The Bannock Thrust Zone Southeastern Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 374–J

Prepared partly on behalf of the U.S. Atomic Energy Commission

Armstrong and Cressman—THE BANNOCK THRUST ZONE, SOUTHEASTERN IDAHO—Geological Survey Professional Paper 374–J

The Bannock Thrust Zone Southeastern Idaho

By FRANK C. ARMSTRONG *and* EARLE R. CRESSMAN

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 374-J

Prepared partly on behalf of the
U.S. Atomic Energy Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

THE BANNOCK THRUST ZONE, SOUTHEASTERN IDAHO

By Frank C. Armstrong and Earle R. Cressman

ABSTRACT

The Bannock overthrust in southeastern Idaho and north-central Utah was originally described by Richards and Mansfield (1912) as a single large thrust fault that formed at the close of the Laramide orogeny and was folded by renewed compression near the end of Pliocene time. Later Mansfield expanded and revised his interpretation of the Bannock overthrust so that at least the northern part of the overthrust was thought to be a thrust zone in which the individual faults originated in a folded sole thrust.

Detailed mapping in areas critical to Richards and Mansfield's interpretations has shown that the faults thought by them to be parts of one large thrust are separate faults, and that, although some of the thrust surfaces are curved, they were not folded in Pliocene time but probably were folded during a late stage of the thrusting. Extensions of the Bannock thrust to the north, south, east, and west based upon extrapolation of a single large folded thrust surface are not warranted.

The Bannock overthrust is reinterpreted as a westward-dipping imbricate thrust zone possibly several tens of miles wide extending at least from southwestern Montana to north-central Utah. It is recommended that the name "Bannock overthrust" no longer be used, and that this zone of imbricate thrusts in the southeast corner of Idaho be called the Bannock thrust zone. The thrusts range in age from Late Jurassic to post-Early Cretaceous and are progressively younger from west to east; strong regional compressive forces do not appear to have been active in the area as late as Pliocene time. The upper plates of the thrusts moved to the northeast in response to an unknown force. Steep eastward-trending tear faults formed during thrusting probably in response to differential movement among the eastward-moving thrust plates. In Tertiary and Quaternary time block faulting was extensive; it formed the northward-trending graben valleys seen in the area today.

INTRODUCTION

Laws regulating the disposal of public lands require that the lands be classified as to their character before disposal, and the responsibility for this classification was given to the United States Geological Survey in its organic act of 1879. Accordingly, in December 1908 the Secretary of the Interior withdrew from entry large areas of public land in southeastern Idaho and adjacent parts of Utah and Wyoming, pending an examination of their phosphate resources. In order that the phosphate deposits, which became known later as part of the western phosphate reserve, might be developed under the mineral-leasing laws, classification of these lands was started by the Survey in 1909. Hoyt S. Gale was in charge of the work from 1909 to 1910; R. W. Richards, from 1910 to mid-1912; and George Rogers Mansfield, from mid-1912 to about 1936. Although classification of these lands has continued intermittently to the present time, the major job of classification was done under Mansfield's guidance during the period 1909–36. The final results of this work appeared in Geological Survey Professional Papers 152 and 238 by Mansfield, and Geological Survey Bulletins 430 by Gale and Richards, 470 and 577 by Richards and Mansfield, 713 and 803 by Mansfield, and 923 by G. B. Richardson. The geologic maps and descriptions published in these reports not only contributed greatly to an understanding of the geology and structural evolution of the Rocky Mountains, but effectively guided exploration for minable phosphate deposits in this area.

Early in their work, Richards and Mansfield found several rather widely separated individual thrust faults of large displacement. As the work progressed, they found evidence that led them to conclude that these thrusts were parts of a single large folded thrust fault which they named the Bannock overthrust (1912).

In 1947 the Geological Survey started a new study of the western phosphate field. This work was undertaken on behalf of the Division of Raw Materials of the United States Atomic Energy Commission because uranium was known to occur in small amounts in the phosphate rock and in the phosphatic shale associated with it. As it seemed apparent that uranium could be produced economically from these deposits only as a byproduct of phosphate mining, a study was also made of the amount, grade, and distribution of the phosphate deposits and the vanadium and other minor constituents of the phosphatic rocks that might be recovered as byproducts in an integrated operation. The work included detailed stratigraphic studies and geologic mapping. During this study much of the area in southeastern Idaho covered by the previous land-classification work was reexamined, some of it being remapped; in addition, an area west of the earlier work was mapped for the first time. Some of the findings of this later work have already been published and the rest are being prepared for publication.

The new study, as one of its results, indicates that interpretation of the Bannock overthrust requires modification. Although the new work confirms most of the findings of the earlier investigation, it shows that individual faults that were thought to be parts of a single folded thrust are in reality separate imbricate thrusts and that these thrusts were not all formed at the same time. The purpose of this paper is to describe some of these faults, to give the evidence that they are not parts of one fault and that they are of different ages, and to discuss the implications of the new data and interpretation in relation to the structural evolution of this part of the Rocky Mountains. In order to make clear the differences between the old and new interpretations and the reasons for them, Mansfield's concept of the Bannock overthrust is reviewed in some detail at the outset. From a review of Mansfield's changing concept of the Bannock overthrust, it is possible to speculate that had Mansfield lived and continued to work in southeastern Idaho, he may have come to many of the same conclusions we have.

Like the original paper on the Bannock overthrust, this paper is a byproduct of work on the phosphate deposits. It is based on detailed geologic mapping in restricted areas and on reconnaissance in southeastern Idaho and adjacent parts of Utah and Wyoming during several field seasons. Although our work has covered only part of the area finally interpreted by Mansfield to be involved in the Bannock overthrust, a large part of the mapping was in the area where the concept of the Bannock overthrust originated and in other areas which are critical to that interpretation. We have not solved all the problems, and the structure of some complex areas is open to alternative interpretations, yet the new data suggest a reinterpretation of the thrust structure in southeastern Idaho. Cressman is responsible for the main structural interpretations in an area of about 180 square miles that extends about 15 miles northward from the south end of Snowdrift Mountain and lies between Crow Creek on the east and the town of Georgetown, Idaho, on the west. Armstrong is responsible for all other data and interpretations in the report.

We acknowledge with thanks the benefit of discussions with a number of our Survey colleagues, many of whom have contributed to a better understanding of the geology of southeastern Idaho. We are particularly indebted to William W. Rubey (who at the start of our work pointed out some of the weaknesses of the concept of the Bannock overthrust as a single feature) for his counsel in the field, and his discussions of the stratigraphy and structure of southeastern Idaho and western Wyoming. We are also indebted to Mr. Rubey and to Steven S. Oriel for information on the ages of thrust faults in western Wyoming, and particularly for discussion of evidence in western Wyoming that has a bearing on the interpretation of the structural evolution of southeastern Idaho.

FIRST INTERPRETATION OF THE STRUCTURE OF SOUTHEASTERN IDAHO

Geologic mapping in southeastern Idaho and the adjoining part of northern Utah in the summers of 1909 and 1910 by geologists of the U.S. Geological Survey disclosed the presence of several thrust faults that crop out in the ranges adjacent to Bear River and Bear Lake Valleys (Gale and Richards, 1910; Richards and Mansfield, 1911). As used in this paper, "Bear River Valley" refers to the geographic feature that is the almost uninterrupted northward continuation of Bear Lake Valley and that extends from Georgetown to Threemile Knoll. Between Georgetown and Nounan low hills of Triassic and Tertiary rocks indistinctly separate Bear Lake Valley from Bear River Valley.

At the end of the 1910 field season the structure of the area was interpreted as shown on plate 1*A*. Several discontinuous, separate thrust faults were recognized. The thrust fault west of Bear Lake Valley was thought to continue northward past Nounan at least as far as Threemile Knoll, where a patch of quartzite boulders on top of the knoll was mapped as an outlier of the thrust (Richards and Mansfield, 1911, p. 400). A steep normal fault, with the downthrow on the west side, was mapped from a point northeast of Threemile Knoll southward along the east side of Bear River and Bear Lake Valleys to a point near the Utah-Idaho boundary. Numerous springs, hot and cold, and travertine deposits along most parts of the projected course of this fault were interpreted as indicating the position of the fault where it was poorly exposed or covered (Richards and Mansfield, 1911, p. 398). Another normal fault that branches from the first one south of Georgetown was mapped southward along the west side of Bear Lake Valley. Downthrow on this fault is on the east side. Bear Lake Valley thus was interpreted as a graben tapering northward (Richards and Mansfield, 1911, p. 398–399), but no mention was made of the structure of Bear River Valley.

THE BANNOCK OVERTHRUST

ORIGINAL INTERPRETATION

As the result of mapping east and northeast of Georgetown, Idaho, in the summer of 1911, the structural interpretation of southeastern Idaho was revised. A sinuous thrust fault was recognized that extended from the Left Fork of Twin Creek on the west, across Georgetown Canyon, around the south end of Snowdrift Mountain, and into Crow Creek on the east (pl. 2*A*). The western part of the trace of the fault is convex to the north, and the eastern part concave to the north; the dip along the trace is to the north side of the fault. From the outcrop pattern and direction of dip, two northward-plunging folds were interpreted in the thrust surface, an anticline on the west and a syncline on the east; the sinuousity of the fault was believed to result principally from folding of the thrust surface. Recognition of two folds raised questions as to whether there might be other folds in the thrust, and led to the interpretation that the known folds continued to the west in another syncline and anticline. From this interpretation it was deduced that the known thrust faults of the area, rather than being separate and discontinuous as previously believed, were all parts of one large folded overthrust. This thrust fault was described and named the Bannock overthrust after Bannock County, Idaho, from its exposures in the eastern part of the county (Richards and Mansfield, 1912). In 1919 the original Bannock County was divided into Bannock County on the west and Caribou County on the east; consequently the exposures from which the fault took its name are now in Caribou County.

As a result of this later interpretation, faults were connected that would not otherwise be thought of as the same fault. Faults dipping in opposite directions, as well as those with flat or steep dips, could thus be interpreted as parts of the same feature. The sinuous, disconnected thrusts exposed in southeastern Idaho were therefore supposed to result from erosion of a single folded thrust surface. The outcrop pattern and amount and direction of dip of any part of this master fault would therefore depend not only on topography and the original dip of the fault, but also on the later folding of the thrust surface and the position of the outcrop on a later fold. Consequently, faults interpreted as thrusts could have any dip and the direction of dip had no relation to the direction of movement (Richards and Mansfield, 1912, p. 697).

This expanded and revised structural interpretation (Richards and Mansfield, 1912) is shown in plate 1*B*. Two major changes from the interpretation of 1910 (pl. 1*A*) should be noted: (a) the normal fault along the east side of Bear River Valley was interpreted as a thrust fault; and (b) Bear River Valley was considered to be a window in the thrust surface.

MANSFIELD'S FINAL INTERPRETATION

As more of southeastern Idaho was mapped, details of the thrusting were worked out and the folded-thrust interpretation was amplified and extended to apply to a larger area (Richards and Mansfield, 1914; Mansfield, 1920, 1921, 1927, 1929, 1952; Richardson, 1941). The concept of the Bannock overthrust thus grew and changed so that its final form, although preserving the idea of a folded thrust, was different from that first presented. The early mapping covered the southern part of the Bannock and in this area it was considered to be a single thrust fault (Richards and Mansfield, 1912, p. 695; 1914, p. 35). Textbooks on structural geology (Willis and Willis, 1934, p. 181; Nevin, 1942, p. 111; Billings, 1942, p. 183; Hills, 1943, p. 120; Eardley, 1951, fig. 184) ordinarily refer only to the earliest and simplest interpretation of the Bannock overthrust: the single folded thrust fault in the southern part of the area. Later, as mapping progressed northward, the Bannock was recognized at some places as a single fault and at other places as a fault zone made up of several branch faults (Mansfield, 1921, p. 451; 1927, p. 150, 151, 152; 1929, p. 55). Finally, in the northern part of the area, a broad zone of thrust faults was recognized that was believed to be the northward continuation of the Bannock (Mansfield, 1952, p. 61). In this area the Bannock overthrust was considered to be made up of "three principal branches * * * and several minor faults that * * * are conceived as originating in a sole, or great thrust fault * * * shallow enough to permit its exposure at the surface where affected by gentle folding or faulting" (Mansfield, 1952, p. 67).

It thus appears to us: (a) that Mansfield finally interpreted the northern part of the Bannock overthrust as an imbricate thrust zone originating in a concealed folded sole thrust, and the southern part in Bear River and Bear Lake Valleys as a single large folded thrust fault; and (b) that this single fault is the exposed sole of the zone to the north. Mansfield's final interpretation of the Bannock overthrust (1952, p. 64–68), and its extensions as suggested by other geologists is shown in plate 1*C*.

EXTENT

As finally interpreted (Mansfield, 1952, p. 66), the Bannock overthrust extended from Woodruff Creek, Utah, to the southeast edge of the Snake River Plain southeast of Idaho Falls, Idaho, an airline distance of about 140 miles and a distance along the major traces of the fault of about 270 miles.

