Bedded Precambrian Iron Deposits of the Tobacco Root Mountains, Southwestern Montana

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By HAROLD L. JAMES

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A geologic description and resource appraisal of the iron-formation found in several localities

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BEDDED PRECAMBRIAN IRON DEPOSITS OF THE TOBACCO ROOT MOUNTAINS, SOUTHWESTERN MONTANA

By Harold L. James

ABSTRACT

Bedded deposits of iron-formation are minor components of the thoroughly metamorphosed and deformed Precambrian rocks that make up the core of the Tobacco Root Mountains. The rocks are Archean in age; they predate a major Precambrian orogeny that affected all of southwestern Montana about 2,750 m.y. ago. The principal bed of iron-formation occurs within a metasedimentary sequence that has dolomite marble at the base and rests on quartzofeldspathic gneiss of uncertain origin. The stratigraphic thickness of the preserved part of the metasedimentary group cannot readily be established because of structural complexities, including both thickening and attenuation, but it probably does not exceed 300 m. The true (original) thickness of the iron-formation is even more difficult to determine because of the structural incompetence of the rock, but it ranges from 15 to 30 m. All the rocks, with the exception of a few younger Precambrian (Proterozoic Y) diabase dikes, are metamorphosed to amphibolite or hornblende granulite facies. The iron-formation typically consists of quartz and magnetite, with subordinate amounts of iron silicates, mainly hypersthene, garnet, clinopyroxene, and grunerite.

The principal deposits of iron-formation are in the Copper Mountain area, an area of about 13 km^2 in the west-central part of the Tobacco Root range that has been mapped in some detail. The structure consists of an early set of tight isoclinal folds, trending north-south and overturned to the east, that are deformed by later crossfolds that trend and plunge northwest. The most prominent belt of iron-formation is on a tight anticlinal buckle within the north-south-trending Ramshorn syncline, a major structure of the first fold set. This belt of iron-formation is estimated to contain about 63 million t of potential low-grade ore (taconite) to a depth of 100 m. The rock contains about 35 weight percent Fe, mostly in the form of magnetite.

Iron-formation occurs in many other localities in the region as distinctive but thin and discontinuous units. Some deposits probably are stratigraphically equivalent to the iron-formation of the Copper Mountain area, but others have quite different lithologic associations and probably different ages.

INTRODUCTION

The Tobacco Root Mountains constitute one of several block uplifts in southwestern Montana that have been eroded to expose a core of older Precambrian rocks (fig. 1). The range occupies an area about 65 km long by 50 km wide, bounded on the north and west by the Jefferson and Ruby Rivers and on the east by the Madison River. Elevations range from about 4,500 ft in the bounding valleys to nearly 11,000 ft in the highest part of the range. Accessibility is fairly good; surfaced highways traverse the major valleys, and dirt roads extend up most of the tributary streams. The rugged uplands, however, can be reached only by foot, horseback, or off-road vehicles. Most of the area is within or adjacent to Beaverhead National Forest.

The present investigation, which has been carried on intermittently since 1961, focuses on the distribution and economic potential of banded iron-formation that occurs at several stratigraphic horizons within a complex sequence of metamorphic rocks. The principal area of interest (fig. 2) is a belt about 11 km long on the west flank of the range, east of the town of Sheridan, Mont. (fig. 2). The southern part of this belt, centering on Copper Mountain in sec. 1, T. 5 S., R. 4 W., was mapped by planetable (James and Wier, 1962); other areas were mapped or otherwise located on enlargements of the Copper Mountain 1:24,000-scale topographic base map.

The geology of the region has been described in a number of reports, notably those by Peale (1896), Tansley, Schafer, and Hart (1933), Reid (1957, 1963), and Burger (1967, 1969). The occurrences of iron-formation were described in summary fashion in a general study of Precambrian iron-formations of the United States (Bayley and James, 1973), and a comprehensive report on the mineralogy of these rocks was presented by Immega and Klein (1976). Data significant to the present report have been obtained from unpublished thesis studies, particularly those by Root (1965), Hess (1967), Gillmeister (1971), and Cordua (1973). C. J. Vitaliano, under whose direction many of these thesis studies were made, and his colleagues have prepared and recently published a generalized map incorporating the available data, both published and previously unpublished (Vitaliano and Cordua, 1979; see also Vitaliano and others, 1979).

Acknowledgments.—I have received assistance and information from many sources. Particular thanks are due to: the Northern Pacific Railway Co., for making available the results of a regional survey by geologists E. E. Thurlow, L. C. Binon, D. W. Lindgren, and R. K. Hogberg; the staff, visiting scientists, and students of the Indiana University Field Station in the northern part of the range, for their cooperation and many courtesies; and, finally, my colleague K. L. Wier, for his invaluable contributions to all phases of the field study.

GENERAL GEOLOGY

The Precambrian core of the Tobacco Root Mountains consists mainly of felsic to mafic gneiss and amphibolite, within which occur some strata of recognizably sedimentary origin, such as dolomite marble and quartzite. Throughout this assemblage the metamorphic grade is high, and structural complexity is the rule. The rocks, which are of Archean age (James and Hedge, 1980), are transected by undeformed diabase dikes of Proterozoic age (Wooden and others, 1978), and remnants of unmetamorphosed Precambrian sedimentary strata occur locally at the extreme north margin of the range (McMannis, 1963). These strata presumably represent a marginal facies of the Belt Supergroup, which was deposited in great thicknesses a short distance north and west of the present Tobacco Root Mountains during later Precambrian time (less than 1,600 m.y. ago).

The entire region was submerged during most of Paleozoic time, and the core rocks of the different ranges, including the Tobacco Root, Ruby, Gravelly, and Madison, were blanketed by a mantle of mostly marine sedimentary strata and, later, by a discontinuous cover of Mesozoic and Tertiary continental sedimentary and volcanic materials. The present distribution of these younger strata is related chiefly to late Mesozoic and early Tertiary deformation and subsequent erosion. During the earlier stages of this interval of crustal disturbance, igneous bodies of intermediate to felsic composition, some of batholithic dimensions, were emplaced. The block faults that control the form of the present mountain ranges were de-

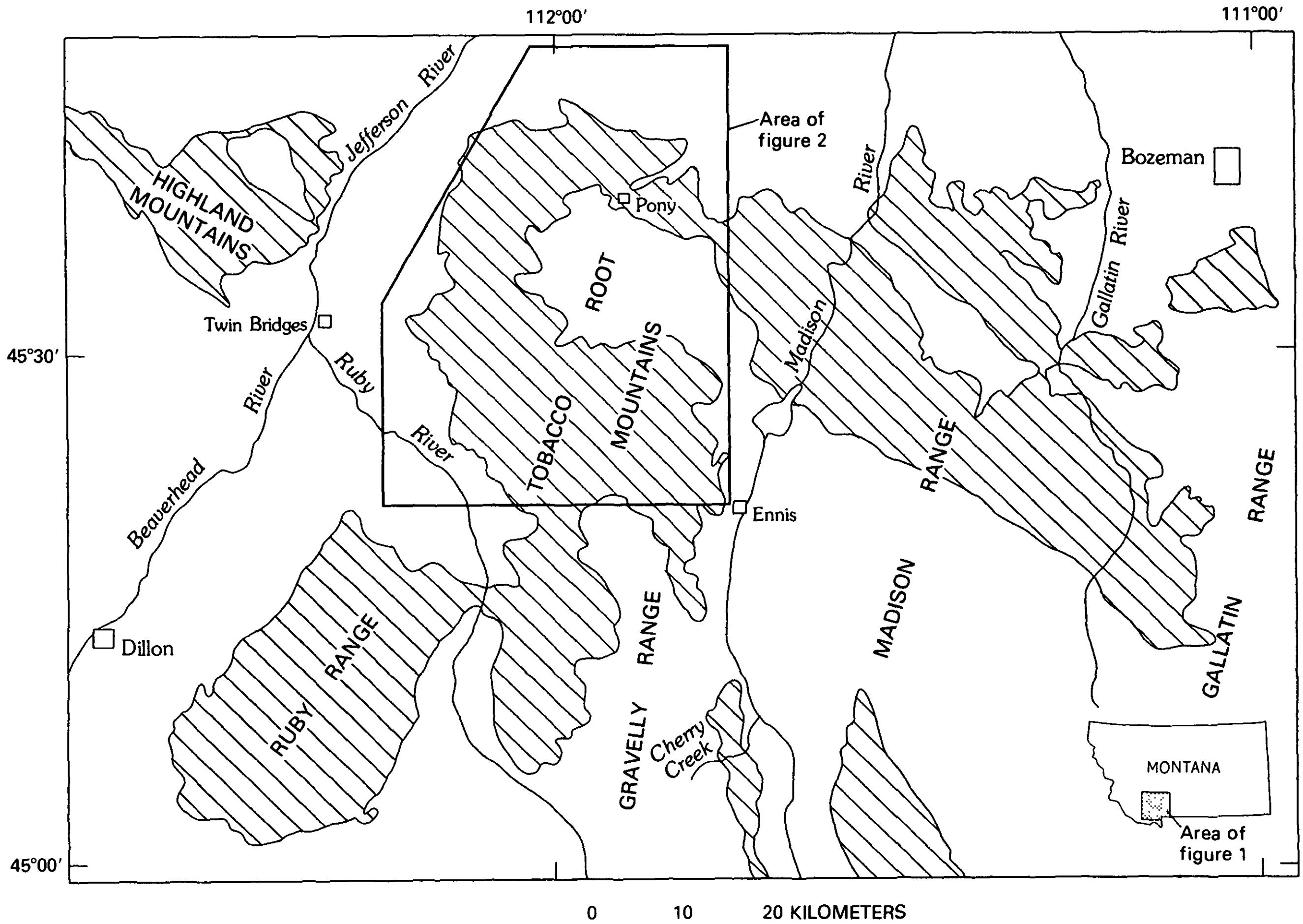

FIGURE 1.—Part of southwestern Montana, showing distribution of older Precambrian rocks (crosshatched areas) and outline of study area (fig. 2).

veloped later, mainly during middle and late Cenozoic time.

