reservoir pressure gradients are about 0.42 to 0.46 psi/ft (9.5-10.4 kPa/m). Reservoir pressure gradients in excess of 0.5 psi/ft (> 11.3 kPa/m) are considered overpressured. However, most overpressured reservoirs have pressure gradients greater than 0.6 psi/ft (> 13.6 kPa/m). Although a variety of conditions can cause overpressuring, most high pressures in the region are interpreted to be caused by the "active" generation of oil and gas in sequences that still contain organic matter capable of yielding thermally generated hydrocarbons. Several authors have proposed that hydrocarbon generation can cause overpressuring. It is important to note that significantly overpressured water reservoirs are rare in the Rocky Mountain region and, where present, are usually in pressure continuity with overpressured oil and gas reservoirs. Some slightly overpressured water reservoirs can be explained by local conditions, such as a pressure measurement at a location significantly lower than a topographically high-elevation water recharge area (artesian conditions).

Rocks with above normal pressure in Rocky Mountain basins range in age from Late Devonian to Tertiary and are commonly associated with low-permeability (tight) reservoirs. Most overpressured reservoirs occur in Cretaceous and Tertiary sandstone sequences. Overpressuring is not common in rocks older than Cretaceous except in very organic-rich sequences, probably because lean source beds that have been heated over a long period of time are no longer capable of yielding enough hydrocarbons to maintain abnormal pressure.

Statistically, nearly all overpressured reservoirs and source rocks have temperatures of about 200°F (93°C) or higher. In many basins, the onset of overpressuring occurs rather abruptly at this temperature in organic-rich sequences. In addition, available data indicate that hydrocarbon-related overpressuring does not usually occur if vitrinite reflectance values are $< R_o = 0.5\%$ in oil-prone sequences or $< R_o = 0.7\%$ in gas-prone sequences. These reflectance values are the lower limit for onset of significant generation of oil and gas, respectively.

Hydrocarbons expelled into widespread, high-permeability reservoirs probably migrate owing to hydrodynamic flow and buoyancy. These reservoirs usually have normal pressures. In contrast, low-permeability (tight) reservoirs retain the overpressuring and have maximum pressures about equal to the natural fracture gradient for rocks in a given area. In a 1978 study, F. F. Meissner proposed that pore pressures in excess of the natural fracture gradient initiate formation fracturing, and the hydrocarbons are expelled laterally and vertically until the pore pressure is reduced and the fractures close. These fracture-initiation pressure gradients range from ≈ 0.7 psi/ft (15.8 kPa/m) to > 0.85 psi/ft (> 19.2 kPa/m). The highest reservoir pressure observed to date in the Rocky Mountains is in the Merna area (T36N, R112W), Sublette County, Wyoming, where reservoir pressure gradients in Upper Cretaceous sandstones exceed 0.9 psi/ft (>20.4 kPa/m). Artificial hydraulic-fracturing pressure data indicate that in this area regional fracture gradients also are higher than normal.

Regional pressure analyses indicate overpressured hydrocarbon-bearing reservoirs occur in the following Rocky Mountain basins: Williston, Powder River, Bighorn, Wind River, Hanna, Green River, Washakie, Great Divide, Sand Wash, Piceance, Uinta, and Paradox.

SPENCER, MARY ALICE S., Bur. Land Management, Billings, MT

Inexpensive Remote Sensing Techniques

Professional aerial photographic missions are expensive, but periodic updates can be obtained for considerably less money using a hand-held camera in a small plane.

Environmentally related problems such as strip-mine reclamation can be monitored by periodic photography, both color and false-color infrared, obtained in this manner. Problem areas such as uneven settling of leveled spoils can be identified for further work.

Photography and imagery available from government agencies can also be used to supplement data from a baseline aerial photographic mission. Landsat imagery acquired during periods of snow cover may accent subtle structural features concealed by vegetation.

Examples of such techniques, and supporting data, will be on display at the poster session.

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Considerations of Vertical Tectonics for Big Horn Basin

Referring to the tectonic style of the Big Horn basin as either "horizontal" or "vertical" is an oversimplification. However, these terms have come into vogue and I support vertical tectonics. This term implies that on most structures the vertical component of displacement is larger than the horizontal component of displacement. It does not imply that all faults are absolutely vertical, nor does it preclude crustal shortening. If high-angle reverse faults (dips steeper than 45°) dominate in a basin, a net shortening will result even in a vertical tectonic domain. Furthermore, when applied to the Big Horn basin, the expression "vertical tectonic style" only characterizes behavior 10 to 15 km (6 to 9 mi) into the basement. It implies nothing concerning causative conditions in the lower crust or upper mantle. A given mantle stress condition can produce several different displacement fields in the upper crust depending upon the behavior of the crust.

