Reconnaissance Geology Geophysics, and Geochemistry of the Southeastern Part of the Lewis and Clark Range, Montana

GEOLOGICAL SURVEY BULLETIN 1252-E

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With spectrographic data

By G. C. CURTIN *and* A. P. MARRANZINO

and a section on ISOTOPIC COMPOSITION OF LEAD

By R. E. ZARTMAN

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A study identifying a weak lead-zinc mineralized belt, 30 miles long, that is stratigraphically and structurally controlled

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RECONNAISSANCE GEOLOGY, GEOPHYSICS, AND GEOCHEMISTRY OF THE SOUTHEASTERN PART OF THE LEWIS AND CLARK RANGE, MONTANA

By MELVILLE R. MUDGE, RALPH L. ERICKSON, and DEAN KLEINKOPF

ABSTRACT

Weak lead-zinc mineralization was general in a narrow northwest-trending belt about 30 miles long in the southeastern part of the Lewis and Clark Range, Mont. Reconnaissance geological and geochemical studies identify the belt and indicate the stratigraphic and structural control of the mineralization; geophysical data permit inferences of the location of buried plutons that may have been the source of the metals.

The mineralization appears to be spatially related to the South Fork thrust zone. This zone, containing Precambrian and Paleozoic rocks, is part of the easternmost major thrust block in this range. In this zone, anomalous quantities of lead and zinc occur in the Spokane Formation and Helena Dolomite of Precambrian age, the Flathead Sandstone of Cambrian age, and the Jefferson and Three Forks Formations of Devonian age. Most of the mineralization is in the nearest permeable and porous carbonate or calcareous sandstone bed to the westernmost thrust fault of the South Fork thrust zone.

Magnetic and gravity data were used in defining the area for geological and geochemical studies of the many major magnetic anomalies that indicate buried plutons. One large positive anomaly, in particular, that lies just west of the center of the belt may have a genetic relationship to the lead and zinc mineralization. This mass is interpreted to be a quartz monzonite pluton lying just below the westward-dipping South Fork thrust at a calculated depth of about 10,500 feet beneath the surface.

INTRODUCTION

Detailed geological studies in the Sun River canyon area and regional gravity studies of the northern disturbed belt (Sawtooth and Lewis and Clark Ranges) indicated that buried plutons and associated mineralization might be present in the southeastern part of the Lewis and Clark Range from the West Fork of the Sun River south to the Dearborn River (fig. 1). Hence, in 1964 reconnaissance geological, geochemical, and geophysical studies were begun in this area to determine if geochemical and magnetic anomalies were present and, if so, whether they were spatially related to the known gravity

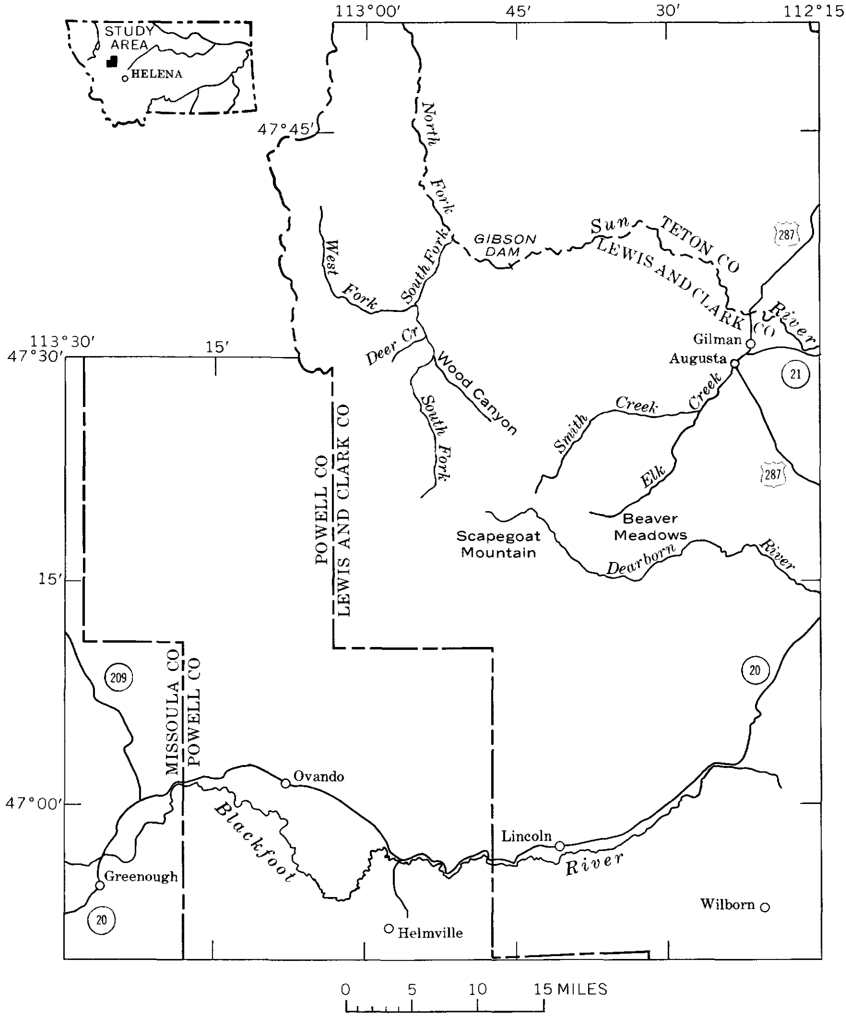

FIGURE 1.—Index map of study area in Montana.

anomalies. Knowledge of such relationships would help to outline areas favorable for the occurrence of concealed metal deposits. The area north of the Dearborn River has no history of metal production, and only a few small lead prospects and copper prospects are known.

Whether or not the lead-zinc mineralization discussed in this report will lead to the discovery of deposits of economic value, the purpose of the report will be served if it points out the potential value of an integrated approach to exploration for ore deposits.

The authors thank the many persons who have contributed in various ways to this project. George F. Roskie, Forest Supervisor of

Lewis and Clark Forest, and Henry Greitl, District Ranger, were most cooperative in assisting with helicopter access to the area. Most of the regional gravity data were made available through the courtesy of the 1381st Geodetic Survey Squadron, Air Photographic and Charting Service, U.S. Air Force.

Many U.S. Geological Survey colleagues contributed much time and effort to the project. Most of the samples were prepared and analyzed in the field, in a truck-mounted spectrographic laboratory, by G. C. Curtin and A. P. Marranzino. In the Survey's Denver laboratories, mercury analyses were done by H. W. Knight, W. W. Janes, and J. H. McCarthy, Jr.; citrate-soluble heavy-metal analyses by G. H. VanSickle, J. B. McHugh, and W. L. Lehmbeck; and chemical analyses for copper, lead, and zinc by G. H. Van Sickle and J. B. McHugh. The computation and compilation of the Bouguer gravity map from the Air Force data were made by C. P. Eaton and D. L. Peterson with additional measurements obtained in the field by D. L. Peterson.

GEOLOGIC SETTING

The geology of parts of the Lewis and Clark Range has been described by many geologists. Walcott (1910) made stratigraphic studies of the Precambrian and Cambrian rocks, and Clapp (1932) published the first geologic map of the area. The Coopers Lake quadrangle, which includes the area discussed in this report, was mapped by C. F. Deiss in 1939, but that work was never published; he did write many reports on stratigraphy, structure, and paleontology (Deiss, 1933, 1939, 1943a, b). More recently, the stratigraphy of the Dearborn and Wood Canyon areas has been studied by Viele (1960), McGill and Sommers (1967), and Knapp (1963). In compiling the reconnaissance geologic map (pl. 1), use was made of these studies and of supplemental mapping by Mudge on aerial photographs and topography using four-wheel-drive vehicle and helicopter traverses.

The southeastern part of the Lewis and Clark Range consists mainly of folded and thrust-faulted Precambrian and Paleozoic sedimentary rocks; it also contains a few Precambrian diorite sills. The structure of interest in this report is the easternmost major thrust plate and fault zone of this range (pl. 1). This plate of westward-dipping Precambrian and Paleozoic rocks was translated by thrust faulting on a lower plate of westward-dipping Paleozoic and Mesozoic rocks. The fold in the upper plate was very likely a result of stress that formed the subsequent thrust to the west (pl. 1).

The zone separating the two plates is called the South Fork thrust zone. Along the west side of the South Fork of the Sun River and in Wood Canyon, this zone consists of many thrust faults that repeat the Empire and Spokane Formations and the Helena Dolomite (Mudge, 1966b; McGill and Sommers, 1967). In the upper part of Smith Creek the zone consists of many westward-dipping thrust faults of small displacement that repeat parts of the Empire and Spokane Formations and a diorite sill that has intruded the Spokane. In the Elk Creek-Dearborn River area the thrust zone attains its maximum width of 3 miles, and consists of complexly folded and faulted Precambrian, Cambrian, and Devonian rocks.

