UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Resource potential of the Bear Trap Canyon Instant Study Area, Madison County, Montana

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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In accordance with the provisions of the Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976), the Geological Survey and the Bureau of Mines have conducted mineral surveys on certain areas, which formally had been identified as "natural" and "primitive" areas prior to November 1, 1975. This report discusses the results of a mineral survey of Bear Trap Canyon, Madison County, Montana.

Geology and geochemistry of the Bear Trap Canyon Instant Study Area

By Darrell M. Pinckney

INTRODUCTION

The Bear Trap Canyon Instant Study Area is a narrow strip of land in southwestern Montana (fig. 1) along the canyon of the Madison River between Ennis Lake and the mouth of Hot Springs Creek. The study area is part of a northwesterly trending ridge that is an extension of the Madison Range. The ridge was uplifted in the late Tertiary and the Madison River incised the canyon through the ridge. The canyon walls are very steep, and the entire bottom of the canyon, throughout much of its length, is occupied by the bed of the river. Near the mouth of Bear Trap Creek, the east rim of the canyon is 2,200 ft (670 m) above the river. The country east of the canyon and south of Bear Trap Creek is timbered and rugged. The remainder of the area shown on plate 1, except for the canyons, is a high, rolling grassland. The walls of the canyon are very steep and are accessible only with great difficulty in most places and the study area is small. Therefore, a larger area was geologically mapped and sampled in order to obtain a broad knowledge of the geology and geochemistry of the rocks of the canyon and provide a regional perspective. Rocks in the map area are briefly described on the geologic map. The mafic and ultramafic intrusive rocks are komatiites, a suite of basic rocks. These are discussed in more detail because of their possible economic importance.

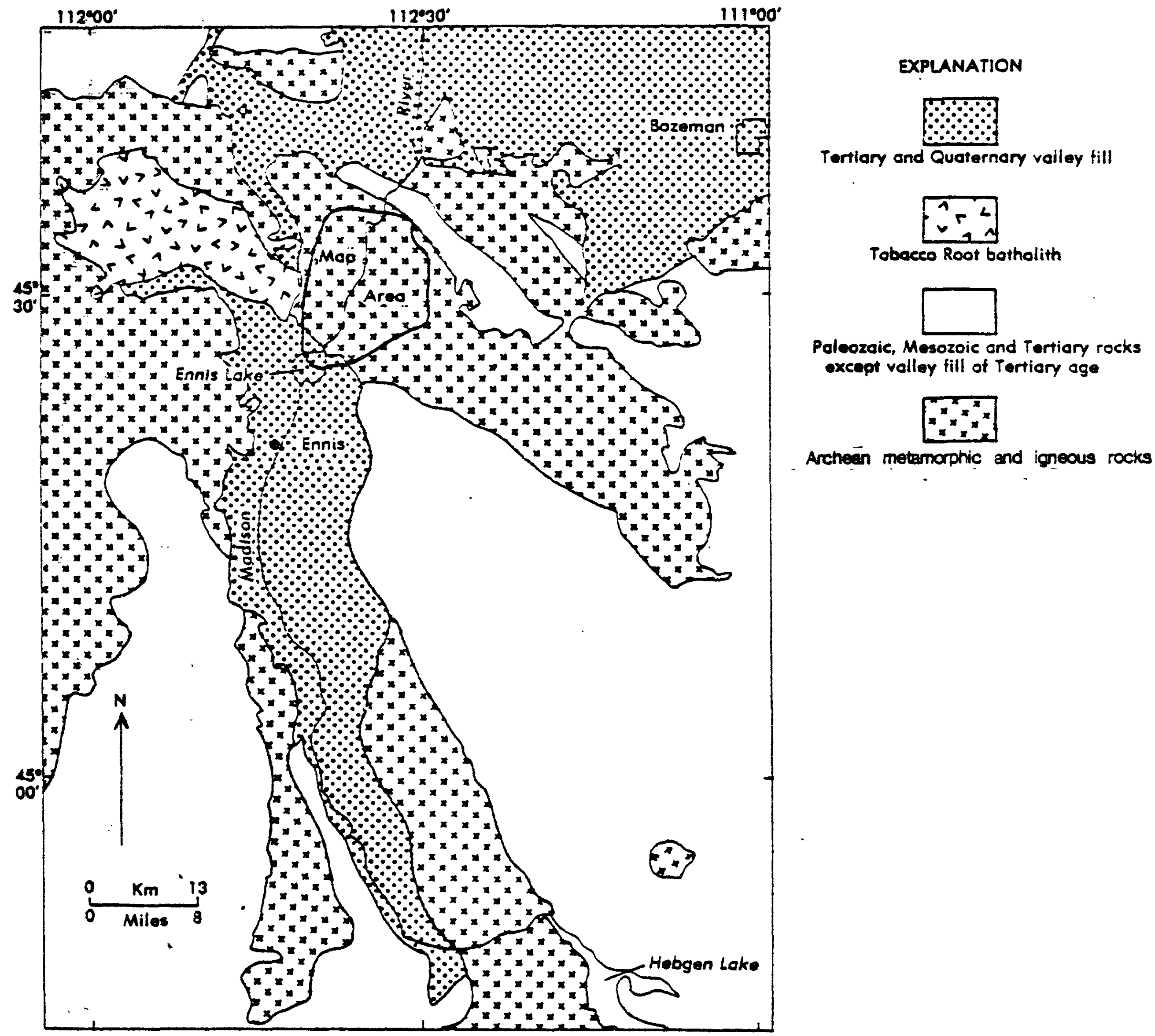

Figure 1.--Geologic index map of the Bear Trap Canyon Instant Study Area.

STRUCTURE

The map area (pl. 1) is divided into three structural blocks separated by the Barn Creek and Bear Trap faults. From north to south, the blocks are referred to as the north canyon block, the middle canyon block, and the Ennis Lake block.

Ennis Lake block

The Ennis Lake block is down dropped south of the Barn Creek fault. The Barn Creek fault is a range-front fault that separates the Madison Range from the valley of the Madison River south along the southern part of the mapped area.

North canyon block

The north canyon block lies north of the Bear Trap fault. The country rock is chiefly microcline gneiss intruded by numerous pegmatites, ultramafic rocks, and small plugs of rhyolite. The structure of the gneiss, west of the Madison River and south of Hot Springs Creek, was not determined because of poor exposures. North of Hot Springs Creek, the rocks dip to the north and the lower units are deformed by many small sill-like intrusives. East of the Madison River the gneiss is folded into synforms and antiforms.

Middle canyon block

The middle canyon block lies between the Barn Creek and Bear Trap faults. The structure is dominantly that of the quartzite synform, a structure consisting of a smaller inner part encompassed by quartzite bed 3, in which the beds are folded into broad arcs around the west end of the fold, and a larger outer part, in which the fold pattern shows strong flowage of beds on the southwest end of the fold. McThenia (1960) made a detailed study of the southwest part of the fold. Along the west side of the mapped area, the rocks dip, and progressively steepen, to the southeast. In the canyon, the rocks typically dip between 75° and 80°. In the central part of the synform, within the area bounded by quartzite number 7, dips are gentler.