In accepting either horizontal or vertical as the tectonic style of a region, all of the structures produced during the deformation episode should be considered together as opposed to examining one feature at a time. It is also important to separate second and third order features from primary features. Finally, if there is a governing style, it should be consistent with three-dimensional movements, not just individual cross sections.

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Laramide Sedimentation, Folding, and Faulting in Southern Wind River Range, Wyoming

Surface observations along the southern margin of the Wind River Range in Fremont County, Wyoming, indicate that early motion along the Wind River and Continental faults controlled depositional patterns and lithologic characteristics of the local syntectonic sediments, and that the latest motion on a segment of the Wind River fault between Oregon and Pacific buttes folded some of these same sediments into a monocline. The stratigraphic sequence exposed in the monocline consists (in ascending order) of a lower distal fan or alluvial plain unit (main body of the Wasatch Formation), a lake margin unit (Tipton Tongue of the Green River Formation), a fluvial and deltaic sandbody (Tipton Sandstone), and an alluvial fan unit (Cathedral Bluffs Tongue of the Wasatch Formation). Current direction, clast composition, and clast-size data indicate that a granitic and mafic distal source to the east and a proximal granitic source to the north supplied sediment. Subsequent movement on the Wind River fault warped this sequence into a monocline 2 mi long. This structure dies out in both a northwest and southeast direction along the inferred trace of the Wind River fault and is overlain by undeformed middle Eocene sediments.

Other syntectonic units (e.g., Fort Union, Ice Point, White River, Arikaree, and South Pass conglomerates) occur in patches along the Wind River and Continental faults in this area. Each deposit is of local extent, exhibits rapid thickness and petrofacies changes, and probably represents proximal alluvial fan deposition. These characteristics are typical of syntectonic sediments in transcurrent-faulted terrains, and we are investigating the possibility of such faulting in this area.

Tectonic implications of these interpretations are: (1) early motion on the Wind River fault controlled the margin of Eocene Lake Gosiute and generated a distal sediment source to the east; (2) late early Eocene uplift of the north side of the Continental fault provided a proximal source for pegmatitic and granitic boulders to the north; (3) last motion on the Wind River fault was latest early Eocene or earliest middle Eocene between Oregon and Pacific buttes; (4) the Wind River fault consists of several segments which moved separately rather than as one, long continuous zone of concurrent faulting; (5) while the Wind River Range was being thrust to the southwest it may have been uncoupled from the basins to the south by a zone of transcurrent faulting; (6) Pliocene or younger recurrent motion along the Continental fault was opposite to that in the Eocene.

SUNDELL, KENT A., Univ. California, Santa Barbara, CA, and Ram Oil Co., Inc., Casper, WY

Volcanic Stratigraphy, Timing, and Petroleum Exploration in Southeastern Absaroka Range, Big Horn Basin, Wyoming

The southeastern Absaroka volcanic sequence consists mainly of middle Eocene (50 to 43 m.y.B.P.) epiclastic rocks with minor pyroclastic rocks and lava flows near vent areas. The Wood River–Greybull River volcanic center is a major source of reworked material. From oldest to youngest, moderately colorful tan, brown, green, and maroon volcanic claystones, siltstone, and sandstones predominate in the Aycross Formation (1,000 ft, 305 m, thick); olive-drab volcanic sandstones and breccias predominate in the Tepee Trail Formation (2,500 ft, 760 m, thick); and light gray volcanic conglomerates and tuffaceous sandstones are most common in the Wiggins Formation (2,000 ft, 600 m, thick). The Aycross Formation contains abundant bentonitic material, forms a perched water table, and is probably an effective caprock. The Blue Point marker, a distinctive sequence of white bentonite beds, separates the Aycross and Tepee Trail Formations and is the best horizon for structural contouring within the volcanic rocks.

Broad gentle folds and horst blocks within Aycross, Tepee Trail, and lower Wiggins strata indicate movement on "Laramide structures" until approximately 45 m.y.B.P. However, several episodes of large-scale Eocene detachment faulting and mass movements locally obscure this relationship. Domal features beneath the volcanics and stratigraphic traps at the volcanic-nonvolcanic contact are the primary exploration targets, but significant traps related to the volcanic activity may be present locally.

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Macrofossils of Bakken Formation (Devonian and Mississippian), Williston Basin, North Dakota

Results of this study of the macrofossils of the Bakken Formation in North Dakota have reinforced the suggestion, based on previous paleontological work in Saskatchewan, that the Bakken is of both Devonian and Mississippian age, rather than being entirely of Lower Mississippian age as originally considered. Increased drilling and coring activity in the North Dakota part of the Williston basin has provided the opportunity for acquiring a larger fauna than was previously available. Most of the fossils were obtained from the middle part of the Bakken Formation.

