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Geothermal Resources of North Dakota

Since 1979, the North Dakota Geological Survey has been involved in a cooperative study with the U.S. Department of Energy (FC07-79ID12030) to evaluate the hydrothermal resources of North Dakota. Intially, emphasis was placed on using existing data on file with state and federal agencies. Oil and gas well data from the North Dakota Geological Survey and water well data from the U.S. Geological Survey, Water Resources Division, and North Dakota State Water Commission have been compiled into two computer library systems, WELLFILE and WATERCAT. In addition to summarizing existing information, temperature profiles have been measured in available ground-water observation wells throughout the state. We have installed casing in available test holes in selected areas for terrestrial heat-flow determinations.

The information contained in WELLFILE and WATERCAT is being assembled into a catalog of user-oriented aquifer summaries. Depth, thickness, water quality, and temperature data have been summarized for the Madison Group (Mississippian) and the Inyan Kara Formation (Cretaceous) in North Dakota. Work continues on similar data summaries for other Mesozoic and Cenozoic aquifers.

The data from temperature logs run in ground-water observation wells have been incorporated in WATERCAT. This information can be displayed as temperature profiles for individual wells, as "shallow" geothermal gradient maps, and as "slice" maps of expected temperatures at various depths.

Interest in geothermal energy, particularly residential heat pump applications, is increasing in North Dakota. User-oriented data summaries of the information collected during our study are available through the North Dakota Geological Survey.

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Reefs of Smackover Formation, An Upper Jurassic Carbonate Shelf Sequence Rimming U.S. Gulf Coast

The occurrence of reefs and oolitic sands in the Smackover Formation, an Upper Jurassic (Oxfordian) sequence that has been recognized in the subsurface of the U.S. Gulf Coast, adds significantly to our knowledge of depositional models for Jurassic carbonate shelf deposits. Models for the upper Smackover Formation have been based exclusively on subsurface data gathered from non-skeletal carbonate reservoirs. The widespread occurrence of buildups within the upper Smackover requires a revision of the existing models. These reefal buildups are 3 to 40 m thick, commonly elongate, and several square kilometers in plan. They developed seaward of oolite shoals on paleostructures that created subtle topographic highs on an otherwise ramp-like sea floor. Reef-rubble zones have reservoir-quality porosity throughout the Smackover trend, but reef framework is a target only where diagenesis has been favorable.

The biota forming Smackover reefs are similar to those described for sponge-algal buildups and patch reefs from the Upper Jurassic of Europe. Reef framework is constructed by digitate and branching "stromatolitic" blue-green algae and to a lesser extent by agglutinated worm tubes, *Tubiphytes morronensis,* and marine cements. The biota varies throughout the Smackover trend. Reefs in southern Arkansas and northern Louisiana are more diverse. In these reefs, encrusters and binders produce constructional microframework cavities on and between corals (primarily *Actinastrea*), skeletal algae (*Parachaetetes* sp. and *Cayeuxia* sp.), lithistid and hexatinellid sponges, bryozoans, and hydrozoans. The cavities are commonly filled with marine cements or geopetal sediments. The reefs are commonly underlain and overlain by subtidal peloidal lime packstones containing oncolites and scattered fossils and they can develop in close proximity to subtidal quartz sands.

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AAPG Presidential Address

No abstract.

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Geological Setting and Production History, Grosmont Pilot Project, Northern Alberta

Enormous quantities of bitumen are contained along the eastern margin of the Upper Devonian Grosmont Formation in northern Alberta. This formation can be readily subdivided into four informal stratigraphic units which represent, along with several smaller scale internal depositional cycles, successive stages in the evolution of a hugh carbonate complex: argillaceous slope sequences pass upward to a spectrum of shallow-platform facies and these then are capped by shoreline deposits and horizons of exposure and erosion. Although almost exclusively secondary in nature, the type and distribution of pore fabrics appear to have been at least initially controlled by original depositional facies.

In 1975, Union Oil Co. of Canada initiated a single well steam stimulation program to evaluate the potential for recovering bitumen from the upper Grosmont Formation. In 1977, the Alberta Oil Sands Technology and Research Authority (AOSTRA) and Canadian Superior Oil joined the project and further tests (steam stimulation, steam drive, combustion) were undertaken at a new site with Union continuing as operator. The 1980-81 "huff and puff" stimulation program consisted of one injection/production well and four closely spaced observation wells. Four production cycles have been completed to date, yielding attractively high production rates. An expanded evaluation program is currently under way and will utilize a five-spot scheme of injection/production wells augmented by four or more observation wells.

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Late Pleistocene Deposits of Florida Keys

The sedimentology and diagenesis of the late Pleistocene carbonates of the Florida Keys have been studied in a series of shallow cores from Key Largo and Big Pine Key. On Key Largo three stratigraphic units—defined by paleo-exposure surfaces—were wholly or partly penetrated. Skeletal grainstones and packstones are the dominant lithofacies and enclose abundant massive corals, especially in the upper parts of the two youngest stratigraphic units. This lithology, typical of the Key Largo Limestone of the northern keys, is interrupted by a single thick horizon of mollusk-rich quartz sand derived from paleo-highlands to the north. On Big Pine Key, the youngest stratigraphic unit grades laterally from an ooid grainstone (Miami Limestone) in the northwest to a skeletal-peloid packstone/grainstone (Key Largo Limestone) to the southeast. The latter facies also characterizes older underlying units which are again defined by paleo-exposure surfaces.

