complexes of northeastern Washington and northern Idaho.

Regional cross sections show no serious obstacles to the presence of an autochthonous or detached slab of Paleozoic rocks beneath the overthrust Belt section, although subhorizontal mylonitic rocks are not outside the realm of geologic possibility. Nevertheless, oil and gas favorability beneath Belt rocks is affected by such factors as ratio of source rock to reservoir rock, thermal and/or pressure conditions after overthrusting, and the postmigrational effects of Eocene extensional tectonism (i.e., dip reversals, magmatism, and fragmentation).

RIGGERT, V. L., Univ. Calgary, Alberta, Canada

Geometry and Mechanical Development of Heart Mountain Thrust Stack, Exshaw, Alberta

Heart Mountain is located near Exshaw, Alberta, and forms a peculiar localized thrust stack along the otherwise relatively linear Exshaw thrust trace in the Canadian front ranges. Data from stratigraphic and structural mapping on a scale of 1:5,000 were used in the construction of balanced cross sections, longitudinal sections, and stratigraphic separation diagrams to reveal the true three-dimensional geometry of the mountain. The structure (the "heart") is composed of a gently south-plunging canoe-shaped body of rock. Near its southern termination, however, the heart plunges steeply northward.

Several previously unrecognized features of the Heart Mountain structure were discovered during mapping. The heart is a faulted syncline with its east limb thrust up relative to its west limb. The heart's "collar" is composed of the Loomis Member of the Mississippian Mount Head Formation, not the Mississippian Livingstone Formation as previously mapped. The panel of Livingstone rocks west of the heart is stratigraphically up to the east.

Based on both stratigraphic and structural considerations, the thrust stack formed in an east-to-west sequential development from rock panels of relatively local origin. Mechanical considerations of the mountain's east-to-west sequential development require the location of the Exshaw thrust to be along the eastern margin of the structure. The Heart Mountain thrust stack, therefore, formed in the hanging wall of the Exshaw thrust.

Hydrocarbons have been found in structural traps similar to Heart Mountain. Understanding the geometry and order of mechanical development of these traps is essential to profitable exploration ventures.

ROBERTSON, CHARLES E., Missouri Geol. Survey, Rolla, MO

Landsat and Field Studies Link Structural Lineaments and Mineralization in St. Francois Mountains, Missouri

Late-stage Precambrian granites in the St. Francois Mountains are among the most uraniferous in North America. The St. Francois province has potential for uranium mineralization of economic importance, especially in the later differentiates.

Structural lineaments and circular features displayed on images produced by electronic data processing of Landsat multispectral scanner data may be related to late-stage intrusives with uranium potential. Strong north-south lineaments and associated circular and arcuate features may correspond to major weaknesses in the earth's crust along which fracturing, faulting, and volcanism have occurred. The strike of the lineaments transects the older dominant northwest-southeast and northeast-southwest structural grain of the region. This, and the remarkable preservation of Precambrian structures of volcanic origin, indicate that the lineaments may be related to late-stage, uranium- and thorium-rich intrusives. The Ironton lineament, a major north-south lineament, is closely related spatially to Precambrian iron and manganese deposits.

Field work along the Ironton lineament suggests that it is related to a late period of Precambrian volcanism and that structural deformation along the lineament continued into early Paleozoic time. Areas of faulting, shearing, and hydrothermal alteration affecting both Precambrian and Paleozoic rocks have been located. A circular feature along the lineament has been found to be centered by a manganese deposit of possible hydrothermal origin.

RUSSON, MIKE, Brigham Young Univ., Provo, UT

Stratigraphy and Economic Potential of Castle Gate Area, Carbon County, Utah

Unexcelled exposures of the coal-bearing Blackhawk Formation near Castle Gate, Utah, provide a cross section of sediments deposited by wave-dominated deltas along the western shoreline of the Cretaceous Interior seaway. Four sandstone tongues resulted from deltaic sedimentation, each overlain by thick coal. A clear genetic relationship exists between the occurrence of coal and geometries of paleoshorelines and fluvial channels. Coals are thickest where underlain by thin shoreface sandstones, and they pinch out abruptly against beach-ridge sandstones responsible for swamp proliferation. Fluvial channels subsequently cut wide swaths in swamp deposits normal to shoreline trends. Commonly, thick coals of different seams occur together, as the compaction of vegetation controlled subsequent swamp accumulation. Excellent exposures and considerable subsurface data provide the details necessary to construct a predictive exploration model useful in the Cretaceous coals of the central Rockies. Cretaceous deltaic deposits also create hydrocarbon potential, as three facies associated with Blackhawk deposition produce ideal stratigraphic relationships for hydrocarbon accumulation. Porous delta-front sandstones interfinger with the underlying organic-rich marine shale of the Mancos formation. Shale and siltstone of the flood plain then cap the sandstone. Hydrocarbons derived from the marine shale or from associated coal may accumulate in porous sands of stream channels or in mouth-bar or beach-ridge deposits of the delta front. A clear understanding of deltaic sedimentation, provided by analysis of the Blackhawk model, could aid in predicting the occurrences of similar subsurface sandstones.

