Medicine Lodge Thrust System, East-Central Idaho and Southwest Montana

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1031

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By EDWARD T. RUPPEL

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A summary of geologic data on a major segment of the North American Cordilleran fold and thrust belt

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By EDWARD T. RUPPEL

ABSTRACT

The Medicine Lodge thrust system, exposed in east-central Idaho and southwest Montana, is a major segment of the North America Cordilleran fold and thrust belt on which Precambrian and Paleozoic rocks have been telescoped and transported far east of their depositional area. The fault has overlapped rocks that initially were deposited in differing sedimentary environments on opposite sides of the northwest-trending geanticlinal Lemhi arch. The nature of the arch itself has been obscured by later thrusting, but it can be roughly reconstructed as a major landmass recurrently uplifted from Precambrian Y time at least through the Mesozoic. Although sections of the large landmass have been identified in the past as small islands, the landmass was instead a southern extension of Belt island, and it exerted a major influence on sedimentation patterns.

The thrust has obscured recognition of correlative sedimentary rock units. It also appears to have controlled the distribution of volcanic rocks in satellite centers of the main field of Tertiary Challis Volcanics. The thrust system has exerted a major influence on the emplacement of granodiorite–quartz monzonite stocks and related mineral deposits in east-central Idaho. Recognition of the fault as a major influence in intrusive activity and deposition of metallic mineral deposits suggests new possibilities for mineral resource exploration in this region. And consideration of the stratigraphic, paleogeographic, and structural framework of sedimentary rocks beneath the thrust suggests the possibility of petroleum and natural gas resources in the region north of the Snake River Plain.

INTRODUCTION

The Medicine Lodge thrust fault system of east-central Idaho and southwest Montana has long remained one of the least known segments of the North America Cordilleran fold and thrust belt, and its singularly significant role in confusing the geology of this part of the Rocky Mountains has not been understood. As a result, most stratigraphic studies in this region have failed to consider that great masses of sedimentary rocks have been telescoped and transported far east of their depositional sites; structural studies have not considered the pervasive effects of major thrusting; and the controlling influence of thrust faults on the emplacement of intrusive igneous rocks and related mineral deposits has not been recognized.

Recent field studies indicate more clearly the full significance of this major fault system, and suggest that most geologic problems in this region cannot be resolved without a clear understanding of Medicine Lodge thrusting. They show that the Medicine Lodge thrust system underlies much of southwest Montana and all of east-central Idaho, and that the possible overthrust distance, although uncertain, could be as much as 160 km.

SUMMARY OF EARLIER STUDIES

Kirkham (1927, p. 26–27) first mapped the trace of the Medicine Lodge fault near Medicine Lodge Creek, Idaho (fig. 1), north of the Snake River Plain, and clearly recognized its regional importance. Later the thrust system was traced into southwestern Montana by Sloss and Moritz (1951, p. 2160). Scholten, Keenmon, and Kupsch (1955, p. 382) mapped several thrusts in the Beaverhead and Tendoy Mountains, and traced the main Medicine Lodge thrust and its branches from the Idaho-Montana State line to Horse Prairie, Mont. Maps by Lowell (1965) and Myers (1952) extended other thrust faults from Horse Prairie northward into the Pioneer Mountains east of the Big Hole Basin. Later mapping by Staatz (1973) and by me in the present study, extended the Medicine Lodge thrust into the Beaverhead Mountains and the Lemhi Range. In all, the trace of the thrust system now has been mapped for a distance of more than 200 km.

At the time the fault was mapped near Horse Prairie, Lowell and Klepper (1953) also mapped and named the Beaverhead Formation, which they considered to be a syntectonic conglomerate related to thrust faulting. The tectonic significance of the Beaverhead Formation has recently been discussed in detail by Ryder and Scholten (1973), Ryder and Ames (1970), and Wilson (1970).

Stratigraphic and lithologic differences in rock units of similar age in the upper and lower plates across the

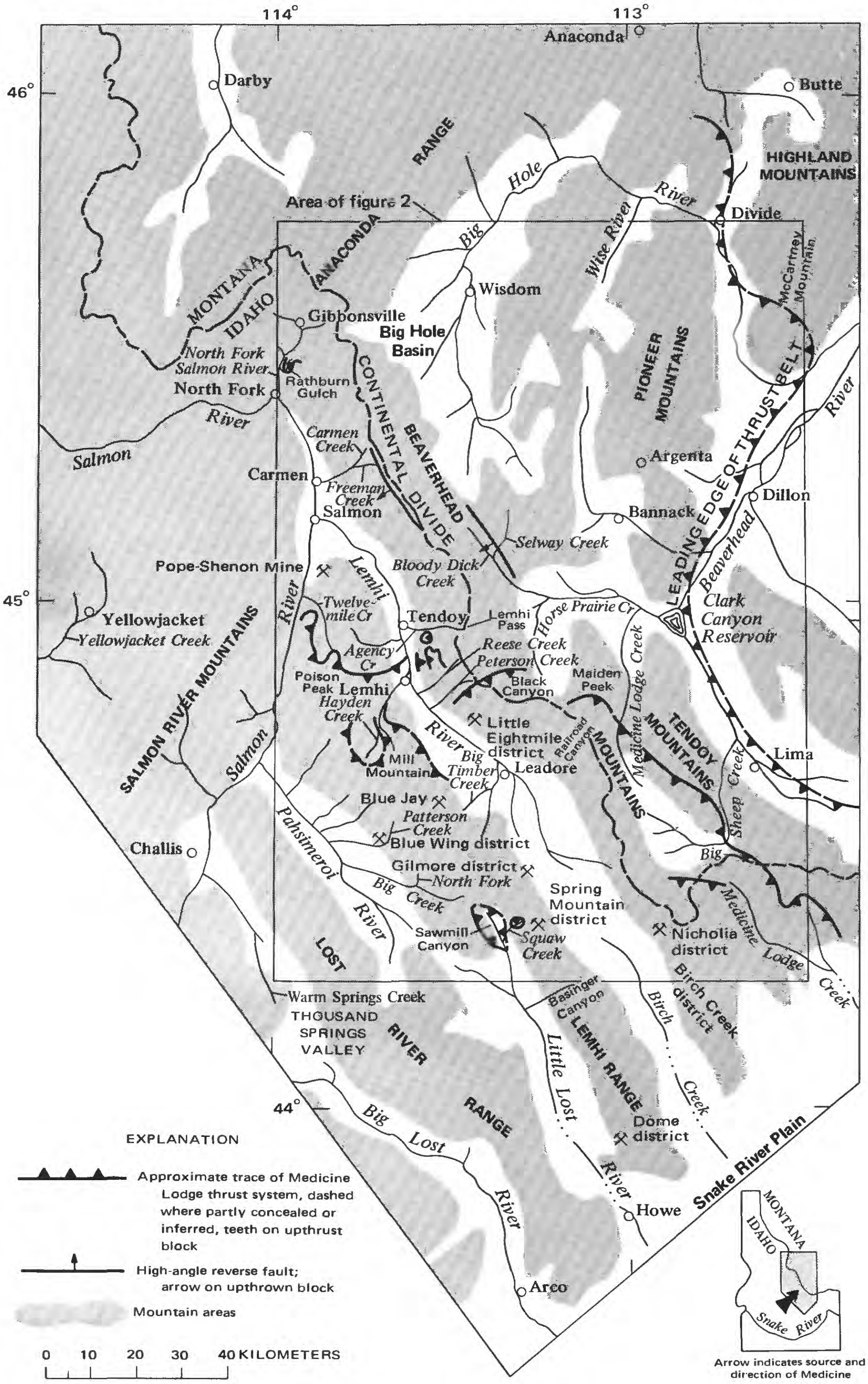


FIGURE 1. — Index map, east-central Idaho and southwest Montana. Base modified from U.S. Geological Survey, 1:500,000, Idaho, 1968, Montana, 1966. Mountain areas are patterned.

thrust are of critical importance in understanding the magnitude of thrusting. Such differences are summarized in this report, and more detailed descriptions of the various formations are available in published reports by Sloss and Moritz (1951), Scholten, Keenmon, and Kupsch (1955), Myers (1952), Shannon (1961), Lowell (1965), Huh (1967), Mamet, Skipp, Sando and Mapel (1971), Mapel, Read, and Smith (1965), Luchitta (1966), Hait (1965), Ross (1961, 1962), Ruppel (1968, 1975), Ruppel, Watts, and Peterson (1970), Ruppel, Ross and Schleicher (1975), and Embree, Hoggan, Skipp, and Williams (1975). Regional differences in lithology of Paleozoic rocks in east-central Idaho and adjacent Montana were discussed by Scholten (1957), who also showed some thickness data on isopachous maps. Ross (1962) summarized the Paleozoic stratigraphy of central Idaho in some detail.

Earlier studies of mining districts also have contributed information useful in understanding the effects of thrusting, for many mineral deposits are localized by the Medicine Lodge thrust. Additional information on these mining districts can be found in the following reports: Little Eightmile district (Thune, 1941; Umpleby, 1913; Staatz, 1972, 1973); Nicholia and Birch Creek districts (Shenon, 1928; Scholten and Ramspott, 1968; Anderson and Wagner, 1944); Gilmore and Spring Mountain districts, (Umpleby, 1913; Hait, 1965; Ruppel and others, 1970); Blue Wing district (Callaghan and Lemmon, 1941); Dome district (R. A. Anderson, 1948; Ross, 1933, 1961); Pope-Shenon mine (Ross, 1925).

ACKNOWLEDGMENTS

A significant part of the necessary background for this summary of geologic data on the Medicine Lodge thrust system was provided by the works of Scholten (1968, 1973), Scholten and Ramspott (1968), and Ryder and Scholten (1973). I am indebted to J. E. Harrison, M. R. Klepper, S. S. Oriel, C. A. Wallace, and I. J. Witkind for many discussions on the concepts developed in this paper, and to David A. Lopez for his help in mapping part of the trace of the fault. This report represents part of a more general study by the U.S. Geological Survey of the geology and mineral deposits of the central part of the Lemhi Range, Idaho.

REVISED DEFINITION OF THE MEDICINE LODGE THRUST SYSTEM

I propose that the name Medicine Lodge thrust system be applied to the major system of flat faults of eastern Idaho and southwestern Montana, a fault system that is a major segment of the North America Cordilleran fold and thrust belt, and that is comparable to the Bannock system in southeastern Idaho and western Wyoming and to the Montana disturbed belt of west-central and northwestern Montana.

The known main trace of the Medicine Lodge fault system extends northward in the Beaverhead Mountains from the margin of the Snake River Plain to the west margin of the Big Hole Basin, Mont. (fig. 2). It is also widely exposed in the central part of the Lemhi Range, west of the Beaverhead Mountains, as a result of uplift on younger, steep normal faults. The stratigraphic and petrologic changes across the thrust along its trace indicate that rocks from very different sedimentary facies have been tectonically overlapped (table 1). The rocks tectonically displaced in the thrust plate were deposited in Precambrian and Paleozoic geosynclines in what is now central and western Idaho. The rocks tectonically overlapped were deposited in a relatively shallow marine embayment or seaway east of the main Cordilleran geosyncline. Movement on the thrust probably occurred mostly in Late Cretaceous and Paleocene time and, as indicated by geologic and radiometric evidence, it was completed by early Eocene time. The total eastward displacement of the upper plate, or allochthon, possibly was as much as 160 km (Ruppel, 1975, p. 16).

