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TECTONIC DEVELOPMENT OF IDAHO-WYOMING THRUST BELT[1]

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ABSTRACT

Three stages are evident in the tectonic development of southeastern Idaho and western Wyoming. First are 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 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 feet in the eastern part, with 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 were relocated progressively eastward; maximum thicknesses of succeeding geologic systems are not superposed. In Late Triassic a belt on 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 toward 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 on 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.

INTRODUCTION

Many hundreds of man-years have been devoted to geologic studies of the thrust belt of southeastern Idaho and western Wyoming. The stimulus has been economic.

Classic reports resulted from the search for coal, oil, and gas (Veatch, 1907; Schultz, 1914), and phosphate (Mansfield, 1927). The region

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[2] United States Geological Survey.

Material for the paper has been assembled from many sources and we gratefully acknowledge this debt. We also thank many of our colleagues on the U.S. Geological Survey for their constructive discussion and criticism. Special thanks are due E. D. McKee, W. W. Mallory, A. E. Roberts, A. L. Benson, C. A. Sandberg, W. W. Rubey, and J. I. Tracey for use of unpublished material. Our greatest debt is owed William W. Rubey. Much of the information and many of the ideas on which this paper is based were originally set forth by him (Rubey, 1955; Rubey and Hubbert, 1959), and the paper was greatly improved as the result of his criticism. The paper also profited from the suggestions of G. D. Robinson and W. H. Hays.

contains the best deposits of the western phosphate field, one of the large phosphate fields of the world, and the phosphate is being mined at an increasing rate for fertilizer and chemicals. Along its eastern margin the region contains oil and gas fields that likely are but a small sample of potential reserves. Coal continues to contribute to the region's economy in the new steam-generating plants constructed by Utah Power and Light Company, near strip mines a few miles south of Kemmerer, Wyoming.

Geologic complexities of the region have made a sound scientific approach necessary for intelligent exploration. It is thus no accident that economically motivated studies have resulted in important contributions to geologic science. The region contains some of the earliest thrust faults described in North America; the Bannock and Absaroka thrust faults are widely known and discussed in many textbooks on structural geology.

Despite the amount of work already done, parts of the region have not been studied since Peale's (1879) reconnaissance for the Hayden Territorial Survey and answers to fundamental questions continue to be elusive. Accordingly, this paper is a progress report that summarizes some of the information and ideas that have emerged in recent years and some of the problems that remain.

SCOPE OF PAPER

The region discussed is southeast of the Snake River Plain, west of the Green River basin, and north of the Utah State line (Fig. 1). The discus-

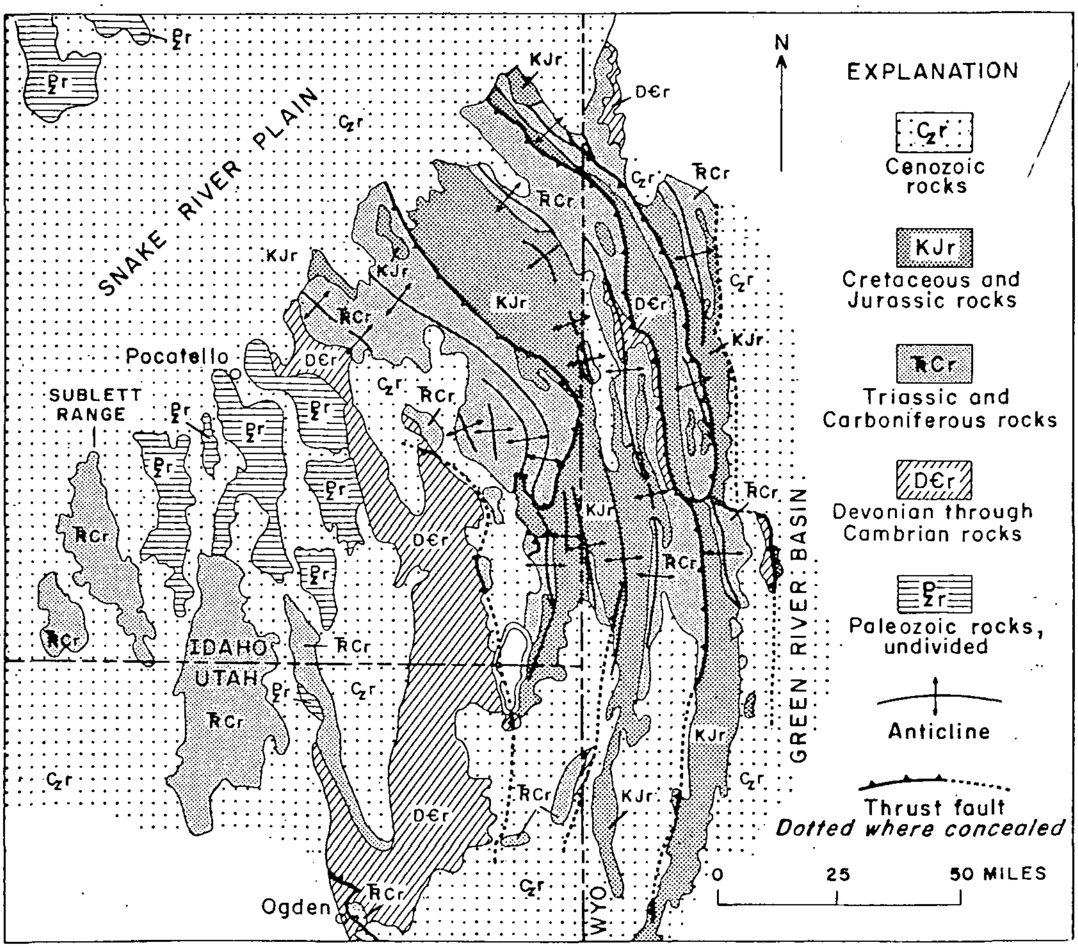

FIG. 1.—Generalized geologic map of Idaho-Wyoming thrust belt. Modified from "Geologic Map of the United States" (Stose, 1932).

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sion is divided into three parts. The first deals with the changing patterns of deposition during the tectonic evolution in Paleozoic and early Mesozoic time of a miogeosyncline on the west and a shelf on the east; the second deals with regional deformation that formed northward-trending folds and large thrust faults in late Mesozoic and early Tertiary time; and the third deals with block faults, active since Eocene time, that have produced the present horst ranges and graben valleys.

Part 1. Depositional History

Aggregate thicknesses of sedimentary rocks deposited in southeastern Idaho and adjacent western Wyoming during Paleozoic and Mesozoic time are about 100,000 feet. The entire thickness was not deposited at any one place, however; rather, the site of maximum deposition changed with time. The changing patterns of deposition are shown in isopachous maps and diagrammatic cross sections for each of the geologic systems of the Paleozoic and Mesozoic Eras. Elements emphasized are: the platform on the east, where the sedimentary rocks are thin; the miogeosyncline on the west, where the rocks are thick; and a transitional area between. The position of this transitional area changed from system to system. Where data are available the sites of maximum deposition are shown; the positions of these also changed from system to system. The isopachous maps show the present distribution of thicknesses; the region is not yet sufficiently well understood to construct worthwhile palinspastic maps.

CAMBRIAN

The isopachous map of the Cambrian System excludes the basal quartzite (Fig. 2). A meaningful isopachous map of the quartzite is difficult to construct because different geologists have placed the Cambrian-Precambrian contact at different places in the thick sequence of conformable quartzite and argillite in the western part of the area. Accurate placement of this contact is one of the problems yet to be solved. The basal quartzite in the diagrammatic cross section is transgressive and is called Brigham on the west and Flathead on the east. Early Cambrian trilobites are present near the top of the Brigham Quartzite in the Portneuf Range (Oriel, 1964). The Flathead is Middle Cambrian.

Above the quartzite is a thick sequence of carbonate rocks, shale, and some arkosic quartzite; the sequence thins eastward. The isopachous map includes essentially the rocks deposited during Middle and Late Cambrian time. Westward thickening appears about 15 miles east of the Idaho-Wyoming State line and the site of maximum deposition was somewhere on the west. The Worm Creek Quartzite Member of the St. Charles Limestone contains abundant detrital cleavage fragments of potassium feldspar and some of the rock is arkose. The Worm Creek is not present in Wyoming; in Idaho it thickens westward and its feldspar content increases. This evidence indicates that during Late Cambrian time there was a source area at the west underlain by granite or granitic metamorphic rocks. During most of Paleozoic time major source areas both on the east and on the west (Rubey, 1955; Ross, 1962) shed detritus recurrently into the miogeosyncline.

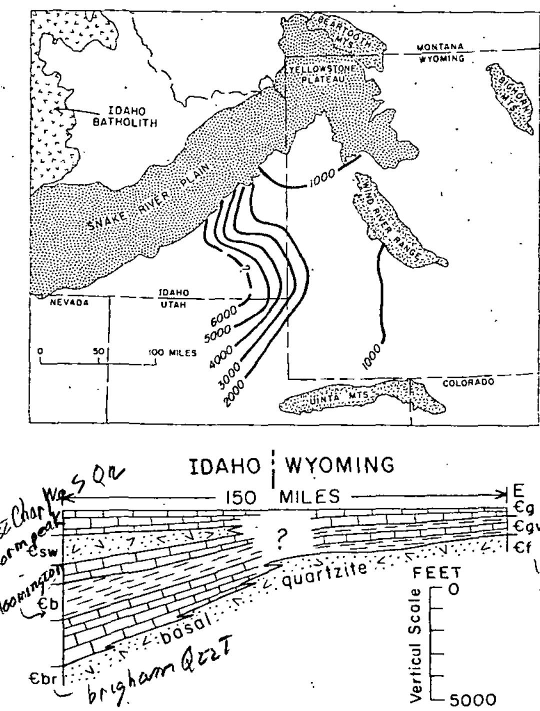

FIG. 2.—Isopachous map of Cambrian System and generalized section. Contoured thicknesses are of Cambrian rocks above basal quartzite. Thicknesses drawn in part from Lochman-Balk (1960) and Trimble and Carr (1962). Stratigraphic units shown in section: Єsw, Worm Creek Quartzite Member of St. Charles Limestone; Єb, Bloomington Formation; Єbr, Brigham Quartzite; Єg, Gallatin Limestone; Єgv, Gros Ventre Formation; Єf, Flathead Quartzite.