In much of the microcline and plagioclase gneisses, bedding is extremely well preserved. Beds range in thickness from laminations to several centimeters and tend to be in units about 10 in. (30 cm.) to a few meters thick. Layering is parallel and regular in thickness in many outcrops. Most of it is primary bedding; even rare crossbeds are locally preserved.

Many small folds, unrelated to the quartzite synform, look like anticlinal crests or limbs of drag folds. Their axial planes tend to strike northeasterly rather than parallel to the axial plane of the synform. The beds of these folds are folded around and over the tops of small plugs. The intruding plugs apparently produced many local contortions in the otherwise parallel beds. Hence, much of the local folding is probably an indication of nearby plugs.

Sequence of beds in the middle canyon block

Rocks of the map area include a thick sequence of metamorphosed sedimentary, and intrusive and extrusive igneous rocks consisting chiefly of plagioclase gneiss, microcline gneiss, amphibolite, and quartzite. They contain a variety of disconformable and intrusive rocks and some conformable layered rocks that probably were lava flows or sills. These bedded gneisses are divided into three sequences for the area of the middle canyon block (pl. 1). In this area, eight beds of quartzite were mapped and are numbered on the map in order to show the general structure of the area and the stratigraphic sequence. If the quartzite synform (pl. 1) is a syncline, the older and stratigraphically lower units are in the outer part of the synform. The middle canyon sequence, then, is oldest of the three sequences and extends from the west edge of the mapped area to the base of quartzite bed

3. This sequence is dominantly plagioclase gneiss, but includes two quartzite units and a group of amphibolites which are prominent in the area between quartzite bed 1 and the west edge of the Madison River canyon. The middle canyon sequence forms the walls of the canyon between the Barn Creek and Bear Trap faults.

One group of beds is distinctive in that the beds form crags and cliffs along the west wall of the canyon, and the rocks weather to a pale-brownish color rather than the usual gray. This group is termed the west wall group and is shown separately on the map. Exact upper and lower limits were not determined.

The sequence of rocks above the base of bed 3, herein called the quartzite sequence, differs from the middle canyon sequence in that quartzite and amphibolite units are more numerous. This sequence also contains sills or flows of mafic and ultramafic composition. One mafic unit (represented by sample 51) is very thick and may occupy much of the central part of the synform.

The Red Knob sequence consists of a unit about 300 ft (90 m) thick, characterized by amphibolites, a unit of mixed amphibolites and plagioclase gneisses, and a prominent quartzite at Red Knob. The relation of the Red Knob sequence to the middle canyon and quartzite sequences is unclear. North of Red Knob the Red Knob sequence appears to overlie the plagioclase gneiss units of the middle canyon sequence. However, the middle canyon rocks at the south end of the Madison River canyon are too thick to fit between the Red Knob and quartzite synform sequences in the area east of Cowboy's Heaven. The Red Knob sequence may be separated from the middle canyon and quartzite sequences by a premetamorphic fault.

Metamorphic grade

The highest grade of metamorphism is the granulite facies, indicated by the assemblage of orthopyroxene and garnet. Granulite facies minerals have been partly to completely replaced by amphibolite facies minerals, chiefly hornblende and feldspar. The amphibolite facies minerals, in turn, have been partly replaced by greenschist facies minerals, chiefly chlorite and sericite. The paragenesis for several localities is given in table 1. Granulite facies minerals were found chiefly in the quartzite syncline and the Red Knob sequence. Elsewhere the highest grade mineral assemblages of the middle canyon and the north canyon blocks are of the amphibolite facies. However, in and near some of the small intrusives, in the middle canyon sequence, orthopyroxene and garnet are present; elsewhere the metamorphic grade is amphibolite facies.

James and Hedge (1980) pointed out that the age of the layered metamorphic rocks in nearby mountain ranges is about 2,730±85 million years. The rocks described by them are very similar to those of the map area.

Mafic and ultramafic intrusive rocks

Many small bodies of mafic and ultramafic intrusive rocks occur in the area. About twenty of them are shown on the map; many others were observed. The most easily recognized intrusives are small pipes or plugs, many of which are syntectonic intrusives; they deformed the sediments around them and were subsequently deformed and foliated during metamorphism. All of them are

Table 1.--Mineralogy and paragenesis of selected samples

[Primary minerals indicate the oldest minerals recognized in the rock; secondary minerals resulted from alteration of primary minerals, and tertiary minerals resulted from another alteration of primary or secondary minerals or both, (---) indicates no alteration; ant, antigorite; anth, anthophyllite; bio, biotite; chl, chlorite; clen, clinoenstatite; chp, chalcopyrite; chr, chrysotile; CO_3, carbonate mineral; diop, diopside; epi, epidote; en, enstatite; gr, garnet; hbl, hornblende; hed, hedenbergite; hem, hematite; hyp, hypersthene; idd, iddingsite; ilm, ilmenite; mc, microcline; mt, magnetite; musc, muscovite; ol, olivine; pc, plagioclase; px, pseudomorph of pyroxene; qtz, quartz; ser, sericite; serp, serpophite; trem, tremolite; (-) minor constituent]

Field sample No.	Form of rock body	Character of rock	Minerals		
			Primary	Secondary	Tertiary
29	bed	quartzite	qtz, pc, mc, hbl, gr	---	---
51c	bed	quartzite	qtz, musc	---	---
16	bed	pc gneiss	pc, mc(-), bio, qtz	(in part melt)	ser
18	bed	schist	pc, qtz, mic(-), bio	chl, ser, epi	---
73a	bed	schist	hbl, pc, qtz	ser	---
29	bed	mic gneiss	qtz, mic, pc, bio, gr	ser	chl, hem
2b	bed	amphibolite	hbl, pc, gr, qtz, hem	ser(-)	---
5	bed	amphibolite	diop, pc, qtz, mt	hbl, hem	ser
10	bed	amphibolite	hbl, gr qtz	pc	ser, act