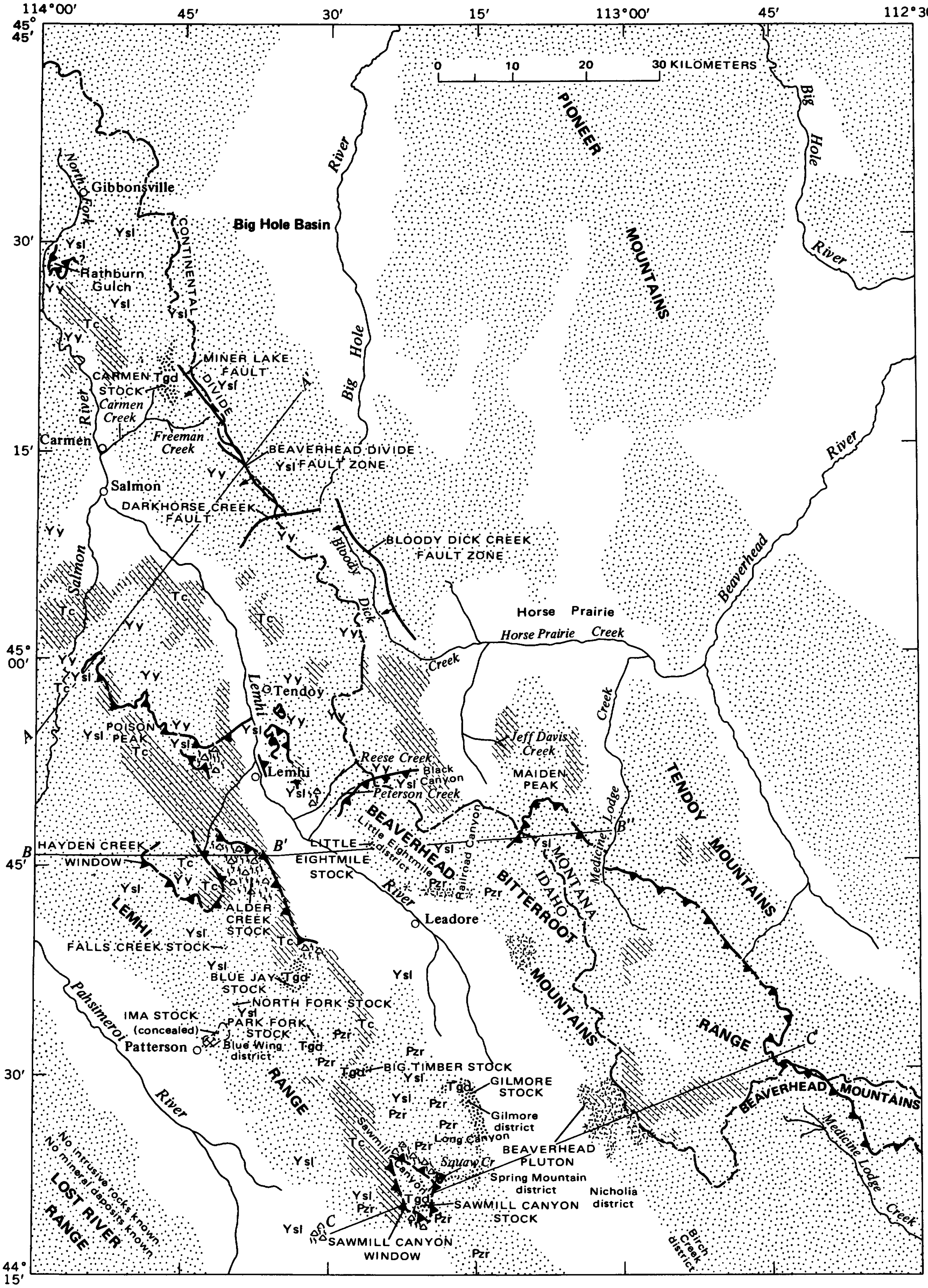
THE MAPPED LOCATION OF THE MEDICINE LODGE FAULT

BEAVERHEAD MOUNTAINS

In the Beaverhead Mountains, the long but interrupted trace of the Medicine Lodge fault is known mainly from reconnaissance mapping, supplemented in only a few areas by more detailed geologic maps. In the vicinity of Medicine Lodge Creek, Idaho, in the southernmost Beaverhead Mountains, Carboniferous rocks of the White Knob Limestone are thrust over syntectonic red conglomerate of the Beaverhead Formation, and over Paleozoic and Mesozoic sedimentary rocks (Scholten and others, 1955, p. 382; Ryder and Scholten, 1973, p. 783).

Farther north in Medicine Lodge Creek, Mont., near Maiden Peak, and near Bloody Dick Creek (Scholten and others, 1955; M'Gonigle, 1965; Coppinger, 1974, p. 167) (figs. 1, 2), sedimentary rocks of the Lemhi Group of Precambrian Y age (Ruppel, 1975, p. 15–16) are thrust over Precambrian X crystalline metamorphic rocks.

The Medicine Lodge thrust fault has been recognized (M. H. Staatz, oral commun., 1973) and mapped in reconnaissance in Black Canyon, in the Beaverhead Mountains west of the upper part of Horse Prairie Creek, and mapped as the Peterson Creek fault on the west side of the Beaverhead Mountains (Staatz, 1973).



114°00'
45'
30'
15'
113°00'
45'
112°30'
45° 45'
30'
15'
45° 00'
45'
30'
44° 15'
0 10 20 30 KILOMETERS
PIONEER
MOUNTAINS
Big Hole Basin
Big Hole River
Gibbonsville
North Fork
Rathburn Gulch
CONTINENTAL DIVIDE
MINER LAKE FAULT
CARMEN STOCK
Carmen Creek
Carmen
Freeman Creek
Salmon
Salmon River
BEAVERHEAD DIVIDE FAULT ZONE
DARKHORSE CREEK FAULT
BLOODY DICK CREEK FAULT ZONE
Bloody Dick Creek
Horse Prairie
Horse Prairie Creek
Beaverhead River
Tendoy
Lemhi River
Lemhi
POISON PEAK
Reese Creek
Black Canyon
Peterson Creek
Jeff Davis Creek
MAIDEN PEAK
TENDOY MOUNTAINS
HAYDEN CREEK WINDOW
LITTLE EIGHTMILE STOCK
Little Eightmile district
BEAVERHEAD
BITTERROOT
MOUNTAINS
Railroad Canyon
IDAHO
MONTANA
Medicine Lodge Creek
Leadore
LEMHI
RANGE
ALDER CREEK STOCK
FALLS CREEK STOCK
BLUE JAY STOCK
NORTH FORK STOCK
IMA STOCK (concealed)
PARK FORK STOCK
Patterson
Blue Wing district
Pahsimeroi River
BIG TIMBER STOCK
GILMORE STOCK
Gilmore district
Long Canyon
BEAVERHEAD PLUTON
Sawmill Canyon
Squaw Cr
Spring Mountain district
Nicholia district
SAWMILL CANYON STOCK
SAWMILL CANYON WINDOW
Birch Creek district
BEAVERHEAD MOUNTAINS
LOST RIVER RANGE
No intrusive rocks known
No mineral deposits known
A
A'
B
B'
B''
C
C'
Ysl
Yy
Tc
Tgd
Pzr

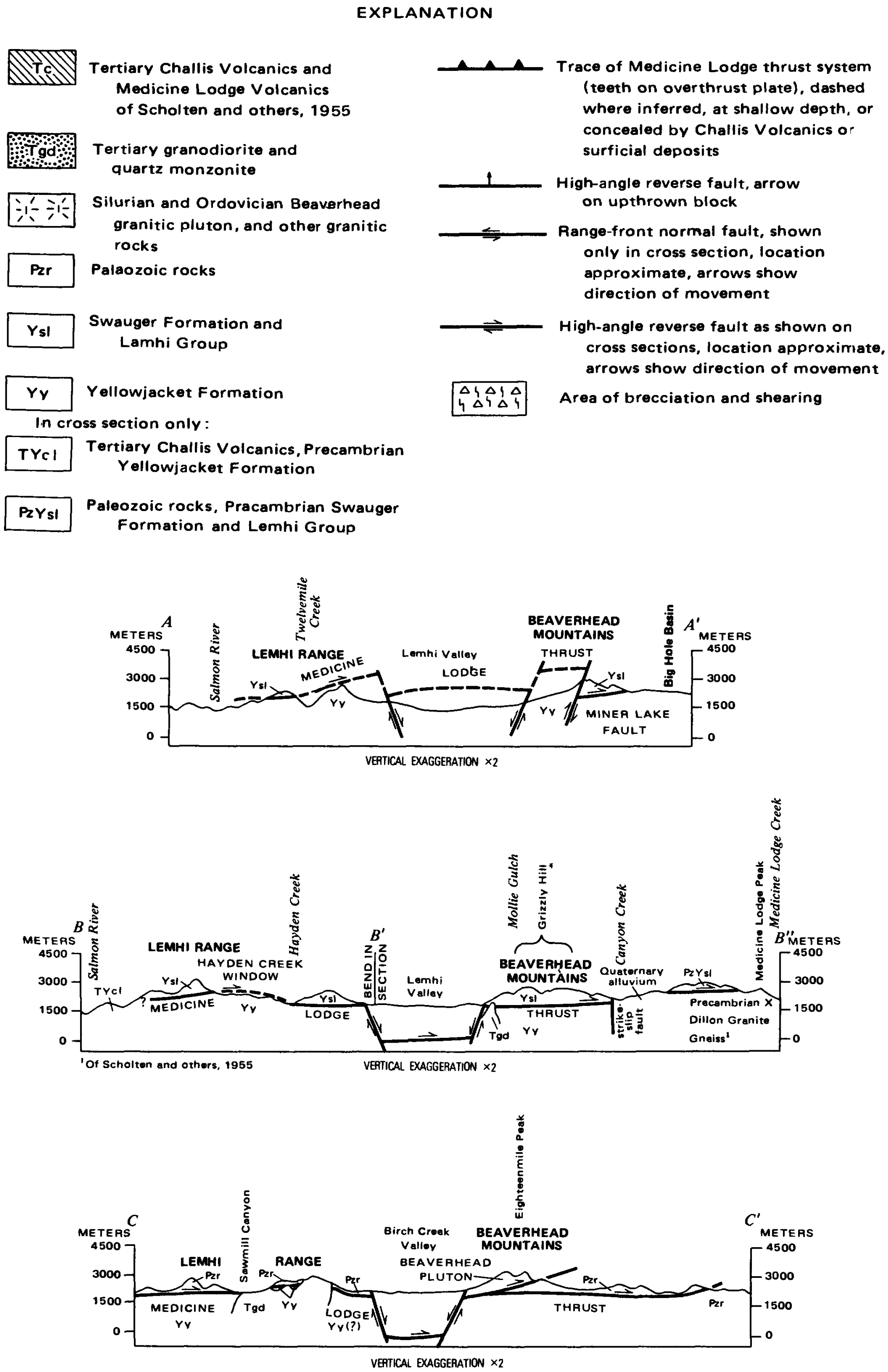


FIGURE 2. (left and above). — Generalized geologic map of the Medicine Lodge fault trace, east-central Idaho and southwest Montana, showing associated stocks, plutons, and mining districts; with schematic cross sections *A–A'*, *B–B'–B''*, and *C–C'*, showing interpreted relations at depth of Medicine Lodge thrust. Younger normal faults that break the Medicine Lodge thrust are known or inferred from geologic field studies, but are not shown on the map. Datum of cross sections is mean sea level. Base modified from U.S. Geological Survey 1:250,000, Dillon, 1955, Dubois, 1955.