Much of the rock that makes up the Precambrian terrane is well layered. Gneiss of various compositions and indeterminate origin is interleaved with amphibolite and with metasedimentary rocks, among which dolomite marble, quartzite, and iron-formation are the most distinctive. Analysis of age relations and reconstruction of the original stratigraphy are greatly hampered, however, by the effects of intense metamorphism and deformation. Intrusive contacts that originally may have been crosscutting have been rotated into structural parallelism. Unconformities that may have been present within the sequence are no longer recognizable because of metamorphism and internal distortion. No indicators of original top directions (such as crossbedding) are preserved, and direction of dip in the metasedimentary strata means little except for general structural analysis. Although the age relations between the different lithologic units may ultimately be established by isotopic methods of analysis, progress will not be made readily because most of the isotopic systems were reset during the major metamorphic event, so that the earlier history has been largely lost. At the present time, determination of relative ages rests almost wholly on the physical distribution of strata involved in major structures—that is, on the assumption that metasedimentary strata within a major syncline, for example, are younger than the bounding strata. This assumption can be verified only by demonstration of the repeated occurrence of similar distribution patterns in the region.

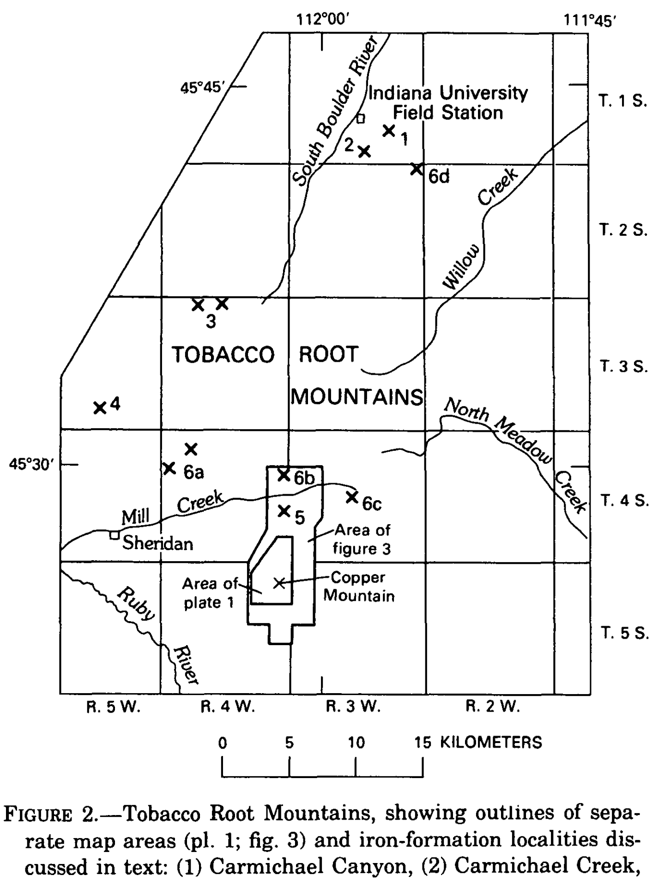

FIGURE 2.—Tobacco Root Mountains, showing outlines of separate map areas (pl. 1; fig. 3) and iron-formation localities discussed in text: (1) Carmichael Canyon, (2) Carmichael Creek, (3) Boulder Lakes-Brannon Lakes, (4) Dry Georgia Gulch, (5) Currant Creek, and (6) other reported localities: a, Indian Creek; b, Johnson Creek; c, South Fork of Mill Creek; d, Antelope Creek. See figure 1 for location. Base from U.S. Geological Survey Bozeman and Dillon quadrangles, scale 1:250,000.

The formal nomenclature available for classification and discussion of the Precambrian terrane is still primitive and unsatisfactory. The two names that have been used—the Cherry Creek Group and the Pony Group of Tansley, Schafer, and Hart (1933)—are of uncertain definition and validity.

The name "Cherry Creek" was introduced by Peale (1896) to designate a dolomite-bearing sequence of limited areal extent on the east flank of the Gravelly Range, physically separate from and some tens of kilometers southeast of the Precambrian terrane of the Tobacco Root Mountains. This name has been extended to adjacent ranges, including the Tobacco Root Mountains, solely on the assumption that the presence of dolomite (or dolomite marble) is definitive. This assumption has yet to be either proved or disproved. Correlation is further hampered by the fact that even at the type locality the nature of the succession is poorly known, and relations to other Precambrian rocks in the area are obscure (see Hadley, 1969).

The Pony Group of Tansley, Schafer, and Hart (1933) is a loosely defined sequence of gneiss, schist, and amphibolite, exposed in the northeastern Tobacco Root Mountains and assumed to be older than dolomite-bearing strata assigned to the Cherry Creek Group. The distinction between these two groups, however, is far from clear cut; both sequences contain similar lithologic assemblages, both have undergone similar metamorphism and deformation, and no conclusive field evidence as to relative age has emerged from the rather considerable amount of mapping done since 1933.

Broader regional relations in several ranges with Precambrian cores in southwestern Montana tend to support the general concept of a dominantly metasedimentary sequence distinguished by the presence of thick beds of dolomite marble and underlain by gneisses of indeterminate origin. Wider use of the names "Cherry Creek" and "Pony" is not justified, however, until more adequate definitions are available and until objective criteria for correlation have been established.

Currently, most workers in the region avoid using formal nomenclature and rely wholly on lithologic designations ("quartzofeldspathic gneiss," for example), a practice followed in this report. Ultimately, however, the strata grouped in this report under the heading "metasedimentary sequence" may be shown to be correlative at least in part with the dolomite-bearing sequence of the Cherry Creek area. Both sequences are characterized by beds of iron-formation.

Amphibolite of multiple origin, abundant throughout the Precambrian terrane, ranges in form from thin layers and boudins in felsic gneiss to concordant sheets hundreds of meters thick and kilometers in strike length. Although the thin layers may represent either original interbedded volcanic material or impure carbonate sediment, most of the thicker, homogeneous bodies probably originated as mafic sills, or as dikes that have been rotated into structural parallelism. No primary structures or textures are preserved, however, and so the nature and form of the original rock must remain speculative. Most of the amphibolite bodies have been metamorphosed and deformed to the same degree as the enclosing rock. A few of these bodies, however, were emplaced as dikes during some intermediate orogenic stage; these dikes, though converted entirely to pyroxene-garnet-hornblende amphibolite, retain their original form and sharply transect the foliation and layering of the country rock (Cordua, 1973).

Structural features in the areas of the Tobacco Root Mountains that have been studied in detail generally trend north-south. In the western part of the range, east of the town of Sheridan, Mont., the structural pattern is dominated by a series of tight folds outlined by a thin bed of dolomite marble (Burger, 1967, 1969). The major occurrences of iron-formation are within the most easterly of these structures, designated by Burger (1967) as the Ramshorn synform and referred to in this report as the Ramshorn syncline (fig. 3). Burger (1969) interpreted the structural pattern in this area as indicating an early phase of recumbent folding, followed by a refolding around north-south-trending axes to produce the present system of isoclinal folds. The present study confirms the conclusion that more than one period of strong deformation was involved, but it does not provide support for the concept of an initial recumbent folding. Rather, the observed north-south-

