PHYSIOGRAPHIC RELATIONS OF THE LEWIS OVERTHRUST IN NORTHERN MONTANA.

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ABSTRACT.

The Lewis overthrust is considered by some geologists to be an "erosion thrust." The pre-Cambrian rocks are supposed to have been driven northeasterly over a peneplain cut on Cretaceous sediments. On such an hypothesis the erosion surface is older than the overthrusting, but the reverse is true. Moreover, the absence of overridden talus and gravels along the thrust plane indicates that the Lewis overthrust is not an "erosion thrust," but a subsurface fault. Daly's conclusion that the overthrust is of Laramide age is correct.

PROBLEM.

The classic paper by Bailey Willis on the Lewis and Livingston Ranges of Montana appeared thirty-five years ago (12).[1] Further studies in the area have merely confirmed or elaborated his conclusions on the stratigraphy and structure. His most spectacular concept, the Lewis overthrust, has withstood the test of time.

One part of Willis' interpretation, however, is erroneous. He believed that the overthrust sheet moved across a peneplain, remnants of which are still preserved on the Great Plains, and he considered the fault to be an "erosion thrust." The erosion surface to which Willis refers, however, is younger than the overthrust; there is no evidence that the fault is an "erosion thrust"; and there is every reason to believe that the thrust is of Laramide age.

The present writer reached these conclusions in the field and later discovered that Daly (4, pp. 605-610), MacKenzie (8, pp. 115-116), and Alden (1, p. 7) had already given their reasons for believing that the Lewis overthrust is older than the date proposed by Willis. It seems desirable, however, to consider the question further, inasmuch as the present writer in reaching his conclusions used evidence differing from that employed by Daly, MacKenzie, and Alden. Secondly, some of the objections raised by these authors do not appear valid.

[1] Numbers in parentheses indicate references at end of paper.

Finally, as recently as 1934 Willis reiterated his belief that the Lewis overthrust is an "erosion thrust," saying:

"The Lewis overthrust is comparable in superficial character with the Rome and Cartersville thrusts of the southern Appalachians" (13, p. 181). "Hayes explained this anomalous condition by assuming that in an adjacent section erosion had removed the crest of a slight fold in such a manner as to expose the edge of a rigid stratum, and the latter, meeting with no resistance, rode forward on the eroded plane" (13, p. 179).

The present writer spent six days, September 8 to 13, 1937, in the field, chiefly in Glacier National Park and the western part of the Blackfeet Indian Reservation. On such a basis it may seem presumptuous to discuss so large an area that has been well studied by others. But, although the ideas presented here were evolved as a working hypothesis in the course of a brief field inspection, the analysis has had the advantage of all the well-established facts presented in detail in the excellent papers by Willis (12), Daly (4), Campbell (2), MacKenzie (8), Stebinger (11), Clapp (3), and Alden (1).

STRUCTURE.

The Lewis overthrust extends northwesterly along the Rocky Mountain front in Alberta and Montana. Daly (4, pp. 90-95), MacKenzie, and Rose have traced it 85 miles north from the International boundary (8, p. 110-111). Willis (12), Campbell (2), and Clapp (3) have accurately mapped it for 50 miles south of the boundary (Fig. 1). According to Clapp (3, p. 25) the thrust has been traced by reconnaissance mapping for 175 miles still further southeast. The length of the Lewis overthrust is thus at least 135 miles, and probably over 300 miles. The dip ranges from 0 to 50 degrees west-southwest, but on the east side of Glacier National Park, the section of the thrust with which the present paper is concerned, the dip averages seven degrees west-southwest (3, p. 25). The maximum stratigraphic throw is 40,000 feet (3, p. 25), and the net slip is not less than 15 miles (2, p. 12). In Glacier National Park the pre-Cambrian Altyn formation has been thrust over the Cretaceous shale and sandstone (Figs. 3, 4, and 5). The structure of the pre-Cambrian sediments southwest of the thrust is essentially a simple, broad, open syncline 20 miles wide.