TABLE 1. — *Comparison of formations across the Medicine Lodge thrust system, east-central Idaho and southwest Montana*

[Figures following formation descriptions are approximate thicknesses, in meters]

Age		Autochthon			Allochthon	
Mesozoic	Cretaceous[1]	Bannack — Argenta area Colorado Formation sandstone and shale 45 m Kootenai Formation sandstone and shale 365 m	Tendoy Mountains Colorado Group equivalents sandstone and shale 1,065 m Kootenai Formation sandstone and shale 455 m	Medicine Lodge Thrust System	None	
Mesozoic	Jurassic	Morrison Formation shale and sandstone 90 m Ellis Group 15–90 m			None	
Mesozoic	Triassic	Bannack — Argenta area Thaynes Formation, Woodside Formation, Dinwoody Formation } 275–550 m	Tendoy Mountains Thaynes Formation, Dinwoody Formation } 455 m		South Beaverhead Mountains Dinwoody Formation (Local only) 35 m	Lemhi Range None
Paleozoic	Permian	Phosphoria Formation and equivalent rocks, sandstone, phosphatic shale and phosphate rock, chert, limestone and dolomite 100–260 m			South Beaverhead Mountains Phosphoria Formation and equivalent rocks, cherty phosphatic limestone and shale about 100 m	South Lemhi Range Unnamed Limestone and sandstone 150 ± m
Paleozoic	Pennsylvanian	Quadrant Quartzite, sandstone and quartzite 825 m Amsden Formation, limestone and sandstone 30–90 m			South Beaverhead Mountains Unnamed Upper sandstone, Alternating limestone, dolomite, and sandstone, Lower sandstone } about 900 m	South Lemhi Range Unnamed Limestone and sandstone 915 ± m
Paleozoic	Mississippian	Big Snowy Formation, limestone and shale 100– m in Tendoy Mountains Madison Group Mission Canyon Limestone, Lodgepole Limestone } 610 m (as much as 1,035 m in Argenta area)			South Beaverhead Mountains Big Snowy Formation, limestone and shale 200 m Surrett Canyon Formation, limestone 65 m South Creek Formation, limestone 90 m Scott Peak Formation, 300–400 m Middle Canyon Formation limestone, sandstone, and siltstone, Unnamed Lower Mississippian shale and limestone } about 1,000 m	South Lemhi Range Surrett Canyon Formation, limestone 65 m South Creek Formation, limestone 90 m Scott Peak Formation, limestone 700 m Middle Canyon Formation, limestone, sandstone, and siltstone 305 m McGowan Creek Formation, shale 150 m

Era	Period				Medicine Lodge Thrust System		
Paleozoic — Continued	Devonian	Three Forks Formation, shale and limestone 60 m Jefferson Formation, dolomite 0–230 m				Beaverhead Mountains Jefferson Formation dolomite 25–65 m	Lemhi Range Three Forks(?) Formation, shale and limestone 30–90 m Jefferson Formation (in Gilmore area), limestone breccia, limestone, dolomite, and sandstone 915 m Middle Devonian channel sandstone 0–150 m
	Silurian	None				Laketown Dolomite, light-gray dolomite 0–60 m (thins northward to 0 m, thickens westward to 610 m in Lost River Range)	
	Ordovician	None				Saturday Mountain Formation (Fish Haven Dolomite of some reports), gray dolomite 425 m Kinnikinic Quartzite light-gray vitreous quartzite 370 m (thins to 0 m in South Beaverhead Mountains) Summerhouse Formation sandstone and shale, calcareous and dolomitic 0–300 m [Bayhorse area Ella Dolomite 215 m]	
	Cambrian	Bannack-Argenta area Pilgrim Dolomite 0–90 m Wolsey Shale 60 m Flathead Sandstone 150 ± m	Clark Canyon Reservoir Meagher Limestone 60 m Wolsey Shale 45 m Flathead Sandstone 35 m	Tendoy Mountains Meagher Limestone 5 m Flathead Sandstone 5 m		Lemhi — Lost River Ranges Beaverhead Mountains None known	Bayhorse Area Cash Creek Quartzite 365–395 m
Precambrian	Z	None				Wilbert Formation, quartzite and conglomerate 0–305+ m	In the Bayhorse area, the Middle Ordovician Ella Dolomite is underlain with apparent conformity by the Clayton Mine Quartzite (600+ m) which in part is similar to the Wilbert Formation but is of Middle Ordovician or older age. The relation of the Clayton Mine Quartzite to the Lower or Middle Cambrian Cash Creek Quartzite is unknown.
	Y	Lemhi Range and north part Beaverhead Mountains Yellowjacket Formation, biotitic feldspathic quartzite 3,050+ m				Swauger Formation, quartzite 0–3,050 m Lemhi Group, feldspathic quartzite and siltite 7,620 m	
	X	Dillon Granite Gneiss of Scholten and others (1955) and related rocks				None known in report region	

[1] Beaverhead Formation not included

In this area the allochthonous rocks are part of the Lemhi Group and the autochthonous rocks are part of the Yellowjacket Formation (Ruppel, 1975, p. 21). Farther north along the west flank of the Beaverhead Mountains, the fault has been mapped between Reese Creek and Agency Creek, where the fault breccia is mainly of Big Creek and Gunsight Formations of the Lemhi Group and is above the Yellowjacket Formation.

From Agency Creek northward to Rathburn Gulch in the Beaverhead Mountains, and west of Bloody Dick Creek the fault is not known to be exposed. Rocks of the Yellowjacket Formation, beneath the fault, crop out from the Peterson Creek segment of the fault, across Lemhi Pass, at the head of Agency Creek, and northward along the west flank of the Beaverhead Mountains to Freeman Creek. The rocks along the crest and east flank of the mountain range are not known, but the presence of Lemhi Group rocks in glacial deposits at the head of Bloody Dick Creek suggests that the thrust fault is present at depth west of Bloody Dick Creek, and could be exposed in places not yet mapped.

At the head of Freeman Creek, the Yellowjacket Formation is faulted against quartzite that probably is part of the Wilbert Formation; the steep west-dipping Miner Lake fault that separates the two formations is thought to be a high-angle reverse fault (MacKenzie, 1949, p. 34–36). The Medicine Lodge thrust presumably is present at depth east of the Miner Lake fault, beneath the Wilbert Formation rocks. The Miner Lake fault continues to the northwest into the upper part of Carmen Creek, where it separates light-colored feldspathic quartzite of the Big Creek Formation, east of the fault, from Yellowjacket rocks to the west; the Medicine Lodge thrust probably is beneath the Big Creek quartzites. Both the Yellowjacket and Big Creek have been intruded by the complex granodiorite Carmen Creek stock, but the relation of the stock to the Miner Lake fault is not known.

Tucker (1975, p. 136–146) considered the Beaverhead Divide fault zone, which he mapped along the Continental Divide south of the Freeman Creek area (MacKenzie, 1949), to be a southern extension of the Miner Lake fault and a link between the Miner Lake fault and the Bloody Dick Creek fault of Coppinger (1974, p. 167). The Beaverhead Divide fault zone as thus extended is a high-angle reverse fault, but Tucker suggested that it was originally a low-angle thrust fault, placing the Yellowjacket Formation over the Big Creek Formation. The relation of the Beaverhead Divide fault zone to the Medicine Lodge thrust fault is unknown, but most probably the Medicine Lodge thrust zone simply is broken by the high-angle Beaverhead zone, and the thrust is concealed to the east beneath the upper plate rocks of the Big Creek Formation and is eroded away to the west.

North of Carmen Creek, the quartzite and siltite of the Yellowjacket Formation crop out in the canyon of the Salmon River and its North Fork, and are overlapped by Challis Volcanics. The Challis is broken to the east by steep normal faults that are part of the range front system, and quartzite of the Big Creek Formation is exposed on the high peaks in the Beaverhead Mountains. The Medicine Lodge fault is beneath the Big Creek rocks, but no exposures of the fault are known.

At Rathburn Gulch, near Gibbonsville, Idaho, the Big Creek and Gunsight(?) Formations of the Lemhi Group overlie the Yellowjacket Formation. The contact has been interpreted as a gradational, depositional one (Anderson, 1959, p. 18; Ruppel, 1975, p. 6), but reconnaissance mapping shows that the supposed contact dips gently west, across bedding, and that Lemhi Group quartzites are extensively brecciated. The field relations suggest that the exposures near Gibbonsville are the northernmost known outcrops of the Medicine Lodge fault.

LEMHI RANGE

In the Lemhi Range (figs. 1, 2), the main thrust zone is exposed in several places beneath complexly deformed rocks (Ruppel, 1968). Here, as in the western part of the Beaverhead Mountains, repeated exposures of the fault result from comparatively recent uplift of these block-faulted mountain ranges, and the thrust system has been folded and repeatedly broken by several generations of younger, high-angle faults (Ruppel, 1964). The best exposures of the Medicine Lodge fault system are on the northeast flank of Mill Mountain (in the central part of the Lemhi Range), and northwest from Hayden Creek and the Hayden Creek window to the Poison Peak area and the west flank of Twelvemile Creek. These are the westernmost known exposures of the Medicine Lodge thrust fault system. At all of the localities allochthonous rocks immediately above the thrust are part of the Lemhi Group or Swauger Formation, and autochthonous rocks beneath the thrust are part of the Yellowjacket Formation. The thrust zone ranges in thickness from about 50 m to more than 300 m, and includes stretched, intensely brecciated, and mylonitized rocks that grade upward into less internally sheared, but complexly folded and faulted rocks of the upper plate. West and south of Mill Mountain, as in many other places, the thrust zone is concealed by Challis Volcanics.

The thrust zone is exposed southwest of Gilmore in a small window at Squaw Creek where the Kinnikinic Quartzite of Middle Ordovician age is thrust over the Yellowjacket Formation. The entire Lemhi Group and Swauger Formation, about 10,000 m thick, are missing and the Kinnikinic Quartzite is intensely shattered. The widespread distribution of shattered Kinnikinic in outcrops in Sawmill Canyon west of Squaw Creek suggests that this wide basin is underlain at shallow depth by the fault, beneath blanketing Challis Volcanics. The thrust also might be exposed farther south in Basinger Canyon, where descriptions by Umpleby (1917, p. 23) suggest that the lower part of the Lemhi Group is missing above Yellowjacket-like rocks.

The exposures of the fault in the Lemhi Range suggest that it lies at relatively shallow depth beneath the central part of the range. Aeromagnetic evidence (U.S. Geological Survey, 1971) also suggests a magnetic surface which slopes gently westward and which probably is the thrust surface. The magnetite-bearing quartzites of the Yellowjacket may be the source of the magnetism.

STRATIGRAPHIC CHANGES ACROSS THE MEDICINE LODGE THRUST SYSTEM

The major changes in rock units across the Medicine Lodge thrust (table 1) suggest that the allochthonous rocks in the upper plate (fig. 3) have been tectonically transported far east of the Cordilleran miogeocline where they were deposited. These rocks now overlap other rocks that were deposited in a shallow shelf embayment or seaway. Paleogeographic reconstruction suggests that the miogeocline and the shelf embayment or seaway were separated by an intermittent uplift, an expanded Lemhi arch, during part of Precambrian and Paleozoic time. The changes in stratigraphic units across the thrust are summarized on table 1, and the rocks deposited in the miogeocline and in the seaway, on opposite sides of the Lemhi arch, are briefly discussed in the following paragraphs. The Lemhi arch is discussed more fully in a later section of this report.

