It is suggested that the southeast-trending structures may be at the base and in the lower part of the crust, and may have controlled the shallower and more obvious structures at the surface. This perhaps could be tested by determining whether the foci of deep-seated earthquakes (ca. 65 kms.) under the Rocky Mountains have a different distribution pattern from the shallow ones (<45 km).

If similar structures can be identified elsewhere in the northern hemisphere, and if a counter set of northeast-trending structures with left-lateral displacement could be found in the southern hemisphere, this would be compelling structural evidence that the crust is drifting eastward on top of the mantle and that the Mohorovicic discontinuity is a shear plane, or rather a float plane.

The merit in this hypothesis of continental rifting is chiefly in the possibility it provides of explaining the forces required to form geosynclines and to form folded mountains and overthrusts. Too, it offers a mechanism for generating magmas, whether basalt derived from the base of the crust or silicic magmas derived by palingenesis of higher parts of the crust.

18. Structural Evolution of Part of Southeastern Arizona: R. W. JONES, Standard Oil Company of California, Western Operations, Inc., Salt Lake City, Utah

The structural evolution of southeastern Arizona has been dominated by the differential vertical uplift of the Precambrian and Triassic-Jurassic granites. Most of the ranges are complex anticlines with Precambrian or Triassic-Jurassic granites in their core. Some uplifts exceed 25,000 feet. Many of the ranges began to rise in Triassic-Jurassic time and have continued to rise intermittently in essentially the same position at least through Miocene time. This conclusion is supported by: (1) truncation of Paleozoic strata on the flanks of the present ranges in pre-Lower Cretaceous time, (2) depositional thinning of Cretaceous strata down the flanks of the present ranges and the development of Cretaceous basins adjacent to and parallel with incipient ranges rising in Cretaceous time, (3) high-angle "Laramide" reverse faults which define the flanks of present ranges and uplift the granite cores with respect to the schist which underlies the range flanks, and (4) Basin-and-Range type faulting which further developed uplifts already in existence.

Most of the previous investigators of the structural geology of southeastern Arizona have described intensive and extensive overthrusting. Overthrusting has probably been overemphasized, primarily because of a failure to discriminate between large overthrusts and detached blocks which have moved down the flanks of large anticlines under the influence of gravity. This conclusion is based on recognition of a possible source and an available declivity, and, in particular, on a study of the internal structures of the detached blocks which has often shown that the blocks moved down the mountain flank rather than out of the valley onto the uplifted mountain block.

Of interest to the petroleum geologist are the structural and stratigraphic variations along the flanks of the intermittently rising anticlines and the comparatively simple structure which may exist in the intervening valleys.

19. *Structural Development of Salt Anticlines of Eastern* Utah and Western Colorado: FRED W. CATER and D. P. ELSTON, U. S. Geological Survey, Denver, Colorado

The salt anticlines of eastern Utah and western Colorado formed in the deepest part of Paradox basin, a basin developed during Pennsylvanian time and filled by great thicknesses of upper Paleozoic sediments, including a thick sequence of evaporites belonging to the Paradox member of the Hermosa formation. The salt anticlines originated either as tectonic folds or as folds over basement faults soon after the evaporites were deposited, probably in Middle Pennsylvanian time. These structures were parallel to and probably formed concomitantly with the rise of the ancestral Uncompahgre highland, the front of which paralleled rather closely that of the southwest front of the present-day Uncompahgre Plateau. Rapidly accumulating arkosic sediments of the Permian Cutler formation, derived from this highland, probably buried parts of the salt anticlines; elsewhere along the anticlines the salt rose isostatically as rapidly as the sediments were deposited. In places the Cutler was later intruded by the cores of the buried salt anticlines. Parts of the cores were exposed at the surface at least until the Morrison formation was deposited in Late Jurassic, so that the formations pinch out along the flanks of the salt cores. Variations in thicknesses—chiefly thinning—of the Morrison and later Mesozoic formations over the crests of the salt cores indicate that salt flowage was still active after the salt cores were buried.

The salt anticlines attained their present form—except for modifications imposed by later collapse of the crestal parts of the anticlines—during the early Tertiary when the rocks of the region were folded, and the salt anticlines were accentuated.

20. Laramide Faults and Stress Distribution in Front Range, Colorado: JOHN C. HARMS, Ohio Oil Company, Denver Research Center, Littleton, Colorado

The Front Range of Colorado is a large uplift about 180 miles long and 40 miles wide. Precambrian rocks along the crest of the range are three to five miles above the basement rocks of the adjacent Denver basin.

The eastern flank of the Front Range is marked by faults with large vertical displacements or by steep monoclinal folds, so that the change in elevation of the Precambrian surface takes place in a relatively narrow belt. South of Denver, large Laramide faults, upthrown to the west, place Precambrian rocks in contact with sediments as young as Tertiary in age. Stratigraphic displacement ranges up to 15,000 feet.

An analysis of sandstone dikes in the upthrown blocks leads to the conclusion that the stress distribution causing the injection of the dikes is governed by dip-slip movement along steeply westward dipping, convex upward fault surfaces. Therefore, the major structures outlining the flank of the range south of Denver are high-angle reverse faults whose dips steepen with depth. Other large reverse faults whose dips probably also steepen with depth are found at Golden and Boulder and along the west flank of the range. These faults are bordered in the downthrown block by a narrow belt of steeply dipping or overturned faulted and fractured sediments. Any undiscovered petroleum accumulations associated with the Front Range are probably limited to this narrow belt, but the structural complexity makes the location of such reserves a difficult task.

If elastic theory and model experiment work can be extrapolated to a large crustal block of complex composition, faults of the type observed may be formed only by vertical normal stresses arranged to create a step-like displacement or an unbroken upwarp along the bottom surface of the block. Horizontal normal and shear stresses are only incidental to maintaining equilibrium conditions.

