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Morphologies of Gypsum on a Modern Sabkha: Clues to Depositional Conditions

Gypsum is the dominant evaporite mineral across the Holocene marine sabkha of the northwest Gulf of California, Baja California, Mexico. This sabkha is a complex of mud flats and saline pans in which gypsum occurs as layers and isolated intrasediment crystals. Six distinct morphologies of gypsum were found: flat plates, acicular prisms, bladed prisms, blocky prisms, blocky hemipyramids, discoidal hemipyramids. *Flat plates* (< 0.5 mm wide) and *acicular prisms* (< 1 mm long), in the form of radiating clusters and interpenetrating twins, crystallize at the brine-air interface during the temporary saline lake stage of the pan. These tiny crystals settle out on the bottom of the pan as a cumulate layer. *Bladed prisms* (0.5-1.5 mm long) nucleate on this cumulate layer and grow upward as vertically oriented prisms (commonly swallowtail twins) making a "grass-like" layer. *Blocky prisms* (up to 2 cm long), barrel-like in shape with swallowtail twin terminations, are found as pendant cements in shelter vugs formed by buckling of the gypsum layers of the pan. *Blocky hemipyramids* (up to 1 cm across) are found as a loose mush making a diapir-like mound beneath m-scale polygonal cracks in the layered gypsum of the pan. These clear. blocky hemipyramids grow diagenetically in the vadose zone during the dry stage of the pan when evaporative pumping draws subsurface brine up along the polygonal cracks. *Discoidal hemipyramids* (up to 2 cm long) occur as isolated crystals. clusters of crystals, and rosettes within the siliciclastic sediment of the mud flats surrounding the pan. They are of vadose and phreatic origin.

Gypsum morphologies clearly vary with depositional conditions across this sabkha and this finding should allow us to use morphological variation in gypsum as a sensitive interpretative tool for ancient evaporites and evaporitive sediments.

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Anatomy of a Modern Marine Sabkha in a Rift Valley Setting, Northwest Gulf of California, Baja California, Mexico

An extensive sabkha, 100 by 20 km (62 by 12 mi), caps Holocene siliciclastic tidal flats along the coast of Baja California in the northwest Gulf of California structural trough. This sabkha, bounded on the west by alluvial fans, is a complex of sand flat, saline mud flat, gypsum-halite pan, and supratidal mud flat subenvironments. The sand flat, transitional between the fans and the sabkha, consists of horizontally to wavy laminated sand washed onto the flats by sheetfloods from the fans under upper-flow-regime conditions. The sand flat passes into saline mud flats characterized by massive mud crowded with discoidal gypsum crystals grown within the sediment, destroying the layering. This intrasediment growth of gypsum is driven by evaporative pumping of brine from a shallow subsurface brine body. A gypsum pan occupies a wide, shallow depression within the saline mud flat. After storm flooding (either marine or meteoric) the pan becomes a temporary saline lake with an algal mat overgrowing a siliciclastic storm layer. Precipitation of gypsum needles from the open lake brine and bottom growth of gypsum prisms produce a gypsum layer that mimics the algal mat topography. Evaporation of the lake leads to (1) vadose diagenetic growth of gypsum that distorts and polygonally disrupts the gypsum layers (2) deposition of a surface halite layer in the center of the pan. These layered pan deposits are the evaporites of the sabkha. Seaward of the saline mud flats are supratidal mud flats underlain by millimeter-thick laminites with deep prism cracks, sheet cracks, and scattered gypsum discoid crystals. Pervasive mud cracking during long periods of nondeposition completely disrupts layering, creating a massive arid "soil." A beach ridge separates this sabkha complex from the burrowed and ripple cross-laminated intertidal sediments.

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Strike-Slip-Influenced Sedimentation in Norfolk Basin, Southeastern Massachusetts

Pennsylvanian coarse-grained fluvial sedimentation in the Norfolk basin of southeastern Massachusetts occurred in a tectonically active environment, possible related to sinistral strike-slip motion on faults west of the basin. Detailed measured sections reveal an overall upward-fining succession, with humid alluvial fan facies and braided stream sub-facies with associated overbank/flood-plain deposits. The humid alluvial fan contains massive bedded, clast supported conglomerates with infiltrated sandstone and siltstone. Fluvial dominance during deposition is indicated by frequent upward-fining cycles, lack of evidence of debris flow, and clast rounding and imbrication.

The braided stream sub-facies is distinguished by a reduction in bed thickness and clast size (maximum clast size = 5 cm), and commonly contains upward-fining cycles. Although trough cross-bedding angles are low throughout the basin, low angle (< 10°) troughs upslope grade into distal very low angle (< 5°) troughs to plane beds, indicating lesser channel incision and greater sheetflood conditions downslope. The overbank/flood-plain deposits include plane laminated siltstone and claystone with common desiccation cracks.

