

attempts the direct detection of oil by virtue of its intrinsically high resistivity. Although success has been reported for several very shallow fields, strong theoretical arguments indicate that direct detection is untenable as a standard exploration technique. A second approach utilizes magnetotelluric or similar techniques to map deep, very large-scale structures, but high cost and poor resolution confine this work primarily to areas where seismic is unobtainable. A third approach is mapping electrochemical alteration patterns in the top 1,000 m (3,000 ft) of sedimentary overburden. These patterns are attributed to clay-mineral alteration or sulfide precipitation resulting from upward seepage of light hydrocarbons and brines from the traps below. Recent advances in instrumentation and data processing have made alteration mapping a promising supplement to ongoing seismic and geologic exploration programs, especially in the search for subtle stratigraphic traps, and in distinguishing productive from nonproductive structures.

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Depositional Environments of Devonian Cairn Formation, Rocky Mountain Foothills, Alberta, Canada

The Cairn Formation is a carbonate sequence of Frasnian (Late Devonian) age that is the stratigraphic equivalent of the major oil-producing Leduc Formation of southern Alberta. During the summers of 1982 and 1983, detailed stratigraphic sections were measured near Canmore where the Cairn Formation is a platform sequence of carbonates approximately 50 km (31 mi) from the nearest reef edge.

The entire sequence consists of sediments deposited in a subtidal environment. No evidence of intertidal or supratidal deposition was found. The formation consists of very fine to medium crystalline, buff to dark gray dolomite, in which original textures (usually mudstones, grainstones, and stromatoporoid floatstones) often can be identified. The sequence contains fair to good intercrystalline, biomoldic, and vuggy porosity. Some of the vuggy porosity has been infilled by very late, coarse crystalline dolomite and calcite.

Individual beds typically are composed of a consistent lithologic character throughout. These beds are usually 10 cm to 2 m (1 in. to 6 ft) thick, and are virtually always bounded by disconformities. Some individual beds can be seen to swell and pinch out.

The stromatoporoid floatstones are composed of 10–40% fossils consisting of *Amphipora*, *Euryamphipora*, bulbous stromatoporoids (5–20 cm, 2–8 in.), tabular stromatoporoids, horn corals, and colonial corals. All organisms are not in place but have only moved a short distance.

Some thin beds consist of a black bituminous dolomite and probably represent a restricted lagoon environment of deposition.

Although most beds are horizontal, some constructional bioherms up to 5 m (16 ft) in relief have been recognized in the sequence.

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Geology of Oscar Range (Devonian) Reef Complex, Canning Basin, Western Australia

The Oscar Range is a Late Devonian reef complex that formed at the margin between the Precambrian Kimberley craton and the Canning basin. The range covers an area of 80 × 10 km (50 × 6 mi), and resembles a large atoll in that Frasnian and Famennian reef, marginal-slope, and back-reef subfacies grew around an exposed Precambrian core.

Frasnian reefs are dominated by stromatoporoids and *Renalcis*, and the reefs show periods of upbuilding, drowning, backstepping, and basinward progradation. Fault-controlled reef growth is developed locally. Marginal-slope deposits contain stromatoporoid debris, sponge boundstone, and crinoids. Back-reef deposits are generally *Amphipora*-rich biostromes, although fenestral oolite-intraclast-peloid beds are widespread in the southern Oscar Range. Dolomite is best developed in Frasnian back reef and, to a lesser extent, in reef-margin and reef-flat subfacies. In the area of the Precambrian core, conglomerates of Precambrian debris are interbedded with Frasnian limestones that are in depositional contact with basement. Hills of Precambrian rocks rise tens of meters above these peritidal back-reef deposits, indicating perhaps sev-

eral hundred meters relief during the Frasnian.

The exposed Frasnian-Famennian contact is a disconformity. Famennian reefs are dominated by *Renalcis* and associated algal stromatolites; the equivalent marginal-slope is characterized by allochthonous reef blocks, sponge bioherms, and crinoidal debris. Steeply dipping (40°) basinward-prograding reef and marginal-slope tongues make up the shelf margin. The Famennian back reef is composed of fenestral oolite-peloid lithologic units with common teepee structures, flat-pebble conglomerates, and cryptalgal fabrics.

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Early to Middle Pennsylvanian Changes in Paleoslope and Sediment Source Terranes in Northwest Illinois

The Abbott Formation (Atokan) conformably overlies the Caseyville Formation (Morrowan) which unconformably overlies Silurian and Mississippian units in the Rock Island area, Illinois. The two formations have a similar composition of Qm_{95-100} , Ls_{0-5} . More than 70% of quartz and heavy mineral grains (tourmaline and zircon; minor rutile and garnet) are rounded to well rounded. Their source is interpreted as a mature sediment on the craton, whereas equivalent sandstones in southern Illinois have an inferred metamorphic terrane component in the source.

