In the fall of 1981, Northwest Exploration Co. drilled the discovery well for Haybarn field. The field is located in the Wind River basin of Wyoming and produces stratigraphically trapped 43° API gravity, 80°F pour point oil and associated gas from the Paleocene upper Fort Union Formation; these rocks are thought of generally as poor exploration targets and gas-prone at best. The reservoir is an arkosic sandstone deposited along the front of a lacustrine delta system. Clays in the reservoir are almost entirely secondary. Despite the precipitation of diagenetic kaolinite and chlorite, the reservoir capacity has remained high with porosities ranging from 18 to 26% and averaging about 20%. Reservoir permeabilities average about 7 md. Transmissibility has been enhanced in some zones by natural vertical fractures. The fractures also provide an avenue for water from lower water sands. The resistivities of the formation waters are variable, making electric log calculations difficult. The R_w of the productive sand tongue in the discovery well ranges from 0.35 ohm-meters at the top to 1.40 at the base, over a vertical distance of 75 ft (23 m). Oil production is limited to the upper, more saline portion. Both the petroleum source and the trapping mechanism for the field appear to be the lacustrine Waltman Shale. The depositional system responsible for Haybarn field is not unique. Similar oil fields remain to be found in other parts of the Wind River basin.

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Three-Dimensional Seismic Survey Applied to Field Development in Williston Basin

The Medicine Lake field of Sheridan County, Montana, was discovered in March 1979 by the drilling of a seismic anomaly. Production is obtained from Paleozoic carbonate reservoirs ranging in age from Ordovician to Mississippian. Cumulative production from the field, as of March 1982, is 1.2 million bbl.

A mini-3D seismic survey was acquired in October 1981 to facilitate development drilling. The survey covered 2.4 mi^2 (6.2 km^2), encompassing the field's seven producing wells and two dry holes. The purpose of this survey was to provide an accurate image of the subsurface structure and delineate the extent of the producing formations.

The areal coverage and improved subsurface imaging of the 3D survey provided a detailed view of the Medicine Lake anomaly. The seismic data reveals that the structure results from a local basement (Precambrian) high. Mapping of the Ordovician Winnipeg Formation revealed a domal structure covering approximately 0.6 mi^2 (1.5 km^2) with closure in excess of 180 ft (55 m).

Although all producing wells are located on the Medicine Lake structure, stratigraphic variations within the reservoirs may localize production within structural closure. Porosity in several producing formations is diagenetic; prediction of reservoir trends from well data alone is difficult. Inversion and interactive modeling were used to study these stratigraphic variations. A correlation between relative acoustic impedance and porosity was established for several formations. Vertical and horizontal relative acoustic impedance sections were then employed to locate zones of possible porosity. This information, combined with the improved structural data, should aid in further development of the Medicine Lake field.

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Lemhi Arch

The Lemhi arch was a northwest-trending landmass that controlled marine depositional patterns in southwest Montana and east-central Idaho during the late Proterozoic and early Paleozoic, and provided a source for early Paleozoic clastic sediments. The arch persisted as a landmass until Late Devonian, when it was finally covered by marine sediments.

The arch first formed in the late middle Proterozoic, when middle Proterozoic miogeoclinal sedimentary rocks, the Lemhi Group and Swauger and Lawson Creek Formations were arched into an elongate dome. It was deeply eroded in late Proterozoic, and as much as 5,000 m (16,400 ft) of clastic rocks were stripped away. The eroded edges of the middle Proterozoic rocks on the west flank of the arch were partly covered in late Proterozoic(?) and Early Cambrian by the onlapping Wilbert Formation and Tyler Peak Formation of McCandless, but sedimentation apparently did not continue into the later Cambrian. On the east flank of the arch, marine sedimentation began with deposition of the Middle Cambrian Flathead Formation, and continued through the Late Cambrian, leaving a westward-thinning wedge of marine rocks against this flank.

During the Ordovician and Silurian, the east flank of the arch was emergent. The west flank was partly submerged in the Early Ordovician, and the onlapping nearshore clastic and carbonate rocks of the Summerhouse Formation were deposited. These rocks are successively overlain by the eastward-thinning marine rocks of the Kinnikinic Quartzite (Middle Ordovician) and the Saturday Mountain Formation (later Ordovician and Silurian?). The west flank of the arch was briefly exposed to erosion after deposition of the Saturday Mountain Formation, but was again partly submerged in Middle and Late Silurian, when the eastward-thinning Laketown Dolomite was deposited.

