mation. The Uncompahgre uplift established an initial ancestral pattern of northwest-trending anticlinal structures. These propagated northeastward throughout the Uinta and Piceance basins as a result of compression during the Pennsylvanian Period. Planes of weakness were imprinted vertically along the axes of these folds and subsequently affected the overlying Mesozoic sediments. Next, the Uinta uplift reenforced these northwest-trending folds and planes of weakness during the early Laramide orogeny. The third stage of formation involves contemporaneous deposition of Eocene sediments, including the kerogen of the Green River Formation. Differential compaction during diagenesis, over the northwest-trending residual highs formulated subperpendicular, localized tensile stresses. Vertical fractures propagated rapidly in an en echelon fashion along the imprinted axial planes of weakness. In the fourth stage of formation, fractures penetrated overlying reservoir intervals, which contained various combinations of liquid hydrocarbons and connate water. Released fluids entered the low-pressure voids and spread laterally and vertically throughout the Eocene sediments. A final period of inspissation and/or metamorphosis quickly altered the various liquid hydrocarbon deposits to form gilsonite and other bitumens.

The variation of these bitumens is dependent on the original chemical composition of the individual reservoir zones during deposition.

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Regional Lithostratigraphy of Permian Phosphoria Formation, Western Overthrust Belt

A regional synthesis of the lithostratigraphic relationships for the Permian Phosphoria Formation illustrates the cyclic lithofacies types, carbonate reservoir, and potential organic facies for the western Overthrust belt of Wyoming, Idaho, and Utah. Palinspastically restored subsurface control sections (70) and measured outcrop sections (35) indicate a complex, intertonguing, transgressive-regressive sequence of shallow-water carbonates, clastics, and highly organic phosphatic mudstone deposited in a shallow marine shelf-margin environment. Distribution of facies types was affected by paleostructural growth of late Paleozoic structural elements including the Sublette basin of Utah and Bannock highs of western Wyoming-southeastern Idaho. These highs helped define the Wyoming shelf-margin slope. Identification of paleostructural growth is based on interpretation of depositional environments and thickness patterns of the Permian deposits.

The Phosphoria Formation and the equivalent beds of the Park City Formation are divisible into two main depositional cycles—the Meade Peak-Franson Members and the Retort-Ervay Members—based on the regional correlation network generated for the Overthrust belt. Carbonate deposition and reservoir development occurred during maximum transgressive stages, whereas deposition of phosphorite and organic shales occurred during maximum regressive stages. The reservoir facies is closely associated with early diagenetic dolomitization of carbonate shelf deposits concentrated along paleostructural high areas of the shelf-margin environment.

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Influence of Tectonic Terranes Adjacent to Precambrian Wyoming Province of Petroleum Source and Reservoir Rock Stratigraphy in Northern Rocky Mountain Region

The perimeter of the Archean Precambrian Wyoming province can be generally defined. A Proterozoic suture belt separates the province from the Archean Superior province to the east. The western margin of the Precambrian rocks lies under the western Overthrust belt, but the Precambrian province extends at least as far west as southwest Montana and southeast Idaho. The province is bounded on the north and south by more regionally extensive Proterozoic mobile belts. In the northern belt, Archean rocks have been remobilized by Proterozoic tectonic events, but the southern belt does not appear to contain rocks as old as Archean. The tectonic response of these Precambrian terranes to cratonic and continental margin vertical and horizontal forces has exerted a profound influence on Phanerozoic sedimentation and stratigraphic facies distributions. Petroleum source rock and reservoir rock stratigraphy of the Northern Rocky Mountain region has been correlated with this structural history. In particular, the Devonian, Permian, and Jurassic sedimentation patterns can be shown to have been influenced by articulation among the different terranes comprising the ancient substructure. Depositional patterns in the Chester-Morrow carbonate and clastic sequence in the Central Montana trough are also related to this substructure. Further, a correlation between these tectonic terranes and the localization of regional hydrocarbon accumulations has been observed and has been useful in basin analyses for exploration planning.

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Implications to Exploration of Porosity Relationships and Paragenetic Sequences, Jurassic Navajo (Nugget) Sandstone, Utah and Southwestern Wyoming

We have studied in outcrop and in the subsurface the reservoir characteristics and diagenesis of the Early Jurassic, eolian, Navajo (Nugget) Sandstone in Utah and southwestern Wyoming. Principal topics include: texture, framework constituents, intergranular and intragranular cements, matrix, directional porosity, porosity types, and hydraulic conductivity.

Present characteristics of the sandstone are related to variations in dune and interdune environments, fluctuating ground-water chemistry, and postdepositional environments. Diagenesis, in which an open-system diagenetic model is considered, superimposes and is influenced by these variations and events.