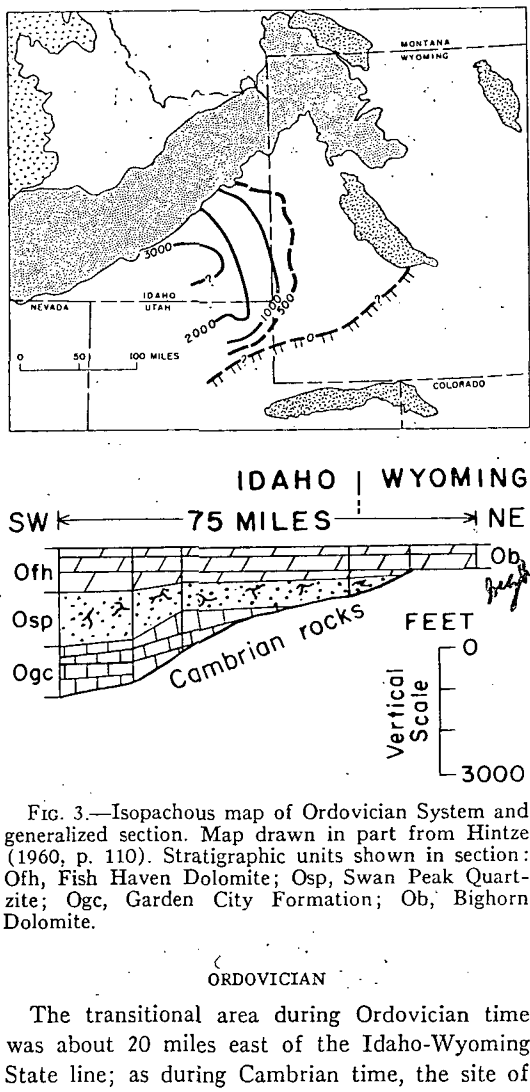

FIG. 3.—Isopachous map of Ordovician System and generalized section. Map drawn in part from Hintze (1960, p. 110). Stratigraphic units shown in section: Ofh, Fish Haven Dolomite; Osp, Swan Peak Quartzite; Ogc, Garden City Formation; Ob, Bighorn Dolomite.

ORDOVICIAN

The transitional area during Ordovician time was about 20 miles east of the Idaho-Wyoming State line; as during Cambrian time, the site of maximum deposition was on the west (Fig. 3). In Idaho, Lower and Middle Ordovician rocks are assigned to the Garden City Limestone and Swan Peak Quartzite, respectively. The entire thickness of Ordovician rocks in western Wyoming is included in the Upper Ordovician Bighorn Dolomite, which is correlative with the Fish Haven Dolomite in Idaho.

The Swan Peak is white, pure quartzite composed of uniformly medium-sized, frosted, well-rounded quartz grains of high sphericity. The grains are probably of second or higher cycle. In this part of Idaho, most of the sand may have been derived from the north, as suggested by Ross (1964, p. 1542, 1551), but it is difficult to visualize only a northern source for the large volume of quartzose detritus in the Ordovician quartzites that extend southwest through Utah and into Nevada.

SILURIAN

Silurian rocks, represented by the Laketown Dolomite in southeastern Idaho and adjacent Utah (Fig. 4), have not been found in western Wyoming (Berdan and Duncan, 1955). The absence of Lower and Middle Ordovician and Silurian rocks in Wyoming was formerly interpreted as suggesting non-deposition during those times. The recent discovery of fossiliferous exposures of Middle (?) and Upper Ordovician and Silurian rocks among the Precambrian crystalline rocks 22 miles southeast of Laramie, Wyoming (Chronic and Ferris, 1961), however, suggests a different interpretation. Consequently, the zero lines on the Ordovician and Silurian isopachous maps (Figs. 3 and 4) probably are erosional rather than depositional limits.

DEVONIAN

The isopachous map of the Devonian System shows local basins west of the Idaho-Wyoming State line in which thick deposits accumulated (Fig. 5).

Devonian rocks in western Wyoming have been mapped as the Darby Formation, which is divisible into a lower dolomite, comparable and correlative with the Jefferson Dolomite, and an upper siltstone and limestone unit that is correlated with the Three Forks Limestone. In southeasternmost Idaho the names Jefferson and Three

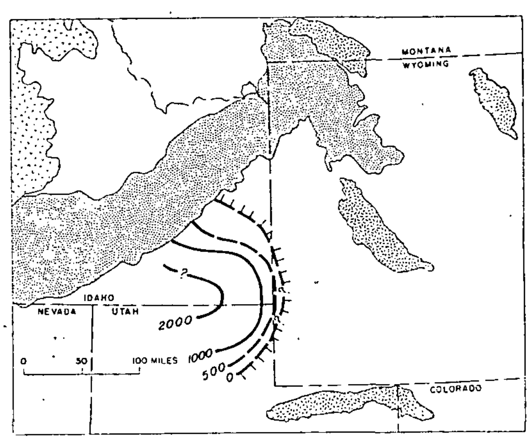

FIG. 4.—Isopachous map of Silurian System. Thicknesses in Utah from Hintze (*in* Rush, 1963, p. 17).

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Forks have been used. In north-central Utah the Jefferson Formation is divided (Williams, 1948, p. 1140) into a lower member, the Hyrum Dolomite Member that correlates with the Jefferson Dolomite, and an upper member, the Beirdneau Sandstone Member that correlates with the Three Forks Limestone. Because fine-grained quartz sandstone is present in the top of the Jefferson in part of southeastern Idaho, and because farther northeastward the sandstone of the Beirdneau grades laterally into the siltstone and limestone of the upper division of the Darby, the sandstone in the Beirdneau likely was derived from the west or southwest.

Below the Hyrum in Utah (Williams, 1948, p. 1138; Williams and Taylor, 1964) and in extreme southeastern Idaho (Armstrong, 1953; Coulter, 1956, p. 30) is the Lower Devonian Water Canyon Formation, which consists of interbedded dolomite, argillaceous and silty dolomite, cross-bedded quartz sandstone, and calcareous quartz sandstone. Lower Devonian rocks of this type have not been recognized in western Wyoming. The presence of the Bighorn Dolomite on the east in Wyoming, blanketing underlying possible sources of quartz sand, requires that Osmond's (1962, p. 2052-54) interpretation of an eastern provenance for the quartz sand in the Water Canyon Formation and Sevy Dolomite in Utah and Nevada be modified for the sand in the Water Canyon in Idaho. The writers interpret the quartz sand in the Water Canyon in southeastern Idaho as having been derived from the southwest, transported by long-shore currents flowing northeastward along the eastern margin of the miogeosyncline.

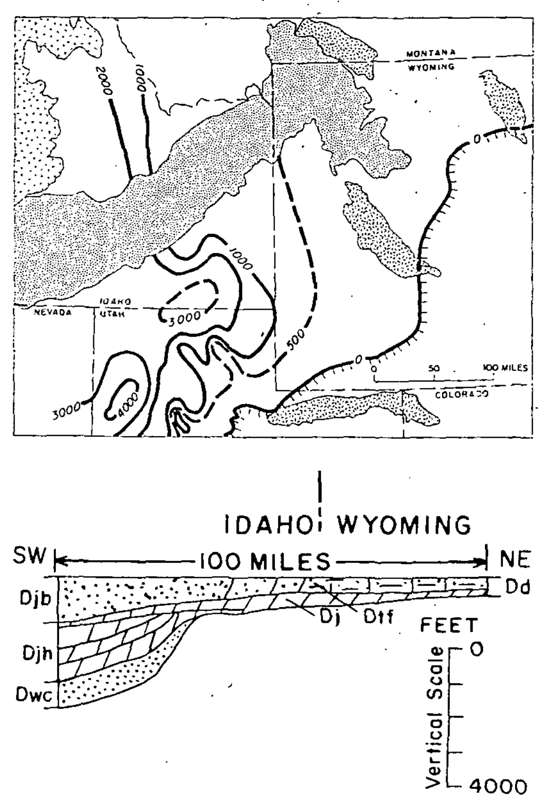


FIG. 5.—Isopachous map of Devonian System and generalized section. Thicknesses in Utah from Rigby (1963, p. 78); in Wyoming, partly from C. A. Sandberg (unpub. data). Stratigraphic units shown in section: Djb, Beirdneau Sandstone Member of Jefferson Dolomite; Djh, Hyrum Dolomite Member of Jefferson Dolomite; Dwc, Water Canyon Formation; Dtf, Three Forks Limestone; Dj, Jefferson Dolomite; Dd, Darby Formation.

MISSISSIPPIAN

Mississippian rocks thicken markedly westward from about 40 miles west of the Idaho-Wyoming State line (Fig. 6). During Cambrian through Devonian time this transitional area between miogeosyncline and shelf was east of its position in Missisippian time. From Mississippian time on, however, the position of the transitional area reversed with time and thenceforth it lay progressively farther to the east.

Because of facies changes and other stratigraphic complexities, Mississippian rocks in the region have been mapped in different ways and assigned different formational names. In the westernmost part of the region (not shown on Figure 6) Mississippian rocks have been called, in ascending order, Lodgepole Limestone, Deep Creek Formation, Great Blue Limestone, and Manning Canyon Shale (Carr and Trimble, 1961). In most of southeastern Idaho, however, Mississippian rocks have been mapped as two formations, the Madison Limestone and the overlying Brazer Limestone (Mansfield, 1927). In parts of adjacent western Wyoming the Mississippian consists of a basal carbonate unit and the lower part of the overlying Amsden Formation. In surface mapping the Madison and Brazer have not been differentiated; instead they have been mapped together as the basal carbonate unit, Madison and Brazer undivided (Rubey, 1958).