Both flanks of the arch were exposed in Early Devonian, but in Middle Devonian, deposition was renewed on the west flank as fresh- and brackish-water sandstone was deposited in channels cut deeply in the Ordovician rocks. Later Middle and Upper Devonian sandstone, algal dolomite, and sedimentary carbonate breccia indicate eastward, onlapping deposition in a nearshore environment, and these are succeeded by Upper Devonian marine dolomite and limestone; all of these rocks above the channel sandstone are included in the Jefferson Formation. The east flank of the arch was exposed through much of the Devonian, but late in the period a thin sequence of marine carbonate rocks of the Jefferson Formation was deposited across the top of the arch, and marine sedimentation in this region was continuous from the miogeocline far onto the craton for the first time since uplift of the cratonic region early in the Middle Proterozoic.

The Lemhi arch continued to influence marine deposition even after it was submerged, separating the region of shelf deposition in southwest Montana and east-central Idaho from the region of miogeoclinal deposition in central Idaho. The arch apparently was a landmass again through much of the Mesozoic; it was overridden by the Medicine Lodge thrust plate, which is composed of miogeoclinal sedimentary rocks, in late Early and Late Cretaceous.

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Seismic Interpretation of Basement Block Faults and Associated Deformation in Rocky Mountains Foreland

The reflection seismic method is the most effective technique for the interpretation of buried block fault/forced fold structures. Recent advances in seismic acquisition and processing have improved the interpreter's ability to define fold and fault geometry but limitations still exist. Two major problems involve lateral velocity changes and complicated raypath geometry. It is, therefore, desirable to study surface exposures to use as a guide for mapping buried features. The block fault/forced fold concept has been used effectively to provide models for analyzing foreland structures as demonstrated by seismic lines from several Wyoming basins.

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Foreland Deformation—A Critique of Cause

The cause of foreland deformation has been argued for nearly 100 years, and despite definitive stratigraphy, superb exposure, and extensive seismic and well data, the mechanism and geometry remain elusive. It is necessary to separate arguments for cause from arguments that only support a particular geometric interpretation.

The following statements are presented for discussion and are not advanced as "the answer."

(1) Foreland deformation is caused by end-load buckling in a plate tectonic setting driven by abnormally shallow subduction. (2) The crust is the active (competent) unit, and the plastic subcrust is a passive cushion allowing the great vertical component, though a slight slope forced on it by the subducting slab may have aided telescoping of the crust above. (3) No strictly vertical cause can allow the basins to go down as much as they did, and active (causal) intrusion under uplifts only is not likely. (4) While reverse faults and modest shortening predominate, fault attitudes can

have greater diversity than in the thin-skinned regime because the plastic substratum allows easy vertical motion; nearly vertical faults are allowable. (5) The basement does fold, but with difficulty and in broad wavelength. (6) Because of the broad arching, a "neutral surface" exists well within basement over uplifts, allowing high-level features, such as Rattlesnake Mountain, to be bounded by high-angle normal faults. (7) This same neutral surface forces out-of-the-basin crowding, causing the steep flanks of most basin folds to face toward the adjacent uplift.

(8) The "Hafner approach" illustrates the diversity of curved faults that can be generated in a vertically sinusoidally loaded beam, and which can be generated equally well in an end-loaded sinusoidally buckled beam, as long as it sits on a passive plastic substratum. (9) The Sanford model is excellent for depicting the fault configuration generated in sediments above a high-angle fault. (10) Faults such as Dinosaur Monument can be seen to steepen downward, but my models suggest that they go listric at their lower transition with the plastic substratum. (11) The COCORP trace of the Wind River fault indicating a nearly planar 35° dipping fault most of the way through the crust is probably real; arguments that you cannot see a fault of "granite" against "granite" do not apply. (12) Gravity highs over uplifts, models, and later collapsed uplifts speak for a flexed and jostled slab configuration and against a buoyant root configuration.

(13) Thrusting from several different directions appears not to be a problem when viewed in the context of "jostled slabs." (14) Blocky corners do place limits on amount of thrust and strike-slip translation. (15) The argument for pure verticality to solve a presumed "space problem" in the Piney Creek structure loses validity as soon as the bounding tears are allowed to stray from a perfectly vertical dip. (16) The argument at Elk Mountain that the dip of the bounding structure must be at least as low-angle as the degree of overturning of sedimentary panels is wrong (proven by Five Springs).

(17) Sales' eastward crowding of the Colorado Plateau and development of a "Wyoming couple" north of it still seems cogent. (18) The Chapin and Cather, and Gries subdivision into movement phase also appears to be correct. (19) If horizontal compression is a reality, Stone must be correct in principle; there have to be logical connecting structures. (20) The crust can transmit stress over great distances because it is weak enough; southeast Asia tectonics require greater distances of stress transmittal than Laramide foreland tectonics.