The South Fork thrust zone is very complex, and the origin of parts of it are somewhat in doubt. The individual faults of the zone are rarely exposed; but where exposed in some streambanks, the faults dip 45°–65° W. (pl. 1). Between Elk Creek and the Dearborn River the fault slice included in the zone is very likely a part of an earlier thrust sequence that was deformed and truncated by the South Fork thrust. It also may be the remnant of a fold from which the South Fork thrust was derived. Regardless of its origin, these thrusts are included in the South Fork thrust zone in this report, and all the thrusts of the zone probably join at depth along a sole thrust, as shown in the cross sections of plate 1.

The small northeastward-trending normal faults in the Smith Creek area are younger than the thrusting and the mineralization. The normal faults are alined with a northeastward-trending subsurface structure known as the Scapegoat-Bannatyne trend in the Sweetgrass Arch to the northeast (Dobbin and Erdmann, 1955). This trend, first described as the Genou trend, is a major tectonic feature on the Sweetgrass Arch that involved the basement and was active mainly during Precambrian and early Paleozoic time (Alpha, 1955). It very likely was rejuvenated at various times during the subsequent history of the arch. If the Scapegoat-Bannatyne structure continues beneath the Smith Creek area as a fault in the basement, movement on it could have formed the young normal faults.

The stratigraphy of the area is summarized in table 1, and those rocks that contain anomalously high amounts of metals are described in more detail in the following paragraphs.

PRECAMBRIAN ROCKS

The Precambrian rocks (Belt Series) consist of thick clastic units, a relatively thin carbonate unit, and one or more diorite sills. These rocks are exposed locally in Wood Canyon, in the upper reaches of Ford, Smith, and Elk Creeks, and along the Dearborn River (pl. 1). In most places they form the lower slopes and small ridges beneath the prominent cliff-forming Cambrian rocks. Only the Empire and Spokane Formations undifferentiated, the Helena Dolomite, and a sill of late Precambrian age are discussed.

TABLE 1.—*Geologic formations in the southeastern part of the Lewis and Clark Range, Mont.*

Era	System	Group	Formation	Member	Thickness (feet)	Description
MESOZOIC	CRETACEOUS		Kootenai Formation			Mudstone, maroon and gray-green, and sandy mudstone; interbedded with greenish-gray sandstone and nodules of brown sandy limestone.
	JURASSIC		Morrison Formation		170–250	Mudstone, bright-orange-red to red-brown; some poorly sorted conglomeratic crossbedded sandstone.
		Ellis	Swift Formation	Upper member	140–300	Sandstone, gray-brown, thinly bedded, fine-grained; some crossbedding, ripple marks, and wood fragments.
				Lower member		Mudstone, dark-gray, sandy; abundant thin beds of sandstone; thin, poorly indurated glauconitic sandstone at base.
						UNCONFORMITY
			Rierdon Formation		150–350	Mudstone, dark-gray, calcareous; with many thin beds of argillaceous limestone; weathers yellowish gray.
						UNCONFORMITY
			Sawtooth Formation	Upper member	40–200	Possibly absent. To the north a grayish-brown to yellowish-gray calcareous siltstone.
				Middle member		Shale, gray, calcareous, thinly bedded; locally, contains conglomeratic lenses.
				Lower member		Sandstone, yellowish-gray very fine grained; weathers to moderate-brown; well-sorted well-rounded quartz grains.
						UNCONFORMITY

TABLE 1.—*Geologic formations in the southeastern part of the Lewis and Clark Range, Mont.*—Continued

Era	System	Group	Formation	Member	Thickness (feet)	Description
	MISSISSIPPIAN	Madison	Castle Reef Dolomite	Sun River Member	300–450	Dolomite, finely crystalline to medium-crystalline, very light gray; massive beds; some gray chert nodules.
				Lower member	250–475	Dolomite, calcitic dolomite, and magnesium limestone, finely to coarsely crystalline; medium- to light-gray; some dark-gray chert nodules and lenses.
			Allan Mountain Limestone	Upper member	200–350	Limestone with some dolomitic limestone, medium- to dark-gray, thin- to thick-bedded; local dark-gray chert lenses and nodules.
				Middle member	150–200	Limestone, dark-gray, in beds 1–2 ft thick; dark-gray chert lenses and nodules abundant and spaced at intervals of 6–12 in.
				Lower member	160–225	Limestone with some shaly limestone, dark-gray; very thin bedded with thicker beds in lower part.
						UNCONFORMITY
	DEVONIAN		Three Forks Formation		300±	Shale and siltstone in upper part; thick massive intraformational breccia in middle part; gray to light-gray-brown magnesium limestone in lower part.
			Jefferson Formation	Birdbear Member	200	Dolomite, yellowish-gray, saccharoidal; in pinch-and-swell beds that range in thickness from 2 in. to 1 ft.
				Lower member	500	Thin beds of grayish-brown fetid dolomite, calcitic dolomite, and limestone; thin intraformational breccias in lower part.

PALEOZOIC			Maywood Formation		150–300	Gray-green dolomitic mudstone in lower part; dark-gray thin-bedded dolomite and calcitic dolomite in upper part.
						UNCONFORMITY
	CAMBRIAN		Devils Glen Dolomite		350–565	Dolomite, very light gray, finely to coarsely crystalline, thick-bedded.
			Switchback Shale		70–250	Shale, dull-green, fissile, micaceous; some olive-drab-gray sandstone in lower part. Thin sandy and shaly limestone beds in upper part.
			Steamboat Limestone		250–300	Limestone, thin- to thick-bedded, gray-brown; distinctively mottled yellowish gray to gray orange; interbedded with greenish-gray mudstone.
			Pagoda Limestone		295–395	Limestone, thin- to thick-bedded tan and gray; numerous light-gray clay flakes; some mudstone in lower part.
			Dearborn Limestone		250–355	Limestone, thin- to thick-bedded, gray to tan-gray; some arenaceous and micaceous beds; green mudstone in lower part.
			Damnation Limestone		150–170	Limestone, thin- to thick-bedded, tan-gray; green mudstone in lower part.
			Gordon Shale		200–275	Shale, olive-green with some chocolate-maroon; fissile, micaceous; much thin-bedded sandstone in lower part.
			Flathead Sandstone		70–105	Sandstone and quartzite, fine- to coarse-grained, light-gray to tan-gray; scattered quartz pebbles; crossbedded; abundant iron-stained spots.
						UNCONFORMITY

TABLE 1.—*Geologic formations in the southeastern part of the Lewis and Clark Range, Mont.*—Continued

Era	System	Group	Formation	Member	Thickness (feet)	Description
PALEOZOI	PRECAMBRIAN		Garnet Range Formation		200±	Present only west and northwest of area. Olive-gray to olive-brown siltstone; some thin interbedded sandstone.
			McNamara Formation		500±	Present only west and northwest of area. Greenish-gray and gray sandy mudstone; many thin beds of sandstone.
			Bonner Quartzite		250–400	Sandstone, moderately well sorted, moderate-red and gray, mottled grayish-orange; some crossbedding.
			Shields Formation [1]	Red siltstone member	500–925	Siltstone, pale-reddish-brown, nonresistant; some beds of sandstone and greenish-gray siltstone.
				Red sandstone member	300–825	Sandstone, dark-reddish-brown, thinly bedded, resistant; interbedded with siltstone.
			Shepard Formation		300–800	Siltstone, dolomitic, gray to yellowish-gray; much interbedded sandstone, some glauconitic. Some thin dolomite beds in lower part.
			Snowslip Formation [1]		250–700	Siltstone, green, maroon, and gray; some thin beds of sandstone.
			Helena Dolomite		575–650	Sandstone, thin, poorly sorted, calcareous; overlain by gray with some red and green siltite in lower part. In middle and upper parts, thin beds of dolomite, some with stromatolites.

		Empire and Spokane Formations		1, 200±	Argillite and siltite, pale-red, green, and gray; some thin beds of dolomite and sandstone; upper part gray to gray-green siltite with sandstone beds.
		Greyson Formation		1, 000+	Siltite and argillite, greenish-gray, thinly bedded, finely laminated.

[1] Of Childers (1963).

NOTE.—Formation thicknesses and partial description were abstracted from the following: Precambrian, Mudge (1966b), McGill and Sommers (1967); Cambrian, Deiss (1939); Devonian, Sloss and Laird (1946), Viele (1960); Mississippian, Mudge (1966a, b); Jurassic, Merrill (1965).

The Empire and Spokane Formations, about 1,200 feet thick, are undifferentiated in this area because the Empire, 50–200 feet thick, is lithologically similar to the Spokane. The Empire consists mainly of gray to grayish-green siltite with some interbeds of fine-grained sandstone. The Spokane Formation consists of finely micaceous very thinly bedded pale-red, green, and gray argillite and siltite, interbedded dolomitic sandstone, and thin beds of dolomite (Mudge, 1966b). The sandstone is thinly bedded (as much as 1 ft thick) and fine to medium grained. Locally, there are a few thin beds of stromatolites and edgewise conglomerates.

