The Lewis Thrust Fault and Related Structures in the Disturbed Belt, Northwestern Montana

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1174

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By MELVILLE R. MUDGE *and* ROBERT L. EARHART

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Major structures reflect large-scale easterly displacement of early Tertiary age

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THE LEWIS THRUST FAULT AND RELATED STRUCTURES IN THE DISTURBED BELT, NORTHWESTERN MONTANA

By MELVILLE R. MUDGE and ROBERT L. EARHART

ABSTRACT

The classical Lewis thrust fault in Glacier National Park has now been mapped 125 km south of the park to Steamboat Mountain, where the trace dies out in folded middle Paleozoic rocks. The known length of the fault is 452 km, extending northward from Steamboat Mountain to a point 225 km into Canada, where the fault also dies out in Paleozoic rocks.

At the south end, the surface expression of the Lewis thrust begins in a shear zone in folded Mississippian rocks. To the north, the thrust progressively cuts downsection into Proterozoic Y (Belt) rocks near Glacier National Park.

Displacement on the Lewis plate increases northward from approximately 3 km on an easterly trending hinge line at the West Fork of the Sun River to a postulated 65 km at the southern edge of the park, where the stratigraphic throw is about 6,500 m. Present data indicate the thrust formed during very late Paleocene to very early Eocene time.

The Lewis thrust and related structures, the Hoadley thrust and the Continental Divide syncline, probably formed concurrently under the same stress field. The northern limit of the trace of the Hoadley thrust is within the lower portion of the Lewis plate, about 28 km north of where the Lewis thrust develops, and the Hoadley extends for at least 125 km to the south. Displacement of the Hoadley increases southward from about 1 km at the hinge line to an inferred 70 km near its known southern extent. If our inference is correct, the Hoadley is nearly the southern mirror image of the Lewis to the north. The Continental Divide syncline, a doubly plunging, broad, northerly trending open fold that is about 120 km long, is a major fold within the Lewis plate.

INTRODUCTION

The Lewis thrust fault was named in 1902 by Willis from exceptional exposures along the east and south sides of Glacier National Park in northwestern Montana. Since then it has been considered a classical thrust fault, and it is discussed in most textbooks on structural geology.

Prior to our studies, the Lewis thrust fault had been mapped for 327 km in Glacier Park and adjacent parts of Canada. The fault is exposed at many places for approximately 80 km along the front of the Lewis Range from near Marias Pass to the Canadian border (Campbell, 1914; Billings, 1938; and Ross, 1959). North of the border, the fault has been traced along the Clarke Range, the Canadian continuation of the Lewis Range (Clark, 1954); north of the Clarke Range, the trace of the fault approximately parallels the British Columbia–Alberta provincial boundary and terminates in Paleozoic rocks at least 225 km beyond the U.S. border (Douglas, 1958; Price, 1965). This paper discusses new descriptive data of the Lewis thrust fault and related structures south from Glacier National Park for 125 km to Dearborn River canyon, where the trace of the Lewis developed from fractures in a fold (fig. 1). The Hoadley thrust originated in the Lewis plate, about 28 km north of the point of origin of the Lewis, and extends at least 125 km to the south.

The Lewis thrust fault and related structures form the western structures of the disturbed belt of Montana. To the north the Lewis is the westernmost thrust fault, whereas to the south the Hoadley is westernmost. They are west of the intricately thrust faulted and folded Paleozoic and Mesozoic rocks that compose the eastern and central parts of the disturbed belt south of Glacier National Park. In the park most of these structures plunge beneath the Lewis thrust plate; some extend northwest just east of the park.

The disturbed belt lies west of the Sweetgrass arch, a structurally high area that consists of the south arch and Kevin-Sunburst dome (Dobbin and Erdmann, 1955; Alpha, 1955). The Sweetgrass arch was active tectonically at various times from Precambrian time to near the end of the Cretaceous (Mudge, 1972b). The position and configuration of the Sweetgrass arch influenced the structural development of the disturbed belt, which was formed in early Tertiary time.

Three major structures along the west side of the arch (Dobbin and Erdmann, 1955) affected the deformation pattern of the disturbed belt. A broad,

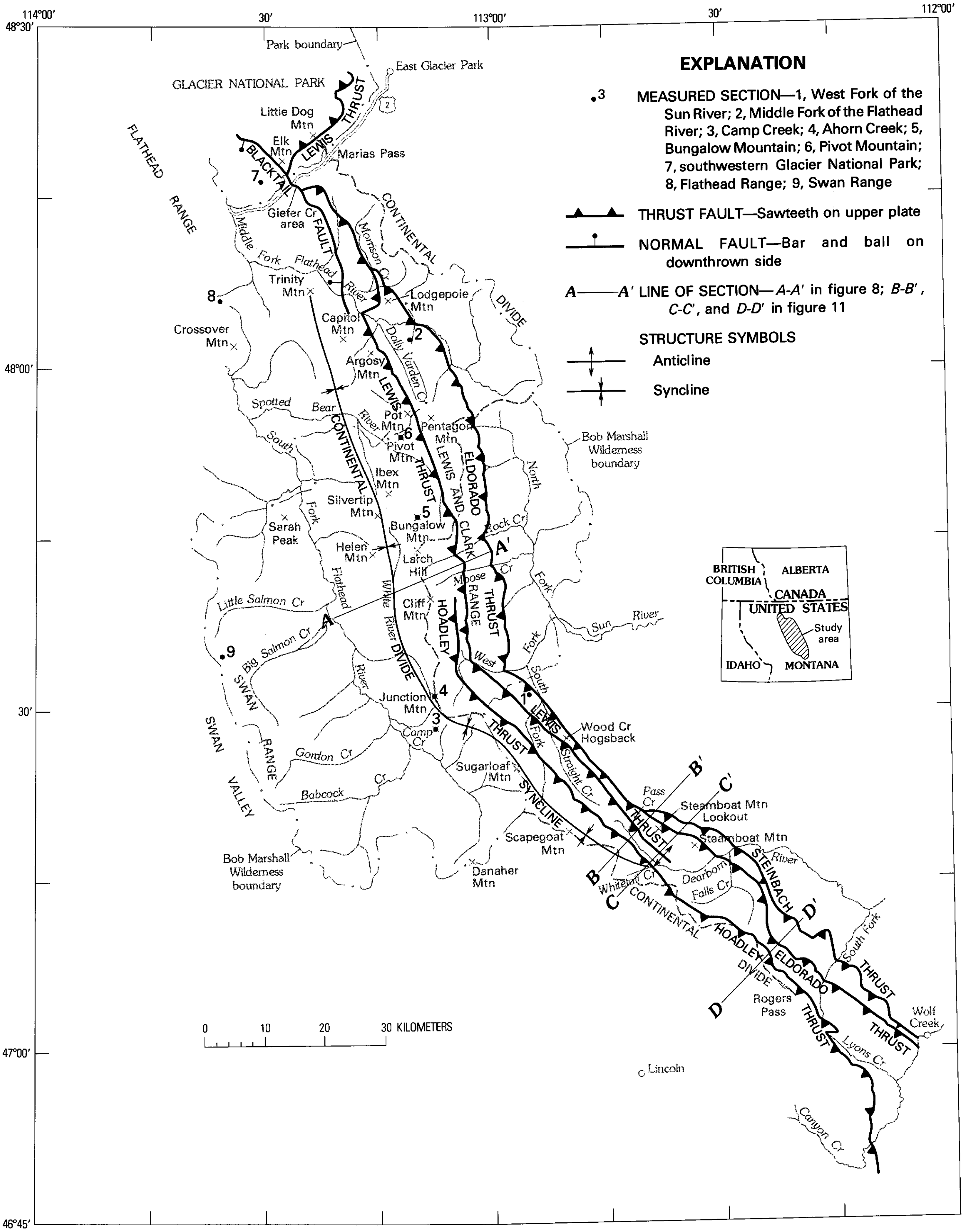
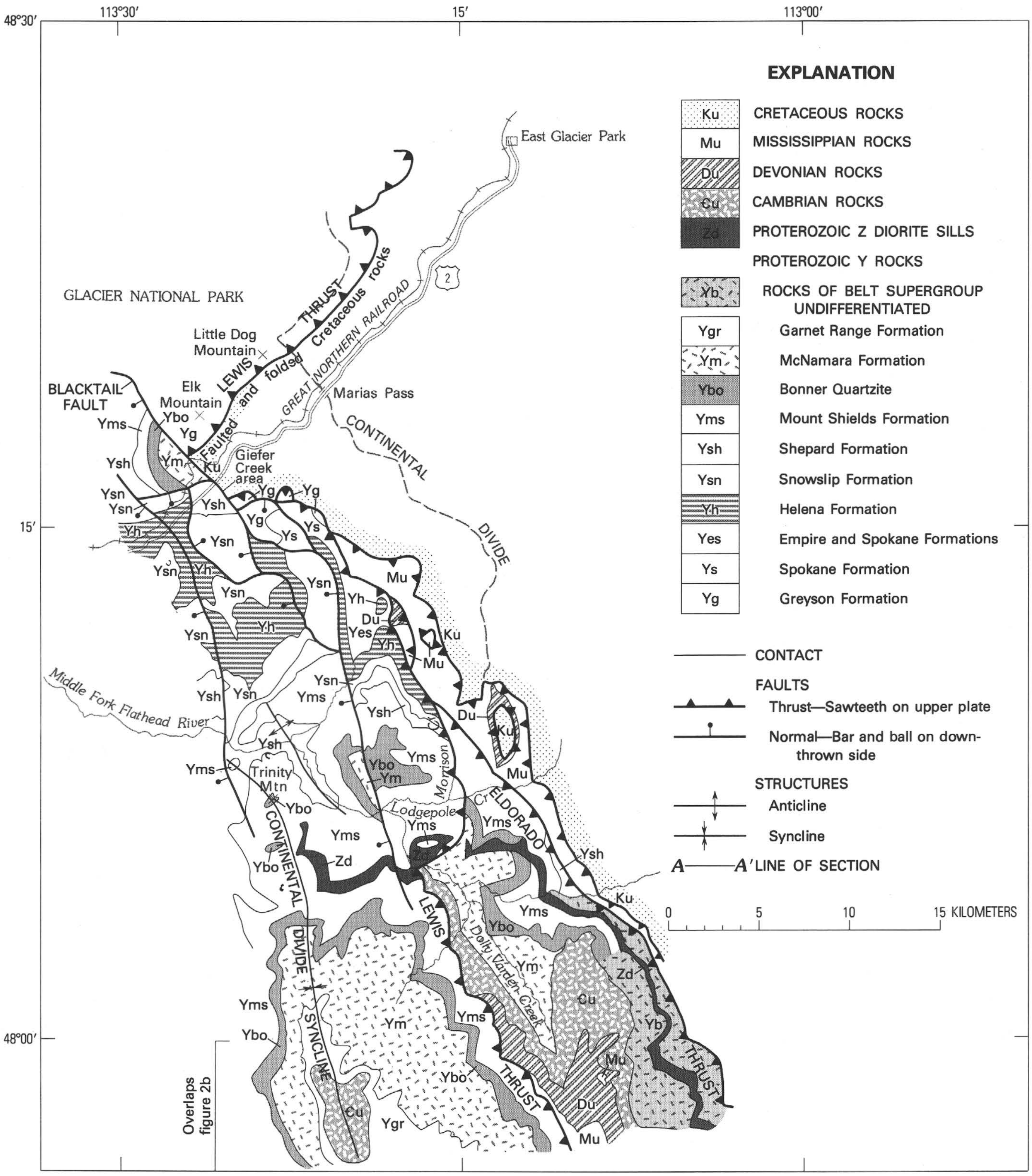
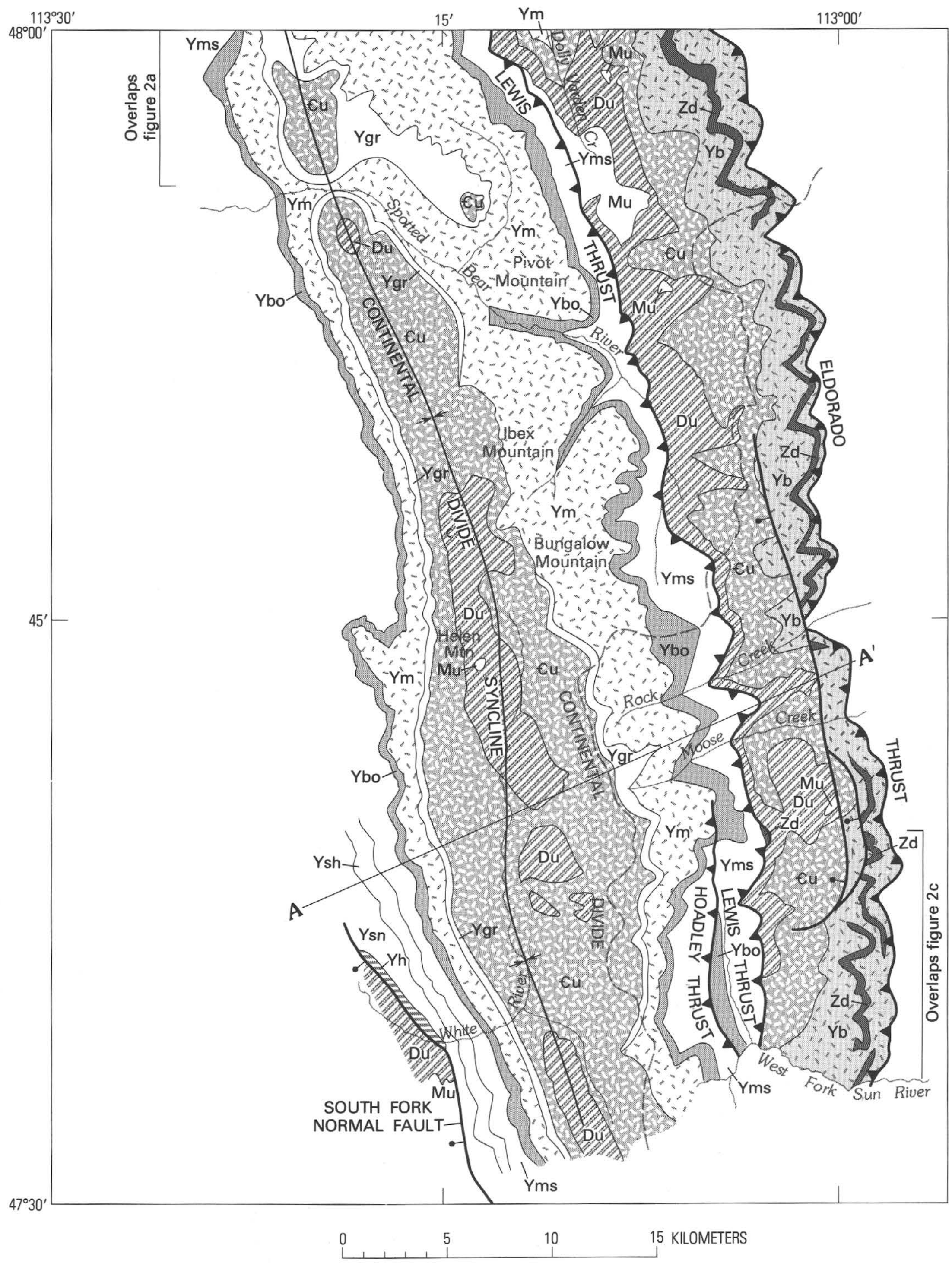


