nation of orogenic activity. Some intense folding and thrusting post-dates those events just mentioned but is reasonably certain that Laramide compressional deformation had ceased before middle Eocene time in western Montana.

14. E. EARL NORWOOD, Continental Oil Company, Billings, Montana

GEOLOGICAL HISTORY OF CENTRAL AND SOUTH-CENTRAL MONTANA

Central Montana has had a complex structural and sedimentary history, especially the area of today's Central Montana uplift.

Precambrian and Cambrian subsidence allowed deposition of 1300+ feet of clastics in an east-west trending trough roughly coincident with the present-day uplift.

Pre-Devonian uplift and erosion followed stable depositional conditions during Ordovician time. Ordovician has been eroded from the western one-half of the study area. Silurian is absent from the entire study area.

Central Montana uplift area remained high during Lower, Middle and part of Upper Devonian time. Upper Devonian rocks lap onto the uplift and uppermost Devonian finally covered the area. Pre-Mississippian uplift removed these carbonates and shales completely from a large area of the uplift.

Mississippian system is comprised of the carbonate evaporite Madison Group and clastic Big Snowy Group. Stable conditions prevailed through most of Madison deposition, but central Montana began to subside in Late Madison time. The Big Snowy Group was restricted by continued subsidence which downwarped central Montana into a synclinorium.

Early Pennsylvanian streams draining eastern Montana cut valleys in the Central Montana trough. These valleys were filled as the streams attained old age primarily with Big Snowy Group derived sands and shales. This stream-channel deposit, the Lower Tyler Formation, contains the major reservoirs of central Montana, Middle and Late Pennsylvanian sediments covered central Montana, but all of the Late Pennsylvanian was eroded pre-Jurassic time. Pre-Jurassic folding accentuated Mississippian structure.

Jurassic saw uplift in the Belt Mountain area to the west. Jurassic laps onto this high and thickens eastward as well as in the trough area.

Lower Cretaceous deposition was controlled by uplift to the south and thickens from south to north.

The Laramide revolution upwarped the old trough into the Central Montana uplift and also generally folded the old synclines into anticlines as at the Sumatra trend. Isostatic adjustment at basement fault blocks was the force behind the down up down up movements of central Montana.

15. FRANK C. ARMSTRONG and STEVEN S. ORIEL, U. S. Geological Survey, Federal Center, Denver, Colorado

TECTONIC DEVELOPMENT OF IDAHO-WYOMING THRUST BELT

Three stages are evident in the tectonic development of southeastern Idaho and western Wyoming. First, the changing patterns of tectonic elements during deposition; second, development of northward-trending folds and thrust faults; and third, development of block faults that produced horst ranges and graben valleys.

During Paleozoic time about 50,000 feet of marine sediments, mostly limestone and dolomite, were deposited in a miogeosyncline and about 6,000 feet of mixed marine sediments were deposited on the shelf to the east. Detritus came from both east and west recurrently from Cambrian time on. Starting in Mississippian time, the belt between shelf and miogeosyncline, where thicknesses increase markedly, shifted progressively eastward.

During Mesozoic time about 35,000 feet of marine and continental sediments were deposited in the western part of the region and about 15,000 in the eastern, terrestrial deposits becoming increasingly dominant. Western positive areas became the chief source of detritus. The belt of maximum thickening and the site of maximum deposition shifted progressively eastward; maximum thicknesses of succeeding geologic systems are not superposed. In Late Triassic a belt to the west rose and the miogeosyncline started to break up. As Mesozoic time progressed the western high spread eastward, until by the end of the Jurassic the miogeosyncline gave way to intracratonic geosynclinal basins that received thick deposits, particularly in Cretaceous time. Cenozoic sedimentary rocks are products of orogeny in the region.

The second stage which overlapped the first, produced folds overturned to the east and thrust faults dipping gently west in a zone, convex to the east, 200 miles long and 60 miles wide. Stratigraphic throw on many larger faults is about 20,000 feet; horizontal displacement is at least 10 to 15 miles. Lack of metamorphism and mylonite along the faults is striking. From west to east, the thrust faults cut progressively younger beds, have progressively younger rocks in their upper plates, and are estimated to be successively younger. Thrusting started in the west in latest Jurassic and ended in the east perhaps as late as Early Eocene time; detritus shed from emergent upper plates is preserved in coarse terrestrial strata of corresponding ages.