Vadose diagenesis during sea-level lowstands has largely resulted in alteration of the sediments to low-Mg calcite, but minor amounts of aragonite remain in the youngest stratigraphic unit. Pervasive development of secondary moldic and irregular dissolution porosity has accompanied this mineralogic transformation. Submarine cementation is insignificant, and freshwater phreatic lenses, if and where present, have failed to leave a distinctive petrographic imprint.

Overall, the Florida Keys (as manifest by the youngest stratigraphic unit) represent relatively high-energy deposits which accumulated on a slight but significant break in slope. Water depths were not great, and it is unlikely that a major contemporaneous reef barrier lay seaward at that time.

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Comparative Organic Geochemistry of Shales and Coals from Cherokee Group and Lower Part of Marmaton Group of Middle Pennsylvanian Age, Oklahoma, Kansas, Missouri, and Iowa

Mid-Continent middle Pennsylvanian rocks are a complex assemblage of coal-cyclothem lithologies. Organic-matter-rich rocks in the section include coals (33 to 76% organic carbon—org. C), marine, dark-gray to gray-black shales (1 to 8% org. C), and laminated, phosphatic black shales (4 to 28% org. C). Organic matter in these rocks came mostly from peat swamps, as shown by similarities between coal and shales in organic petrography, hydrogen (H) and oxygen (O) indices (Rock-Eval pyrolysis), pyrolysis-gas chromatographic analyses, and gas chromatographic analyses of saturated hydrocarbon fractions of $CHCl_3$ extracts. A halocline, resulting from the river waters that transported the dissolved and fine particulate organic matter from the extensive swamps, may have been the principal mechanism for restricting circulation in the shale-depositing environments.

Some organic geochemical properties vary significantly within and between the coal and shale lithologies, reflecting inferred differences in intensity of depositional and diagenetic anoxic conditions and degree of thermal maturation. For shales with comparable thermal maturities, deposition and diagenesis under more intense anoxic conditions result in higher org. C, P, U, Se, Mo, V, Ni, Ag, and Cr contents, H indices, saturate/aromatic and NSO/asphaltene ratios in $CHCl_3$ extracts, and lower O indices, pristane/phytane ratios, and organic carbon $\delta^{13}C$ values (more negative by 1 to 2 per mil). H and O indices in coals resemble those of shales deposited under the most intense anoxic conditions. In contrast, saturate/aromatic, NSO/asphaltene, and pristane/phytane ratios in coal extracts, trace- and minor-element contents, and organic carbon $\delta^{13}C$ of coals resemble shales deposited under relatively oxic conditions. A few coals are overlain by black phosphatic shales and have been subjected to more intense anoxic diagenesis. These coals have higher U, Se, Mo, V, Ni, and Cr contents, lower pristane/phytane ratios, and more negative (~ 1 per mil) organic carbon $\delta^{13}C$ values. When normalized to n-C_{18}, most pristane/phytane variability in all rock types appears to be related to variation in amounts of pristane, phytane content remaining relatively constant. With increased degree of thermal maturity, (1) H and O indices decrease in both coals and shales; (2) total bitumen/org. C and pristane/phytane ratios increase in shales but decrease in coals; and (3) saturate/aromatic ratios increase significantly only in shales that were subject to high levels of anoxic diagenesis. The black phosphatic shales contain extractable organic matter that is most similar to Cherokee crude oils from northeast Oklahoma and southeast Kansas.

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Mesozoic Paleo-Oceanography of Atlantic and Western Interior Seaway

Mesozoic oceans were filled with warm, salty water formed in marginal seas in the arid zones, rather than by cold water from polar sources as is the modern ocean. The early Atlantic and Gulf of Mexico were sites of significant salt extraction, serving as evaporative basins refluxing dense brine to the world ocean. As connection with the world ocean became better established, salt deposition in these basins ceased but sea level rose in response to growth of the mid-ocean ridge system, resulting in extensive flooding of the continents. Marginal seas and that part of the seaway through the Western Interior of North America lying in the arid zone then became sites of formation of plumes of dense, warm, salty, oxygen-poor water. These dominated the structure of the adjacent oceans. Periodic filling of individual basins by especially dense warm salty bottom water caused partial overturning and high productivity, followed by temporary stagnation and oxygen depletion, with the result that organic carbon-rich sediments were preserved. Because such "anoxic events" were dependent on local climatologic factors they were not necessarily synchronous in different basins.

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Continental Lower Cretaceous Stratigraphy, Sweetgrass Arch Area, Southern Alberta and Northern Montana

An integrated regional scheme of lithostratigraphic nomenclature is proposed to encompass the Lower Cretaceous strata on both sides of the international border. The Blairmore Group, defined in the southern Alberta Foothills, is extended to encompass the entire Sweetgrass arch area. The informal Cut Bank sandstone member of northern Montana is raised to formation status and extended into southern Alberta. The Cut Bank Formation is correlated with the Cadomin Conglomerate of the Alberta Foothills.

The Mannville Group formerly was extended to the Lower Cretaceous continental strata of the southern Alberta plains. This name is now restricted to strata occurring north and east of the Sweetgrass arch area which resemble the type Mannville. The Kootenai Formation (Group?) nomenclature, formerly used in Montana, is discarded because of continued confusion with the older, formally defined Kootenay Group of the Alberta Foothills. Most of the informal members defined in various oil fields should be confined strictly to the areas in which they are defined.

The present configuration of the Sweetgrass arch is the product of Late Cretaceous–Early Tertiary Laramide deformation, but the presence of a paleotectonic high coinciding with the present arch trend can be documented from the early Paleozoic. Sedimentation and erosional patterns were greatly affected by the ancestral arch and produced marked stratigraphic variations