FIGURE 1.—Index map of the area showing the Lewis, Hoadley, and Eldorado thrust faults from Glacier National Park south to Canyon Creek, northwestern Montana.



A. SOUTHERN PART OF GLACIER NATIONAL PARK AND DRAINAGES OF THE MIDDLE FORK OF THE FLATHEAD RIVER

FIGURE 2.—Geologic maps of the Lewis and Eldorado thrust plates from the southern part of Glacier National Park to Steamboat Mountain. Cross-section *A-A′* shown in fig. 8. Cross-sections *B-B′* and *C-C′* shown in fig. 11.

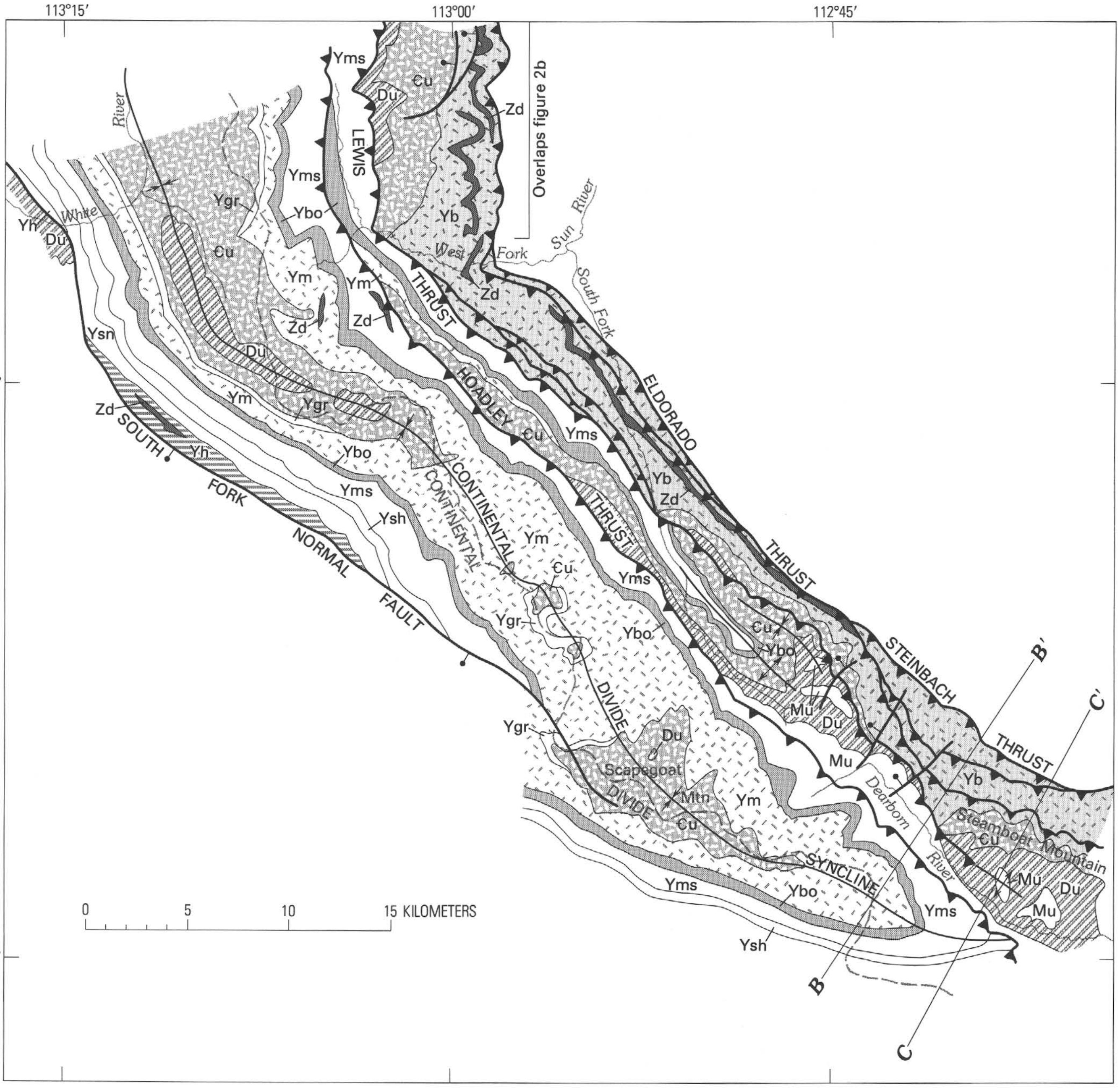


B. SPOTTED BEAR RIVER AREA TO THE WEST FORK OF THE SUN RIVER

FIGURE 2.—Continued.

gently westerly dipping structural low area extends beneath Glacier National Park (Mudge, 1977). The structurally high south arch extends west beneath the central part of the disturbed belt. Farther south, a broad, southwest-dipping structural low area extends beneath the southern part of the disturbed belt.

