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CHANNEL SANDSTONES AND RELATED ERODED AND COMPACTED INTERVALS IN LUDLOW FORMATION OF SOUTHWESTERN NORTH DAKOTA

The Ludlow Formation (lower Paleocene) of southwestern North Dakota contains elongate lenticular light- to medium-gray sandstone bodies several kilometers long, hundreds of meters wide, and more than 30 meters thick. Internal sedimentary structures, relation to surrounding beds, and fossil content indicate a fluvial-channel origin for these sandstone bodies. Marginal and bottom relations between these channel-sandstone bodies and the enclosing rocks are typically crosscutting, with the sandstone being inset in trough-shaped channels.

One sandstone body, otherwise typical of the above sandstone bodies, is not inset but is a thick lens between marker lignite beds. Lignite beds are separated by less than 1.5 m of sediment at the margins of this body. A kilometer distant, the lignite beds are separated graphically by more than 30 m of channel sandstone. The underlying marker lignite beds are not eroded or crosscut but remain intact and are split or wedged from the overlying marker lignites by the sandstone body. This relation indicates that the channel-fill sandstone occupies a preexisting, largely non-stream-eroded depression, and lies with minimal erosional unconformity on the underlying sediments. The occupied depression was probably formed as a result of localized compaction of sediments. Other possibilities for the development of the depression include intermittent deformation associated with the nearby Cedar Creek anticline, or the possible solution of underlying salt beds of Paleozoic and Mesozoic ages. Whatever the origin of the depression, it was occupied and back filled by channel deposits of a stream. Other channel-sandstone bodies in this area combine the inset and wedging relationship in the interval between marker lignite beds.

This rapid, large-scale wedging part of marker lignite beds creates problems in detailed correlation within the Ludlow Formation.

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BIOSTRATIGRAPHY OF *GLOSSOPLEURA* ZONE OF WEST-CENTRAL UTAH

In 2 measured sections in the House Range and Drum Mountains, the Chisholm and Dome Formations have a combined thickness of approximately 600 ft. The Chisholm Formation consists of shale and thin-bedded limestone. In the House Range the Dome Limestone forms massive cliffs, but in the Drum Mountains it is thin-bedded and forms slopes.

Trilobite faunas of the lower half of the Chisholm Formation in the House Range and the entire Chisholm of the Drum Mountains are typical of the *Glossopleura* assemblage zone. These include 12 genera and 19 species. Faunas from the Dome Limestone and the upper half of the Chisholm Formation in the House Range are not diagnostic of either the *Glossopleura* or *Bathyuriscus-Elrathina* Zones. In the Drum Mountains the Dome Limestone in unfossiliferous.

Poliella is the only trilobite found in the upper half of the Chisholm Formation in the House Range. It has been reported previously below and, in one place, in association with *Glossopleura*. The reversed stratigraphic occurrence of *Glossopleura* and *Poliella* in the House Range indicates that the use of *Poliella* as an index to a lower Middle Cambrian zone should be evaluated.

The *Glossopleura* fauna of western Utah shows strong affinities with faunas of the upper Arrojos Formation of Sonora, Mexico; upper Bright Angel Shale of the Grand Canyon, Arizona; lower Stephen Formation of British Columbia; upper Pioche Shale of the northern Egan Range, Nevada; and the Chisholm Shale of the Pioche District, Nevada. Trilobites of the Dome Limestone do not correlate well with any described faunas of similar facies or stratigraphic position.

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DEPOSITIONAL ENVIRONMENTS OF ENTRADA FORMATION (JURASSIC), NORTHEASTERN UTAH

In northeastern Utah the Entrada Formation contains 2 lithologic units; a lower pale yellowish-orange, fine- to medium-grained sandstone; and an upper moderate reddish-orange, very fine-grained silty sandstone. The upper unit is present only locally and where present interfingers with the lower unit. The rocks of the lower unit were deposited in 2 environments, beach and dune. The upper unit is a shallow-water marine deposit.

The beach sequence is usually the thickest part of the lower unit. These deposits are characterized by horizontal stratification, disturbed bedding, and small- to medium-scale wedge- and tabular-planar cross-stratification mostly of low angle. In the backshore zone channels containing medium-scale trough cross-stratification parallel the shoreline. Ripple marks and burrowed structures are uncommon in the lower unit.