Table 1.--Mineralogy and paragenesis of selected samples--Continued

Field sample No.	Form of rock body	Character of rock	Minerals		
			Primary	Secondary	Tertiary
51a	layer	amphibolite	gr, hbl, qtz	pc	ser, chl
53a	layer	amphibolite	gr, hed, hem, pc	hbl, pc, hem	chl, idd, epi
71a	plug	amphibolite	hbl, pc, qtz	ser	---
72a	plug	amphibolite	gr, qtz, hed	hbl, pc, mt	chl, epi
73a	bed	amphibolite	hbl, pc, qtz	ser	---
85	plug	amphibolite	hed, gr, pc, qtz	hbl, pc	---
6	massive layer	hornblendite	hbl	talc, hem	---
25	plug	hornblendite	augite, mt, ilm, chpy	hbl	---
7	plug	pyroxenite	en, gr(-)	anth, hem	---
8	plug	pyroxenite	en, gr(-)	trem, hem	---
24	pipe	pyroxenite	px	ant, CO_3, hem	---
51b	layer	pyroxenite	hed, gr, hem	act	---
73b	plug	pyroxenite	ol, hyp, gr	act	ant, hem
13	pipe	dunite	ol, px	serp, chr, idd, CO_3, hem	---
53b	layer	pyroxenite or dunite	ol, px	ant, chr, serp, hem	---

Table 1.--Mineralogy and paragenesis of selected samples--Continued

Field sample no.	Form of rock body	Character of rock	Minerals		
			Primary	Secondary	Tertiary
54	pluton	dunite	ol, px	chr, ant, hem	---
54B	layer in dunite pluton	aluminous pyroxenite	en, clen, hyp, pc, mt	---	---
78	sill below pluton	pyroxenite	en	anth, chr	ant, serp, hem

altered or metamorphosed; their mineral paragenesis is given in table 1.

The largest of the mafic to ultramafic intrusive bodies is a funnel-shaped body in sections 22 and 23, T. 3 S., R. 1 E. This body is in the central part of a small syncline, and the layered wall rocks dip inward toward it. The main part of the body was dunite, now altered to serpentine. It is underlain by a thick and separate sheet-like layer of ultramafic rock most of which is altered to serpentine, but some is altered to anthophyllite and tremolite. The funnel body also contains an unaltered upper layer, exposed along the western and northern parts. This layer consists chiefly of ortho- and clinoenstatite, plagioclase, and magnetite.

Another ultrabasic body, at the Blue Agate prospect, occurs just to the north of the funnel-shaped body. It is a breccia of serpentine, formerly dunite, which was thoroughly carbonatized and silicified.

Alteration of mafic and ultramafic rocks

Nearly all of the mafic and ultramafic rocks are at least partially altered to serpentine; only relics of original igneous minerals are present in a few rocks. Most of the mafic rocks appear to have adjusted to the granulite facies and later re-equilibrated to amphibolite facies conditions. Their mineralogy is given in table 1. Most of the serpentines are unsheared and apparently the parent rock was altered in place. These serpentinites contain abundant magnetite and hematite and ubiquitous but small amounts of a carbonate mineral. Considering the above, and the abundant silica at the Blue Agate prospect, it is concluded that the altering solutions were oxidizing waters carrying fairly abundant carbon dioxide and varying amounts of silica.

Komatiites

Most of the mafic and ultramafic rocks belong to the komatiite class according to chemical criteria of Naldrett and Cabri (1976). Partial chemical analyses of the mafic and ultramafic rocks are given in table 2. The quantitative data for separating rocks of the komatiite suite from those of the tholeiite suite were given by Naldrett and Cabri (1976, figures 1 and 2), and their diagrams are used for figure 2, showing the rocks to be komatiites. Komatiites occur as synvolcanic and imediately post-volcanic intrusives which rose to or near the surface and spread out as flows or sills. They are thought to come from a deep zone within the mantle which is enriched in sulfides, especially nickel sulfide. Komatiite magmas are thought to contain an immiscible sulfide melt. After extrusion or intrusion of the magma, the sulfide melt may settle to the bottoms of flows or sills resulting in accumulations rich in nickel (Naldrett and Cabri, 1976, p. 1142-1143).

The chemical data of table 2 represent both intrusive rocks and thick mafic layers, usually referred to as amphibolites. The amphibolites appear to be be conformable to the bedding in the gneisses and quartzites. Also, the amphibolites seem to have the composition of the intrusive igneous rocks. Chemically, nearly all of them plot in the komatiite field of figure 2, along with the intrusive rocks. For these reasons the amphibolites are considered to be metamorphosed lava flows and sills.

Lower Hot Springs mining district

The lower Hot Springs mining district (Winchell, 1914), located 3 mi (5 km) west of the study area, produced gold and silver from narrow veins and stringers of quartz within wide and poorly defined shear zones in Archean gneiss. The principal minerals found on dumps are quartz, carbonate, pyrite, sphalerite, galena, and chalcopyrite; the sulfides are sparse. Alteration minerals are mainly sericite and chlorite. The veins of the district are zoned (fig. 3) such that a small central zone of veins containing sulfides and carbonate is surrounded by an intermediate zone of carbonate veins without sulfides, and a peripheral zone of veins containing hematite and limonite,

Table 2.--Partial chemical analyses of mafic and ultramafic rocks, in percent

[Thick mafic layers (amphiboles): samples 5, 6, 10, 51a, 51b, and 53b; Pipes and small plugs: samples 7, 8, 24, 25, 71a, 73a, 73b, and 85; Feldspathic layer in funnel-shaped intrusive body: sample 54b; Serpentine of funnel-shaped intrusive body: sample 54d; Post-metamorphic basalt dike: sample 74]

Field sample No.	5	6	7	8	10	24	25	51a	51b	53b	54b	54d	71a	73a	73b	74	85
SiO_2	52.5	49.2	53.3	49.4	52.4	35.8	46.6	49.6	44.5	36.6	37.0	37.1	47.4	50.4	47.5	50.0	48.4
Al_2O_3	14.9	6.69	4.7	8.02	14.5	1.4	4.6	14.6	6.06	0.53	22.2	0.3	14.2	14.9	5.53	13.1	13.3
Fe_2O_3	10.1	12.5	7.97	11.4	12.7	11.5	22.0	14.0	9.97	13.3	15.0	9.70	13.4	11.1	10.6	17.2	9.84
MgO	7.89	18.2	23.5	21.2	6.45	35.9	12.0	7.05	28.1	35.8	7.88	38.2	9.33	7.72	29.0	4.2	11.4
TiO_2	0.59	0.56	0.21	0.33	0.79	0.07	0.81	1.03	0.24	0.04	0.96	<0.02	0.86	0.67	0.31	2.91	0.46
LOI*	1.19	0.99	0.49	0.72	0.89	12.12	0.46	0.71	1.65	11.60	1.74	11.75	0.64	1.39	2.51	1.56	0.60
Other	13.56	10.92	8.23	8.91	12.81	0.27	14.57	13.33	7.33	0.03	10.33	0.1	14.2	14.43	3.41	12.21	16.11
Total	100.73	99.06	98.4	99.98	100.53	97.14	101.04	100.32	97.85	97.9	95.11	97.15	100.06	100.61	98.86	101.18	100.11

