composed primarily of solid solutions of silicates plus cations, primarily $Ca^{2+}$, $Mg^{2+}$, and to a lesser degree $Fe^{2+}$. Distinct zones observed correspond to temperature thresholds, which can be distinguished by increasing degrees of silicification of the carbonate-rich raw oil shale. Trace element partitioning parallels closely the mineral assemblages, with the synthesis of insoluble minerals in the hottest most intensely altered zones, minimizing the extractability of potentially detrimental materials from the residue of in-situ combustion.

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## Sedimentology and Depositional Environments of Emery Sandstone, Emery and Sevier Counties, Utah

From a sedimentologic study of the Emery Sandstone Member of the Mancos Shale (Upper Cretaceous) in southern Castle Valley, Utah, it is possible to determine depositional environments, paleogeography, textural and mineralogical characteristics, and possible sediment sources.

Tidal-flat deposits are dominant in the Emery, but subtidal (shoreface) and offshore deposits also occur. The paleotidal range is estimated to have been 1.3-1.7 m (4.3-5.6 ft). Many asymmetric, transgressive-regressive cycles of two different magnitudes and periods are present. They formed in response to minor fluctuations in sea level combined with slight variations in the subsidence rate.

The Emery Sandstone was deposited in the foreland of the Sevier orogenic belt. The average orientation of the paleoshoreline, as determined by paleocurrent analysis, was N9°W. Sediment was probably transported southward from the Utah-Idaho-Wyoming border area by longshore currents.

Well-sorted, subrounded to subangular, very fine-grained subarkose is the dominant rock type in the Emery. Dolomite and calcite are the major cements. Average porosities, based on thin section analysis, are less than 2%.

Abundant chert grains and reworked authigenic quartz overgrowths suggest a sedimentary source terrane. The observed amounts of feldspar could have been derived from Mesozoic sedimentary rocks exposed in the Sevier orogenic belt.

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## Geologic Setting of Petroleum Source Rocks in Permian Phosphoria Formation

The Permian Phosphoria Formation in the northwestern interior United States contains two phosphatic and organic-carbon-rich shale members—the Meade Peak Phosphatic Shale Member and the Retort Phosphatic Shale Member. These rocks were formed at the periphery of a foreland basin between the Paleozoic continental margin and the North American cratonic shelf. The concentration, distribution, and coincidence of phosphorite, organic carbon, and many trace elements within these shale members probably were coincident with areas of optimum trophism and biologic productivity related to areas of upwelling. Upwelling is indicated to have occurred in the Phosphoria sea by the presence of sapropel that was deposited adjacent to shoals near the east flank of the depositional basin.

Maximum organic-carbon concentration is as much as 30 wt. % in the organically richest beds in the shale members and the maximum average in each member is about 10 wt. %. A close association occurs in the distribution of the organic carbon, silver, chromium, molybdenum, nickel, titanium, vanadium, and zinc. Phosphorous differs slightly from the distribution of organic carbon and by contrast seems typically associated with copper, lanthanum, neodymium, strontium, yttrium, and ytterbium.

Burial of the sapropelic muds by Triassic and younger sediments and the consequent rise in ambient temperature has led to catagenesis of hydrocarbons from the kerogen in these rocks. In some areas of southwestern Montana, hydrocarbons have not been generated; however, burial has been minimal and temperatures have remained low. Consequently, these rocks remain organic-rich shales that have the potential for producing synthetic oil and gas.

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## Stratigraphic Relationships and Distribution of Hydrocarbon Source Rocks in Greater Rocky Mountain Region

"Hydrocarbon Source Rocks of the Greater Rocky Mountain Region " is the title of the Rocky Mountains Association of Geologists 1984 contribution to its annual symposium-guidebook series. This volume is comprised of over 25 papers that describe Precambrian through lower Tertiary source rocks and their associated maturation, migration, and accumulation patterns.

Placement of source rocks within a regional depositional framework indicates that they are generally associated with specific depositional environments associated with recognizable cycles of transgression and regression. When placed in a framework of depositional sequences, the source rocks can easily be related to the geometry of the associated reservoirs that they charge and to the seals that restrict hydrocarbon migration and control accumulation.

A series of maps shows distributions of source rocks for each critical stratigraphic sequence, and places the data and concepts of individual symposium papers in a regional context.