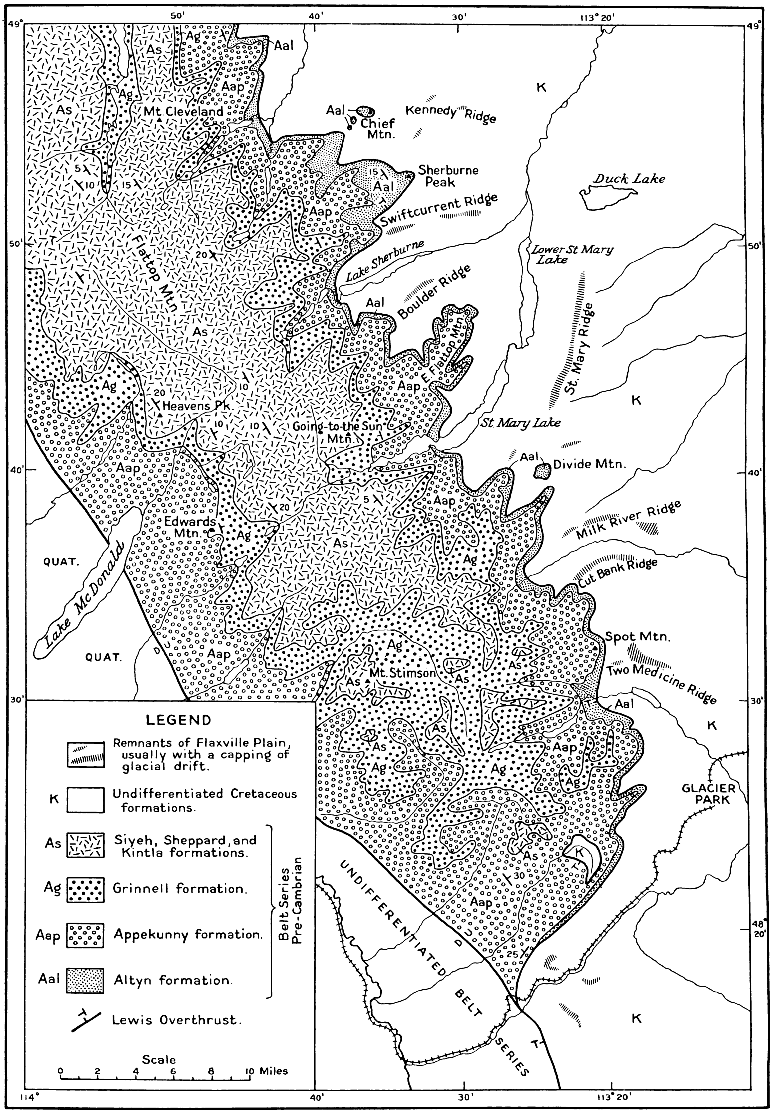

Fig. 1. Geological sketch map in the vicinity of Glacier National Park, Montana. Lewis overthrust after M. R. Campbell (2) ; distribution of formations after C. H. Clapp (3), E. Stebinger (11) ; remnants of Flaxville plain after W. H. Alden (1). Some modifications based on personal observations.

Willis (12, p. 332) showed that the thrust plane is somewhat warped and calculated that the strike ranges from N to N 59° W. Northwest from Glacier National Park station the thrust plane is thus thrown into broad folds which plunge southwest. Observations by the present writer indicate that the major streams are developed along the crests of these folds. If one were to follow a straight line trending N 30° W along the mountain front, and could reconstruct the fault in those places from which it has been eroded, one would find that the thrust plane is higher above the central portions of the valleys than under the intervening ridges.

Stebinger (11, pp. 292-294) states that in a belt 20 miles wide directly northeast of the trace of the thrust the Cretaceous rocks are folded and broken by numerous thrusts (Fig. 2). The details, however, are not known in many places because of the lack of good exposures.

PHYSIOGRAPHY.