Sediments of the Spoon Formation (Desmoinesian) conformably overlie the Abbott Formation, but their sandstones differ in composition. Spoon sandstones comprise Qm_{45-60} , Qp_{7-20} , F_{5-10} , Lm_{5-18} , Ls_{1-8} , and heavy minerals (tourmaline and zircon; minor sphere, garnet, hornblende). More than 55% of grains are angular to subrounded. The compositional change reflects a new sediment supply to the Rock Island area during the Desmoinesian. Grains from a metamorphic terrane are inferred to be mixed with those from a mature sediment.

Paleocurrent data indicate that a change in paleoslope near Rock Island coincided with the compositional change. The early Pennsylvanian fluvial system was probably locally controlled by the Mississippi River arch and flowed to the north. The arch could then have been submerged during the Desmoinesian, and flow was toward the southwest down cratonic paleoslope (which had influenced regional flow since the Morrowan).

Paleocurrent and petrologic data indicate that lower Pennsylvanian basin fill in western Illinois was derived from the northeast rather than the northwest (Transcontinental arch) as previously suggested.

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A Sedimentologic Model for a Microtidal Flood-Tidal Delta—San Luis Pass, Texas

San Luis Pass is a microtidal inlet located at the southwest end of Galveston Island, Texas. Continuous cores taken with a portable vibracoring rig, and surface grab samples provide data for developing a 3-dimensional sedimentologic model of the flood-tidal delta complex located landward of the tidal inlet. This model is based on the type, and vertical and lateral distribution of lithologic units, sedimentary structures, textures, and trace fossils.

A complete bayward vertical sequence in the flood-tidal delta complex consists (from base to top) of highly bioturbated bay clays and associated oyster reefs, highly bioturbated clayey sands/sandy clays of the delta margin, variably burrowed sand to shelly sand of the delta, and rooted or burrowed muds of the marsh or mud flat. Washover shell-hash deposits may occur at random intervals throughout this sequence. A more seaward sequence in the vicinity of San Luis Pass consists of a basal tidal inlet deposit of graded layers of sand and shell overlain by burrowed to shelly sand of the barrier spit.

This model for microtidal flood-tidal deltas differs significantly from models presented for mesotidal flood-tidal delta systems in the general lack of large-scale, high-angle sedimentary structures; the presence of intense bioturbation; the presence of washover deposits; and the general upward-coarsening nature of the vertical sequence. Mesotidal flood-tidal deltas with clean, coarse to medium-grained sands may make good petro-

leum reservoirs. Microtidal flood-tidal deltas with highly bioturbated clayey sands to sandy clays would undoubtedly prove to be poor petroleum reservoirs.

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Intracrystalline Porosity—A Newly Discovered Pore Type in Dolomite Reservoirs and Implications for Dedolomitization and Pseudospiculites

Intracrystalline porosity consists of hollow dolomite crystals. It forms when anhydrite, which had replaced cores of dolomite crystals, was dissolved. Significant volumes of intracrystalline porosity have been preserved in subsurface Permian dolostones of the Permian basin and in outcrops of Lower Cretaceous dolostones of Texas.

Anhydrite can be seen replacing organic-rich cores of dolomite crystals in Permian and Jurassic (Smackover) dolostones. Dolomite crystals, which replace original carbonate, commonly appear cloudy because of organic inclusions. After dolomitization, continued flux of the dolomitizing fluid causes precipitation of clear rims on the "cloudy" crystals. Anhydrite tends to replace the organic-rich cores, leaving the clear epitaxial rims to form "pill box" structures.

When anhydrite was dissolved, many hollow dolomite crystals collapsed and fragments became transported as vadose internal sediment. Obtuse and acute angles of these hollow dolomite rims superficially resemble sponge spicules, and pseudospiculites are layers of vadose internal sediment in which numerous fragments of hollow dolomite rims have been deposited in solution channels. Hollow dolomite crystals and pseudospiculites constitute evidence for unconformity and also represent subtle indications of vanished sulfates.

In many instances, calcite cement was precipitated within intracrystalline pores and is misinterpreted as partial dedolomitization. Such calcite cement can be distinguished from dedolomite, because the calcite is not syntaxial with dolomite rims, as it would be in dedolomitization.

In some Permian dolomite intervals, intracrystalline porosity is the predominant pore type. Molds formed by dissolution of replacement porphyroblasts and nodules of anhydrite also commonly were formed along with intracrystalline pores and all represent tertiary (third order) voids.

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Emplacement of Nonevaporitic Sulfates in McKnight Formation, Maverick Basin, and Associated Complex Diagenesis

In the Maverick basin the so-called upper and lower anhydrites of the McKnight Formation (Edwards Group) predominantly consist of nonevaporitic anhydrite which was emplaced within limestones, dolostones, and dedolostones. Most nonevaporitic anhydrite has been emplaced within fossiliferous limestones, which had been subjected to freshwater diagenesis, leaching, and lithification, and in dedolostones.