DISPLACEMENT

The Bannock overthrust was thought to have been formed by northeast-southwest compressional forces that pushed the overriding block northeastward. A horizontal displacement of at least 12 miles and possibly slightly more than 35 miles was postulated (Richards and Mansfield, 1912, p. 703–704; Mansfield, 1921, p. 447; 1952, p. 64).

The stratigraphic throw on the Bannock, that is, the stratigraphic throw on the sole fault or the sum of stratigraphic throws on branch faults in the thrust zone, ranges from about 1,000 feet to perhaps as much as 20,000 feet (Mansfield, 1927, p. 158). The points of minimum and maximum stratigraphic throw are about 15 miles apart near the East and West Stump branches of the Bannock (pl. 1*C*). Proximity of the points of minimum and maximum throw was explained by the fact that stratigraphic throw at any point on the thrust is not a true measure of movement on the fault. Prior to the thrusting, the sedimentary rocks were folded into a series of anticlines and synclines. Then the Bannock cut obliquely and irregularly through the folds and moved folded upper plates over folded lower plates, so that the stratigraphic throw at any one point represents only chance juxtaposition, at the time thrusting ceased, of previously folded formations. Amount of stratigraphic throw thus varies widely.

FOLDING

An important feature of the Bannock overthrust interpretation, in both its first and final forms, is the folding of this originally nearly horizontal and rather regular thrust surface (Richards and Mansfield, 1912, p. 704; Mansfield, 1921, p. 451; 1927, p. 159; 1952, p. 65). Renewed compressional forces, acting in the same direction as the original thrusting, folded the fault surface into anticlinal and synclinal folds, some of which were locally overturned to the northeast. In the southern part of the area four folds, two anticlines and two synclines, were recognized in the sole thrust (Richards and Mansfield, 1912, fig. 2; Mansfield, 1927, pl. 37) (pl. 2*A*). The western anticline arches over Bear River Valley; the syncline next east passes beneath the Aspen Range and the towns of Georgetown and Montpelier; the crest of the eastern anticline is exposed in Georgetown Canyon, on the Left Fork of Twin Creek, and in the Slug Creek window; the eastern syncline passes beneath Snowdrift Mountain.

Folding of the thrust surface brought the crests of the anticlinal folds close enough to surface so that subsequent erosion could cut through the overlying block, expose the underlying block, and thereby form windows in the thrust. Two such windows, the Bear River Valley and Slug Creek windows, were thought to have been formed on the crests of the anticlines in the sole thrust (Richards and Mansfield, 1912, fig. 2; Mansfield, 1927, pls. 1, 37) (pl. 2*A*); farther north two other windows were mapped (Mansfield, 1952, p. 65, fig. 25) (pl. 1*C*).

Recognition of folds and windows in the thrust surface led to the interpretation that a large folded thrust fault underlay a large part of southeastern Idaho. If the presence of a folded thrust were accepted, then it became possible to interpret other folds and windows in the thrust from evidence that in itself was inconclusive. As is suggested below (p. J17), the Portneuf and Paradise Valley windows are perhaps two such windows.

AGE

The Bannock overthrust was believed to have formed during Late Cretaceous or early Tertiary time (Richards and Mansfield, 1912, p. 704), probably near the end of the Laramide orogeny (Mansfield, 1921, p. 465; 1952, p. 73). The youngest rocks involved in the thrusting are those of the Upper Cretaceous (and Lower(?) Cretaceous) Wayan formation (Mansfield, 1927, p. 151, pls. 2, 4, 5, 11; 1952, p. 44, 68, pls. 1, 2). The oldest rocks concealing the trace of the fault are those of the Eocene Wasatch formation, probably the lower part of the Wasatch (Richards and Mansfield, 1911, p. 394, pl. 16; Mansfield, 1927, p. 109, 155, pl. 9). In the southern part of the area, where the Bannock is interpreted as a single thrust fault, all the now-isolated parts of that once continuous thrust were considered to be of the same age.

Another important feature of the Bannock overthrust interpretation is that the thrust surface was thought not to have been folded until late Pliocene or post-Pliocene time, long after thrusting had ceased (Mansfield, 1921, p. 465; 1927, p. 203; 1929, p. 62; 1952, p. 73). It was believed that the shape of the folds and degree of folding in the thrust surface resemble the low dips and open folds in the Salt Lake formation (Pliocene(?)) and some of the associated lavas, and that these similarities indicated that all had been folded at the same time.

EXTRAPOLATION OF THE BANNOCK OVERTHRUST

In the original paper on the Bannock overthrust, the possibility was recognized that the Bannock and "known thrust faults of probably identical age" in southeastern Idaho and nearby Wyoming and Utah might all be parts of one fault which are now isolated by erosion (Richards and Mansfield, 1912, p. 706–707). There can be little doubt that "known thrust faults of probably identical age" included all thrusts from the Willard on the west to the Darby on the east. Since 1912 several more specific extensions of the Bannock have been suggested, all of which greatly increased its possible length and horizontal displacement. These extrapolations of the Bannock were based on, and made possible by, the assumption that a large folded thrust underlay the area.

Various extensions of the Bannock overthrust to the north were proposed. Originally the Putnam overthrust was mapped as a separate fault (Mansfield, 1920, p. 62), but later it was interpreted as a branch of the Bannock that connected with the main overthrust to the southeast along a line passing through the Portneuf window (Mansfield, 1929, p. 56) (pl. 1*C*). Southeast of Idaho Falls the Bannock passes beneath Tertiary lava and sediments of the Snake River Plain. North of the plain along the projected strike of the Bannock is the Medicine Lodge thrust, and it has been suggested that it is the northward continuation of the Bannock (Kirkham, 1927, p. 27; Mansfield, 1929, p. 58; 1952, p. 67).

A westward extension of the northern part of the Bannock was postulated by Ludlum (1943, p. 984–985). He suggested that the Putnam-Bannock fault emerged somewhere between the Putnam overthrust and the Bannock Range, arched over the range, and descended again to the west. According to this interpretation, the Bannock Range is in a large window in the Putnam-Bannock fault, and the root of the fault is somewhere west of the range.

The Auburn and Star Valley faults were suggested as possible eastward extensions of the Bannock (Mansfield, 1927, p. 159). As the master fault was believed to be folded, eastward dips of the Auburn and Star Valley faults were explained by those faults' being on the eastern flank of an anticlinal fold in the master fault. According to this interpretation, the area between the Auburn and Star Valley faults and the Bannock fault is a window whose boundaries are not completely known.

Originally the Bannock was interpreted as connecting southward with a thrust near the southeast corner of Bear Lake (Richards and Mansfield, 1912, fig. 1), but later it was interpreted as connecting with a fault near the southwest corner of Bear Lake (compare pls. 1*B* and 1*C*). Beyond this point the Bannock was projected southward to connect with the thrust exposed along Woodruff Creek, Utah (Richards and Mansfield, 1911, p. 397; Mansfield, 1929, fig. 2; 1952, fig. 25; Richardson, 1941, fig. 2).

The possibility that the Bannock connects with the Willard thrust south and west of Woodruff Creek was recognized early (Richards and Mansfield, 1912, p. 707), and fieldwork, though at first contradictory (Blackwelder, 1910), later suggested that such a connection was probable (Blackwelder, 1925). Still later work suggested that the trace of the probable connection between the two thrusts is about as shown on plate 1*C* (Eardley, 1944, p. 866–872; 1951, figs. 185, 189; Crittenden, 1959, fig. 1; 1961).

THE BANNOCK THRUST ZONE: PRESENT INTERPRETATION

We have traced the development of the interpretation of the Bannock overthrust from its original to its final form, and have shown how the overthrust has been interpreted to extend beyond its original suggested limits. Let us now examine that interpretation and its extrapolations in the light of recent field work. Although the new mapping confirms most of the earlier mapping, certain important differences require modifications of some of the previous structural interpretations.

AREA EAST AND NORTH OF GEORGETOWN

East and north of Georgetown, where the Bannock overthrust interpretation originated, remapping confirms the presence of flexures (pl. 2*B*) in the surfaces of several thrust faults, but it seems probable that the flexures were formed during the later part of the same orogeny that produced the thrusts, rather than in late or post-Pliocene time, and that the thrust fault does not continue many miles to the north. Evidence from key areas that supports these conclusions is given in the following sections.

LEFT FORK OF TWIN CREEK AND GEORGETOWN CANYON

The structure of the Left Fork of Twin Creek and Georgetown Canyon area is complex, and because of incomplete exposures some of the details may never be correctly deciphered. Several intimately and complexly related thrust faults occur there (pl. 3). The thrust surfaces have been bent and broken, and the abrupt bend in the thrust originally interpreted as an anticlinal fold in the thrust surface (Richards and Mansfield, 1912, p. 697; Mansfield, 1927, p. 153) is at a point where the thrust is cut by a later, nearly vertical fault. Only that part of the geology on plate 3 that immediately concerns the Bannock overthrust interpretation will be mentioned.

A short distance southwest of Shale Spring (pl. 3) an anticline in the Twin Creek limestone is cut at its north and south ends by thrust faults that join farther southwest to form one thrust. Displacement on the southern branch brings Twin Creek limestone over Nugget sandstone and Upper Triassic rocks; displacement on the northern branch is within the Twin Creek.

The southern branch is probably the main thrust surface; the upper plate probably buckled from continued compression and finally broke along the northern branch to form a small imbricate thrust above the main fault.

A little northwest of these thrusts, a larger thrust brings Carboniferous rocks over Jurassic and Triassic rocks, and near its southwest end the larger thrust covers the thrust between the Twin Creek and Upper Triassic rocks (pl. 3). West of Shale Spring the upper plate of the large thrust is broken by a tear fault and by a small imbricate thrust fault that probably formed in the same manner as the earlier imbricate thrust in the Twin Creek. About three quarters of a mile east of Shale Spring a straight steep fault cuts the large thrust, and on the west, near the south end of Dairy syncline, another fault cuts both thrusts (pl. 3). The faults that cut the thrusts have much in common; along both, Brazer limestone (Mississippian) is in contact with Twin Creek limestone (Jurassic). The northern part of the western fault, however, separates Wells formation (Pennsylvanian and Permian) from Madison limestone (Mississippian), and the northern projection of the eastern fault is within the Brazer. Insufficient movement occurred along these faults, therefore, to explain the large stratigraphic throws shown along some parts of their traces. Most of this large stratigraphic throw is clearly a result of thrusting; Brazer rocks of the upper plate of the large thrust have been dropped down along the east and west faults so that Brazer is in contact with Twin Creek and other Mesozoic rocks of the lower plate.

Between the Left Fork of Twin Creek and Georgetown Canyon and along the south side and at the west end of Georgetown Canyon are areas of Madison limestone that also are interpreted as parts of the upper plate of the large thrust (pl. 3). Although the nature of the fault that separates Carboniferous rocks on the west from Mesozoic and Carboniferous rocks on the east near the mouth of Georgetown Canyon cannot be stated with certainty, it is interpreted as a later range-front fault similar to the fault that cuts the thrusts near the south end of Dairy syncline. A similar fault along the range front is the east boundary of a small area of Madison a third of a mile southeast of the Left Fork of Twin Creek.

The thrust pattern thus is not simple, but one in which thrust plate is thrust on thrust plate, each bending and breaking to form a complex imbricate structure. Cutting this complex thrust pattern are later faults.

The steep fault three-quarters of a mile east of Shale Spring was not mapped by Richards and Mansfield, and the sharp bend where the thrust meets the steep fault was interpreted as an anticlinal flexure (Richards and Mansfield, 1912, p. 697) in the thrust surface. In the critical area to the north, exposures are sparse and a displacement of several hundred feet in the Brazer could go undetected. The fault was not found during remapping of this critical area, but the bend in the trace of the axial plane of the Summit View anticline, which probably was caused by offset on the steep fault, may mark its northward continuation.

The steep fault served only to modify the thrust pattern, for if the rocks are restored to their positions prior to movement on the steep fault east of Shale Spring, an anticlinal bend in the thrust surface still seems necessary to allow the thrust to pass under Snowdrift Mountain. Had this bend in the thrust surface resulted from folding after thrusting had ceased, there should be a similar bend in the rocks above the thrust. No such fold was recognized, however, in remapping the rocks of the upper plate of the thrust. The absence of such a fold in the rocks above the thrust suggests that the bend in the thrust surface was not formed after thrusting had ceased, and that this bend, like the others in the area, was formed at the time of thrusting.

SLUG CREEK

Recent mapping in the area of the Slug Creek window (Cressman and Gulbrandsen, 1955, pl. 27), about 6 miles north of Shale Spring, shows that the faults bordering the east and west sides of the window are normal and that the west sides dropped downward (pl. 2*B*). The eastern fault has a stratigraphic throw of only a few hundred feet at its north end and cannot be traced the length of the window with confidence; the western fault also has a stratigraphic throw of only a few hundred feet, but it can be traced north and south of the limits of the window. If a fault is present along the south margin of the window, it is of small displacement; the fingerlike projection of Wells formation (Pennsylvania and Permian) at the south end of the window that Mansfield (1927, pl. 6) showed overlying Rex chert (Permian) is now interpreted as Tertiary gravel that lies on top of the Rex chert member of the Phosphoria formation. The absence of the window eliminates its use as corroborative evidence for the northward continuation of the thrust fault on the Left Fork of Twin Creek.