The structures composing the disturbed belt of Montana are a result of an early Tertiary orogeny and are equivalent in age *only* to the easternmost



C. WEST FORK OF THE SUN RIVER TO STEAMBOAT MOUNTAIN

FIGURE 2.—Continued.

thrust faults in the Idaho-Wyoming thrust belt and to the foothills and possibly the eastern main range structures in Alberta and British Columbia.

Previously, the location and character of the Lewis thrust south of Marias Pass were uncertain because of the lack of adequate geologic mapping. The Lewis thrust was traced 21 km south of Marias Pass by Childers (1963), at which point he shows the thrust terminated by a normal fault. Earlier investigators (Clapp, 1932, Deiss, 1943a, b; and Ross, 1959) speculated that the Lewis continued to the southeast for an undetermined distance. In the Sun River area they applied that name to the thrust mapped as the South Fork thrust zone by Mudge (1966a and b; 1972a and b), and Clapp (1932) connected the Lewis with the Lombard thrust to the southeast in the Three Forks area. Their speculation was based on the observation that Precambrian rocks are thrust over rocks of late Paleozoic to Cretaceous age, at these places, as they are along the Lewis thrust in Glacier National Park. Mudge (1972b, p. B27-B28) described more than one thrust fault to the south that juxtaposes Precambrian rocks on Paleozoic and Mesozoic rocks and also noted that the Precambrian rocks in the other plates to the south are a nearshore facies, whereas rocks of the Lewis plate are of a basinward facies. As discussed by Mudge (1972b, p. B27), the data at that time were insufficient to determine the relationship, if any, between the Lewis, Lombard, and South Fork thrusts. Our studies show the Lewis to be a thrust fault west of the South Fork and Lombard thrusts. Mapping southeast of the area by M.W. Reynolds (oral commun., 1978) has established the South Fork thrust of Mudge (1972b) as the Eldorado thrust. We, therefore, adopt the name Eldorado for the South Fork thrust.

Our study of the Lewis fault started in 1968 south of Glacier National Park in conjunction with mineral resource evaluations, including reconnaissance geologic mapping, of the Bob Marshall, Great Bear, and Scapegoat Wilderness areas and their proposed additions. We plotted all geologic contacts and structures of most of the area shown in figure 1 on 1:24,000-scale topographic maps from mapping traverses 3 to 6 km apart that were supplemented by aerial mapping from a helicopter. These data were then compiled on a single 1:125,000 topographic map. The area studied, approximately 8,100 km², extends from the northern part of the Flathead Range, west of the park, south to Lincoln, Mont. (190 km), and east from the Swan River valley to the eastern edge of the Sawtooth Range (84 km)—thus including an area of intense deformation called the northern disturbed belt in Montana.

GEOLOGY

The Lewis thrust plate consists entirely of Precambrian rocks in Glacier National Park (fig. 2A), but farther south, in the Bob Marshall, Great Bear, and Scapegoat Wilderness Areas, it also contains Paleozoic rocks as young as Mississippian in age (figs. 2B, 2C). The nomenclature of the Precambrian units now used in this region is compared with older nomenclature in figure 3. The results of our mapping of the Sun River Canyon area confirmed the correlation of the Precambrian units as projected by McGill and Sommers (1967), and Mudge (1972a). The units are described in Glacier National Park by Willis (1902) and Ross (1959 and 1963), in the Marias Pass area by Childers (1963), in the Wood Creek Hogsback-Camp Creek area by McGill and Sommers (1967), in the Sun River Canyon area by Mudge (1972a), in the Scapegoat Wilderness by Mudge and others (1974), and in the Swan, Flathead, Lewis and Clark, and Sawtooth Ranges by Mudge and Earhart (1978). Cambrian rocks in the thrust plates have been described thoroughly by Deiss (1933, 1939, 1943a), and the Devonian and Mississippian rocks by Sloss and Laird (1945) and Mudge (1972a).

LEWIS THRUST FAULT

The geology of the Lewis thrust plate in Glacier National Park has been described by Willis (1902), Campbell (1914), Billings (1938), and Ross (1959). The erosional front of the Lewis thrust at Glacier National Park is along the eastern edge of the mountains, but both north and south of the park it swings abruptly westward into the mountains (Ross, 1959, p. 76). In Canada the westerly bend in the thrust trace begins about 40 km north of the international boundary (Price, 1965, fig. 1). At the south edge of the park the westerly bend begins about 74 km south of the international boundary (Ross and others, 1955; Ross, 1959). Everywhere in Glacier National Park the Lewis thrust plate contains Precambrian rocks and overlies Cretaceous mudstones and sandstones. The Lewis thrust has an average strike of N. 30° W. and dips west at a low angle, mostly less than 10° (Ross, 1959, p. 76). Within the Lewis plate in the central part of the park, the west limb of a large, broad, northwesterly trending, doubly plunging syncline (Mudge, 1977) was displaced by a large normal fault, variously called the North Fork normal fault, the Flathead fault, and the Blacktail fault (Childers, 1963, p. 159). Discussions of the geology at the southern edge of the park by Childers (1963), Mudge, Earhart, and Rice (1977), Mudge and others (1977), and Mudge (1977) are pertinent to this report.

The Lewis fault is well exposed along the south edge of the park for a distance of 19 km (figs. 4, 5, 6, and 7). The dip of the fault plane along most of the trace is between 15° and 25° NW.; it strikes N. 20° E. (fig. 4). At the west end of a salient, south of Elk Mountain, the fault surface dips 15° to 40° SW.; broad, open, southwesterly plunging folds cause variations in its strike (Childers, 1963, p. 158).

The Precambrian Altyn and Greyson Formations compose the Lewis thrust plate at the south end of the park. The Altyn Formation (figs. 4, 5, 6, and 7) forms the sole of the plate as far southwest as 1.6 km southwest of Little Dog Mountain. Along the southern part of the park the Altyn and Greyson are complexly folded, brecciated, and in places repeated

Age	Group	Sun and Dearborn Rivers[1]	Marias Pass (Childers, 1963)	Glacier Park (Willis, 1902)	Northeastern Rocky Mountains[2]
Cambrian		Flathead Quartzite			
		UNCONFORMITY			UNCONFORMITY
Precambrian	Missoula	Garnet Range Formation			Garnet Range Formation
		McNamara Formation	Unnamed rocks		McNamara Formation
		Bonner Quartzite	Red Plume Quartzite		Bonner Quartzite
		Mount Shields Formation	Shields Formation	Kintla Formation	Mount Shields Formation
		Shepard Formation	Shepard Formation	Shepard Quartzite	Shepard Formation
		Snowslip Formation	Snowslip Formation	Siyeh Limestone	Snowslip Formation
		Helena Dolomite	Siyeh Formation		Helena Formation
	Ravalli	Empire and Spokane Formations	Grinnell Formation	Grinnell Argillite	Empire Formation Spokane Formation
		Greyson Formation	Appekunny Formation	Appekunny Formation	Greyson Formation
	Pre-Ravalli	Thrust fault	Thrust fault	Altyn Limestone	Altyn Formation
				Thrust fault	Thrust fault

[1]McGill and Sommers, 1967; Mudge, 1972a; and Mudge and others, 1974.
[2]McGill and Sommers, 1967; Mudge, 1972a; Harrison, 1972; Mudge and others, 1974; Mudge, Earhart, and Rice, 1977; and Mudge and Earhart, 1978.

FIGURE 3.—Correlation of Precambrian rocks of the Belt Supergroup in the eastern part of the Rocky Mountains in northwestern Montana.

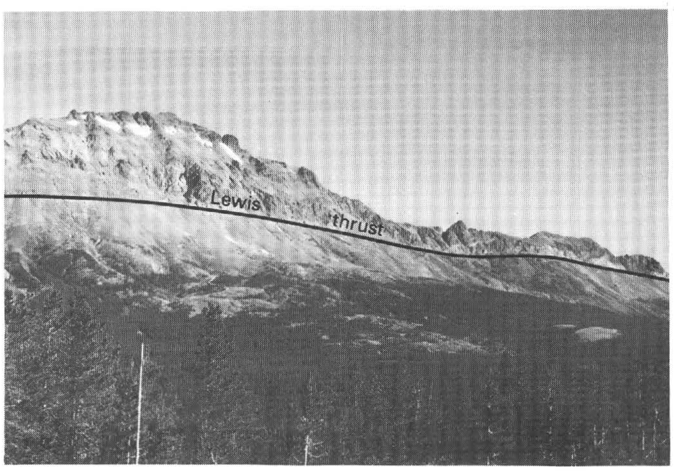


FIGURE 4.—View northeast of the Lewis thrust at the south end of Glacier National Park. The light-gray band in the middle of the photo is deformed Altyn Formation, which overlies the Lewis thrust. The Greyson Formation overlies the Altyn. Folded and faulted Cretaceous rocks underlie the Lewis thrust.

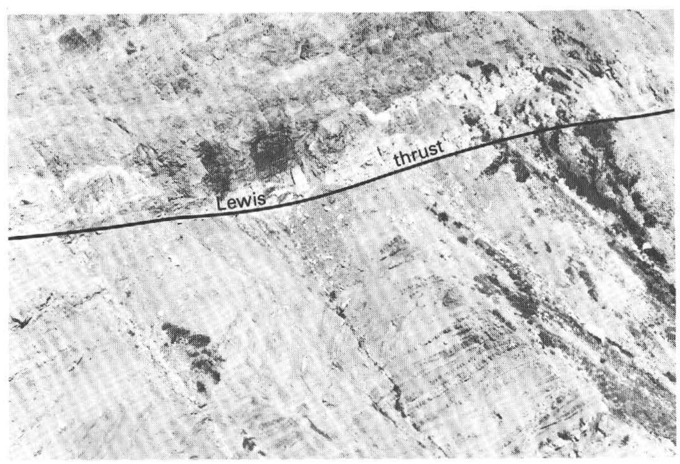


FIGURE 5.—Closeup aerial view of the Lewis thrust fault above folded and faulted Lower Cretaceous rocks south of Little Dog Mountain, south end of Glacier National Park.

by small easterly and westerly dipping thrust faults. The Greyson Formation overlies the Altyn, and farther south it is the oldest unit in the plate.