West of the thrust belt is a northwestward-trending area underlain mostly by lower Paleozoic rocks and flanked on east and west by upper Paleozoic and Mesozoic rocks. Scattered pieces of eastward-dipping thrust faults have been reported west of the older rocks. This central area of old rocks has been interpreted as (1) part of a large continuous thrust sheet moved scores of miles from the west, or (2) an uplifted segment of the earth's crust from which thrust sheets to the east and west were derived. Both interpretations have defects: relative thrust ages are difficult to explain under the first; a large positive gravity anomaly, expectable under the second is apparently absent.

Block faulting, the third stage of tectonic development, started in Eocene time. Faulting has continued to the Recent, as indicated by broken alluvial fans, displaced basalt flows less than 27,000 years old, and earthquakes. North-trending and east-trending fault sets are recognized. Old east-trending steep faults in the Bear River Range may be tear faults genetically related to thrusting. Movement along many faults has been recurrent. Patches of coarse Tertiary gravel on the flanks and crests of ranges, for which there is no provenance with present topography, may record reversed vertical movement along some north-trending faults. Present topographic relief of basins and ranges is tectonic.

16. R. J. ROBERTS, E. W. TOOKER, H. T. MORRIS, M. D. CRITTENDEN, and R. K. HOSE, U. S. Geological Survey, Menlo Park, California, and T. M. CHENEY, Palo Alto, California

OQUIRRH AND PHOSPHORIA BASINS IN NORTHWESTERN UTAH, NORTHEASTERN NEVADA, AND SOUTHERN IDAHO

The Oquirrh and Phosphoria basins in northwestern Utah, northeastern Nevada, and southern Idaho are downwarped segments of the Cordilleran geosyncline superposed on a complex structural pattern of Precambrian and early and middle Paleozoic age.

The Oquirrh basin contains Pennsylvanian and Early Permian sedimentary rocks as much as 26,000 feet thick; the area of maximum sedimentation was in west-central Utah. Three principal units are recognized: a lower unit of cyclically bedded bioclastic limestone and sandy limestone, a middle unit of interbedded limestone and quartzite, and an upper unit of quartzite. The lower and middle units were mostly deposited in an offshore shallow water environment; the upper unit in offshore moderately deep water; these grade laterally both eastward and westward into shallow nearshore facies.

The Middle Permian Phosphoria basin was partly coextensive with the Oquirrh basin, but the area of maximum sedimentation was in northeastern Nevada and southern Idaho, where locally 3,500 feet of shale, cherty shale, chert, dolomite, and limestone accumulated. This facies was deposited in an offshore deep-water environment, favoring formation of thick sponge-spicule chert and cherty shale units; these grade southward and eastward into carbonates and shales that were deposited in shallow nearshore environment.

In Cretaceous time the Paleozoic and early Mesozoic rocks of northeastern Nevada and western Utah moved eastward on great thrust plates that extended from southern Utah into Idaho. Movement took place on the Willard-Charleston-Nebo thrust belt in the Wasatch Mountains. Westward continuations of these thrusts crop out in northwestern Utah and eastern Nevada. Imbricate thrusts and tear faults within the upper plate have resulted in complex distribution of late Paleozoic facies.

17. J. G. C. M. FULLER, Amerada Petroleum Corporation, Calgary, Alberta

INDUSTRIAL BASIS OF STRATIGRAPHICAL GEOLOGY

An unprecedented need for a new source of mechanical power in 18th century England, capable of functioning at rates beyond horse-power capacity, was met by coal-fuelled atmospheric engines. They propelled the country into an industrial revolution. Economic force-exerted by big population changes greatly altered husbandry, industry, and transportation. Acts of Parliament relating to surveying and draining of lands, mines, and construction of roads and canals multiplied six-fold in the second half of the century.