*Loss on ignition

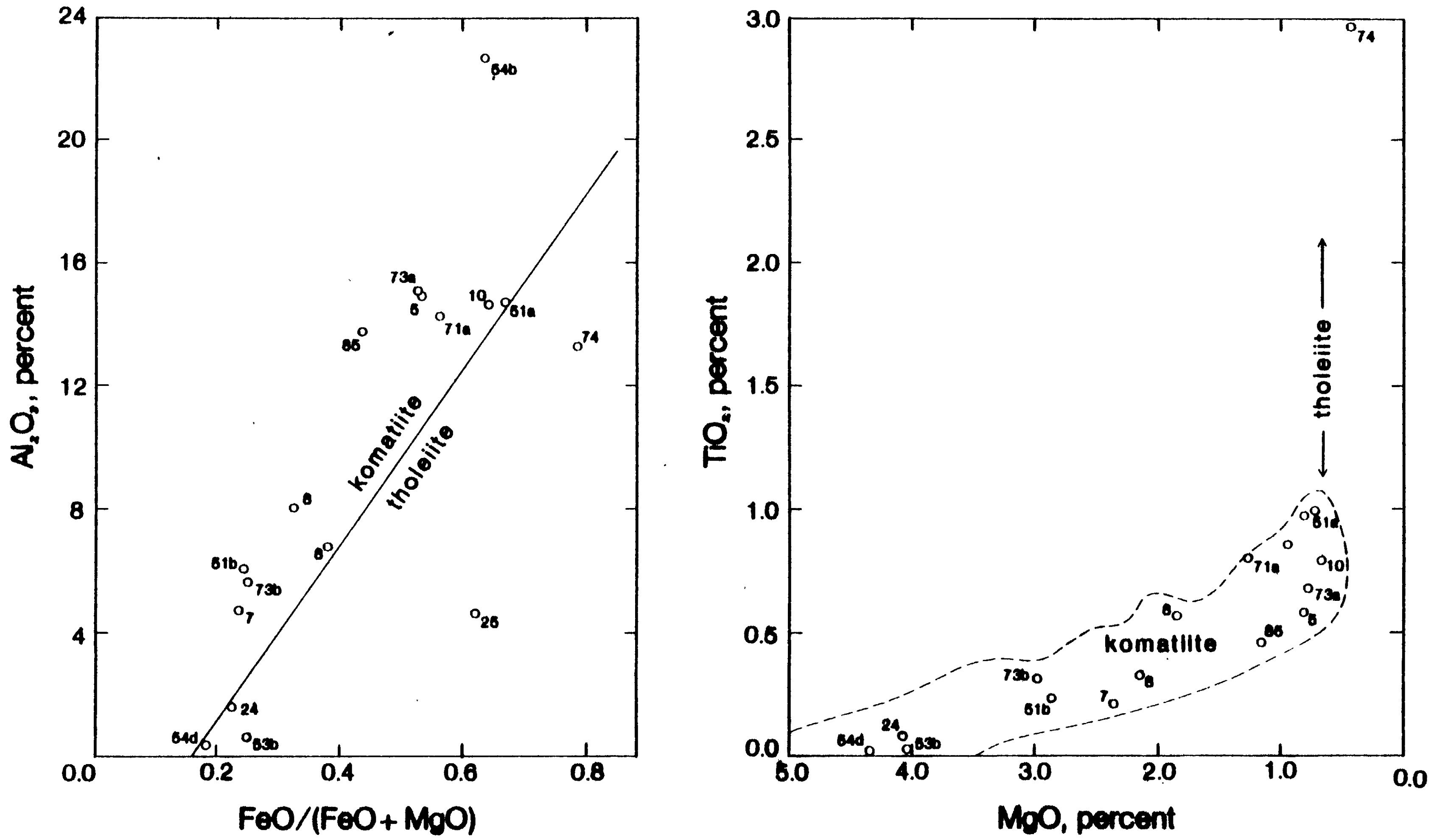

Figure 2.--Chemical fields of the komatiite and tholeiite suites of igneous rocks (from Naldrett and Cabri, 1976, figures 1 and 2).

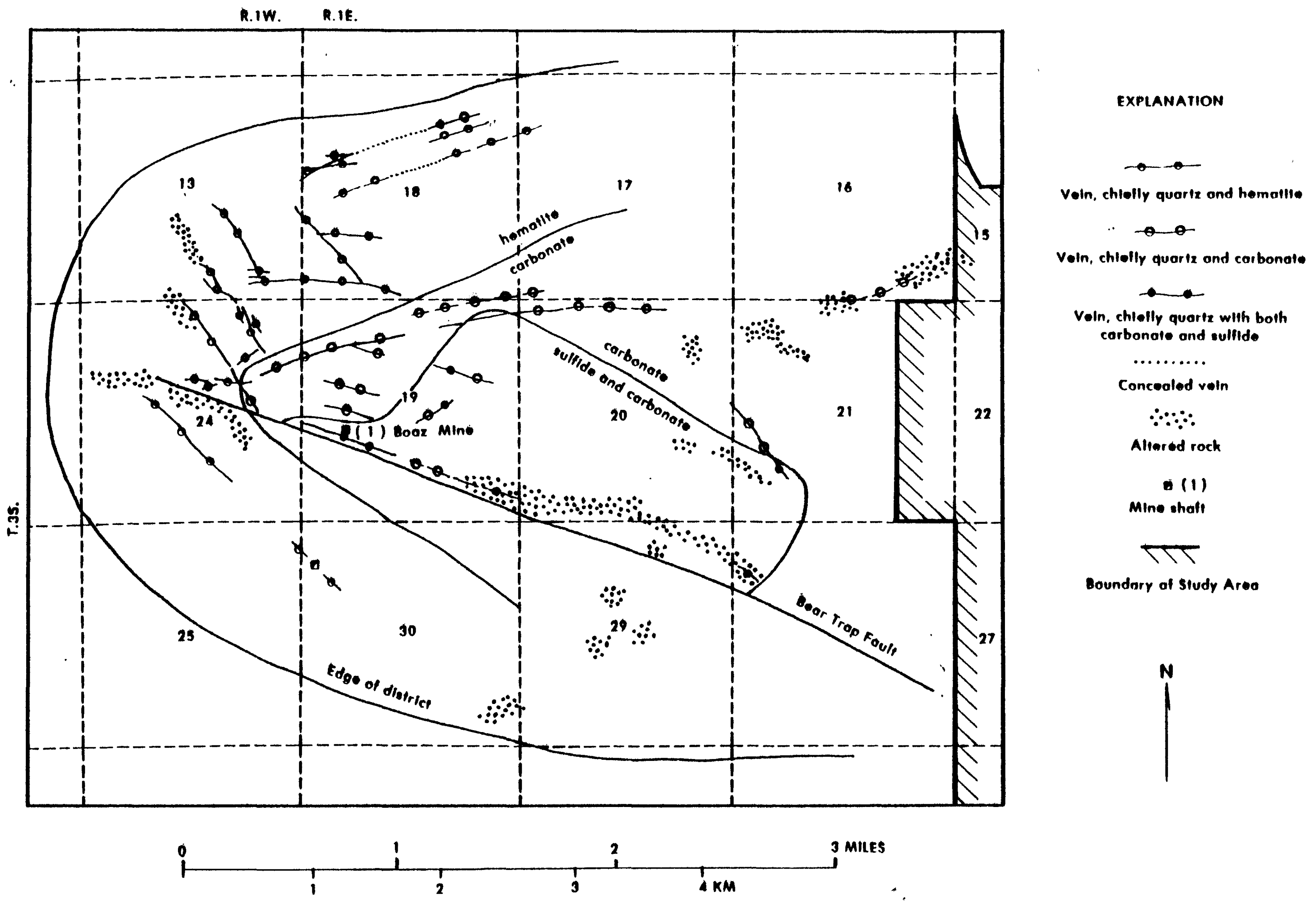

Figure 3.--Veins and mineral zoning of the lower Hot Springs mining district.