Along the southern edge of the park, the Lewis plate everywhere rests on Cretaceous rocks (figs. 4, 5, 6, and 7). Southeast of Elk Mountain, the plate mostly overlies the Lower Cretaceous Kootenai Formation, which commonly dips 45° to the southwest and is repeated by numerous steep, westerly dippling thrust faults. East of this area, the Lewis plate rests on progressively younger Cretaceous rocks that are repeated by many westerly dipping low-angle thrust faults. East of Little Dog

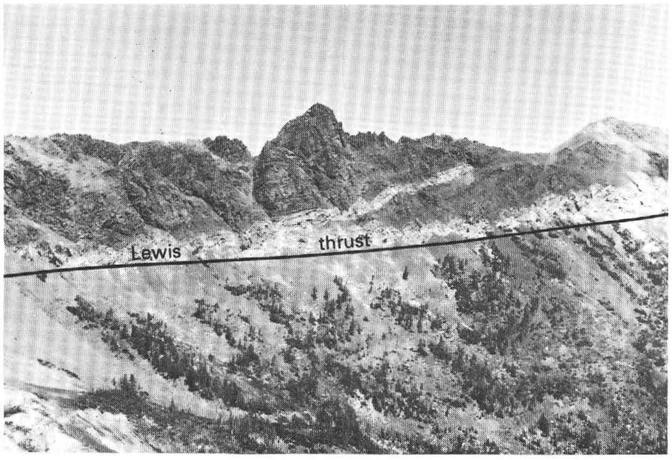


FIGURE 6.—Aerial view of the Lewis thrust fault at the south end of Glacier National Park. Note the small imbricate thrust that repeats the Altyn and Greyson Formations (light and dark units, respectively).

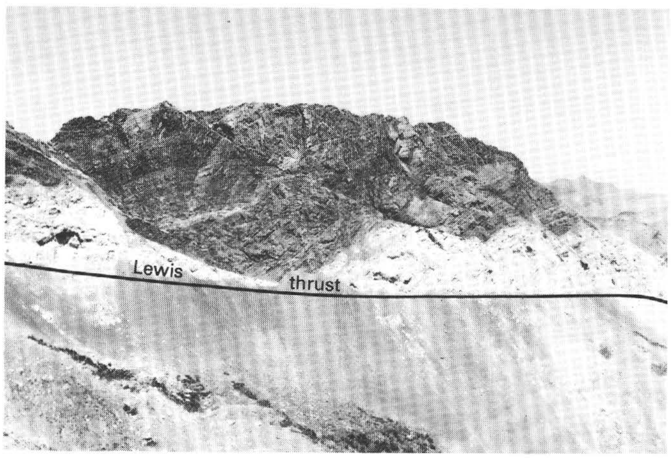


FIGURE 7.—Aerial view to the north showing the Lewis thrust at the base of deformed Altyn (light) and Greyson (dark) Formations at the south end of Glacier National Park. Thrust-faulted and folded Cretaceous rocks are below the Lewis but are covered here by talus. Note the easterly dipping low-angle normal faults, one of which extends to the Lewis.

Mountain, the Lewis overlies an imbricate thrustfault zone in the westerly dipping Blackleaf Formation (Lower Cretaceous) that strikes N. 30° to 50° E. and dips 15° to 50° NW. (Mudge and others, 1977; Mudge, 1977). The Blackleaf is repeated by westerly dipping (30° to 40° W.) thrust faults and folds. The thrust-fault imbrications originate from a low-angle, northwesterly dipping thrust underlain by the same complexly deformed Upper Cretaceous rocks that underlie the Lewis farther east.

The trace of the Lewis thrust is almost completely exposed in the Lewis and Clark Range from a point about 3 km south of Glacier National Park to the vicinity of the Dearborn River, 125 km farther south, where it dies out in folded Paleozoic rocks (fig. 1). South of the park, the Lewis plate contains Precambrian and Paleozoic rocks that form a broad open fold, the Continental Divide syncline (figs. 2 and 8). West of the synclinal axis, the upper plate of the Lewis thrust cuts upsection from the Spokane and Empire Formations to within the Mount Shields Formation. The thrust plane is more than 3,200 meters stratigraphically lower on the west limb than it is on the east. An unfaulted section including rocks as old as the Helena Formation crops out on the west flank, whereas Mount Shields is the oldest unit exposed on the east flank (fig. 8).

The trace of the Lewis is concealed for 3 km south of the park by Quaternary deposits in the vicinity of Giefer Creek, north and south of U.S. Highway 2. In this interval, the fault probably either connects with the Blacktail fault or is displaced by it (Childers, 1963, pl. 1). The first exposure of the thrust south of the covered interval is near a ridge southeast of Giefer Creek. Here the Greyson Formation forms the basal unit in the upper plate, and the Kootenai Formation is the uppermost unit in the lower plate, the same relationship as at Elk Mountain in the southern part of the Park. This observation confirms Childers' (1963, pl. 1) identification of the Lewis thrust in the Giefer Creek area. The trace of the Lewis thrust can be extended southeast from the Geifer Creek area with certainty. We essentially agree with Childers' (1963, pl. 1) map except that we show the Lewis continuing southeast from the Morrison Creek area (fig. 2A) instead of being cut by the Blacktail fault. We also mapped the southern trace of the Blacktail fault differently.

In the Morrison Creek area, the Lewis thrust cuts southward upsection from the Spokane Formation through the Helena, Snowslip, and Shepard Formations and into the lower part of the Mount Shields Formation. A similar change in the stratigraphic position of the Lewis thrust fault was noted by Price (1965, p. 100–101) at the boundary between the Clarke and Flathead Ranges in British Columbia, northwest of Glacier National Park. There the fault position changes abruptly northward from the Altyn to the Siyeh or Helena Formation. Price relates the change to transverse structures above and below the thrust. He (1965, p. 100) states that a northwest-dipping monocline is superposed across the fault and is reflected by the transverse step of the Lewis. The relatively abrupt change in stratigraphic position is comparable to a tear fault except that the "tear fault" does not cut strata above or below the thrust. Northeast of Morrison Creek, the

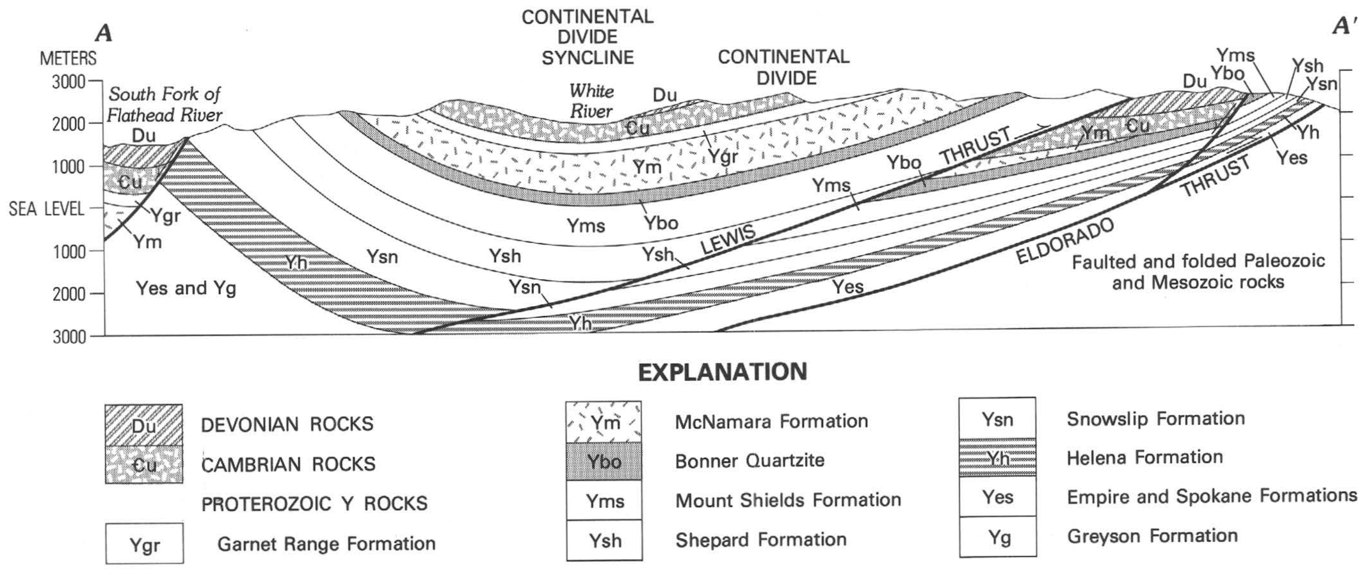


FIGURE 8.—Cross-section A-A' showing the Lewis and Eldorado thrust plates. Approximate position of line of section is shown in figure 2*B*. The Belt units between the Eldorado and Lewis thrusts are shown individually on the section but are consolidated on the geologic map.

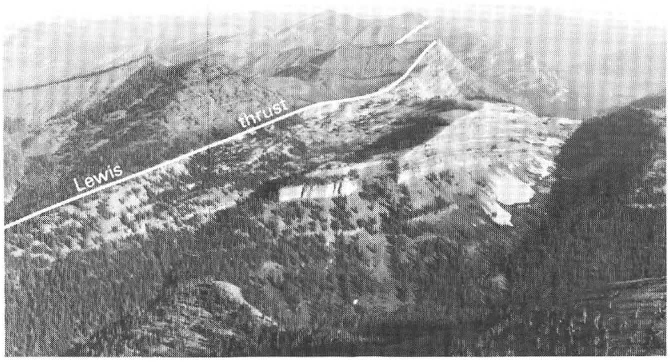


FIGURE 9.—Aerial view of the Lewis thrust fault from Pot Mountain north along the west side of Dolly Varden Creek. The thrust fault juxtaposes light-gray Mississippian carbonate rocks and the dark-gray rocks of the Mount Shields Formation. View is northwest.

westerly trend of some folds noted by us and the series of northeasterly trending normal and tear faults mapped by Weimer (1955) and by Mudge, Earhart, and Rice (1977) may reflect the northeasterly trend of a pre-thrust structure that may have influenced the stratigraphic level of the Lewis south of the park.