Mississippian nomenclature in the region has been modified in recent years. The name Brazer

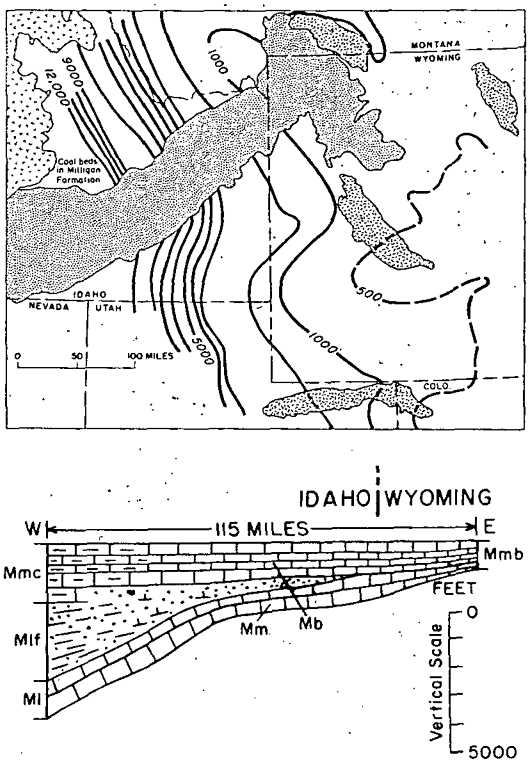


FIG. 6.—Isopachous map of Mississippian System and generalized section. Thicknesses partly from Strickland (1956, p. 52) and A. E. Roberts (unpub. data). Stratigraphic units shown in section: Mmc, Monroe Canyon Formation; Mlf, Little Flat Formation; Ml, Lodgepole Limestone; Mb, Brazer Limestone; Mm, Madison Limestone; and Mmb, Madison and Brazer Limestones, undivided. Lower part of Amsden Formation not shown in section.

was restricted in 1959 to its occurrence in the Crawford Mountains, Utah (Sando, Dutro, and Gere, 1959), and the Brazer Limestone of former usage in southeastern Idaho was subsequently redescribed as the Chesterfield Range Group, consisting of the Little Flat Formation and the overlying Monroe Canyon Limestone (Dutro and Sando, 1963). In the same article (Dutro and Sando, 1963) the name of the unit previously mapped as Madison Limestone (Mansfield, 1929, p. 23) was changed to Lodgepole Limestone. Fine-grained sandstone in the lower part of the Brazer, now named the sandstone member of the Little Flat Formation, is the stratigraphic equivalent of the Humbug Formation to the southwest, The Humbug is slightly thicker and coarser-grained than the sandstone member of the Little Flat, and contains detrital grains of microcline and plagioclase (Gilluly, 1932, p. 26-29); both minerals have been recognized recently in the Little Flat Formation in the Fish Creek Range. Accordingly, the sand in the Little Flat is interpreted as having been derived from a source area on the southwest.

The presence in Mississippian time of land on the northwest also is indicated by coal beds in the Milligen Formation (Umpleby, Westgate, and Ross, 1930, p. 26) in the Wood River region of Idaho north of the Snake River Plain (Fig. 6).

PENNSYLVANIAN

A large amount of westward thickening of Pennsylvanian rocks is apparent about 20 miles west of the Idaho-Wyoming State line (Fig. 7), and the site of maximum deposition is farther west, as shown. The upper part of the Amsden Formation and the lower and middle parts of the Wells Formation make up the Pennsylvanian in

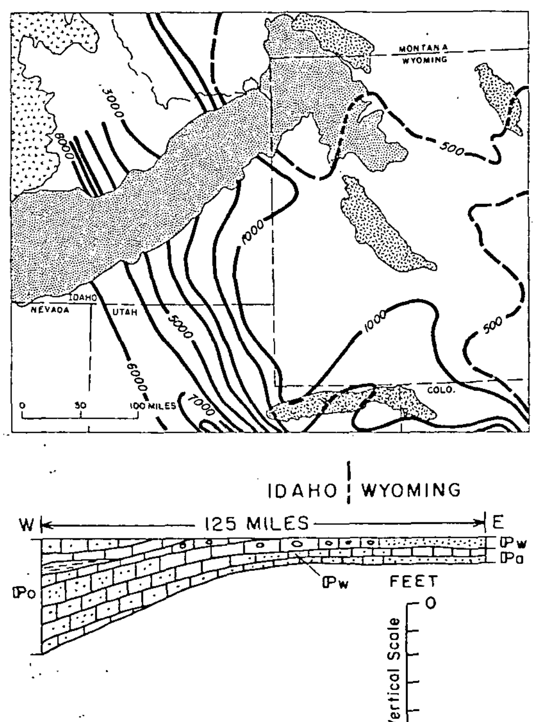


FIG. 7.—Isopachous map of Pennsylvanian System and generalized section. Thicknesses partly from Williams (1962, p. 181) and W. W. Mallory (unpub. data). Stratigraphic units shown in section: IPo, Oquirrh Formation; IPw, Wells Formation, lower and middle parts; and IPa, Amsden Formation, upper part.

western Wyoming. In southeasternmost Idaho the lower and middle parts of the Wells are the only Pennsylvanian rocks. Farther west in Idaho, Pennsylvanian rocks are assigned to the Oquirrh Formation (Carr and Trimble, 1961). The proportion of sandstone in Pennsylvanian rocks increases eastward, which suggests a source on the east. Westward from southeasternmost Idaho, however, Pennsylvanian rocks contain a large amount of sandstone and, although the writers do not have supporting quantitative data, their impression is that the total amount of the quartz sand fraction in the thick western sequence exceeds that in the thin eastern sequence. The large amount of sandstone in the Pennsylvanian rocks on the west, the presence of thick, coarse conglomerate beds in the Wood River Formation north of the Snake River Plain and east of the Idaho batholith (Umpleby, Westgate, and Ross, 1930, p. 32; Ross, 1937, p. 37), near the 8,000-foot isopachous line (Fig. 7), indicate a western source. Detritus in Pennsylvanian rocks of southeastern Idaho and adjacent Wyoming probably was derived both from the east and from the west.

PERMIAN

By Permian time, the eastern margin of the miogeosyncline was still farther east, close to the Idaho-Wyoming State line. The axis of maximum deposition lies between the 9,000-foot isopachous lines and trends northeastward (Fig. 8). A high area of similar trend was present farther to the west (McKee, Oriel, and others, in press).

The upper part of the Wells Formation, now assigned to the Grandeur Tongue of the Park City Formation (McKelvey and others, 1959, p. 12), and the Phosphoria Formation were deposited in Permian time. Pronounced thickening westward resulted almost wholly from thickening of the lower unit that is roughly equivalent to the top of the Wells. The Wells is interbedded sandstone and limestone that probably were deposited in shallow water. The sand may have been derived from both east and west. The Phosphoria is mudstone, chert, phosphorite, and limestone and was deposited in deep water.

TRIASSIC

All Paleozoic rocks in southeastern Idaho were deposited in a marine environment. Lower Triassic rocks are also marine, but the rest of the Triassic is non-marine.

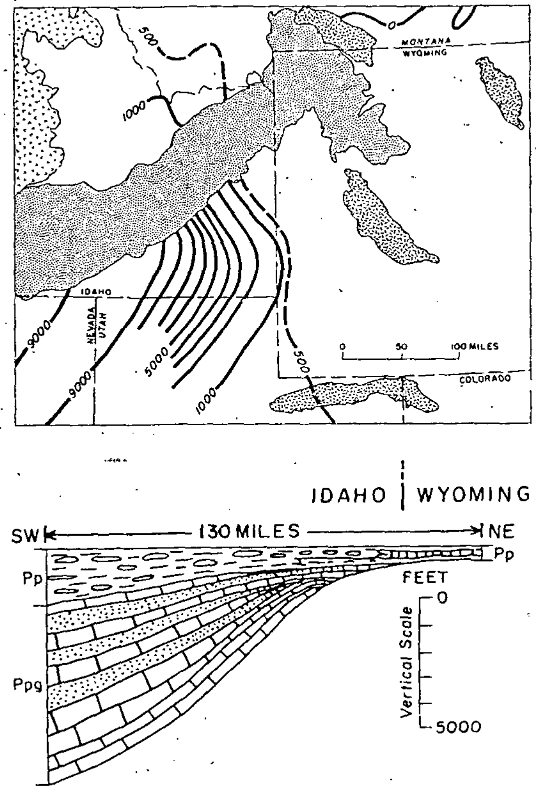


FIG. 8.—Isopachous map of Permian System and generalized section. Map generalized after McKee, Oriel, and others (in press). Stratigraphic units shown in section: Pp, Phosphoria Formation; and Ppg, Grandeur Tongue of Park City Formation which occurs at top of, and has been mapped with, upper part of Wells Formation.

Triassic sediments thicken markedly westward from about 30 miles east of the Idaho-Wyoming line, and the center of a deep basin is shown by the 8,000-foot isopach line (Fig. 9). In central Idaho west of the basin, a northeast-trending ridge rose early in Late Triassic time, and shed coarse detritus into the basin on the southeast to form the Higham Grit, which probably was deposited as coalescing fans along a mountain front (McKee and others, 1959, p. 17). The rise of this ridge, perhaps foreshadowed in the Permian, indicates the start of the breakup of the miogeosyncline.