both of which were deposited with quartz. The zoning is best developed on the west side of the district. To the east, no veins were found between secs. 21, west of the study area, and 24, east of the study area, T. 3 S., R. 1 E. The zonal pattern appears to be incomplete, that is, where the boundary between the intermediate and peripheral zones is missing in this area. The vein in sec. 24, T. 3 S., R. 1 E. is chalcedony and hematite and may represent the peripheral zone and the east edge of the district. If so, the district extends across the Madison River and through the study area. However, analyses of stream sediment samples from the study area show only background amounts of copper, zinc, and silver.

Minor elements

Spectrographic analyses of 47 rock samples and 42 stream-sediment samples are given in table 3. The data for chromium and nickel are of greatest interest. All rocks with a nickel content of 500 ppm or more are mafic or ultramafic rocks and have chromium values of 500 ppm or more. Only two rocks (samples 5 and 85) with a chromium content of 500 ppm or more contain nickel in amounts of less than 500 ppm. Hence, the presence of greater amounts of chromium in the rocks is a reasonable guide to rocks containing nickel. This may be of significance in considering the data from the stream sediments because the stream-sediments are from areas not necessarily represented by rock samples. Stream-sediment samples 17, 20, 22, 47, 58, 79, and 88, contain more than 500 ppm chromium and seem to be indicative of areas containing mafic and ultramafic rocks. However, these samples contain very little nickel, even though one of them (58) is from a stream wherein nickel-bearing rocks (rock samples 6, 7, and 8) occur at the edge of its drainage basin. On the other hand, stream-sediment samples 26, 55, and 87, have a higher content of nickel associated with chromium, and these samples are from streams draining the

Table 3.--Minor elements in rock and stream-sediment samples

[Zn analyses for stream-sediment samples are by atomic absorption; all other analyses are by spectrographic methods. The limits of detection are given in parenthesis above the element. Elements looked for, but not found and their limits of detection in ppm are: Ag (0.5), As (200), Au(10), Bi(10), Cd (20), Sb (100), W (50), and Zn (200). All values listed are in parts per million (ppm), (-) indicates no data]

Rock samples

Field sample no.	(5) Co	(10) Cr	(5) Cu	(5) Ni	(10) Pb	Remarks
			Rock samples			
2a	-	-	-	-	30	Feldspathic quartzite.
2b	-	-	5	-	50	Hornblende-garnet gneiss.
4	70	-	200	100	-	Amphibolite layer.
5	70	500	20	100	-	Do.
6	70	3,000	100	500	-	Do.
7	70	2,000	-	500	-	Pipe.
8	100	3,000	-	1,500	-	Do.
10	50	50	50	100	15	Amphibolite layer.
13	100	5,000	-	1,500	-	Pipe.
16	20	300	10	100	50	Plagioclase gneiss.
18	20	200	30	100	30	Do.
19	10	15	10	10	20	Do.
24	100	5,000	-	1,500	-	Plug (serpentine).
25	70	300	100	200	-	Plug.
29	10	15	-	10	20	Microcline gneiss.
51a	50	150	200	100	-	Amphibolite layer.
51b	100	5,000	10	1,000	-	Do.
51c	-	200	-	15	-	Quartzite
53a	50	150	200	100	-	Amphibolite layer.
53b	50	1,000	5	2,000	-	Serpentine layer.
54a	100	5,000	7	1,500	10	Serpentine.
54b	70	300	5	150	30	Feldspathic segregation.
54d	70	3,000	10	1,500	-	Serpentine.
54e	70	5,000	10	2,000	10	Do.
54f	70	3,000	15	1,500	-	Do.

Table 3.--Minor elements in rock and stream-sediment samples--Continued

Field sample No.	(5) Co	(10) Cr	(5) Cu	(5) Ni	(10) Pb	Remarks
71	-	-	-	-	-	Quartzite.
71a	50	300	20	100	50	Plug.
72	5	10	-	7	-	Plagioclase gneiss.
72a	50	300	20	100	10	Plug.
72b	50	50	200	50	-	Do.
73a	50	300	50	70	-	Plagioclase gneiss.
73b	100	3,000	50	1,500	-	Plug.
74	50	100	50	50	10	Dike.
78a	70	1,500	5	1,000	-	Sill.
78b	100	3,000	-	1,500	-	Do.
80	15	200	7	70	80	Plagioclase gneiss.
82a	30	200	20	70	20	Do.
82b	20	150	15	50	20	Do.
85	70	1,500	150	200	10	Plug.
89a	50	500	-	500	-	Serpentine.
89b	5	20	-	20	-	Silicified serpentine.
89c	100	700	10	1,500	-	Serpentine.
89d	70	3,000	15	1,000	-	Do.
89e	20	30	-	300	-	Silicified serpentine.
92	-	20	10	30	15	Altered gneiss.
95	-	-	7	-	30	Microcline gneiss.
98	-	50	20	20	20	Altered silt.