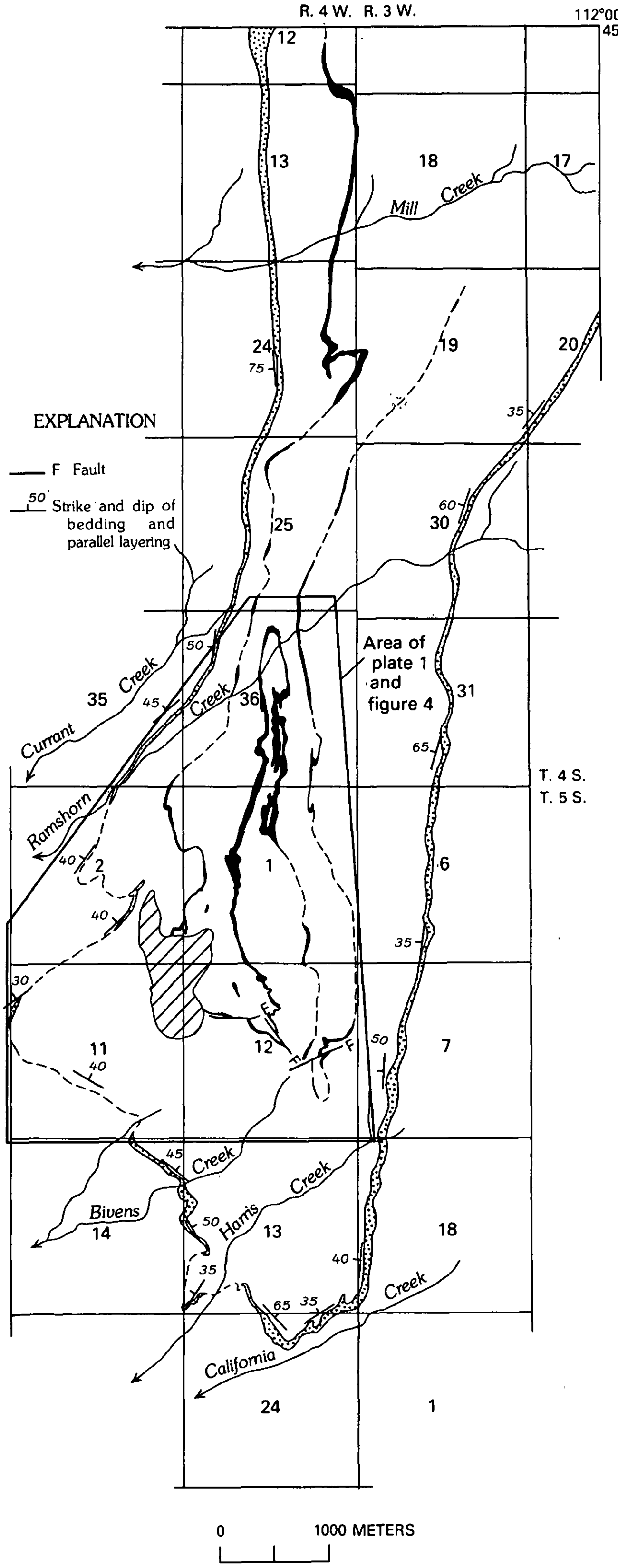

FIGURE 3.—Outline of Ramshorn syncline, as defined by dolomite marble (stippled areas), showing distribution of iron-formation (dark areas). Stratigraphic continuity is indicated by dashed lines. Younger intrusive bodies are not shown, except for stock between Ramshorn Creek and Bivens Creek (crosshatched area). Distribution of units north of Mill Creek is from Burger (1967). Area of detailed map (pl. 1) is outlined. See figure 2 for location.

trending isoclinal folds are believed to reflect the first and principal deformation, and the local structural complexities are due not to an earlier recumbent folding but to a later refolding around axes that trend and plunge about N. 20° W. These later crossfolds are clearly reflected by the map patterns in the Copper Mountain area (pl. 1; fig. 4). Except in the areas of crossfolding, therefore, the principal structures are considered to be overturned but otherwise normal anticlines and synclines, rather than stratigraphically indeterminate antiforms and synforms.

The system of overturned isoclinal folds and open crossfolds was further deformed at some later date into broad arches, such as those that dominate the structural pattern in the northern part of the range (Reid, 1957). The age of this arching is not precisely known, but it presumably postdates the major orogenic event about 2,750 m.y. ago and predates the emplacement of the earliest diabase dikes, about 1,400 m.y. ago. All the Precambrian rocks, including the unmetamorphosed diabase dikes, were, of course, also affected by much later movements related to the Laramide orogeny, with a mean age of perhaps 75 m.y. (Robinson and others, 1968), and by Cenozoic block faulting. Although the internal structures of the Precambrian complex were not greatly disturbed by these later movements, the gross pattern of rock distribution was strongly modified, particularly by displacement along north-south- and northwest-trending faults.

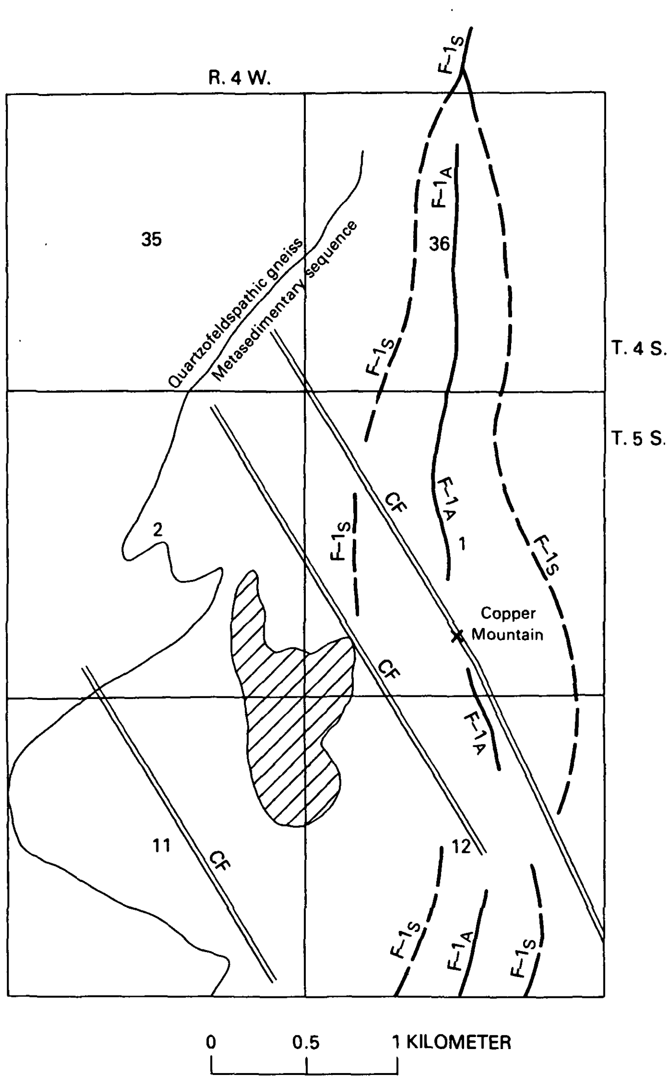

FIGURE 4.—Principal structural elements in Copper Mountain area. $F-1_A$, anticline of F−1 system; $F-1_S$, syncline of F−1 system; CF, crossfold. Quartzofeldspathic gneiss contact and Laramide stock (crosshatched area) are shown for reference. See figure 3 for location.

GENERAL FEATURES OF IRON-FORMATION

Bedded iron-formation is a minor component of most Archean terranes throughout southwestern Montana (Bayley and James, 1973). Few, if any, of these iron-formation units had initial thicknesses of as much as 30 m, but locally the apparent thicknesses may be much greater because of squeezing and complex internal folding. None of the deposits has been developed commercially, although many have been explored by trenching and drilling.

The different occurrences of iron-formation in the region are not necessarily stratigraphically equivalent. All are of Archean age, but the times of deposition of specific units could differ by tens of millions or even hundreds of millions of years. Some local correlations, however, do appear probable. The principal deposits described in this report—those of the Copper Mountain area and of other areas within the Ramshorn syncline—probably correlate approximately with the structurally separate iron-formation of the Kelly and Carter Creek areas of the Ruby Range (James and Wier, 1972a, b), some tens of kilometers to the southwest.

DESCRIPTION

Although the iron-formation of the Tobacco Root Mountains occurs at more than one stratigraphic horizon and therefore is not all of the same age, lithologically the rock is similar throughout. Magnetite and quartz are the principal minerals, and the rock is layered on a scale of centimeters or less. The layers generally are not sharply defined, however, and in places the rock appears gneissic. Tight internal folding, typical here as in other iron-formation, doubtless reflects the original finely layered structure, which permitted ready adjustment to external stress. The structural weakness of the rock is further shown by great variations in thickness and continuity that can be attributed to pinching and swelling of beds during deformation.

The iron-formation is not resistant to weathering in this region. Exposures are few, and most tend to be subdued relative to associated quartzite, gneiss, and amphibolite. The rock is readily traceable magnetically, however, and extensive use was made in the present investigation of tripod-mounted or hand-held magnetometers. The distinctive reddish-brown soil derived from weathered iron-formation also is of considerable aid in mapping.

The high content of magnetite in the iron-formation renders a standard Brunton-style compass impractical for measuring structural elements in outcrop or in exploratory trenches. Use of a sundial compass, or some other instrument unaffected by magnetism, is essential for reliable structural determinations in the field.

MINERALOGY AND CHEMISTRY

The iron-formation in the study area is composed of five essential minerals in widely varying proportions: magnetite, quartz, orthopyroxene, clinopyroxene, and garnet. Less common but locally abundant are specular hematite and various amphiboles, including grunerite, cummingtonite, hornblende, actinolite, and riebeckite. Other minerals, such as feldspars and apatite, generally are present only in trace amounts. The rock is medium to coarse grained; individual mineral grains generally are 0.5 to 3.0 mm in diameter, as observed in thin section, and the texture typically is granular. Most minerals are anhedral to subhedral, although magnetite (particularly as smaller grains enclosed in other minerals) may exhibit crystalline outlines.