SALES, JOHN K., Mobil Oil Corp., Dallas, TX

Heart Mountain, Wyoming—Blocks in a Collapsing Volcanic Pile

The Heart Mountain "detachment" was caused by volcanic collapse and not free sliding. These huge blocks could hang together if immersed in volcanics, but not in air. Block separation is logical during sideward volcanic collapse, but inertia and the rate required make free sliding untenable. Lack of erosion of the fault surface requires instant burial if free sliding was the cause. However, if the detachment was part of a volcanic collapse, the fault surface was never exposed. Free-moving blocks would gouge the delicate Grove Creek pavement, but the equal loading by a glacier-like collapse of volcanics would allow this stratigraphy to remain intact. Nothing in present experience moves free blocks on so large a scale on that flat a surface, especially up and over a transgressive ramp in a free setting. A collapsing volcanic pile propelled by its profile of repose, not by the slope under it, would allow movement. Earthquake vibration is ineffective in a free slide, but extremely effective in collapsing a weak pile. The Reef Creek structure is an imbrication; the South Fork is an unloading bulge. A long dip slope with a basin-facing monocline below it, a large young volcanic pile, seismicity, a swampy toe, and artesian pressure combined to cause failure. It may have been steady-state, incremental, or catastrophic, the latter being favored.

SALES, JOHN K., Mobil Oil Corp., Dallas, TX

Collapse of Rocky Mountain Basement Uplifts

Several Rocky Mountain uplifts have collapsed, usually back down the root zone of the thrust that raised the buckled slabs. Basement is juxtaposed against sedimentary fills and subcrust is juxtaposed against granitic crust. Thus, uplifts have "anti-roots" and strong positive gravity anomalies with slabs held up by strength rather than buoyancy, making them susceptible to collapse. The Rio Grande rift trends along the crests of older uplifts. Collapse is accentuated by regional uplift that removes basin fills. This substitution of "air for rock" increased gravity stressing.

Large gravity faults, including the San Luis basin boundary fault with relief that may exceed 20,000 ft (6,100 m), are caused by this mechanism. Their large size may be caused by a significant increment of displacement above the isostatic equilibrium position added to the normal buoyancy mechanism that drives these faults.

The north side of the Brown's Park graben in the Uinta Mountains bears this relationship to the Uinta thrust, increasing in distance from the thrust trace as stratigraphic throw and amount of overhang of the thrust increases. A plunging section of the South Granite Mountains fault system in the area of Ferris Mountain provides a downplunge cross section in which the collapse fault can be seen to join and "back down" the root zone of the thrust. Thus the outer thrust lip "hangs up" and is left standing higher than the core of the uplift. Distance between the two types of faults provides an estimate of the amount of overhang.

SCHIRMER, TAD W., Utah State Univ., Logan, UT

Correlation of Ogden Thrust, Durst Mountain Thrust, and Allochthonous Precambrian Farmington Canyon Complex in North-Central Wasatch Mountains, Utah

The Precambrian Farmington Canyon complex crops out in the Wasatch Mountains between Ogden and Bountiful, Utah. Additional exposures are present at Durst Mountain and at Antelope Island.

East of Ogden, between Ogden Canyon and Strongs Canyon, the Farmington Canyon complex has been thrust eastward over Lower Cambrian Tintic Quartzite and Middle Cambrian shales and limestones of the Ophir Formation and Maxfield Limestone. This thrust is named the Ogden thrust. Similarly, at Durst Mountain, east of Morgan Valley, the Farmington Canyon complex has been thrust over Lower Cambrian Tintic Quartzite and Middle Cambrian shales and limestones. This thrust fault is the Durst Mountain thrust. If subsequent vertical offset of 2,000-4,000 ft (610-1,220 m) down to the west on the Morgan Valley normal fault is restored, it appears that the two similar thrusts involving the Farmington Canyon complex could once have been continuous. Such a reconstruction requires a minimum of 12 mi (19.3 km) of thrust displacement of the complex eastward over the sequence of basal Cambrian rocks.

This evidence is significant for two reasons: (1) the Farmington Canyon complex of the Wasatch Mountains may not be in place, but may be allochthonous above a decollement at depth; and (2) the Paleozoic-Mesozoic sequence east of Morgan may also overlie the same decollement, which would increase the potential for petroleum plays in the area north of Croyden.

Thus, the northern Utah uplift, proposed for this area by A. J. Eardley and discussed by M. D. Crittenden, may result from a sequence of Farmington Canyon complex thrust upsection eastward, rather than a vertical uplift of basement.