Table 3.--Minor elements in rock and stream-sediment samples--Continued

Field sample No.	(5) Co	(10) Cr	(5) Cu	(5) Ni	(10) Pb	(10) Sn	Zn
Stream-sediment samples							
9	30	150	50	30	20	-	85
11	30	300	30	30	15	-	50
12	30	200	30	30	20	-	55
14	50	300	30	30	20	-	55
15	50	300	30	30	20	-	45
17	50	1,000	30	30	20	-	35
20	20	500	30	30	20	-	40
21	30	300	50	30	20	-	100
22	30	500	30	30	20	-	75
23	50	300	30	20	15	-	40
26	70	>5,000	50	1,500	15	-	35
27	50	700	30	30	15	-	50
28	50	300	50	50	20	-	75
36	30	200	20	30	30	-	50
41	50	300	30	50	30	-	50
43	30	150	50	50	30	-	75
45	50	300	30	70	30	-	50
46	30	200	50	70	30	-	70
47	70	700	70	70	20	-	50
50	30	150	50	50	20	-	65
52	30	150	50	50	20	-	50
55	70	5,000	30	500	20	50	40
56	30	150	70	50	20	-	55
57	50	300	50	50	20	-	60
58	50	500	50	70	20	-	45
59	50	200	30	50	15	-	40
60	30	300	50	50	20	50	55
61	30	150	20	30	15	-	20
63	30	300	30	50	20	-	40
65	30	200	30	50	30	-	40
68	20	150	30	50	20	-	50
69	30	300	50	70	15	-	60
70	30	300	50	70	20	-	65
76	20	200	30	50	15	-	55
79	30	700	30	70	20	-	45

Table 3.--Minor elements in rock and stream-sediment samples--Continued

Field sample No.	(5) Co	(10) Cr	(5) Cu	(5) Ni	(10) Pb	(10) Sn	
86	20	500	30	70	20	-	45
87	30	3,000	30	200	20	30	30
88	30	700	30	70	20	-	40
93	15	100	20	20	50	-	35
94	20	300	70	70	30	-	70
97	20	200	30	30	70	-	40

funnel-shaped intrusive and its wall rocks. Possibly, nickel is removed from the stream sediments in a short distance, whereas chromium persists for a greater distance.

Geophysical Investigations

by

W. F. Hanna and H. E. Kaufmann

General

Geophysical investigations of the study area are confined to compilation and analysis of previously acquired gravity and magnetic anomaly data (pls. 2, 3, and 4). The compilation of magnetic data vividly illustrates that broad-wavelength anomalies, measured high above terrain (pls. 2 and 3), are caused by relatively shallow sources having distinct short-wavelength anomalies measured low over terrain (pl. 4). This observation, which holds true for at least the northwest quarter of the study area where the two data sets overlap, signals caution for interpreting high-level data over the remaining three-quarters of the area. Thus, the smooth broad-wavelength features of the high-level survey, which might otherwise be interpreted to have large deeply buried sources, may simply comprise a number of short-wavelength anomalies generated by multiple shallow sources. This concept is important because most of the recent geologic mapping in the study area, of greatest interest in the present investigation, is covered only by the high-level survey.

Gravity Investigations

The regional Bouguer gravity anomaly map (pl. 2) is generally flat throughout the study area, exhibiting an average gradient of about 1 milligal per kilometer, increasing northeastward. This gentle gradient is an expression of the regionally high density character (Davis, Kinoshita, and

Robinson, 1965b) of the metamorphic rock terrane comprising the mapped structural blocks of the canyon of the Madison River. The southwestward steepening of this gradient, at the southwest corner of the study area, marks the confluence of two distinctly different effects manifested mainly outside the study area: first, the large-amplitude negative anomaly, GA1, associated with relatively low density plutonic rocks (Smith, 1970) of the Tobacco Root batholith and; second, the elongate negative anomaly, GA2, associated with basin deposits of the Madison River valley south of Ennis Lake.

Density data for rock samples in the newly mapped area have expectedly high values: densities of gneiss, amphibolite, pyroxenite, and dunite range from 2.67 to 3.12 g/cm^3, except for one altered dunite, which has a density of 2.32 g/cm^3 (table 4).

Magnetic Investigations

The regional high-level magnetic anomaly map (pl. 2), which covers the same area as the regional gravity anomaly map, shows at least 10 major anomalies or clusters of anomalies. These anomalies are labeled M1 through M10 on the map which designates individual anomalies of a cluster. The purpose of studying the relationships of exposed source rocks to anomalies outside of the study area is to obtain clues about completely hidden sources within or immediately adjacent to the study area.

The most prominent cluster of anomalies, M1A through M1H, is associated with plutonic rocks of the Tobacco Root batholith. Rocks samples of this batholith, both inside and outside the study area, have strong induced magnetizations (map locality numbers 4 and 5, table 4). The broad high-amplitude positive anomaly, M1A, occupying the southwest corner of the study area, marks the southeastern boundary of batholitic rocks. Negative anomaly, M1D of the cluster, is especially interesting because it occurs over the

Table 4.--Magnetization and density data for selected rocks from the study area and vicinity

[REM J: Magnitude of remanent magnetization, x 10^{-5} emu/cm^3. K: Intrinsic magnetic susceptibility, x 10^{-5} emu/cm^3. IND J: Magnitude of induced magnetization x 10^{-5} emu/cm^3. Q: Koenigsberger ratio of magnitudes of remanent magnetization to induced magnetization. p: Dry bulk density, g/cm^3. J-type of Likely Anomaly Source: Type of magnetization which is sufficiently strong (at least 10^{-3} emu/cm^3) to serve as a source for high-amplitude anomalies. R: remanent magnetization; I: induced magnetization; NON: relatively nonmagnetic. *, very strong magnetizations, that is, greater than 10^{-2} emu/cm^3. ND: Not determined. All numerical values have been rounded to 2 significant figures. Data for map localities 2, 2a through g, 4, 5 and 6 are from Hanna (1965, 1967, and 1973). Data for map locality 3 are from Colville (1961). All other data are new to this study]

Map locality No.	Rem J	K	IND J	Q		J-type of Likely Anomaly Source	Remarks
			Samples within regional map (pl. 2) but outside of study area				
1	540	910	520	1.0	2.87	R, I	Basaltic dike, 16 samples
2a	5,300	340	200	27.	2.62	R*, I	Augite hornblende andesite
2b	140	280	160	0.88	2.76	R, I	Andesite flow; 4 samples.
2c	1,300	300	170	7.6	2.64	R*, I	Trachyandesite; 8 samples.
2d	1,400	260	150	9.3	2.60	R*, I	Andesine andesite; 16 samples.
2e	71	34	20	3.6	2.36	NON	Andesitic welded ash flow; 4 samples.
2f	110	340	200	0.55	2.63	R, I	Andesine andesite porphyry; 10 samples.
2g	300	40	23	13.	2.79	R	Trachyandesite; 13 samples.
3	290	610	350	0.83	ND	R, I	Amphibolite; 12 samples.
4	26	300	170	0.15	2.65	I	Quartz monzonite; 22 samples.
			Samples within the study area (pl. 3)				
5	65	330	190	0.34	2.72	I	Quartz monzonite; 23 samples.
6	83	93	53	1.6	2.64	NON	Altered basalt; 11 samples.
13	350	850	490	0.72	2.71	R, I	Dunite (komatiite) pipe; 1 sample.
53	8.3	78	45	0.18	3.11	NON	Layered amphibolite; 1 sample.
54	3.5	98	56	0.062	2.32	NON	Altered dunite; 1 sample.
73	18	8.2	4.7	3.9	2.97	NON	Amphibolite; 1 sample.
78	17	85	49	0.34	3.12	NON	Pyroxenite sill; 1 sample.
80	0.57	3.6	2.1	0.27	2.67	NON	Gneiss; 1 sample.
82	19	5.1	2.9	6.4	2.76	NON	Gneiss; 1 sample.

central part of the batholith, much as negative anomalies occur over the central part of the larger Boulder batholith (Hanna, 1969) many miles to the northwest. The negative feature is probably associated with rocks that are unusually silicic and thus magnetite-deficient; rocks in which magnetite has been altered to relatively nonmagnetic iron oxides; rocks which possess strong reversed remanent magnetization (Hanna, 1973); or combinations of these effects.

