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STABLE OXYGEN ISOTOPIC COMPOSITION OF CARBONATE ROCKS IN GREEN RIVER FORMATION, EASTERN UTAH AND WESTERN COLORADO

Stable oxygen isotope ratios and calcite-dolomite ratios were determined for 40 samples of various lacustrine carbonate rocks from the Green River Formation (Eocene) of the eastern Uinta basin and the central Piceance Creek basin. Petrographic studies indicate there are five main carbonate rock types: (1) micrite and dolomicrite; (2) algal biolithite; (3) oolite and pisolite; (4) structureless microcrystalline carbonate aggregate (pellet); and (5) kerogen-rich dolomitic claystone (oil shale). The respective δO^{18}_{PDB} isotopic ranges in per mille for these rocks are: -3.27 to -15.85; -2.43 to -7.19; $+2.73$ to -4.54; $+2.60$ to -3.43; and $+0.67$ to -9.51. The percent dolomite in the carbonate fraction is from 0 to 100.

These isotopic values, which are similar to values obtained by other workers for lacustrine carbonate of various ages, suggest that the oxygen isotopes in the carbonate material comprising the algal biolithite, oolite, pisolite, and oil shale were biologically fractionated to isotopically heavier values relative to the inorganically precipitated micrite. The similarity in isotopic values between the structureless microcrystalline carbonate ($+2.60$ to -3.43) and the oolite ($+2.73$ to -4.54) also suggests that the former may be a dolomitized and recrystalized form of the latter. No correlation between percent dolomite in the carbonate fraction and the oxygen isotopic composition was found for the oolite, pisolite, and algal biolithite rocks, suggesting that the dolomite in these samples formed by diagenetic replacement of primarily precipitated calcite. A positive correlation was found for the oil shale and some of the micrite, suggesting that the dolomite in these samples was primary.

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RESISTIVITY MAPPING OF SANDSTONE STRATIGRAPHIC TRAPS

Many Cretaceous stratigraphic oil accumulations of Wyoming may be mapped with log resistivity, because the clay-rich edges of sandstone bodies have lower resistivity and the clay poor centers of the sandstones have higher resistivity. Although many factors affect log resistivity, variation of the clay content of a sandstone body causes several orders of magnitude change in resistivity in and around a given stratigraphic trap.

Resistivity maps generally agree with SP isopach maps, but tend to show the location of the most porous and permeable clay-poor sandstones, rather than the total sand thickness. Resistivity maps are also useful when no SP is evident outside the developed sand body or when clay fill makes SP unreliable.

Although the presence of carbonate cement, coals, and lignites, *etc.*, complicate interpretation of resistivity maps in some formations, the tool is usually effective in simple clay-quartz formations. The tool is particularly useful during development drilling of a stratigraphic trap.

The use of resistivity mapping is illustrated with a number of Muddy and Dakota stratigraphic oil fields in the Powder River basin of Wyoming at Hilight, Recluse, South Glenrock, Gas Draw, and Coyote Creek.

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PETROLOGY AND HYDROCARBON POTENTIAL OF MISSISSIPPIAN RATCLIFFE BEDS IN SOUTH-CENTRAL SASKATCHEWAN, CANADA

A detailed petrologic investigation of a Mississippian carbonate-evaporite rock unit interrelates depositional environment, sequence of diagenesis and porosity-permeability in each of 8 rock types distinguished. Structural considerations are introduced and hydrocarbon potential assessed.

Deposited on the northern slopes of the Williston basin, the strata of the Ratcliffe Beds in this area include 3 basin-fringing evaporites, the Midale, the Oungre, and the upper Ratcliffe evaporites. Successively younger evaporites overlap toward the southwest and in much of the western part of the area the Ratcliffe Beds are exclusively carbonates.

Most of the original sediments of the microcrystalline limestones, saccharoidal dolomites, and the sparry, oolitic, pelletoid limestone were deposited in an open marine, shallow-water environment. The bedded anhydrites, dolomitic anhydrites, and anhydritic dolomites were formed in supratidal evaporitic pans, maritime lakes, or lagoons. The microcrystalline dolomites and associated nodular anhydrite reflect a supratidal environment.