The Helena Dolomite is the only predominantly carbonate unit in the sequence of Precambrian clastics in this area; it ranges in thickness from 575 to 650 feet. The Helena can be traced from the Deer Creek area (fig. 1; Mudge, 1966b) southeast along the west side of Wood Canyon (McGill and Sommers, 1967) to the upper reaches of Smith and Elk Creeks, and on to the Dearborn River where it is completely exposed (pl. 1). The Helena, as herein defined, consists of three units, which are, in ascending order: a thin sandstone unit, a thin siltite unit with interbeds of dolomite, and a thick dolomite sequence. The lower two units, which have a combined thickness of as much as 110 feet, represent a transition zone from the argillites of the underlying Empire Formation to the dolomites of the overlying Helena. In the Wood Creek area these two units are included in the Empire Formation by McGill and Sommers (1967, fig. 2a).

The lower sandstone unit of the Helena was examined at several localities from Deer Creek southeastward to the Dearborn River area (fig. 1; pl. 1). In the Deer Creek area this unit is about 3 feet thick, and consists of two or three thin (0.4–0.8 ft) light-gray beds of sandstone separated by equally thin beds of gray shale. The sandstone consists of fine to very fine poorly sorted clear quartz grains that are cemented by calcite and dolomite. The unit thickens southeastward, and near the junction of Fairview and Wood Creeks it attains the maximum known thickness (7.4 ft) and porosity. In the upper part of Smith Creek and in the saddle between Elk Creek and the Dearborn River, the unit is 3.5 feet thick; but locally between these two points, it has been omitted by thrust faulting. In Smith Creek this unit consists of thin-bedded poorly indurated and sorted fine- to medium-grained sandstone; some of the beds are 5–6 inches thick and are crossbedded. In the Dearborn River area it is a very fine grained well-sorted firmly cemented quartzite. In the headwaters of Wood Creek these sandstone beds were metamorphosed to a dense quartzite during the intrusion of the upper Precambrian diorite sill.

The siltite unit of the Helena, above the basal sandstone unit, in the Deer Creek area consists of about 100 feet of moderate-red and gray siltite with thin interbeds of dolomite. This siltite unit thins southward to the Wood Canyon and Dearborn River areas, where it is composed of a gray dolomitic siltstone, many beds of dolomite, and very fine grained sandstone.

The thick dolomite sequence, the upper unit of the Helena, is composed of many thin beds of dolomite and some thin interbeds of argillaceous dolomite. The lower beds are 0.2–5 feet thick; most are 0.4–0.8 foot thick. They grade upward into thicker beds of dolomite, calcitic dolomite, and dolomitic limestone that are very finely crystalline, hard, and dark gray, and that weather yellowish gray. The upper part of the Helena is characterized by abundant stromatolite colonies, as much as 8 feet thick, that in most places are overlain by thin beds of edgewise conglomerate and thin beds of oolite.

A diorite sill, 300–400 feet thick, intruded the Precambrian rocks throughout much of the area (pl. 1). In the Deer Creek area it occurs in the middle part of the Snowslip Formation of Childers, 1963 (Mudge, 1966b), but to the southeast along the west side of Wood Canyon it is discordant and extends down through the Helena Dolomite (Knapp, 1963, p. 1; McGill and Sommers, 1967). Still farther southeast—in Smith Creek, Elk Creek, and Dearborn River areas—the sill is in the Spokane Formation. This sill was dated as late Precambrian in age (750$\pm$25 million years) by potassium argon methods (John Obradovich, oral commun., June 1966).

The composition of the sill ranges from diorite to gabbro. Along Wood Canyon the sill consists of 45 percent finely to coarsely crystalline plagioclase, 25 percent hornblende, 25 percent clinopyroxene, and 5 percent quartz and feldspar (Knapp, 1963, p. 23–24). Magnetite is scattered throughout the rock and constitutes as much as 14.5 percent of a sample (Knapp, 1963, p. 45, table 2). Contact metamorphism of the adjacent rock ranges from a few feet to as much as 200 feet.

CAMBRIAN ROCKS

The Flathead Sandstone is the basal Middle Cambrian unit in the southeastern part of the Lewis and Clark Range (table 1). It rests unconformably on various Precambrian units from the younger Garnet Range Formation on the west to the older Greyson Formation on the east. This pronounced truncation is evident in a group of sections that extends through three thrust fault blocks from Scapegoat Mountain east to Beaver Meadows.

In the southeastern part of the Lewis and Clark Range, the Flathead ranges in thickness from about 80 to 115 feet (Deiss, 1939, p. 31–37). It consists of 2- to 8-inch-thick beds of yellowish-gray to gray poorly sorted poorly indurated quartz sand that locally grade into well-indurated quartzite; many beds have abundant low-angle crossbedding. In the Dearborn River area some of the beds are calcareous (Deiss, 1939, p. 34). In most places the grain size ranges from fine to very coarse; some scattered well-rounded quartz pebbles are as much as 4 inches across. Very thin beds of red and gray shale are locally interbedded with the sandstones. Characteristically, the weathered sandstone is freckled with brown iron oxide stains.

DEVONIAN ROCKS

The youngest rocks discussed are the Jefferson and Three Forks Formations of Devonian age (table 1). These formations crop out in the relatively undisturbed upper plate in the area of the headwaters of the Dearborn River and Straight Creek and in the complexly folded and faulted area extending from the head of Goss Creek southeast to the Dearborn River (pl. 1). Devonian rocks, including the Maywood Formation, are about 1,200 feet thick on Monitor Mountain (Sloss and Laird, 1946) and about 950 feet in the Sun River area north of the area of plate 1 (Mudge, 1966a).

The Jefferson Formation, about 700 feet thick, is divisible into two members: an unnamed lower member and the Birdbear Member (table 1). The lower member, about 500 feet thick, contains thin even-bedded grayish-brown fetid dolomite, calcitic dolomite, and limestone; locally, it contains thin intraformational breccias. The Birdbear Member, about 200 feet thick, consists mostly of yellowish-gray saccharoidal dolomite, but it also contains some calcitic dolomite. Individual beds pinch and swell and range in thickness from 2 inches to 1 foot.

The Three Forks Formation, about 300 feet thick, contains thin gray to light-gray-brown magnesian limestone in the lower part; a thick massive intraformational breccia in the middle part; and a green mudstone, yellowish-gray siltstone, and carbonaceous shale in the upper part. The breccia unit, which commonly forms resistant ledges, is 85 feet thick in the Dearborn River area (Viele, 1960, p. 33), and contains angular blocks of dolomite more than 2 feet across. In Elk and Clemons Creeks, this breccia is porous and contains many small caverns.

GEOPHYSICAL RECONNAISSANCE

Aeromagnetic and gravity surveys have added to our knowledge of the structural framework of the southeastern part of the Lewis and Clark Range and have aided in outlining areas favorable for geochemical exploration.

The aeromagnetic data are part of a more widespread survey flown in 1964 by the U.S. Geological Survey. Total-intensity magnetic measurements were made with a continuously recording ASQ 10 fluxgate magnetometer installed in a Convair aircraft. The traverses were flown at a 2-mile spacing with an orientation of east-northeast, which is at right angles to the strike of the geology. A barometric elevation of 9,000 feet above sea level with deviations to 10,500 feet to clear the mountain peaks was maintained. The flightpaths were recorded by a gyrostabilized 35-mm continuous strip camera for the purpose of ground orientation.

Regional gravity data for 200 stations were obtained from the U.S. Air Force; supplemental data were obtained by the U.S. Geological Survey. These data are considered reconnaissance in nature because of the broad station spacing and the poor control on station elevations, particularly in the mountains where spot elevations on topographic maps and altimetry were used. Many of the stations east of the mountain front were set on U.S. Geological Survey and U.S. Coast and Geodetic Survey bench marks. The estimated accuracy of the Bouguer gravity data is 3–5 mgal (milligals).

The gravity control is referenced to the absolute value determined by Woodland (1958, p. 533) for Station WA124, Great Falls, Mont., airport. All gravity data were corrected for drift, latitude, elevation, and terrain effects. Terrain corrections were computed using the inclined plane approximation of Sandberg (1958) for the Hammer zones A through G, the Hammer 1939 chart for zones H and I, and the method of Plouff (1966, p. 109) beyond zone I to 166.7 km. An elevation factor of 0.06 mg per ft (milligrams per foot), based on an assumed density of 2.67 g per cm^3 (grams per cubic centimeter), was used in the calculations of elevation and terrain corrections.

MAGNETIC PATTERNS

The total-intensity magnetic patterns are principally of three major types (pl. 2). The most pronounced type is exemplified by four large positive anomalies numbered as 5, 10, 11, and 14 on plate 2. These anomalies are two to four townships (165–330 km^2) in size and have amplitudes of as much as 420 gammas.