Between Morrison Creek and the head of Dolly Varden Creek the Lewis thrust rests at progressively higher stratigraphic levels in the lower plate. In Morrison Creek the Lewis cuts the Eldorado thrust plate, and to the north it rests on Mississippian and Devonian rocks. To the south, the Eldorado thrust is east of and subparallel to the Lewis thrust (fig. 2). Both plates contain the same Precambrian formations, but the rock facies differ in that those of the Eldorado plate are a thin shoreward facies, whereas those in the Lewis plate are a thicker basinward facies. South of Morrison Creek the Lewis rests at progressively higher stratigraphic levels from Precambrian to Mississipian rocks.

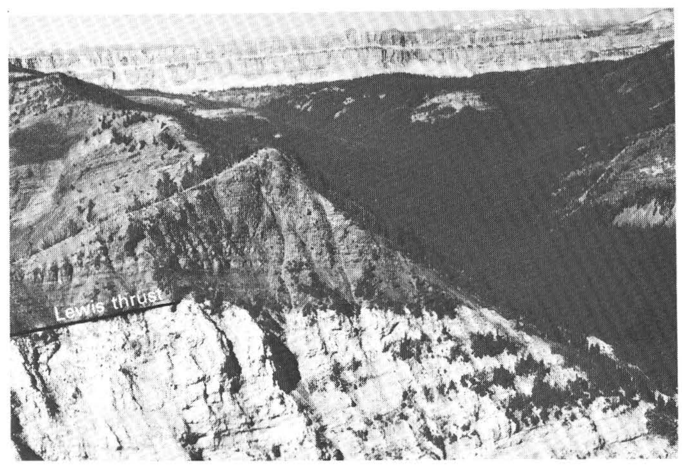


FIGURE 10.—View west at the Lewis thrust near the head of Moose Creek. The Precambrian Mount Shields Formation rests on Devonian carbonate rocks. Cambrian rocks of the upper plate form the cliffs along the skyline known as the Chinese Wall.

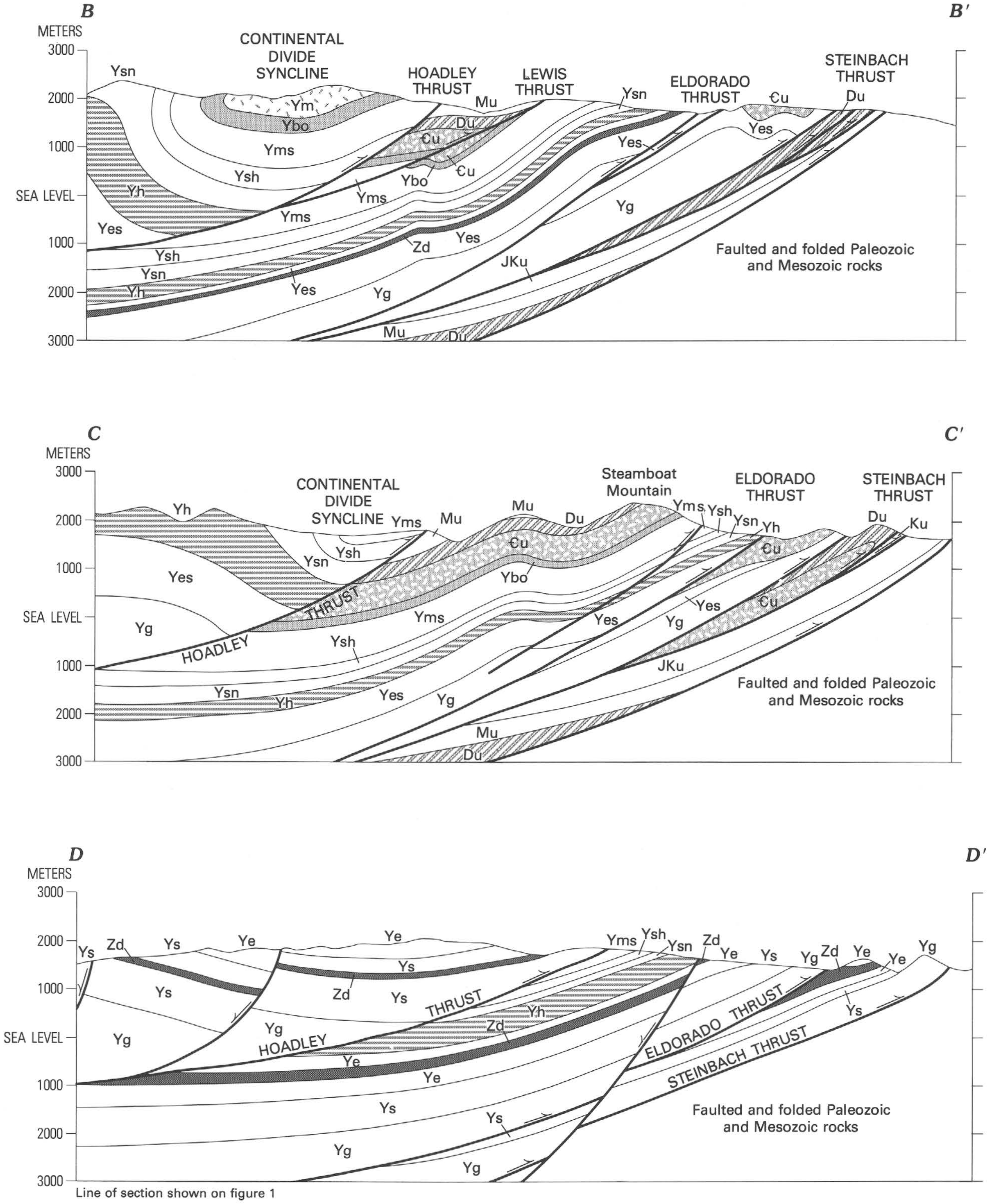


FIGURE 11.—Cross sections of the Hoadley and Eldorado thrust plates, not shown to scale. Approximate position of lines of section are shown in fig. 1; those of section *B-B′* and *C-C′* are also shown on fig. 2*C*. The Belt units in the thrust plates are shown individually on the sections, but are consolidated on the reduced geologic map.

The Lewis is in the lower part of the Mount Shields Formation from Morrison Creek south to Straight Creek (figs. 1 and 2), a distance of about 87 km. As far south as the West Fork of the Sun River, the Lewis

EXPLANATION

Ku	CRETACEOUS ROCKS
JKu	CRETACEOUS AND JURASSIC ROCKS
Mu	MISSISSIPPIAN ROCKS
Du	DEVONIAN ROCKS
Cu	CAMBRIAN ROCKS
Zd	PROTEROZOIC Z DIORITE SILLS
	PROTEROZOIC Y ROCKS
Ym	McNamara Formation
Ybo	Bonner Quartzite
Yms	Mount Shields Formation
Ysh	Shepard Formation
Ysn	Snowslip Formation
Yh	Helena Formation
Yes	Empire and Spokane Formations
Ye	Empire Formation
Ys	Spokane Formation
Yg	Greyson Formation

FIGURE 11. Continued.

rests mostly on Paleozoic rocks in the Eldorado plate (figs. 2, 9, and 10). At the West Fork of the Sun River, the Lewis cuts downsection across the underlying Paleozoic rocks and rests on Precambrian strata.

Along the southerly trace of the Lewis, strata adjacent to the thrust are mostly undisturbed. However, in a cirque northeast of Argosy Mountain, the thrust truncates diagonally across Devonian strata that form overturned isoclinal folds.

From the Middle Fork of the Flathead River to the West Fork of the Sun River, the Lewis thrust has nearly the same strike as the strata in the upper and lower plates. However, the dip of the fault plane commonly differs from that of the strata. The average strike of the fault and of the strata in both plates is N. 15° W. From the Middle Fork of the Flathead River to Moose Creek the fault plane dips 40° to 45° W., whereas south of Moose Creek it dips mostly 20° W. The dip of the Mount Shields in the upper plate ranges between 25° and 45° W., whereas that of the Paleozoic strata in the lower plate is 10° to 15° W. Locally, strata of the upper plate dip the same as the fault plane.

At the West Fork of the Sun River, the strata in both plates change strike abruptly to about N. 55° W. Mudge (1972b, p. B34) noted that the West Fork of the Sun River was incised along an east-west line of flexure along which all strata and structures abruptly change strike. In this area, Mudge (1972b, p. B32) described the West Fork thrust zone (herein redesignated the Lewis) as containing three thrust faults that merge to the north and south into a single thrust fault. The lowest and largest thrust in the zone dips about 25° SW. and has a stratigraphic throw of about 457 m.

The Lewis thrust cuts upsection from Straight Creek southward, and its trace extends into folded middle Paleozoic rocks (fig. 11, section *B–B′* and *C–C′*). At Straight Creek, the Lewis cuts upsection into Cambrian rocks which are thrust on younger Cambrian and Devonian rocks (fig. 2*C*). About 6 km farther south, near Pass Creek, Devonian rocks are at the base of the plate. Southeast of Pass Creek, the Lewis thrust dissipates in a zone of brecciated, much deformed Mississippian rocks for a distance of about 3 km along strike. The last vestiges of offset are traceable southward into a chevron fold in the Eldorado thrust plate (fig. 12) about 2.4 km southwest of the lookout tower on Steamboat Mountain. Within a kilometer, the folding changes from a chevron fold to an open fold (fig. 11, section *C–C′*) to unfolded westerly dipping rocks. During reconnaissance studies, Mudge and others (1968, pl. 1, and 1974, pl. 1) originally mapped the beginning of the Lewis (West Fork) in the canyon on the west side of Steamboat Mountain and the Mississippian rocks there as a klippen. Our subsequent mapping demonstrates that the chevron fold marks the termination of the Lewis thrust.