Evidence for active faulting during deposition includes: mismatch of detrital grain mineralogy with adjacent source terrains; soft sediment boudinage; mixtures of fresh and altered feldspar; and rapid lateral and vertical facies changes.

Provenance studies suggest a source area for many of the sediments might be metabasalts and marbles of the Blackstone Series of northern Rhode Island. If correct, these results support paleomagnetic and other regional studies suggesting sinistral strike-slip motion may have formed the Carboniferous basins of Massachusetts and Rhode Island.

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Preliminary Study of Palynomorphs and Other Plant Fossils from Mississippian Clastic Sediments, Antler Basin, Nevada and Utah

A preliminary study of palynomorphs and other plant fossils from Mississippian clastic sediments in the Antler basin, Nevada and Utah, suggests that much of the Upper Mississippian sediments were deposited in a transitional environment rather than a marine environment, as previously thought. The Antler basin received most of its clastic sediments from the east flank of the north-south-trending Antler orogenic belt in central Nevada. The clastic sediments generally become finer and thinner eastward until they interfinger with a carbonate platform in central Utah.

Numerous fossil plant taxa have been found in these clastic sediments from central Nevada to central Utah. Assemblages of terrestrial palynomorphs associated with lycopod bark impressions (*Lepidodendron*), leaf impressions (*Lepidophyllum*), fruiting body impressions (*Lepidocarpon*), and, most importantly, impressions and casts of rootlike rhizomes (*Stigmaria*) suggest that the plants grew in place during periods of nonmarine deposition.

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Eocene Wave-Dominated Deltaic Sedimentation, Oregon Coast Range

The Eocene Tyee and Coaledo Formations of southwest Oregon together illustrate vertical and lateral facies changes in delta-front and prodelta-to-shelf deposits, which prograded into a forearc basin. Prevalent coarse sandstone bodies with wood also contain large-scale, contorted cross-bedding; they show north-northwest paleocurrent transport directions. An abundance of hummocky stratification and symmetrical ripples in the prodelta and shelf sandstones indicate the dominance of wavy processes.

Conglomeratic, coaly, cross-bedded coarse sandstone, hummocky-bedded, and siltstone-mudstone facies are distinguishable in the Eocene strata. These five well-defined facies are interpreted to represent fluviodeltaic, marsh-swamp, delta-front distributary, prodelta, and shelf deposits, respectively. Burrowed medium sandstone and shelly coarse sandstone facies in the Coaledo Formation are inferred to represent delta-margin deposits. Delta-front and prodelta deposits show soft-sediment deformation features, which indicate rapid deposition during erratic episodes of river flooding. Hummocky cross-stratification and burrowed beds with truncated tops indicate episodic storm events in the prodelta and shelf deposits.

Vertical successions in the Coaledo Formation typically show siltstone-mudstone facies at the base, overlain by the hummocky-bedded facies, and capped by coarse delta-front or delta-margin deposits. These upward-coarsening or progradational sequences number at least 15 in the Coaledo Formation alone, and indicate a complex history of delta-distributary switching coupled with subsidence and/or eustatic changes.

Wave-dominated deltaic deposition was a repetitive and persisting style of sedimentation throughout much of the Eocene period in southwest Oregon. This scenario is useful for distinguishing vertical and lateral relationships applicable to other ancient wave-dominated systems and to predictions in potentially economic units of the Pacific Northwest.

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Developing an Oil Generation Model for Resource Assessment of Bakken Formation, Williston Basin

A model was developed for oil generation in the Devonian and Mississippian Bakken Formation, which has been proposed as the main hydrocarbon source rock within the Williston basin. The data consisted of formation temperatures and of density, neutron-porosity, resistivity, and gamma-ray logs from more than 250 wells in North Dakota and Montana. The upper and the lower shale members of the Bakken Formation were studied. Regression analysis, analysis of residuals, and cluster, discriminant, and factor analyses were used in an attempt to separate depositional effects—especially variations in organic content—from maturity.

Regression and analysis of residuals indicate differences both areally and between the upper and lower members. In the upper member, and less strongly in the lower member, the center of the basin differs from the basin margins in that it has extreme residuals—either high or low. Clustering and residual analyses show roughly the same areal patterns.

Inverse relationships, similar to those suggested by other workers, were found between formation temperature and organic content and between density logs and organic content. Also found, though, was that the addition of other factors, such as neutron porosity, helps to indicate organic content.

Preliminary results show that it may be possible to model oil generation by using statistical techniques on well-log data. In particular, the model has the potential to refine estimates of the amount of hydrocarbons generated by the Bakken Formation in the Williston basin.