The second type of pattern is the sharp low-amplitude anomalies that are mainly in the mountainous areas (pl. 2). Many of the narrow northwestward-trending positive and negative anomalies are correlated with exposed Precambrian and Cretaceous diorite sills. Some of the more equidimensional and low-amplitude magnetic expressions, particularly in the southeastern part, reflect exposed quartz monzonite stocks and other shallow intrusives.

The third type of pattern is the northwesterly gradient zones extending across the area. These are about 100 gammas in amplitude and are probably related to structural trends in the thrust belt.

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GRAVITY PATTERNS

The reconnaissance Bouguer gravity map (pl. 2) shows the major distortions of the earth's gravity field in this area. The regional gradient dips gently to the southwest across the area at about 0.4 mgal per mile.

A major gravity maximum in the southern part of the area trends eastward and is nearly at right angles to the predominant structural trend of the thrust belt (pl. 2). It appears to form the southern terminus of the Sawtooth Range. The west end of the anomaly is defined by a discrete, nearly equidimensional gravity maximum in the area of the North Fork of the Blackfoot River.

A first-order gravity maximum occurs in the northwestern part of the area over Paleozoic and Mesozoic rocks in the thrust belt of the Lewis and Clark and Sawtooth Ranges (pl. 2). The culmination of this anomaly is northwest of the report area. The trace of the South Fork thrust zone lies along the east flank of this anomaly.

In the eastern part of the disturbed belt, gravity minimum extends from the head of Elk Creek northward for about 35 miles; its axis is mostly over Paleozoic and Mesozoic sedimentary rocks.

INTERPRETATION OF THE GEOPHYSICS

The magnetic data were interpreted from gradient analyses and application of the methods and assumptions of Vacquier, Steenland, Henderson, and Zietz (1951) and Zietz and Henderson (1956). The magnetic-anomaly patterns may reflect ferromagnetism of the crystalline rocks with a polarization vector paralleling the present earth's field. Effects of remanent magnetism not in the direction of the earth's field has not been determined, but it is considered negligible. The magnetic effect of the sedimentary rocks also is considered negligible. The depth determinations to the source of the anomalies were estimated by measuring the horizontal extent of the steepest gradient at a position where the gradient apparently was not compounded by contiguous gradients from other sources.

The magnetic susceptibility contrasts assumed for the prediction of anomaly source lithologies are from susceptibility measurements of surface rock samples in the region reported by Davis, Kinoshita, and Robinson (1965, p. 1–5) after the method of Hyslop (1945).

The Bouguer gravity data (pl. 2), because of their reconnaissance nature, were used largely to supplement the magnetic interpretation. The interpretations of the gravity features will be discussed generally as they relate to the magnetic anomalies and patterns. Density considerations are based on the results reported by Davis, Kinoshita, and Robinson (1965) in their study of the Three Forks Basin, Mont.

MAGNETIC ANOMALY 5

The high-amplitude magnetic positive anomaly 5 (pl. 2) just northeast of the Mike Horse mine area very likely indicates a large mafic mass at a calculated depth of 6,000±1,000 feet beneath the ground surface. Susceptibility calculations on the anomaly using the map-model method of Vacquier, Steenland, Henderson, and Zietz (1951), give an average value of 0.002 cgs (centimeter-gram-second) units, which is in the range for gabbroic rocks in this region (Davis and others, 1965). The small quartz monzonite stocks and numerous diorite sills exposed in the area may be related to the gabbroic mass or one of its apophyses.

Magnetic anomaly 5 correlates approximately with a poorly controlled 5- to 10-mgal gravity maximum closure which lies along the regional east-west gravity maximum trend in the southern part of the report area.

MAGNETIC ANOMALY 10

An isolated magnetic positive anomaly of more than 200 gammas amplitude is southwest of Scapegoat Mountain (pl. 2). The depth of burial of the anomalous mass was computed to be 10,500±1,200 feet below the ground surface. The average susceptibility contrast of 0.001 cgs units suggests that the rock is quartz monzonite.

The area of the anomaly is underlain mostly by Precambrian sedimentary rocks of the Belt Series that are in westward-dipping thrust plates. Anomaly 10 corresponds to a large magnetic anomaly observed on profile 4 described as the "western magnetic anomaly" by Mudge, Robinson, and Eaton (1966, p. B111) in their study of four regional magnetic profiles across the northern thrust belt. They postulated that it may be part of a large gabbroic batholith extending 60 miles to the northwest. A study of both the magnetic and gravity anomalies (pl. 2) suggests that anomaly 10 is the expression of a much smaller buried pluton.

The anomaly 10 mass is on the southwesterly extension of the Scapegoat-Bannatyne trend as shown by Dobbin and Erdmann (1955). Alpha (1955, p. 138) described the trend as a basement Precambrian ridge with a northeastward-trending system of fractures.

The large gravity maximum southwest of Scapegoat Mountain, although poorly controlled, correlates with magnetic anomaly 10 (pl. 2). The gravity configuration and gradient suggest that the Scapegoat-Bannatyne trend continues southwest of the outcrop of the South Fork thrust zone.

MAGNETIC ANOMALY 11

Magnetic anomaly 11 is a discrete magnetic positive anomaly (pl. 2) that lies at the northwest corner of the area; it corresponds to the western magnetic anomaly on profile 3 of Mudge, Robinson, and Eaton (1966, p. B111). The area of the anomaly is underlain by Belt and Paleozoic rocks.

At the south end of the anomaly the trend of the South Fork thrust zone changes from northwest to northerly. A depth of 9,500 ± 1,100 feet below the surface was computed for the source of the anomaly. It has a susceptibility contrast of 0.001 cgs unit, and hence may reflect a large quartz monzonite pluton that is possibly part of a northward-trending batholith. The east flanks of the magnetic positive and the corresponding gravity maximum are terminated near the South Fork thrust fault zone.

MAGNETIC ANOMALY 14

A prominent magnetic positive anomaly of more than 350 gammas amplitude and six townships (500 km^2) in size lies to the east of the overthrust belt at the edge of the plains where there are outcropping Mesozoic sedimentary rocks (pl. 2). The configuration of the anomaly infers that remanently magnetized rocks not in the direction of the earth's present field may exist. This anomaly is elongated north-south, but the high-amplitude part is oriented approximately at an azimuth 60° from magnetic north.

The source of the anomaly is interpreted to be a gabbroic body 6,200 ± 1,100 feet below the ground surface. Based on regional dips and projected basement depths from well control, these depths would place the lower Paleozoics on the pre-Belt basement surface. On this anomaly a well[1] bottomed in the Steamboat Limestone (Middle Cambrian) at a total depth of 6,775 feet beneath the ground surface (fig. 1; pl. 2).

Profile 3 and the "Eastern anomaly" of Mudge, Robinson, and Eaton (1966, p. B111) cross the north side of magnetic anomaly 14 at a point about 200 gammas below the high point. They propose that the gravity maximum of only 2 and 3 mgal coincident with the eastern magnetic anomaly precluded the presence of any sizable highly magnetic basic mass. New magnetic data, however, indicate that the mass may be of basic composition, and furthermore, later gravity work more clearly defines a correlative gravity maximum of about 5 mgal.

Anomaly 14, like anomaly 10, lies along the Scapegoat-Bannatyne trend. The emplacement of both inferred igneous masses may have been controlled by this northeastward-trending fracture system.

The eastern limit of the Belt rocks may be approximately defined by a study of magnetic gradients extending to the southeast of anomaly 14 (pl. 2). The Belt rocks are not known to be magnetic in this area,

[1] Phillips Petroleum, Randall 1, CNE¼SE¼ sec. 6, T. 21 N., R. 5 W., Teton County, started in Two Medicine Formation (Upper Cretaceous).

but the eastern erosional edge or depositional edge of these Precambrian rocks appears to have had a structural control that is reflected in the magnetic data. This may have been an ancient flexure zone with enough associated magmatic action and emplacement of magnetite to produce a characteristic magnetic gradient.

GEOCHEMICAL RECONNAISSANCE

Reconnaissance geochemical studies in the southeastern part of the Lewis and Clark Range have revealed a narrow northwest-trending belt of weak lead-zinc mineralization that extends about 30 miles from Falls Creek northwest to Deer Creek (fig. 1). Mineralization, which appears to be spatially related to the northwestward-striking South Fork thrust zone, occurs in the Spokane Formation, the Helena Dolomite, the Flathead Sandstone, and the Jefferson and Three Forks Formations.

The geochemical study was begun in 1964 with a 10-day stream-sediment and float-sampling program adjacent to and within the Sun River drainage, and in a few areas of known mineralization in the Blackfoot River drainage near Lincoln, Mont. (fig. 1). In 1965 about 3 weeks were devoted to additional sampling and to further investigation of geochemical anomalies detected in the previous year. In this investigation 402 rock samples and 144 stream-sediment samples were analyzed. Most of the samples were prepared and analyzed for 30 elements in the field in a truck-mounted spectrographic laboratory. Citrate-soluble heavy metals, mercury, copper, lead, and zinc were determined in the U.S. Geological Survey laboratories in Denver, Colo.