PRECAMBRIAN X

Precambrian X crystalline metamorphic rocks are widespread in southwestern Montana east of the Medicine Lodge thrust, but are not known in the allochthonous block unless fault-bounded granitic rocks near Leadore, Idaho (Ruppel, 1968), similar to the Dillon Granite Gneiss of Scholten, Keenmon, and Kupsch (1955) farther east, represent slices of these basement rocks caught up in the thrust where it overrode the crystallite rocks. Problems posed by these granitic rocks in the allochthonous block are briefly discussed in a later section on the Beaverhead pluton.

PRECAMBRIAN Y

The Precambrian sedimentary rocks of the upper plate are the Lemhi Group and Swauger Formation. These rocks do not occur east of the Medicine Lodge thrust in the lower plate, and they show no features that suggest an approach to a depositional edge. In southwestern Montana they are in thrust contact with Precambrian crystalline basement rocks. The association of very different rocks across the thrust strongly suggests major eastward transport of the Lemhi and Swauger rocks. In the Lemhi Range and part of the Beaverhead Mountains the micaceous, feldspathic quartzite and siltite of the Yellowjacket Formation are beneath the thrust, but Yellowjacket rocks have not been recognized farther east. Yellowjacket rocks are not known to occur any place in the upper plate.

PRECAMBRIAN Z

The Wilbert Formation, tentatively of Precambrian Z age (equivalent to part of the Brigham Quartzite south of the Snake River Plain), has been recognized in the upper plate in several areas in east-central Idaho (Ruppel and others, 1975, p. 27–29). The formation has not been definitely recognized east of the thrust trace.

CAMBRIAN

No rocks of Cambrian age are known in the Lost River and Lemhi Ranges in the eastern part of the allochthonous block, but they have been found about 50 km farther west near Clayton, Idaho, in the western part of the block where the Lower or Middle Cambrian Cash Creek Quartzite has been described (Hobbs and others, 1968, p. J18–J19). The distribution of Cambrian rocks in the allochthonous block suggests that they must originally have thinned to the east.

In the autochthon the thicknesses and distribution of Cambrian rocks indicate that they thin to the south and west in southwestern Montana, partly as a result of Middle Cambrian deformation (Myers, 1952, p. 6). Cambrian rocks apparently were not deposited in the area now immediately east of the trace of the Medicine Lodge thrust.

ORDOVICIAN

The Kinnikinic Quartzite and dolomites of the Saturday Mountain Formation (of Middle and Late Ordovician age), are widespread in the central and southwestern Lemhi Range, and the Lower Ordovician Summerhouse Formation crops out locally in the same region. The Saturday Mountain Formation thins by onlap onto a high area at the south end of the range, where it includes thin sandstone interbeds.

In the Beaverhead Mountains the Kinnikinic Quartzite thins to the south by onlap onto the Skull Canyon uplift (Scholten, 1957, p. 166) in the southern part of the range. The Saturday Mountain Formation has been mapped in thrust plates near Leadore, Idaho, but probably is present there only because of tectonic transport within the allochthonous block. The Summerhouse Formation crops out on and near Maiden

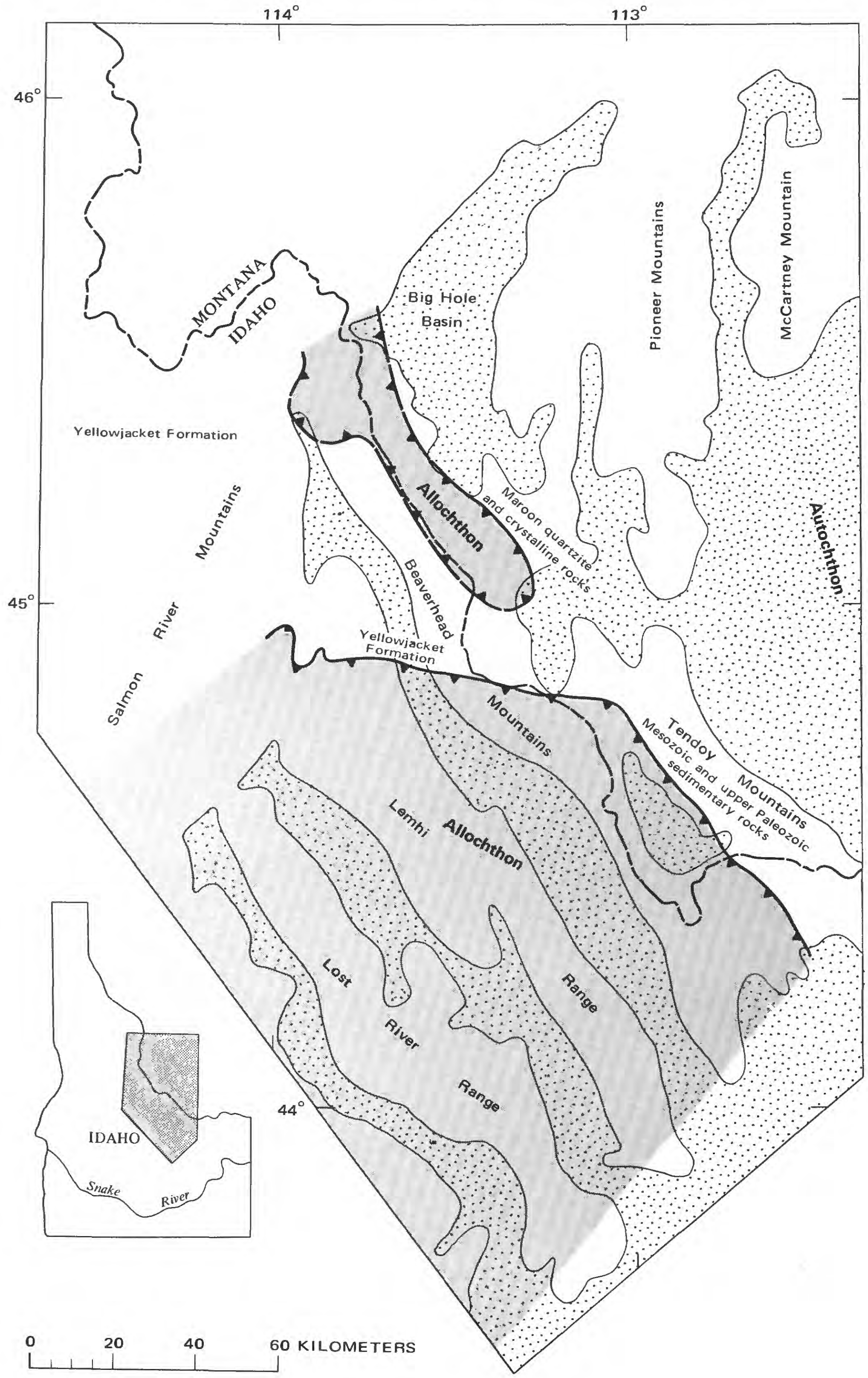


FIGURE 3. — Sketch map of regions of autochthonous and allochthonous rocks, east-central Idaho and southwest Montana, indicating rocks overridden by Medicine Lodge thrust system. Heavy solid line, trace of Medicine Lodge thrust (teeth on overthrust plate), dashed where inferred.

Peak, where M'Gonigle (1965, pl. 1) considered it to be in depositional contact with the Dillon Granite Gneiss. If the contact is depositional, the Summerhouse must have been deposited in shallow seas and tidal flats that covered all of east-central Idaho and adjacent southwestern Montana. The Maiden Peak outcrops of the Summerhouse Formation are complexly folded, thrust faulted, and broken by many younger faults, however, and are exposed only where the Precambrian Y Lemhi Group rocks have been thrust over the older crystalline rocks on the Medicine Lodge fault. I believe that it is most likely that the Summerhouse Formation near Maiden Peak is part of the upper plate of the Medicine Lodge thrust system, and so is in fault contact with the Dillon Granite Gneiss, rather than depositional contact as shown by M'Gonigle. If my interpretation is correct, there are no Ordovician rocks east of the Medicine Lodge fault trace.

The sedimentation patterns and distribution of Ordovician rocks suggest that they, like the Cambrian rocks, originally thinned to the east in the allochthonous block, and that they were not deposited on the autochthon east of the Medicine Lodge fault trace.

SILURIAN

In the allochthonous block Silurian rocks are represented by the upper part of the Saturday Mountain Formation, which in the Leadore quadrangle may be as young as Silurian, and by the Laketown Dolomite. The Laketown thins northward and eastward and disappears in the central part of the Lemhi Range, and Laketown rocks have not been recognized in the Beaverhead Mountains. The upper part of the Laketown was weathered and eroded before deposition of Devonian rocks in the Lemhi Range, and the formation thins both by onlap onto a lower Paleozoic high area and by later Silurian and Early Devonian erosion. No Silurian rocks are known east of the Medicine Lodge fault trace in southwestern Montana.

DEVONIAN

In the Lemhi Range the thick section of Devonian rocks in the allochthonous block includes: (1) a channel sandstone deposit that cuts deeply into the Saturday Mountain Formation at the head of Spring Mountain Canyon and which contains Middle Devonian freshwater fish remains; (2) a thick section of marine rocks of the Middle and Upper Devonian Jefferson Formation that is well exposed near Gilmore; and (3) a 100-m-thick shale and limestone section of the Upper Devonian Three Forks(?) Formation. The lower part of the Jefferson contains sandstone lenses and sandy carbonate rocks; the upper part is a syndepositional limestone breccia that may represent an off-reef accumulation. In the Beaverhead Mountains, the much thinner Jefferson Formation laps onto and finally overlaps a lower Paleozoic topographic high area called the Lemhi arch by Sloss (1954, p. 368) or the Tendoy dome by Scholten (1957, p. 167). The Three Forks Formation apparently is too thin to map separately in the Beaverhead Mountains. In the Tendoy Mountains autochthonous Devonian rocks include both the Jefferson and Three Forks Formations.

The pattern of eastward-thinning allochthonous rocks and westward-thinning autochthonous rocks in early and middle Paleozoic time is clearly repeated in Devonian rocks.

UPPER PALEOZOIC

The stratigraphic nomenclature of upper Paleozoic rocks in east-central Idaho remains in a state of flux, as continuing efforts are being made to apply the terminology developed by Huh (1967) and Mamet and others (1971) to this thick, structurally complicated, and tectonically telescoped group of rocks. But stratigraphic nomenclature is a secondary issue; the primary one, as first pointed out by Sloss and Moritz (1951, p. 2156–2160), is that the upper Paleozoic rocks of the allochthonous block in the Beaverhead Mountains, the Lemhi Range, and farther west are radically different from rocks of somewhat similar age in the autochthonous section immediately east of the Medicine Lodge fault in the Tendoy Mountains of Montana.

The Mississippian rocks in the allochthon include shale and limestone of the McGowan Creek, Middle Canyon, Scott Peak, South Creek, Surrett Canyon, and Big Snowy Formations. East of the Medicine Lodge thrust autochthonous Mississippian rocks are dominated by limestones of the Lodgepole and Mission Canyon Limestones of the Madison Group. The Big Snowy Formation is also present but it differs in thickness and in lithofacies from place to place (Scholten and others, 1955, p. 364).