DISPLACEMENT ALONG THE LEWIS THRUST FAULT

The eastward displacement along the Lewis thrust fault increases northward from zero near Steamboat Mountain to possibly more than 65 km at the south end of Glacier National Park (fig. 13). In the park, the measured minimum net slip is 24 km (Campbell, 1914). At the south edge of the park, the minimum net slip is 19 km (Clapp, 1932, p. 25; Childers, 1963, p. 157). In southeastern British Columbia, northwest of Glacier National Park, Price (1965, p. 115) measured 51 km of minimum displacement. Thus the displacement seems to be rotational eastward in the park relative to a hinge at the West Fork of the Sun River.

Our computation of displacement along the Lewis thrust is based on the relative difference between the projected average strike of strata south of a hinge line that crosses the fault at the West Fork of the Sun River and the average strike north of the hinge line. Regional structural trends, including fault traces,

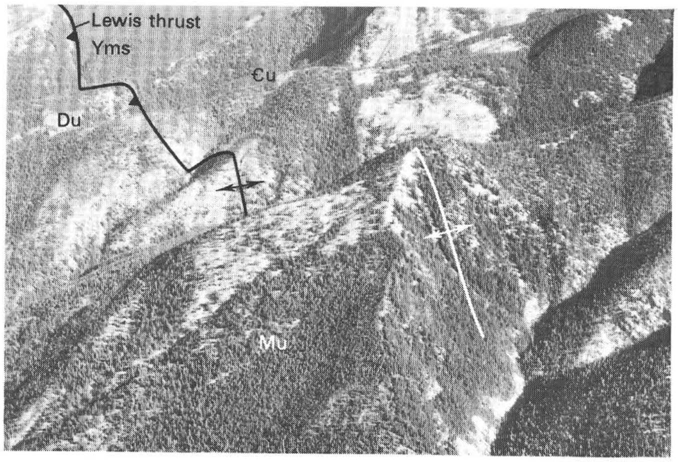


FIGURE 12.—Southern limit of the Lewis thrust at the southwest side of Steamboat Mountain. The thrust developed from fractures in folded Mississippian strata. View to the northwest. Yms, Precambrian Mount Shields Formation; €u, Cambrian rocks; Du, Devonian rocks; Mu, Mississippian rocks.

fold axes, and attitudes of all strata, change from about N. 45° W. south of the line to about N. 15° W. north of the line (fig. 13). The computation of 65 km of displacement assumes that strikes were about the same to the north and south of the hinge line prior to the formation of the Lewis. We recognize that any rotational movement on the previously formed Eldorado thrust fault would introduce a small unknown element of error by this method of estimation.

Large eastward transport of the Lewis plate is also indicated by comparing its stratigraphic sequence with that in the underlying Eldorado thrust plate (fig. 14). At Morrison Creek, 18 km south of the park, the Lewis thrust truncates all strata in the Eldorado thrust plate. Farther south, most units in the Lewis plate are more than twice as thick as their counterparts in the Eldorado plate. Data are not available to determine the distance that originally separated the plates. The Eldorado thrust plate also is warped about the hinge line at the West Fork of the Sun River.

As shown in figure 14, the Helena Formation and younger Belt rocks, in general, thicken westward and southwestward from the Sun River area in both the Lewis and Eldorado plates. The eastern edge of the Belt basin had a northwest trend in this area (Harrison, 1972; Harrison and others, 1974). Therefore, the northerly increase in thickness of units in the Lewis plate suggests an increase in displacement northward from the hinge point.

A comparison of stratigraphic data from the southwest corner of Glacier National Park with that from near the West Fork of the Sun River support the hypothesis of increasing eastward displacement to the north. These data are insufficient, however, to determine the amount of displacement, because basinward thickening of the Precambrian formations was irregular. Formations in the Glacier National park sequence are thicker than those at the West Fork of the Sun River, but somewhat thinner than those at the Camp Creek section southwest of the West Fork section (fig. 14). From the West Fork of the Sun River the Bonner Quartzite thins northward, whereas the McNamara Formation thickens. The McNamara also shows a noticeable change in facies to the north. In the southern section, greenish-gray argillite, siltite, and quartzite compose the lower half of the McNamara, whereas reddish-brown quartzite composes the upper half. To the north the McNamara is almost all greenish-gray argillite and siltite with negligible amounts of interbedded quartzite. Thus the northern sequence was originally deposited more basinward (farther west) than the southern one.

The amount of stratigraphic throw along the Lewis thrust fault has little meaning unless considered with other geologic relations in the upper and lower plates (Table 1). For example, in the lower part of Morrison Creek, the Mount Shields Formation is the basal unit in the Lewis thrust plate and the upper unit in the Eldorado plate. Here the stratigraphic throw could be interpreted as being minor, whereas the slip actually is quite large.

A series of well-exposed sections of the rock units in the Lewis and Eldorado thrust plates illustrates the increase in stratigraphic throw to the north (fig. 14). The estimated displacement, determined graphically, is shown for each locality. From the Dearborn River to the West Fork of the Sun River, both the stratigraphic throw and the slip are small. At the hinge line, near the West Fork of the Sun River, the amount of stratigraphic throw is about 460 meters and the slip is about 3,000 meters. North of the hinge line, toward the structural low to the north of the south arch, both the stratigraphic throw and the slip increase dramatically. As the thrust cuts upsection through Belt rocks to a position near the top of the Cambrian rocks, the stratigraphic throw is disproportionately greater than the slip. Farther north, the amount of slip increases more rapidly than the amount of stratigraphic throw.

The results of preliminary paleomagnetic studies on Belt rocks in the region by D. P. Elston (oral

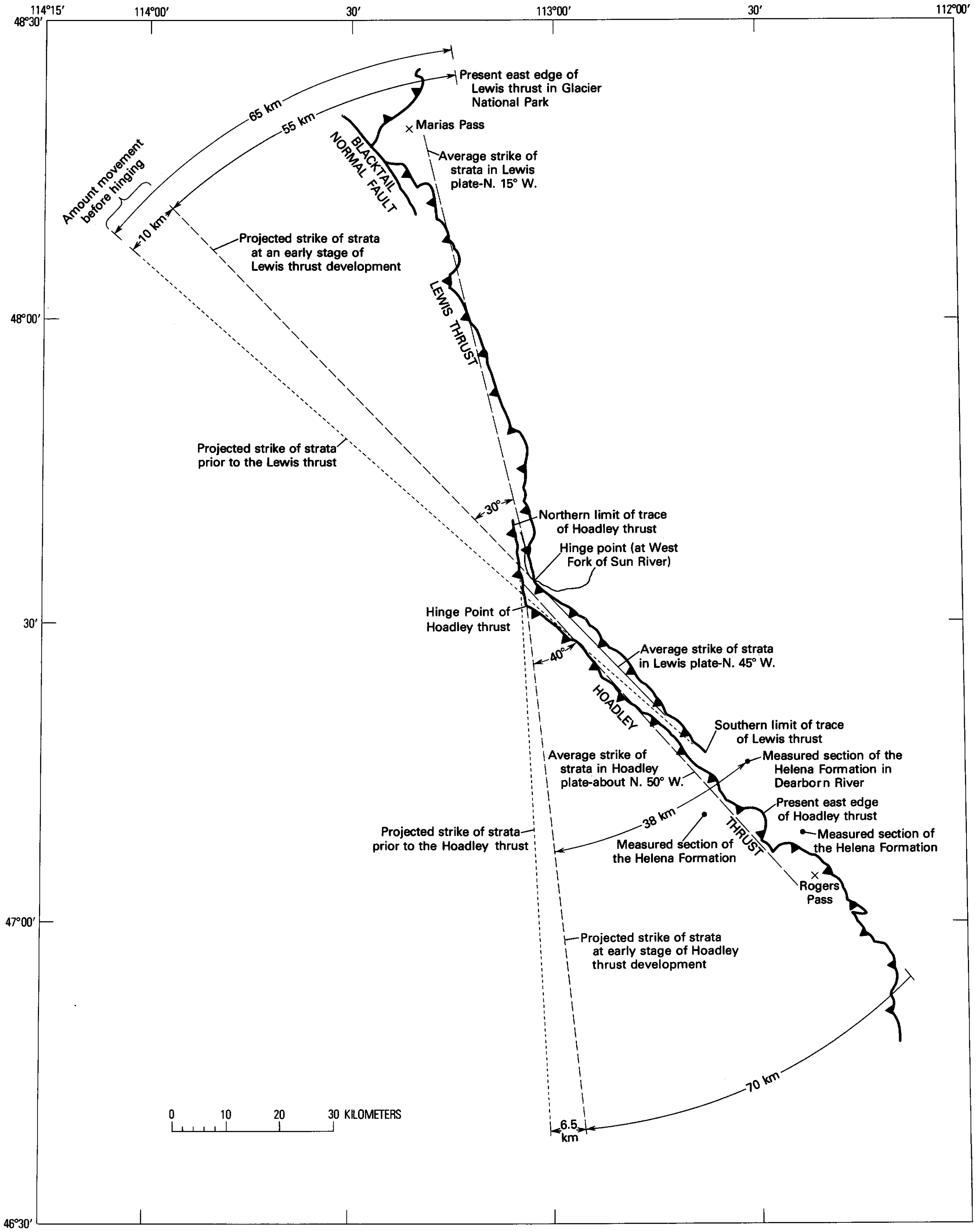


FIGURE 13.—Projected strikes of strata in the Lewis and Hoadley thrust plates north and south of the hinge points before and after faulting.

Formation	ELDORADO THRUST PLATE		LEWIS THRUST PLATE Southwest	South ———		→ North		Northwest	West
	1 West Fork of the Sun River area (Mudge, 1972a)	2 Middle Fork of the Flathead River area[1]	3 Camp Creek (McGill and Sommers, 1967)	4 Ahorn Creek[1]	5 Bungalow Mountain[1]	6 Pivot Mountain[1]	7 Southwest Glacier Park (Childers, 1963)	8 Flathead Range[1]	9 Swan Range area[1]
Garnet Range Formation			225–300		61±	61±		61±	274
McNamara Formation	0–175	0–183±	810	747–808	1128	1647	30+	1464	915
Bonner Quartzite	335	259±	386	427	320	259	241	259	351
Mount Shields Formation	555	442	833	366+	824+	930+	778	961	2181
Shepard Formation	248	183	604				473	762	900
Snowslip Formation	107	214	682	Thrust fault	Thrust fault	Thrust fault	488	976	1662
Helena Formation	191	Thrust fault	451+				1159	1967	2852
Spokane and Empire Formations	366+ Thrust fault		Covered				732	610+ (incomplete)	1403+

[1]Unpub. mapping by Mudge and Earhart, 1969–1979.