The physiography of the Great Plains east of the Lewis overthrust was originally described by Willis (12), and more recently by Alden in an elaborate monograph (1). The feature most pertinent to the present problem is an uplifted and dissected erosion surface, termed the Blackfoot peneplain by Willis, and the Flaxville plain or No. 1 bench by Alden (Fig. 1). This surface, which truncates the deformed Cretaceous rocks (Fig. 2), gradually rises from 2,500 feet in eastern Montana to 6,000 feet along the Rocky Mountain front at Glacier National Park. In eastern Montana river gravels on this surface carry vertebrate fossils, and aid in dating the surface. Alden believes that although the cutting of this surface was essentially completed by upper Miocene, streams continued to flow on it until early Pleistocene (1, pp. 13-14).

In an area 12 to 15 miles wide directly east of the Rocky Mountain front the Flaxville plain (Fig. 1) is usually covered by early Pleistocene (Kansas or Nebraskan ?) glacial drift 50 to 250 feet thick (1, pp. 33-40). Remnants of the Flaxville surface, covered by this drift, are found on Swiftcurrent Ridge, Boulder Ridge, St. Mary Ridge, Milk River Ridge, Cut Bank Ridge, and Two Medicine Ridge. Near the mountains the crests of these ridges are generally 6,000-6,400 feet above sea level.

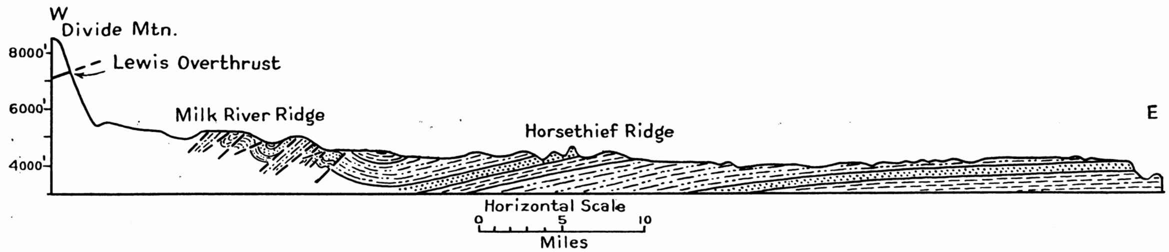

Fig. 2. Structure of Cretaceous formations east of Lewis overthrust, after E. Stebinger (11, plate XXIV). Vertical scale exaggerated. Also shows discrepancy in elevation between Flaxville plain (crest of Milk River Ridge), and the Lewis overthrust.

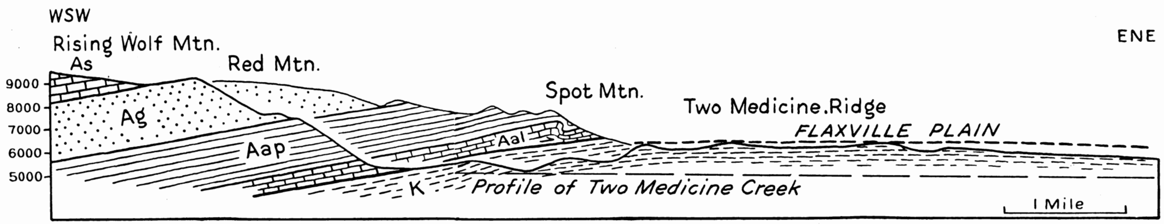

Fig. 3. Relation between Lewis overthrust and Flaxville plain at Spot Mountain. Aal = Altyn formation, Aap = Appekunny formation, Ag = Grinnell formation, As = Siyeh formation, K = Cretaceous formations. Structure of Cretaceous diagrammatic.