The microcrystalline dolomites and associated anhydrite nodules are both early diagenetic in origin, having formed under sabkhalike conditions. The saccharoidal dolomites are late diagenetic; formed after the initial lithification of the sediments by refluxing magnesium-rich, hypersaline waters, derived from supratidal zones. The accompanying anhydrite masses probably had a similar origin.

Intercrystalline porosity combined with small interconnected vugs in the dolomites make this the best reservoir rock in the area studied. Solution vugs in the limestone also may provide effective porosity for hydrocarbons. The oil accumulation is due to structural-stratigraphic trapping.

The collapse of the Ratcliffe Beds into salt-leached areas has affected the structural pattern and influenced hydrocarbon accumulation. Possibilities of further oil discoveries in this area are good.

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STRUCTURAL GEOLOGY OF CRAZY MOUNTAINS BASIN

The Crazy Mountains basin is a physiographic depression, as well as a structural basin in south-central Montana. The basin is bounded on the north by the Castle Mountains, Shawmut anticlinal trend, and the Huntley-Lake basin fault zone; on the west by the Bridger and Big Belt Mountains, on the south by the Nye-Bowler lineament and the Beartooth Range; and on the east by the Pryor-Big Horn uplift. Separation of the Crazy Mountains basin from the Big Horn basin to the south is arbitrarily placed along the Nye-Bowler lineament.

The Crazy Mountains are a passive intrusive complex occupying the deeper part of the basin. This setting is analogous to the Raton basin of the Colorado and its associated Spanish Peaks intrusives.

The structural pattern of the Crazy Mountains basin is somewhat enigmatic, being most varied and diverse. Structures within the basin resulted from the superposition of Laramide compression on an earlier fragmented Precambrian crystalline basement. The resulting structures are folds related to thrusting; drape folds over faults with dip-slip movement; and en échelon folds with "gash" fractures related both to left-lateral and right-lateral transcurrent fault movement.

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PETROLEUM EXPLORATION AND NEW BASEMENT TECTONICS

Mounting evidence from important geologic studies of many types—surface geology, standard airphoto interpretation, space photography, gravity, magnetics, and side-looking radar imagery—demonstrates that the earth's Precambrian crust is profoundly and systematically fractured. These basement fractures fall into a few sets of parallel structures that have been reactivated by local and regional tectonism at various times subsequent to their formation. Thus, they control, to a very large degree, all geologic structures, particularly structures in the sedimentary blanket overlying Precambrian basement. An understanding of basement fracturing is thus of enormous importance in petroleum exploration and will become a major exploration technique in the coming years. Strain theory is relegated to a much lesser role than formerly, applying only to blocks of *unfractured* rock a few kilometers on a side, if such exist.

The studies to date indicate that the basement fracture sets formed in orthogonal, *i.e.*, right angle, patterns; that the fractures of different sets trend through one another with little or no displacement, and hence resulted from vertical, rather than horizontal forces; and that they are very old. One key study of aeromagnetics on the Colorado Plateau indicates that the minimum age of the fracturing is 1.7 billion years. Several mechanisms for the formation of these sets have been proposed.

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CONTRASTING THE EFFECTS OF COAL MINING IN WYOMING AND PENNSYLVANIA

Acid mine water and increased stream siltation are both attributable to Pennsylvania's coal mining and are significant polluters of their water resources. Coal mining affects Wyoming's waters minimally because there are no acid water and very little siltation of permanent streams. In Wyoming coal mining can improve groundwater recharge and store much needed water.

Pennsylvania's coal-mined land is adversely affected by (1) subsidence; (2) total disturbed, surface-mined acreage (350,000 acres) and its rate of increase (12,000 acres in 1971 for 27 million tons of coal); and (3) slides on hillsides. Wyoming's sparse population makes subsidence effects minimal. Disturbed surface land effects are minimized by the (1) small total acreage (3,936 acres) and small annual increase (averages 170 acres for 8 million tons); (2) low-relief, flat, basinal rangelands mined; (3) remoteness from population centers; and (4) similarity of mine spoils with some natural landforms.

Wind-blown dust and fumes from burning culm banks and mine fires are accentuated in Pennsylvania because of their closer proximity to populated areas.

Although at least 80% of the disturbed surface acreage in Pennsylvania is recreational woodland, most disturbed acreage is remote, sparsely vegetated rangeland in Wyoming. Although vegetation in both states can be reestablished by planting or more slowly by natural revegetation, toxicity of mine wastes in Pennsylvania commonly retards its reestablishment and kills vegetation adjacent to the mine as well.