The composition and character of the principal mineral phases were well described by Immega and Klein (1976). Orthopyroxene, generally the most abundant silicate, is a ferrohypersthene that in thin section is weakly pleochroic in tints of pink and green. The composition ranges from Fs_{60} to Fs_{75} (Immega and Klein, 1976, p. 1122); no exsolution is evident. The clinopyroxene is salite to ferrosalite, very pale green and nonpleochroic in thin section, and all grains of appropriate orientation show very fine exsolution lamellae. According to Immega and Klein (1976, p. 1124), these lamellae are orthopyroxene of the same composition as the coexisting separate grains—that is, ferrohypersthene in the compositional range Fs_{60-75}. Garnet, isotropic and faintly pink, is almandine containing less than 20 mol percent pyrope-spessartite. The amphiboles are a complex assemblage, both mineralogically and paragenetically. The most abundant varieties are members of the grunerite-cummingtonite series, which may occur as separate nearly colorless polysynthetically twinned grains, as exsolution lamellae in other amphiboles, or as fibrous marginal replacements of pyroxenes. The separate grains probably were formed in stable equilibrium with pyroxenes during prograde metamorphism, whereas the fibrous varieties were formed later as retrograde products, together with green hornblende, actinolite, and riebeckite—all of which occur as replacements of earlier minerals.

Table 1 lists chemical analyses of iron-formation from four localities in the Tobacco Root Mountains. The samples, each aggregating several kilograms, consisted of rock chips selected to be as representative of the iron-formation as possible without resorting to a more complex sampling procedure. The narrow range of iron contents in all samples (33–38 weight percent Fe—values characteristic of this facies of iron-formation) indicates that the samples were reasonably well chosen. Average analyses of two samples (5, 6) of iron-formation from the Carter Creek and Kelly areas of the nearby Ruby Range are listed for comparison.

Samples 1 and 2, from stratigraphically equivalent localities within the Ramshorn syncline, are similar in composition. Samples 3 and 4, of iron-formation from the Carmichael Creek and Boulder Lakes localities,

TABLE 1.—*Chemical analyses of iron-formation*

[Results in weight percent; n.d., not detected. Analyses of samples 1–4 by Vertie C. Smith; location data as follows: (1) Copper Mountain area, 1,600 ft N., 2,560 ft E. of SW. cor. sec. 36, T. 4 S., R. 4 W.; (2) Currant Creek area, 700 ft W., 2,700 ft N. of SE. cor. sec. 24, T. 4 S., R. 4 W.; (3) Carmichael Creek, 1,100 ft E., 1,000 ft S. of NW. cor. sec. 34, T. 1 S., R. 3 W.; (4) Boulder Lakes, 2,100 ft E., 1,500 ft S. of NW. cor. sec. 5 (unsurveyed), T. 3 S., R. 4 W. Samples 5–6 from Bayley and James (1973, table 5): (5) average of two analyses (A and B) from Carter Creek area; (6) average of two analyses (C and D) from Kelly area]

	Tobacco Root Mountains				Ruby Mountains	
Sample	1	2	3	4	5	6
SiO_2	42.24	49.04	44.47	42.13	44.61	39.79
Al_2O_3	1.34	1.35	4.01	2.17	.69	2.21
Fe_2O_3	34.26	30.85	24.42	29.55	35.17	32.49
FeO	18.17	14.99	20.30	20.44	14.07	19.05
MgO	1.66	1.13	2.19	2.14	2.68	2.43
CaO	.68	1.26	1.29	1.51	1.30	1.88
Na_2O	.01	.03	.28	.08	.32	.10
K_2O	.00	.01	1.47	.54	.12	.71
H_2O^+	.21	.13	.40	.37	.39	.32
H_2O^-	.15	.13	.12	.08	.04	.15
TiO_2	.03	.01	.19	.01	.01	.09
P_2O_5	.02	.02	.06	.10	.53	.10
MnO	1.52	1.50	.56	.86	.05	.74
CO_2	.01	.01	.00	.06	.08	.15
Cl	n.d.	n.d.	.01	n.d.	.01	.00
F	n.d.	n.d.	.01	n.d.	.02	.01
S	<.05	<.05	.00	<.05	.00	.06
C	.08	.06	n.d.	.06	.01	.01
Subtotal	100.38	100.52	99.76	100.12	100.10	100.29
Less O	------	------	.01	------	.01	.03
Total	100.38	100.52	99.75	100.12	100.09	100.26
Fe	38.08	33.23	32.86	36.56	35.53	37.53
Mn	1.18	1.16	.44	.67	.04	.57

respectively (neither of which is believed to be correlative with iron-formation of the Ramshorn syncline), contain substantially more Al_2O_3, MgO, CaO, and K_2O, reflected mineralogically in a greater variety and abundance of silicate minerals.

The manganese content of all four samples from the Tobacco Root Mountains, as well as of an average sample (6) from the Kelly area of the Ruby Mountains, is distinctly higher than that of most iron-formation of similar mineralogy, but otherwise the analyses fall within a normal compositional range (see James, 1966, p. 21).

Table 2 lists the minor-element contents of four analyzed samples from the Tobacco Root Mountains, along with average crustal abundances for comparison. The compositions of samples from stratigraphically equivalent deposits in the Copper Mountain and Currant Creek areas are, as might be expected, much alike, whereas samples from deposits in the outlying Carmichael Creek and Boulder Lakes areas are appreciably richer in several elements. All samples, however, are distinctly depleted in minor elements in comparison with crustal abundances in general.

ORIGIN

Despite the high grade of metamorphism, the iron-formation of the Tobacco Root Mountains retains most of its primary compositional and structural features. The original material can reasonably be inferred to have been a chemical sediment, which after diagenesis probably consisted of interlayered chert, magnetite, and such iron silicates as greenalite and chamosite—that is, rock similar to the magnetitic facies of relatively unmetamorphosed iron-formation, such as that of the western Mesabi Range in Minnesota. The principal effects of metamorphism have been a great increase in the grain size of the persistent minerals (quartz and magnetite) and the formation of higher grade iron silicates (pyroxenes, garnet, and amphiboles). The bulk chemistry and the layered structure remain essentially unchanged.

The principal beds of iron-formation—those in the Copper Mountain area—are associated stratigraphically with clastic rocks and dolomite that suggest accumulation in a shallow-water, shelf, or shallow-basin environment.

TABLE 2.—*Minor-element content of iron-formation from the Tobacco Root Mountains*

[Six-step semiquantitative spectrographic analyses by Harriet G. Neiman. Results in parts per million; n.d., not detected. Not detected in any samples: Ag, Au, B, Be, Bi, Cd, Ce, Eu, Ga, La, Mo, Nb, Pb, Pd, Pt, Sb, Sc, Te, U, W, Zn. Values shown are midpoints of geometric brackets whose boundaries are 12, 8.3, 5.6, 3.8, and so on. Precision is approximately one bracket at the 68-percent confidence level. Location data same as in table 1]

	Copper Mountain	Currant Creek	Carmichael Creek	Boulder Lakes	Average crustal abundance (Mason, 1958, p. 44)
Sample	1	2	3	4	
Ba	20	10	500	150	400
Co	n.d.	n.d.	15	5	23
Cr	10	3	100	20	200
Cu	10	15	15	15	45
Ni	5	20	50	5	80
Sr	5	7	30	30	450
V	5	n.d.	50	7	110
Y	n.d.	n.d.	n.d.	10	40
Zr	10	n.d.	20	n.d.	160

COPPER MOUNTAIN AREA

The Copper Mountain area, on the west flank of the Tobacco Root Mountains east of the town of Sheridan, Mont., contains the thickest and most extensive deposits of iron-formation in the range. This area has, therefore, been mapped in some detail (see pl. 1), to unravel the complex structural and lithologic relations and to provide a sound basis for resource evaluation.

The mapped area (fig. 3) covers about 15 km^2 of foothills, mainly between Ramshorn Creek on the north and Bivens Creek on the south. Elevations range from about 6,000 to 7,334 ft, at Copper Mountain. Much of the area is covered by an open pine forest, interrupted by broad patches of grass and sagebrush. Dirt roads extend eastward from the main highway in the Ruby Valley up most streams; these roads connect to form a network that provides ready access to all parts of the area.

Other than certain igneous or metaigneous rocks, only two lithologic units in the area are entirely distinctive and stratigraphically definable: dolomite marble and iron-formation. These two units serve to define the metasedimentary sequence that rests on quartzofeldspathic gneiss.

QUARTZOFELDSPATHIC GNEISS

The quartzofeldspathic gneiss, represented on the map only by a narrow belt along the west margin of the Copper Mountain area, is part of a gneiss unit of wide extent in the Precambrian complex constituting the core of the Tobacco Root Mountains (Vitaliano and Cordua, 1979). The gneiss underlies much of the adjoining Sheridan district immediately to the north of the Copper Mountain area, well described by Burger (1967), and is particularly well exposed in prominent bluffs along the several valleys incised into the west flank of the range.