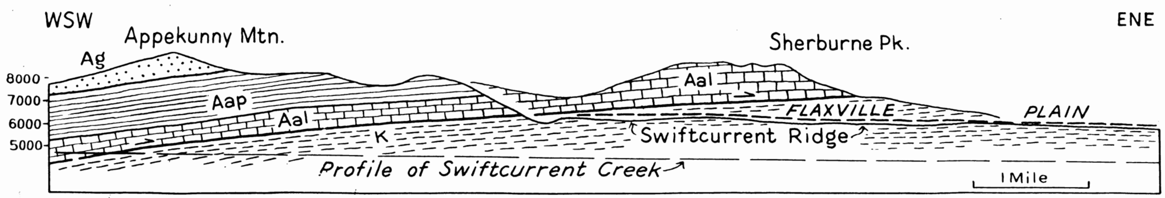

Fig. 4. Relation between the Lewis overthrust and the Flaxville plain at Sherburne Peak. Aal = Altyn formation, Aap = Appekunny formation, Ag = Grinnell formation, K = Cretaceous formations; structure of Cretaceous formations diagrammatic.

The Blackfoot peneplain of Willis is the same as the Flaxville plain of Alden. Willis, referring to Plate 47, Fig. 1, of his paper, says:

"At the left is St. Mary Ridge, the crest of which is somewhat built up as a lateral moraine of the St. Mary Glacier, but which from this point of view corresponds closely with the profile of the old peneplain" (12, p. 336).

Alden (1, p. 15) lists the crests of St. Mary ridge as a remnant of the Flaxville plain, capped by drift.

RELATION BETWEEN PHYSIOGRAPHY AND STRUCTURE.

Willis presented the following picture of the evolution of the Lewis overthrust (12, particularly plate 53).

(1) Folding at the close of the Mesozoic, with the formation of an anticline west of the Lewis overthrust.

(2) Erosion in early Tertiary time, exposing the pre-Cambrian rocks in the center of the anticline. The Blackfoot peneplain (= Flaxville plain) was developed on the Cretaceous rocks occupying what are now the Great Plains. On the pre-Cambrian rocks to the west there was probably a "low, hilly, post-mature relief." The erosion surface was completed by mid-Tertiary time.

(3) With renewed compression in the mid-Tertiary, a break-thrust formed on the northeast limb of the anticline and the pre-Cambrian rocks were thrust northeasterly; where the thrust emerged at the surface the pre-Cambrian rocks moved over the peneplain.

In some places along the mountain front the apparent coincidence of the Flaxville plain and the plane of the Lewis overthrust seems to lend support to the sequence outlined above. Around East Flattop Mountain (Fig. 1), for example, the altitude of the trace of the overthrust (6,300 to 6,500 feet) is within a few hundred feet of the Flaxville plain on St. Mary's ridge (altitude 6,100 feet, less 100 to 200 feet because of the capping of glacial drift). Just north of Two Medicine Lake the altitude of the frontal part of the overthrust almost corresponds with the most southwesterly remnant of the erosion surface (Fig. 3).

In places, however, the Flaxville plain extends several miles southwest of the mountain front. A notable example is found between Sherburne Peak and East Flattop Mountain (Figs. 1 and 4), where remnants of the erosion surface are found on

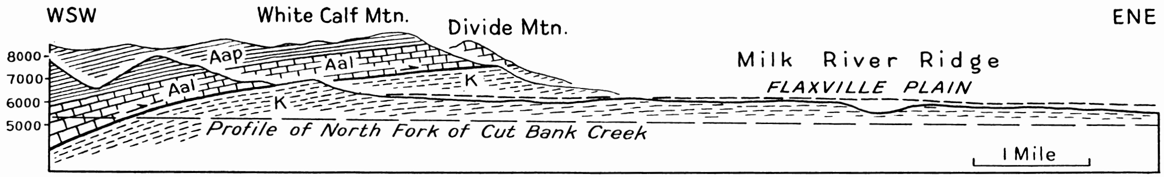

Fig. 5. Relation between the Lewis overthrust and the Flaxville plain at Divide Mountain. Aal = Altyn formation; Aap = Appekunny formation, K = Cretaceous formations; structure of Cretaceous formations diagrammatic.