Pennsylvanian rocks in the southern Lemhi Range and Beaverhead Mountains are mainly sandstone and sandy limestone and dolomite. The sandstone is most common at the base and top of the section and most of the Pennsylvanian rocks are carbonate (Shannon, 1961, p. 1830). In contrast, the Pennsylvanian section in the Tendoy Mountains 10–20 km to the east includes limestone and fine-grained clastic rocks of the Amsden Formation, overlain by the thick well-sorted quartzite of the Quadrant Quartzite.

Unnamed Permian rocks in the allochthonous block have been reported near the southern tip of the Lemhi Range, and although they have not been described in detail they are known to be mostly sandstone and limestone (Shannon, 1961, p. 1830). Permian phosphatic limestones and shales of the Phosphoria Formation and equivalent units are known from the southern Beaverhead Mountains, and apparently are in normal stratigraphic sequence. East of the thrust the Permian section includes phosphatic carbonates and organic carbon-rich shales typical of the Permian shelf deposits in Idaho and Montana (Maughan, 1975).

In summary, upper Paleozoic rocks west of the Medicine Lodge thrust in the upper plate differ greatly from the lower plate rocks east of the Medicine Lodge thrust. For the most part, the differences in lithofacies and thickness are so profound that the two sequences of rocks cannot be correlated.

MESOZOIC

There are almost no allochthonous Mesozoic rocks in east-central Idaho or in southwestern Montana, except for a small area near the south end of the Beaverhead Mountains where the Triassic Dinwoody Formation has been reported. East of the fault, autochthonous rocks of Mesozoic age are widespread and relatively thick. In the Bannack area, the Mesozoic section includes the Triassic Dinwoody, Woodside, and Thaynes Formations overlain by the Jurassic Ellis Group and the Cretaceous Kootenai and Colorado Formations. Farther south, in the northern part of the Tendoy Mountains, only the Dinwoody and Thaynes are present. Jurassic rocks of the Ellis Group and the Morrison Formation are restricted to the central and southern parts of the Tendoy Mountains, as are Cretaceous rocks represented by the Kootenai Formation and a thick section of rocks equivalent to part of the Colorado Formation. This thick section of Mesozoic rocks abruptly disappears at the east edge of the Medicine Lodge fault, and probably is concealed beneath the allochthonous block.

THE LEMHI ARCH

Topographic highs described as small islands have been invoked to explain shoaling patterns of rocks deposited from Cambrian through Mississippian time (Sloss, 1954; Scholten, 1957), but the telescoping effect of the Medicine Lodge thrust on lithofacies distribution has never been considered. These small islands now appear to be displaced parts of what was once a major landmass that was overridden by the allochthonous block of the Medicine Lodge thrust. The first high area or island recognized was named the Lemhi arch (Sloss, 1954). I retain the name, but redefine it as an intermittently emergent major landmass that separated the Cordilleran miogeocline in western Idaho from a shelf embayment or seaway in southwestern Montana during Precambrian and Paleozoic time (fig. 4). As redefined, the Lemhi arch may have been connected at its northern end to Belt island (Harrison and others, 1974, p. 2–3, 5–6, fig. 2). Its south end is unknown. Its maximum width probably was about 160 km, the inferred distance of movement on the Medicine Lodge thrust (Ruppel, 1975, p. 15–16). Lower and middle Paleozoic rocks in the upper plate thin eastward, and I interpret this thinning to reflect the former western shore of the Lemhi arch. Rocks of similar age thin westward in the lower plate, and I interpret this thinning to reflect the eastern shore of the arch. As a result of thrust faulting, the two shores are now placed nearly together, to create a false impression of a system of small islands.

The effect of tectonic fluctuations of the Lemhi arch on regional sedimentation patterns differed from Precambrian through Paleozoic time. The oldest rocks, those of the Yellowjacket Formation (Precambrian Y), are widely exposed beneath the Medicine Lodge thrust plate in east-central and central Idaho. Their distribution suggests that they were deposited across central and east-central Idaho and probably lapped against crystalline rocks someplace near the present Idaho-Montana boundary. This distribution suggests that the Lemhi arch did not exist during deposition of the Yellowjacket sediments, and that the Precambrian geosynclinal shoreline was near southwest Montana, much farther east than at any later time.

The Lemhi Group and Swauger Formation, which everywhere are part of the allochthonous block above the Medicine Lodge thrust, are thrust across the older Yellowjacket Formation. The Lemhi and Swauger are thought to have been deposited in the Precambrian Cordilleran miogeocline (Ruppel, 1975, p. 15). The lithologic and stratigraphic differences between these rocks suggest that by later Precambrian Y time the Lemhi Arch had risen and had separated the Precambrian miogeocline in western Idaho from the cratonic region in east-central Idaho and southwest Montana. The arch may have separated depositional areas in Precambrian Z time, but almost nothing is known of rocks in southwest Montana that might be of this age, and so equivalent to the allochthonous Wilbert Formation.

Shoaling patterns of sedimentation against the opposite shores of the Lemhi arch are evident in Cambrian rocks, for rocks deposited in the seaway in Montana thin to the west against the eastern shore of the arch, and miogeoclinal rocks thin to the east in Idaho, against the western shore of the arch. By Ordovician time, the eastern side of the arch probably was continuous with the large landmass to the east, for Ordovician and Silurian rocks are absent in southwest Montana.

The earliest rocks of Devonian age are Middle Devonian channel sandstones containing freshwater fish remains (Denison, 1968) which are present on the block

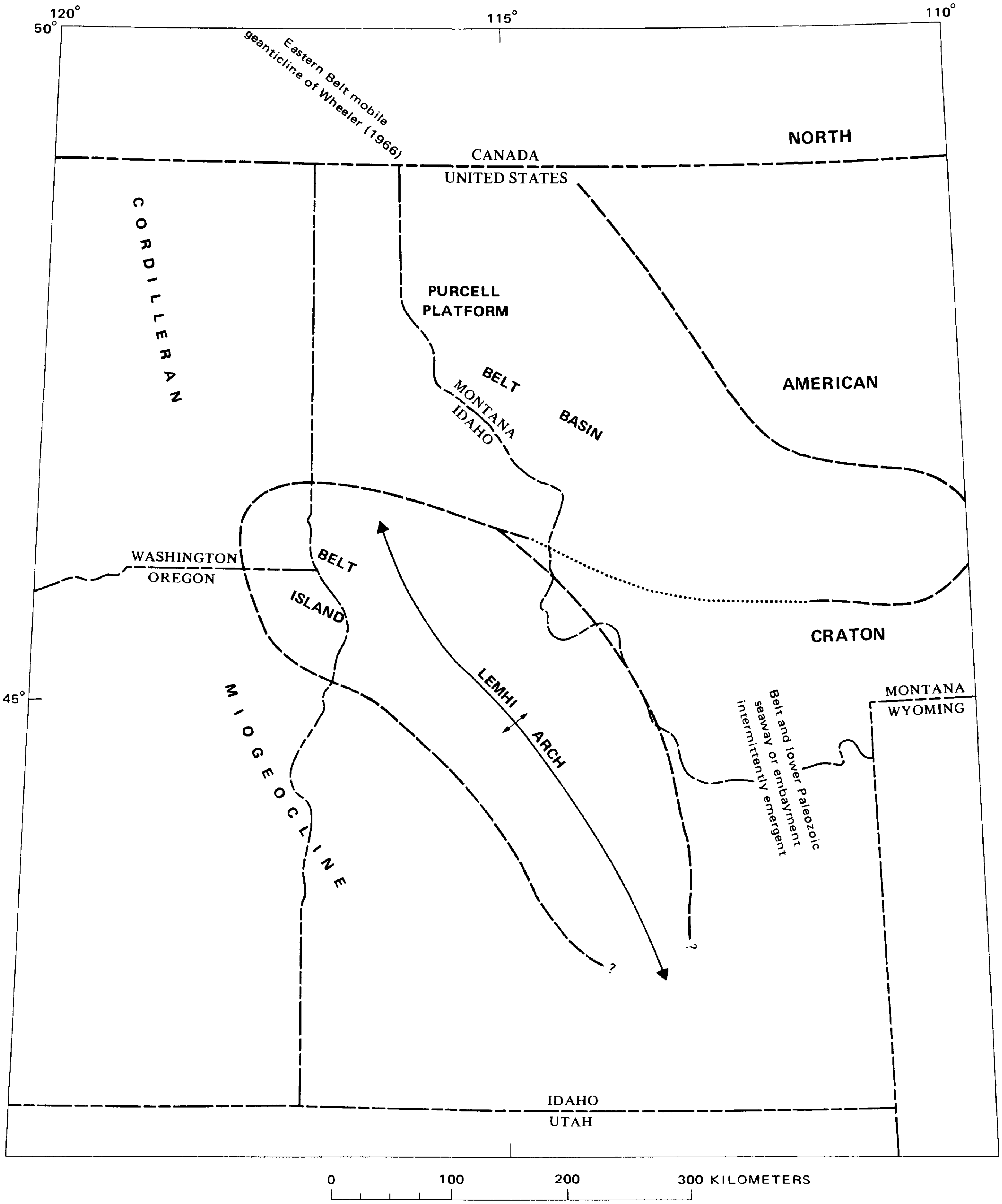


FIGURE 4. — Map showing approximate location of Lemhi arch. Queried where boundary unknown; dashed line outlines approximate maximum extent of Belt island–Lemhi arch; dotted line shows region where seaway may have reached south from Belt basin to miogeocline along east shore of Lemhi arch.

that represents the western shore of the arch. These sandstones are overlain by transgressive marine blanket sandstones which, in turn, are overlain by carbonate rocks. Marine carbonate rocks (the main part of the Jefferson Formation in Montana) were deposited against the eastern shore of the arch until later Devonian time, when for the first time the Lemhi arch was overlapped by marine deposits. Only then did the rocks on both sides of the arch acquire some lithofacies characteristics in common, for at least some of the western miogeoclinal Jefferson Formation rocks do resemble the type Jefferson rocks east of the arch.

The effect of the uplift seems to have persisted into later Paleozoic time, inasmuch as it influenced depositional patterns of Mississippian and Pennsylvanian rocks, as suggested by Sloss and Moritz (1951, p. 2161) and Scholten (1957, p. 167). During Mesozoic time the Lemhi arch probably was a persistent high area, supplying sediments rather than receiving them. In late Mesozoic and early Tertiary time the arch was overridden by the Medicine Lodge thrust, which shifted together or overlapped rocks from very different depositional environments from opposite sides of the arch. Various uplifts described in earlier reports, such as the Skull Canyon uplift, Tendoy dome, Beaverhead arch (Scholten, 1957, p. 167), and the Salmon River arch (Armstrong, 1975, p. 452), are all displaced parts of this single fluctuating but persistent pericratonic upwarp, the Lemhi arch.