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## Applied Depositional Modeling for Developing Western Coal Deposits

Geologic data from Mesaverde Group (Upper Cretaceous) strata in the Rocky Mountain region indicate that two major depositional models can be used to evaluate the geology and mining conditions of many western coal deposits. Marine and continentally deposited strata that enclose coal seams are characterized by physical and chemical characteristics which, if recognized, will permit more efficient mine planning and development. These characteristics impact selectively and differently on underground coal mining including longwall and room-and-pillar methods.

Continentally deposited strata in the roof and floor of coal seams require closely spaced data points for predicting geologically related mining conditions due to the lenticularity of the component beds. Fluvial sandstones are commonly associated with "wants," rolls, water inflows, and thinned coal. Channel-margin strata are notorious for roof control problems. Mudstones deposited in interchannel areas are prone to rapid decomposition with the introduction of water, humidity, and stress release.

Marine-deposited strata enclosing coal seams require less closely spaced data points than continentally deposited strata for predicting mining conditions because of the lateral continuity of such strata. Roof and floor strata and mining conditions are characteristically uniform over wide areas except near the termination of strata. Shoreline sandstones form very competent roofs and floors although they are locally associated with reduced seam thicknesses. The immediate association of marine-deposited strata and coal commonly results in higher sulfur values at the contacts of these strata.

Where marine and continental strata interfinger, the prediction of mining conditions becomes complex and requires an understanding of the depositional and erosive capabilities of the associated facies.

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## Geology of Scipio Pass Quadrangle, Millard County, Utah

The Scipio Pass quadrangle is comprised of three separate packages of stratigraphy: (1) the Canyon Range Precambrian and Cambrian allochthonous section, (2) the Pavant allochthon of Paleozoic carbonates and quartzites, and (3) a thick Cretaceous to Quaternary blanket of coarse clastics that unconformably overlies the other packages. A fourth package, the Pavant autochthon, is inferred in the subsurface. Mesozoic rocks of this package crop out farther south where the Jurassic Navajo Sandstone is overlain in thrust contact by the Cambrian Tintic Quartzite.

Based on lithology and biostratigraphic evidence, the heretofore undivided Cambrian section of the Pavant allochthon correlates well with the

East Tintic section to the north, but differs notably from the Cambrian section of the Canyon Range allochthon, which closely parallels the House Range stratigraphy. Juxtaposition of two separate Cambrian packages is attributed to a major Cretaceous thrusting episode during the Sevier orogeny. The Canyon Range allochthon placed Precambrian and Cambrian rocks on top of Cambrian through Devonian rocks of the Pavant allochthon. Later detachment of the Pavant allochthon emplaced the Paleozoic section over the Mesozoic rocks farther east. Movement of the Pavant allochthon carried the Canyon Range allochthon "piggyback." Folding of both allochthonous sheets occurred, and Precambrian klippen of the Canyon Range allochthon are preserved, in two major synclinal troughs. Miocene to Holocene block faulting elevated and exhumed both the Canyon and Pavant Ranges from beneath their cover of self-derived conglomerates.

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Utah State Prison Geothermal System

A geothermal space heating project was recently completed at the Utah State Prison complex at Crystal Hot Springs located near Murray, Utah. The project was initiated in 1978 as a joint U.S. Department of Energy and State of Utah project.

Geologic and geophysical investigations initiated in 1979 consist of surface geologic mapping and aeromagnetic and detailed gravity surveys. This exploration program along with several shallow thermal-gradient holes provided the structural details for a subsequent exploration drilling program.

The exploration drilling program involved deepening an existing well (SF-1) to 500 ft (150 m) and drilling a new hole (USP/TH-1) to 1,000 ft (300 m) to test the extent of the thermal anomaly. Well SF-1 intersected 175°F (79°C) temperatures in a low permeable quartzite, and well USP/TH-1 intersected highly fractured quartzite in the lower section of the well. A temperature reversal was noted in USP/TH-1 below 700 ft (213 m) with a maximum temperature of 175°F (79°C) occurring in the zone from 300 to 700 ft (90 to 215 m).

Flow testing of USP/TH-1 indicated the well would flow at 1,000 gpm with a sustained flow of 400 gpm at a 3.5 psi drawdown over the heating season. Testing also indicated interference with other nearby wells and thermal springs.

Fluid production for space heating of the prison facilities took place during the winter of 1983-84. This production will give more data to refine the calculations of reservoir producibility and provide information on the economics of utilizing geothermal fluids for space heating.