The gneiss varies but most typically is a massive distinctly layered medium-grained gray rock. The layers range from centimeter-thick laminae defined by varying proportions of mafic minerals (generally biotite, less commonly garnet or hornblende), to sheets of amphibolite 300 m or more thick. Thinner layers of amphibolite locally have been broken into boudins as large as 10 m in maximum dimension. Some outcrops of the gneiss are migmatitic and exhibit seams and veins of granitic or pegmatitic aspect; others are rich in garnet. Burger (1967, p. 5) reported that persistent thin beds of quartzite are dispersed throughout the gneiss in the Sheridan district, but none has been observed within the Copper Mountain area.

In view of the heterogeneity of the gneiss, no single description can adequately depict its mineralogy. The most common assemblage is quartz-perthite-oligoclase in which quartz and perthite generally make up 70 to 90 percent of the rock. The texture is allotriomorphic, granular to irregular; cataclastic textures are not particularly prominent, but in some specimens the larger quartz and perthite grains are lenticular and are set in a matrix of smaller quartz grains and nonperthitic microcline. A less common rock type, well exposed along Ramshorn Creek in the NE¼NW¼ sec. 2, T. 5 S., R. 4 W., is a migmatite containing, in order of abundance: quartz, albite or oligoclase (in clear twinned grains), nonperthitic microcline, biotite, and green hornblende. The texture of the migmatite is allotriomorphic to hypidiomorphic granular and shows no evidence of cataclasis.

Other rock types within the quartzofeldspathic gneiss in the Copper Mountain area include garnet-plagioclase-quartz gneiss and, at one locality in the SW¼ sec. 2, T. 5 S., R. 4 W., cordierite gneiss.

METASEDIMENTARY SEQUENCE

The sequence here designated the "metasedimentary sequence" is distinguished by the presence of two marker beds—dolomite marble and iron-formation—that constitute the two main mappable units. The gneiss, quartzite, and schist unit between the dolomite marble and the iron-formation units, and the quartzite and schist unit above the iron-formation unit, are composite, consisting in part of such recognizable metasedimentary rocks as quartzite and in part of schist and gneiss of indeterminate origin. These two composite units are defined almost wholly by their stratigraphic relation to the two marker beds, rather than by any distinctive lithology.

DOLOMITE MARBLE

The dolomite marble unit is discontinuous within the Copper Mountain area but forms a persistent marker bed that outlines the Ramshorn syncline (fig. 3). The true thickness of the unit probably is no more than about 30 m. Gaps in areal continuity may be due either to structural attenuation or to such primary factors as nondeposition or erosion.

In outcrop the dolomite marble is characteristically dove gray to tan. The texture is sugary, and on exposed surfaces scattered grains of such silicate minerals as forsterite and diopside commonly project above the less resistant carbonate matrix. On fresh break the rock is pale gray, and the colorless silicates are inconspicuous; more readily recognizable are the minor constituents phlogopite and graphite. Calc-silicate gneiss of various types locally is present as marginal facies or as extensions along strike beyond pinchout of the carbonate unit; these rocks consist of varying proportions of diopside, garnet, amphiboles, quartz, and plagioclase.

Retrograde or hydrothermal alterations of the dolomite marble commonly are profound, although the general appearance of the rock remains unchanged. Forsterite is altered to pale-green serpentine, and in places all the metamorphic minerals have been replaced by talc, which is commercially exploited elsewhere in the region. Calc-silicate gneiss typically is altered to epidote or clinozoisite.

GNEISS, QUARTZITE, AND SCHIST

The gneiss, quartzite, and schist unit is lithologically complex; it comprises all the strata between the dolomite marble and the principal iron-formation units. The constituent rock types are tonalite gneiss, garnet gneiss, quartzite, schist, iron-formation, and amphibolite.

Tonalite gneiss, which probably make up 50 percent or more of the unit, generally is poorly exposed and forms a matrix for more resistant strata, such as quartzite. The gneiss generally is moderately well layered. The essential minerals are quartz and oligoclase (rarely andesine), with minor potassium feldspar and varying amounts of biotite, green hornblende, and garnet. *Garnet gneiss* (including garnet amphibolite) is characteristic of the basal part of the unit, directly overlying the dolomite marble. The proportion of garnet varies but in places is more than 50 percent of the rock. Some of the gneiss appears quartzitic but in thin section is seen to be composed, in addition to garnet, principally of microcline and quartz, with minor albite-oligoclase and reddish-brown biotite. Garnet-rich amphibolite is a common associate. In places the garnet in the gneiss and amphibolite is sufficiently abundant to give rise to a reddish-brown iron-rich soil similar to that developed on iron-formation; this material has been extensively trenched in the W½ sec. 7, T. 5 S., R. 3 W., just beyond the limits of the Copper Mountain area. *Quartzite* is the most prominently exposed rock type in the unit, and several individual beds have been mapped (pl. 1). The quartzite is not restricted stratigraphically within the unit, but it is more abundant in the upper part than in the lower.

Although none of the individual beds can be traced for much more than a kilometer, they do serve as excellent indicators of local structure. The quartzite that has been mapped separately, such as at Copper Mountain, typically is coarse grained and yields a hackly, rough outcrop. The color is gray on fresh break but pink, tan, or yellowish on exposed surfaces. Bedding is poorly preserved, although the rock tends to be layered or sheeted parallel to contacts. Quartz makes up more than 95 percent of the rock. Green chrome mica is a scarce but distinctive accessory, and in thin section occasional grains of microcline and needles of sillimanite are also observed. *Schist* is particularly abundant in the uppermost part of the unit, underlying the principal iron-formation of the area, where it is commonly interbedded with quartzite. Most varieties are rich in quartz and contain varying amounts of biotite, microcline, garnet, and sillimanite, as well as rare albite and muscovite. *Iron-formation*, a distinctive but very minor component of the unit, rarely is exposed, although its presence is readily evident from float. None of the observed beds is thicker than 3 m, and most are much thinner. The most persistent, though not the most continuous, layer is near the base of the unit, 30 m or so stratigraphically above the dolomite marble and associated with garnet gneiss and quartzite. Physically the rock is essentially identical with the main iron-formation; it consist of interlayered magnetite and quartz and contains varying amounts of hypersthene, clinopyroxene, and garnet. The gneiss, quartzite, and schist unit encloses several large bodies of *amphibolite*, separately designated on the map (pl. 1), and contains many smaller unmapped layers and pods. The amphibolite in these smaller bodies differs from that in the larger only in that it commonly shows more evidence of metamorphic reaction and exchange with the adjoining more felsic rocks.

IRON-FORMATION

The general properties of iron-formation in this region are described in a previous section, and so the discussion here is limited to those aspects specific to the stratigraphic unit so designated on the map (pl. 1). The bulk of this iron-formation occurs on the nose and flanks of a central anticlinal buckle within the Ramshorn syncline. The average outcrop width of iron-formation in this anticlinal belt is about 30 m. Dips are generally steep. Complex folding can be observed in all exploration trenches that cross the unit; axial planes vary in direction and amount of dip, but the fold axes plunge consistently to the north. On the west limb of the central anticline, the bed of iron-formation is readily traceable for more than 3 km and ranges in outcrop width from 10 to 120 m. The east limb is complex in map pattern at this particular level of truncation; outcrop widths are 100 m or more in several localities, but the bed pinches out entirely in the N½ sec. 1, T. 5 S., R. 4 W.

Throughout the remainder of the Copper Mountain area the iron-formation unit is relatively thin (generally thinner than 6 m), and pinchouts are common. Complex but complete structural closure at the south end of the area (pl. 1) reflects the larger structure of the Ramshorn syncline.

At the north end of the Copper Mountain area (pl. 1) the iron-formation is present on both limbs of the Ramshorn syncline, although the unit is thin and discontinuous. As indicated on the more general map of the syncline (fig. 3), sparse evidence permits extension of the bed on the east limb of the structure for about 3 km beyond the map area, into the N½ sec. 19, T. 4 S., R. 3 W. On the west limb of the Ramshorn syncline the bed can be traced with considerable assurance across Mill Creek to an apparent pinchout in sec. 12, T. 4 S., R. 4 W. The original bed now represented by the iron-formation of the Copper Mountain area probably had an average thickness of about 15 m. Greater apparent thicknesses and pinchouts are attributed principally to structural deformation.

QUARTZITE AND SCHIST

Like the units that separate the dolomite marble from the principal iron-formation, the uppermost unit of the metasedimentary sequence—the quartzite and schist unit—is composite. The most prominently exposed rock within the unit is quartzite, one bed of which has been traced around the nose of the central anticlinal buckle within the larger Ramshorn syncline and for some distance along the flanks of the adjacent marginal synclines. The quartzite is coarse grained, massive to poorly bedded, and white to mottled yellow or pink in outcrop. Green chrome mica, perthitic microcline, and fibrous sillimanite are accessory minerals. The matrix within which the quartzite layers occur is very poorly exposed but appears to consist principally of schist and various gneisses. Quartz-biotite schist, which stratigraphically overlies the iron-formation in several trench exposures, consists of crenulated layers of quartz separated by biotitic layers that commonly contain some garnet, more rarely microcline and sillimanite.