SYNCLINE UNDERNEATH SNOWDRIFT MOUNTAIN

Richards and Mansfield traced what they believed to be a single thrust fault from the Left Fork of Twin Creek southeastward around the south end of Snowdrift Mountain and from there to the northeast into Crow Creek valley where Mansfield (1927, pl. 1) showed the thrust dividing into several branches. The faults dip toward Snowdrift Mountain (pl. 2*A*). Remapping of this area shows that the thrust along the southwest side of Snowdrift Mountain, which has a stratigraphic throw of about 14,000 feet, splits into several branches near the south end of Snowdrift Mountain. East of where the branching occurs, the stratigraphic throw is distributed among the branches and decreases progressively toward the northern end of each branch (pl. 2*B*). No stratigraphic throw was found along Preuss Creek, but at this locality complex structure within the Twin Creek limestone necessitates an extension of a thrust fault around the southeast end of Snowdrift Mountain to join with one of the faults in Crow Creek valley.

Although the accompanying map (pl. 3) of the Georgetown Canyon-Snowdrift Mountain-Crow Creek area differs in some details from that of Richards and Mansfield, it supports their main interpretation: the curving fault trace around the south end of Snowdrift Mountain can be interpreted as the surface expression of a north-plunging gentle synclinal fold in the fault surface.

CROW CREEK FAULT ZONE

In contrast to the fault along the southwest side of Snowdrift Mountain where all the throw is on one fault, the thrust fault zone in Crow Creek valley consists of discontinuous, branching, subparallel thrust faults (Mansfield, 1927, pl. 7; Cressman, 1957). Stratigraphic throw on the individual thrusts exceeds 1,500 feet at only a few places.

A fault zone consisting of branches of the Bannock overthrust was shown as extending north of Crow Creek for about 12 miles and then northwestward for about 55 miles to the Snake River Plain (pls. 1*C* and 2*A*) (Mansfield, 1927, pl. 1; 1952, pl. 1). The ranges west of the fault zone were thus thought to be part of the Bannock overthrust plate. For about 30 miles north and northwest of Crow Creek, however, the branches of the thrust lie for the most part between formations that are adjacent in the stratigraphic column; perhaps some of the thrusts would not have been mapped if their presence had not been required by the regional structural interpretation. Furthermore, the East Stump and West Stump branches of the Bannock (pl. 1*C*) appear from their traces to dip steeply eastward (Mansfield, 1927, pl. 5); possibly they are normal faults. The character of the faults from the head of Crow Creek to the East and West Stump faults and the absence of the Slug Creek window suggest to us that individual thrusts are not continuous from Crow Creek to the Snake River Plain, and that the thrust beneath Snowdrift Mountain and the southern parts of Dry Ridge and the Aspen Range dies out northward.

Much of the horizontal movement on this thrust may have been taken up along tear faults such as those in Crow Creek valley (pl. 2*B*). The Blackfoot fault, about 23 miles north of Georgetown (pl. 4), whose south side has moved east nearly 2 miles (Young, 1953, p. 83), and a similar but smaller fault about 3 miles north of the Blackfoot fault (V. E. McKelvey, written communication, 1958) are other tear faults along which movement may have been taken up.

BEAR RIVER VALLEY

Recent mapping of critical areas shows that Bear River Valley is a graben and that the thrust fault along the west side of the valley and that on the Left Fork of Twin Creek are not parts of one large thrust fault. Data supporting these conclusions are discussed in the following paragraphs.

AREA NORTHWEST OF NOUNAN

Northwest of Nounan, Brigham quartzite (Cambrian) has been thrust over Thaynes formation (Lower Triassic) along a westward-dipping thrust fault. Richards and Mansfield (1911, p. 426, pl. 14) originally mapped the quartzite as Brigham, but later Mansfield (1927, p. 155, pl. 6) showed the quartzite as Swan Peak (Ordovician). Remapping of a small part of this area confirms the quartzite as Brigham and shows that the thrust, which has a stratigraphic throw of about 20,000 feet, is cut by at least two steeply eastward-dipping normal faults which strike north-northwest (pl. 2*B*). Where examined, the traces of the normal faults are marked by linear outcrops of intensely brecciated quartzite and eastward-facing scarps, and on aerial photographs they form moderately straight lineaments, locally marked by scarps, which can be traced on the photographs about 2 miles north and about 8 miles south. These faults and other similar, approximately parallel lineaments roughly mark the topographic western border of Bear River Valley.

West of Liberty, Brigham quartzite is thrust over Thaynes formation along a westward-dipping thrust fault, as it is northwest of Nounan. The similarity of geologic structure suggests that these thrusts are parts of the same fault and connect under cover along the west side of Bear River Valley in a manner similar to that shown on plate 2*B*. The possible northward continuation of this thrust is discussed in the next section.

THREEMILE KNOLL

On top of Threemile Knoll a patch of large quartzite boulders overlies Thaynes formation. Originally the quartzite was thought to be Cambrian, probably Brigham (Richards and Mansfield, 1911, p. 404), but later was referred to the Ordovician Swan Peak (Mansfield, 1927, p. 234, pl. 44). The supposed similarity of the structural relations at Threemile Knoll to the thrust fault northwest of Nounan (that is, Cambrian or Ordovician quartzite overlying Thaynes at both places) led to the interpretation that the quartzite boulders were erosional remnants or an outlier of a thrust plate that once extended over the top of Threemile Knoll (Richards and Mansfield, 1911, p. 404; Mansfield, 1927, p. 156).

Remapping of Threemile Knoll and the surrounding area confirms the identification of the quartzite boulders as Swan Peak. The quartzite occurs as conspicuous white boulders, cobbles, and pebbles. Although quartzite of the Swan Peak formation makes up most of the "erosional remnant," relatively inconspicuous cobbles and pebbles derived from other Paleozoic formations are also present. All the fragments lie in a red sandy matrix locally calcite-cemented and are of the same resistant rocks that commonly occur as fragments in Tertiary (?) gravels nearby; they could have been derived by erosion from nearby hills. Patches of this bouldery material occur also on the flanks and along the base of Threemile Knoll, as well as nearby (pl. 2*B*), and on the crest and west flank of the north end of the Bear River Range. The material on top of Threemile Knoll is therefore interpreted to be a Tertiary(?) gravel, and not an outlier of the Nounan thrust—a possibility that Mansfield (1927, p. 234) considered but, on the basis of the evidence then available, rejected as the less probable of the two interpretations.

The large thrust fault near Nounan continues northwestward under cover for an unknown distance. Mansfield (pls. 1*C*, 2*A*) projected it from near Nounan to a point a short distance west of Threemile Knoll and thence to the Portneuf window and beyond. Although the thrust may extend as far as Threemile Knoll, we believe that it dies out northwest of Nounan and that it probably extends no farther than Tenmile Pass, about 20 miles northwest of the outcrop near Nounan (pl. 4).

The geologic structure of the Chesterfield Range north of Tenmile Pass, although partly concealed by Tertiary cover, appears to contrast strongly with the structure of the Soda Springs Hills and the north end of the Bear River Range, south of the pass. North of the pass, Paleozoic rocks are folded and faults are not abundant. South of the pass, Paleozoic rocks that dip moderately and uniformly eastward are cut by two sets of steeply dipping faults; one set strikes about north, the other nearly east. The eastward-trending (tear?) faults have a cumulative left-lateral offset probably in excess of 10,000 feet. We think that the eastward-trending faults partly absorbed the movement along the thrust and that they probably indicate the northern end of the thrust plate.

Moreover, north of Tenmile Pass in the area between the Portneuf window and Reservoir Mountain (pl. 1*C*), the presence of a large thrust fault is not necessary to a logical explanation of the geologic structure. On the contrary, if a large thrust fault is projected through this area, it must be projected beneath cover, for no such thrusts were seen where Paleozoic and Mesozoic rocks are exposed (Mansfield, 1927, pl. 3; 1929, pl. 1). The improbability of the existence of the Portneuf window is discussed below (p. J17).

EAST BORDER OF BEAR RIVER VALLEY

Remapping the east border of Bear River Valley shows that a steeply westward dipping normal fault, or series of faults, extends along the west front of the Aspen Range between Georgetown and Threemile Knoll. Mapping near Soda Springs indicates that in this area springs and travertine deposits similar to those that are numerous along the east side of Bear River and Bear Lake Valleys are associated with recent block faults and not with thrust faults. New mapping in the Aspen Range immediately east of Bear River Valley shows that, although a few thrust faults are present, they have only minor displacement and that many of the thrusts previously mapped in this area "do not exist or are better interpreted as normal faults" (Gulbrandsen and others, 1956, p. 16–17).

The presence along the east side of Bear River Valley of a westward-dipping normal fault, instead of an eastward-dipping thrust fault as previously believed, and the absence of an outlier on Threemile Knoll eliminate the basis for the postulation of the western synclinal and anticlinal folds in the Bannock overthrust and also of the Bear River Valley window. Bear River Valley is thus a graben bounded on the east and west by normal faults. The thrust along the east side of Bear River Range, best exposed west of Paris (pl. 4), and the one in the Georgetown Canyon area, well exposed near Meade Peak (pl. 2*B*), are separate thrusts. To emphasize their separate nature they are here named the Paris and Meade thrusts, respectively.

AGES OF THRUSTING

Probable differences in age among the thrust west, and those east and northeast of Georgetown support the conclusion that they are not parts of one large thrust.

PARIS THRUST FAULT

The Paris thrust cuts Thaynes formation (Lower Triassic) and the trace of the thrust is covered by

Wasatch formation [1] (Eocene) (Mansfield, 1927, pl. 9). A more precise dating of the thrust is suggested, however, by fragments in rocks mapped as Ephraim conglomerate on Red Mountain in the Gannett Hills (pl. 2*B*).

At its type locality in the Gannett Hills (pl. 2*B*) the Gannett group (Lower Cretaceous) is between 3,000 and 3,500 feet thick and has been divided into five formations, from bottom to top: Ephraim conglomerate, Peterson limestone, Bechler conglomerate, Draney limestone, and Tygee sandstone. Lower Cretaceous fresh-water faunas have been found in the Peterson and Draney limestones (Mansfield, 1927, p. 101–105; Moritz, 1953, p. 63–68). To the north and east the Gannett group thins rapidly, becomes finer grained, and contains only a few feet of conglomerate in the entire section; its five formations lose many of their distinguishing characteristics, and consequently recognition of the different formations is somewhat uncertain (Moritz, 1953, p. 66–68; Wanless and Gray, 1955, p. 53–57; Rubey, 1958).

On Red Mountain (pl. 2) exposures of rocks mapped as Ephraim conglomerate (Mansfield, 1927, pl. 9) consist of numerous outcrops of thick resistant beds of poorly sorted red conglomerate separated by areas of red soil in which are small sparse outcrops of red sandstone. Although most outcrops are conglomerate, conglomerate beds make up probably less than half the total stratigraphic thickness at this locality. The Ephraim on Red Mountain can be divided roughly in half into a lower and an upper part on the basis of the character of the conglomerate beds present.

The lower part of the Ephraim is characterized by beds of pebble conglomerate that contain dark-colored chert pebbles set in a red sandy matrix. Most of the pebbles are less than 2 inches but some are as much as 5 inches in diameter. In addition to chert, these conglomerates also contain a small proportion of sandstone pebbles and quartzite pebbles. A second type of conglomerate occurs in lesser amounts in the lower part of the Ephraim. This is a cobble conglomerate and contains cobbles of limestone, sandstone, chert, and quartzite in about equal amounts. The cobbles average about 3 inches and reach a maximum diameter of about 6 inches. In the lower part of the Ephraim, limestone fragments seem to be restricted to the cobble conglomerates.

Although the precise stratigraphic sources of the pebbles and cobbles cannot be identified with certainty, their general aspect suggests that almost all were derived from upper Paleozoic formations. Most pebbles in the lower part of the Ephraim are dark-colored chert. Generally the chert does not occur as large pieces; where the conglomerate is coarse, it occurs as small fragments among the large ones; where the conglomerate consists of pebbles about 2 inches or less in diameter, the pebbles may be almost exclusively chert. With the aid of a hand lens it can be seen that many of the chert pebbles are spicular. Examination of a thin section of a maroon chert pebble shows it to contain silicified spicules and a few individual carbonate rhombs, and to lack detrital quartz grains; that is, it strongly resembles chert from the Rex chert member of the phosphoria formation (Permian). Many Paleozoic formations in the region contain abundant chert; for example, the cherty shale and Rex members of the Phosphoria formation (Permian), the Wells, the Brazer, and the Fish Haven formations. In contrast to the Paleozoic rocks, the only Mesozoic rock that contains significant amounts of chert is the Portneuf limestone member of the Thaynes formation, and the Portneuf contains abundant chert only in its northwesternmost part at Fort Hall, about 60 miles northwest of Red Mountain. South and east of Fort Hall the Portneuf rapidly changes in character and the chert disappears (Kummel, 1954, pl. 38, 39). It is not possible, of course, to identify the source formations of individual chert pebbles, but to one familiar with the Paleozoic rocks of the region, it is apparent that all the chert pebbles could have been derived from Paleozoic formations. Because of the abundance of chert pebbles, the several possible Paleozoic sources, and the restricted possible Mesozoic sources for them, it seems highly probable that the chert pebbles were derived almost entirely from upper Paleozoic formations.