Only three other major anomalies of the high-level survey have suggestive sources: M2 is probably associated with amphibolite (Colville, 1961); M3 is associated with a pile of nearly flat lying mafic volcanic rocks (Hanna, 1967); and M9 is associated with sparsely exposed patches of volcanic rocks. There is some uncertainty about the principal source of anomaly M9, and there is great uncertainty about the sources of M4, M5A-C, M6, M7, and M10. Negative anomalies M5D and M8 generally subtend gneissic and quartzitic terrane which is relatively nonmagnetic. More will be said about M1A, M8, and M9 with reference to the low-level survey.

The low-level magnetic anomaly map (pl. 4), which covers the northwestern quarter of the study area, is highly revealing of the specific locations of magnetic source rocks. For convenience of discussion, labels L1 through L17 are attached to conspicuous anomalies within the study area. As evidence of the filtering effect which is operative by increasing the height of the measurement datum above the ground, negative anomaly M8 of the high-level survey is seen in the low-level survey to be composed of the combination of negative anomalies L1 and L8 and positive anomalies L2, L3, L12, and L13. Similarly, positive anomaly M9 of the high-level survey, including its eastern and south-southwestern extensions, consists of positive features L11, L14, L15, and L17 and negative feature L16. Finally, positive anomaly M1A of the high-level survey comprises positive anomalies L4, L5, L6, L7, and L9, and L10 of the low-level survey. Further discussion of these low-level features is warranted.

Most of the positive anomalies of the low-level survey in the study area share a remarkable characteristic: they do not occur over mapped intrusive igneous rocks (Davis, Kinoshita, and Robinson, 1965b) which normally are expected to be magnetic, but rather they do occur over metamorphic rock terrane which normally is expected to be relatively nonmagnetic. This unexpected correlation of anomalies to mapped geology might be explained in several ways. The absence of anomalies over the intrusive rocks may be attributed to an unusually low magnetite content or to the presence of a nearly horizontal magnetization direction which causes an anomaly to be far displaced from the top of its source. The presence of anomalies over metamorphic rock terrane could mean that the sources are part of the metamorphic rock complex itself as, for example, amphibolite units; mafic or ultramafic intrusive rocks which have invaded the metamorphic rock terrane to a shallow depth of emplacement; or unmapped mafic volcanic rocks which are outliers of nearby volcanic fields.

In only one place in the study area is there evidence that a horizontal magnetization direction may contribute to the development of a displaced anomaly. Positive anomaly L3, which is centered (1 km) south of an igneous rock body similar in shape and size to the anomaly, is spatially related to the body as though the source were magnetized nearly horizontally to the north. Rock magnetic data (Hanna, 1965, 1967) show that the vector sum of the reversed remanent magnetization direction and the induced magnetization direction results in a total magnetization which is inclined about 25° upward in a northward direction. This textbook example of the displacement of an anomaly due to an anomalous total magnetization direction possesed by the source, however, may apply only in a limited way here: first, the sampled igneous rocks are surprisingly weakly magnetic (map locality no. 6, table 4) and, second, the anomaly may be caused by unmapped mafic units of the metamorphic rock terrane.

Inspection of the northwestward extension of L3, which peaks at high-amplitude anomaly L2, and of positive anomalies L13, L14, and L15 shows that these features are similar to anomaly M2 of the high-level survey (fig. 4) which is associated with highly magnetic amphibolite (Colville, 1961). It is suggested, in view of the gravity data, that these positive anomalies are associated with amphibolite within the metamorphic rocks rather than with hidden intrusions of intermediate, mafic, or altered ultramafic rock. More local positive features L7, L9, L10, L11 (a southerly extension of gradient L17), and L12, are likely associated with one of two types of hidden source rocks: amphibolite or ultramafic intrusive rocks. Although a number of surface samples of highly mafic rock, including pyroxenite, amphibolite, and altered dunite have been found to have relatively weak magnetizations (table 4), at least one komatiitic sample of a dunite pipe is highly magnetic, with both its induced and remanent magnetization capable of generating a high-amplitude anomaly in a low-level survey. Negative anomalies L1, L8, and L16, nested within the numerous highs, mark terrane consisting predominantly of relatively nonmagnetic gneiss and quartzite.

The Tobacco Root batholith is also seen to have a more complex anomaly expression in the low-level magnetic data. Positive flexure L4 and anomaly L6 appear to reflect highly mafic plutonic rocks at the margin of the batholith; positive nose L5, while partly associated with high topography, presumably marks a northwest-trending mafic pluton or intrusive within the batholith.

Geophysical Summary

The aeromagnetic anomaly data show that the central part of the study area is underlain by relatively nonmagnetic gneissic and quartzitic metamorphic rocks. To the northeast, but well within the area, magnetic rocks occur in greater abundance. These magnetic rocks are inferred to be primarily amphibolite, making up part of the layered metamorphic rock complex and secondarily local ultramafic intrusive rocks. The magnetic data also show that a similar abundance of magnetic rocks occurs at the southeast margin of the study area and that these rocks have a pronounced northwest strike. Gravity data indicate that plutonic rocks of the Tobacco Root batholith do not extend at depth beneath the metamorphic rock terrane in the study area.

Mineral resource potential of the

Bear Trap Canyon Instant Study Area

By

Darrell M. Pinckney and Charles E. Larson

Geologic and geochemical studies indicate that the mineral resource potential of the Bear Trap Canyon Instant Study Area, Montana, is low for all resource types that could be evaluated. The principal types that had to be evaluated in this examination included possible extension of the Hot Springs mining district located 2.5 miles (4.0 km) west of the study area, and the possible nickel concentrations in dark-colored Precambrian intrusive rocks (komatiites). Analyses of stream-sediment samples from the study area do not indicate the presence of these resources and the presence of concealed deposits could not be determined by this survey. A low to moderate potential for nickel is inferred, but additional work, including physical exploration, would be required to determine its potential.

