havior of the crust beneath the relatively thin sedimentary veneer has been more important in structural evolution than heretofore reported.

23. Gas Occurrence in Piceance Basin, Colorado: Clark Millison, Consultant, Denver, Colorado

Mostly gas is produced in the Piceance basin of western Colorado. The basin, containing about 4,000 square miles, is well defined by the Tertiary-Cretaceous outcrop contact beyond which are the surrounding elevated areas. The basin is in the early stages of development with a density of only one well for every 25 square miles. The lack of pipeline outlet prior to 1956 resulted in slow development but now three pipelines serve the area and drilling activity has been at an accelerated pace. Of the total wells drilled, approximately one half are capable of producing gas from the Tertiary and upper Cretaceous rocks. Due to the thickness of the section, 22,000 feet to the basement, only six wells have tested the pre-upper Cretaceous section.

Most accumulations of gas are due to stratigraphic traps. The paucity of subsurface data is the cause for the present disagreement among geologists of the stratigraphy and geologic history. Tentative correlations from the outcrops on the periphery of the basin are carried across the basin, particularly of the Mesaverde and upper Mancos beds, with a discussion of how the depositional history complicates the problem. The development history which includes the identification of the multiple gas-producing zones indicates that this basin will become one of the important gas-producing areas of the Rocky Mountains.

24. Geology and Occurrence of Gas and Oil, Wamsutter Arch, Wyoming: HOWARD R. RITZMA, Dan Turner & Associates, Inc., Denver, Colorado

The Wamsutter arch is a poorly defined, low-order, positive structural element of southwestern Wyoming. The arch plunges eastward from the northeast bulge of the Rock Springs uplift toward the Rawlins uplift and Sierra Madre uplift, but does not definitely join either of these latter structural elements. The stronger south flank of the arch dips into the Washakie segment of the Green River Basin. The north flank fades gradually into the Red Desert segment of the Green River Basin.

The stratigraphic section follows.

Eocene
Tipton tongue of Green River formation
Very gentle unconformity
Hiawatha member of Wasatch formation (minor gas)
Paleocene
Fort Union formation
Gentle unconformity
Upper Cretaceous
Lance formation
Lewis shale (with associated sandstones) (oil and gas)
Mesaverde group
  Almond formation (oil and gas)
  Ericson sandstone (minor gas)
  Rock Springs formation
  Blair formation
Baxter shale

Gas and oil has been found in the Mesaverde group, mostly in sandstones in the Almond formation. To a lesser extent production has been obtained from sandstones within the Lewis shale and near the Lewis-Lance transition zone and from the Ericson sandstone. There is also minor production indicated from sand lenses in the Hiawatha member of the Wasatch.

Table Rock anticline on the southeast flank of the arch is the only structure with demonstrable surface closure. Tertiary gas was discovered here in 1946 with deeper Lewis and Mesaverde discoveries in 1954. Discovery of major gas reserves at Desert Springs in 1958 triggered rapid expansion of exploratory and development drilling which continues to date. Major new field discoveries include Patrick Draw, Arch, Playa, and West Desert Springs. Productive areas have expanded across original Federal unit boundaries and have overlapped and coalesced, causing numerous problems in nomenclature.

Except for Table Rock, all fields discovered to date are stratigraphic traps with minor structural complexities. Usually the oil and gas is found trapped in closed sandstone bodies formed as offshore bars in the shallow Lewis and Almond seas.

The Wamsutter arch is a young upwarp (possibly Pliocene) superimposed across older Tertiary and late Cretaceous structural trends. The older structural patterns are, as yet, imperfectly known and understood.