JURASSIC

During Jurassic time the familiar pattern of shelf on the east and geosyncline on the west,

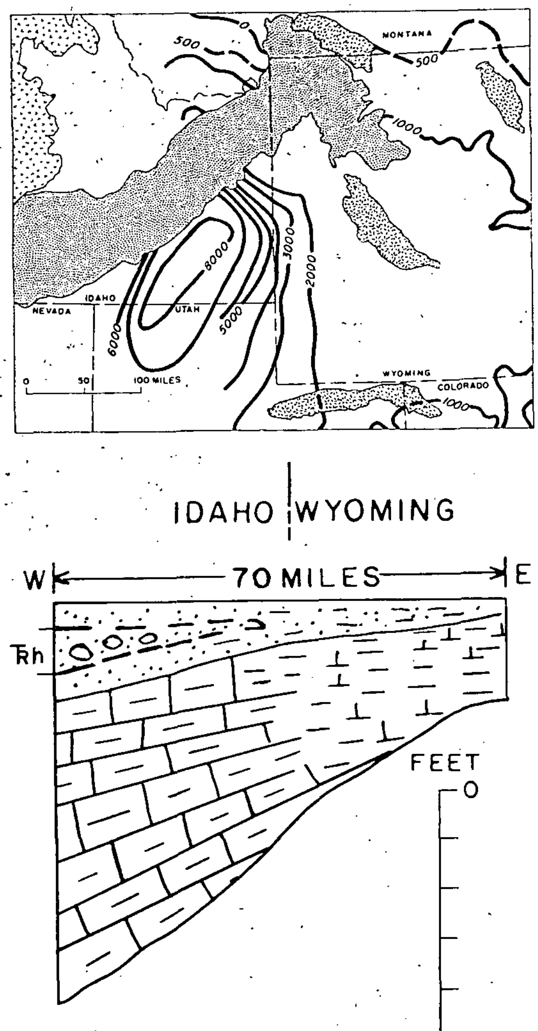


FIG. 9.—Isopachous map of Triassic System and generalized section. Map generalized from McKee and others (1959, pl. 5). Stratigraphic unit designated on section is Higham Grit, Trh.

though evident, is not as sharply defined as in older systems, and thick deposits of sedimentary rocks are present in western Wyoming (Fig. 10). The location of the western margin of the basin is not known, but it probably was not very far west. The non-marine conditions of Late Triassic persisted into Early Jurassic time. The Late Triassic northeast-trending high in central Idaho persisted into the Early Jurassic and supplied detritus for the Nugget Sandstone. During this time the high appears to have spread eastward and perhaps the relief was less. Subsequently the sea returned and the Twin Creek Limestone, Preuss Sandstone, and Stump Sandstone were deposited under marine conditions. In early Late Jurassic time the high on the west rose, again spread eastward, and shed detritus now found in the Preuss and Stump.

LOWER CRETACEOUS

During Early Cretaceous time the axis of a deep, north-trending basin was 5-10 miles west of the Idaho-Wyoming line (Fig. 11). In latest Jurassic or earliest Cretaceous time, parts of southeastern Idaho were raised and mountains were formed. Coarse detritus was deposited in

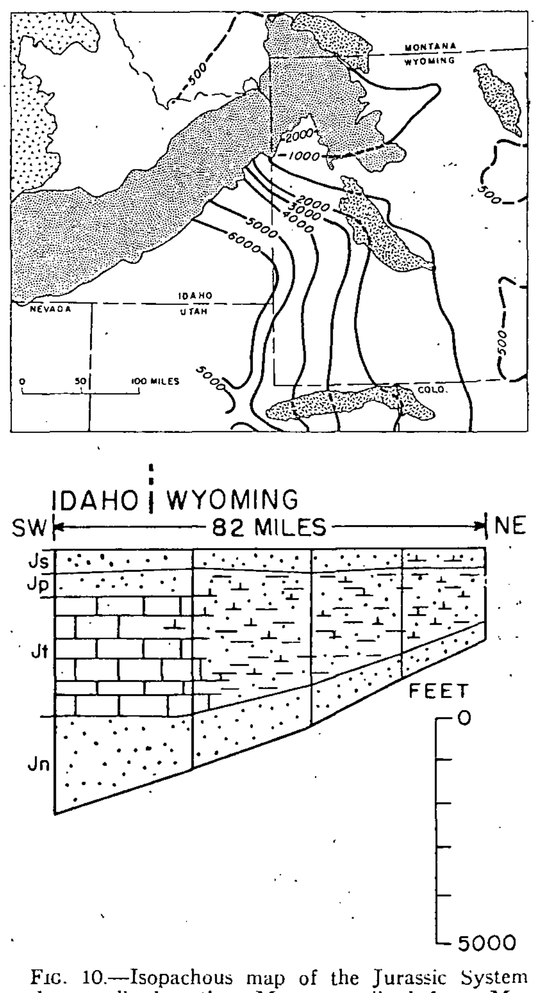


FIG. 10.—Isopachous map of the Jurassic System and generalized section. Map generalized from McKee and others (1956, pl. 3). Stratigraphic units shown on section are: Js, Stump Sandstone; Jp, Preuss Sandstone; Jt, Twin Creek Limestone; Jn, Nugget Sandstone.

coalescing alluvial fans to form the Gannett Group, and orogenic sediments, such as the Wayan Formation,[3] continued to be deposited throughout Early Cretaceous time. Because Lower Cretaceous sediments probably were not deposited west of the Bear River Range (Armstrong and Cressman, 1963, p. J11), the western parts of the isopachous lines may be shown incorrectly on the map. The Gannett and Wayan thin markedly eastward and become finer-grained.

UPPER CRETACEOUS

In Late Cretaceous time an axis of maximum deposition was 10-15 miles east of the Idaho-Wyoming line (Fig. 12). Farther east are other basins in which thick prisms of sediments were deposited. In the western basin probably more than two-thirds of the rocks were deposited in early Late Cretaceous (Colorado) time, whereas in the eastern basins most of the rocks were deposited in late Late Cretaceous (Montana) time. In a sense this reflects continued eastward movement with time of the site of maximum deposition. Detritus in sandy and partly conglomeratic tongues in the Frontier, Hilliard, and Adaville Formations was derived from the west and northwest.

PATTERNS OF DEPOSITION

The systemic isopachous maps show gross patterns, in addition to the features already mentioned. These gross patterns, however, because of insufficient information, may be more apparent than real. Isopachous lines on the Cambrian through Silurian maps are strongly concave westward, and the axis of concavity trends slightly north of east. The Devonian map is characterized by a subdued westward concavity and a northward trend for the eastern margin of the miogeosyncline. After Devonian time the eastern margin of the miogeosyncline had a well-defined northward to northwestward trend, and the axis of concavity had a northeastward trend. These changes in pattern in the transitional Devonian

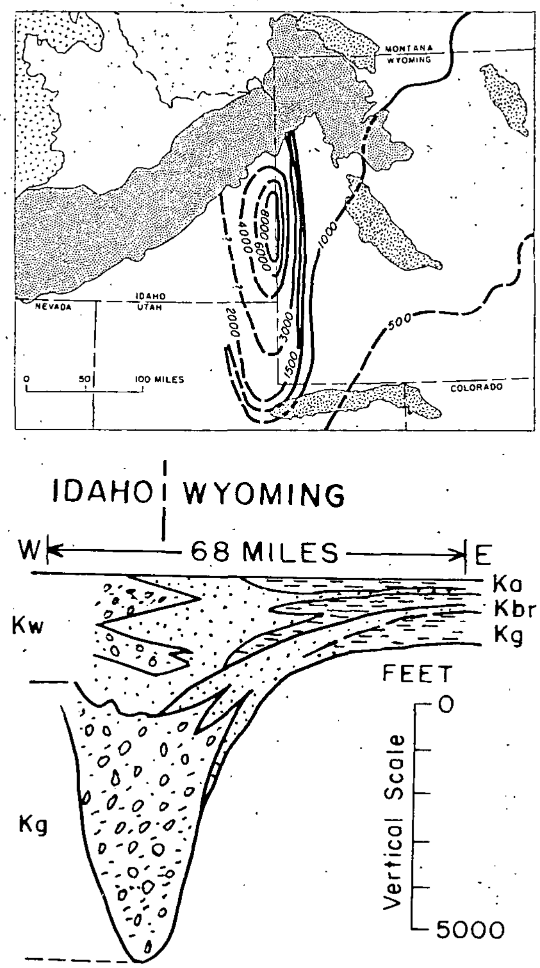


FIG. 11.—Isopachous map of the Lower Cretaceous Series and generalized section. Map modified from Haun and Barlow (1962, p. 16). Stratigraphic units shown on section: Kw, Wayan Formation; Kg, Gannett Group; Ka, Aspen Formation; Kbr, Bear River Formation.

Period may be related to tectonic activity—perhaps the Antler orogeny (Roberts and others, 1958)—on the west. These changes in pattern also may help explain the greater continuity northward, across the eastern part of the Snake River Plain, for upper than for lower Paleozoic stratigraphic units.

The northerly trend of the eastern margin of the miogeosyncline persisted into Cretaceous time and the isopachous lines lost their former westward concavity. During Jurassic time, however, the eastern margin of the miogeosyncline is not well defined. Can the Jurassic Period be compared

[3] Although the Wayan Formation has previously been assigned to the Lower(?) and Upper Cretaceous, it is here regarded as Lower Cretaceous. Recent studies in the type area, particularly by W. W. Rubey, have shown that many of the rocks mapped as Wayan belong to the Gannett Group. The younger rocks present are western facies of the Bear River and Aspen Formations of Early Cretaceous age and are arbitrarily depicted in the Figure 11 cross section to be about 3,000 feet thick.