The dune sequence is characterized by medium- to large-scale wedge-planar cross-stratification of high angle. The cross-strata are tangential to the lower bounding surface. Trough cross-stratification is present, but not common. Most cross-stratification is faint and indistinct on weathered surfaces, suggesting that water probably reworked the sand after deposition.

The upper silty sandstone unit is "structureless," except for sparse horizontal stratification.

Dominant paleocurrent directions, based on 275 measurements, are west and southwest. Nine of 11 locations show a unimodal distribution, and 79% of these measurements are between 151 and 300°. The other 2 locations show bimodal distributions; southeast-northwest and southeast-northeast.

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GEOTHERMAL RESOURCES OF COLORADO

The United States is facing serious energy crisis. It is estimated that the electrical requirements of the United States will reach 5.8 × 10^{12} Kwh by 1990. Most of the future electrical power will be produced by conventional generating plants; however a large share will have to be produced by other sources, such as nuclear and geothermal generating plants.

Geothermal resources—the natural heat of the earth's interior—have been used increasingly since the start of the century to generate electricity. The present worldwide geothermal generating capacity has reached nearly 900,000 kw and will probably increase tenfold in the near future.

On a worldwide basis, geothermal exploration efforts today are directed primarily to areas of surface heat leakage in regions which have experienced volcanism in the recent geologic past. Exploration for a commercial geothermal reservoir is similar to that for metalliferous mineral and hydrocarbon deposits, and involves common geologic, geophysical, and geochemical techniques. All conventional geologic exploration methods are used, such as surface and subsurface mapping, and photogeologic and remote sensing techniques to delineate the more favorable parts of the area. In conjunction with geologic mapping, geophysical methods are used. These include surface and shallow-subsurface temperature and heat-flow measurements, heat discharge from springs, rock thermal conductivity measurements, and electrical resistivity measurements. The geochemical character of the thermal springs in the region affords a rapid, preliminary evaluation of the reservoir temperature. Among some of the more useful geochemical thermometers used are the chloride and silica contents of the waters and sodium/potassium ratio.

The geothermal resources of Colorado are indicated by 113 thermal springs and wells having a temperature higher than 21° C. Most of these springs and wells are in the southern Rocky Mountains of southwestern Colorado.

The temperature of the thermal waters in Colorado ranges from a low of 21°C at Eldorado Springs to a high of 84°C at

Hortense Hot Springs. The waters issue from rocks of various compositions, ranging in age from Precambrian to Tertiary.

Sixteen surface or near-surface measurements of flow of heat from the interior of the earth have been made in Colorado and published. These measurements range from a low of 1.4 H.F.U. (heat flow units) at Yellow Creek in the northwest part of the state to a high of 3.7 H.F.U. at Ouray, Colorado, in the San Juan Mountains.

It appears, from interpreting published data, that the San Juan volcanic region of southwestern Colorado has the most potential for the development of a commercial geothermal reservoir.

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EPIGENETIC ALUNITE PISOLITES FORMED BY NATURAL GASES IN WESTERN MERCED COUNTY, CALIFORNIA

Chemical and mineralogic processes related to the migration of natural gases are of importance for petroleum geology. An unusual alteration of sedimentary formations by hydrogen sulfide-bearing natural gases in western Merced County, California, has been described. The alteration created an acidic medium (with pH values ranging from 0.5 to 4.5) containing sulfur, sulfides, sulfates, and black and white discoloration.

A peculiar layer of pisolitic sandstone was noted in the altered area near the boat-launching ramp on the southeastern shore of the O'Neill Reservoir. Individual pisolites 2-15 mm in diameter are present as an undulatory layer in a bed of light-gray, fluvial sandstone of the Tulare Formation, below the Pleistocene Corcoran Clay Member. X-ray diffraction of the sandstone cement yielded abundant alunite.

Data collected during studies of iron sulfide concretions from the same locality yielded some information on origin of pisolites. An aluminum sulfate-bearing gel was repeatedly obtained by solution of concretions in concentrated nitric acid. Aluminum was produced by decomposition of alumosilicates with sulfuric acid derived from oxidation of sulfides cement.

Alunite pisolites probably originated by decomposition of alumosilicates occurring in sandstone by reaction with sulfuric acid created by oxidation of hydrogen and/or iron sulfides in excavations. Natural gases in the area, following joints, tend to cause dome-shaped uplifts in overburden, which explains the undulatory occurrence of pisolitic layers. Their position could be controlled by a capillary uplift.

