MISSISSIPPIAN CHARLES FORMATION AND THEIR SIGNIFICANCE TO THE DOLOMITE PROBLEM

Samples of grey-buff, hard and brittle, cryptocrystalline evaporitic dolomite from the Charles Formation of southern Saskatchewan have an average δO^{18} value of +0.64 per mil relative to the PDB standard. Compared to normal marine calcite limestones of the same age ($\delta O^{18} = -6.21$, standard deviation = 0.89%), the dolomite is depleted in O^{16} to the extent of 6.85 per mil. This result does not preclude a primary chemical origin for the dolomite as do the isotopic data of Degens and Epstein (Geochim. Cosmochim. Acta, *28*, 23, 1964).

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LATE CRETACEOUS DELTAS, ROCKY MOUNTAIN REGION

During the Late Cretaceous, a basin of deposition covered the western interior of the North American continent, extending from the present Gulf of Mexico to the Arctic. Large quantities of detrital sediment were transported from a source area along the western margin of the basin and deposited in coastal plain, shoreline, and marine environments. Rivers carrying the sediment load formed three large delta complexes: one in central Montana; a second in central Wyoming; and, a third in northern Colorado and southwest Wyoming. These three deltaic centers formed dispersal points from which sediment was carried and distributed within the basin by marine processes. Of the three delta complexes, the northern Colorado-southwest Wyoming delta contains the greatest volume of sediment, representing 2 to 3 times the volume of each delta to the north.

Deltas are defined by establishing time-stratigraphic units in the marine shale formations, either by faunal or physical criteria, and by tracing these units into the shoreline sandstone and coastal plain deposits. Lithofacies maps, isopachous maps, and restored sections are prepared for each time-stratigraphic unit. The recognition of a delta is based on two or more of the following criteria: 1) an arcuate lithofacies pattern of coastal plain strata (nonmarine) protruding into the marine basin; 2) for a designated time-stratigraphic unit, thickest deposits in the general shoreline zone (area of topset and foreset strata) associated with this lithofacies pattern; 3) a complex intertonguing of marine (foreset and bottomset) and nonmarine (topset) strata; 4) rapidly changing shoreline sandstone trends from one time-stratigraphic unit to another; 5) abundance of stream deposits over deposits of other environments of coastal plain; 6) biological criteria in marine strata, especially lack of fossils (absence of pelagic calcareous foraminifera); arenaceous benthonic forms tend to dominate; 7) persistence of above criteria in vertical stratigraphic sequence indicating semi-permanency of drainage systems responsible for deltaic deposits.

In Upper Cretaceous strata, topset strata are characterized by lenticular sandstone, siltstone, claystone, shale, and coal. Depending on the nature of the river load and the energy of the basin, the foreset strata may be interbedded siltstone and shale, or large sheets of sandstone forming a partial aureole around the nose of the delta. Bottomset strata are shale or interbedded shale and siltstone with minor amounts of sandstone.

The Upper Cretaceous (Campanian and Maestrichtian) of southern Wyoming and northern Colorado illustrates deltaic sedimentation and its influence on oil accumulation. Localized deltaic loading caused penecontemporaneous differential deformation of the subsiding basin floor. Incipient structural highs between the more rapidly subsiding delta areas controlled early migration of petroleum in stratigraphic traps. Where subsequent geologic history has favored preservation of these early traps, large petroleum accumulations have been discovered.

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ILLINOIS BASIN: DEPOSITIONAL OR POST-DEPOSITIONAL?

Pre-Pennsylvanian stratigraphic and tectonic patterns of the Illinois Basin region are revealed through analysis and segregation of the Sauk (Late Cambrian-Early Ordovician), Creek (Middle and Late Ordovician), Tutelo (Silurian-Late Devonian), Piankasha (intra-Devonian), and Tamaroa (latest Devonian-Mississippian) sequences. To relate the Illinois Basin to its regional setting, these pre-Pennsylvanian (pre-Absaroka) unconformity-bounded successions are delineated from Wisconsin to Tennessee and from Ontario to Oklahoma. Abundant Absaroka strata of the Illinois and other major basins involved are excluded because the regional identity of an adequate number of intra-Pennsylvanian stratigraphic datum surfaces is uncertain.

Approximate basin limits are customarily outlined by the outcrop of the base of the Absaroka sequence in Illinois, western Indiana, and northwestern Kentucky. Original interregional continuity of most units comprising the five pre-Absaroka sequences, and the differential degradation patterns beneath each and beneath the Absaroka, deny inception of basin development until at least Pennsylvanian time. For example, the Creek sequence of the basin is neither depositionally nor preservationally thicker than that to the west in Iowa or to the north in southeastern Wisconsin; but it is both depositionally and preservationally thinner than that to the east and south in Indiana, Kentucky, and Tennessee. Except for areas of its later erosional removal, such as the Cincinnati Arch and the Nashville and Ozark Domes, the Tutelo sequence is at least as well preserved in areas adjacent to the Illinois Basin as it is within. The Piankasha and Tamaroa sequences thicken depositionally from north to south across the basin.

Although these patterns do not date the actual onset of basin formation, they nevertheless demonstrate that the long-prevailing hypothesis that the Illinois Basin was persistently negative during most of Paleozoic time is invalid, and that subsidence was post-depositional at least with respect to its pre-Absaroka content.

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DEPOSITIONAL AND STRATIGRAPHIC FEATURES OF LITTORAL ALGAL BIOHERMS AND BASIN FACIES

The Devonian Nubrigyn Reef Complex, Australia, consists of a littoral and a sublittoral facies. The former is composed of numerous abruptly intertongued lithologies: impure algal detritus, andesite pebble lenses, Devonian erosional remnants of andesite lava flows, and over 300 pure algal atoll-like bioherms (some fringing the andesite hills) and biostromes with lagoonal codiaceae-calcarenite. Numerous depositional and diagenetic features are suggestive of a turbulent intertidal environment.

