

mound scour channel; (3) mound transition; (4) intermound; (5) blanket; (6) laterally linked hemispheroid; (7) mud flat; and (8) tidal channel. Each of these microfacies is characterized by a particular algal mat frequency, the degree of development and the nature of laminations, and by the amount of mechanically deposited sediment.

Major rock types are stromatolite-constructed dolomite mudstone, wackestone, and packstone. Nearly all samples are characterized by the partial or pervasive development of a filamentous (and presumably algal) microstructure. Burrows and pellets are uncommon in all of the microfacies. Ostracods are common. Laminations are well developed in all of the microfacies except the mound microfacies. Breccias are common especially in algal mounds and are due to mineralization by sulfate minerals, and dedolomitization, desiccation, and solution collapse.

The general sequence of mineralization was: (1) formation of microcrystalline xenotopic dolomite, probably by replacement of an initial CaCO_3 mud, accompanied by the formation of gypsum and anhydrite; (2) dedolomitization, primarily in the mound microfacies; (3) partial replacement of calcite and dolomite by celestite; (4) replacement of some calcite, dolomite, and celestite by fluorite; and (5) limited formation of medium crystalline, idiotopic, and hypidiotopic dolomite by a process of local source dolomite crystallization and recrystallization.

Comparison with several Recent carbonate analogs in the Persian Gulf and Bahamas suggests that most of the eight microfacies were formed in a supratidal environment.

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CLAY MINERALS AS CUMULATIVE RECORDS OF THEIR ENVIRONMENTS

The environmental aspects of clay minerals include relations of clay minerals to two environments that may differ radically from each other: the environment of origin (where *formed*) and the environment of deposition (where *found*).

Environmental aspects are viewed as parts of geologic history and change. Three components constitute geologic history and change: (1) earth materials that undergo the changes and simultaneously serve as substantive records of the geologic changes, (2) the energies (climate, weathering, sedimentation, *etc.*) that effect the changes on the materials, and (3) the flow of time through which the energies act on the materials.

Parent materials of clay minerals are argillaceous and nonargillaceous parent rocks, plus ions added minus ions removed during genesis. Energies effecting argillation include activities of the H^+ (protons), other cations (notably K, Mg, Ca, Na, Fe) and anions (carbonate and silica complexes), oxidation potential (electrons, e^-), and organisms. Geological terms for these agents are fresh rain water, alkaline ocean water and brines, and hydrothermal solutions, but they can be quantified with the equilibrium diagrams and thermodynamic calculations of the geochemist. Time in geology correlates with kinetics of geochemistry.

In the environment of deposition the already formed clay minerals may respond to (1) mechanical energy of sorting, (2) colloidal effects of flocculation or dispersion with consequent modification of surface

areas and surface chemistry, ion exchange, dialysis, and the probably important but poorly understood interactions with organic materials, and (3) reaction with the ions of the aqueous medium in which deposition occurs.

Following deposition, the clay minerals respond to the energies of mechanical compaction and mechanical dehydration, further thermal dehydration that is significantly important near the temperature of boiling water, activities of ions of concentrated brines accelerated in reactivity by high temperatures, and decrease in oxidation potential of surroundings.

A cumulative record of events is imprinted on clay minerals insofar as changes are produced in the minerals. A specimen of clay minerals extracted from a core of shale from a 3-mi depth may have an exceedingly complicated genealogy, not completely interpretable. Its interpretation is a function of both the fidelity of the mineral record, and the competence of the interpreter.

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SUBMARINE CHANNEL AND FAN DEPOSITS, SILURIAN OF CENTRAL WALES, UNITED KINGDOM

Mapping and detailed sedimentological study of a group of geosynclinal formations of Llandoveryan age (Lower Silurian) around Rhayader, central Wales, have been undertaken jointly by the writer and M. A. Woollands (University College, London). These formations occur near the southeastern margin of the Welsh trough and consist essentially of bodies of sandstone and conglomerate, lenticular through distances of several kilometers, and enclosed within a framework of graptolite-bearing argillaceous sediments.

Marked lateral and vertical variations in the geometry, internal features, and transport patterns of the coarser intercalations may be demonstrated and are attributed to differences in the mechanisms and sites of deposition. On the southeast, an argillaceous facies with a few thin, laterally derived tractional sandstone beds and calcareous bands, displaying slumps, is interpreted to represent a slope environment. This facies contains a few longitudinally derived distal turbidite units which appear in more profusion on the north-west in an argillaceous facies of inferred basin-plain origin.

Mantling the pelagic sediments are broadly lenticular bodies of coarse sandstone interpreted as proximal turbidites. Sole marks in these sandstone beds present a complex but essentially longitudinal transport pattern but ripple marks and other depositional features indicate modification of the northeast-southwest longitudinal pattern by lateral tractional currents (from the southeast). Such proximal turbidites grade both laterally and vertically into more distal turbidites and into coarse granule-gritstone and boulder conglomerate.

The rudites occupy successive, steep-sided channels excavated in the pelagic basin floor and slope sediments, and display features characteristic of fluxoturbidite associations. The orientation of channels, sole marks, ripples, and pebble imbrication consistently indicates current movement toward the north-northwest whereas the internal features and fabric of the coarse sediments suggest emplacement by a sand-avalanche

mechanism in which shearing processes were dominant.