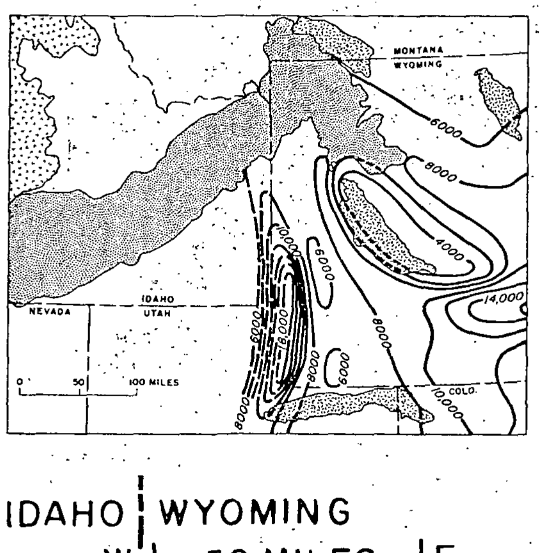


FIG. 12.—Isopachous map of the Upper Cretaceous Series and generalized section. Map generalized from Weimer (1961, p. 18). Stratigraphic units shown in section: Kav, Adaville Formation; Kh, Hilliard Shale; Kf, Frontier Formation; Kl, Lance Formation; Klw, Lewis Shale; Krs, Rock Springs Formation; Kb, Baxter Shale. Relation of western sequence to eastern sequence, shown as now commonly accepted, has not been established.

with the Devonian as an unsettled, transitional period after which a different pattern emerged in response to new forces? Were the deep, north-trending Cretaceous basins true descendants of the miogeosyncline? They may not have been, for these deep basins developed on the edge of a cratonic area that had been moderately stable for the previous 450 million years. Certainly during Late Cretaceous time a different pattern developed in Wyoming. During latest Cretaceous (Lance) time two deep eastward-trending basins began to form on the shelf in Wyoming, one across northern Wyoming and the other across southern Wyoming (Love and others, 1963, Fig. 4). The northern basin extended from the vicinity of Yellowstone Park east to the Black Hills and later developed into the Wind River and related basins; the southern one extended across south-central Wyoming and later developed into the Great Divide and related basins.

The sedimentary record thus indicates that during Paleozoic time there was a miogeosyncline on the west and a platform on the east. A thick accumulation of marine strata, mostly limestone and dolomite, was deposited across the area. Throughout Paleozoic time detritus came recurrently from both the east and the west. Beginning in Mississippian time the miogeosyncline was shifted eastward; at the same time the site of maximum deposition may also have shifted eastward, a trend which, with temporary reversal in the Permian, continued into the Mesozoic.

These shifts in the position of the miogeosyncline continued during the Mesozoic when marine and continental sedimentary rocks were deposited across the area. A "high" on the west became the principal source of detritus, and with the passage of time increasing proportions of continental strata were deposited, finally to the exclusion of marine sediments. As Mesozoic time progressed, the high on the west spread eastward until the miogeosyncline was destroyed in Late Jurassic time. In Late Cretaceous time basins developed on what had been the stable, cratonic platform on the east.

Destruction of the miogeosyncline in late Mesozoic time was accompanied by the development of large north-trending folds and by eastward movement on thrust faults along the eastern flank of the miogeosyncline. Thus the second chapter of tectonic history is entered.

PART 2. THRUST FAULTING

The thrust belt forms an eastwardly convex, arcuate zone about 200 miles long and 60 miles wide, extending from the Snake River Plain southward into Utah (Fig. 13). It has been said (Rubey, 1955, p. 125) to consist of parts of Idaho and Utah that were pushed, or slipped, into Wyoming between the Teton Mountain and Uinta Mountain buttresses of Precambrian rock. The major thrusts to be discussed are, from west to east, the Paris, the Absaroka, the Darby, the Prospect, and the Hogsback.[4] The probable ages of the Meade, Crawford, and La Barge thrusts are shown in illustrations.

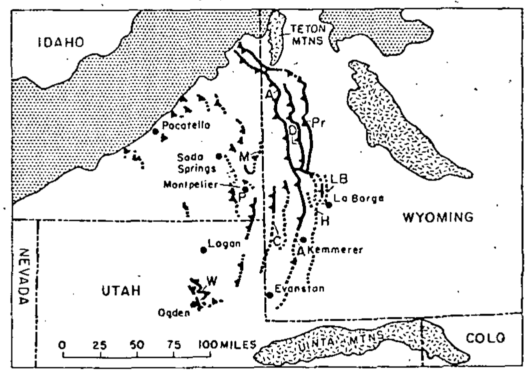


FIG. 13.—Mapped traces of major thrust faults. Solid line indicates exposed fault trace; broken line indicates concealed fault trace. Major faults shown: P, Paris; M, Meade; C, Crawford; A, Absaroka; D, Darby; Pr, Prospect; H, Hogsback; LB, La Barge; W, Willard. Modified from Rubey (1958); and Armstrong and Cressman (1963).

STRUCTURAL RELATIONS OF FAULTS

The thrust faults of the Idaho-Wyoming thrust belt are unlike many in the world in that strata involved are unmetamorphosed and no major fault breccia or mylonite is present. In structure sections (Fig. 14) prepared by Rubey (Rubey and Hubbert, 1959, p. 188), the Absaroka, Darby, and Prospect thrust faults are shown dipping slightly to moderately westward. Drilling has confirmed low westward dip for the Hogsback thrust (not shown in Figure 14) about 40 miles south of the cross sections; there the average dip of the Hogsback thrust, which has been penetrated by several wells across a downdip direction of 10 miles, is about 15° W. The Darby and Prospect faults mostly parallel bedding in the upper plates of the thrusts, although locally they cut across bedding. In the upper two cross sections the Absaroka fault cuts across bedding both above and below the fault surface, whereas in the lower two cross sections the Absaroka is like the Darby and Prospect faults and parallels bedding in the upper plate. Strata above and below all the faults are folded. Although folding formerly was thought to have preceded thrusting, it is now believed to have accompanied the faulting. Minimum horizontal displacements along the faults were 10-15 miles and may have been considerably more.

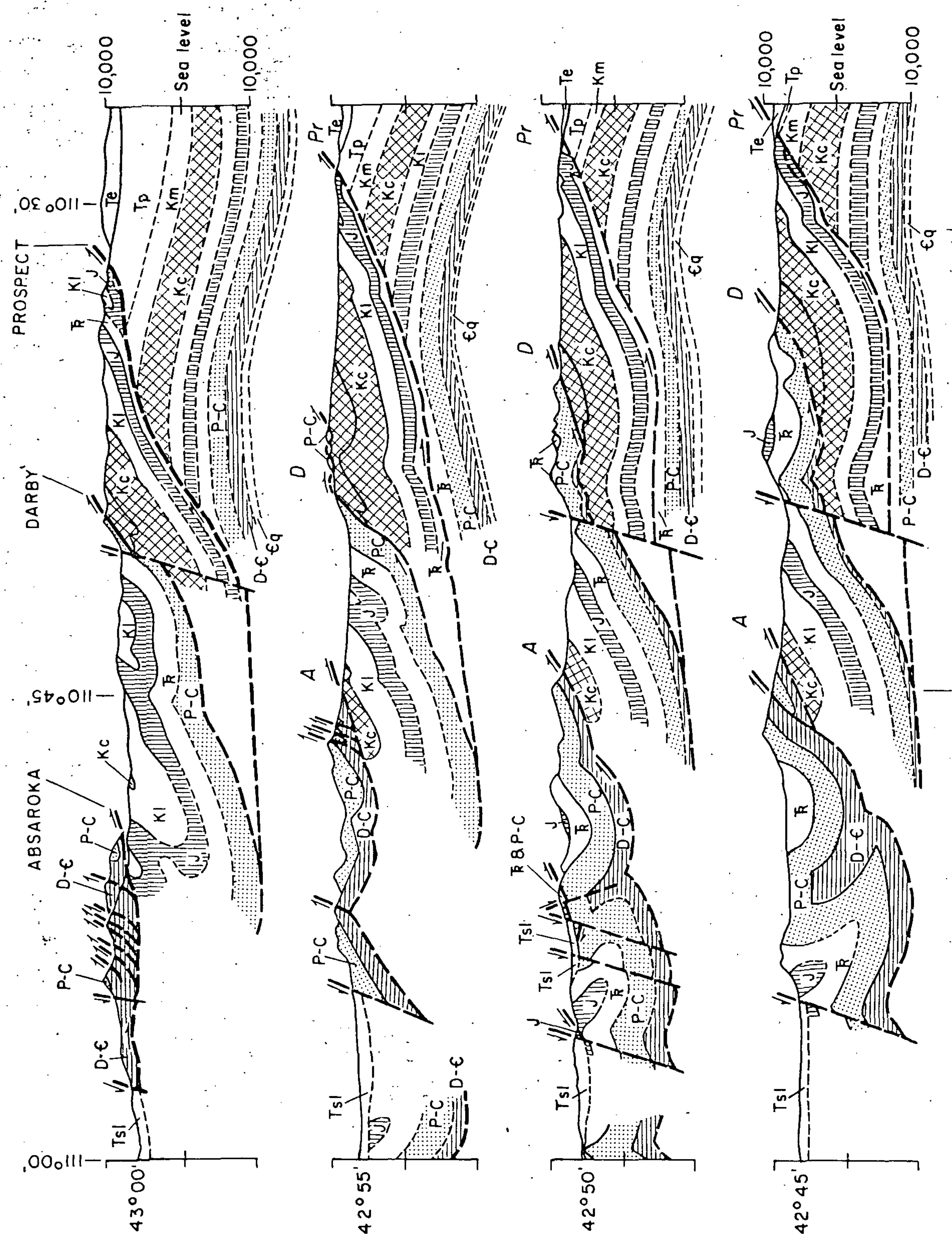
Stratigraphic throw on each of the major thrust faults is about 20,000 feet, as indicated by the vertical scale in Figure 15. Also illustrated is the fact that the upper plate of each successively more eastward thrust fault contains successively younger strata.