The sublittoral deposits consist of uniformly-bedded detrital algal limestones with interbedded claystones. Most of the former are graded and are believed to be turbidites. There are scattered, thick, lens-like "dump"—deposits composed of an unsorted mixture of clay and limestone fragments. These are thought to be fluxoturbidites or slumps.

Intermittent subsidence of the Nubrigyn shelf caused periodic transgression of basinal sediments over the littoral accumulations with the result that a complex interfingering of both facies developed near the former shoreline. This seems to indicate that the eastern limit of the reefs was *not* determined merely by a sudden increase in gradient of the shelf.

The intimate association of cross-bedding and grading in the littoral units suggests that grading can form under relatively shallow-water conditions, and one should be circumspect in using it as a depth indicator. Application of the "Law of Minimum in Environmental Reconstruction" is more reliable in establishing conditions of sedimentation.

Inasmuch as the basinal carbonate detritus is composed of material derived from the littoral bioherms, the *syngenetic* chemical composition of the material is an unreliable parameter for the discrimination between shallow- and deep-water limestones. Only if characteristic *diagenetic* differentiation occurred may chemical composition be useful in this regard.

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Sedimentologic Design of Deltaic Sequences, Devonian Catskill Complex of New York

Recent investigations of modern deltas permit a refined interpretation of sedimentation in the Catskill Deltaic Complex. This complex demonstrates two separate patterns related to delta growth and migration in a framework of basin-source area tectonism.

The Middle and Upper Devonian stratigraphy of New York can be broadly separated into lithologic phases that can be related to distinct environments of deltaic sedimentation which recur during the clastic deposition of this period. These include:

Phase	*Deltaic Environment*
"Cleveland" ("Marcellus")	Delta toe (bottomset)
"Chagrin" ("Portage")	Prodelta slope (foreset)
"Big Bend"	Distal delta platform (topset)
"Smethport" ("Chemung")	Proximal delta platform (topset)
"Catskill" and "Pocono"	Alluvial delta platform (topset)

The initial pattern of delta growth in Middle Devonian time was produced during a period of constant subsidence in which a progressive increase of Hamilton clastics eventually exceeded the rate of basin downwarping and established the growth and migration pattern of the deltaic environments across the state. During periods of negligible source contribution, regional subsidence of the sub-basin, together with local compaction, caused a landward shift in the marine environments on the delta platform. These transgressive migrations permitted rhythmic deposition of limestones and enabled the shallow seas and interdistributary bays on the proximal delta platform to encroach and rework the nearshore or alluvial delta platform deposits. Following Hamilton time, renewed compaction and strong subsidence in the eastern part of the sub-basin permitted formation of the Tully Limestone on the distal delta platform at the beginning of the Upper Devonian.

Continued basin subsidence and renewed clastic deposition during this period established the second major deltaic pattern. This pattern contrasts with that displayed by the Hamilton delta in that it formed under nearly continuous sedimentation throughout Late Devonian time with frequent changes in the stratigraphic succession of deltas during times when subsidence predominated over deposition.

Each period of dominant subsidence in the Upper Devonian delta was marked by the formation of a black shale (delta toe environment) over a previously deposited gray shale or siltstone (prodelta slope or distal delta platform deposit) and initiated a new sub-phase of delta deposition and a new delta. The amount of subsidence controlled the thickness and relative position of the black shale on the previous delta slope or distal delta platform deposit, and was also reflected nearshore by the emplacement of marine tongues into the eastern red-bed deposits on the alluvial delta platform.

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Modern Role of Paleontology in Basin Geology

The coming of age of facies geology is sharply highlighting the significant role that paleontology plays in understanding basin geology. Growing recognition that exploration for stratigraphic traps requires close time-stratigraphic control is also bringing paleontology increasingly into exploration work. As key members of stratigraphic teams, paleontologists must not only pick "tops" but, equally, must be aware of environmental effects on organisms in order to evaluate time-significance of so-called "marker bugs." Moreover, fossil assemblages must be analyzed comprehensively to facilitate interpretation of depositional patterns.

Increased need for paleontology has stimulated research on little-known fossils to supplement forms conventionally used. Improvements in microscopes have materially aided these investigations; magnifications of 500 to 2,500× can now be used routinely, and X-ray techniques permit examination at 10,000× or more. As a result of notable advances in techniques, concepts, and knowledge, a number of fossil groups, including spores, pollen, "hystrichs," coccoliths, tintinnids, favreinids, nannoconids, conodonts, and chitinozoans, have been increasingly used for dating and correlating, and for interpreting depositional environments. These "new" forms fill gaps in existing control based largely on foraminifera. Effort is also being made to expand knowledge and application of macrofossils and of biofacies to understand more fully the interrelationships of fossils and facies. This expanding knowledge of faunas and floras is bringing paleontology into its proper role as a key to basin geology and as the indispensable tool in stratigraphic-trap exploration.

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High-Pressure Assemblage Changes Near Moho Depths

Laboratory studies have been carried out on synthetic mineral systems representative of basalt, on natural basalts and eclogites, and on peridotites reconstructed from natural minerals. The transformation from basalt through pyroxenite to eclogite was found to take place over a broad pressure range, approximately 4 to 8 kb, depending on bulk composition and temperature. The mineralogical changes involve complex solid solutions of phases varying in velocity of transmission of compressional waves from about 5.5 to 8.5 km./sec. The series of assemblage changes do not appear to be accompanied by marked changes in velocity of compressional waves. High-pressure changes in hydrous sediments which produce assemblages of uniquely dense hydrous minerals or metamorphic assemblages will probably have