SCHMIDT, CHRISTOPHER, Western Michigan Univ., Kalamazoo, MI

Late Cretaceous and Paleocene Faulting in Rocky Mountain Foreland and Frontal Thrust Zone, Southeastern Montana

The Late Cretaceous and Paleocene structural pattern in southwestern Montana is comprised of three spatially and temporally overlapping sets of structures whose positions strongly reflect the influence of previous basement faults and whose kinematics imply dominantly west-to-east compressive forces.

The first of these patterns is a set of steep northwest-trending faults involving the metamorphic basement rocks of the Rocky Mountain foreland. Movement on these faults was oblique (left-reverse) and occurred as a reactivation of faults which developed initially in middle Proterozoic time. Net horizontal shortening by faulting and associated large-scale folding is 10-20 km (6-12 mi).

Another fault pattern within the foreland is a set of widely spaced, gently west-dipping thrusts. These thrusts also involve basement rocks and appear to have been controlled by previous zones of weakness within the crust. Movement is principally dip-slip and latest movement appears to involve tearing on the northwest-trending fault set. Shortening by basement thrusting and associated folding is 20-25 km (12-15 mi).

The other structural pattern is that of the frontal fold and thrust zone on the western boundary of the foreland and the zone of transverse thrusting on the northern boundary. These zones of impinging thrusts also involve basement rocks principally as slices that were "picked off" from underlying basement highs during ramping. As the thrusts of the frontal zone advanced to the east they impinged on northwest-trending foreland anticlines and were torn on the northwest-trending faults. The transverse thrust zone on the north involves right-reverse movement with about 20 km (12 mi) of west-east displacement. The zone is fundamentally a transverse ramp produced by deflection along the east-trending Willow Creek fault zone of Proterozoic age.

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Provenance Control of Fluvial Sandstone Diagenesis, Frontier Formation (Upper Cretaceous), Wyoming-Idaho-Utah Thrust Belt

Meandering stream channel sandstones and associated conglomerates of the Frontier Formation (Upper Cretaceous) in the Wyoming-Idaho-Utah thrust belt provide an excellent example of provenance (compositional) influence on diagenetic history. Fluvial sandstones in the southern thrust belt (northeastern Utah and southwestern Wyoming) are litharenites and sublitharenites dominated by chert, carbonate rock fragments, and monocrystalline quartz derived from erosion of Paleozoic strata exposed in thrust plates to the west.

Early diagenetic phenomena include compaction, as evidenced by deformed mudstone clasts and micas, and quartz overgrowth development. Subsequent diagenesis is variable and may include precipitation of sparry calcite, clay minerals (chlorite or kaolinite), or a combination of calcite and clay. Porosity values typically range from 3 to 15%. Porosity is dominantly secondary in origin and formed by dissolution of carbonate rock fragments and cement.

Frontier fluvial sandstones in the northern thrust belt (northwestern Wyoming and adjacent southeastern Idaho) are feldspathic litharenites, lithic arkoses, and arkoses derived from erosion of both sedimentary and volcanic terranes. Sedimentary detritus includes chert and carbonate rock fragments; volcanic detritus includes tuffaceous volcanic rock fragments and plagioclase. Diagenesis is characterized by extensive albite, chert, and kaolinite cementation and almost total concomitant porosity occlusion. Rarely, sandstones may possess several percent porosity due to secondary dissolution of detrital plagioclase.

Albite cement occurs as pore-filling aggregates of twinned euhedral crystals rather than as overgrowths, and it is interpreted to have been derived through dehydration reactions involving zeolite precursors such as heulandite or analcime.

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Tertiary Age Extension of Leppy Hills Area (Southwest Silver Island Mountains) Near Wendover, Nevada

In the Leppy Hills, a series of 11.6 Ma volcanic flows is separated from the underlying Permian limestone by an angular unconformity of about 15°, indicating the Paleozoic sedimentary rocks dipped gently and the area had low topographic relief as little as 11.6 Ma. Faulting ended by the Pleistocene, for Quaternary deposits overlap the faults.

Most of the rocks in the Leppy Range dip 10°-60° west. Normal faults are common and generally trend north. During extension, the limestone beds deformed brittlely and faulted while shaly beds were stretched ductilely. The fault surfaces range from distinct planar zones with narrow gouge zones to large brecciated zones. Commonly, breccia fragments are covered with concentric bands of fibrous calcite that indicate a cavity filling. Calcite-filled extension fractures increase in abundance toward fault zones. Locally, up to 25% of the rock volume is veined. Some faults up to 100 m (330 ft) long curve to become subparallel to bedding, producing a spoon-shaped geometry, with the bowl of the spoon facing upward. Multiple generations of faulting have subsequently rotated faults and beds. Space problems along curved faults on the tens of meters scale were accommodated by: (a) intense brecciation and formation of calcite-filled veins or voids, (b) cataclastic flowage of limestone or ductile flowage of shale into the space, or (c) antithetic faulting or "passive listric folding" of the hanging wall.

The extension in the Leppy Hills, calculated along the simplest cross section, is at least 70%. In summary, the complicated faulting history resulted from crustal extension since the Miocene.