In Wyoming, the adverse effects of coal mining other than subjective, esthetic criticisms of temporary surface land disturbances are less damaging than in Pennsylvania.

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SALT DEPOSITION IN NORTH ARM, GREAT SALT LAKE, UTAH

Construction of a semipermeable, rock-fill railroad causeway across the Great Salt Lake has caused a severe imbalance in concentrations of lake brines north and south of the causeway. Ninety percent of freshwater inflow enters the lake south of the causeway. South arm brines are becoming progressively fresher as salts are deposited on the floor of the north arm where there is no freshwater inflow other than rainfall and minor springs. The water surface of the south arm is as much as 40 cm higher than the surface of the north arm.

Logging of 38 cores up to 1.5 m long drilled on a 4-mi grid shows a maximum salt thickness of about 1.5 m and an average thickness of more than 0.6 m covering 1,250 sq km of the north arm. Nearly 2 billion tons (metric) of salts have been deposited in the north arm since the causeway was completed 13 years ago; a rate of 150 million tons per year.

X-ray diffraction analysis of more than 150 samples shows that the salt in the north arm is almost entirely halite. Minor amounts of sylvite are present in some samples, but it is uncertain whether it was deposited in the lake with the halite or from occluded brines partly evaporated from the core tubes during prolonged storage. Preliminary electron microprobe studies indicate that potassium occurs in local concentrations within halite crystals and not along crystal boundaries, suggesting that the sylvite may be primary.

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ENVIRONMENTAL IMPLICATIONS OF DEVELOPING COAL RESOURCES

There are new things in reclamation but mostly there are just increased awareness and better performance by industry. Most of us in this business consider ourselves good citizens and dislike the label of a "despoiler of America's pristine beauty." Yet we are torn between that which is desirable and that which is economically feasible.

In approaching the subject of reclamation the problem must be put into perspective. It is established that the United States will approximately double its present consumption of minerals and mineral fuels each 15 years. During the past 30 years the United States has used more minerals and fuels than did the entire world in all previous history.

There is increased demand for great amounts of energy from oil, natural gas, coal, and hydroelectric power, not to mention atomic energy and solar energy. Shortages in some of these areas are already appearing with the discovery of natural gas and oil now falling behind the consumption. Present estimates by the industry are that 6 million bbl of this oil must come from synthetic sources including coal and oil shale.

We will be disturbing ever-increasing areas of the earth's surface to recover the fuel we need and surface mining must of necessity increase many fold. Therefore, we must expect increasing pressure from citizen's groups, sportsmen's organizations, environmental study groups, newspapers, and state and federal governments.

It is incumbent on us as an industry to actively and accurately tell our story to the public, so that every citizen in the states where we operate realizes that we are doing more than just making money—we are also providing them with needed electric power with fuel for the many industries that give them the civilization they demand; we are contributing substantially in taxes to provide schools, hospitals, and other civic benefits; and we provide the base for a thousand and one other products and services used in everyday life.

Because laws are obviously going to come, it is only sensible that the mining industry take a heavy part in drafting them so that insofar as possible they not be restrictive or punitive or otherwise unfavorable to such an extent that mining operations are curtailed or placed in a poor competitive position with other fuels.

Reclamation must be a part of our every day mining operation and must be an anticipated expense. This reclamation must be the result of combining the best technical assistance we can get to the hard economic facts of the coal mining business. This reclamation must be carried on with sensitivity to the needs of the area we are mining and to the feelings of the residents of the area. As increased federal interest in spoils reclamation is a certainty, we must ask companies to participate aggressively in establishing just and realistic reclamation laws. We must overcome the ostrich attitude our industry has had in the past because the conservation movement and increased awareness by the public of our environment are here to stay.

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PYROLYSIS AND THIN-SECTION EXAMINATION OF PETROLEUM SOURCE ROCKS

The lack of rapid, but geochemically sound, methods for identifying organic-rich rocks in small samples (potential petroleum source rocks) was a major obstacle to the application of petroleum origin and migration concepts in oil and gas exploration. More than 4,000 ft of near-surface stratigraphically continuous core, primarily shales, was obtained from the marine Cretaceous of central Wyoming by use of a variety of geologic,