The rudites are interpreted as a complex of submarine channel fills, excavated in base-of-slope sediments and possibly representing the lower ends of small submarine canyons. The more extensive proximal turbidite bodies may then be regarded as fan accumulations fronting the canyon mouths and feathering out into the distal representatives. One of the most interesting features of this sequence is the abruptness of the change from channel rudite through proximal facies to distal turbidites, which in several localities may be shown to occur within less than 8 km down-current. The short-lived and unusual character of the turbidity currents in this example may be linked to the clean, mud-deficient nature of the original supply of gravel and sand.

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MODES OF FORMATION, SEDIMENTARY ASSOCIATIONS, AND DIAGNOSTIC FEATURES OF SHALLOW-WATER AND SUPRATIDAL EVAPORITES

Production of a brine depends critically on favorable geometry and climate. The required geometry rarely is achieved on a large scale but commonly is developed on a small scale in the form of lagoons, pans, and supratidal areas, during processes of near-shore sedimentation; large brine basins normally will exhibit these environments peripherally. The small size and exposed nature of shallow brine bodies and supratidal surfaces give them an inherent instability, e.g., short-term, extreme temperature fluctuations, brine dilution, or brine concentration. These instabilities may be reflected by features of the sediments and evaporite minerals.

Stability and kinetic data indicate that gypsum is always the first calcium sulfate mineral precipitated and that anhydrite is either an early or late post-burial diagenetic mineral. Gypsum crystals precipitated from brine bodies normally lack inclusions and are elongated whereas those precipitated diagenetically within supratidal sediments or below the sediment-brine interface in brine pans commonly contain inclusions of host sediment and are lensoid and stubby. Rate of crystal growth is thought to account for these differences in crystal morphology. Anhydrite in supratidal sediments exhibits a nodular structure. Recent occurrences in the Persian Gulf and Baja California indicate that anhydrite is precipitated where mean annual air temperatures exceed 22°C., only gypsum being precipitated below this temperature. Gypsum and anhydrite emplaced diagenetically within supratidal sediments are in places crudely layered but not laminated; brine-pan environments may exhibit sediment-evaporite laminae, each couplet representing a period of dilution and evaporation. Elongate gypsum crystals occur in the evaporite laminae whereas early diagenetic stubby gypsum crystals may occur in both evaporite and sediment laminae.

Several other evaporite minerals may be developed in these environments. Celestite occurs as a trace mineral. Halite may be dominant under high net evaporation conditions and a triplet of sediment-gypsum-halite may be developed as a result of one dilution-evaporation cycle, the halite normally being redissolved, however, at the next influx of dilute water. Polyhalite may replace early gypsum under very high

net evaporation conditions. Small amounts of bassanite may result from near-surface dehydration of gypsum in supratidal environments. If local sediments are carbonate, then dolomitization is common. Magnesite and huntite are other recorded minor carbonate minerals. Some of these minerals are stable for only limited periods of time or under a limited set of conditions and are not carried into the subsurface.

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MUSKEG EVAPORITES OF WESTERN CANADA AND ASSOCIATED OIL

The Muskeg or Prairie Formation is part of the Middle Devonian Elk Point Group of Western Canada. Muskeg rocks grade from marine shale and carbonate in northeastern British Columbia through anhydrite and salt to highly concentrated potassium salts in Saskatchewan. The same progression from less to more concentrated end members is repeated in vertical succession in six composite lithologic units. The cyclic succession of beds and their lateral and vertical facies relations provide a textbook example of an intracratonic salt basin, barred by prominent barrier reefs and fringed by reefoid banks and vast anhydrite platforms.

Large reserves of oil are trapped in pools arranged along the western and southern edge of the Muskeg salt. This association is too consistent to be accidental.

Growth patterns and distribution trends of porous carbonate and sandstone facies from Devonian to Cretaceous suggest that the rim of the salt basin was a persistent locus of epirogenic differentiation. The regional tectonic trends were modified further by movement of salt and possibly salt solution, providing a variety of local structures where oil was pooled.

In northwestern Alberta Muskeg evaporites are directly involved in the pooling of oil as source rocks, as cap rocks, and as flank seals to prolific pinnacle reefs. Some reef sections are equivalent in age to Muskeg evaporites in the salt basin. Muskeg carbonates sandwiched between evaporites also produce oil.

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AAPG RESEARCH COMMITTEE

Over the years the AAPG Research Committee has maintained a strong interest in evaporites, largely encouraged by the discovery of major quantities of hydrocarbons in an evaporitic environment. Many of the papers in the main session of this annual meeting deal with "giant fields" which have been found associated directly with or very near to evaporites. The symposium of 12 papers presented earlier today gave a closer look at many of the details involved with evaporite deposition, oil generation, porosity development, environmental conditions, etc. In brief, from this symposium the listener has heard about supratidal and conventional deeper water evaporitic deposits. Also he has heard that bedded salt is a normal marine sediment and not a "chemical freak." Source beds occur in the basin deep and moderately tectonic shelf areas where porosity conveniently is available in reefs (limestone) and dolomite. Oil accumulations occur in both environments. Salt movement and solution fur-