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LATE MISSISSIPPIAN CYCLOTHEMS OF HEATH FORMATION, WESTERN NORTH DAKOTA

On the south flank of the Williston basin in western North Dakota, the Heath Formation (Chester) produces from several fields including Rocky Ridge field. In 1969 Shell Oil Company discovered additional Heath production several miles southeast of Rocky Ridge. Cores cut during this drilling program provided the basic data for this study.

Lithologies represented in the cores run the complete spectrum of sandstone, siltstone, shale, limestone, dolomite, coal, and even subaerial, lateritic soils and subaqueous, underclay soils. Mechanical log correlations create the impression of erratic depositional patterns typical of alluvial deposits. Faunal data, however, indicate oscillating brackish to shallow-marine depositional environments, the several coals and underclays indicate periods of marsh conditions, the crossbedded, conglomeratic sands are interpreted as fluvial to estuarine, and the lateritic soils are indicative of subaerial exposure. Such sequences or rock types are typical of the cyclothems of Illinois and Kansas.

At least 3 cyclothems are represented in the Heath. The initial basal transgressive sands were deposited above or at sea level in the topographic lows eroded during the preceding regression. As sea level rose, depositional environments covered a progressively greater area, depending on the amount of topographic relief. Consequently, an underclay lying on a previously formed lateritic soil may represent the basal unit of the cycle. In areas of greatest relief only the deposits of maximum transgression are represented. The complete succession of members of the classical cyclothem is present in very few places.

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SEDIMENTARY LAYER PROPERTIES OF GRADED-SHELF DEPOSITS, COLORADO GROUP (CRETACEOUS), SASKATCHEWAN

Middle Albian to Santonian detrital sediments were deposited in a shallow sea east of the Rocky Mountain geosyncline. Two transgressive phases of dominant mud deposition were separated by a major regressive phase, represented by a northeastward-thinning wedge incorporating conglomerate and sandstone.

The transgressive Joli Fou Formation is represented on the east by the Spinney Hill Sandstone, comprising cosets of planar sandy foresets and subordinate mudstone intercalations (proximal fluviomarine deposits). These grade westward into a succession of vertically repeated, sandy, fining-upward sequences (distal fluviomarine deposits) overlain by and passing laterally into mudstone. The fining-upward sequences comprise, in ascending order, planar sandy foresets, bioturbated sandstone, alternating sandstone and mudstone, and mudstone. The sequence probably reflects lateral migration of the tidal channels of an estuarine delta.

The regressive Viking Formation gave rise to deposits in which size fractionation through increase in the proportion of admixed mud northeastward is accompanied by progressive change in assemblages of sedimentary structures. A thick sequence of planar sandy foresets and subordinate mudstone intercalations (nearshore deposits) is replaced by clinobeds composed of coarsening-upward sequences (proximal shelf deposits), which northeastward grade to bioturbated, muddy sandstone (distal shelf deposits) and mudstone (shelf muds). The Flatten Lake sand displaying southwestward diminution of grain size along the erosional edge of the Colorado succession is referable to the regressive phase.

The pre-Cenomanian (Big River Formation) of the late transgressive phase is predominantly mudstone, replaced northeastward by fine-grained, horizontally laminated and micro-crosslaminated sandstone and bioturbated sandstone, with abundant discontinuous mudstone intercalations (St. Walburg Sandstone). These beds are succeeded by a thick mudstone incorporating northeastward-thinning units rich in bioclastic debris: a basal unit rich in fish remains (fish-scale marker) and 2 main calcareous units containing coccolith aggregates and pelecypod debris (Greenhorn and Niobrara equivalents). The bioclastic debris commonly is in thin, graded layers passing upward into mudstone. Lateral size fractionation within the units occurs by progressive decrease in proportion of sand and silt and concomitant increase in mud content.

The principal agents of sediment transportation recognized are tidal currents occasionally augmented by storm-surge waves giving rise to both laterally migrating channels and large-scale sand ridges. Mass movement of sand downslope apparently was confined to local salt-solution sinks.

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UTAH'S OIL-IMPREGNATED SANDSTONE DEPOSITS—A GIANT UNDEVELOPED RESOURCE

Fifty deposits or groups of deposits of oil-impregnated sandstone (tar sand) in Utah contain between 20 and 25 billion bbl of oil, about 95 % of the nation's resource. The Uinta basin, northeast Utah, is ringed by 25 deposits, estimated to contain 10.5 to 11.0 billion bbl of oil in place, with about 95 % in 4 giant