Based on lithologic character, the Bakken has been divided into three informal members. These consist of a calcareous siltstone unit between two lithologically similar units of carbonaceous shale. These black shales contain similar faunas distinct from that of the middle member. The black shales contain inarticulate brachiopods, conchostracans, and rare cephalopods and fish remains as well as more abundant conodonts, ostracods, and palynomorphs. The middle siltstone unit contains a more abundant and diverse fauna consisting of inarticulate and articulate brachiopods together with corals, gastropods, cephalopods, ostracods, echinoderm remains, and trace fossils. This is the first report of cephalopods, conchostracans, ostracods, corals, trace fossils, and some of the brachiopods in the Bakken, although all, except the gastropods, have been reported from stratigraphic equivalents (Exshaw Formation of Alberta, the Sappington Member of the Three Forks Formation of south-central Montana, the Leatham Formation of northeastern Utah, and the middle member of the Pilot Shale in western Utah and eastern Nevada). The Bakken macrofauna adds another dimension to interpretation of the depositional environment and paleoecology of offshore, sediment-starved, basinal units.

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Possible Tectonic Influence on and Facies Distribution of Shannon Ridge Sandstones, Wyoming

In the Powder River basin of Wyoming, Upper Cretaceous Shannon Sandstone shelf sand ridges are formed along the crest of a broad, subtle, southwest to northeast-trending paleoarch. During Shannon deposition, relief on the arch was great enough to alter shelf energies and cause sand ridges to develop within a predominantly silty shale interval.

Possible recurrent movement in the Salt Creek anticline created a paleohigh which strongly localized development of thick sand ridge complexes in the Shannon Sandstone. During Shannon deposition, relief on the paleohigh apparently was strong enough to cause ridges to build laterally as well as vertically. Shannon ridge complexes at Salt Creek are more oblate, bigger, thicker, and more closely spaced than most central Powder River basin ridges. Also, there are two vertically stacked ridge systems developed within the Shannon Sandstone. While the lower ridge system is coeval with the Shannon ridge system in the central basin, the upper ridge system is only developed locally and, we believe, is related to active growth on the paleohigh during Shannon deposition. At no time, however, did the paleohigh cause ridges to be subaerially exposed.

Eleven Shannon shelf ridge and ridge-associated facies were defined in outcrops on the Salt Creek anticline. Vertical and lateral changes in facies are relatively abrupt where observed in closely spaced outcrop sections and, in general, facies are stacked in coarsening-upward sequences with central bar facies commonly immediately overlying interbar sandstone facies. Porous and permeable potential reservoir facies include: central bar facies, a clean, cross-bedded sandstone; bar margin facies (Type 1), a highly glauconitic, cross-bedded sandstone containing abundant shale and limonite (after siderite) rip-up clasts and lenses; and bar margin facies (Type 2), a cross-bedded to rippled sandstone. These facies were formed by sediment transported and deposited in the form of medium to large-scale troughs and sand waves on and across the tops of ridges by moderate to high-energy shelf currents.

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

The perimeter of the Archean Precambrian Wyoming province can be defined generally. A Proterozoic suture belt separates the province from the Archean Superior province to the east. The western margin lies under the western Overthrust belt and 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 incorporated into the Proterozoic rocks, 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 distribution. Petroleum source rock and reservoir rock stratigraphy of the northern Rocky Mountain region can be 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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Depositional Environments of Middle Minnelusa "Leo" (Middle and Upper Pennsylvanian), Wyoming, South Dakota, and Nebraska

The informal middle member of the Minnelusa Formation, commonly known as Leo, consists of a spectrum of sediments including sandstone, dolomite, anhydrite, bedded chert, limestone, and radioactive carbonaceous shale. Deposition within the upper Paleozoic Alliance basin of the present day tri-state area of South Dakota, Wyoming, and Nebraska occurred in sabkha, tidal flat, and shallow subtidal environments. Major and minor cycles of eustatic sea level changes are manifest by the Leo section. Eolian sands, organic "black shales," supratidal to subtidal carbonates, and evaporites are intercalated in close vertical and lateral proximity.

Early Desmoinesian (lowermost Leo) sediments are open marine, upper subtidal limestone interbedded with restricted marine upper subtidal dolomite, anhydrite, and radioactive organic-rich dolomite. During the upper Desmoinesian and lower Missourian, most of the Alliance basin was a restricted carbonate tidal flat. Throughout the remainder of the Pennsylvanian, the prevalent environment was a restricted coastal to