The connecting of the Lemhi arch and Belt island, as shown in figure 4, is conjectural, particularly because so little is known — or perhaps knowable — of the Paleozoic history of Belt island (Harrison and others, 1974, p. 6). In reviewing the Paleozoic and early Mesozoic history of the Belt basin, Harrison, Griggs, and Wells (1974) discussed an intermittently emergent sill, or mobile geanticline, described by Wheeler (1966) in the eastern tectonic belt of the southern Canadian Cordillera, and suggested that his "mobile geanticline" could have included Belt island. Perhaps, instead, Belt island is a northern part of the Lemhi arch, and together these features form a second mobile geanticline, south of the Belt basin. The intermittent but persistent uplift described by Wheeler is similar in many ways to the Lemhi arch. In a summarizing paragraph, Wheeler (1966, p. 37) stated:

> The tectonic evolution indicates that until the mid-Paleozoic the eastern belt was essentially a locally fluctuating zone of transition between a eugeosyncline to the west and a miogeosyncline to the east, within which the Purcell region remained as a relatively elevated block. During late Paleozoic and early Mesozoic times, however, the eastern belt was the site of an intermittently emergent sill — essentially a mobile geanticline — which, except in its southernmost part, separated the two kinds of geosynclines. In late Mesozoic and Tertiary time the eastern belt was entirely land. At this time it was repeatedly the site of plutonic pulses, episodes of deformation and uplift, and the principal source of Cretaceous sediments deposited to the east * * *

This paragraph serves equally well in most respects for describing the Lemhi arch. The eastern belt and the Lemhi arch occupied similar tectonic settings and have had largely parallel tectonic histories. Both features have left their imprint one way or another on rocks from Precambrian Y time to the Tertiary, and have been focal points of many major tectonic episodes affecting these regions. Two major intermittently positive regions along the margin of the Cordilleran miogeocline are defined by (1) the mobile geanticline of Wheeler and (2) the Lemhi arch joined to Belt island.

THE BEAVERHEAD FORMATION AND THE AGE OF THE MEDICINE LODGE THRUST SYSTEM

The Beaverhead Formation, named by Lowell and Klepper (1953), is recognized as a syntectonic deposit that resulted from regional overthrusting. Scholten (1973, p. 477–480) noted that "extensive remains of the subaerial Beaverhead conglomerate occur at the eastern margin of the overthrust belt. This conglomerate attains thicknesses of at least 5,000 m and a large part is composed of highly rounded pebbles and cobbles of lower Paleozoic and Belt quartzite, deposited continuously from Early Cretaceous (Albian) to Early Tertiary (Paleocene or early Eocene) time * * *."[1] He suggested that eastward transport of the clastic debris that forms the Beaverhead Formation indicates the beginning of major regional uplift and tectonism to the west. The Beaverhead Formation is itself intensely folded and cut by thrust faults (Lowell, 1965), and must reflect several stages of tectonism extending from the initial uplifts in central Idaho to the eventual arrival of the Medicine Lodge thrust plate.

Although the age of the Beaverhead Formation is reasonably well known, the time of movement on the Medicine Lodge overthrust system is not. It is possible, however, to establish a minimum age of movement, for in the central part of the Lemhi Range folded and imbricate thrust-faulted rocks of the upper plate are cut by many undeformed monzonitic and granodioritic stocks; the stocks are obviously postthrusting in age, and were intruded and partly exposed by erosion before eruption of the Challis Volcanics. Potassium-argon age determinations on biotite from one of these stocks, the Blue Jay stock, indicate an age of 51.3 ± 1.5 m.y., and

[1] The Belt quartzites referred to by Scholten presumably are the Precambrian Y sedimentary rocks of east-central Idaho (Ruppel, 1975), but pebbles and cobbles of Precambrian rocks in the Beaverhead Formation have not been sufficiently studied to tie them to more specific source areas.

biotite from a stock-related dike in Long Canyon near Gilmore provides a K-Ar age of 49.4 ± 1.7 m.y. (John D. Obradovich, written commun., 1971). Therefore, the Medicine Lodge fault block was in its present position by early Eocene time. Fault movement occurred between Early Cretaceous (Albian) and early Eocene time; probably most movement occurred in Late Cretaceous and early Paleocene time.

The mechanism that caused the Medicine Lodge thrust remains uncertain. Scholten (1973) has suggested a model that requires gravitational gliding of allochthonous blocks from a rising region in central Idaho which is now occupied by the Idaho batholith. Scholten's model (1973, p. 485) requires that, "a pelitic, low viscosity potential decollement zone existed somewhere near the middle of the Belt at around 13 km below sea level prior to deformation * * * ." According to present interpretations of Precambrian stratigraphy (Ruppel, 1975), some of these conditions appear to be met in east-central Idaho where Precambrian rocks above the Yellowjacket Formation are 7–10 km thick, and younger rocks have a total thickness of 4–5 km; the base of this part of the Medicine Lodge thrust zone presumably is at or near the contact of the Yellowjacket Formation and the younger Precambrian sedimentary rocks. North of the Snake River Plain, however, the southern part of the thrust brings miogeoclinal Paleozoic sedimentary rocks, at most 4–5 km thick, over shelf-deposited sedimentary rocks of Paleozoic and possible Mesozoic age. Perhaps it is fairest to conclude that the proposed requirements for gravitational gliding are only partly met by what is now known of the Medicine Lodge thrust system.

DEFORMATION IN THE ALLOCHTHON

Throughout east-central Idaho and adjacent Montana, rocks in the allochthonous block above the Medicine Lodge thrust are complexly folded and are cut by many imbricate thrusts of comparatively minor displacement. Scholten and Ramspott (1968, p. 25–37) concluded that the predominantly quartzitic lower Paleozoic and Precambrian rocks at lower stratigraphic and structural levels in the block are less intensely deformed than younger Paleozoic carbonate rocks higher in the block. In general this seems to be true throughout the Beaverhead Mountains, Lemhi Range, and Lost River Range, although the degree of deformation is relative and probably reflects the different response of different rocks to the stress field. However, the regional distribution of thrust-related deformation requires a broader explanation than that applied locally in the southern Beaverhead Mountains by Scholten and Ramspott (1968).

In the southern Beaverhead Mountains, Scholten and Ramspott (1968) described the lower layer structural zone as characterized by: (1) open northwest-trending folds that are asymmetric to the northeast and superposed on a series of broad northwest-trending undulations; (2) short steeply dipping to vertical faults which trend northeast and northwest and which may not be related to thrusting; and (3) older medium- to high-angle northwest-striking thrusts which appear to steepen with depth and which are broken by the steep faults. Scholten and Ramspott attributed the lower layer structure to compressional stresses and the rise of an anticlinorium in the Beaverhead Mountains. The upper layer structure is characterized by strongly overturned folds, recumbent folds or intense contortions, and by masses of rock displaced along nearly flat lying faults that displace rocks no older than Mississippian. The folds are asymmetric or overturned to the northeast, although some are locally asymmetric to the southeast. Near the Beaverhead pluton the folds are asymmetric away from the pluton. In some areas the structure is almost chaotic. The disharmonic zone between the upper and lower layers is in Mississippian shale and shaly limestone. Scholten and Ramspott considered upper layer deformation a result of radial gravitational movement away from the rising Beaverhead anticlinorium.

In the northern part of the Beaverhead Mountains and in the central part of the Lemhi Range, deformation in the allochthonous block is characterized by: (1) strongly overturned and nearly isoclinal northwest-trending folds, which are asymmetric to the northeast; and (2) closely spaced imbricate thrust faults that generally dip 20°–25° to the west or southwest and show no indication of steepening with increasing depth. The rocks involved in thrusting are of Precambrian or early Paleozoic age; younger Paleozoic rocks are present only in a few small areas.

In the southern part of the Lemhi Range (Ross, 1961; Beutner, 1968), rocks involved in the thrust are later Paleozoic carbonate rocks, and the type of deformation resembles that of the upper layer structural zone of the southern Beaverhead Mountains. Similar deformation is present in the Lost River Range where upper Paleozoic carbonate rocks are involved in overthrusting (Mapel and others, 1965; Mapel and Shropshire, 1973), and spectacular isoclinal folds are prominently exposed in many cliffs.

The differences noted by Scholten and Ramspott (1968) and described by them as structural "layers" probably result from the different physical responses of brittle quartzite and more plastic carbonate rocks in the same regional stress field. The brittle, quartzitic rocks are everywhere in asymmetric and overturned folds cut by low-angle imbricate thrusts. The more plastic carbonate rocks are similarly folded and at least locally similarly faulted; but these structures, the primary response to the stress field, are complicated and partly masked by secondary features formed by internal gravitational sliding and cascading flow as these rocks piled up on successive imbricate thrusts. The apparent layered structure therefore reflects (1) the original sedimentary layering of quartzitic rocks in the Precambrian and lower Paleozoic section and carbonate rocks in the upper Paleozoic section, and (2) the different response of these different rocks to regional stress during thrusting.

SOME REGIONAL RELATIONS, IMPLICATIONS, AND PROBLEMS

Recognition of the great extent and of the structural and stratigraphic significance of the Medicine Lodge thrust system has lagged far behind studies of other tectonic elements of the North America Cordilleran fold and thrust belt. Perhaps one reason for this lag is that, even now, much of the region underlain by this large fault is either unmapped or inadequately mapped, and the pervasive consequences of Medicine Lodge thrusting have not been recognized. Most geologic problems in this region cannot be resolved without a clear understanding of the Medicine Lodge thrust system, and many of the regional geologic problems previously thought to be resolved now need reconsideration.

THE NORTHWARD EXTENSION OF THE MEDICINE LODGE THRUST SYSTEM

The Cordilleran fold and thrust belt has generally been assumed to pass through southwestern Montana, somehow linking the southeast Idaho segment with the "disturbed belt" farther north in Montana. The actual link has remained obscure, in the absence of detailed geologic mapping. What is now known about the Medicine Lodge thrust system indicates that it does not tie directly to the Montana disturbed belt farther north, but instead extends to the northwest along the west rim of the Big Hole Basin of western Montana (figs. 1, 5). The divergent traces of the thrust systems suggest that southwestern Montana is a region where different segments of the fold and thrust belt come together and overlap, and where the northern disturbed belt segment disappears.

The continuation of the Medicine Lodge thrust system north of the Big Hole Basin is not known. It may extend northward into the zone of thrust faults near Phillipsburg, Mont. (35 km northwest of Anaconda), but the rocks of the intervening region north of the Big Hole Basin are not mapped; the thrust faults near Phillipsburg have recently been described as part of the eastern boundary of the Sapphire tectonic block (Hyndman and others, 1975, p. 401–402). If the fault continues northward beyond the Big Hole Basin, it crosses the Belt island that separated the Belt basin reentrant from the geosyncline to the south (Harrison and others, 1974, p. 3), approaches the Idaho batholith, and enters a different structural province. The Medicine Lodge thrust may disappear between the Big Hole Basin and the Phillipsburg area, to be replaced by another structural system more compatible with the changed geologic framework. Scholten (1973, p. 487) has suggested that "different models are probably necessary for different segments (of the Cordilleran fold and thrust belt) in view of major differences in geosynclinal evolution, rock types, plutonism, and structural style between the segments," a view that helps explain the apparent overlapping of divergent thrust systems in southwest and western Montana. (See also Harrison and others, 1974, p. 7–9.)