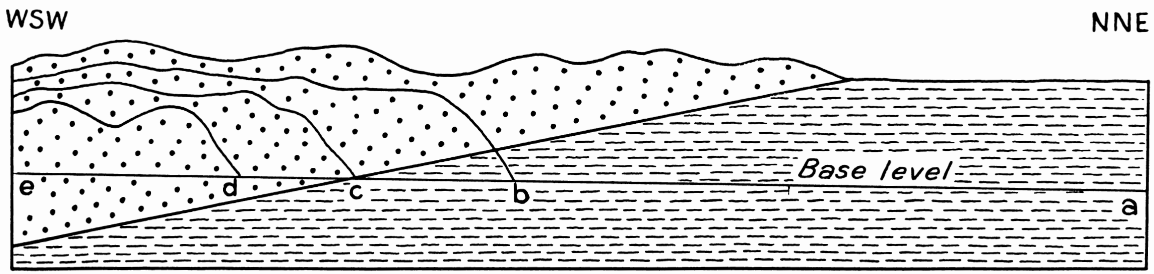

Fig. 6. Cross section to illustrate the erosion of a scarp. Stippling = hard rocks; broken lines = soft rocks. See text for explanation.

Swiftcurrent Ridge and Boulder Ridge. Fig. 4 is the view one would obtain looking north-northwest from a point on Boulder Ridge. It is clear that the thrust plane and the erosion surface do not correspond. The thrust dips southwest at an angle of three degrees; the erosion surface dips northeast at an angle of about one degree. An "overlap" relation is shown throughout a breadth of several miles. On the east slope of Sherburne Peak the thrust plain is 1,000 feet higher than the Flaxville plain. The fact that the thrust plane is a warped surface, thrown into broad folds plunging southwest, does not affect this argument. In fact, as mentioned on an earlier page, the thrust plane is somewhat higher where crossed by the valleys than it is beneath the northeasterly trending spurs.

Similar relations are found near Divide Mountain (Figs. 1 and 5). The Flaxville plain is represented by the crest of Milk River Ridge and Cut Bank Ridge. Fig. 5 is the view one would obtain looking north-northwest from a point on Cut Bank Ridge. The thrust fault dips southwest at an angle of three degrees; the erosion surface dips northeast at approximately one degree. The "overlap" relation is shown throughout a breadth of about one mile. On the east slope of Divide Mountain the thrust plane is 1,300 feet higher than the Flaxville plain.

We conclude, therefore, that although the overthrust plane and the erosion surface coincide in places, there are numerous exceptions to this rule. Some may wonder why there is coincidence in any localities, but this subject can best be discussed after considering the age of the thrust relative to the Flaxville plain.

The profiles in Figs. 4 and 5 show that the base of the overthrust sheet in places is 1,000 feet or more above the Flaxville plain. If the erosion surface were older than the thrusting, the overthrust sheet would in places have hung suspended in space. This is manifestly absurd. Therefore, the erosion surface is younger than the thrusting.

On the geological sketch map (Fig. 1) large lobes of the Flaxville plain extend westward into the area once occupied by the pre-Cambrian thrust sheet. The most pronounced of these lobes, with remnants of the Flaxville plain still preserved, is found between Sherburne Peak and East Flattop Mountain. Fairly good examples are found north and south of Divide Mountain.

We may now answer the question as to why the altitude of the trace of the overthrust even approximates the altitude of the Flaxville plain. Fig. 6 shows diagrammatically structural relationships similar to those found along the Lewis overthrust: hard rocks overlie weak rocks, the contact dipping gently to the west-southwest. Assume that in a particular erosion cycle the base-level of erosion is represented by the line *abcde*. The soft rocks are reduced to the new base-level relatively rapidly. At a given stage a scarp is present at *b*. But the scarp will retreat rather rapidly, due to the easy erosion of the soft rocks and the undermining of the hard rocks. But once the scarp has reached *c*, further recession is slow. At *c* the elevation of the trace of the overthrust is the same as the elevation of the thrust plane. In the actual case projecting spurs, such as Chief Mountain, Sherburne Peak, and Divide Mountain have relations similar to those of the diagram at *b*, the trace of the thrust plane having a greater altitude than the erosion surface. In deeper valleys cut back into the overthrust sheet the relations would be similar to those at *d*, with the thrust plane lower than the erosion surface.