Geochemical-distribution maps (pl. 3) show the sample localities and the lead, mercury, and citrate-soluble heavy-metal contents of stream sediments, and the lead content of float and outcrop samples. The lead-zinc belt is best shown on the map of the lead content of float and outcrop samples. The lead content and citrate-soluble heavy-metal content of stream sediments show a spotty pattern, but they generally reflect the northwestward trend of the belt.

The mercury content in stream sediments from the lead-zinc belt is less that 100 ppb (parts per billion), whereas it is more than 100 ppb in stream sediments from most of the drainages tributary to the North Fork of the Sun River. This slightly anomalous mercury probably reflects small amounts of mercury in the outcropping fine-grained pyritic clastic sediments of Mesozoic age. The high mercury content of stream sediments southeast of Lincoln reflects the old Stemple Pass mining district.

Only the spectrographic analyses of samples containing anomalous amounts of metals are listed in table 2; all the samples are within

TABLE 2.—*Analyses of rocks and soils*

[All analyses are spectrographic analyses, by G. C. Curtin and A. P. Marranzino, except that mercury is by atomic absorption analyses, by H. W. Knight and J. H. McCarthy, Jr., and lead and zinc are by chemical analyses, by J. R. McHugh and C. H. Van Sickle. n.d., indicates not determined; < indicates less than the amount shown; Sc content <50 in all samples. > indicates greater than the amount shown]

Description	Sample No. CH-	Percent			Parts per million																		
		Ca	Mg	Fe	Ti	Mn	Ag	B	Ba	Cd	Co	Cr	Cu	Ga	Hg	Mo	Ni	Pb	Sr	V	Y	Zn	Zr
Spokane Formation																							
Yellow powdery material from altered greenish-gray argillite	120A	7.0	1.0	5.0	1,000	1,500	<1	50	200	<20	<5	20	7	10	0.04	<2	5	300	150	20	20	100	200
Iron-rich red-brown gossanlike material	[1] 120B	.2	.5	15	n.d.	2,000	5	100	200	<20	<5	15	30	20	.07	20	2	8,000	50	20	15	1,500	150
Sandstone, gray-brown, calcareous, fine- to medium-grained; contains sparsely disseminated gray sulfide	120C	10	.7	.5	n.d.	2,000	<1	30	200	<20	<5	30	5	10	.09	<2	2	500	200	30	20	5,000	150
Iron-rich, brown, soft material; about 50 ft up in stratigraphic section	120D	.3	.5	5	n.d.	2,000	1	50	500	<20	<5	15	10	20	.05	2	3	150	100	20	10	<25	200
Argillite, stained orange, brown; about 200 ft downstream from CH-120A	120E	.2	.5	2	n.d.	150	<1	50	500	<20	<5	15	30	15	.025	3	2	100	50	30	10	<25	300
Argillite, iron stained at contact with overlying Helena Dolomite	[2] 119	2	1	7	1,500	200	1	50	300	<20	15	20	50	20	.19	15	20	150	50	50	30	<200	150
Hornfels, red-brown, altered; at contact with overlying diorite sill	[2] 154	.2	1.5	15	2,000	200	15	500	300	<20	<5	30	200	50	n.d.	<2	10	500	100	70	10	200	150

Sandstone, greenish-gray, fine-grained; contains abundant pyrite and minor sphalerite and galena about 30 ft below sill	[2] 154A	3	1.5	5	1,000	5,000	5	150	50	30	<5	5	50	<10	n.d.	<2	<2	1,500	<50	30	10	7,000	150
Sandstone, red-brown; disaggregated oxidized part of sample CH-154A	[2] 154B	5	1.5	5	700	3,000	2	20	700	50	<5	5	70	10	n.d.	<2	5	1,000	<50	20	10	>10,000	100
Hornfels, red-brown, altered, leached, gossan-like; contains some fresh sulfide	[2] 160B	3	2	20	1,000	1,000	7	15	200	<20	100	20	5,000	50	n.d.	10	30	20	<50	300	30	<200	100
Helena Dolomite																							
Sandstone, gray, very fine grained to medium-grained, poorly sorted; calcareous in lower part; weathers to tan to brown blocks; joints and bedding planes are iron stained. Contains spots and streaks of interstitial galena; forms prominent ledge. Unit is 4 ft thick. From top to bottom (in feet):																							
0.3	110H	0.5	0.05	<0.1	100	100	1	30	300	30	<5	<5	5	<10	0.60	<2	<2	15,000	<50	<10	5	7,000	70
.9	110G	1.5	.7	.5	100	2,000	2	20	>5,000	20	<5	<5	15	<10	.26	<2	<2	30,000	200	<10	5	15,000	150
.9	110F	.7	.02	.2	50	100	2	10	>5,000	50	<5	<5	7	<10	.60	<2	5	40,000	200	<10	5	7,000	70
.2	110E	.05	.05	.5	200	50	10	20	500	<20	<5	<5	15	<10	.20	<2	<2	100,000	50	<10	5	1,000	100
.7	110D	.1	.05	.5	300	100	<1	10	700	20	<5	5	10	<10	.14	<2	2	300	<50	<10	5	7,000	100
.7	110C	1.5	.2	.5	300	300	1	20	>5,000	70	<5	<5	5	<10	.05	<2	5	250	100	10	5	12,500	150
.3	110B	2	.5	.5	200	1,000	<1	20	200	<20	<5	<5	15	<10	.09	<2	3	1,500	<50	<10	5	10,000	70

See footnotes at end of table.

TABLE 2.—*Analyses of rocks and soils*—Continued

Description	Sample No. CH-	Percent			Parts per million																			
		Ca	Mg	Fe	Ti	Mn	Ag	B	Ba	Cd	Co	Cr	Cu	Ga	Hg	Mo	Ni	Pb	Sr	V	Y	Zn	Zr
Helena Dolomite—Continued																							
Soil, dark-brownish-gray; overlies galena-bearing sandstone bed, 0.5 ft thick	110	5	3	3	7,000	2,000	1	200	300	<20	10	50	30	15	.50	<2	10	5,000	50	70	20	2,500	300
Soil, dark-brownish-gray; overlies thin-bedded gray shaly siltstone about 10 ft above galena-bearing sandstone unit	110-1	5	2	2	5,000	2,000	<1	200	300	<20	10	70	15	30	.20	<2	15	200	70	70	30	3,000	200
Soil, yellow-brown to red-brown, sandy; consists mostly of weathered bedrock. About 30 ft south along strike of galena-bearing bed	110-2	3	1.5	3	500	2,000	3	50	1,500	100	5	5	50	10	.40	15	3	30,000	50	10	10	15,000	70
Sandstone, iron-stained, soft, porous, leached. Unit is 4 ft thick; from top to bottom (in feet):																							
1	111D	5	2	.7	70	2,000	<1	10	>5,000	20	<5	<5	5	<10	.12	<2	<2	1,000	150	<10	5	10,000	30
1	111C	.1	.1	2	300	20	<1	20	>5,000	<20	<5	5	20	<10	.17	<2	2	100	150	<10	5	600	100
1	111B	.1	.05	.5	70	300	<1	10	>5,000	50	<5	<5	5	<10	.07	<2	3	100	300	<10	5	6,000	50
1	111A	.3	.3	.7	300	300	<1	10	5,000	30	<5	10	5	<10	.10	<2	5	300	100	10	5	6,000	50
Small moss-covered sandstone outcrop on heavily forested hillside. About 1,000 ft northwestward along strike of sandstone unit	112A	3	1	.5	150	2,000	<1	10	2,000	<20	<5	5	5	<10	n.d.	<2	<2	8,000	<50	<10	5	4,000	70

Soil adjacent to sandstone outcrop	112	5	1.5	3	5,000	2,000	1	200	300	<20	10	70	30	30	n.d.	<2	10	2,000	100	70	30	4,000	300
Small overgrown prospect about 40 ft north of CH-112 on steep slope in dark-brown iron-stained calcareous sandstone. No visible galena; quartz crystals fill vugs and veinlets and ribbon the sandstone	112B	15	.2	.7	100	3,000	<1	10	1,000	<20	<5	<5	7	<10	n.d.	<2	15	2,000	<50	10	10	4,000	30
Iron-rich fracture zone about 4 in. wide in lower part of Helena Dolomite. South Fork Sun River	[2] 22	10	.2	7	700	3,000	5	20	500	<20	30	10	70	10	n.d.	5	20	1,500	<50	20	20	2,000	100
Sandstone, stained and impregnated with brown to black minerals. Float very close to being in place	[2] 149E	.3	.1	1	300	700	<1	20	3,000	<20	<5	<5	5	<10	.02	<2	<2	70	50	10	5	300	50
Soil, brown, from 6-in. depth at CH-149E locality	[2] 149F	15	3	1.5	3,000	500	<1	50	300	<20	<5	20	7	20	.01	<2	3	1,000	50	50	7	200	100
Sandstone, same as CH-110 except more calcareous. Unit is 7.3 ft thick; from top to bottom (in feet):																							
2.4	127F	5	.7	.7	200	3,000	<1	20	2,000	50	<5	<5	30	<10	.04	<2	15	3,000	<50	10	<5	12,500	100
1.4	127E	3	.2	.5	500	1,500	<1	50	3,000	30	<5	10	50	<10	.09	<2	5	4,000	70	10	5	6,000	50
.4	127D	5	3	1.5	1,500	3,000	<1	150	70	20	5	30	10	20	.04	<2	10	300	50	30	10	600	100
.8	127C	5	1	.7	200	1,500	1	30	3,000	100	<5	5	10	<10	.10	<2	2	12,500	100	10	7	15,000	50
.2	127B	3	1	1	300	1,500	2	50	50	150	5	7	70	<10	.35	<2	5	20,000	<50	10	10	17,500	50
.1	127A	10	5	1.5	700	3,000	<1	50	100	20	5	20	15	10	.14	<2	10	600	50	20	5	1,000	50

See footnotes at end of table.