25. Relation of Latest Cretaceous and Tertiary Deposition and Deformation to Oil and Gas Occurrences in Wyoming: J. D. LOVE, U. S. Geological Survey, University of Wyoming, Laramie; PAUL O. MCGREW, Professor of Geology, University of Wyoming, and HORACE D. THOMAS, State Geologist, Geological Survey of Wyoming, Laramie

Oil and gas have been known in non-marine Tertiary rocks in Wyoming since 1896. Commercial oil or gas pools have been discovered in Paleocene and Eocene rocks in the Green River, Washakie, and Wind River basins. The source of most of this oil and gas is believed to be sediments deposited under lacustrine conditions during Paleocene time and again during Eocene time. Oil and gas production from nonmarine beds of latest Cretaceous age is a recent development.

The diastrophic and depositional history from latest Cretaceous through Tertiary time has a significant bearing on essentially all Wyoming oil and gas fields. The Laramide orogeny began with gentle folding in latest Cretaceous time, reached a climax of intense folding and thrust faulting in earliest Eocene time in most parts of Wyoming, and was essentially completed by latest Eocene time. Conventional Wyoming oil and gas fields are those related to structural traps formed during this orogeny.

The Green River, Wind River, and Hanna basins were sites of deposition of more than 20,000 feet of latest Cretaceous, Paleocene, and Eocene strata. Oligocene, Miocene, and Pliocene beds were deposited across the now completely filled basins and high onto the flanks of partly buried mountains. Volcanic debris from centers within or near Wyoming comprises the bulk of these young strata. Regional uplift, large-scale normal faulting, and rapid degradation that exhumed the mountains and re-excavated the basins occurred in late Pliocene and Pleistocene time. During this episode some of the structures containing oil and gas were significantly modified.

26. Relation of Uplifts to Thrusts in Rocky Mountains: A. J. EARDLEY, University of Utah, Salt Lake City, Utah

The Rockies concerned are those of Montana, Wyoming, Colorado, New Mexico, and the Colorado Plateau of Utah and Arizona, east of the Paleozoic miogeosyncline.

Evidence is presented that suggests that all the Rocky

Mountain features of this region are the result primarily of Laramide vertical uplifts of oval or irregularly broad shape. They generally lack linear, narrow, or sinuous aspect. Some are conspicuously asymmetrical; others are fairly symmetrical; others approach gentle quaquaversal form. The structural relief ranges from 500 feet (Bowdoin dome) to 40,000 feet (Wind River uplift). Later Tertiary faulting, subsidence, sedimentation, and igneous activity have modified these Laramide uplifts considerably in places.

When the thrust faults are charted, they are found to be for the most part marginal to the uplifts. The uplifts of low and intermediate amplitude generally do not have associated border thrusts, but those in which Precambrian rock is exposed in the core commonly are bordered on one side or both by outwardly displaced thrusts. A firmer tie of uplift to border thrust is found in those where a structural relief of 25,000 feet or more exists.

These relations suggest that vertical uplift was the primary deformation and that thrusting was a secondary lateral deformation caused by gravity sliding and flowing. Since the basins were filled with sediments as the uplifts rose, it appears that thrusting is apt not to be related directly to the structural relief of uplift over adjacent basins, but to absolute relief at any one time as uplift exceeded sedimentation.

Anticlines suitable for oil and gas accumulation seem to be related to the marginal gravity creep from the uplifts. The locale is one of interplay of thrusting and folding of the surficial strata, and of sedimentation.

The Rocky Mountain region of uplifts is essentially the igneous province of alkalic and calc-alkalic rocks. Consideration of the origin of these rocks, of the nature of the uplifts, and of geophysical data lead the writer to postulate that the uplifts are due to megasills or lopoliths deep in the silicic (granitic) layer, perhaps near the boundary of the silicic and basaltic layers. It is expected that model experiments will indicate size, shape, and depth of intrusion to produce the various surface structures, and the nature of the border faults.