Anhydrite was emplaced in many grainstone intervals, first as cement and then as replacement of grains. Nodular mosaics of felted-lath anhydrite, emplaced within limestones and dedolostones, closely resemble those formed as evaporites within dolomitic sediments of modern Persian Gulf sabkhas. The most abundantly represented morphology of replacive anhydrite is the blocky porphyroblast with stair-step outlines. Molds formed by dissolution of these porphyroblasts have been misidentified as molds of halite cube aggregates.

Much anhydrite in the McKnight represents a second or third generation, emplaced after dissolution of previous generations. The McKnight contains many dedolomite intervals which probably were produced during episodes of sulfate dissolution. McKnight diagenesis records multicyclic influxes of meteoric groundwater, dolomitizing, anhydritizing, and dedolomitizing fluids. Some McKnight intervals record the sequence of dolomitization, dedolomitization, and partial redolomitization of the dedolostones. Some examples of redolomitization of redolostones have been noted.

Nonevaporitic anhydrite layers do not occur below true evaporite

deposits, and so downward reflux of sulfate enriched brine cannot be invoked as a mechanism of anhydritization. The fact that anhydrite-bearing layers of the upper and lower McKnight alternate with anhydrite-free layers suggests that nonevaporitic anhydrites were emplaced by lateral discharge of calcium sulfate-enriched brines.

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Calcification of Encrusting Aragonitic Algae: Implications for Origin of Late Paleozoic Reefs and Cements

Encrusting aragonitic calcareous algae of the family Peyssonneliaceae are the largest group of calcified red algae except for the well-known Mg-calcite coralline algae. They are distributed worldwide, are most heavily calcified in temperate and tropical waters, and grow as prone but arched sheets on soft mud substrates, on hard rock surfaces, as extensive bridge-like networks between corals in reefs, and as concentric layers in nodules. Calcification is entirely aragonite, species specific, and both intracellular and extracellular below the thallus as a hypobasal layer. The hypobasal layer develops outside the tissue as an encrustation of small aragonite botryoids attached to the lower surface between rhizoids, and on living plants it may exceed the thickness of the thallus. Calcification ranges from nonexistent in some cold-water forms to thallus calcification only, to both thallus and hypobasal calcification, to species in which the thallus is noncalcified but there is a hypobasal layer of aragonite botryoids.

Although the confirmed fossil range of this family extends only to the Early Cretaceous, striking similarities between these aragonitic forms and some late Paleozoic phylloid algae suggest that they may be closely related. Their ability to grow on soft mud substrates and form structures composed of irregular arched sheets with extensive pore space, as well as their brittle nature so susceptible to fragmentation, are all characteristics of mound-forming fossil phylloid algae. The hypobasal layer of botryoidal aragonite, developed while the plant is still growing, could easily act as a nucleation site for further epitaxial submarine precipitation, thus explaining the common association of Paleozoic phylloid algae and extensive fossil reef cements that resemble botryoidal aragonite. The presence of hypobasal botryoidal aragonite on plants with a noncalcified thallus raises the possibility that some fossil reef cements may be related to now-vanished algae.

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Textural and Compositional Controls on Silica Diagenesis—A Case Study from Nugget Sandstone, Washakie Basin, Wyoming

Grain-size laminated quartzose sandstones ($Q_{93}F_5R_2$) illustrate well-defined relations among framework grain size (GS), quartz type, silica cement (SC), and pressure solution (PS). The percentage of monocrystalline quartz grains with well-developed overgrowths (greater than 50% of grain not in contact with adjacent grains containing overgrowth) is related to grain size (71% coarse, 20% medium, 8% fine sand). Regardless of grain size, less than 10% of the polycrystalline quartz population exhibits well-developed overgrowths.

For medium sand-size nonundulose, undulose, and polycrystalline quartz, the portion of grains with well-developed overgrowth is 29%, 8%, and 2%, respectively. All other factors being equal, first-cycle quartzose sandstones derived from metamorphic source rocks will lose porosity and permeability, due to silica cementation, at a slower rate than those sandstones (nonundulose quartz rich) derived from other sources.

The silica cement present in the Nugget Sandstone is largely the result of pressure solution. Over the average grain size range of 0.22–0.35 mm, the volume represented by pressure solution can be depicted by the equation $PS = -54(GS) + 26$ ($r = -0.85$). $SC = 99(GS) - 19$ ($r = +0.80$) defines the relation between grain size and silica cement abundance. Sandstone intervals with an average grain size less than about 0.29 mm are characterized by an excess of silica, whereas for an average grain size above 0.29 mm the opposite is the case. Pressure-solution-produced silica mainly originated in finer grained units and migrated to coarser grained zones. When all grain sizes are considered, the volume of silica generated by pressure solution exceeds the amount of silica precipitated by overgrowths.