Mines and prospects of the Lower Hot Springs mining district, outside the study area and shown on the map, produced gold, silver, lead, zinc, and copper from veins. Prospects outside of the mining district are of low value. The only valuable deposits were near the Boaz mine, within the central zone of the district as shown on figures 3 and 4. Bureau of Mines records show that, between 1902 and 1948, the Boaz mine produced about 61,555 tons (55,842 t) of ore at an average grade of 0.70 oz gold/ton (24 g/t), 0.4 silver/ton (14 g/t), 0.02 percent copper, and 0.3 percent lead. Production from other mines in the district was small by comparison. The patented Morning Star and Copper King claims (fig. 4 and pl. 5) cover the only active mine or prospect in the Lower Hot Springs District. A mineralized shear zone which strikes northwesterly

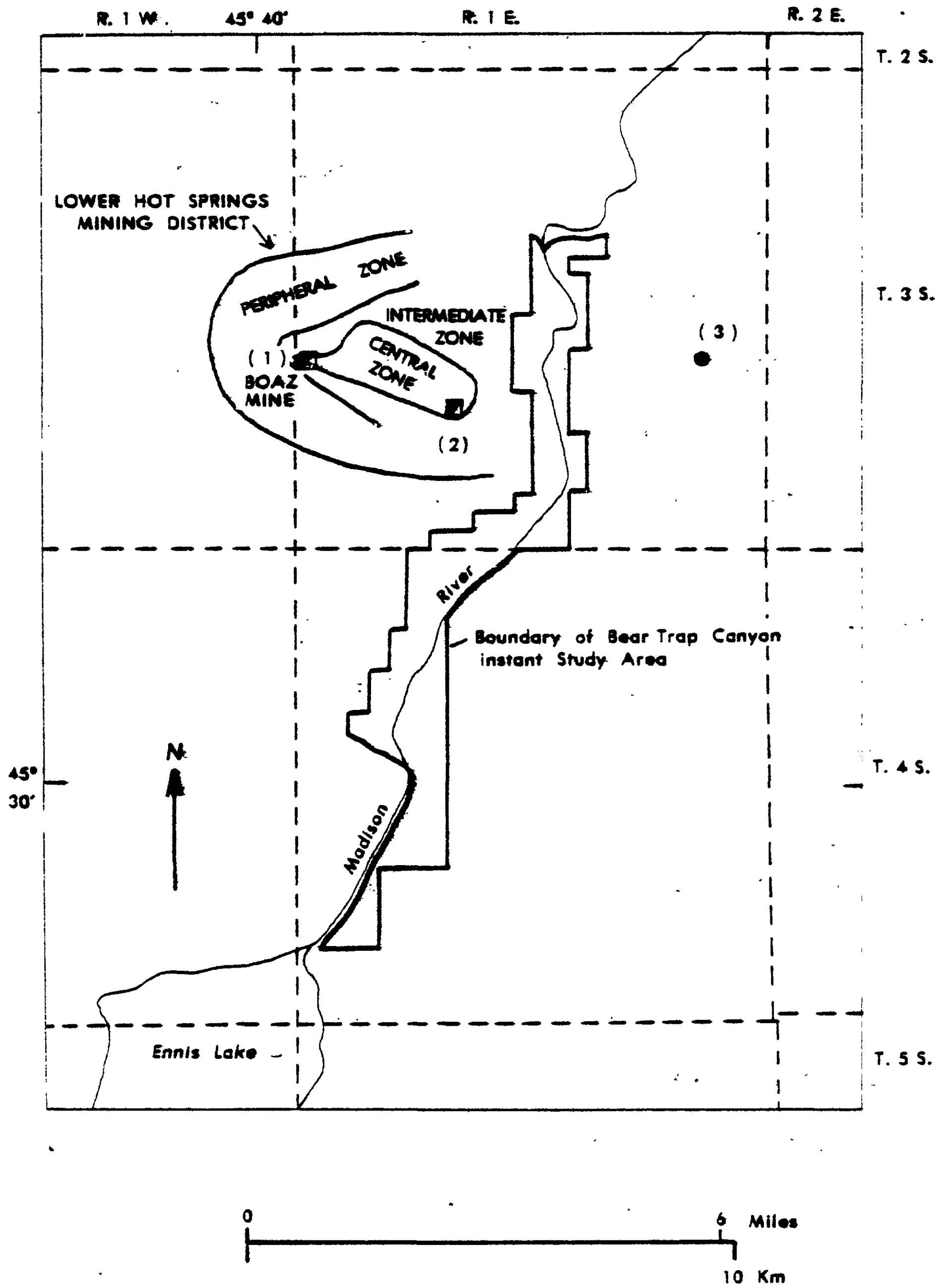

Figure 4.--Mineral resource potential map of the Bear Trap Canyon Instant Study Area showing the location of the Lower Hot Springs Mining District, Boaz Mine (1), Morning Star and Copper King claims (2), and chalcedony-hematite vein (3).

across both claims has been exposed in an adit with about 400 ft (120 m) of workings, including several small winzes, stopes, and cross-cuts. This prospect represents an inferred resource of about 40,000 tons (36,000 t) at an average grade of 3.1 oz silver per ton (106 g/t), assuming a minimum mining width of 5 ft (1.5 m). The veins and altered shear zones extend generally easterly from the mining district toward the study area. Possible extension into the study area, to the vicinity of the chalcedony vein shown on the map, was sought by geochemical surveys. However, as samples of sediment from streams draining the area of this possible extension lacked anomalous metal values, the district appears to end west of the study area. No indication of hydrothermal mineral deposits in the study area was found and alluvial deposits (placers) contained uneconomic traces of gold.

Mafic and ultramafic (komatiites) rocks, interlayered with granitic gneiss, have some potential for concentrations of nickel. These rocks occur in two forms: intrusive bodies in the form of small pipes and plugs that crosscut the wall-rock gneiss, and layers parallel or nearly parallel to the beds of gneiss. The layers are thought to be metamorphosed flows or sills, and the pipes and plugs to have been the feeders. Chemically, the rocks of both forms belong to a recently recognized rock suite called komatiite. Sixteen of 17 rock samples from the mapped area that were analyzed for major elements belong to this suite, according to chemical criteria of Naldrett and Cabri (1976). These samples include all of the dark-colored layered rocks (commonly referred to as amphibolites) analyzed (6 samples). Some amphibolite layers are as much as 330 ft (100 m) thick, indicating a sufficiently thick layer of magma. Thus, enough nickel sulfide might have been available to form deposits of nickel as is known from certain similar sills in Canada, Australia, and South Africa. Because of the presence of these komatiite sills, the study area is considered to have a low to moderate potential for deposits of nickel, although none were found and analyses of stream-sediment samples generally show low nickel values.

Small amounts of sillimanite and corundum occur in areas peripheral to the study area. These have not proved economic, however. No evidence suggests that larger or higher-grade deposits of these minerals might be found within the study area.

Metamorphic and igneous rocks, unfavorable for the occurrence of hydrocarbons, indicate no potential for coal, gas, or oil in the study area.

The temperature of the small felsite plugs shown on the geologic map (pl. 1) apparently is too low for the plugs to be sources of geothermal energy. None of them have either hot springs or hot spring deposits associated with them. Hence their temperature must be low now. Therefore the potential for geothermal energy in the study area is speculative.

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