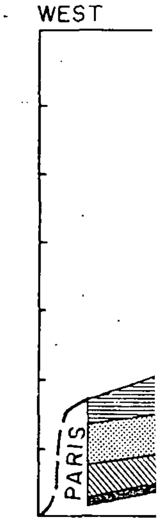
DATING MAJOR MOVEMENTS

Few of the thrust faults can be dated within narrow limits by usual geologic methods. One that can be, however, is the Prospect thrust (Fig. 16). The fault cuts the Hoback Formation of Paleocene and earliest Eocene age; the Eocene part of the Hoback is folded with the underlying strata, but only the Paleocene part is cut by the fault. South of where the fault cuts the Hoback, its trace is overlain by Wasatch strata of late early Eocene age. Major movement on the fault thus occurred in middle early Eocene time.

Somewhat similar evidence is used to date major movement on the Absaroka thrust north of Kemmerer. A short distance south of the area illustrated in Figure 17, the youngest unit cut by the Absaroka is the Adaville Formation, whose topmost part is of latest Cretaceous (Lance or late Montana) age. The Evanston Formation, which is of latest Cretaceous (Lance) and Paleocene age (Rubey, Oriel, and Tracey, 1961), crops out in a north-trending belt close to the trace of the Absaroka; and locally the basal beds of the Evanston, the Lance part, have been cut by late small movement on the Absaroka. Although the Evanston has not been found directly overlying the fault, it overlies rocks above and below the fault with angular unconformity. The Evanston thus was deposited in its present site after most

[4] Hogsback is a new name for the thrust fault south of Snider Basin called Darby by Schultz (1914, pl. 1) and subsequent workers, and Darby (?) by Oriel (1962, p. 2172). The fault is named for its excellent exposures along Hogsback Ridge west of La Barge, Wyoming.





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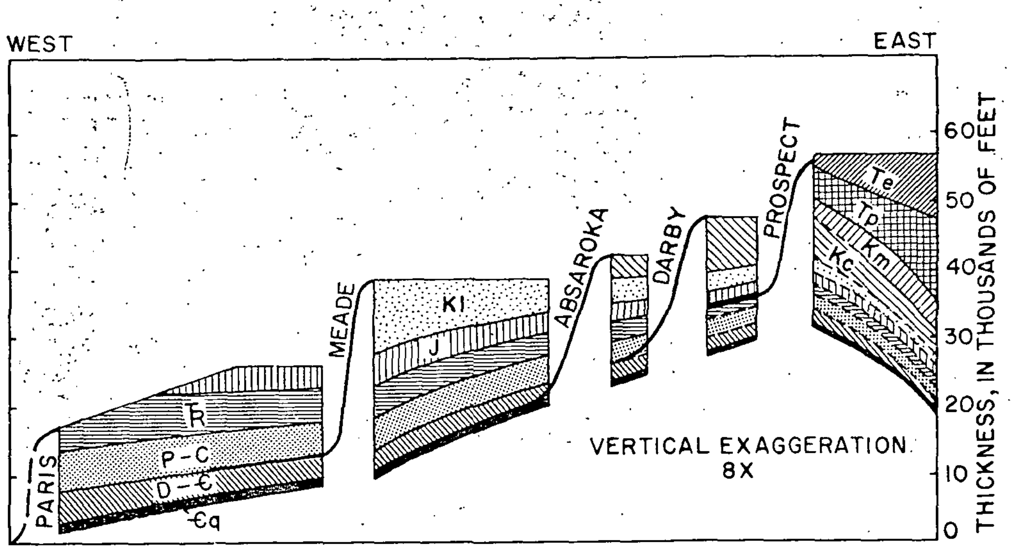

FIG. 15.—Stratigraphic sections in four large overthrust sheets and in Green River Basin. Diagram shows approximate constancy of stratigraphic throw along different faults and progressively younger age of involved rocks from west to east. Formational symbols as in Figure 14. Modified from Rubey and Hubbert (1959, p. 190).

of the movement; major thrust movement on the Absaroka is thereby dated as latest Cretaceous.

Another type of evidence was used to date first movement on the Paris thrust (Armstrong, 1962; Armstrong and Cressman, 1963, p. 48). At Red Mountain in the Gannett Hills (Fig. 18), coarsely conglomeratic redbeds, 5,000 feet thick, are a coarse facies of the lower part of the Gannett Group of earliest Cretaceous age whose basal beds probably are of latest Jurassic age. Examination of nearby Gannett stratigraphic sections shows that the conglomeratic unit coarsens westward and more than doubles in thickness in a distance of 8 miles, thereby indicating a western source for the detritus. A source area only 25-30 miles west is suggested by the rate of increase in pebble size (Rubey, *in* Moritz, 1953, p. 66) and by the survival of non-resistant rocks in the conglomerate (Plumley, 1948, p. 575). Pebbles of Paleozoic rocks in the conglomerate were derived from formations now exposed in the upper plate of the Paris thrust 20-30 miles west of Red Mountain. If the conglomeratic unit on Red Mountain is a synorogenic deposit (Eardley, 1960, p. 37), as the evidence suggests, then first movement on the Paris thrust is dated as latest Jurassic and earliest Cretaceous.

Evidence for accurately dating the other thrust faults shown on Figure 13 is meager. Nonetheless, in Figure 19 an attempt is made to date principal movement on each fault, with the realization that some dates may be slightly in error. Comparison

←««

FIG. 14.—West-east structure sections, somewhat generalized, across Bedford, Blind Bull Creek, and part of Merna Butte Quadrangles, Wyoming. Horizontal and vertical scales same. Єq, Cambrian quartzite; D-Є, Devonian to Cambrian Gros Ventre Formation, inclusive; P-C, Permian to Carboniferous, inclusive; Tr, Triassic; J, Jurassic; Kl, Lower Cretaceous; Kc, Cretaceous (Colorado); Km, Cretaceous (Montana); Tp, Paleocene; Te, Eocene; Tsl, Pliocene Salt Lake Formation. A, Absaroka thrust fault; D, Darby thrust fault; Pr, Prospect thrust fault. From Rubey and Hubbert (1959, p. 188).

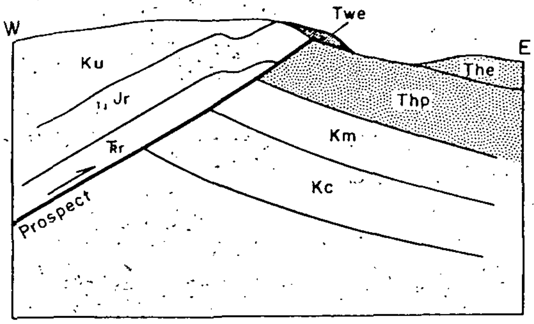

FIG. 16.—Schematic structure section of Prospect thrust fault west of Daniel, Wyoming, showing basis for dating major movement on fault. Twe, Wasatch Formation strata of latest early Eocene age; The, Hoback Formation of Eardley and others (1944), upper part of earliest Eocene age; Thp, Hoback Formation, lower part of Paleocene age; Km, Cretaceous (Montana); Kc, Cretaceous (Colorado); Ku, Cretaceous undivided; Jr, Jurassic rocks; Trr, Triassic rocks.

of Figures 13 and 19 shows that the oldest faults are on the west and the youngest on the east, a fact which has been recognized before. Because the Darby and Prospect thrusts probably are not the northward continuations of the Hogsback and LaBarge faults, these two pairs of faults have been shown one above the other on the right side of Figure 19. Not shown on Figure 19 are times and durations of recurrent movements known or interpreted to have occurred on some of the faults.

Data from Figures 13 and 19 are plotted as a graph in Figure 20[5]; the ordinate is time in millions of years, and the abscissa is distance in miles, measured westward from the trace of the easternmost thrust about normal to the trends of the faults and fold axes. Surprisingly, both the well-supported and indirectly inferred dates cluster along a straight line. Perhaps even more disconcerting is an implication of the westward projection of this straight line. The Antler orogenic belt of Nevada has been inferred to project northward into Idaho (Churkin, 1962, Fig. 11; Roberts and Thomasson, 1964). The distance between the northward projection of the belt and the easternmost fault is plotted in Figure 20; it intersects the line determined by the Idaho-Wyoming thrusts at about 380 million years, or at an age of about Middle Devonian (Holmes, 1959, p. 204). The result is not greatly discrepant from the Late Devonian or Early Mississippian to Early Pennsylvanian age deduced by Roberts

[5] The graph was conceived initially to illustrate the futility of applying the term Laramide to deformations in the thrust belt. Use of the term masks, rather than reveals, temporal relations discovered in the region.

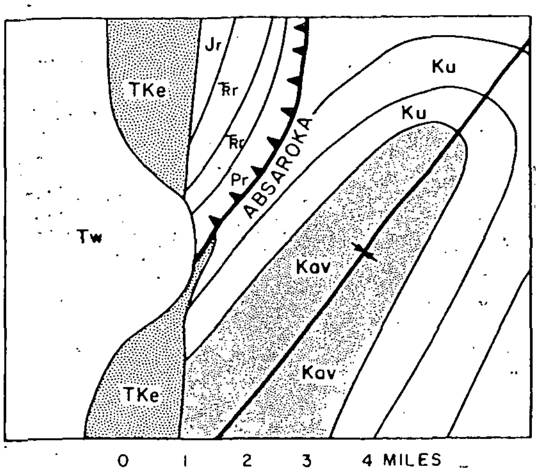

FIG. 17.—Schematic map of part of Absaroka thrust fault, showing the basis for dating major movement on fault in northern part of Kemmerer Quadrangle. Tw, Wasatch Formation (Eocene); TKe, Evanston Formation (Paleocene and uppermost Cretaceous); Kav, Adaville Formation (Upper Cretaceous); Ku, Cretaceous undivided; Jr, Jurassic rocks; Trr, Triassic rocks; Pr, Permian rocks. Modified from unpublished map by W. W. Rubey, J. I. Tracey, Jr., and S. S. Oriel.