FIGURE 14.—Thickness of Precambrian units (in meters) in the Lewis and Eldorado thrust plates. Location of sections shown in figure 1.

commun., 1978) support field evidence indicating rotational movement on the Lewis thrust. Elston measured the orientation of paleomagnetic poles in Precambrian rocks in the upper plate of the Lewis in Glacier Park and in equivalent rocks near the Dearborn River. His comparison suggested the rocks in the park had rotated to the east.

AGE OF LEWIS THRUST FAULT

The Lewis thrust fault has not been dated precisely; present data suggest a very late Paleocene to very early Eocene age. Deiss (1943a, p. 256) interpreted the thrust faults in the eastern part of the disturbed belt as being older than the Lewis because

TABLE 1.—*Stratigraphic throw and estimated slip of the Lewis thrust from the Dearborn River north to Glacier National Park, showing the formations above and below the Lewis thrust*

Location	Stratigraphic unit: Above thrust	Stratigraphic unit: Below thrust	Amount throw (m)	Estimated slip (km)	Distance between locations (km)	Cumulative distance (km)
Dearborn River----	Allan Mountain Limestone (Mississippian).	Allan Mountain Limestone (Mississippian).	0	0	0	0
Straight Creek----	Cambrian rocks----------	Cambrian rocks----------	155	1.6-3.2	21	21
South of West Fork of Sun River.	Snowslip Formation (Precambrian).	Mount Shields Formation (Precambrian).	460	3.2	13	34
North of West Fork of Sun River.	Mount Shields Formation (Precambrian).	Devils Glen Dolomite (Cambrian).	2,290	8	6.5	40.5
Moose Creek-------	-----do-----------------	Lower member, Jefferson Formation (Devonian).	2,775	14	14.5	55
Spotted Bear River	-----do-----------------	Three Forks Formation (Devonian).	3,570	29	11	66
Upper Morrision Creek.	Helena Formation (Precambrian).	Castle Reef Dolomite (Mississippian).	4,880	47	43	109
Glacier Park------	Altyn Formation (Precambrian).	Blackleaf Formation (Cretaceous).	6,560	65	16	126

the Lewis truncates many of them. The relationship of the Lewis to these thrusts is well documented along the south edge of Glacier National Park (Childers, 1963; Mudge, 1977). In the Sun River area, Mudge (1972b, p. B34) noted that deformation in the disturbed belt proceeded from east to west. However, some workers believe that deformation along the belt in Canada proceeded from west to east (Hume, 1957; Scott, 1951; Bally and others, 1966; Price and Mountjoy, 1970; Jones, 1971). Childers (1963, p. 160) and Jones (1971, p. 305) believe the cutting of eastern thrusts by western thrusts is dependent on the duration of the movement of the western thrust. Childers further suggested that the thrust faults of major displacement, such as the Lewis, may have started to move eastward earlier than the thrusts east of it and were active after the thrusts formed on the west side of the Sawtooth Range.

The age of the orogeny that formed the disturbed belt is generally accepted by most workers as probably beginning no later than Late Cretaceous and ending no later than late Eocene (Mudge, 1972b, p. B46). Recent studies on bentonites in Cretaceous rocks that were metamorphosed by burial beneath thrust plates have now further restricted the period of thrust faulting. Hoffman, Hower, and Aronson (1976) report a K-Ar radiometric age of 72 to 56 million years B.P. for such bentonites. The bentonite beds are in folded and faulted Lower and lower Upper Cretaceous strata that lie east of the Lewis thrust in the disturbed belt in the Sun River Canyon area, and south of the Lewis in the Marias Pass area. The metamorphism of these beds was very likely caused by the increased load and higher thermal gradients resulting from the overriding thrust plates.

Recent K-Ar dates of igneous rocks in northwestern Montana establish the younger age limit for thrust faults in the eastern and central parts of the disturbed belt in that area. A hornblende monzonite dike about 24 km east of Rogers Pass cuts a major thrust fault called the Eldorado by Schmidt and Strong (1972). According to R.G. Schmidt (oral commun., 1975) the K-Ar date on hornblende from the dike is 46.3 m.y. H.H. Mehnert and R.G. Schmidt (U.S. Geol. Survey, 1971, p. A37) also obtained a K-Ar of 58.3 m.y. on biotite from a quartz monzonite porphyry sill that intruded along the Steinbach thrust fault (fig. 1), incorrectly called the Eldorado by Schmidt (1972), near Wolf Creek; this provides an upper limit on the movement of the thrust in this area. They believe that fault formed at a late stage in the orogenic history of the region (U.S. Geol. Survey, 1971, p. A37). These data indicate that thrusting in this part of the disturbed belt occurred prior to mid-Eocene time, in agreement with the radiometric ages on bentonites reported by Hoffman, Hower, and Aronson (1976).

The Hoadley, Lewis, and Eldorado thrust faults are west of the Steinbach thrust plate (formerly called the Eldorado) and are younger than it, inasmuch as the Eldorado thrust as used in this report cuts the Steinbach about 4 km northwest of the Steamboat Mountain lookout (fig. 1). However, we believe these faults are older than the sill (58.3 m.y. old) that intruded the Steinbach thrust, because dikes and sills of similar composition intrude the Hoadley plate in the Rogers Pass area.

STRUCTURES RELATED TO THE LEWIS THRUST FAULT

The Hoadley thrust and the Continental Divide syncline are in the upper plate of the Lewis thrust and very likely were formed by stresses that formed the Lewis.

HOADLEY THRUST

The Hoadley thrust is the westernmost major thrust fault in the northern disturbed belt. It originates near the upper reaches of the West Fork of the Sun River and continues south at least to the Canyon Creek valley (figs. 1, 11, and 13), a distance of about 125 km. The amount of displacement along the Hoadley appears to increase southward over the structurally low area south of the south arch. Thus, in many aspects the Hoadley thrust is a near mirror image of the Lewis.

the Hoadley thrust, like the Lewis, hinges at the West Fork of the Sun River, and its average strike of N. 50° W. approximately parallels that of the Lewis. Its thrust plane dips 25° to 50° W. In the upper plate, Mount Shields strata dip between 15° and 30° W., whereas those in the lower plate dip 25° to 45° W. Farther south, the rocks in the lower plate mostly dip 20° and 25° W. (Lange, 1963, pl. 1). As far south as the Dearborn River canyon, the Mount Shields Formation is the basal unit in the Hoadley plate (fig. 2). Between the Dearborn River and Falls Creek, the thrust cuts downsection to within the Spokane

Formation. Farther southeast, between the east side of Rogers Pass and the southern reaches of the South Fork of the Dearborn River, the Greyson Formation is at the base of the Hoadley plate. From Rogers Pass south to the Canyon Creek valley, the Spokane and at places the Greyson form the basal unit of the Hoadley plate. The location and extent of the thrust to the south of Canyon Creek valley has not been determined. The Hoadley is the Lyons thrust fault mapped west of Wolf Creek by Schmidt and Strong (1972).

Strata beneath the Hoadley plate are similar to those beneath the Lewis plate. In most places, almost as far southeast as Lewis and Clark Pass, the upper plate is thrust onto locally folded Paleozoic rocks. Farther southeast, to Rogers Pass, the Hoadley rests on strata as old as the Helena Formation.

At the head of Lyons Creek the Hoadley splits into two thrust faults that repeat the Spokane and Greyson Formations. In most places, the eastern thrust dips between 60° and 90° SW., whereas the western thrust dips less than 50° SW. We infer that the western thrust is the main Hoadley thrust.

We postulate that, from the hinge point at the West Fork of the Sun River, the lateral displacement on the Hoadley increases southward to possibly as much as 70 km near Canyon Creek valley; however, additional studies of the fault and of stratigraphic relations along the fault are needed to better estimate the lateral displacement. South of Lyons Creek, the displacement appears small because the Spokane Formation is repeated by a thrust. However, in the vicinity of Rogers Pass, the Spokane in the Hoadley thrust plate contains a thick, basinward tidal facies, whereas that in the Eldorado thrust plate is a thinner near-shore facies (J.W. Whipple, oral commun., 1978). Thus it appears the Hoadley thrust significantly foreshortens the facies relations.

A significant amount of lateral shortening between the two plates is also suggested by comparing the thickness of formations in the plates (fig. 11). For example, the Helena Formation is 174 m thick in the Eldorado plate on the Dearborn River east of Steamboat Mountain, but 13 km southwest, in the Hoadley plate, it is 1,090 m thick (line of section *C-C′*, fig. 11). The Helena also thickens southward in the Eldorado plate. At 16.8 km to the southeast (line *D-D′*, fig. 11) it is about 488 m thick, which suggests a thickening rate of about 1.8 m per kilometer. If this rate of thickening is applicable to the Helena to the southwest, then the section in the Hoadley plate has been transported more than 48 km from the southwest. However, stratigraphic data suggest that the rate of thickening of the Helena to the southwest is greater than to the southeast; therefore, a more conservative estimate of about 38 km translation, as shown on fig. 12, may be more accurate.

CONTINENTAL DIVIDE SYNCLINE

The Continental Divide syncline is a broad, open, doubly plunging structure that extends from the Middle Fork of the Flathead River south to the Dearborn River, a distance of 116 km. The axis strikes southerly through Trinity and Silvertip Mountains, along the White River, to Junction Mountain (fig. 2). From Junction Mountain southward, the axis follows along the Continental Divide through Sugarloaf and Scapegoat Mountains. The axis of the syncline strikes subparallel to the strike of the Lewis and Hoadley thrust faults. Rocks as young as Mississippian occur in the central part of the fold (fig. 2). At its northern end, the fold is truncated by a high-angle fault northwest of Trinity Mountain. The Hoadley thrust marks the southern terminus of the syncline at Whitetail Creek, 5 km south of Steamboat Mountain lookout. The Continental Divide syncline may have been formed by stresses that produced the Lewis thrust.