Almost all the limestone cobbles strongly resemble Carboniferous limestones that crop out to the west:

[1] The Wasatch group near Evanston, Wyo., was divided by Veatch (1907, p. 87–96) from bottom to top into the Almy, Fowkes, and Knight formations. The Knight, conglomeratic and otherwise lithologically similar to the Almy, was thought to overlie the other two formations unconformably. Fossils from all three formations were considered Eocene, and a close stratigraphic relation was recognized between the Evanston formation (then tentatively regarded as Eocene) and the conformably overlying Almy and Fowkes formations. Work by Tracey and Oriel (1959, p. 128, 129) has shown that in the northern part of the area mapped by Veatch much of the area shown as Almy is underlain by rocks more properly assigned to the Evanston formation of Late Cretaceous and Paleocene age. Diagnostic fossils have not been found at the type locality of the Almy, nor has this area been remapped; however, the stratigraphic position of the type Almy, provided it, too, is not part of the Evanston, indicates a post-Evanston and pre-Knight age. Fossils from the type locality of the Fowkes show it to be of late Eocene or possibly earliest Oligocene age and, therefore, to overlie the Knight. The Knight unconformably overlies the Evanston and at its type locality and elsewhere has yielded fossils of early Eocene age.

Although Richards and Mansfield (1911, p. 394, pl. XVI; 1914, p. 38) originally thought that the conglomeratic beds overlying the trace of the Paris thrust southwest of Paris were correlative with the Almy of Veatch, Mansfield (1927, p. 109) later decided that it was impracticable to distinguish between the Almy and Knight in that area. Accordingly he showed the Eocene Wasatch formation overlying the Paris thrust. His usage is followed in this report.

many are sandy and silty limestones similar to those in the Brazer limestone and Wells formation; a few are composed largely of flattened oolites similar to the limestones that characterize the lower member of the Wells (Cressman and Gulbrandsen, 1955, p. 260); others contain brachiopod and coral fragments and echinoid spines, and a few are coarse crinoidal limestone similar to that in the Madison limestone. A half dozen or so cobbles of the distinctive medium-brown, fine sandy and silty limestone so characteristic of the Triassic formations in the area were also found. Some of these contain large brachiopod fragments and are thought to be from the Dinwoody formation. Many of the sandstone pebbles and cobbles can be referred to the sandy units in the Brazer and Wells formations with a high degree of certainty. One red sandstone pebble may have been derived from the Preuss sandstone (Upper Jurassic). Among the pebbles in the conglomerates are also a few rounded pebbles of white pure quartzite that is composed of uniformly medium-sized well-rounded frosted sand grains of high sphericity. Because of their distinctive lithology, it seems probable that these pebbles were derived from the Ordovician Swan Peak formation.

The upper part of the Ephraim on Red Mountain, from about 7,800 altitude to the top, is characterized by beds of poorly sorted boulder conglomerate that contain abundant carbonate fragments. The fragments occur in a red sandy matrix similar to that of the conglomerates in the lower part of the Ephraim. Cobbles 6 to 10 inches in diameter are common, many boulders are 20 inches in diameter, and a maximum diameter of 24 inches has been reported (Steven S. Oriel, written communication, 1959). The coarsest beds are in a zone near the middle of the upper part of the Ephraim; slightly less coarse but otherwise similar conglomerates lie stratigraphically above and below it.

The main constituents of these conglomerates are cobbles and boulders of limestone; conspicuous, though less abundant, are cobbles and boulders of quartzite, dolomite, and sandstone; and even a few shaley fragments were found. Chert is moderately abundant but is not conspicuous as it occurs mostly as pebbles interstitial to the larger fragments.

Most of the limestone fragments again strongly resemble the Carboniferous limestones that crop out to the west: many are sandy and silty limestones similar to those in the Brazer and Wells formations; several contain abundant flattened oolites similar to limestones in the lower member of the Wells; a number contain brachiopods and corals similar to the Carboniferous limestones, and one is a coquina. Most of the sandstone fragments found also resemble units in Carboniferous formations. Several fragments of medium brown, silty limestone from the Dinwoody(?) formation, a few containing brachiopods, also were found. A few red sandstone pebbles and cobbles found in these conglomerates may possibly have been derived from the Preuss sandstone; and the single glauconitic sandstone pebble found may have come from the Stump sandstone.

The chert pebbles are similar to those in the lower part of the Ephraim. One brown and tan chert cobble was found that is like the brown- and tan-weathering chert characteristic of the phosphatic chert horizon at the base of the Brazer. Thin section examination shows that it contains detrital sand grains like chert from the Brazer limestone.

Cobbles and boulders of quartzite derived from the Swan Peak formation of Ordovician age are conspicuous and numerous throughout the upper part of the Ephraim, but they are most conspicuous and perhaps most abundant in the coarse conglomerates near the middle part of that unit. Several quartzite fragments were found that, in addition to displaying the distinctive Swan Peak lithology, contain numerous small pits characteristic of the quartzite in the upper part of the Swan Peak formation (Armstrong, 1953); one such boulder is 21 inches in diameter.

The upper part of the Ephraim also contains numerous cobbles and boulders of dolomite. Some are white, coarsely crystalline dolomite like many of the beds in the Laketown dolomite (Silurian); some are medium-brown, medium-crystalline dolomite similar to the Fish Haven dolomite (Ordovician) and to a few thin dolomite beds in the upper member of the Wells; and others are dark-brown, medium-crystalline, petroliferous-smelling dolomite like the Jefferson dolomite (Devonian). With the exception of the beds in the Wells, dolomites of these types are not known to occur stratigraphically above the Jefferson in the Ephraim source area to the west.

Fragments of quartzite from the Worm Creek quartzite member of the St. Charles limestone (Upper Cambrian) and Brigham quartzite (Lower(?) and Middle Cambrian) were looked for but not found. Both quartzites are easily recognized; the Worm Creek contains abundant white porcelaneous feldspar grains, and almost all units of the Brigham are characterized by a wide range in grain size. Fragments from these quartzites are conspicuous in the Evanston formation (Late Cretaceous and Paleocene) in nearby western Wyoming and in later Cenozoic conglomerates of the area.

A number of conclusions are suggested by the character of the Ephraim on Red Mountain: (a) The differences between the conglomerates in the lower and upper parts of the Ephraim suggest that the source area was farther to the west or that there was less relief between the source area and Red Mountain in early Ephraim time than in late Ephraim time. (b) The lack of fragments from Mesozoic formations, particularly the distinctive medium-brown fine sandy limestone and limy sandstone so characteristic of the Triassic formations in the area, suggests that the Mesozoic formations were largely stripped from the source area by the start of Ephraim time. Fragments from these Triassic formations are common elsewhere in the region in Cenozoic gravels that contain other carbonate rock fragments. (c) The lithologies of the fragments in the upper part of the Ephraim suggest that more and older Paleozoic rocks were exposed in the source area as Ephraim time progressed. (d) The apparent absence of quartzite fragments from the Worm Creek quartzite member of the St. Charles limestone and Brigham quartzite suggests that Cambrian formations had not been exposed in the source area by the end of Ephraim time.

The U.S. Geological Survey considers the Ephraim conglomerate, the basal formation of the Gannett group, to be of Early Cretaceous age. Although at most places the Ephraim rests with apparent conformity on the Upper Jurassic glauconitic marine Stump sandstone (Mansfield, 1927, p. 101; Moritz, 1953, p. 66), Mansfield (1927, p. 101) thought that the stratigraphic break between the two formations might be a large one. At least locally there is a hiatus at the base of the Ephraim for about 20 miles east of Cokeville, Wyo. (pl. 4), in the southeastern part of the Cokeville quadrangle, the Stump is absent at most places (W. W. Rubey, written communication, 1960) and the Ephraim overlies the Upper Jurassic Preuss sandstone (Imlay, 1950, p. 41). The Ephraim has not yielded diagnostic fossils, but on the basis of stratigraphic position and the presence of nonmarine Lower Cretaceous fossils in the overlying Peterson limestone, it has been thought that the basal part of the Ephraim is possibly as old as late Late Jurassic and that the upper part is Early Cretaceous (Cobban and Reeside, 1952, p. 1030; Wanless and Gray, 1955, p. 55; McKee and others, 1956, p. 3).

The stratigraphic thickness of rocks mapped as Ephraim on Red Mountain is about 5,000 feet and is considerably more than was believed previously (Mansfield, 1927, pl. 12, section W–W′). The original thickness of this conglomeratic unit must have been more than 5,000 feet for that thickness is preserved in the center of an eroded syncline. Near Miller ranch, about 19 miles north by east of Red Mountain, a measured section of Ephraim is 1,025 feet thick (Mansfield, 1927, p. 103). There it is a red conglomerate that contains some red sandstone and a few thin beds of limestone, and it appears to lie conformably between the Stump sandstone and the Peterson limestone. To the east and north of Miller ranch, the Ephraim thins rapidly, becomes finer grained, and contains very little conglomerate; about 40 miles northeast of Miller ranch, it is about 175 feet thick and consists mostly of siltstone (Moritz, 1953, p. 66, fig. 2; Wanless and Gray, 1955, p. 55–56). Near Thomas Fork Canyon, Wyo., about 9 miles southeast by east of Red Mountain, the Ephraim has a maximum thickness of 800 feet (Moritz, 1953, p. 66).

From Miller ranch to Red Mountain the Ephraim thickens at a rate of at least 1 foot in 25 feet horizontally, and from near Thomas Fork Canyon to Red Mountain it thickens at the rate of at least 1 foot in 11. If an isopach map is constructed using the thicknesses of the Ephraim at Red Mountain, Thomas Fork Canyon, and Miller ranch, the rate of thickening normal to the isopachs is 1 foot in 8 for a distance of about 6 miles. As these rates of thickening are rather large and are minimum rates, it seems probable to us that the thick conglomeratic unit underlying Red Mountain contains more than the basal Ephraim formation of the Gannett group and that stratigraphic equivalents of several formations of the Gannett group may be present. If, in addition to the Ephraim, other formations of the Gannett are present on Red Mountain, then the fivefold division of the Gannett group disappears to the south and west as it does to the north and east. Consequently, only the very basal part of the conglomeratic unit on Red Mountain could be as old as latest Jurassic.

The marked westward increase of thickness and grain size in the Ephraim indicates a source only a short distance west of Red Mountain (Moritz, 1953, p. 66), and the rate of increase in grain size suggests that the source was perhaps 25 miles or less west of the Gannett Hills (Rubey *in* Moritz, 1953, p. 66). The abundance of carbonate and sandstone fragments in the conglomerates also suggests a nearby source area, if the results of Plumley's studies (1948, p. 575, fig. 15) can be extended to include the Ephraim conglomerate. In a study of stream terrace gravels on the east flank and immediately east of the Black Hills, S. Dak., he found that in a stream transport distance of 30 miles, 90 percent of the limestone plus sandstone pebbles 16 to 32 mm in diameter were removed from the terrace gravels along Rapid Creek. A source for the fragments in the Ephraim 25 miles west of the Gannett Hills would be about 10 miles west of the east margin of the present Bear River Range. The rocks exposed in the present Bear River Range are early Paleozoic in age, including the Swan

Peak formation, of course, and occur in the upper plate of the Paris thrust.

The presence of the Ephraim conglomerate has long been recognized as evidence of a Late Jurassic or Early Cretaceous orogeny to the west (Mansfield, 1927, p. 194; Wanless and Gray, 1955, p. 55, 56), but the location of the orogeny and its mechanism have not been specified. The abundance of soft rock fragments in the Ephraim conglomerates, the direction and rate of increase in grain size, and the direction of thickening of the Ephraim point to an orogeny not far west of the Gannett Hills, and the preservation of Thaynes strata in Bear River and Bear Lake Valleys (Mansfield, 1927, pls. 6, 9, 44) suggest that the eastern margin of the area most affected by the orogeny approximately coincided with the east side of the present Bear River Range. The mechanism and time of orogeny remain to be established.