There is another fact, not known at the time of Willis' study, which strongly favors the hypothesis that the Flaxville plain is younger than the Lewis overthrust. Stebinger (11) has shown that the Cretaceous rocks directly east of the mountains are folded and broken by numerous thrust faults. These folds and thrusts are truncated by the Flaxville plain (Fig. 2). It seems most logical to consider these thrusts as related in origin and age to the Lewis overthrust. Hence, inasmuch as they are pre-Flaxville, the Lewis overthrust is pre-Flaxville. MacKenzie (8), although he did not recognize the existence of an erosion surface, has given excellent reasons for believing that the thrusts cutting the Cretaceous rocks in the Great Plains of Alberta are essentially contemporaneous with the Lewis overthrust.

Although we have shown that the Lewis overthrust is older than the Flaxville plain, we have not eliminated the possibility that the pre-Cambrian rocks were thrust northeasterly over some higher erosion surface, remnants of which might still be preserved on the Great Plains. Such a suggestion is given further credence by flattish surfaces, possibly representing an erosion surface, which are found at approximately the elevation of the thrust plane in several places. The most extensive of these surfaces bevels the Cretaceous rocks at an altitude of 7,100 feet directly north of Sherburne Peak. The thrust plane crops out at the same altitude. A less extensive surface at an altitude of 7,100 feet is found on the east slope of Divide Mountain, also near the altitude of the thrust plane.

But there are other facts which militate against this hypothesis. On the east slope of Chief Mountain this same surface is prominent at an altitude of 7,200 feet, but the thrust plane crops out at nearly 8,000 feet. Finally, a similar surface seems to be developed on East Flattop Mountain, and near the mountain front has an altitude of 7,200 feet. But here the surface bevels the pre-Cambrian rocks above the thrust plane.

In summary, if there is an erosion surface at altitudes of 7,000-7,200 feet, it does not generally agree in elevation with the thrust plane. Even more significant is the fact that it truncates the rocks both above and below the thrust plane, and hence would be younger than the thrusting. It should be noted, moreover, that Alden (1) does not record a surface at this elevation on the Rocky Mountain front. He believes that the Cypress plain, which is the next surface above the Flaxville plain, should be found at about 8,300 feet in the front range of the Rocky Mountains of northern Montana (1, p. 6; 9, p. 871).

Although we have shown that the erosion surfaces on the Great Plains are younger than the Lewis overthrust, we have not yet eliminated the possibility that the pre-Cambrian rocks were thrust along an erosion surface much older than any of the present physiographic features of the Great Plains. But, if a thrust sheet of pre-Cambrian rocks moved across an erosion surface, gravels and talus should have been deposited in front of the thrust block, as Longwell, Knopf, and Flint (7, p. 396) have shown. With further compression, the thrust sheet should have overridden its own debris. If such a thrust plane were exposed by erosion in subsequent geological periods, some of this debris should be found along the thrust plane. Goldschmidt has described such features in Scandinavia (6, p. 59).

The present writer examined the trace of the Lewis overthrust for four miles north of Lake Sherburne, and saw no evidence of such debris along the thrust plane; in two localities the fault was located within a few feet. Four miles is, of course, a small fraction of the full extent of the Lewis overthrust, but those who have studied it carefully—Willis (13), Campbell (2), Clapp (3), and Daly (4)—do not report any such debris.

In view of all the facts, therefore, it seems unlikely that the Lewis overthrust is an "erosion thrust." Rather, that portion of the thrust which we now see was probably a sub-surface fault.

PREVIOUS DISCUSSIONS.