27. Laramide Sediments along Wind River Thrust, Wyoming: ROBERT R. BERG, Embar Oil Company, Denver, Colorado

The Wind River Mountains of west-central Wyoming are bounded on the southwest flank by a thrust fault which dips 20° NE. and has a maximum vertical displacement of 35,000 feet. Seismic data show the magnitude and character of the fault zone. The fault originated from an overturned basement fold which was subsequently broken and thrust toward the southwest. Uplift of the mountains began by folding during the late Cretaceous, continued throughout the Paleocene, and culminated in thrusting at the end of the Paleocene. Non-marine sediments in the Green River basin adjacent to the uplift were deposited without interruption in a dominantly quiet-water environment, but as uplift progressed, increasingly numerous coarse clastics were derived from the mountain flank. After thrusting, early Eocene fluvial sediments from the uplift spread basinward. Gas occurs at Pinedale in tight sandstones of the Paleocene Hoback formation in a basinal facies. Possibilities for both gas and oil exist farther west where cleaner fluvial sandstones interfinger with the basinal shales.

28. Tectonics and Oil Accumulation in Central Montana: JOHN R. FANSHAWE, Consultant, Billings, Montana

The east-west structural complex, known as the Big Snowy anticlinorium, is believed to be mid-Miocene in age. It was a stable area during the Laramide orogeny, which terminated during the Eocene. Injection of igneous material accompanied and followed the deformation in central Montana. The then increase of crustal thermal conditions probably aided the structural growth, which was principally vertical in expression rather than arcuate and compressional.

Jurassic formations overlie the Amsden, of Pennsylvanian age, throughout the structural province. Paleozoic structure is at variance with the observable surface geology (involving Paleocene through Jurassic formations). This ancient tectonic control is more significant in areas not affected by the mid-Miocene deformation that formed the big and obvious features like Porcupine dome, the Big Snowy Mountain dome, and Woman's Pocket anticline.

Generation and accumulation of oil and gas occurred under structural conditions that existed before the mid-Miocene tectonic pulsations. The present distribution of petroleum pools is due to traps that were not materially affected by the post-Laramide deformation, or traps that were due to secondary migration into newly formed structures. The latter condition has been subject to severe attrition by the increasing effect of artesian waters. The search for new oil should be guided by the more subtle geologic factors of Jurassic and pre-Jurassic stratigraphy and tectonics.

29. Possible Early Devonian Seaway in Northern Rocky Mountain Area: CHARLES A. SANDBERG, Geologist, U. S. Geological Survey, Denver, Colorado

A seaway may have occupied a geosynclinal trough in Washington and Oregon during Early Devonian time. Its existence is postulated from the distribution and sedimentary environment of isolated deposits of Early Devonian and probably Early Devonian age in the northern Rocky Mountains. Regional evidence suggests that the Beartooth Butte formation of Early Devonian age was laid down along the eastern margin of a sea and on the landmass that bordered it in southern and central Montana and northern Wyoming. The Williston basin area in North Dakota was apparently a part of the landmass. The Water Canyon, Maywood, and Ghost River formations which may be in part correlative with the Beartooth Butte were laid down in a near-shore, shallow-water marine environment in northern Utah and southern Idaho, western Montana, and west-central Alberta, respectively. These lie west of the marginal marine deposits of the Beartooth Butte but several hundred miles east of the postulated north-south axis of the seaway.

Discontinuous deposits of the Beartooth Butte formation, which formerly was considered to be a local channel filling at a few localities in northern Wyoming, have now been widely recognized. The formation consists of grayish red and yellowish gray silty dolomite and dolomitic siltstone, sandstone, conglomerate, and breccia. It is generally less than 10 feet but locally as much as 170 feet thick. The continental beds of the Beartooth Butte were laid down on a land surface of generally low relief with karst topography in places. Redbeds filling channels and sinkholes were derived mostly from red soils that had developed on carbonate rocks possibly in a humid, tropical, or subtropical climate. Marginal marine beds of the formation were probably deposited in estuaries, bays, and lagoons along a drowned coast characterized by long, narrow marine embayments.

The Water Canyon formation of Early Devonian age in northern Utah is about 400 feet thick. It is composed of intraformational breccia, silty dolomite, cherty dolomite, and dolomitic sandstone and sandy dolomite con-