Many varieties of gneiss have been observed in the unit. In the SW¼ sec. 1, T. 5 S., R. 4 W., west of Copper Mountain, is a body of pink foliated aplitic gneiss that consists mainly of granular quartz, oligoclase, potassium feldspar, and very minor biotite. Hypersthene-rich gneiss or its altered equivalent has been observed in several places; the rock is dark, well layered, and composed of mixtures of hypersthene, plagioclase, biotite, garnet, and quartz. Alteration to pale-green amphibole and epidote is common. Other gneisses are tonalitic to granitic in composition.

AMPHIBOLITE

As previously noted, the amphibolite of this region probably is of multiple origin. On the basis of distribution and internal homogeneity, however, the larger, separately mapped bodies within the Copper Mountain area (pl. 1) are believed to have originated as mafic sills that since have been metamorphosed and reshaped by deformation. The typical rock is dark, massive to poorly layered, and medium grained. Foliation commonly is distinct, lineation less so. Despite a general uniformity of appearance in outcrop, however, the microscope reveals considerable variation in the mineralogic makeup. The most common assemblage comprises three essential minerals—green to brownish-green hornblende, plagioclase (andesine to bytownite), and quartz—in a proportion of about 40:40:20. In other assemblages, hypersthene, diopside, or garnet are major constituents. Sphene and magnetite are the usual accessory minerals, and alterations to epidote, actinolite, and cummingtonite are also common.

The principal bodies of amphibolite range from structurally concordant sheets, continuous for a kilometer or more along strike, to thick lenses and pods whose form appears clearly related to their structural position on major folds. Although no proof is available, the general pattern suggests that the amphibolite behaved plastically during the major deformations and that its present forms and distribution are in considerable part due to postemplacement flowage.

ULTRAMAFIC ROCKS

Several small bodies of ultramafic rocks are present in the Copper Mountain area (pl. 1); the largest body is at Copper Mountain itself. In outcrop the rock generally is dark gray to greenish gray, massive, and dense to fine grained. The largest ultramafic body varies greatly in appearance and mineralogy. The central part is composed principally of serpentine, loosely studded with grains of nearly colorless clinopyroxene (probably diopside) and scarce grains of brown chromite. Thin trails of magnetite dust mark the location of preexisting olivine. In places this assemblage is almost completely replaced by dark carbonate in which a few relict blebs of serpentine and colorless amphibole are preserved. Toward its margins the ultramafic body is progressively altered to dark amphibole, black in hand specimen but pale bluish green in thin section. This amphibole-rich schist is in contact with biotite schist, some of which probably represents an end product of metamorphic reaction between the ultramafic rocks and the enclosing schist and quartzite (here showing copper mineralization).

Elsewhere in the area the ultramafic rocks show still other mineralogic associations, including partially serpentinized olivine and enstatite, serpentine with relict olivine and metamorphic tremolite, and hypersthene with phlogopite and pleonaste.

The complex mineralogy of the ultramafic rocks reflects an equally complex structural and metamorphic history. The location of the rock bodies with respect to structural features indicates that these bodies were emplaced by flowage during deformation. The Copper Mountain mass is a diapir emplaced along the axis of an anticlinal crossfold, and a similar origin is likely for the dikelike mass a kilometer or so to the southeast. Although the loci and timing of emplacement of the initial ultramafic intrusive bodies in the supracrustal rocks of the region are unknown, the bodies probably were initially emplaced early in the structural and metamorphic history of the area, possibly even before deposition of the metasedimentary sequence.

DIABASE

The late Precambrian—that is, the Proterozoic—is represented in the Copper Mountain area by a few scattered diabase dikes that sharply truncate the structures of all other Precambrian strata. The diabase is gray on fresh breaks, brown on weathered surfaces. Exposures generally are poor, but spheroidal weathering gives rise to a distinctive gravellike rubble. Mineralogically the rock is composed essentially of labradorite, clinopyroxene, and magnetite-ilmenite, and ranges in texture from intersertal to ophitic. Despite the fresh appearance in hand specimen and the complete retention of primary textures, the rock typically shows a significant degree of alteration; labradorite is marginally altered to albite and sericite, and the pyroxene in places is almost completely replaced by hornblende and biotite.

The several dikes in the Copper Mountain area are part of a northwest-trending swarm that crosses the southern part of the Tobacco Root Mountains. According to Wooden, Vitaliano, Koehler, and Ragland (1978), the dikes have Rb-Sr ages that range from about 1,120 to 1,455 m.y.

QUARTZ DIORITE AND PORPHYRY

The magmatic phase of the Laramide orogeny is represented in the Copper Mountain area by a small stock of quartz diorite (pl. 1) that centers on the common corner of secs. 1, 2, 11, and 12, T. 5 S., R. 4 W., and by many small bodies of monzonite(?) porphyry. The probable age of these intrusive rocks is about 75 m.y. (Robinson and others, 1968).

The quartz diorite is massive fine- to medium-grained dark-gray rock that in places is somewhat porphyritic. In thin section the texture generally is dominated by phenocrysts, as long as 6 mm, of plagioclase and green hornblende, set in a finer grained matrix of plagioclase, potassium feldspar, and quartz. The plagioclase is strongly zoned (commonly in oscillatory fashion) andesine to albite. Augite and brown biotite are present in a few samples, and magnetite is an abundant accessory mineral.

The porphyry is buff in outcrop, dark gray on fresh break. Blocky white feldspar crystals, some a centimeter long or longer, establish the porphyritic texture. All specimens examined in thin section are so profoundly altered to sericite, quartz, potassium feldspar, and chlorite that the original mineral assemblage cannot be established with certainty. Relict crystals of plagioclase, potassium feldspar, and (more rarely) quartz are partially preserved in some specimens, and so the rock probably can be classed as monzonite porphyry (or, possibly, quartz monzonite porphyry).

STRUCTURE

The principal element governing rock distribution in the Copper Mountain area is a structural triad that consists of a central anticlinal buckle and a complementary pair of flanking synclines, all within an upward bulge along the axis of the Ramshorn syncline (fig. 4). These folds, considered to have formed during the first major structural deformation of the region, are here designated the "F–1 system." The F–1 structures are tightly isoclinal and strongly overturned to the east; the regional trend is about N. 15° E., and the plunge is at low angles to the north. In detail, however, particularly in and adjacent to such structurally incompetent strata as iron-formation, structural attitudes may diverge markedly from regional trends.

In the south half of the Copper Mountain area, the map expression of the F–1 folds is profoundly affected by a series of crossfolds, here designated the "F–2 system." Copper Mountain itself lies at the intersection of the central anticlinal buckle ($F–1_A$, fig. 4) with an F–2 crossfold that is also reflected by a reversal of dip in the belt of iron-formation that flanks Copper Mountain on the west: from about 70° W. in the north to about 45° E. in the south. The F–2 crossfolds trend about N. 25° W., or at an angle of about 40° to the regional trend of the F–1 system. As in the F–1 system, fold axes plunge to the north at relatively low angles, generally about 35°; axial planes, however, appear to be essentially vertical, in contrast to the strongly overturned F–1 system.

A notable feature of the F–2 crossfolds is the great thickening of certain rock units, notably quartzite and amphibolite, at structural troughs and crests. Some quartzite masses have become entirely isolated, as at Copper Mountain, where the crossfold axis also is marked by a diapiric body of ultramafic rock. Greatly overthickened masses of quartzite and amphibolite also lie along the axes of other crossfolds, such as that in sec. 11, T. 5 S., R. 4 W. The plastic behavior of these rocks strongly indicates that the crossfolding, like the initial folding that created the isoclinal F–1 system, took place while the rocks were still deeply buried.

Minor folding is particularly characteristic of the iron-formation; in fact, every clear exposure, such as those in the many exploration trenches, reveals intense crumpling, commonly with infolding of the adjacent quartzite and schist. These folds differ from those produced by contemporaneous ("soft rock") deformation in that their patterns are, within moderate limits, systematic with respect to larger structures.

Several faults of small displacement have been mapped in the southern part of the area; they commonly are marked by wide zones of loose deeply oxidized breccia and probably were formed during the Laramide orogeny. A few zones show minor mineralization.

GEOLOGIC HISTORY

Except for the late Precambrian diabase dikes and the Laramide intrusive bodies, the bedrock strata of the Copper Mountain area are of Archean age; all were profoundly metamorphosed during an orogenic event about 2,750 m.y. ago (James and Hedge, 1980). This event, generally referred to as the Beartooth orogeny, is deeply engraved in the Precambrian rocks throughout the Rocky Mountains of Wyoming and Montana. In its type area, the Beartooth Mountains of Montana, a partial geochronology of earlier events has been established, notably by Reid, McMannis, and Palmquist (1975) for the North Snowy block. The metasedimentary component of that terrane, which has a minimum age of about 3,100 m.y., was metamorphosed and intruded by the Mount Delano Gneiss of Reid, McMannis, and Palmquist (1975) and underwent further metamorphism and igneous intrusion during the Beartooth orogeny. Page (1977) concluded that the Stillwater Complex of the Beartooth Mountains intruded a metasedimentary sequence (including iron-formation) with a minimum age of 3,140 m.y.