Absence of major depositional breaks in the pre-Stump stratigraphic sequence of the region is evidence that deposition across the site of the ancestral Bear River Range was continuous from Cambrian to the end of Stump time. Paleotectonic studies of the rocks of the Jurassic system show that about 6,000 feet of Jurassic strata were deposited across the ancestral Bear River Range (McKee and others, 1956, p. 1, pl. 3). Stratigraphic studies of the Triassic of this area show that about 7,400 feet of Triassic strata were deposited in the Fort Hall area several miles northwest of the Bear River Range and that at least 4,700 feet were deposited along the east side of the range near Paris, where an incomplete section that thick is exposed (Kummel, 1954, pl. 34). Paleotectonic studies of the rocks of the Triassic system show that probably at least 7,000 feet of Triassic strata were deposited in the area of the ancestral Bear River Range (McKee and others, 1959, p. 18, pl. 5). The thickness of post-Swan Peak Paleozoic strata deposited at the site of the ancestral Bear River Range was about 9,000 feet as shown by the stratigraphy in the areas north, east, and south of the present range (Mansfield, 1920; 1927; 1929; Williams, 1948).

From this depositional history it follows that the orogeny and the Paris thrust are post-Stump in age.

The direction of thickening and of increase in grain size of the Ephraim and, to a lesser degree, the change from marine to continental conditions of deposition are evidence that the ancestral Bear River Range had been uplifted and was being eroded at the time of deposition of the Ephraim. That the area started to rise even before the end of Stump time is suggested by grit beds in the Preuss a short distance north of Kemmerer (pl. 4) (W. W. Rubey, written communication, 1960), by the clastic nature of the Stump (Peterson, 1955, p. 79), by the apparent absence of the Stump in the westernmost exposures in the Wasatch Range (Stokes, 1959, p. 110), and by the presence of a few pebbly beds in the top of the Stump (Rubey, quoted in Imlay, 1952, p. 966). The lack of Mesozoic pebbles and the abundance of upper Paleozoic pebbles in the Ephraim in the Gannett Hills indicate that at the time of deposition of the Ephraim at this locality about 13,000 feet of Mesozoic strata had been largely stripped from the ancestral Bear River Range; and the presence of Swan Peak pebbles in this same Ephraim is evidence that an additional thickness of about 9,000 feet of Paleozoic strata had been cut through by erosion, at least locally, to expose outcrops of Orodovician Swan Peak from which the pebbles could be derived.

The coarseness of the Ephraim conglomerate is evidence that the source area was uplifted to form mountains. Between Stump and the end of Ephraim time about 22,000 feet of erosion took place in the ancestral Bear River Range, and there is some suggestion that the erosion may have been accomplished in two steps: the first slow and probably in part pre-Stump, the second rapid and post-Stump. At Threemile Knoll in Bear River Valley a few red beds occur in the Thaynes; they probably are part of the Lanes tongue of the Ankareh formation in the Portneuf limestone member in the upper part of the Thaynes. Beds that also are probably correlative with the Portneuf crop out near Paris along the west side of Bear Lake Valley (Kummel, 1954, p. 175). These Portneuf equivalents are roughly 4,000 feet above the base of the Triassic. Outcrops of Thaynes occur elsewhere in Bear Lake and Bear River Valleys between the Paris and Threemile Knoll occurrences. Lack of Mesozoic pebbles in the Ephraim on Red Mountain might be explained by slow gentle uplift of the source area prior to the time of deposition of the Ephraim and by the fact that during this interval the upper part (but less than 9,000 feet) of the Mesozoic rocks was slowly eroded from the source area and deposited as fine sediments somewhere to the east. When erosion had cut down to a point an unknown distance above the Portneuf limestone member, the source area was suddenly raised and in consequence coarse continental(?) Ephraim conglomerate was deposited directly on marine Stump sandstone. Pebbles from the 4,000+ feet of Mesozoic rocks remaining to be eroded from the source area were either carried east of the Gannett Hills (where most such pebbles are found today) or were so diluted in the flood of Paleozoic pebbles that they do not now form a conspicuous part of the Ephraim. If the upper part of the Mesozoic rocks was not slowly eroded during a gentle uplift prior to the sudden uplift that produced the Ephraim, exclusion of Mesozoic pebbles from the Ephraim is even more difficult to explain and the sudden rise of the area to the west must have been even more catastrophic.

The manner of uplift of the ancestral Bear River Range is suggested, and in part restricted, by the geologic structure of the present Bear River Range. Not all the Bear River Range has been mapped geologically, but its structure is moderately well known from the mapping that has been done (Mansfield, 1927, pls. 6, 9; Hardy and Williams, 1953; Armstrong, unpublished) and from reconnaissance by Armstrong. Gently folded Paleozoic rocks are in (Paris) thrust-fault contact with gently folded Triassic rocks along the east margin of the range. The thrust cuts folds in both the upper and lower plates. In the interior of the range the Paleozoic rocks occur in the gently dipping limbs of an open syncline whose form has very nearly been destroyed beyond recognition by numerous block faults, most of which are Cenozoic in age. No thrusts other than the Paris have been recognized in the range, and no block faults older than the Paris thrust have been recognized. Folding followed by thrust faulting are thus the first deformations to which the rocks of the Bear River Range were subjected. The thrust faulting in this region has been thought to be the culminating effect of the compressive forces that produced the folds (Mansfield, 1927, p. 170, 198; 1952, p. 76; Williams, 1948, p. 1158), and this idea is supported at least in part by rather widespread occurrence of westward-dipping thrust faults of small displacement that cut folds overturned eastward (pls. 2*B*, 3) (Cressman and Gulbrandsen, 1955, pl. 27; Gulbrandsen and others, 1956, pl. 1; Cressman, 1957).

If the rocks of the Bear River Range were deformed first by folding and if the block faults in the range are younger than the Paris thrust, it seems extremely unlikely that the ancestral Bear River Range could have been raised up by block faulting. If the ancestral Bear River Range had been warped up gently without folding as in epeirogeny, it is doubtful that a conglomerate like the Ephraim could have formed. Moreover, such an arching would have produced a dome rather than a basin in the rocks of the range. Of course, the possibility that later deformation reversed the structure cannot be completely eliminated. It seems to us that the sudden appearance in the stratigraphic column of a coarse conglomerate like the Ephraim argues for a catastrophic event to explain its presence. This argument, together with the elimination of block faulting and the probable elimination of gentle uplift as a means for raising the ancestral Bear River Range, leaves only folding and thrusting, that is, orogeny in its strictest sense, as the mechanism of uplift.

Whether the ancestral Bear River Range was uplifted by folding only or by folding and thrust faulting—that is, whether the Paris thrust is significantly younger than the Ephraim conglomerate—remains to be determined. We know of no evidence that can conclusively date the Paris thrust and the Ephraim, but a few general considerations suggest that they are of about the same age: (a) First, we have no evidence that they are of different ages. In many places in the region, failure by thrust faulting appears to be the final mechanism of yielding in response to the compression that produced the folds. Considered in this light, at least some of the thrust faulting is the final expression of and part of the folding process. (b) Further, the folds in the Triassic rocks in Bear River and Bear Lake Valleys are not significantly different from those in the Paleozoic rocks in the Bear River Range, yet the rocks in the ancestral and present ranges were raised at least 13,000 feet higher than the rocks in the valleys. This difference in uplift cannot be explained solely by difference in degree of folding. (c) Finally, it might be argued that as the Ephraim is the coarsest, thickest conglomerate in the Mesozoic of the area, it represents a major tectonic event, and that, as the major structural feature in the Ephraim source area is the Paris thrust, the Ephraim is therefore a product of the same orogeny that produced the Paris thrust. The evidence, although not conclusive, suggests to us that the Paris thrust and Ephraim conglomerate are of about the same age and that the Ephraim is the product of an orogeny that involved folding and thrust faulting in the ancestral Bear River Range.

To the south in central Utah, coarse conglomerates similar to the Ephraim also have been interpreted as being evidence of orogeny to the west. The Indianola group in the Wasatch Plateau (Spieker, 1946, p. 126–130) and the Kelvin formation in the north-central Wasatch mountains (Eardley, 1944, p. 838–840) contain conglomerate beds that rapidly thicken and increase in grain size westward. Both Eardley (1944, p. 859–860, 865, fig. 2) and Spieker (1946, p. 149–152) visualized the orogeny as involving compressive forces that produced uplift, folds, and thrust faults. Although the Ephraim, Indianola, and Kelvin have not been closely dated, it seems probable that the basal part of each contains conglomerates that are correlative to the east with the Morrison formation of late Late Jurassic age (Stokes, 1955, p. 80; McKee, and others, 1956, p. 3), and that at least along their western limits the lower parts of all three are of about the same age. It thus appears probable that practically contemporaneous orogeny in Late Jurassic or Early Cretaceous time extended northward from a short distance west of the Wasatch Plateau along the west margin of the north-central Wasatch Mountains to the north end of the Bear River Range.

In summary, the ancestral Bear River Range started to rise slowly, probably before the end of Stump time; as it rose, erosion kept pace and fine debris was shed to the east. Uplift was then suddenly accelerated, and this change was marked by the start of deposition of the Ephraim. Whether the Paris thrust formed at the instant uplift was accelerated or later to coincide with the coarser conglomerate in the upper part of rocks mapped as Ephraim on Red Mountain is not known, but a post-Stump limiting maximum age is certain and an immediately pre-Ephraim limiting maximum age may be indicated. If the Ephraim on Red Mountain contains stratigraphic equivalents of several formations of the Gannett group, a pre-mid-Gannett limiting minimum age for the start of movement on the Paris thrust is required by our interpretation of the rocks on Red Mountain. We cannot be certain, however, that movement ceased in Gannett time. Abundant fragments from the Worm Creek quartzite member of the St. Charles limestone and the Brigham quartzite in the Evanston formation (Late Cretaceous and Paleocene) in nearby western Wyoming indicate that by Evanston time Cambrian formations had been exposed in the ancestral Bear River Range. No other possible source area for these fragments is known. The absence of these quartzites in the Ephraim on Red Mountain and their presence in the Evanston suggest that the ancestral Bear River Range continued to be tectonically active after Ephraim time. This activity and perhaps movement on the Paris thrust may have continued into late Evanston (Paleocene) time. All major folding and thrust faulting in southeastern Idaho have previously been thought to have occurred in post-Wayan (Early(?) and Late Cretaceous) time, but we believe that folding in the Bear River Range and movement on the Paris thrust started in latest Jurassic or earliest Cretaceous time.

THRUST FAULTS BETWEEN CROW CREEK AND SNAKE RIVER PLAIN

Overlapping of thrusts in the Left Fork of Twin Creek and Georgetown Canyon area (pl. 3) indicates slightly different ages among the thrusts, but beds necessary to date the thrusts closely are lacking. The same zone of thrusting can be traced around the south end of Snowdrift Mountain into Crow Creek and thence to the north about 10 miles, where thrusts cut Ephraim and the overlying Peterson limestone of the Gannett group, and the traces of these thrusts are covered by Pliocene(?) Salt Lake formation (Mansfield, 1927, pl. 12 sec. *O′–O″*). The Peterson is middle Early Cretaceous in age (Cobban and Reeside, 1952, pl. 1), and the thrusts are therefore no older than post-middle Early Cretaceous and are no younger than Pliocene.

About 20 miles northwest of this Peterson locality, in the area north and northeast of Paradise Valley window (pl. 1*C*), thrust faults cut Wayan formation of Late Cretaceous (and Early(?) Cretaceous) age (Cobban and Reeside, 1952, pl. 1; Moritz, 1953, p. 72) and are overlain by Pliocene(?) Salt Lake formation (Mansfield, 1927, pls. 2, 4; 1952, pl. 1). Between these thrusts and the Peterson locality are the East Stump and West Stump branches of the Bannock; the East Stump also was mapped as cutting Wayan (Mansfield, 1927, pl. 5). The East Stump and West Stump faults, however, are steeply eastward-dipping and may be normal faults rather than thrusts.

All the thrust faults from Crow Creek to the Snake River Plain were interpreted by Mansfield as branches of the Bannock overthrust and were thought to be post-Wayan and pre-Salt Lake in age. We doubt that any one fault is continuous from Crow Creek to the Snake River Plain; it appears rather that a zone of thrust faults extends between these points. All the thrusts from Crow Creek to the Snake River Plain are older than Salt Lake (Pliocene) and younger than Peterson (middle Early Cretaceous), and many or perhaps all of them are younger than Wayan (post-Early(?) and Early Late Cretaceous). All the thrusts in this zone are therefore younger than the Paris thrust.