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Permo-Triassic of Northwestern Paradox Basin Area, Utah

The Moenkopi Formation contains estimates of over 1 billion bbl of oil in the northwestern part of the Paradox basin in Emery, Garfield, and Wayne Counties, Utah. The Moenkopi is comprised of four members. The basal unit, the Black Dragon Member, is the most variable member in thickness as a result of infilling topographic relief of the post-Permian topography. The upper three units—the Sinbad, Torrey, and Moody Canyon Members, in ascending order—are principally marine deposits that thicken to the west. The distribution of the underlying Permian units appears to have controlled, in part, the deposition of the Black Dragon Member, with perhaps the Paradox evaporites of Pennsylvanian age adding to the control of the deposition. The Emery uplift did not influence deposition of the Moenkopi, and had ceased influencing deposition of units by the time the Permian White Rim was deposited.

The origin of the oils in the Moenkopi Formation is still open to debate. The writer believes that due to the presence of a high percentage of marine rocks, the tight and discontinuous nature of the reservoir rocks, and the character of the oils from the Moenkopi, the source rocks for the oils in the Moenkopi are contained within the Moenkopi Formation. Generation of hydrocarbons occurred in the areas near the accumulations with limited migration distances being necessary.

By combining surface and subsurface data on the underlying Permian units, the Moenkopi Formation, and the overlying Upper Triassic Chinle Formation, a more complete stratigraphic and depositional framework for the Moenkopi Formation is possible. The result is a better understanding of the surface accumulations and a better exploration strategy for subsurface accumulations.

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Kaiparowits Basin: An Old Frontier with New Potential

Situated in the western part of the Colorado Plateau in Utah, the Kaiparowits basin is one of the least explored of the major Rocky Mountain geologic provinces. The Kaiparowits is not a topographic but a stratigraphic basin that began as an early to middle Paleozoic oceanic embayment that stretched slightly east of the shallow shelf transitional hinge line. The full depositional history of the Kaiparowits area records the alternation of basinal sedimentation (early to middle Paleozoic, parts of the Permian, middle to late Mesozoic) and plateau uplift (late Paleozoic-early Mesozoic, late Tertiary-Holocene). Its present configuration is the result primarily of Laramide tectonism. In its overall tectonic aspects, the Kaiparowits describes a large triangular region in which, from west to east, the structural grain rotates about 70° from a northeast to a northwest trend, with the intensity of deformation decreasing considerably.

To date, the only commercially productive area in the basin is the Upper Valley field, where hydrocarbons have been recovered primarily from dolomitized carbonates of the Kaibab Formation and Timpoweap Member of the Early Triassic Moenkopi Formation. Entrapment is within the strongly asymmetrical, doubly plunging Upper Valley anticline, where an active water drive has offset the oil pool onto the steeply dipping western limb. Live oil shows have been reported from nearly every pre-Jurassic formation in the region. Despite this, very few (170) exploratory wells have been drilled in this vast territory of nearly 22,000 $mi^2$ (57,000 $km^2$).

Recently, however, a discovery of a different type has indicated the basin contains tremendous amounts of $CO_2$ gas reserves that could prove useful for both ongoing and future secondary recovery programs. At the very least, it is probable that most of the true potential of the Kaiparowits has thus far been overlooked, partially due to the rugged and isolated terrain. It is one of the least densely drilled provinces in the Rockies with one of the highest concentrations of probable source and reservoir rocks.

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Oil and Gas Prospective Thrust Belts, West-Central North America

The prospective oil and gas producing thrust belt areas, now defined in west-central North America, should be expanded to include all shortened sequences of rocks where the overthrust (hanging wall) sequences have been emplaced over organic-rich rocks of all ages.

The western part of the much-publicized Sevier thrust belt should be considered where any older sequence is emplaced over younger organic-rich rocks, if the younger rocks were not previously mature or if all hydrocarbons were not expelled from them before thrusting occurred. Where overthrusting has emplaced older rocks over younger organic-rich rocks, the added overburden can cause initial or additional hydrocarbon generation and expulsion into available traps.

This thrust loading can cause hydrocarbon generation and expulsion on a selected basis where the depth of overburden is adequate with the temperature high as needed. The very deep organic-rich sediments can generate hydrocarbons by thrust loading, with the oil and gas migrating into the shallow immature sediment trap. Because of basin downwarping and sedimentation, the additional sediment load can cause initial or additional hydrocarbon generation.

The COCORP seismic reflection data from western Utah indicate major regional detachment (decollement) horizontal planes for structural shortening in most of the Basin and Range province of western North America.