A comparably complex history is likely for the Archean strata of the Tobacco Root Mountains, but, as yet, geochronologic investigations have not been able to penetrate the 2,750-m.y. veil. Geologic relations suggest that the oldest rock is quartzofeldspathic gneiss, probably in part igneous and in part sedimentary in origin. The gneiss precursor, whatever it may have been, was then overlain by a sequence of shallow-water marine deposits, now represented by the dolomite marble, quartzite, and iron-formation that are the distinctive units of the metasedimentary sequence in the Copper Mountain area. By analogy with other Precambrian areas in Montana, these sedimentary rocks could be 3,000 m.y. old or older.

The Archean history subsequent to deposition of the metasedimentary sequence is highly complex and incompletely understood. It involves, minimally: emplacement of the tonalitic and granitic rocks that are now interlayered as gneiss with schist and quartzite; widespread emplacement of mafic dikes and sills, now represented by ubiquitous amphibolite; intense isoclinal folding along northeast-trending axes (F–1 system), accompanied by dynamothermal metamorphism to amphibolite or granulite facies and probably also by syntectonic emplacement of granitic intrusive bodies; refolding on northwest-trending axes (F–2 system), with characteristic intense squeezing of such units as quartzite and amphibolite, and diapiric emplacement of the ultramafic rocks; and remetamorphism of the entire terrane, again to amphibolite facies. Many of these events may have been overlapping in time, or even contemporaneous, in some areas.

At a later time, presumably after the 2,750-m.y. orogeny, the Archean strata in parts of the Tobacco Root Mountains were further deformed into broad arches, and many rocks were affected by retrograde metamorphism. These retrograde alterations—possibly entirely unrelated to the regional arching—may reflect a thermal event known to have reset the K-Ar isotopic system in this part of Montana so as to yield apparent ages of about 1,600 m.y. (Giletti, 1966). Scattered dikes of tourmaline pegmatite (none within the Copper Mountain area) probably were emplaced at that time.

The Tobacco Root Mountains appear to have been largely emergent in Proterozoic time, when the enormous thickness of clastic rocks that make up the Belt Supergroup was deposited a short distance to the north and northwest. In the main part of the range, the only preserved rocks that record this period are undeformed diabase dikes, ranging, according to Wooden, Vitaliano, Koehler, and Ragland (1978), from 1,120 to 1,455 m.y. in age. Thus, this region was stable for many hundreds of millions of years before it was blanketed by sedimentary and volcanic deposits of Cambrian and younger age and underwent, during late Mesozoic and Cenozoic time, the structural dislocations that created the present mountain ranges.

EXPLORATION

The iron-formation of the Copper Mountain area was actively explored during the decade 1955–65, largely under the auspices of the late Lester Sheridan of the F & S Construction Co., Butte, Mont., with technical advice from the Anaconda Co. of Butte. The claims at that time were held by William Bray, Harry Stein, and Lloyd Miller of Sheridan, Mont.; present ownership is not known.

The exploration consisted of about two dozen trenches across the iron-formation, as well as several (perhaps as many as a dozen) diamond-drill holes. The trenches range in length from 15 to 150 m, and in depth from 2 to 6 m; the aggregate length of cut is about 1,500 m. These trenches provide by far the best exposures in the area for examination and sampling of the iron-formation, although deep oxidation and hillslope creep must be taken into account. No records of the drill holes are available, although several drill sites with discarded core nearby were recognized during the field mapping.

OUTLYING AREAS OF IRON-FORMATION

Although the iron-formation of the Tobacco Root Mountains occurs principally in the Copper Mountain area, as described above, iron-formation is known to be present in several other localities (fig. 2). Some exposures, such as those in the Currant Creek and Johnson Creek areas, are simply stratigraphic continuations of the iron-formation of the Copper Mountain area and are separately denoted only because of increased dimensions or exploration activity. Others, such as those in the Boulder Lakes-Brannon Lakes area, are of undetermined stratigraphic position. Most deposits are either too small or too poorly exposed to warrant more than a brief note. The descriptions that follow are keyed by locality number to the index map (fig. 2).

CARMICHAEL CANYON (1)

The Carmichael Canyon area (so designated for want of a geographically more appropriate label) is in the northern part of the Tobacco Root Mountains, within the drainage of the South Boulder River. The deposits are in the NE¼ sec. 26, T. 1 S., R. 3 W. (fig. 5), at an elevation of about 6,500 ft, and are accessible by a dirt road. The iron-formation occurs as narrow discontinuous vermicular stringers in a matrix of quartzite, schist, and amphibolite. The mineralogic makeup typical for the iron-formation of this region consists dominantly of quartz and magnetite and includes varying amounts of clinopyroxene, hypersthene, and grunerite. The iron-formation has been explored by a number of shallow trenches and scrapings, but the aggregate amount revealed in these developments and in outcrop is insignificant.

CARMICHAEL CREEK (2)

The Carmichael Creek occurrence of iron-formation is in the NW¼ sec. 34, T. 1 S., R. 3 W., about 2½ km southwest of the Carmichael Canyon locality. It is accessible, with some difficulty, by a jeep track that extends from the Carmichael Canyon road in sec. 27, T. 1 S., R. 3 W. The elevation is about 6,000 ft.

Much of the area is wooded, and exposures are scarce, but iron-formation is known to be present in an east-west-trending belt, a hundred meters or more wide, that crosses north-flowing Carmichael Creek in the N½ sec. 34. The belt has been explored by several long trenches and scrapings that expose iron-formation either interlayered or infolded with quartzite, schist, and amphibolite. Dips are to the north at moderate to steep angles (55°–75°). The longest cut, about 200 m long parallel to and a short distance west of the creek, intersects several layers of iron-formation, the largest about 20 m thick. A second cut, east of the creek and about 90 m long, cuts about 30 m of iron-formation that is bounded on the north by quartzite and schist and on the south by slope wash. Although both the natural and manmade exposures are inadequate to characterize the geology of the area reliably, the available data are consistent with the concept of a single layer of iron-formation, no more than 15 m in true thickness, tightly and complexly folded with quartzite and schist on structures trending generally east to southeast. As shown by Reid (1957, pl. 1), the entire area is on the northeast flank of a broad northerly plunging arch.

A complete analysis of the Carmichael Creek iron-formation is given in table 1 (sample 3); the sample consisted of carefully selected fragments of fresh rock from a broken outcrop about 335 m east and 300 m south of the NW. cor. sec. 34, a short distance east of the creek. The analysis is notable only for the unusually high content of alkalis, reflected mineralogically in the presence of riebeckite-like amphibole and scarce potassium feldspar; the rock otherwise consists chiefly of quartz, magnetite, and hypersthene. An analysis of one sample from the Carmichael Creek area, given by Immega and Klein (1976, table 1), also showed a high content of Na_2O.

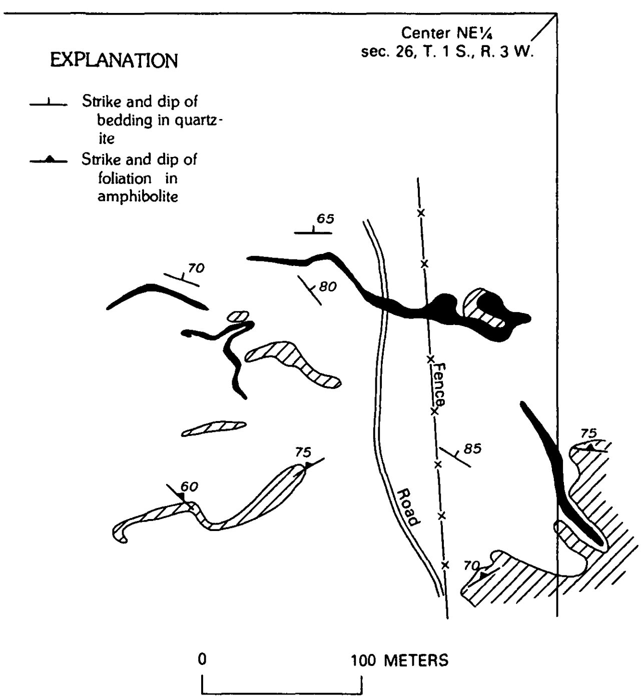

FIGURE 5.—Carmichael Canyon area, showing distribution of iron-formation (dark areas) interbedded with schist and quartzite, and of amphibolite (crosshatched areas). See figure 2 for location.

BOULDER LAKES-BRANNON LAKES (3)

Minor occurrences of iron-formation have been noted in the rugged northwestern part of the Tobacco Root Mountains, in secs. 4 and 5 (unsurveyed), T. 3 S., R. 4 W. The Boulder Lakes area, in the NW¼ sec. 5, is accessible by a jeep trail that ascends Dry Boulder Creek from the Jefferson River valley. Iron-formation is exposed in a shallow gorge between the lower and upper lakes, about 250 m east of Lower Boulder Lake at an elevation of about 8,700 ft. The iron-formation exposed in the gorge has a maximum aggregate thickness of 10 m and is interleaved with amphibolite and intruded by irregular bodies of pegmatite and aplite. The country rock is mainly quartzofeldspathic and mafic gneiss that trends about N. 60° E. and dips 40°–50° NW. The bulk composition of a selected sample of the iron-formation (sample 4, table 1) is normal for this type of iron-formation, which consists essentially of quartz, magnetite, hypersthene, clinopyroxene, and garnet, with a moderate amount of alteration to fibrous grunerite.