THRUST FAULTS IN WESTERN WYOMING

The pattern of older thrust faults to the west and younger ones to the east is continued eastward into Wyoming (fig. 1). West and northwest of Kemmerer, Wyo., the youngest beds involved in the major deformation accompanying the Absaroka thrust, but not cut by it, are in the upper part of the Adaville formation (Veatch, 1907, p. 75, 76, pls. 3, 4) of Montana to early Lance age (Cobban and Reeside, 1952, pl. 1; Dorf, 1955, p. 99, fig. 1). Mapping in the area by Tracey and Oriel (1959, p. 128) and by Gazin (1959, fig. 1) shows that basal beds of the Evanston formation of latest Cretaceous (Lancian) to early late Paleocene (Tiffanian) age are cut by (and are also affected by minor movement along) the Absaroka thrust. However, the areal distribution of most of the Evanston, which over a wide area lies with marked angular unconformity on both the overriding and underlying blocks of the thrust, suggests that most of the movement on the Absaroka was completed before deposition of the bulk of the Evanston formation (W. W. Rubey, S. S. Oriel, J. I. Tracey, Jr., written communications, 1959, 1960). Most of the movement along the Absaroka fault near

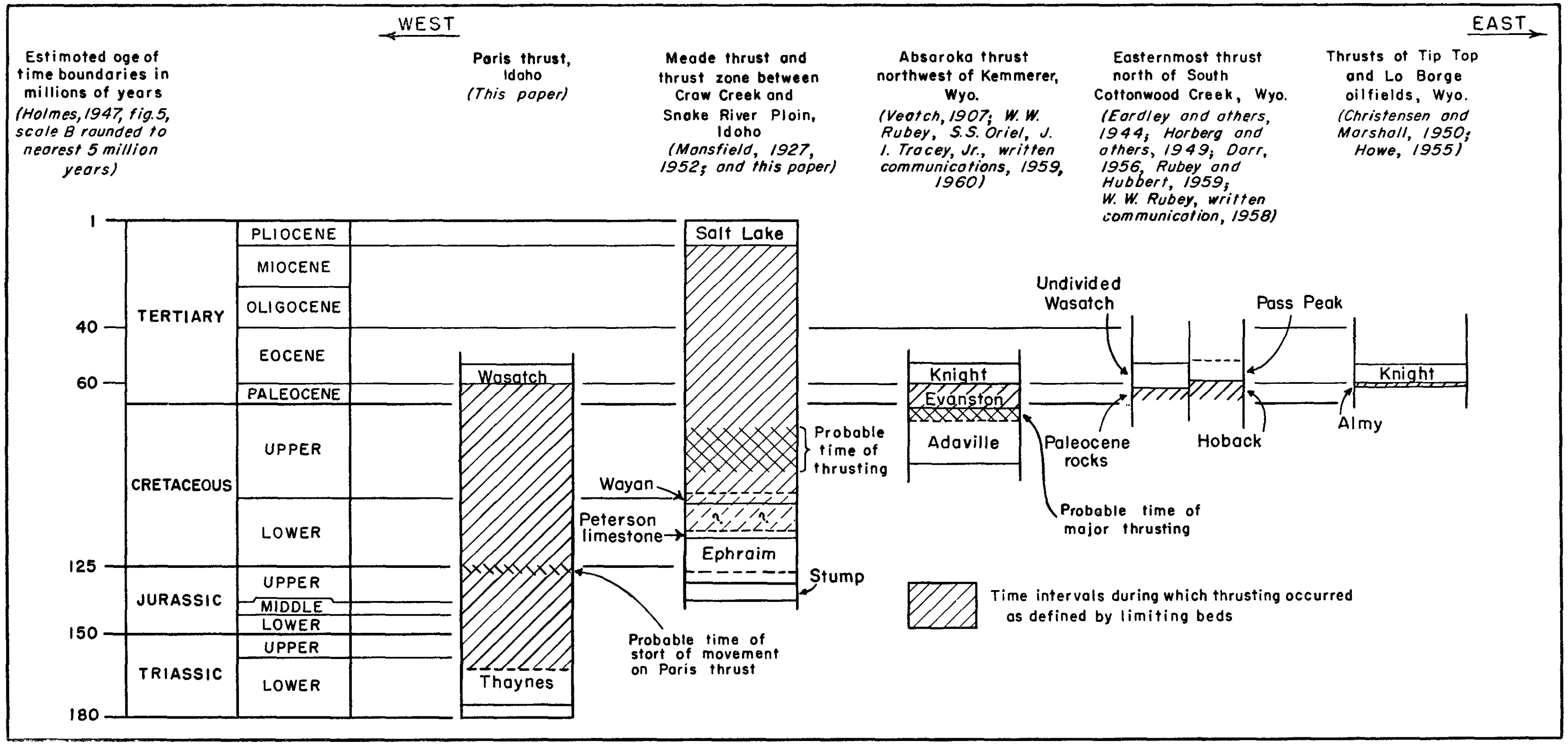

FIGURE 1.—Diagram illustrating progressive decrease in age of thrust faults from west to east.

Kemmerer, therefore, probably occurred during latest Cretaceous (Lancian) time.

From South Cottonwood Creek north to lat 43° (pl. 4) the easternmost thrust, the Prospect, cuts Paleocene rocks (Rubey and Hubbert, 1959, p. 188, fig. 6), and at several places the fault is overlain by undivided Wasatch (Eocene) that has been folded but not thrust faulted (W. W. Rubey, written communication, 1958). These Wasatch rocks, undivided, may include beds older than Eocene. North of lat 43° the easternmost thrust (called Game by Eardley and others, 1944, Cliff Creek by Horberg and others, 1949, p. 201, and Jackson by Dorr, 1956, p. 101) cuts the lower part of the middle Paleocene to early Eocene Hoback formation and is overlain by the Eocene Pass Peak formation (Dorr, 1956, p. 101, 102, 106, figs. 1, 2).

A little farther east at Tip Top oil field (pl. 4), Howe (1955, p. 174, 176, fig. 4) mapped thrust faults that cut Almy formation of late Paleocene age and that are overlain by slightly tilted Knight formation of early Eocene age (Gazin, 1959, fig. 1). About 10 miles to the southeast at La Barge oil field (pl. 4), Christensen and Marshall (1950, p. 106, sec. *A–A′* 107) mapped a subsurface thrust fault that also cuts Almy. About 10 miles west of La Barge oil field, a series of beds mapped as Eocene Almy by Schultz (1914, p. 71, pl. 1) have yielded fossils of latest Paleocene (Clarkforkian) age (Gazin, 1959, p. 132). Schultz (1914), Christensen and Marshall (1950), and Howe (1955) followed Veatch in assigning the first conglomeratic Tertiary beds unconformably beneath the Knight to the Almy. It is not known whether the sequence of beds mapped as Almy by these geologists (including Veatch) constitute the same stratigraphic interval and are of the same age, but the evidence seems to suggest that the thrusting in the Tip Top and La Barge oil fields was a little later than that along the easternmost thrust north of South Cottonwood Creek, that is post-Almy (latest Paleocene, Clarkforkian) and pre-Knight (early Eocene).

The thrust faults in southeastern Idaho and adjacent western Wyoming cut progressively younger beds from west to east. Deformation seems to be generally progressively younger from Bear River Range on the west to Tip Top and La Barge oil fields on the east, this relation has been postulated previously for this area and for other areas in western North America (Thom, 1923, p. 4; Mansfield, 1927, p. 401; Nolan, 1943, p. 172; Longwell, 1950, p. 424; Eardley, 1950, p. 90; 1951, p. 323; Hume, 1957, p. 411; Rubey, 1955, 1958; Rubey and Hubbert, 1959, p. 188, 190). The thrust faults between Crow Creek and the Snake River Plain cannot be dated closely because of the relatively great age difference between the limiting formations. If the pattern of progressively younger thrust faults to the east (fig. 1) is more or less uniform, however, the thrusting between Crow Creek and the Snake River Plain occurred during Late Cretaceous time, probably during middle Late Cretaceous. In southeastern Idaho and western Wyoming thrusting thus occurred intermittently over a minimum period of about 60 million years (fig. 1).

TIME OF FOLDING OF THRUST SURFACES

Although a few folds, whose limbs dip as much as 35°, occur in the Salt Lake formation between Liberty and Nounan, no folded thrust surfaces have been recognized whose folds can be shown to have formed at the time the Salt Lake formation was folded, and there is no readily apparent similarity between the folds in the thrusts and those in the Salt Lake, as previously believed. Moreover, the large areas of horizontal beds of Wasatch south of Bear Lake (Richardson, 1941, p. 36) and the gentle dips in the Wasatch east of Bear Lake suggest that the rocks in southeastern Idaho have not yielded to strong regional compressive forces since Eocene time. These facts, along with the probably slight age differences among the bent imbricate thrust faults in the Left Fork of Twin Creek and Georgetown Canyon area, suggest that the folds in the thrust surfaces were formed penecontemporaneously with the thrusting, a possibility that Mansfield (1927, p. 170) considered but rejected as a less probable interpretation.

To the east in western Wyoming it also appears that folding of the thrust surfaces occurred at about the same time as the thrusting. At several places in that area, a thrust fault and the rocks on both sides of it have been bent in the same direction as though they had all been folded together, but there is no evidence that this apparent folding of the fault surface is significantly later in age than the thrusting itself (W. W. Rubey, written communication, 1958).

AMOUNT OF DISPLACEMENT

The amount of horizontal displacement on the Paris thrust is not known, but it must be large because the stratigraphic throw is about 20,000 feet.

The Meade thrust plate probably originated from the east side of Bear River Valley and therefore its eastward horizontal displacement could be as little as 8 miles. The thrust plate east of Montpelier (pl. 2*B*) probably is part of the same zone of thrusts exposed east of Georgetown, and it probably also came from the east side of the valley, as Richards and Mansfield suggested originally (1911, p. 399).

COMMENTS ON EXTRAPOLATIONS OF THE BANNOCK

Most interpretations of the structure of southeastern Idaho have been made on the premise that a single large folded thrust, the Bannock, underlies the region. As this premise is now untenable, it is desirable to re-examine extrapolations of the Bannock.

NORTHERN EXTENSIONS

The Portneuf window in the Bannock overthrust is a small, elongate area in which Rex chert is shown in fault contact on each side with Brazer limestone (Mansfield, 1929, pl. 1). Mansfield's (1929, pl. 2) cross section C–D shows the west fault dipping southwest and the east fault dipping northeast, but outcrop patterns of the faults on the two sides of the window indicate that at the surface both faults dip southwest. We examined this area and doubt that the material in the supposed window is the Rex chert member. Elsewhere in the nearby area the Rex is characteristically "flinty shale" (Mansfield, 1929, p. 29), but in the window it is massive chert. Moreover, northwest and southeast of the window along the projected strike of the faults, Mansfield (1929, p. 35) mapped lenses of fault breccia which he described as "cherty material similar to that of the more massive facies of the Rex chert, solidly cemented by silica."

Five thin sections of chert from the window, five from the fault breccia, and one from the contact between the window and fault breccia were examined and compared with thin sections of Rex chert from Trail Canyon, about 25 miles southeast of the window where the massive chert facies of the Rex is well developed. It was found that microscopically the chert from the window cannot be distinguished with certainty from the chert of the fault breccia. Furthermore, from among more than 40 thin sections of Rex chert from Trail Canyon, only 4 are sufficiently similar to the cherts of the window and fault breccia that they might be mistaken for them. And even these four Rex chert sections differ from the window and fault breccia cherts in that they are darker in color, contain numerous small individual carbonate rhombs which are absent from the window and breccia cherts, and do not contain small rounded detrital quartz grains with quartz overgrowths which are moderately abundant in all the window and breccia cherts examined. Detrital quartz grains of this type are common in the phosphatic chert unit at the base of the Brazer. About half a mile north northwest of the west end of the window, the top of the basal chert unit of the Brazer crops out along the crest of Twentyfour Mile anticline. We believe that the chert in the window is a large lens of silicified fault breccia, and thus find no support for the hypothesis that this area is a window exposing Rex. Rather the fault at the window is a minor thrust of small stratigraphic throw (Brazer against Brazer) on the crest of the overturned Twentyfour Mile anticline (Mansfield, 1929, pl. 1).

Ludlum (1943, p. 984–985) suggested that the rocks of the Bannock Range (pl. 1*C*) are exposed in a large window in the Putnam-Bannock fault. In the Bannock Range he mapped folds whose axial planes are overturned to the west; he also pointed out that to the east, where the Bannock overthrust crops out, the folds are overturned to the east. He suggested that "westward overturning would be difficult to explain in an overthrust segment moving eastward," but that "* * * westward overturning in a segment underthrust relatively westward is expectable." This explanation appears mechanically unlikely. Westward overturning of the fold axes is more likely related to westward movement on the eastward-dipping thrust fault shown on Ludlum's map and cross section (1943, figs. 2, 3). This thrust fault is not mentioned in Ludlum's text, but according to Anderson (1928, p. 8) "the fault involves a displacement of several thousand feet" and movement on this "overthrust fault is to the west." Before the suggestion that the Bannock Range is in a window of a thrust fault is accepted, more of the geology of the area should be mapped.

About midway between Idaho Falls and Soda Springs (pl. 1*C*) is a complexly faulted area that was mapped as the Paradise Valley window of the Bannock overthrust (Mansfield, 1952, pls. 1, 2). We have not examined this area, but the published map and cross sections contain questionable features. Outcrop patterns of some faults require dips different from those shown in the sections, and in the area of the window it seems difficult to demonstrate clearly the presence of a westward-dipping thrust fault as shown in Mansfield's sections *L–L′* and *M–M′* (1952, pl. 2). In and near the window, folds above and below the Bannock thrust are shown as overturned to the southwest, a direction of overturning that is less likely if the overriding block moved from southwest to northeast as postulated. For these reasons, we question whether the complexly faulted area is a window in a thrust fault.