TABLE 2.—*Analyses of rocks and soils*—Continued

Description	Sample No. CH–	Percent			Parts per million																	
		Ca	Mg	Fe	Ti	Mn	Ag	B	Ba	Cd	Co	Cr	Cu	Ga	Hg	Mo	Ni	Pb	Sr	V	Y	Zn	Zr
Flathead Sandstone																							
Sandstone, pale-yellow, medium- to coarse-grained; contains sparsely disseminated galena. Shallow prospect pit	118	0.1	0.1	0.1	1,000	70	7	10	300	<20	<5	5	50	<10	0.40	<2	<2	15,000	<50	10	5	50	100
Sandstone like CH-118. Dump beside vertical shaft	118B	.05	.1	<.1	3,000	20	2	10	200	<20	<5	5	10	<10	.05	<2	<2	20,000	<50	<10	<5	<25	300
Sandstone like CH-118 with few apple-green crystals on surface. Dump beside vertical shaft	118C	.05	.1	.2	3,000	30	15	10	>5,000	<20	<5	5	300	<10	.20	2	<2	50,000	1,000	15	<5	50	300
Limestone, light-gray, coarse-grained; interlayered with fine-grained diabase; contains stringers of galena. Found as float on slope below dump	[2] 118E	>20	.7	2	3,000	5,000	<1	<10	300	<20	7	20	20	10	.02	<2	5	>75,000	150	150	50	200	20
Dolomite, light-gray; cut by white quartz veinlets containing shiny black specks of copper surrounded by a secondary green mineral. Found as float on slope below dump	[2] 118F	15	10	1	100	2,000	<1	70	150	<20	<5	5	1,000	<10	.04	<2	<2	3,000	50	15	10	<200	5

Devonian rocks

Dolomite, gray-brown, brecciated. Contains few thin orange-brown iron oxide films on fractures. Fines from dump	[2] 102	15	7	0.5	700	150	<1	70	70	<20	<5	30	3	<10	0.06	<2	5	1,500	1,000	30	5	300	15
Dolomite like CH-102; contains galena as breccia filling. Channel sample, 30 ft. long, of dump next to caved shaft	[2] 104B	15	7	.5	300	100	<1	10	50	<20	<5	15	3	<10	.05	<2	<2	10,000	200	30	<5	250	510
Soil zones in prospect pit that does not expose bedrock:																							
A zone, black soil about 4 in. thick	104A	10	7	1	300	70	<1	10	50	<20	<5	10	2	<10	n.d.	<2	2	>5,000	150	50	<5	300	<10
B zone, pale-yellow-brown soil, 3-4 in. thick	104B	15	7	1.5	200	70	<1	10	n.d.	<20	<5	10	3	<10	n.d.	<2	5	>5,000	200	70	<5	500	<10
C zone, rubble	104C	15	7	.5	1,000	100	<1	<10	20	<20	<5	7	2	<10	n.d.	<2	2	>5,000	150	30	<5	700	<10
Dolomite like CH-102. Fines from dump at east edge of prospected area	[2] 107	10	5	.5	700	100	<1	30	<20	<20	<5	30	3	<10	n.d.	<2	7	>5,000	200	100	<5	1,500	<10

[1] Contains 1,500 ppm As, as shown by spectrographic analysis.

[2] Spectrographic analyses; Be 1 or <1, As <500, Bi <10, Sn <20, Sb <100, Wc 50.

TABLE 3.—*Spectrographic analyses of Precambrian diorite sills*

[G. C. Curtin and A. P. Marranzino, analysts]

Field No.	Percent			Parts per million																	
	Ca	Mg	Fe	Ti	Mn	Ag	B	Ba	Co	Cr	Cu	Ga	Mo	Ni	Pb	Sc	Sr	V	Y	Zn	Zr
CH-10	5	1.0	10	>10,000	1,500	<1	10	300	20	<5	200	<10	3	20	20	30	>5,000	200	70	<200	100
20	5	2	7	>10,000	2,000	<1	10	150	15	30	200	<10	5	50	10	30	>5,000	300	50	<200	100
74	2	2	7	7,000	3,000	<1	10	200	20	70	150	30	<2	30	<10	30	200	300	15	<200	50
75	3	2	7	7,000	1,500	<1	10	300	20	50	100	30	2	20	<10	30	200	300	30	<200	70
85	5	1.5	15	>10,000	1,500	<1	20	1,000	15	<5	200	70	<2	2	20	30	500	150	15	<200	70
88	5	1.5	10	>10,000	1,500	<1	10	300	20	<5	200	50	<2	2	<10	30	300	200	5	<200	100
117	2	2	5	>10,000	1,000	<1	10	200	50	<5	200	20	2	15	<10	30	200	700	20	<200	70
160 [1]	3	3	20	>10,000	1,500	3	20	300	------	50	1,500	50	<2	30	1,000	7	100	200	20	1,500	100
118	3	3	15	>10,000	2,000	<1	10	200	30	15	200	20	2	30	70	30	500	500	20	<200	150
133	3	1.5	7	10,000	1,500	<1	10	200	20	15	150	30	2	20	150	30	300	300	70	<200	70
148	3	2	7	10,000	1,500	<1	10	70	30	20	100	30	<2	20	10	20	150	300	20	<200	100
149	10	3	7	>10,000	1,500	<1	15	200	20	50	150	30	<2	30	15	30	200	300	30	<200	100
153C	7	3	15	>10,000	2,000	<1	10	500	50	20	500	50	<2	30	20	50	300	500	50	200	100
153 [1]	1	.3	>20	5,000	2,000	5	150	300	20	5	1,500	50	<2	15	200	20	<50	100	30	<200	50
153A [1]	1	.7	>20	7,000	3,000	2	150	700	50	5	2,000	50	<2	20	50	20	<50	150	20	<200	70
156	3	3	15	>10,000	2,000	<1	20	300	50	30	300	50	<2	30	70	30	500	500	50	200	100
M-546	10	2	10	>10,000	3,000	<1	20	200	50	------	500	50	7	20	30	50	150	300	50	200	200

[1] Limonitic gossan shear zones in sill.

NOTE.—In all samples Be 1 or <1 ppm, Cd <20, Sn <10, La <20, Bi <10 (except in CH-153 and CH-153A, Bi equals 30 and 50 ppm, respectively); As <500 (except in CH-153 and 153A, As=5,000 and 2,000 ppm, respectively); Sb <50 (except in CH-153, Sb = 70 ppm); W <50.

the northwest-trending lead-zinc belt. The gold content of most of the intensely mineralized samples from each of the stratigraphic units, determined by H. W. Lakin and Harry Nakagawa, was less than 0.05 ppm (parts per million), the limit of detection by their method of gold analysis (Lakin and Nakagawa, 1965).

Precambrian diorite sills normally contain 100–500 ppm copper. In a few places (pl. 3, loc. 153, 160) copper minerals have been deposited in shear zones in the sills (table 3). The copper in the shear zones was probably derived from the sill rock by selective leaching of sparsely disseminated chalcopyrite and redeposited along the shears. In the area of this report, all the known copper prospects are in or adjacent to Precambrian sills.

SPOKANE FORMATION

The Spokane Formation along the Dearborn River, about 1,000 feet west of a creek draining Beaver Meadow, contains a few veinlets, as much as one-eighth inch thick, of coarse-grained pink carbonate and sparsely disseminated specks of sphalerite and galena. The veinlets occur along bedding planes and fractures in interbedded fine-grained calcareous sandstones, red and green thin-bedded argillite, and argillitic dolomite (table 2, samples CH-120A–CH-120E). The 50–60 feet of beds that contains the veinlets is part of the shear zone associated with the uppermost fault in the South Fork thrust zone. The veinlets are irregular in their vertical extent and are thickest in the sandstone beds. They may be channelways used by metal-bearing fluids to more favorable host rocks higher in the section, or they may be leakage channelways from metal deposits in more favorable host rocks lower in the section. However, to judge by the small amount of alteration and the small size of the fractures, the volume of metal-bearing solution that has passed through these rocks at this locality is probably small.