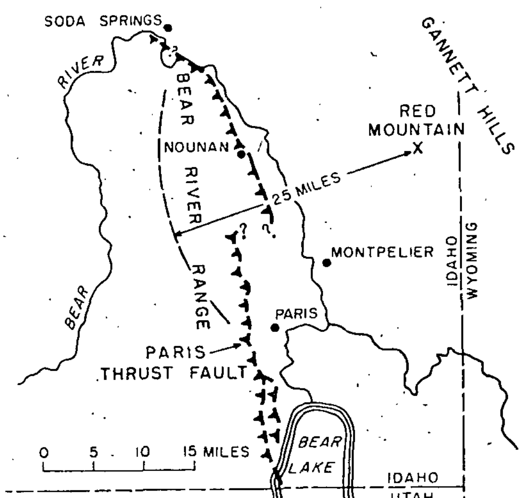

FIG. 18.—Map of localities cited in dating first movement on Paris thrust fault.

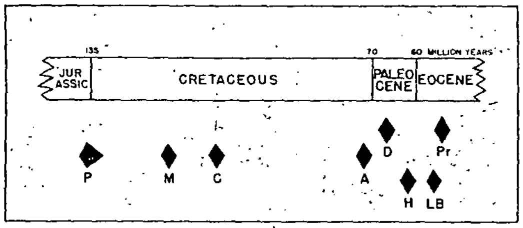

FIG. 19.—Estimated ages of principal movement on major thrust faults. Not shown are times of recurrent movements on some faults. Numerical ages from Holmes (1959, p. 204). Letter symbols are same as on Figure 13, with which this figure should be compared.

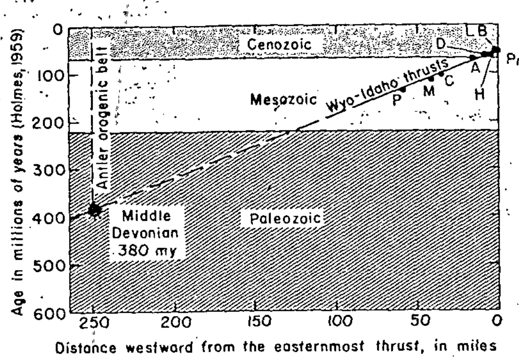

FIG. 20.—Relation of dates of principal movement to positions of present traces of major thrust faults. Curiously, extension of line in graph, based on Idaho-Wyoming thrust dates, yields possible age for northward projection of Antler orogenic belt on west surprisingly close to age inferred by Roberts and others (1958). Based on data in Figures 13 and 19. Letter symbols same as on Figure 13.

and others (1958, p. 2850) from other evidence. The graph may or may not have real meaning.[6]

GROSS STRUCTURE WEST OF THRUSTS

A question of some concern is, what is the gross crustal structure of the area of mainly lower Paleozoic rocks that extends northward from Ogden, Utah, and lies west of the Idaho-Wyoming thrust belt (Fig. 1)? The contrast in detail shown on the east and on the west in Figure 1 reflects contrasts in what is known about the area. Most of the area between Ogden and Pocatello is underlain by rocks of the Brigham through Ordovician units; upper Paleozoic and Mesozoic units are present on both sides of the area. Triassic rocks occur in the Sublett Range on the west and all Mesozoic systems are present in the thrust belt on the east.

East-dipping thrust faults (Fig. 13) near the western margin of the area of Paleozoic rocks have been reported by Blackwelder (1910, Figs. 4 and 6) and Eardley (1944, pl. 1) in the Ogden area, by Murdock (1961, p. 42) just north of the Utah-Idaho State line, by Anderson (1928, p. 8) and Ludlum (1943, Figs. 2 and 3) southeast of Pocatello, and by W. J. Carr and D. E. Trimble (oral communication, 1963) southwest of Pocatello.

Many geologists (Richards and Mansfield, 1912, p. 706, 707; Richardson, 1941, p. 39; Eardley, 1944, p. 869, 870; Crittenden, 1961) have inferred that the Willard thrust near Ogden connects with the Paris thrust to the east. On the basis of this interpretation (Fig. 21) the area of Paleozoic rocks from Ogden northward is regarded as a remnant of the upper plate of a large thrust that moved scores of miles from the west and is therefore allochthonous. In addition to other objections (Armstrong and Cressman, 1963, p. J18), this interpretation is difficult to reconcile with the progressively younger ages of the thrust faults eastward from the Paris thrust, particularly if there is more than one major eastward-dipping thrust on the west. Moreover, if this block is allochthonous and did move scores of miles eastward, it is surprising that nowhere in southeastern Idaho or western Wyoming has a western facies of any stratigraphic unit yet been recognized east of an eastern facies.[7]

An alternate interpretation for the area of older Paleozoic rocks has been suggested (Eardley, 1944, p. 867-869). According to this interpretation (Fig. 22) the area was raised as a large wedge-shaped segment of the earth's crust from which the thrust plates were pushed or slid, and the area is thus autochthonous. If a segment of the earth's crust were raised as postulated, one might expect crystalline rocks of the basement to have been brought close enough to the surface so that their presence would be indicated, because of

[6] An inference that could be drawn from the graph, for example, by projecting the line toward the right, would be the location of the next thrust faulting on the east.

[7] On the south in Utah, however, the Willard thrust fault separates a western thick sequence on the east from an eastern thin sequence on the west (Blackwelder, 1925; Crittenden 1961). Juxtaposition of western and eastern sequences is also evident still farther south, east of Provo, along the Charleston-Nebo thrust (Baker, 1959; Crittenden, 1959; 1961).

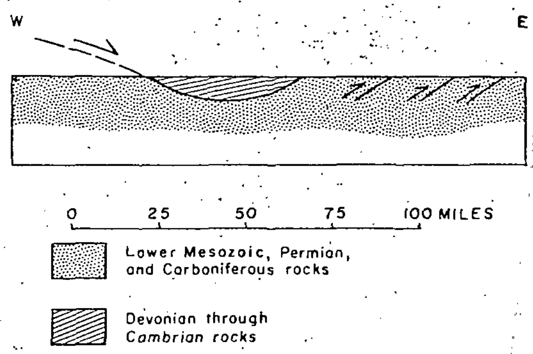

FIG. 21.—Schematic structure section illustrating overthrust origin inferred for area of Paleozoic rocks. Area extends north-northwestward from Ogden, Utah. See Figure 1.

their greater density, by a gravity high. The gravity map of Idaho (Bonini, 1963, pl. 1), however, does not show a gravity high southeast of Pocatello suitable to support this wedge hypothesis.

These two interpretations are based on the assumption that the westward-dipping eastern thrusts and the eastward-dipping western thrusts are connected—if not physically, then at least temporally and genetically. As yet, however, data are inadequate to date accurately the western thrusts and to demonstrate that they are the same ages as the eastern thrusts. Accordingly, a third possibility is that the faults are in fact unrelated, at least in the ways suggested thus far.

PART 3. BLOCK FAULTING

Block faulting, the third and latest chapter in the tectonic evolution of the Idaho-Wyoming thrust belt, began during the Eocene and has continued to the present.

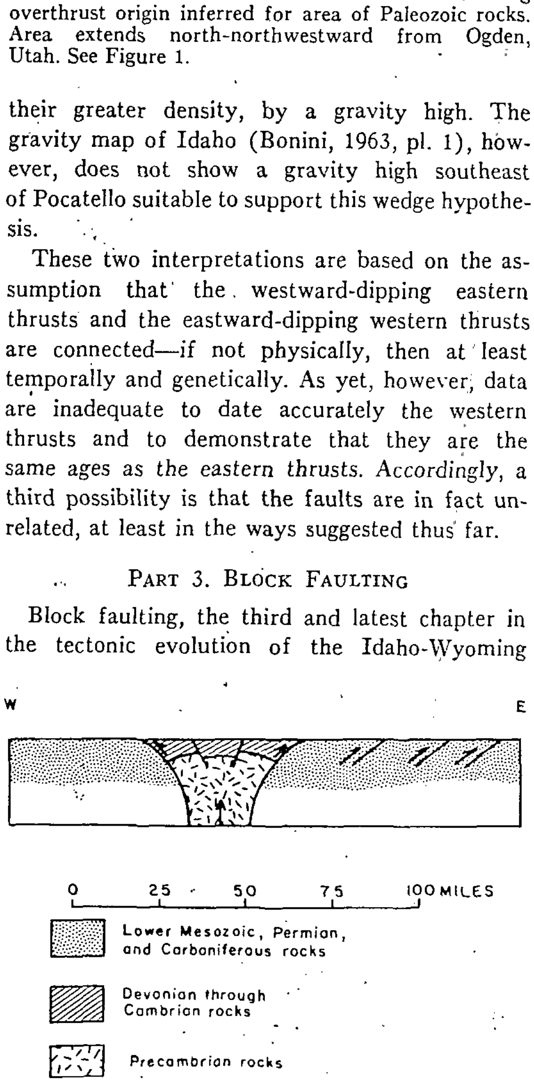

FIG. 22.—Schematic structure section illustrating uplifted wedge origin inferred for area of Paleozoic rocks.

Northeast of Kemmerer, Wyoming, several steeply dipping faults cut the plate of Mesozoic rocks (Fig. 23) that lies above the late Paleocene Hogsback thrust fault (Fig. 19). Some of the high-angle faults also cut the Wasatch Formation of late early Eocene age that unconformably overlaps the rocks above the thrust. Other steep faults, probably of early Eocene age, do not offset the Wasatch.

Eocene block faults have not been recognized in the western part of the region because Eocene rocks, used to date the faults, are absent where needed.

On the west, many block faults can not be dated within narrow limits. In a part of the Portneuf Range within the Bancroft Quadrangle, Idaho, three sets of block faults have been mapped (Fig. 24). The oldest trends northwest and does not cut the Salt Lake Formation; the next set trends northeast and cuts the Salt Lake; and the youngest set trends north to northwest, cuts the Salt Lake, and parallels present mountain fronts. Fossils have not been found in the Salt Lake in this area, and the formation is assumed to be Pliocene as it is at many places nearby.