That the Medicine Lodge overthrust north of the Snake River Plain is part of the northward continuation of the thrust zone south of the plain seems very probable (Scholten and others, 1955, p. 389), but the specific correlation of the Bannock with the Medicine Lodge (Kirkham, 1927, p. 27; Mansfield, 1952, p. 67) is unlikely, for, as previously mentioned, individual faults within the Bannock zone are discontinuous.

Mansfield's (1927, p. 159) suggestion that the Auburn and Star Valley faults (pl. 1*C*) may be eastward extensions of the Bannock thrust was based on the assumption that a folded thrust fault of regional extent underlies the area. As we have seen, however, this assumption is unwarranted. Mapping by Rubey (written communication, 1958) in the area of the Auburn and Star Valley faults made him doubt the existence of the Auburn fault; he suggested that the Star Valley fault may be a high-angle normal or reverse fault rather than part of a thrust fault.

SOUTHERN EXTENSIONS

Similar comments apply also to the extension southward of the Paris thrust, which formerly was interpreted as part of the Bannock overthrust. Near Liberty a single large thrust brings Brigham over Thaynes, a stratigraphic throw of about 20,000 feet. From Liberty southward the stratigraphic throw progressively decreases, and from a little north of St. Charles southward (pl. 1*C*) the fault splits into several branches among which the total stratigraphic throw is distributed (Mansfield, 1927, pl. 9). The westernmost branch was connected with another fault exposed 7 miles to the south in Utah, near the southwest shore of Bear Lake (Richardson, 1941, p. 39, pl. 1). Where exposed 4½ miles north of the Utah-Idaho State line, the fault mapped by Mansfield is the principal and westernmost of four thrust faults that dip at low angles to the west. The fault mapped by Richardson is a single fault, and, although this was shown in cross sections as dipping 20° westward (Richardson, 1941, pl. 1, sec. *A–A′*, *B–B′*), its outcrop pattern indicates a steep dip westward along its northern half and a steep dip eastward along its southern half.

Joining the fault mapped by Mansfield with the fault mapped by Richardson seems questionable. The fault to the south seems more likely to be a high-angle fault downthrown to the east, perhaps related in some manner to the graben faulting on the west side of Bear Lake Valley. From brief inspections we suggest that the progressive decrease in stratigraphic throw from Liberty southward and the branching of the fault near St. Charles southward indicate that the Paris thrust dies out southward and may not extend beyond the State line into Utah.

The steeply dipping fault near the southwest shore of Bear Lake was projected 34 miles southward beneath cover of Wasatch formation to join a thrust fault along Woodruff Creek (pl. 1*C*) (Richardson, 1941, pl. 1; Mansfield, 1952, fig. 25). The northern 5 miles of the projection is controlled by an inlier of Brigham quartzite on the west and one of Garden City formation (Ordovician) on the east, the same formations that adjoin the steeply dipping fault to the north. The southern 5 miles of the projection is controlled by an inlier of Brigham(?) quartzite (Richardson's query (1941, p. 8, 39)) on the west and one of Jurassic rocks (Nugget sandstone and Twin Creek limestone) on the east which are three-fourths of a mile apart and are separated by a cover of hill wash. In the 24 miles separating the two pairs of inliers no control determines the course of the projected fault, and there is no assurance that a fault exists.

Along Woodruff Creek, Weber quartzite (Pennsylvanian) and Park City formation (Permian)[2] on the west have been thrust eastward over Woodside, Thaynes, and Ankareh formations (Triassic), and Nugget sandstone (Jurassic) on the east (Gale and Richards, 1910, p. 527, pl. 13). Within 4½ miles along Woodruff Creek the stratigraphic throw ranges from perhaps as little as 300 feet, where the phosphatic shale unit in the upper part of the Park City is in contact with the Woodside (Gale and Richards, 1910, p. 527), to about 4,000 feet, where the middle of the Park City is in contact with the lower part of the Nugget. This is a much smaller stratigraphic throw than that between the southern pair of inliers only 5 miles to the north where it is in excess of 14,000 feet (Richardson, 1941, pl. 6). This large difference makes it clear that the projection of the Woodruff Creek thrust only 5 miles to the north is not without complications and that the projection of it an additional 24 miles to the north, under cover, is open to question. Our present state of knowledge does not justify connecting the thrust on Woodruff Creek with the Paris thrust.

It has been suggested that the Paris thrust continues southward to Woodruff Creek and from there swings westward, mostly beneath Tertiary cover, to connect with the Willard thrust near Ogden (pl. 1*C*) (Richards and Mansfield, 1912, p. 706, 707; Blackwelder, 1925; Richardson, 1941, p. 39; Eardley, 1944, p. 869, 870; 1951, p. 329, 330; Crittenden, 1959, fig. 1; 1961). Disregarding for the moment the possibility that the Paris thrust may not extend as far south as Woodruff Creek and regardless of whether the Willard connects with the thrust on Woodruff Creek, it appears unlikely that the Willard and the Paris thrusts can be parts of the same fault because of probable age differences between them. Although the Willard is not in contact with the Henefer formation of late Colorado age (Cobban and Reeside, 1951, pl. 1), Eardley (1944, p. 860, 871) believed that the sharp asymmetrical folds in the Henefer were formed by the same compressive forces that produced the Willard thrust. The Willard thrust thus is post-Henefer, that is, Late Cretaceous or early Paleocene in age (Eardley, 1951, p. 323, fig. 185), whereas according to the interpretation of the Ephraim conglomerate

[2] In 1910 the rocks now assigned to the Phosphoria formation were included in the Park City formation. For a later interpretation of the relation of the Park City to the Phosphoria, see McKelvey and others (1956).

given above, the Paris thrust is Late Jurassic or Early Cretaceous in age.

If the Ephraim conglomerate and Kelvin formation are evidence of contemporaneous orogeny to the west, then the Paris thrust is probably contemporaneous with the Ogden and Taylor thrusts (Eardley, 1951, fig. 185) and not with the Willard thrust.

STRUCTURE AND STRUCTURAL EVOLUTION OF A PART OF SOUTHEASTERN IDAHO

Although we have mapped only a small part of the area included in the supposed extent of the Bannock overthrust, the new work permits interpretations beyond the immediate area of mapping. Our interpretation of the structure and structural evolution of a part of southeastern Idaho is shown in plates 2*B* and 4—the former for the area in which we have done most of our work, the latter embodying our broader and more speculative interpretations. Plate 4 was compiled from several sources that were supplemented by our own work. Besides the sources shown on plate 4 we used unpublished maps of the central part of the Portneuf Range by D. A. Holmes,[3] L. O. Storey,[4] D. M. Schwarze,[5] and A. J. Nalwalk.[6] Interpretations of local areas were changed where new field data or interpretations based on the new data made changes seem necessary. A few changes also were made where the original interpretations do not appear to be the best ones permitted by data shown on the geologic maps. Although the broad structural interpretations presented appear to us to be in accord with the known facts, we present them as hypotheses only, partly because the geologic mapping of some of the area needs revision but mainly because a large area west of Bear River has yet to be mapped.

A zone of westward-dipping imbricate thrust faults, possibly a few tens of miles wide, extends at least from southwestern Montana through southeastern Idaho and western Wyoming to north-central Utah. We propose that that part of the imbricate thrust zone lying west of the Wyoming border between the Snake River on the north and the Utah State line on the south and including all the thrusts formerly interpreted as branches of the Bannock overthrust, be called the Bannock thrust zone. The proper name, which is firmly entrenched in geologic literature, is thus retained, but the name "Bannock thrust zone" should be divorced completely from the concept of a single large folded thrust.

The thrusts formed in response to east-northeast compressive forces, and the direction of movement of the overriding blocks was to the northeast. Individual thrusts within the Bannock thrust zone are discontinuous, and the connecting of widely separated individual thrusts is not warranted. Bends or folds in the thrusts probably result from deformation of the thrust surface during late stages of the thrusting, and not from a distinctly later period of folding. Individual thrust faults within the zone are successively younger eastward, and the rocks exposed in the overriding plates above these successive thrusts are also commonly younger to the east. Thrusting in the Bannock thrust zone began in Late Jurassic or early Early Cretaceous time and continued intermittently at least until post-early Late Cretaceous but not as late as Eocene (Wasatch) time. There seems to be no evidence that strong compressional forces were active in southeastern Idaho after the deposition of the Salt Lake formation (Pliocene), and the lack of folds in the Eocene Wasatch in extreme southeastern Idaho east of Bear Lake suggests that strong compressive forces may not have been active there since the Eocene. To the east in westernmost Wyoming, however, thrusting started later and continued until post-late Paleocene time, but early Eocene beds are not known to be cut by thrusts. The Bannock thrust zone and the large thrust faults to the east in Wyoming are all parts of the same structural system; all probably developed in response to similar forces but not at the same time.

The salient shown by the eastward convexity of the Bannock thrust zone (pl. 4) is also reflected in a similar eastward convexity of traces of the axial planes of folds. The salient could have formed in response to a shove from the west-southwest; it probably is the area of greatest eastward movement. Rocks within the salient yielded by folding, by thrust or tear faulting, and by combinations of these mechanisms at different places and at different times. As the rocks within the salient moved eastward, they broke into blocks. The larger transverse faults probably are genetically related to the differential eastward movement among these blocks, and most of the smaller transverse faults probably are also related to this movement or to failure by tear faulting near the ends of thrust faults.

The thrusts in the Bannock thrust zone dip westward and the upper plates of the thrusts moved eastward. In the Wasatch Range north and east of Ogden, the Taylor, Ogden, Durst, and Willard thrusts dip to the east, and southeast of Pocatello an unnamed thrust also dips eastward (pl. 4). Although Kirkham (1930, p.

[3] Holmes, David A., 1958, Cambrian-Ordovician stratigraphy of the northern Portneuf Range: Idaho Univ. Master's thesis, Moscow, Idaho.

[4] Storey, Lester O., 1959, Geology of a portion of Bannock County, Idaho: Idaho Univ. Master's thesis, Moscow, Idaho.

[5] Schwarze, David M., 1959, Geology of the Lava Hot Springs Area, Idaho : Idaho Univ. Master's thesis, Moscow, Idaho.

[6] Nalwalk, Andrew J., 1959, Geology of a portion of southern Portneuf Range, Idaho: Idaho Univ. Master's thesis, Moscow, Idaho.

736) stated that he traced the Willard thrust northward into Idaho to a point where it is masked by Snake River lava flows, we do not know of a published map that shows this northward extension of the Willard. The upper plates of all the eastward dipping thrusts except the Willard are thought to have moved relatively westward (Eardley, 1944, p. 853, 854; 1951, p. 328; Anderson, 1928, p. 8). Direction of movement on the Willard is not known. Some geologists believe the upper plate moved westward (Hardy, 1957), others that it moved eastward (Crittenden, 1961), and still others have believed first the former and then the latter (Blackwelder, 1925; Eardley, 1939, fig. 4; 1951, p. 330). In postulating eastward movement on the Willard, Blackwelder (1925), Eardley (1951, p. 330), and Crittenden (1961) believed that the Willard and Bannock faults were parts of one very large thrust fault. As it now appears that the Bannock is a thrust zone made up of faults of different ages and that the Willard is younger than the Paris thrust, it is unlikely that the Willard can be continuous with the Paris, as formerly supposed.

If the upper plates of the eastward-dipping thrust faults moved relatively westward and if the block between these thrusts and the westward-dipping faults of the Bannock thrust zone acted more or less as a unit, then a segment of the earth's crust between the oppositely dipping thrusts moved upward and outward along its margins. Such a rising and spreading segment of the crust, or orogen, was suggested by Eardley (1944, p. 867–869) as a possible explanation for the relation of the thrusts near Ogden to those of the Bannock thrust zone. Rubey and Hubbert (1959, p. 198–199) pointed out some of the difficulties of this "hypothesis of the orogen," and concluded that if a segment of the earth's crust did move as postulated, it must have been a thin shell of near-surface rocks that was overthrust to the east and underthrust from the west.

The orogen hypothesis implies that sole thrusts underlie each side of the rising segment of the earth's crust; however probably not all the emergent thrusts originated in these sole thrusts. In southeastern Idaho it may be difficult to recognize the sole thrusts, if present, because thrust relations have been obscured by later north-trending normal faults.

Two principal sets of high-angle faults are abundant in southeastern Idaho. The east- to northeast-trending set (p. J6, J7, J8, J19) is the older, and it probably originated as tear faults during the thrusting. The other set generally trends north to northwest, is Pliocene and younger in age, and results from block faulting. Movement has occurred in Recent time on some of the north-trending faults, and movement along them has probably occurred intermittently since at least as early as Pliocene time. Dips in the Salt Lake formation are believed to result mostly from tilting of blocks bounded by these faults. Block faulting cut up the imbricate thrust zone to produce the complex thrust fault pattern now exposed; the block faulting also formed graben valleys and horst ranges. Several horsts and graben have already been recognized (Mansfield, 1927, p. 162) and this type of structure on both large and small scales is probably widespread. The Bear River Range is a horst and the valleys east and west of it are grabens; the valley of Slug Creek (near the Slug Creek window) is a small graben.