The sandstone was deposited principally in dune and interdune settings. Surface and/or near-surface cementation, mostly by grain overgrowth and calcite from ground-water solutions, consolidated the sediment. Thereafter, the succession was uplifted, eroded, and buried by Middle Jurassic formations. During the Late Jurassic through Eocene, the sandstone was affected by compressional folding and thrust faulting in central and northern Utah and southwestern Wyoming. During the Tertiary, extensional deformation occurred.

Petrographic criteria in thin sections indicate that secondary leached porosity generally is common to dominant in surface, near-surface, and possibly in deep subsurface sequences. Variations in porosity and volume of cements with depth exist and are correlative in all areas studied. Porosity changes with depth, as well as the volume of cements, are the result of downward-decreasing surface leaching of intergranular and intragranular cements, creation of secondary porosity, effects of initial stratification types, and facies changes.

Compaction of the sandstone due to mechanical rearrangement of detrital grains and intergranular pressure solution played little or no role in modification of porosity or hydraulic conductivity. Likely, they account for not more than 5% of the porosity reduction. Greatest porosity reduction (16%) was by cementation. Present mean total porosity is 19%, ranging from 3 to 35%.

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Geothermal Exploration Using Surface Mercury Geochemistry

Shallow soil mercury surveys are an inexpensive and effective exploration tool for geothermal resources. In a geothermal system at depth, mercury is leached from the country rock and transported to the surface by the geothermal fluids. The mercury is fixed by clays and organic material in the soil above the geothermal system and can be detected by analyzing the near-surface soil. Surface mercury surveys can be used in regional reconnaissance to discriminate prospective from nonprospective areas. Closely spaced mercury surveys over individual prospects typically enhance the structural understanding of the prospect and show which structures are important as migration pathways.

The use of probability graphs greatly enhances the interpretation of mercury geochemical data. Probability graphs have a logarithmic ordinate scale versus a cumulative percentage abscissa scale. This graph is arranged such that a typical lognormal population plots as a straight line on the graph. Deviations from a straight line show deviations in the data from a standard lognormal population distribution. The mercury data are easily plotted on the graph and can be evaluated visually. Anomalous and background populations can be separated consistently even when considerable overlap occurs between populations. In Nevada and California, soil mercury surveys have detected up to four distinct mercury populations in one area. These populations are related to background

over different bed-rock types and to variations in leakage from the geothermal system at depth. An interpretation of the mercury populations in light of the available geologic and structural characteristics of a prospect can significantly increase the understanding of the geothermal resource.

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Tectonic Significance of Depositional Patterns in Nonmarine North Horn Formation, Central Utah

The Maestrichtian through Paleocene(?) North Horn Formation is a nonmarine sequence of interbedded and intertonguing synorogenic conglomerate, sandstone, algal limestone, and claystone. Deposition occurred within an interior drainage system restricted by the Sevier highlands to the west and the San Rafael swell to the east. It extended south to at least Salina Canyon in central Utah and north to the southern margin of the Uinta basin. The base of the formation is diachronous, unconformably overlying Campanian rocks. Earliest deposition began along the eastern Wasatch Plateau, then shifted westward until late Paleocene beds onlapped deformed Mesozoic rocks associated with Sevier thrusting.

Paleocurrent measurements indicate a general west to east transport direction. Four major depositional facies are recognized: alluvial fan, proximal braid plain, distal braid plain, and lacustrine. Work has been concentrated on the alluvial fan and braid plain facies west of the Wasatch Plateau.

Massive clast-supported cobble to boulder conglomerate characterizes alluvial-fan facies. Deposition on fan surfaces was primarily by sheet-flood or braided stream processes. Conglomerate shows skewed clast populations. Northeast of Mt. Nebo, 60-70% of clasts are carbonate rocks. Clasts range up to 1 m (3 ft) in diameter. Thick Paleozoic carbonate beds associated with the Nebo fold nappe furnished most of them.

Upward-fining sequences of massive to crudely stratified clast-supported conglomerate, conglomeratic sandstone, and sandstone characterize proximal and distal braid plain facies. During transport down the braid plain, mixing of Eocambrian and Cambrian quartzite, Paleozoic carbonate, and Mesozoic sandstone occurred. Conglomerate was deposited in bars within braided stream channels. It displays imbrication of flattened clasts with long axes transverse ($\cong$40-70°) and intermediate axes subparallel to flow direction. Sandstone displays poorly developed cross-stratification, planar stratification, and massive bedding. Rapidly fluctuating episodes of sedimentation with high sediment loads on the proximal braid plain, and extensive bioturbation by infauna on the distal braid plain, are indicated.