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Horizontal Compression and a Mechanical Interpretation of Wyoming Foreland Deformation

If the basement fault-controlled style of deformation in the Wyoming foreland is dominated by elastic response of the upper lithosphere, and the deformation in the foreland is genetically linked to the horizontal compression characteristic of the thin-skinned thrust belt to the west, then concepts of continuum mechanics can be combined with results of experimental rock mechanics to suggest the following.

(1) Basement faults initiate at the basement surface, propagate downward at an approximate 35° dip, and die at a depth dependent upon the magnitude of elastic shortening. Displacement on these faults necessarily decreases with depth. The faults are not expected to be appreciably curved in cross section.

(2) Foreland structures develop early as fault-cored folds of small amplitude (< 1,500 m, 4,900 ft), with selected ones developing to large amplitudes (up to 13,000 m, 43,000 ft). Regions where the entire lithosphere has not "failed" (early stage) show only small-scale structures (e.g., Colorado Plateau), whereas regions where the lithosphere has experienced through-going failure will show small intra-basinal structures (early) isolated by more widely spaced large basin-margin structures (late). This bimodal size distribution of structures is present in the Wyoming foreland.

In this study, horizontal compression as a sole causal mechanism can be combined with accepted mechanical concepts to produce a plausible model which adequately explains the regional features of Wyoming foreland deformation.

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New Sources of Gold in the West

Records show discovery of, perhaps, 40,000 gold and silver deposits in western United States. Mine descriptions give dates of operation and allow correlations with history. These mine histories commonly indicate that the properties have further potential. Many of the prospects left 50, 75, and even 100 years ago are of interest today because of new geological concepts. Simple veins of yesterday may be the exposed parts of larger entities. The old ore controls, structures, or zones may be tied to larger lineaments, elements, or zones. In younger deposits, corollaries are often made with geothermal fields. Lineations and cross lineations require further consideration. Connections with plate tectonics come easily.

As an example of the increase in size of useful parameters, the line of segmentation portrayed in coast ranges of northern California and Oregon might be looked upon as lines marking transverse zones of extension. Better known zones of extension are parts of the very large fault network centering around the San Andreas and Garlock faults, and parts of the Imperial Valley region south of the Salton Sea, a well known geothermal area. Corollaries with such areas are sought, for example, along lines marked by the Antler and Sevier tectonic belts in Nevada.

In other western areas, pillow lavas occur in close proximity with gold occurrences which stimulates thinking along lines of spreading centers and submarine springs.

The old gold and silver deposits appear to fit readily into a framework, in which treatment of prospects as segments within a geothermal model is helpful. Conversely, with the growth of geothermal development, the view of activity will be incomplete without consideration of the potential by-products, precious metals.

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Synorogenic Sedimentation Associated with Development of Paris-Willard Thrust System, Wyoming-Idaho-Utah Thrust Belt

Depositional environments, facies distribution, and provenance analyses of Upper Jurassic through lowermost Upper Cretaceous strata in western Wyoming, eastern Idaho, and northeastern Utah suggest that episodic tectonic activity along the Paris-Willard thrust system strongly influenced deposition during early development of the Wyoming-Idaho-Utah thrust belt and associated foreland basin. Synorogenic conglomerates present at various stratigraphic levels in these strata reveal periods of rapid uplift. In general, the synorogenic units contain proximal cobble-boulder conglomerates (braided stream) which grade downslope into distal pebble conglomerates and coarse-grained sandstones (meandering stream). Periods of relative tectonic quiescence and/or less rapid uplift and erosion are represented by interbedded finer grained fluvial, lacustrine, and marine deposits.

During the Late Jurassic, erosion of incipient highlands prior to thrusting resulted in eastward progradation of beach/barrier sandstones represented by the Stump Formation. Initial intensive thrusting followed in the latest Jurassic and earliest Cretaceous, with the newly formed highlands shedding proximal braided stream cobble-boulder conglomerates and more distal meandering stream pebble conglomerates and sandstones of the Ephraim Formation into the subsiding foreland basin. Continued subsidence coupled with a decrease in clastic input due to subdued uplift, resulted in establishment of extensive lacustrine systems and deposition of the Peterson Limestone. Renewed movement on the Paris-Willard thrust system then gave rise to the proximal conglomerates and distal sandstones and mudstones of the Bechler Formation. The overlying lacustrine Draney Limestone and marginal lacustrine Smoot Formation represent another period of continued basin subsidence with little or no uplift.

The Wayan and laterally equivalent Bear River Formations represent, respectively, near-source fluvial and shallow beach-marine deposition following Smoot/Draney accumulation. Wayan strata were deposited on a meandering stream flood plain and are indicative of slow uplift and erosion in the source area. Bear River strata consist of a beach sandstone unit underlain and overlain by transgressive marine shales. Alternate deposition of transgressive and regressive facies resulted from either eustatic changes in sea level or differential uplift and erosion of the Paris-Willard highlands.