Although many of the ridges in the area owe their topographic relief to differential erosion of soft adjacent formations, the larger topographic features in southeastern Idaho are tectonic in origin rather than erosional; they owe most of their present relief to post-Pliocene movement on the north-trending faults that relatively raised the ranges and lowered the valleys. The still larger topographic patterns of valleys and ranges in southeastern Idaho and adjoining parts of Utah and Wyoming probably predate Pliocene time, but postdate the Eocene. This conclusion is supported not only by the present distribution of the Wasatch (Eocene) and Salt Lake (Pliocene) formations, but also by their lithologic characters. Wasatch occurs on ridges as well as in valleys, whereas Salt Lake occurrences are largely restricted to valleys. The absence of a possible nearby source for many of the pebbles, cobbles, and boulders in the conglomerates of the Wasatch formation suggests that they were deposited far from their source by throughgoing streams in a relatively unconfined environment. On the other hand, all the pebbles, cobbles, and boulders of the conglomerates in the Salt Lake formation could, and probably did, have local sources, and probably were deposited in intermontane basins not very unlike those existing today.

REFERENCES CITED

Anderson, Alfred L., 1928, Portland cement materials near Pocatello, Idaho: Idaho Bur. Mines and Geology Pamph. 28, 14 p.

Armstrong, Frank C., 1953, Generalized composite stratigraphic section for the Soda Springs quadrangle and adjacent areas in southeastern Idaho, *in* Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf., Guide to the geology of northern Utah and southeastern Idaho: Chart, in pocket.

Billings, M. P., 1942, Structural geology: New York, Prentice-Hall, Inc., 473 p.

Blackwelder, Eliot, 1910, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., v 21, p. 517–542.

——— 1925, Wasatch Mountains revisited [abs.]: Geol. Soc. America Bull., v. 36, p. 132–133.

Christensen, H. E., and Marshall, J., 1950, La Barge field, Sublette County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 5th Ann. Field Conf., Southwest Wyoming, 1950: p. 105–108.

Cobban, William A., and Reeside, John B., Jr., 1952, Correlation of the Cretaceous formations of the western interior of the United States: Geol. Soc. America Bull., v. 63, p. 1011–1044.

Cressman, E. R., 1957, Preliminary geologic map of the Snowdrift Mountain quadrangle, Caribou County, Idaho: U.S. Geol. Survey Min. Inv. Field Studies Map MF–118.

Cressman, E. R., and Gulbrandsen, R. A., 1955, Geology of the Dry Valley Quadrangle, Idaho: U.S. Geol. Survey Bull. 1015–I, p. 257–270.

Crittenden, Max D., Jr., 1959, Mississippian stratigraphy of the central Wasatch and western Uinta Mountains, Utah, *in* Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., Geology of the Wasatch and Uinta Mountains, transition area, 1959: p. 63–74.

——— 1961, Magnitude of thrust faulting in northern Utah, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D128–D133.

Dorf, Erling, 1955, Paleobotanical correlations of Late Cretaceous deposits in southwestern Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., Green River Basin, 1955: p. 96–99.

Dorr, John A., Jr., 1956, Post-Cretaceous geologic history of the Hoback Basin area, central western Wyoming, *in* Wyoming Geol. Assoc. Guidebook 11th Ann. Field Conf., Jackson Hole, 1956: p. 99–108.

Eardley, A. J., 1939, Structure of the Wasatch-Great Basin region: Geol. Soc. America Bull., v. 50, p. 1277–1310.

——— 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, p. 819–894.

——— 1950, Snake River region of western Wyoming, *in* Wyoming Geol. Assoc. Guidebook 5th Ann. Field Conf., Southwest Wyoming, 1950: p. 88–92.

——— 1951, Structural geology of North America: New York, Harper & Bros., 624 p.

Eardley, A. J., Horberg, Leland, Nelson, V. E., and Church, Victor, 1944, Hoback-Gros Ventre-Teton [Wyo.] field conference: privately printed, tectonic map, stratigraphic column, geologic map and cross sections; arranged by the staff of Camp Davis, Michigan Univ. Rocky Mtn. Field Station.

Gale, H. S., and Richards, R. W., 1910, Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U.S. Geol. Survey Bull. 430, p. 457–535.

Gazin, C. Lewis, 1959, Paleontological exploration and dating of the early Tertiary deposits in basins adjacent to the Uinta Mountains, *in* Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., Geology of the Wasatch and Uinta Mountains, transition area, 1959: p. 131–138.

Gulbrandsen, R. A., McLaughlin, K. P., Honkala, F. S., and Clabaugh, S. E., 1956, Geology of the Johnson Creek quadrangle, Caribou County, Idaho: U.S. Geol. Survey Bull. 1042–A, p. 1–23.

Hardy, C. T., 1957, Structural features of parts of northern Utah and southeastern Idaho [abs.]: Geol. Soc. America Bull., v. 68, p. 1863.

Hardy, C. T., and Williams, J. Stewart, 1953, Geologic map of the northern Wasatch Mountains, Utah and Idaho, *in* Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf., Geology of northern Utah and southeastern Idaho, 1953: pl. 1.

Hills, E. S., 1943, Outlines of structural geology: New York, Nordeman Publishing Co., Inc., 172 p.

Holmes, A., 1947, The construction of a geological time scale: Geol. Soc. Glasgow Trans., v. 21, p. 117–152.

Horberg, Leland, Nelson, Vincent, and Church, Victor, 1949, Structural trends in central western Wyoming: Geol. Soc. America Bull., v. 60, p. 183–216.

Howe, Richard A., 1955, Tip Top Field, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., Green River Basin, 1955: p. 172–176.

Hume, G. S., 1957, Fault structures in the foothills and eastern Rocky Mountains of southern Alberta: Geol. Soc. America Bull., v. 68, p. 395–412.

Imlay, R. W., 1950, Jurassic rocks in the mountains along the west side of the Green River Basin, *in* Wyoming Geol. Assoc. Guidebook 5th Ann. Field Conf., Southwest Wyoming, 1950: p. 37–47.

——— 1952, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 63, p. 953–992.

Kirkham, V. R. D., 1927, A geologic reconnaissance of Clark and Jefferson and parts of Butte, Custer, Fremont, Lemhi and Madison counties, Idaho: Idaho Bur. Mines and Geology Pamph. 19, 47 p.

——— 1930, Review of Geography, geology, and mineral resources of part of southeastern Idaho by George R. Mansfield (U.S. Geol. Survey Prof. Paper 152): Jour. Geology, v. 38, p. 729–736.

Kummel, Bernhard, 1954, Triassic stratigraphy of southeastern Idaho and adjacent areas: U.S. Geol. Survey Prof. Paper 254–H, p. 165–194.

Longwell, Chester R., 1950, Tectonic theory viewed from the Basin Ranges: Geol. Soc. America Bull., v 61, p. 413–434.

Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming: U.S. Geol. Survey.

Ludlum, J. C., 1943, Structure and stratigraphy of part of the Bannock Range, Idaho: Geol. Soc. America Bull., v. 54, p. 973–986.

Mansfield, G. R., 1920, Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U.S. Geol. Survey Bull. 713, 152 p.

——— 1921, Types of Rocky Mountain structure in southeastern Idaho: Jour. Geology v. 29, p. 444–468.

——— 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 453 p.

——— 1929, Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U.S. Geol. Survey Bull. 803, 110 p.

——— 1952, Geography, geology, and mineral resources of the Ammon and Paradise Valley quadrangles, Idaho: U.S. Geol. Survey Prof. Paper 238, 92 p.

McKee, Edwin D., Oriel, Steven S., Swanson, Vernon E., MacLachlan, Marjorie E., MacLachlan, James C., Ketner, Keith B., Goldsmith, June Waterman, Bell, Ruth Young, and Jameson, Dolores J., 1956, Paleotectonic maps of the Jurassic system with a separate section on Paleogeography, by Ralph W. Imlay: U.S. Geological Survey Misc. Geol. Inv. Map I–175, 6 p.

McKee, Edwin D., Oriel, Steven S., Ketner, Keith B., MacLachlan, Marjorie E., Goldsmith, June W., MacLachlan, James C., and Mudge, Melville R., 1959, Paleotectonic maps of the Triassic system: U.S. Geol., Survey Misc. Geol. Inv. Map I–300, 33 p.

McKelvey, V. E., Williams, James Steele, Sheldon, R. P., Cressman, E. R., Cheney, T. M., and Swanson, R. W., 1956, Summary description of Phosphoria, Park City, and Shedhorn formations in western phosphate field: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 2826–2863.

Moritz, Carl A., 1953, Summary of the Cretaceous stratigraphy of southeastern Idaho and western Wyoming, *in* Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf., Geology of northern Utah and southeastern Idaho, 1953: p. 63–72.

Nevin, C. M., 1942, Principles of structural geology: New York, John Wiley & Sons, Inc., 320 p.

Nolan, Thomas B., 1943, The Basin and Range Province in Utah, Nevada, and California: U.S. Geol. Survey Prof. Paper 197–D, p. 141–196.

Peterson, James A., 1955, Maine Jurassic rocks, northern and eastern Uinta Mountains and adjacent areas, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., Green River Basin, 1955: p. 75–79.

Plumley, William J., 1948, Black Hills terrace gravels—a study in sediment transport: Jour. Geology, v. 56, p. 526–577.

Richards, R. W., and Mansfield, G. R., 1911, Preliminary report on a portion of the Idaho phosphate reserve: U.S. Geol. Survey Bull. 470, p. 371–439.

——— 1912, The Bannock overthrust—A major fault in southeastern Idaho and northeastern Utah: Jour. Geology, v. 20, p. 681–707.

——— 1914, Geology of the phosphate deposits northeast of Georgetown, Idaho: U.S. Geol. Survey Bull. 577, 76 p.

Richardson, G. B., 1941, Geology and mineral resources of the Randolph quadrangle, Utah-Wyoming: U.S. Geol. Survey Bull. 923, 54 p.

Rubey, William W., 1955, Early structural history of the overthrust belt of western Wyoming and adjacent states, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., Green River Basin, 1955: p. 125–126.

——— 1958, Geologic map of the Bedford quadrangle, Wyoming: U.S. Geol. Survey Geol. Quad. Map GQ–109.

Rubey, William W., and Hubbert, M. King, 1959, Overthrust belt in geosynclinal area of western Wyoming in light of fluid-pressure hypothesis [Pt.] 2 *of* Role of fluid pressure in mechanics of overthrust faulting: Geol. Soc. America Bull., v. 70, p. 167–206.

Scholten, Robert, Keenmon, K. A., and Kupsch, W. O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geol. Soc. America Bull., v. 66, p. 345–404.

Schultz, Alfred Reginald, 1914, Geology and geography of a portion of Lincoln County, Wyoming: U.S. Geol. Survey Bull. 543, 141 p.

Spieker, Edmund M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geol. Survey Prof. Paper 205–D, p. 117–161.

Stokes, Wm. Lee, 1955, Nonmarine Late Jurassic and Early Cretaceous formations, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., Green River Basin, 1955: p. 80–84.

——— 1959, Jurassic rocks of the Wasatch Range and vicinity, *in* Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., Geology of the Wasatch and Uinta Mountains, transition area, 1959: p. 109–114.

Thom, W. T., Jr., 1923, The relation of deep-seated faults to the surface structural features of central Montana: American Assoc. Petroleum Geologists Bull., v. 7, p. 1–13.

Tracey, Joshua I., and Oriel, Stevens S., 1959, Uppermost Cretaceous and lower Tertiary rocks of the Fossil Basin, *in* Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., Geology of the Wasatch and Uinta Mountains, transition area, 1959: p. 126–130.

Veatch, A. C., 1907, Geography and geology of a portion of southwestern Wyoming: U.S. Geol. Survey Prof. Paper 56, 178 p.

Wanless, H. R., and Gray, H. H., 1955, Gannett group and Cloverly formation, *in* Wanless, Harold R., Belknap, Ralph L., and Foster, Helen, Paleozoic and Mesozoic rocks of Gros Ventre, Teton, Hoback, and Snake River Ranges, Wyoming: Geol. Soc. America Mem. 63, p. 53–57.

Williams, J. Stewart, 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. America Bull. v. 59, p. 1121–1164.

Willis, Bailey, and Willis, Robin, 1934, Geologic structures: New York, McGraw-Hill Book Co., 544 p.

Young, Jack C., 1953, Geology of the north Dry Valley structure, Caribou County, Idaho, *in* Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf., Geology of northern Utah and southeastern Idaho, 1953: p. 83–85.

Zeni, Milton, 1953, Geology of Sheep Creek anticline, Bear Lake County, Idaho, *in* Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf., Geology of northern Utah and southeastern Idaho, 1953: p. 80–82.

Shorter Contributions To General Geology 1960

GEOLOGICAL SURVEY PROFESSIONAL PAPER 374

This professional paper was printed as separate chapters A–J

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the separate chapters