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High Resolution Seismic Surveys and Their Applications to Coal Exploration and Mine Development: Case Histories

The Wasatch Plateau coalfield of central Utah contains many active coal mines within approximately 1,000 mi^2 (2,590 km^2). More than 20 coal seams, each greater than 4 ft (1.2 m) thick, have been named, and several of these are currently mined. Structurally, the area is dissected by generally north to northwest-trending faults with varying offsets. In 1980 and 1981, initial seismic surveys indicated that several northeast-trending faults existed within the vicinity of East Mountain. The highly favorable results of the initial surveys have led to additional surveys in other areas of the Wasatch Plateau coalfield, and in Colorado, Wyoming, and Washington. The interpretation of these data has pinpointed fault locations, fluvial channel sandstones, thickness trends, and general geologic structure. One area with suspected thin coal was found to contain coal of minable thickness. The results of the seismic surveys have been confirmed by drilling, detailed surface mapping, and Landsat imagery. Numerous seismic data and their interpretation in the various geologic situations have been determined since the initial surveys.

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Alluvial Model for Eocene Wasatch Formation Coal, Powder River Basin, Wyoming

The Eocene Wasatch Formation in the Powder River basin, Wyoming, consists of a conglomerate facies (Kingsbury Conglomerate Member) on the western margin of the basin and a coal-bearing facies near the center of the basin. The conglomeratic facies consists of abundant, basally scoured, pebble to boulder conglomerates and sandstones, and minor rooted siltstones. The conglomerates contain abundant sedimentary and subordinate crystalline rock fragments derived from the adjoining Bighorn uplift. The coal-bearing facies comprises dominant coarse to conglomeratic sandstones and rooted siltstones and claystones. Minor constituents are fossiliferous limestones, carbonaceous shales, and coals. A thick, widespread coal bed (Felix coal) ranges from 10 to 28 ft (3 to 8.5 m) thick within a 400 mi^2 (1,035 km^2) area and splits outward from this area into several beds. Where the coal is thick, it is underlain by sandstones and the coal splits are underlain by finer grained deposits.

The conglomeratic facies represents wet alluvial-fan deposits consisting of graded gravel bars, channel sands, and finer overbank detritus. These sediments grade eastward into the coal-bearing facies that represents deposits of meandering streams and their adjoining flood plain and backswamp. The locations of the thickest, most widespread coal body and its splits in this facies are governed by depositional topography controlled by differential compaction of the substrate. Where the substrate is poorly compactible channel sandstones, the swamp surface was relatively high and free of sediment influx. Where the underlying deposits are fine grained and more compactible, the resulting low-lying swamp attracted water-borne sediments that interrupted peat accumulation.

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Petroleum Source Rocks and Stratigraphy of Bakken Formation in North Dakota

The Bakken Formation (Devonian and Mississippian) of North Dakota consists of upper and lower, black, organic-rich shales separated by a calcareous siltstone middle member. The formation is a relatively thin unit—maximum thickness 145 ft (44.2 m)—with the lower shale attaining a maximum thickness of 50 ft (15.2 m), and the upper shale a maximum thickness of 23 ft (7 m). The shales are hard, siliceous, pyritic, fissile, and noncalcareous. They contain abundant conodonts and tasmanites and have planar laminations accented by pyrite. The upper and lower shales were apparently deposited in an offshore, marine, anoxic environment where anoxic conditions may have been caused by a stratified water column resulting from restricted circulation. Organic matter in the black shales was derived mostly from planktonic algae.

Organic-carbon measurements revealed the Bakken shales to be very organic-rich (average of 11.33 wt. % of organic carbon), and visual kerogen typing revealed this organic matter to be predominantly an amorphous type that is inferred to be sapropelic. The onset of hydrocarbon generation was determined to occur at an average depth of 9,000 ft (2.74 km) by interpreting plots of geochemical parameters with depth (e.g., ratios of hydrocarbon to nonhydrocarbon, saturated hydrocarbon to organic carbon, pyrolytic hydrocarbon to organic carbon, and the pyrolysis production index). Hydrocarbon content and thermal kerogen breakdown increase greatly in the Bakken shales where they are buried at depths greater than 9,000 ft (2.74 km). The effective source area of the Bakken, as determined by maps of the above geochemical parameters, lies mostly in McKenzie, Williams, Dunn, and Billings Counties. Oil generation was probably initiated in the Bakken about 75 Ma (Late Cretaceous) at a temperature of about 100°C (212°F), with initial expulsion of oil from the Bakken probably occurring 70 Ma (Late Cretaceous). The amount of oil generated by the Bakken in North Dakota, as calculated from pyrolysis data, is 92.3 billion bbl. If only 10% of this oil was actually expelled from the shales, it could easily account for the 3 billion bbl of known type II oil reserves in the Williston basin. (This paper is a summary of work done for an M.S. thesis at the University of North Dakota).