Although the present writer agrees with Alden's conclusion that the Lewis thrust is older than the Flaxville plain, the evidence cited by Alden does not seem conclusive. He says (1, p. 7):

"The genetic relations of such a gravel-covered erosional surface to the development of the Lewis overthrust fault are not considered in this paper. It may be noted in passing, however, that the lithologic composition of the Oligocene gravel on the Cypress Hills suggests that the Lewis overthrust faulting and the associated folding occurred long enough before the end of the Oligocene epoch for the pre-Cambrian rocks to be denuded of their covering of Mesozoic and Paleozoic rocks and so exposed as to yield the quartzite gravel. It thus appears that the Lewis overthrust is much older than Willis's 'Blackfoot peneplain,' if by that is meant the plain of the highest benches preserved near the mountains. As shown below, the latter plain is probably the correlative of Collier's 'Flaxville Plain.' "

In Willis's sequence, however, the pre-Cambrian sediments were assumed to have been exposed in early Tertiary time by the erosion of an anticline west of the present thrust. The pre-Cambrian pebbles in the Oligocene gravel on the Cypress Hills could have been derived from this anticline and, as Willis proposed, the overthrusting could have been later.

MacKenzie rejected Willis's hypothesis partly because of the absence of a peneplain in the mountains. He says (8, p. 118):

"The second assumption, that the thrust surface coincides with an early Tertiary peneplain, is the one really essential to Willis' hypothesis. The existence of this peneplain is necessary to his explanation of the Lewis overthrust as an erosion thrust and if the peneplain did not exist his hypothesis is not tenable. An examination of the evidence based on my own field work and that of others leads me to believe that this Tertiary peneplain in the Rocky Mountains did not exist, and consequently some other explanation of the structures and present relief of the region is required."

Such a Tertiary peneplain could have existed, have been uplifted, and then destroyed by erosion.

AGE OF THE LEWIS THRUST.

The primary purpose of the present paper has been to show that the Lewis overthrust is older than the erosion surfaces of which remnants are still preserved on the Great Plains. Consequently, as Daly has already indicated (4, p. 94), we are justified in believing that the post-Cretaceous compressional movements all belong to a single orogenic episode, the Laramide revolution. MacKenzie says (8, p. 106): "Stewart has shown that the Laramide revolution has deformed strata which he correlates with the Fort Union of Montana. . . . The Fort Union formation is generally accepted as Eocene, and if this be so, the Laramide revolution is not older than the early Eocene." Now that we have eliminated the necessity of Willis' "two-cycle" hypothesis, it is permissible to introduce the Oligocene conglomerates of the Cypress Hills as evidence. The revolution is older than these conglomerates.

"The front range of the Rocky mountains north of the boundary, the Clarke range, is bounded on the west by the Flathead valley, the east wall of which is marked by a profound normal fault. This normal fault is later than the compressive stresses of the Laramide revolution, for, as Willis has pointed out the normal fault has detached the Clarke range so that the strata could not in their present position have received the pressure which overthrust and flexed them. The fault probably took place during the relaxation immediately following the compression of the Laramide revolution. The age of the normal faulting is dependent upon the age of the Kishenena formation, which was laid down in the Flatland valley in lake basins consequent on the faulting. The evidence for the age of the Kishenena formation is derived from fossils it contains. . . . The best that can be said for this evidence is that it indicates that the Kishenena formation is probably of Eocene age, and to that extent it indicates that the Laramide revolution is probably not later than Eocene in date. . . . A reasonable interpretation of the stratigraphic evidence summarized above places the Laramide revolution as not earlier than the uppermost Cretaceous, nor later than the latest Eocene." (8, pp. 105-106.)

CONCLUSIONS.

From the analysis given above we conclude:

(1) The Lewis overthrust is older than the Flaxville plain (= Blackfoot peneplain); hence, the old hypothesis that the overthrust sheet was pushed out over the erosion surface is untenable.

(2) The available evidence indicates that the Lewis overthrust is not an "erosion-thrust."

(3) All available data are consistent with the hypothesis, first presented by Daly, and later accepted by MacKenzie, Mansfield, (10, p. 382), and Alden, that the Lewis overthrust was formed during an early Eocene phase of the Laramide revolution.

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