In the next range to the east, the Bear River Range, similarly trending fault sets have been

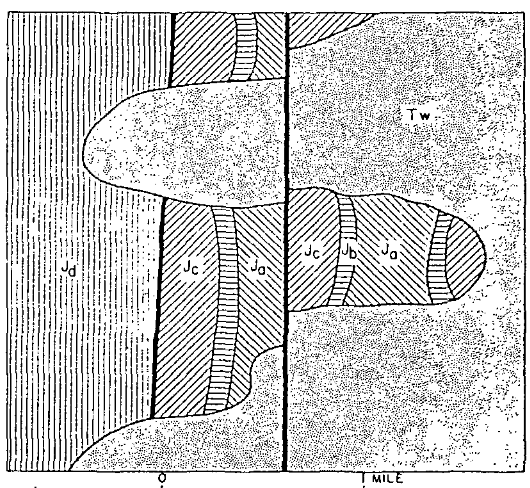

FIG. 23.—Schematic geologic map of part of Fort Hill Quadrangle, Wyoming, showing that Wasatch Formation, Tw, is cut by some steeply dipping faults but not by others. Ja, to Jd, Jurassic units, from oldest to youngest, in plate above Hogsback thrust fault.

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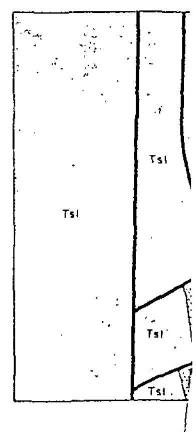

FIG. 24.—Scher
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mapped (Fig. 25). The oldest set, which trends east and northeast, may be tear faults related to thrusting (Armstrong, 1964).

The next set trends northwest, does not cut the Salt Lake Formation, and is cut by a younger northeast-trending set, which in turn is cut by a younger northwest-trending set that cuts the Salt Lake and parallels the mountain front.

In the western part of the region, the late northwest-trending faults served as conduits along which basalt flows rose during Pliocene to Recent time.

Some block faults have clearly moved more than once. Along one fault Tertiary strata have been offset about 1,000 feet vertically, whereas elsewhere along the same fault a modern alluvial fan has been offset only 50 feet (W. W. Rubey, J. I. Tracey, and S. S. Oriel, unpub. data). Vertical movement along some block faults may have been in opposite directions at different times. This conclusion is suggested by the presence, on the crests and flanks of present ranges, of coarse Tertiary gravel for which there is no possible source with the present topography. These gravels were derived from the west, an area that is now low, at a time when the source was higher than the site of deposition.

Movement on the northwestward-trending block faults was principally vertical. Gem Valley is a graben that separates the Fish Creek and Portneuf Ranges from the ranges on the east (Fig. 26). Gravimetric surveys by Mabey

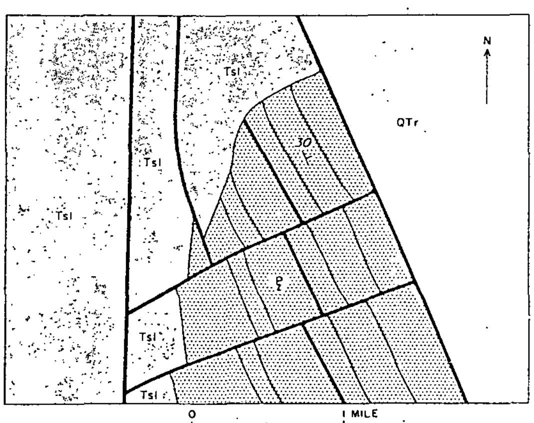

FIG. 24.—Schematic geologic map of part of Bancroft Quadrangle, Idaho, showing sets of faults mapped and their relations to rock units: QTr, Quaternary and uppermost Tertiary rocks; Tsl, Pliocene Salt Lake Formation; Pz, Paleozoic rocks.

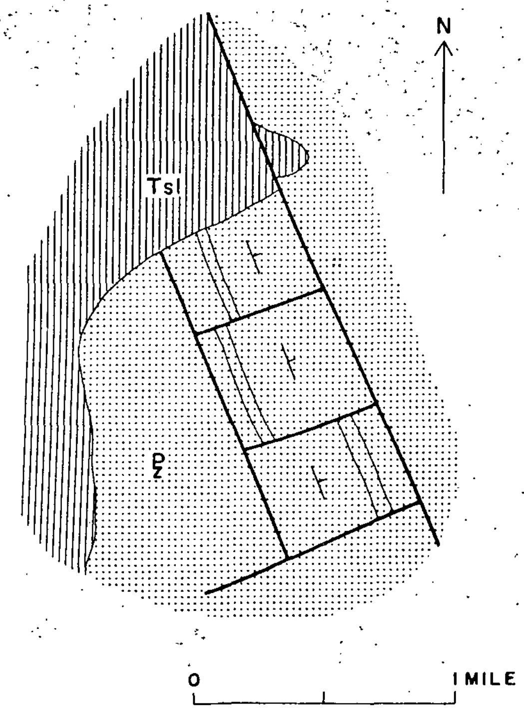

FIG. 25.—Schematic geologic map of part of Soda Springs Quadrangle, Idaho, showing sets of faults mapped and their relations to rock units: Tsl, Pliocene Salt Lake Formation; Pz, Paleozoic rocks.

(Mabey and Armstrong, 1962) reveal marked negative anomalies (Fig. 26) that are interpreted to indicate a relief of 7,000-10,000 feet between the crests of the flanking ranges and the bottom of the Tertiary fill in the valley. This relief is the result of movement on the block faults.

The young age of some block faulting hardly needs emphasis. Fault scarps are abundant, and modern alluvial fans have been cut by Recent faults. Basalt in Gem Valley dated as younger than 27,000 years (Bright, 1963, p. 30) has been cut by faults. Earthquakes continue in the area.

Relation of Geologic History to Petroleum Exploration

The writers have attempted to show the sequence of geologic events in part of an orogenic belt. Gross generalizations, as well as small geologic features, provide clues for petroleum exploration. Only a few can be mentioned here, for most lie beyond the scope of this paper.

The first broad episode in late Paleozoic and Mesozoic time was progressive eastward shift

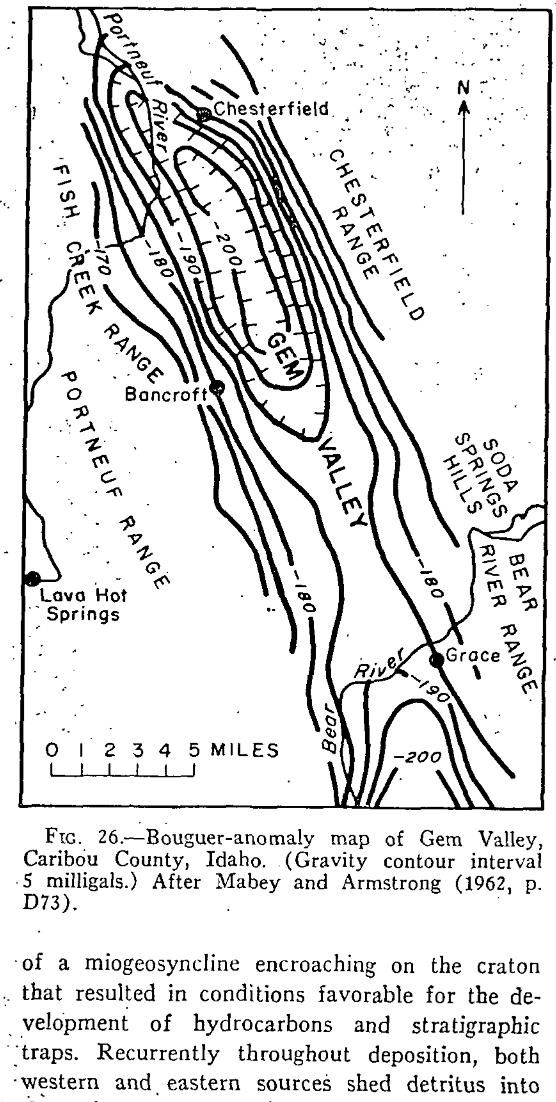

FIG. 26.—Bouguer-anomaly map of Gem Valley, Caribou County, Idaho. (Gravity contour interval 5 milligals.) After Mabey and Armstrong (1962, p. D73).

of a miogeosyncline encroaching on the craton that resulted in conditions favorable for the development of hydrocarbons and stratigraphic traps. Recurrently throughout deposition, both western and eastern sources shed detritus into the miogeosyncline to form eastward-thinning and westward-thinning detrital wedges, respectively. Precise delineation of regional facies changes and of pinch-outs of detrital wedges is critical to exploration.

The second broad episode, which overlapped late stages of the first, produced the folded and thrust belt along the eastern flank of the miogeosyncline; movement along the thrusts, measured in at least tens of miles, was progressively younger eastward. The times of hydrocarbon migration resulting from deformation may also have been progressively younger eastward. Thrust plates cover and conceal oil and gas fields, only a few of which have yet been found. Although some surface and near-surface allochthonous rocks may seem to be unfavorable prospects for drilling, they may conceal distinctly different rocks in underlying autochthonous sequences that are potential oil reservoirs. The structural history of stratigraphic traps is also important, for tilts and rotations accompanying folding during thrusting may have caused hydrocarbons to escape from some and to be concentrated in others.

The latest broad episode involves block faulting that apparently increased in intensity westward and is still active. Some minor dislocations and modifications of hydrocarbon fields are apparent in the east. Block faulting also resulted in the deposition of detrital wedges in Tertiary sequences that have yielded some gas and oil. Some areas in the western part of the region have been so intensely shattered by several sets of block faults that hydrocarbon concentrations accumulated prior to block faulting may have escaped late in the tectonic history. These same sets of faults, however, have provided channels for hydrothermal solutions that locally have deposited base-metal minerals.

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