THRUST SLICES OF LOWER PLATE ROCKS IN THE UPPER PLATE

The presence of rocks that do not fit the local stratigraphic framework in the Hawley Creek and Railroad Canyon area east of Leadore, Idaho (Ruppel, 1968; Luchitta, 1966), has confused both local and regional stratigraphic studies. These anomalous rocks include parts of the Madison Group, Big Snowy Formation, Quadrant Quartzite, Phosphoria Formation and equivalent units, and Dinwoody Formation. All of them are very different from equivalent rocks in the allochthonous block even though they are part of that block, and are most like autochthonous rocks farther east. Because these rocks are in thrust plates, their location is best explained if they are considered as parts of the lower plate section that have been incorporated in the upper plate as thrust slices. Similar thrust slices almost certainly occur elsewhere, although no others have yet been mapped. The somewhat anomalous outcrops of Permian and Triassic rocks in the upper plate at the south end of the Beaverhead Mountains may be such thrust slices, although they might also be explained as resulting from very rapid facies changes.

THE BEAVERHEAD PLUTON AND ITS RELATION TO THRUST FAULTING

Ramspott (1962) and Scholten and Ramspott (1968) described the granitic Beaverhead pluton in the southern part of the Beaverhead Mountains, but did not discuss its relation to the Medicine Lodge thrust. The pluton is dated on the basis of a single K-Ar isotope age determination for biotite as being 441 (±15) m.y. old

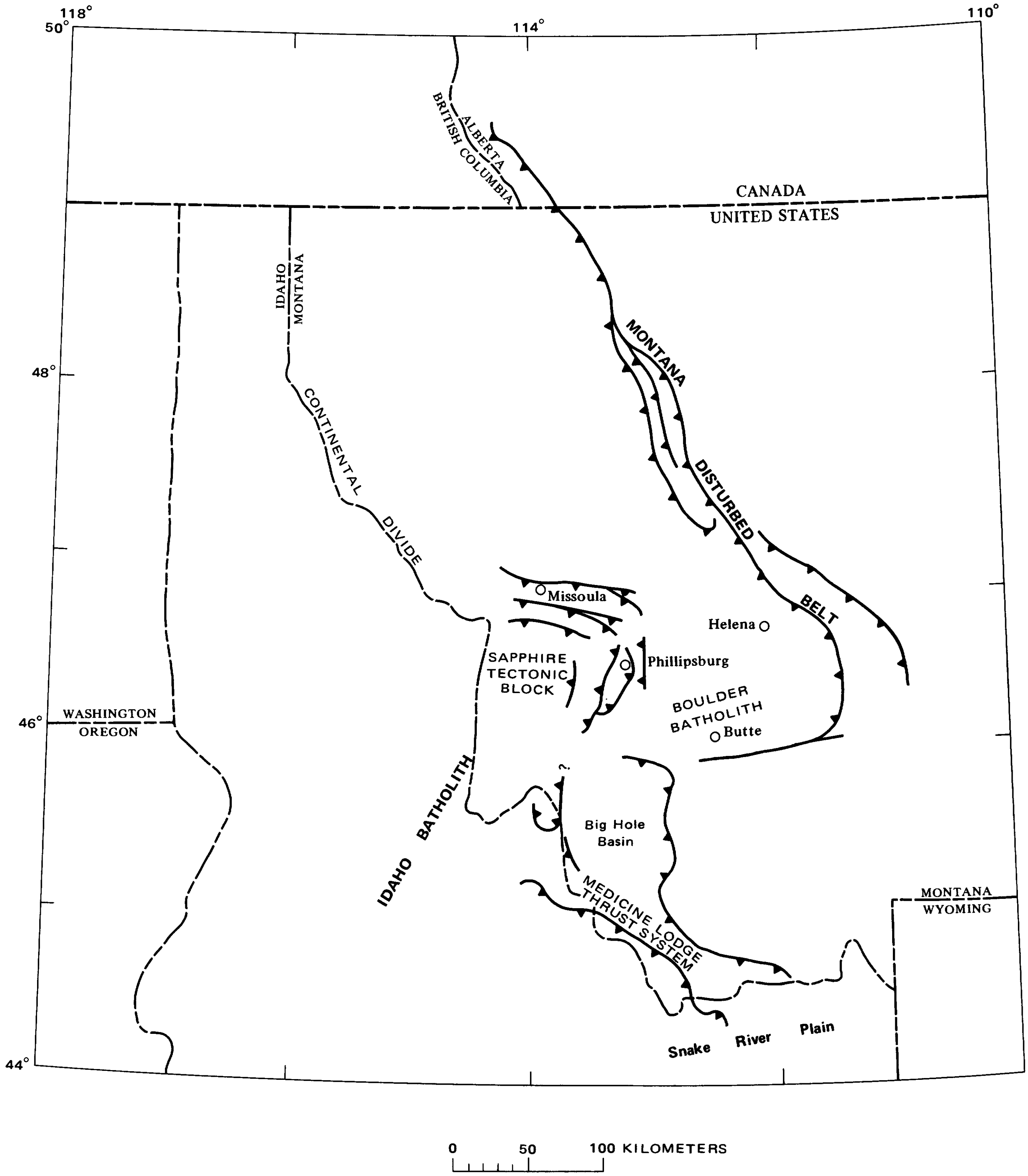


FIGURE 5. — Schematic diagram of the Medicine Lodge thrust system and its relation to the Montana disturbed belt and the Sapphire tectonic block. Solid lines, thrust faults; teeth on overthrust plate; queried where unknown.

(about at the Ordovician-Silurian boundary). This K-Ar determination is remarkably close to two Rb-Sr determinations (potassium feldspar, 435 ± 60 m.y. and whole rock, 430 ± 40 m.y. — recomputed with $\lambda = 1.39 \times 10^{-11}$ yr^{-1}) for somewhat similar, but fault-bounded and strongly sheared granitic rocks farther north in the Beaverhead Mountains (Ruppel, 1968; Luchitta, 1966). These sheared granitic rocks north of the Beaverhead pluton closely resemble the Precambrian X Dillon Granite Gneiss, and I believe that they are thrust slices of Dillon Granite Gneiss in the allochthonous block. This interpretation is also conceivable for the Beaverhead pluton, particularly because aeromagnetic data (U.S. Geological Survey, 1971) in the vicinity of the pluton do not show any significant anomalous pattern, and so suggest that the pluton may be rootless and more probably part of a thrust slice than an intrusive mass. If these granitic rocks, including the Beaverhead pluton, are indeed thrust slices with isotope ages mixed as a result of tectonism, the similarity of the mixed ages is a problem. However, an equally formidable problem seems to exist in explaining how the Beaverhead pluton, if it is truly a lower Paleozoic intrusive body, came to its present position in the allochthonous block of the Medicine Lodge thrust, for it would then have to have been sheared off by the thrust and tectonically transported far eastward. The pluton is surrounded by sedimentary rocks that have been complexly deformed as a result of thrusting, but no similar deformation is reported in the granitic rocks. Perhaps the widespread alteration of the granite and the poorly exposed contacts (Scholten and Ramspott, 1968, p. 18–21) are evidence of more extensive deformation than has been reported. In the absence of more definitive information, several interrelated problems remain unresolved: (1) the relation of the Beaverhead pluton to the Medicine Lodge thrust; (2) an explanation for the presence of that pluton in the allochthonous block; (3) the ages of granitic rocks in the Beaverhead Mountains, whether they are Precambrian X, Ordovician-Silurian, or even Tertiary and so neither deformed nor cut by the thrust; and (4) the structural and (or) intrusive relations of the Beaverhead pluton.

THE RELATION OF VOLCANIC ROCKS AND THE THRUST TRACE

Much of the trace of the Medicine Lodge thrust is paralleled by areas of Challis Volcanics of Tertiary age, and the approximately correlative Medicine Lodge Volcanics (Scholten and others, 1955, p. 375–376) (fig. 2). The allochthonous block had been deeply eroded and the fault zone exposed before eruption of the Challis Volcanics, and the westernmost known exposure of the fault along Twelvemile Creek in the Lemhi Range borders on the eastern edge of the main Challis volcanic field. Locally the fault trace is concealed by these young volcanic rocks (for example south and west of Mill Mountain in the central Lemhi Range).

The close spatial relation of volcanic rocks and the fault trace suggests that the fault could have served as a conduit for local eruptive centers of Challis and Medicine Lodge Volcanics, satellitic to the main Challis volcanic field farther west. In areas where volcanism is not closely associated with the thrust trace, the volcanics might have broken through to the surface from the fault sole at relatively shallow depth, or the volcanics might have been erupted from the fault zone and concealed it. In both the Hayden Creek and Sawmill Canyon windows in the central Lemhi Range (fig. 2) the fault must be at shallow depth, partly concealed only by the blanket of Challis Volcanics.

THE RELATION OF INTRUSIVE IGNEOUS ROCKS AND ASSOCIATED MINERAL DEPOSITS TO THE MEDICINE LODGE THRUST SYSTEM

The distribution of exposed intrusive igneous rocks and known deposits of metallic minerals in and near the central part of the Lemhi Range indicates that their emplacement was to a large extent controlled and limited by structural features associated with the Medicine Lodge thrust system. The close relation of stocks, mineral deposits, and the thrust system in the Lemhi Range suggests that the mineral resource potential of the entire thrust belt region — from the Snake River Plain northward beyond the Big Hole Basin — should be reevaluated, and that a primary factor in this reevaluation should be the structural framework of the Medicine Lodge thrust system.

The relation of quartz monzonite-granodiorite stocks and their associated mineral deposits to the Medicine Lodge thrust system is quite clear in the mining districts of the central part of the Lemhi Range and the adjacent part of the Beaverhead Mountains; almost all of the known occurrences of metallic minerals in this area are in the lower part of the allochthonous block, in or near quartz monzonite-granodiorite stocks that were emplaced low in the block after thrusting. These deposits have been mined or prospected in the Little Eightmile district (antimony, lead, silver, copper), in the Beaverhead Mountains (figs. 1, 2), and in the Gilmore (lead, silver, gold), Spring Mountain (lead, silver, copper, iron), Blue Wing (or Patterson) (tungsten, silver, copper), and Blue Jay (copper, lead) districts in the Lemhi Range. The relation of metallic mineral deposits, granodiorite-quartz monzonite stocks, and the Medicine Lodge thrust system in these mining districts can be briefly summarized. The Blue Jay area is a short distance south and west of the fault exposures on Mill

Mountain. Copper and molybdenum minerals are disseminated in the Blue Jay stock, and lead and silver occur in small vein deposits in quartzite adjacent to the stock. The Gilmore and Spring Mountain districts are east of the Sawmill Canyon window into the fault, and lead and silver sulfide and secondary minerals occur in veins adjacent to the large, irregular Gilmore stock. The Ima mine, the principal mine in the Blue Wing district at Patterson, developed a network of tungsten-bearing veins and disseminated deposits in a complex thrust zone that formed the intrusive roof of the concealed Ima stock, which contains disseminated molybdenite. The prospects in the northern part of the Little Eightmile district explore veins near the Little Eightmile stock, a short distance south of the Peterson Creek segment of the Medicine Lodge fault.

Other granodiorite-quartz monzonite stocks, without known associated metallic mineral deposits or disseminated sulfide minerals, are exposed only in the central part of the Lemhi Range. These stocks, like those with associated mineral deposits, are roofed in or near imbricate thrust faults where geologic and geophysical studies indicate that the Medicine Lodge thrust fault is at relatively shallow depth, and thus it seems clear that no stocks penetrated far into the allochthonous block. Therefore, stocks and associated mineral deposits, if any, are likely to be found only in the lower part of the allochthonous block, and have been exposed only where faulting and erosion have exposed the lower part of that block.

