.

Encouraging but noncommercial gas shows were tested in several zones, particularly in the Lower Cretaceous. A trace of oil was recovered on a test at total depth. Porous sandstone is abundant through most of the section.

The discovery by the Sable Island well of a thick, marine, Cretaceous-Tertiary section with indications of hydrocarbon generation and potential reservoir beds greatly enhances oil and gas prospects in the Canadian Atlantic offshore and the Scotian shelf in particular.

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CRITIQUE OF MEMBRANE-FILTRATION CONCEPTS AS APPLIED TO ORIGIN OF SUBSURFACE BRINES

Membrane-filtration processes capable of filtering dissolved inorganic salts from water have been well documented in the laboratory and in industrial applications (desalination). Application of such processes to earth (sedimentary-basin) models, however, is inadequately documented and subject to several difficulties. These difficulties include the facts that (1) natural pressure gradients adequate to overcome the osmotic pressures required to separate salt from water do not appear to be available or reported in sediment-sedimentary rock environments, and (2) salt exclusion properties of membranes correlate inversely with permeability. To achieve geologically significant enrichment of salts in subsurface fluids requires that large volumes of fluids pass across what would normally be regarded as aquicludes and nonreservoir rocks under relatively leak-free conditions. No proof of such massive movements has been offered. In fact, the consequences of such movements, consistently applied to sedimentary basins, would negate much of the existing principles and practice of petroleum geology and petroleum engineering.

Recent pore-fluid studies from ocean drilling operations show no evidence of membrane filtration in deep-ocean sediments or in geosynclinal sediments from the Gulf of Mexico. These factors contribute to the conclusion that membrane filtration concepts as presently formulated have little importance in enriching subsurface waters in salt, and probably have only minor influence on the ionic composition of subsurface fluids.

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