The east limb of the syncline comprises the upper plate of the Lewis thrust to the north and that of the Hoadley thrust to the south. The west limb was displaced by a longitudinal normal fault (South Fork normal fault) that hinges at Scapegoat Mountain (fig. 2). The easterly dipping strata of the Swan Range are in the downthrown block of the normal fault and form part of the west limb of the syncline (Mudge, 1970).

SUMMARY

The trace of the Lewis thrust fault in Montana has been mapped over a distance of about 227 km. It originates in sheared and folded Mississippian rocks in the Dearborn River canyon, and toward the north it progressively cuts downsection to lower Proterozoic Y rocks near Glacier National Park.

We postulate that the Lewis thrust moved eastward more than 65 km at the south edge of the park and that the stratigraphic throw there is about 6,500 m. The Lewis plate is rotated about an easterly trending hinge line at the West Fork of the Sun River, and its displacement increases northward from that point. The Hoadley thrust originates from a point about 28 km north of where the Lewis thrust develops and extends southward for at least 125 km. The Hoadley appears to be a near mirror image of the

Lewis, as it is rotated eastward at the same hinge line and its displacement increases southward. At the southern end of its known trace, it may have moved eastward more than 70 km. Present data in the northern disturbed belt indicate that the Lewis and the Hoadley are the youngest of the thrust faults in the area; we believe they formed during very late Paleocene to very early Eocene time. The Lewis thrust, the Hoadley thrust, and the Continental Divide syncline probably formed concurrently in the same stress field.

REFERENCES CITED

Alpha, A.G., 1955, The Genou Trend of north central Montana: Am. Assoc. Petroleum Geologists, Rocky Mountain Sec., Geological record, Feb. 1955, p. 131-138.

Bally, A.W., Gordy, P.L., and Stewart, G.A., 1966, Structure, seismic data, and orogenic evolution of southern Canadian Rocky Mountains: Bull. Canadian Petroleum Geology, v. 14, no. 3, p. 337-381.

Billings, Marland, 1938, Physiographic relations of the Lewis overthrust in northern Montana: Am.Jour.Sci., 5th ser., v. 35, no. 208, p. 260-272.

Campbell, M.R., 1914, The Glacier National Park—A popular guide to its geology and scenery: U.S. Geol. Survey Bull. 600, 54 p.

Childers, M.D., 1963, Structure and stratigraphy of the southwest Marias Pass area, Flathead County, Montana: Geol. Soc. America Bull., v. 74, no. 2, p. 141-164.

Clapp, C.H., 1932, Geology of a portion of the Rocky Mountains of northwestern Montana: Montana School Mines Mem. no. 4, 30 p.

Clark, L.M., 1954, Cross-section through the Clarke Range of the Rocky Mountains of southern Alberta and southern British Columbia: Alberta Soc. Petroleum Geologists Guidebook, 4th Ann. Field Conf., Aug. 1954, p. 105-109.

Deiss, C.F., 1933, Paleozoic formations of northwestern Montana: Montana Bur. Mines and Geology Mem. 6, 51 p.

——— 1939, Cambrian stratigraphy and trilobites of northwestern Montana: Geol. Soc. America Spec. Paper 18, 135 p.

——— 1943a, Stratigraphy and structure of southwest Saypo quadrangle, Montana: Geol. Soc. America Bull., v. 54, no. 2, p. 205-262.

——— 1943b, Structure of central part of Sawtooth Range, Montana: Geol. Soc. America Bull., v. 54, no. 8, p. 1123-1167.

Dobbin, C.E., and Erdmann, C.E., 1955, Structure contour map of the Montana plains: U.S. Geol. Survey Oil and Gas Inv. Map OM 178 A.

Douglas, R.J.W., 1958, Mount Head map-area, Alberta: Canada Geol. Survey Mem. 291, 241 p.

Harrison, J.E., 1972, Precambrian Belt basin of northwestern United States—its geometry, sedimentation, and copper occurrences: Geol. Soc. America Bull., v. 83, no. 5, p. 1215-1240.

Harrison, J.E., Griggs, A.B., and Wells, J.D., 1974, Tectonic features of the Precambrian Belt basin and their influence on post-Belt structures: U.S. Geol. Survey Prof. Paper 866, 15 p.

Hoffman, Janet, Hower, John, and Aronson, J.L., 1976, Radiometric dating of time of thrusting in the disturbed belt of Montana: Geology, v. 4, no. 1, p. 16-20.

Hume, G.S., 1957, Fault structures in the foothills and eastern Rocky Mountains of southern Alberta: Geol. Soc. America Bull., v. 68, no. 4, p. 395-412.

Jones, P.B., 1971, Folded faults and sequence of thrusting in Alberta foothills; Am. Assoc. Petroleum Geologists Bull., v. 55, no. 2, p. 292-306.

Lange, S.S., 1963, The geology of the Lewis and Clark Pass area, Lewis and Clark County, Montana: Missouri Univ. unpub. M.A. thesis. 144 p.

McGill, G.E., and Sommers, D.A., 1967, Stratigraphy and correlation of the Precambrian Belt Supergroup of the southern Lewis and Clark Range, Montana: Geol. Soc. America Bull., v. 78, no. 3, 343-352.

Mudge, M.R., 1966a, Geologic map of the Pretty Prairie quadrangle, Lewis and Clark County, Montana: U.S. Geol. Survey Geol. Quad. Map GQ-454.

——— 1966b, Geologic map of the Glenn Creek quadrangle, Lewis and Clark and Teton Counties, Montana: U.S. Geol. Survey Geol. Quad. Map GQ-499.

——— 1970, Origin of the northern disturbed belt in northwestern Montana: Geol. Soc. America Bull., v. 81, p. 377-392.

——— 1972a, Pre-Quaternary rocks in the Sun River Canyon area, northwestern Montana: U.S. Geol. Survey Prof. Paper 663-A, 142 p.

——— 1972b, Structural geology of the Sun River Canyon and adjacent areas, northwestern Montana: U.S. Geol. Survey Prof. Paper 663-B, 52 p.

——— 1977, General geology of Glacier National Park and adjacent areas, Montana: Bull. Canadian Petroleum Geology, v. 25, no. 4, p. 736-751.

Mudge, M.R., and Earhart, R.L., 1978, Geology of the Bob Marshall Wilderness and study areas, Chapter A *of* Mineral resources of the Bob Marshall Wilderness and study areas, Lewis and Clark, Teton, Pondera, Flathead, Lake, Missoula, and Powell Counties, Montana: U.S. Geol. Survey Open-File Rept. 78-295, p. 1-51.

Mudge, M.R., Earhart, R.L., Cobban, W.A., and Rice, D.D., 1977, Glacier National Park and areas to the south and east, *in* Geological guide for the Canadian Soc. Petroleum Geologists 1977 Waterton-Glacier Park field conference: p. 41-62 and 75-82.

Mudge, M.R., Earhart, R.L., and Rice, D.D., 1977, Preliminary bedrock geologic map of part of the northern disturbed belt, Lewis and Clark, Teton, Pondera, Glacier, Flathead, and Powell Counties, Montana: U.S. Geol. Survey Open-File Rept. 77-25.

Mudge, M.R., Earhart, R.L., Watts, K.C., Jr., Tuchek, E.T., and Rice, W.L., 1974, Mineral resources of the Scapegoat Wilderness, Powell and Lewis and Clark Counties, Montana, *with a section on* Geophysical surveys, by D.L. Peterson: U.S. Geol. Survey Bull. 1385-B, 82 p.

Mudge, M.R., Erickson, R.L., and Kleinkopf, Dean, 1968, Reconnaissance geology, geophysics, and geochemistry of the southeastern part of the Lewis and Clark Range, Montana, *with* Spectrographic data by G.C. Curtin and A.P. Marranzino, *and a section on* Isotopic composition of lead by R.E. Zartman: U.S. Geol. Survey Bull. 1252-E, 35 p. [1969].

Price, R.A., 1965, Flathead map-area, British Columbia and Alberta: Canada Geol. Survey Mem. 336, 219 p.

Price, R.A., and Mountjoy, E.W., 1970, Geologic structure of the Canadian Rocky Mountains between Bow and Athabasca Rivers—A progress report: Geol. Assoc. Canada Spec. Paper no. 6, 25 p.

Ross, C.P., 1959, Geology of Glacier National Park and the Flathead region, northwestern Montana: U.S. Geol. Survey Prof. Paper 296, 125 p.

——— 1963, The Belt series in Montana: U.S. Geol. Survey Prof. Paper 346, 122 p. [1964].

Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, Geologic map of Montana: U.S. Geological Survey.

Schmidt, R.G., 1972, Geologic map of the Comb Rock quadrangle, Lewis and Clark County, Montana: U.S. Geol. Survey Geol. Quad. Map GQ-976.

Schmidt, R.G., and Strong, C.P., Jr., 1972, Geologic map of the Roberts Mountain quadrangle, Lewis and Clark County, Montana: U.S. Geol. Survey Geol. Quad. Map GQ-977.

Scott, J.C., 1951, Folded faults in Rocky Mountain foothills of Alberta, Canada: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 11, p. 2316-2347.

Sloss, L.L., and Laird, W.M., 1945, Mississippian and Devonian stratigraphy of northwestern Montana: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 15.

U.S. Geological Survey, 1971, Dating the Eldorado thrust, *in* Geological Survey research 1971: U.S. Geol. Survey Prof. Paper 750-A, p. A37.

Weimer, R.J., 1955, Geology of the Two Medicine-Badger Creek area, Glacier and Pondera Counties, Montana, *in* Billings Geological Society Guidebook, 6th Ann. Field Conf.: p. 143-149.

Willis, Bailey, 1902, Stratigraphy and structure, Lewis and Livingston Ranges, Montana: Geol. Soc. America Bull., v. 13, p. 305-352.

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