Where the higher part of the allochthonous block is still preserved in the southern Lemhi Range, southern Beaverhead Mountains, and Lost River Range, still hidden stocks and associated mineral deposits, if they are present at all, may be suggested by deposits of secondary metallic minerals or by sulfide minerals in small veins. Small deposits of secondary copper carbonates are in imbricate thrusts south of the Little Eightmile stock in the Beaverhead Mountains north of Leadore (Ruppel, 1968; Staatz, 1973), and veins containing small amounts of silver-bearing galena are present in the southern part of the Little Eightmile district. Mineral deposits farther south in the Beaverhead Mountains — the large lead carbonate deposit at the Viola mine in the Nicholia district and small veins containing galena in the Birch Creek district (Shenon, 1928), farther south — are not associated with exposed quartz monzonite–granodiorite stocks. The lead and silver sulfide bearing veins at the Wilbert mine, in the Dome district near the south end of the Lemhi Range, similarly are not near any exposed stock. Most of these deposits are in faults and they could reflect leakage from buried granodiorite stocks deeper in the allochthonous block, or deposition of secondary minerals above a more deeply buried primary sulfide deposit.

The extent of metallic mineral deposits in the brecciated and mylonitized rocks immediately above the fault sole, or in rocks beneath the fault is largely untested and unknown in areas where the allochthonous block is preserved, for no mine workings or drill holes in the districts mentioned above have penetrated deeply enough to go through the Medicine Lodge fault zone or into rocks beneath the fault. North of the fault trace, however, in the lower block, there are many productive mines; for example, copper sulfides have been mined from vein deposits in the Yellowjacket Formation at the Pope-Shenon mine near Salmon, Idaho, and other mines and prospects have yielded cobalt, copper, gold, thorium, and iron.

There appear to be fairly consistent differences in mineral assemblages above and below the fault system at least in east-central Idaho. The mines and prospects in the upper plate yielded lead, zinc, silver, antimony, and tungsten; only a few mines, on the Andy and Martha claims at Gilmore, and at Gibbonsville, yielded a significant amount of gold. Small deposits of copper are widely scattered in the lower part of the upper plate, but few have yielded any quantity of copper ore. In contrast, cobalt, copper, gold, and thorium are the principal metals from mines in the lower plate. The reasons for the different mineral assemblages are not yet known — whether they reflect different periods of mineralization, different levels of mineralization above and beneath the Medicine Lodge fault system, different sources for the metals, or telescoping of unrelated mineral provinces above and beneath the fault system.

The Medicine Lodge thrust system has localized both intrusive activity and mineralization, and this explains the distribution of scattered stocks and mineral deposits in east-central and central Idaho. It also suggests that more widespread mineral deposits, and enhanced prospecting possibilities, may exist in the region from the Snake River Plain northward beyond the Big Hole Basin, and perhaps even farther north into the thrust faulted rocks of the Sapphire tectonic block, east of the Bitteroot Valley, Mont. (C. A. Wallace, oral commun., 1975). Some specific possibilities for finding new mineral deposits include:

(1) Mineralized localities in the lower part of the upper plate near quartz monzonite–granodiorite stocks that are concealed but whose presence is suggested by geophysical or geochemical evidence. Metals likely to occur are copper and molybdenum as disseminated deposits in stocks, and lead, zinc, silver, and tungsten in veins near the stocks. Concealed metallic deposits might be found by geochemical methods or suggested by small sulfide veins and secondary deposits in im-

bricate thrusts or other faults.

(2) The crushed, brecciated, and mylonitized rocks of the Medicine Lodge thrust zone are untested and unknown, but could contain finely disseminated metallic deposits, or other deposits where penetrated by stocks. A specific question: Might the gold-bearing placer deposits at Chinatown, east of the head of Horse Prairie Creek in Montana, be derived from the Medicine Lodge thrust system, which is exposed a short distance farther south? The source of the gold in this placer deposit is not known, although a few small gold-bearing veins do occur at the head of Jeff Davis Creek, which contains the placer gravels.

(3) Mineral deposits in the lower plate, beneath the Medicine Lodge thrust system, perhaps especially near known mining districts and near concealed stocks found by geophysical means. Also, where the upper plate block has been removed by erosion, the Yellowjacket Formation (of the lower plate) contains deposits of cobalt, copper, gold, and thorium. These deposits suggest that similar deposits may underlie the upper plate where it is still preserved.

(4) Mineral deposits at greater depth around the known but seemingly barren stocks in the lower part of the upper plate in the central part of the Lemhi Range, perhaps particularly around those partly concealed by the younger Challis Volcanics, like the stock in Sawmill Canyon at the head of the Little Lost River.

PETROLEUM AND NATURAL GAS RESOURCES BENEATH THE MEDICINE LODGE THRUST SYSTEM

The search for petroleum and natural gas resources in southwest Montana has not been particularly fruitful (Klepper, 1950, p. 80–82; Scholten, 1967), despite the occurrence of feasible source rocks, suitable reservoir rocks of Paleozoic and Mesozoic age, and favorable structures. Recognition that these rocks disappear beneath the leading edge of the Medicine Lodge thrust system in the southern part of the Beaverhead Mountains suggests, however, that there is some potential for occurrences of petroleum and natural gas beneath the thrust system in eastern Idaho north of the Snake River Plain. The rocks overridden by the thrust system in this region range in age from Devonian through Cretaceous, and include the petroliferous rocks of the Jefferson Formation and the organic carbon-rich rocks of the Phosphoria Formation (Maughan, 1975). The Devonian rocks were the first to overlap the Lemhi arch, and suggest the possibility of stratigraphic traps on the flanks of the arch. The later, marine Paleozoic rocks apparently extended across the arch, from the shelf in Montana across a broad region of shallow seas in eastern Idaho to the miogeocline in central and western Idaho. The shelf section is well known in southwest Montana, and the miogeocline section is probably partly represented by the allochthonous rocks of the southern Beaverhead Mountains and the Lemhi and Lost River Ranges.

The Paleozoic rocks beneath the thrust presumably include those interfingering facies that reflect the changes from shelf sedimentation to miogeoclinal sedimentation across the Lemhi arch. Marine and nonmarine rocks of Triassic, Jurassic, and Cretaceous age, overridden by the thrust, probably were mostly deposited as wedges of sediment against the eastern flank of an again emergent Lemhi arch, although some of the lower Mesozoic marine rocks could have extended across it. The northern boundary of Paleozoic and Mesozoic rocks beneath the thrust is unknown. The boundary must be south of Sawmill Canyon in the Lemhi Range (fig. 1) because only rocks of the Yellowjacket Formation are known beneath the thrust from there northward. Also, the nature of the boundary is unknown; it could be either a tectonic boundary, where the Paleozoic and younger rocks have been sheared off by the thrust, or a depositional boundary against the Lemhi arch, modified by later faulting.

The overthrust block of the Medicine Lodge thrust system thus may conceal both source and reservoir rocks in a stratigraphic, paleogeographic, and structural framework favorable for the accumulation of petroleum and natural gas. The stratigraphic and structural setting appears to be comparable in many respects to that of the Idaho-Wyoming thrust belt south of the Snake River Plain (Armstrong and Oriel, 1965; Monley, 1971; Royse and others, 1975), and the potential for accumulations of petroleum and natural gas also seems somewhat similar in the two regions.

SUMMARY

The Medicine Lodge thrust fault system, exposed in east-central Idaho and southwest Montana, is a major segment of the North America Cordilleran fold and thrust belt. The fault extends northward from the north flank of the Snake River Plain a distance of more than 200 km to the west flank of the Big Hole Basin, Montana. Its extension farther north, if any, is unknown. The fault thus does not merge with the Montana disturbed belt. Movement on the Medicine Lodge thrust system began in Early Cretaceous (Albian) time and had ended by early Eocene time; most of the movement probably occurred in Late Cretaceous and early Paleocene time.

As a result of movement on the Medicine Lodge fault, Precambrian and Paleozoic sedimentary rocks deposited in the Cordilleran miogeocline in western

Idaho have been telescoped and transported perhaps as much as 160 km eastward, to rest on rocks of similar age deposited in a marine embayment or seaway in southwest Montana. Sedimentation took place on opposite sides of the north-northwest-trending Lemhi arch, which from Precambrian Y to Late Devonian time was a landmass separating the miogeocline on the west from the marine embayment or seaway on the east. In Late Devonian time, the arch was overlapped by marine sediments, but as a still relatively high area it continued to influence sedimentation patterns through the rest of the Paleozoic. In the early Mesozoic, the Lemhi arch again was apparently emergent, supplying sediments rather than receiving them. In late Mesozoic and earliest Cenozoic time, the arch was overridden by the Medicine Lodge thrust block. Fragments of the arch, caught in the upper plate of the Medicine Lodge thrust, have been interpreted in the past as small islands, but instead they are displaced parts of a once major landmass. The arch probably was a southern extension of Belt island in the Precambrian and early Paleozoic, and the later history of the arch suggests that Belt island also could well have continued as an intermittent positive area through much of Paleozoic and Mesozoic time.

Recognition that the Medicine Lodge thrust fault underlies much of east-central and central Idaho requires that many geological problems be reconsidered besides those relating to the stratigraphy of Precambrian and Paleozoic rocks. One of these problems, unresolved, concerns the granitic Beaverhead pluton, which has been interpreted as an Ordovician and Silurian intrusive body on the basis of isotope age determinations. If this age is correct, the pluton must have been sheared off by the Medicine Lodge thrust, and displaced eastward with the enclosing sedimentary rocks. If the isotope ages have been mixed as a result of tectonism, the pluton could instead be a thrust slice of Precambrian X Dillon Granite Gneiss, an interpretation more in keeping with relations of similar rocks farther north in the Beaverhead Mountains. Or, if the granite of the pluton is as little deformed as published descriptions suggest, it could be of Tertiary age, intruded into the allochthonous block.

The Medicine Lodge thrust was deeply eroded and widely exposed before eruption of the Challis Volcanics in Tertiary time, and the present thrust trace is closely paralleled and partly concealed by volcanic rocks from eruptive centers satellitic to the main Challis volcanic field. The close association of fault trace and volcanic rocks suggests that the fault served as a conduit for local eruptive centers.

The relations of post-thrusting granodiorite–quartz monzonite stocks and related mineral deposits to the Medicine Lodge fault, mainly in the central part of the Lemhi Range, suggest that the stocks and related mineral deposits are largely confined to the lower part of the allochthonous block. Undiscovered mineral deposits possibly could be found by (1) examining areas where the Medicine Lodge fault and the lower part of the allochthonous block are near stocks but concealed either by the higher part of the allochthonous block or by later volcanic rocks; (2) searching for hidden stocks and associated mineral deposits by geophysical or geochemical techniques; and (3) using small sulfide veins and deposits of secondary metallic minerals, apparently not related to intrusive rocks, as guides to concealed stocks and mineral deposits that might be found at greater depth. The brecciated, crushed, and mylonitized rocks of the thrust zone itself have not been prospected, and their mineral potential is unknown. The rocks beneath the thrust have yielded substantial mineral deposits where they are exposed, and might be expected to contain similar deposits yet concealed.

Finally, the Paleozoic and Mesozoic sedimentary rocks beneath the Medicine Lodge thrust system north of the Snake River Plain include both source and reservoir rocks favorable for accumulation of petroleum and natural gas. The stratigraphic, paleogeographic, and structural setting suggests that the energy resource potential of this region should be reevaluated.

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