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Assessment of Role of Metamorphic Remobilization in Genesis of Uranium Ores from Ralston Buttes Area, Colorado

The Ralston Buttes mining district, the principal source of commercial uranium in the Front Range since the late 1940s, is located northeast of Golden and southeast of the Front Range mineral belt. Uranium ore occurs in veins emplaced in fault breccia in Precambrian metamorphic rocks. The progenitors of the metamorphic rocks are a possible source for the uranium. Hornblende gneisses of the Idaho Springs Formation is the major rock type in the area, thus its origin is a major consideration in assessing the quantity of uranium that might have been contributed by metamorphic processes. To evaluate this, 41 rock samples (19 hornblende gneisses, 7 biotite gneisses, 5 chlorite gneisses, and 10 metapelites) were analyzed for major elements, and 3 rock samples (16 hornblende gneisses, 8 biotite gneisses, 4 chlorite gneisses, and 5 mica schists) were analyzed for trace metals (Rb, Sc, Zr, V, Ni, Co, Cr, Ba, U, and Th). Four samples of hornblende gneiss and 1 sample of mica schist were also analyzed for rare earth elements.

Major elements and rare earth data indicate that the hornblende gneiss was derived from sediments and tholeiitic basalts. Trace element data suggest a volcanic provenance for these sediments. Rare earth patterns and uranium and thorium abundances of metapelites are similar to average North American shales. Low uranium and thorium values and low thorium-uranium ratios in hornblende gneisses and mica schists preclude large-scale uranium remobilization during metamorphism of these source rocks.

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Paleoenvironments of Late Albian Stage (Early Cretaceous) of Eastern Trans-Pecos, Texas

Upper Albian rocks in eastern Trans-Pecos Texas consist of a depositional sequence that records a major transgressive-regressive cycle, beginning with an initial transgression of the early late Albian seas over a regionally disconformable surface and ending with the onset of late Albian regression.

The history of these events is recorded in rocks of the Fort Lancaster Formation and its western equivalent, the Boracho Limestone. These rocks were deposited in several depositional systems that developed on the Comanche shelf and an associated shelf basin called the Fort Stockton embayment. These depositional systems include the carbonate-shelf system, the shelf-basin system, and the carbonate-shoal system. Each system is recognized by unique suites of lithofacies, differentiated on the basis of petrographic and outcrop characteristics: skeletal wackestone, interbedded shale and wackestone, oyster packstone/shale, skeletal grainstone, and calcareous shale. Associated with these lithofacies are the following biofacies: *Protocardia-Macraster, Globigerina, Nuculana-Syncyclonema, Texigryphaea, Lopha,* and *Miliolina.*

Within a biostratigraphic framework based on ammonite zones, the geographic and stratigraphic distribution of depositional systems and their associated lithofacies and biofacies indicate that late Albian deposition primarily was influenced by periodic terrigenous influxes from the northwest over the Comanche shelf. This was coupled with tectonically controlled subsidence in the Fort Stockton embayment. The depositional sequence culminated in the development of widespread carbonate sand shoals prior to the onset of emergence.

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Evaluation of Coalbed Methane Resource in Western United States

Of the new or unconventional fossil energy resources studied in recent years with federal, state, or industry funding, the recovery of methane from coalbeds is the one resource with the greatest probable near-term commercial potential. Well completion records and production data indicate that much, if not most, of the gas currently produced from the Fruitland Formation of the San Juan basin, for example, has its origin in or from coalbeds.

All of the intermontane sedimentary basins of the Rocky Mountain region underlain by coal deposits, also contain methane that is genetically associated with those coals. Discussed will be individual characteristics of some of these basins that bear on methane formation and accumulation in each basin, techniques for estimating methane resources and defining target areas for exploration, amounts of gas contained in the basins, and identification of some completion and production problems. Basins specifically discussed will include Piceance, San Juan, Raton, and Powder River.

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Three-Dimensional Plane Pass Filtering as a Regridding and Interpolation Technique

Efficient and accurate interpretation of dense irregular 2-D seismic data is an ongoing problem in virtually every exploration area. Developing interpolation algorithms which would create pseudo 3-D volumes from sparse 2-D data could allow a geophysicist an efficient means of interpreting the broad geologic features in an area. An interpolation algorithm which uses the 3-D nature of the irregular 2-D data can be developed which is analogous to sinc function interpolation in 1-D. A Gaussian 3-D plane pass filter is demonstrated to produce reasonable interpolated results within the pass region of the filter. This particular technique has the built-in flexibility of allowing the geophysicist to choose a broad pass volume which essentially regrids existing data with very little interpolation or allows the choice of a narrow pass volume to interpolate those spatial frequencies which are not aliased by the irregular sampling of the input data.