Spectrographic and chemical analyses of red-brown oxidized veinlet show 8,000 ppm lead, 1,500 ppm zinc, 1,500 ppm arsenic, and 5 ppm silver (table 2, CH-120B); unoxidized veinlet material contains only 500 ppm lead and 5,000 ppm zinc (table 2, CH-120C). Lead apparently is concentrated, and zinc is depleted during oxidation.

Near the mouth of Falls Creek (pl. 3, loc. 154B), outcropping fine-grained greenish-gray pyritic sandstone beds of the Spokane Formation beneath a Precambrian sill contain more than 10,000 ppm zinc and 1,000 ppm lead (table 2). Here, the basal contact of the sill may have been the channel for migrating metals in a manner described by Kiilsgaard (1951) and Lewis (1955).

On Smith Creek a small show of copper has been prospected by an irregular-shaped adit, probably not more than 30 feet long, at the contact of the Spokane Formation with a Precambrian diorite sill (pl. 3, loc. 160). This locality is in the South Fork thrust zone, and the sill appears to be faulted at low angles over intensely pyritized and oxidized red-brown hornfels of the Spokane Formation. A yellowish-brown to reddish-brown iron-stained fracture zone extends vertically for about 20 feet in an inverted V-shape from the roof of the portal. This zone is about 4 feet wide at the adit, but narrows to about 4 inches in width at the top of the exposure. West of locality 160 there are numerous prospect pits for copper in and adjacent to the sill where it has been repeated by many thrust faults.

A grab sample of the altered argillite below the sill contained 5,000 ppm copper and 7 ppm silver; the lead and zinc content is negligible (table 2, CH-160B). A chip channel sample across the vertical fracture zone above the portal of the adit contained 1,500 ppm copper, 1,500 ppm zinc, 1,000 ppm lead, and 3 ppm silver (table 2).

HELENA DOLOMITE

The basal calcareous sandstone unit of the Helena Dolomite contains anomalous amounts of lead and zinc wherever exposed in the area extending from Deer Creek southwest to the head of Elk Creek, a distance of about 18 miles. This sandstone unit is very poorly exposed, and even at the best exposures, along Wood Canyon west of the Benchmark Airfield, the favorable bed can be seen in only a few places.

The sandstone unit was carefully measured, sampled, and analyzed at two localities on Wood Creek; grab samples were taken at other localities along the strike of the bed (table 2). Galena, light-colored sphalerite, and pyrite replace the calcite cement of the sandstone and form discontinuous blotches and streaks. Locally, small amounts of a yellowish-green secondary mineral are associated with concentrations of galena and sphalerite. The most intense lead-zinc mineralization in this sandstone unit noted in this study occurs at locality 110 (pl. 3) on the south side of Wood Creek southwest of the south end of the airport and west of an abandoned log cabin. The unit, prospected here by a caved adit of unknown length, is 4 feet thick and contains 2.7 percent lead and 1 percent zinc. The portal of the adit is in green and maroon argillite in the upper part of the Empire and Spokane Formations; these beds strike N. 15° W. and dip 52° W.

The beds of the Helena Dolomite above the basal sandstone unit are mostly concealed by a forest soil that was sampled at 5-foot intervals for a vertical distance of 100 feet above the unit. Most of these samples contain anomalous amounts of lead and zinc (table 4). However, lead may be concentrated in this soil through residual enrichment, and the parent bedrock may contain smaller, but still anomalous, amounts of lead.

TABLE 4.—*Lead, zinc, and copper content, in parts per million, of soil samples at locality CH–110*

[J. H. Turner, analyst. Samples collected from Helena Dolomite at 5-ft vertical intervals from 100 ft above the basal sandstone unit down to the unit. Analyses on −50 mesh fraction]

Sample	Lead	Zinc	Copper	Sample	Lead	Zinc	Copper
1	120	160	30	11	200	180	40
2	120	200	30	12	200	200	40
3	120	200	30	13	300	200	40
4	160	300	40	14	400	200	60
5	300	160	60	15	200	200	40
6	160	200	40	16	120	100	30
7	120	100	40	17	40	50	10
8	200	160	40	18	25	300	20
9	160	160	40	19	120	160	20
10	300	160	60	20	100	160	30

At locality CH–111, about 300 feet downstream (north) from locality CH–110, the basal sandstone unit of the Helena is exposed in the upthrown block of an eastward-trending normal fault which has a vertical displacement of about 100 feet. At this locality the sandstone unit, about 4.3 feet thick, is heavily iron stained but does not contain visible galena. The unit averages 0.04 percent lead and 0.5 percent zinc, respectively. Within the woods for a distance of about 500 feet north of these exposures, there are numerous small prospect pits along the strike of the sandstone unit.

Also near locality CH–111, a float piece from a stromatolite bed 200–600 feet above the basal sandstone unit contained 6 percent zinc, very little lead, and no silver. This sample suggests that other mineralized beds occur higher in the Helena section but are concealed by the forest cover. As discussed by Callahan (1966, p. 9, 28), stromatolite reefs are favorable hosts for deposits of lead and zinc.

At locality CH–127, about 650 feet upstream (south) from locality CH–110, the lower sandstone unit of the Helena is about 7.3 feet thick and contains 0.4 percent lead and 0.75 percent zinc (table 2).

The northwesternmost samples of the sandstone unit were from an eastward-trending ridge north of Deer Creek and south of the South Fork of the Sun River (pl. 3, loc. 149) where the lower part of the Helena Dolomite is repeated by a small thrust fault and is poorly exposed (Mudge, 1966b). A few float pieces of this unit show sparsely disseminated specks of galena in thin poorly sorted calcite-cemented sandstone beds (p. E10). One soil sample collected over the unit contains 1,000 ppm lead (table 2, sample CH–149F).

The concentration and distribution of lead and zinc in the basal sandstone unit of the Helena Dolomite probably are related to the physical characteristics of the rocks. The metals seem to be most abundant where the unit is thickest, where the sandstone has a high porosity due to poor sorting, and where the cement is calcite rather than silica.

FLATHEAD SANDSTONE

The only metal prospect in the Flathead Sandstone noted in this investigation is in Beaver Meadow, about 1 mile north of the Dearborn River. A Precambrian diorite sill has been thrust over the Flathead along the westernmost thrust fault in the South Fork thrust zone. The fault trends N. 85° W. and dips 63° W. The vertical beds of the Flathead strike west and are in a limb of a drag fold. The fractures on both sides of the fault trend due north and dip 87° W. A shallow vertical shaft on the fault shows sparsely disseminated galena and an apple-green secondary mineral as interstitial fillings in the Flathead for a distance of as much as 12 feet east of the fault. The diorite sill is not mineralized and does not appear to be altered. Grab samples of galena-bearing sandstone contain as much as 5 percent lead; zinc content is very low (table 1, CH–118).

DEVONIAN ROCKS

Lead has been prospected in the upper part of the Jefferson and lower and middle parts of the Three Forks Formations of Devonian age in the area just east of Lead Gulch and north of Elk Creek (pl. 1; fig. 2). These units are in an overturned anticline between two large thrust faults (pl. 1). The axial plane of the fold dips about 50° W. and trends N. 50° W. A small unnamed valley is incised for the most part along the axial plane, and the limbs of the anticline form the adjacent ridges (fig. 2). It is on these ridges where most of the prospecting has taken place.

Numerous pits and a few short adits and shallow shafts (fig. 2) show small irregular masses and pods of galena in the intraformational (collapse) breccia of the Three Forks Formation and the shattered gray-brown fetid dolomite beds of the Jefferson Formation (pl. 3, loc. 102–107). Most of the prospect pits are in those zones where closely spaced fractures are iron stained. Much of the galena is sheared and has a gray steely black color. Analyses of the mineralized rock show that lead and very small amounts of zinc are the only metals present in unusually high amounts (table 2). Weathering of the carbonate has produced a thin soil enriched in lead (table 2, CH–104) with sporadic residual concentrations of galena as much as 2 inches across.

The pine trees of the area of known lead mineralization are dwarfed and misshaped, and their needles are yellow green (figs. 2, 3), perhaps as a result of the high lead content of the rocks.