A land drainer and mineral surveyor, in the course of canal-building in the east Somersetshire coal-field, discovered and then exploited the stratigraphical principle of natural order and regularity in fossil occurrence—each Class assigned to its peculiar Stratum (William Smith, 1796). He had employed the prime stratigraphical principle of order and regularity among the strata (drawing on colliers' lore and probably a published record), during underground surveys of the mines (1791–93). Seventy-two years earlier a wide-ranging account of the same coal-field had illustrated a definitive succession, strike, dip, subcrop, outcrop, concealed faulting and unconformity (John Strachey, 1719), and established by direct measurement underground that "the *Strata* lye shelving and regular, and observe a regular course." It codified the colliers' tradition. A century later this knowledge, unchanged in principle but enlarged in scope, achieved generality in the academic realm.

18. FRANK E. KOTTLOWSKI, New Mexico Bureau of Mines, Socorro, New Mexico

SEDIMENTARY BASINS OF CENTRAL AND SOUTHWESTERN NEW MEXICO

Major sedimentary basins in this, the eastern part of the Basin and Range province, are the Orogrande and Pedregosa basins of Mississippian, Pennsylvanian, and Wolfcampian age, the San Mateo-Lucero and Estancia basins of Pennsylvanian age, the Carrizozo and Quemado-Cuchillo (Foster, 1957) evaporite basins of Leonardian age, the Early Cretaceous basin near the Hatchet Mountains, and the continental basins of vols canic piles of Late Cretaceous age near Elephant Butte and Steeple Rock. Numerous Cenozoic intermontane graben basins dot the region, with the southern part of a long north-south string of interconnected grabens now followed by the Rio Grande and called the Rio Grande structural depression. Sediments filling the Cenozoic basins are mainly of Late Miocene. Pliocene, and Pleistocene in age.

Pre-Mississippian Paleozoic rocks remain only south of about 33°45′ N. Lat. The basal Paleozoic unit, the Cambrian-Ordovician Bliss Sandstone, thickens depositionally southward and southwestward. The Early Ordovician El Paso Limestone thins northward due to intra-Ordovician erosion whereas the Middle and Late Ordovician Montoya Dolomite is relatively uniform in thickness where overlain by Silurian rocks. The Silurian Fusselman Dolomite thins northward partly due to erosion during Late Silurian and Early Devonian time. The Devonian shaly strata are relatively uniform in thickness, although marking the first large scale influx of clay and silt; as with all older Paleozoic rocks they appear to have been deposited in shallow epicontinental seas.

The Pedregosa basin was autogeosynclinal, receiving thick deposits of Middle Mississippian crinoidal limestones, Late Mississippian arenaceous calcarenites, Pennsylvanian limestones, and Wolfcampian interbeds of limestone, black shale, and redbeds. The Orogrande basin began as a poorly defined autogeosyncline in which siliceous Middle Mississippian limestones and Late Mississippian arenaceous calcarenites were deposited, then became zeugogeosynclinal during Late Pennsylvanian time as detritus was swept westward from the Pedernal landmass, and during Wolfcampian time was filled by limestones and shales that grade northward into redbeds. The Estancia basin was a small Pennsylvanian zeugogeosyncline, and the San Mateo-Lucero basins were autogeosynclines connecting the Pennsylvanian seas northward toward the San Juan and Paradox basins.

19. JOHN EMERY ADAMS, Consultant, Midland, Texas

STRATIGRAPHIC-TECTONIC DEVELOPMENT OF DELAWARE BASIN

The Delaware basin of west Texas and southeast New Mexico is the most negative structural unit of the southern Permian basin. It occupies an upper Paleozoic intermontane trough between the Central Basin Platform Mountains and the Ancestral Rockies. Before the development of these ranges, this area formed part of the broad Tabosa sag which accumulated shelf deposits from Lower Ordovician through Mississippian. These sediments consisted largely of carbonates and shallow water shales. The Delaware basin, as a structural and stratigraphic unit, began developing in Early Pennsylvanian. Extensive subsidence coupled with compressive faulting converted the axial portion of the Tabosa sag into the Central Basin Platform Mountains and raised the Diablo arch to the west. An east dipping half graben, the Delaware basin, developed between these uplifts. Water depths in the southern and eastern portions of this basin probably exceeded 2,000 feet throughout the Pennsylvanian. The deep areas are characterized by starved shale sections. Pennsylvanian shelf limestones cover the shallows along the north and northwest margins. Permian tectonism deepened the basin and elevated the marginal mountains. Fault displacements