The Front Range, judged from the configuration of the associated major faults where they are best known, is more likely the result of vertical uplift of the crust than of horizontal compression. Other ranges in the eastern Rocky Mountains appear to have similar structural origins. An understanding of stress distributions related to vertical uplift may aid in the interpretation of potential oil-producing structures related to these ranges.

Wednesday Afternoon, April 26

Presiding: W. W. MALLORY, H. H. R. SHARKEY

21. Dawson Formation as Expression of Laramide Tectonics: HARRY W. OBORNE, Consulting Geologist, 114 Wood Terrace Drive, Colorado Springs, Colorado.

The Dawson formation was named the Dawson arkose in 1915 by Richardson, the type locality being at Dawson Butte, 6 miles southwest of Castle Rock. Because much of the stratigraphic section contains more fine clastics and carbonaceous material than arkose, the change in name seems desirable.

The writer has differentiated at least six sedimentary members of the Dawson on the southwest flank of the Denver basin in addition to rhyolite flows near and possibly at the top of the formation. On the southeast flank of the basin, eight members have been recognized. Another member develops near the southern end of the southwest flank and spans the trough area of the present basin in its southern part. At the northern end of the present outcrop area, a considerable interval of coarse clastic sediments changes rather abruptly to gray shale with minor amounts of arkose.

The Dawson formation on the southwestern flank of the Denver basin is interpreted as a series of alluvial fans and bajada deposits with some intercalated mud flows, all of which were being spread out by streams from the rising Laramide mountains on the west. These fans were formed in varying areas at differing times as uplift was locally intensified or diminished by the shifting of centers of middle Laramide tectonism. Most of the fans coalesce along strike. The section is replete with unconformities. Sediments just east of the fans are mainly fluviatile, becoming lacustrine and paludal in the eastern parts of the basin. The present northwestern limit of the outcrop area contains mainly gray shale of lacustrine origin.

Total thickness is in excess of 2,000 feet, but at no one locality on the west flank of the basin are all of the members present because of the oscillatory nature of the fan-forming processes. The formation thins to the north, southeast, and east from the area of its maximum deposition near Sedalia toward the areas of finer-grained sediments.

The age of the Dawson was accepted as Eocene by Richardson. He considered it to be the southward and southeastward equivalent of the Arapahoe and Denver formations. Lavington (in 1942) believed there was an unconformity between the Denver and the Dawson, and that the Dawson overlapped the Denver. The present investigation disclosed typical Dawson unconformably overlying the Denver formation. The Dawson unconformably overlies all formations from the Pierre shale to the Denver formation in the Colorado Springs area.

Palynological examinations of cuttings from about 750 feet above the base of the Dawson indicate "late Late Cretaceous" age. Earlier work on fossil leaves from near the top of the formation was reported by Richardson to suggest a Green River Eocene age for the containing strata.

The Dawson is in fault contact with the older sediments and with Precambrian rocks along much of the mountain front. In places, the Dawson strata at or near the faults are nearly horizontal while at other localities they are steeply dipping, vertical, or overturned. Folding and faulting are present in the basin to a greater extent than has been heretofore recognized. Some of the folds have dips of as much as 45°. Faults are of both normal and thrust types.

Deformation took place before, during, and after the deposition of the Dawson. The Dawson formation is thus a good expression of Laramide tectonics both in its origin and in its present structural expression.

22. Development of Geologic Structure in Middle Rocky Mountains: D. L. BLACKSTONE, JR., University of Wyoming, Laramie, Wyoming

Hydrocarbons in commercial quantities are produced within this province from rocks ranging in age from Cambrian to Eocene, and from many different types of traps. The geologic environment which led to the origin and entrapment has been influenced by structural history; by climatic factors resulting from crustal movement; and by evolution of organisms.

Some extant mountain ranges and intermontane basins began to evolve in middle Precambrian time. Intermittent vertical oscillation of the foreland contemporaneous with the dominant subsidence of the trough in western Wyoming and southeastern Idaho characterized the events of Paleozoic time to Pennsylvanian. A northwest-trending structural grain related to the Ancestral Rockies evolved in Pennsylvanian time. Major structural relief developed in central and northern Montana along the Sweetgrass and Big Snowy arches before Late Jurassic time, and gave rise to conditions conducive to hydrocarbon accumulations in stratigraphic-type traps.

Major deformation of the Middle Rocky Mountain province resulted from a series of episodes initiated in the Cordilleran trough during middle Cretaceous time and continuing to a climax in Early Eocene time. Intermontane basins were filled with rocks of local derivation of both continental and lacustrine character at least 18,000 feet thick.

The present overthrust belt of southeast Idaho, western Wyoming, and southwestern Montana developed from a geosynclinal prism of sediments which had accumulated during Paleozoic and earlier Mesozoic time.

The structural elements of the province can be classified in three general categories. The first consists of the east-west-trending fold and fault complexes such as the Big Snowy arch, the Lake Basin fault zone, and the Uinta Mountain uplift all of which are located along sites of late Precambrian subsidence. The second comprises large northwest-trending crustal folds, the crests of which have been eroded to the Precambrian cores and the troughs of which have been the sites of accumulation of thick sedimentary sequences of local derivation. The third includes the low-angle thrusts and long sinuous folds of the overthrust belt in which only the sedimentary veneer is involved.

The mechanisms responsible for the formation of these three categories of structure are not readily ascertainable. The structures may have resulted from differing responses to a regional tangential stress system, in which case the patterns of Precambrian deformation influenced the Laramide deformation to a very large degree. The overthrust belt may have had a separate and unique origin not dependent on lateral compression. Be-