The lack of apparent structural control of galena distribution, the lack of alteration of the host dolomite, the deposition of galena in

FIGURE 2.—Helicopter view of the north side of Elk Creek. The lead prospects are on both sides of the small valley shown in the center of the photograph. The left dip slope is the west limb of an overturned anticline in Devonian rocks. The east and overturned limb of the anticline is in the next ridge to the east. The small valley between these ridges is incised on the axial trace of the fold. Note the area of dwarfed and misshaped trees shown in the lower left center. Figure 3 is of the eastern part of that area.

open spaces between breccia fragments in an intraformational collapse breccia, and the virtual absence of other metals suggest a Mississippi Valley type lead deposit.

GEOCHEMICAL RELATIONSHIPS

Observations on the distribution of metals are:

1. Although the lead-zinc ratios in the four stratigraphic units in the mineralized belt range widely from 0.08 to 300, the ratio tends to increase from the lowest to the highest stratigraphic unit. Deposits in the two Precambrian Belt units commonly contain as much zinc as lead, if not more, whereas deposits in the Paleozoic rocks are chiefly lead.

FIGURE 3.—The dwarfed and dying vegetation in the Elk Creek lead prospect area. Some small prospect pits are in the foreground. The vegetation is mainly limber pine and creeping juniper.

2. Mercury content of the lead-zinc-bearing rocks ranges from 10 to 900 ppb (averages about 125 ppb) and shows no preference for any of the four stratigraphic units.
3. The mineralized rock in the lead-zinc belt contains very little silver, gold, arsenic, antimony, tellurium, copper, and other metals common to ore deposits having a close relationship to igneous rocks. The lack of these elements suggests mineralization of the Mississippi Valley type. Numerous stocks of quartz monzonite to diorite composition are exposed in the region, however; others that are buried, as indicated by the geophysical evidence, could be the source of the metals. Thus, the evidence for the type of mineralization and the source of metals is inconclusive.

AGE OF MINERALIZATION

The age of the lead and zinc mineralization in the southeastern part of the Lewis and Clark Range is inferred as Eocene by analogy with deposits associated with the Boulder batholith. The distribution of lead and zinc in a long narrow belt, coincident with the South Fork thrust zone, suggests that mineralization occurred after Laramide thrust faulting. In the southeastern part of the Lewis and Clark

Range, folding and thrusting occurred either at the close of Cretaceous sedimentation or during early Paleocene time, but no later than Oligocene. The metallic mineralization in the Boulder batholith area is very likely late Paleocene (Darrell Pinckney, oral commun., October 1966). His data indicate the mineralization was postbatholith and pre-Lowland Creek Volcanics. The bulk of the Boulder batholith is dated as 82–71 million years (G. D. Robinson, M. R. Klepper, and J. Obradovich, written commun., 1968). The Lowland Creek Volcanics have been dated as early Eocene by Smedes and Thomas (1965, p. 508). A K-Ar age on the Marysville granodiorite stock, south of the Stemple Pass area, is 78 million years, very Late Cretaceous (Baadsgaard and others, 1961, p. 699). This stock, according to Knopf (1963, p. 8), was emplaced contemporaneously with the Clancy Granodiorite phase of the Boulder batholith. The age of the other stocks farther north is not known, but on the basis of similar lithology, some of them were probably emplaced about the same time as the Boulder batholith. Assuming that lead-zinc mineralization in the southeastern part of the Lewis and Clark Range was genetically related to these plutons, it follows that it was in effect contemporaneous with mineralization in the Boulder batholith area.

ISOTOPIC COMPOSITION OF LEAD

By R. E. Zartman

The isotopic composition of the lead in galena from the Cambrian and Devonian rocks is considerably different from that found in the Precambrian rocks (table 5). The isotopic composition of the Cambrian and Devonian leads (enriched in radiogenic isotopes) is not similar to other leads recorded in Montana (Cannon and others, 1962, p. 123). The lead in the Precambrian Spokane Formation and Helena Dolomite is similar in composition (deficient in radiogenic isotopes) to leads in deposits in Precambrian rocks in the Sullivan mine, British Columbia (Leech and Wanless, 1962, p. 260), in the Coeur d'Alene district, Idaho, and in the Flathead Lake area, Montana (Cannon and others, 1962, p. 123).

The model ages of the leads from the four units are inconsistent between samples and not compatible with other geologic data. The model ages range from Precambrian into the future, and yet all the deposits are believed to have formed after Laramide thrust faulting. A similar problem has been discussed for the Coeur d'Alene district (Cannon and others, 1962, p. 121–122; Hobbs and others, 1965, p. 132). It is hoped that further detailed isotopic investigation of lead deposits in and near Belt rocks will lead to a better understanding of the mineralization mechanism in the area.

TABLE 5.—*Isotopic composition of lead deposits in the southeastern part of Lewis and Clark Range, Mont.*

[Determinations by R. E. Zartman. These compositions are of a preliminary nature and are subject to precision uncertainties of ±0.5 percent]

Sample	Formation	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}	Pb^{206}/Pb^{207}	Pb^{206}/Pb^{208}
104	Three Forks Formation (Devonian)	20. 12	16. 14	41. 13	1. 2463	0. 4891
107	-----do-------------	19. 95	16. 03	40. 76	1. 2447	. 4894
118	Flathead Sandstone (Cambrian)	23. 32	16. 28	44. 13	1. 4323	. 5285
110	Helena Dolomite (Precambrian)	16. 57	15. 61	36. 73	1. 0609	. 4511
125A	-----do-------------	17. 11	15. 75	37. 42	1. 0864	. 4573
127B	-----do-------------	16. 56	15. 50	36. 41	1. 0687	. 4549
Bu-20	-----do-------------	17. 15	15. 86	37. 51	1. 0813	. 4571
120	Spokane Formation (Precambrian)	16. 80	15. 81	37. 49	1. 0621	. 4480

SUMMARY OF INVESTIGATIONS

A narrow northwest-trending belt of weak lead-zinc mineralization, about 30 miles long, extends from Falls Creek northwest to Deer Creek (pl. 4). This belt is spatially related to the South Fork thrust zone. Within this zone the mineralization is stratigraphically controlled; it is confined to the most permeable and porous beds in the Empire and Spokane Formations, Helena Dolomite, Flathead Sandstone, and in the carbonate rocks of Devonian age. Most of the mineralization is in the carbonate bed or calcareous sandstone bed that is nearest to the westernmost thrust fault in the zone. The ratio of zinc to lead diminishes upward stratigraphically, as zinc is virtually absent in the Devonian rocks. Silver occurs in very minor quantities in the samples containing high lead and zinc values and was not detected at all in samples from rocks of Devonian age. Negligible amounts of copper locally occur as stains along shears in diorite sills. It is likely that the copper was derived by selective leaching from sparsely disseminated chalcopyrite in the sill rocks. The thrust zone and mineral belt are reflected in the aeromagneitc data as a narrow northwesterly trend.

The relationship of the geophysical anomalies to the lead and zinc mineralized belt can only be speculative. The magnetic and gravity anomaly southwest of the center of the lead and zinc belt may reflect a quartz monzonite mass at a calculated depth of about 10,500 feet beneath the surface (pl. 4). The projected westerly dip of the South Fork thrust places it at or just above the pluton. A magnetic positive anomaly southeast of the end of the belt may be a large mafic mass at a calculated depth of about 6,000 feet (pl. 4). Small gabbroic and quartz monzonite intrusions exposed near this anomaly may be directly related to the mass. Gravity and magnetic anomalies, at the northwest end of the belt, may reflect a quartz monzonite pluton buried at a computed depth of about 9,500 feet (pl. 4). Here also, the projected westerly dip of the northerly extension of the South Fork thrust would place it at or just above this anomalous mass. However, the rocks in the west-dipping thrust zone that crop out east of both the anomalies are not known to be mineralized.

The lead and zinc belt lies across the Scapegoat-Bannatyne trend (pl. 4). The magnetic anomaly, southwest of the belt, lies on the southwest projection of the trend, and a magnetic anomaly, beneath the plains to the northeast, lies on the trend. This structural trend was tectonically active in Precambrian and early Paleozoic time and was the locus of minor activity during Late Cretaceous and early Tertiary; it is presumably a zone of weakness that could have controlled the intrusion of igneous rocks. A similar structural setting is described at Pine Point, Northwest Territories, Canada, by Campbell (1966, p. 953). He suggests that major Precambrian faults controlled emplacement of rich Mississippi Valley-type lead-zinc deposits in the overlying Devonian carbonate rocks.

The areas in the lead and zinc belt that may warrant future exploration are:

1. The heavily forested Wood Canyon area where the basal sandstone unit of the Helena Dolomite contains pyrite, galena, and sphalerite, and where anomalously high lead and zinc content of soil and float samples suggest additional mineralization in stromatolite beds in the upper part of the Helena. Soil sampling may be useful for tracing this unit through the heavily forested area and for locating covered units higher in the Helena that may contain anomalous amounts of metals.
2. The Elk Creek area where mineralized Devonian rocks are intensely fractured in the center of a tight overturned anticline. Prospecting at depth in the anticline would encounter fractured Cambrian carbonate rocks, which should be an equally good host for mineralization.

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