The Brannon Lakes area, in the NW¼ sec. 4, T. 3 S., R. 4 W., is accessible by a rough jeep trail that enters the area from the South Boulder River drainage. Iron-formation is exposed sporadically in the cirque walls west and northwest of the lakes, where it is interlayered with quartzofeldspathic gneiss, garnet gneiss, amphibolite, and (locally) quartzite. The structure trends about N. 50° E. and dips 30°–55° NW. The beds of iron-formation are generally thinner than 1.5 m, and few are continuous for more than 100 m along strike. Although no definitive evidence could be found, the distribution of the iron-formation strongly suggests pinchouts on a series of closely spaced isoclinal folds.

DRY GEORGIA GULCH (4)

The Dry Georgia Gulch occurrence of iron-formation is on the west flank of the Tobacco Root range, in the SW¼SW¼ sec. 27 and in the NW¼NW¼ of adjacent sec. 34 (both unsurveyed), T. 3 S., R. 5 W. The area is readily accessible by dirt road from the town of Twin Bridges, Mont., about 8 km to the west.

The iron-formation unit, about 10 m thick, crosses the access road in a poorly exposed S-shaped belt that terminates against Paleozoic strata on the north and against Tertiary valley fill on the southwest. The aggregate length of the belt is shorter than 1 km; dips are 50°–60° NW. The iron-formation, mineralogically a standard assemblage (quartz, magnetite, hypersthene, clinopyroxene, and garnet), is bounded on both sides by thin screens of amphibolite. The country rock is quartzofeldspathic gneiss. The iron-formation at Dry Georgia Gulch is on the same structural trend as that in the Boulder Lakes-Brannon Lakes area, and the associated strata are also similar.

CURRANT CREEK (5)

The Currant Creek area is on or near the divide between the Mill Creek and Currant Creek-Ramshorn Creek drainages, on the west flank of the Tobacco Root Mountains. The explored area is at an elevation of about 8,000 ft in the E½ sec. 24, T. 4 S., R. 4 W., and the adjoining part of sec. 19, T. 4 S., R. 3 W., and is accessible by a dirt road that follows Currant Creek from its junction with Ramshorn Creek.

As shown on the regional-structure map (fig. 3), the iron-formation in this locality is a continuation of that in the Copper Mountain area to the south, on the west limb of the Ramshorn syncline. The generalized structure is a large dextral drag fold that is overturned to the east and plunges to the north or northwest.

The iron-formation has been explored by a number of shallow trenches and scrapings (fig. 6), but elsewhere it is poorly exposed. The most distinctive lithologic unit exposed in the area is vitreous quartzite, no thicker than 15 m, that stratigraphically overlies the iron-formation and is separated from it by a layer of micaceous quartzite and schist of varying thickness. The quartzite is bounded on the east and north by amphibolite. The iron-formation is underlain stratigraphically by a mixture of quartzite, schist, garnet-diopside amphibolite, and felsic gneiss.

The iron-formation is a coarse-grained mixture of magnetite, quartz, clinopyroxene, and hypersthene. The samples examined under the microscope contained neither garnet nor grunerite, but clinopyroxene (pale green, with exsolved hypersthene) is more abundant that is common in rock of this type.

OTHER REPORTED LOCALITIES

Iron-formation is a distinctive rock type, and so even very minor occurrences have been identified by workers who have mapped in the region. Several of these localities are noted below, but brief field examinations indicated that most deposits are of minor thickness and extent; few, if any, warrant further detailed study.

INDIAN CREEK (6a)

Two occurrences of iron-formation in the Indian Creek area, northeast of the town of Sheridan, Mont., are shown on the map accompanying the petrologic study of iron-formation by Immega and Klein (1976, fig. 2). The existence of these two belts, in secs. 5 and 7, respectively, T. 4 S., R. 4 W., has not been confirmed, but the indicated stratigraphic position relative to a bed of dolomite marble would be appropriate for iron-formation equivalent to that in the Copper Mountain area to the east.

JOHNSON CREEK (6b)

The iron-formation in the Johnson Creek area, about 1 km north of Mill Creek in sec. 13, T. 4 S., R. 4 W., is a northward continuation of the iron-formation in the Copper Mountain and Currant Creek areas, on the west limb of the Ramshorn syncline. The location and extent of the occurrence (fig. 3) are taken without modification from the map by Burger (1967). The substantial outcrop width of iron-formation in the north-

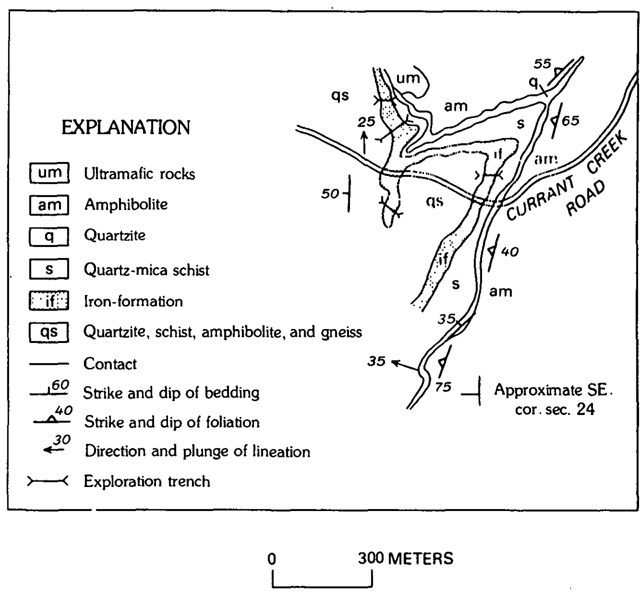

FIGURE 6.—Distribution of Archean rocks of Currant Creek area, E½ sec. 24, T. 4 S., R. 4 W., and W½ sec. 19, T. 4 S., R. 3 W. See figure 2 for location.

eastern part of sec. 13 presumably reflects a large drag fold similar to that at Currant Creek, 2 km south. Brief reconnaissance of the area suggests that the true dimensions of the iron-formation may be appreciably smaller than those indicated on the map.

SOUTH FORK OF MILL CREEK (6c)

Iron-formation is present in a northwest-trending southwest-dipping belt near the foot of a steep escarpment in the NE¼ sec. 21, T. 4 S., R. 3 W., less than a kilometer south of the South Fork of Mill Creek. The iron-formation, locally as much as 100 m in outcrop width, is both underlain and overlain by garnet-rich strata and is interlayered with garnet and hornblende gneiss. The full extent of this deposit is yet to be determined.

The iron-formation in the South Fork area contains a somewhat greater proportion of iron silicates (garnet and hypersthene, particularly) than does most iron-formation of the study area. The rock was well illustrated by Immega and Klein (1976, fig. 5), who also provided a chemical analysis of the rock, described as consisting of ferrohypersthene, quartz, almandine, ferrosilite, magnetite, grunerite, and hornblende. The analysis is notable for the relatively low content of Fe_2O_3 (3.36 weight percent, as compared with 27.2 weight percent FeO), reflected mineralogically in the abundance of ferrous silicates and a relatively low content of magnetite.

ANTELOPE CREEK (6d)

Reid (1957, pl. 1) described magnetite layers in "Pony Gneiss" in a locality within the northeastern Tobacco Root Mountains. Examination of the belt in the NE¼ sec. 1, T. 2 S., R. 3 W., and in the adjoining part of sec. 6, T. 2 S., R. 2 W., revealed magnetite-bearing rock in beds less than a meter thick, in a layered sequence consisting mainly of amphibolite, serpentine, and metaperidotite. The rock consists principally of hypersthene, green hornblende, and magnetite, and could represent a facies of the igneous and metaigneous country rock rather than sedimentary iron-formation.

RESOURCE APPRAISAL

Virtually all the iron-formation of the Tobacco Root Mountains possesses physical, mineralogic, and chemical properties comparable or superior to those of taconite-type deposits currently being exploited elsewhere in the United States and in the world. The rock is coarse grained, and the total iron content (see table 1) is about 35 weight percent, mostly in the form of readily extractable magnetite.

The available tonnage, however, is substantially less than that now required to serve as a base for a modern recovery operation. The only area that warrants serious consideration and appraisal is the Copper Mountain belt, specifically the iron-formation on the east and west flanks of the central anticlinal buckle (see pl. 1); and even this falls considerably short of minimum tonnage requirements. Although no precise estimate can be made on the basis of data now available, the tonnage of iron-formation present can be approximated, assuming that surface widths are reasonably representative and that the rock density is 3.4 g/cm^3. Three segments are considered: (1) the west flank, from the east-west centerline of sec. 1 northward to Ramshorn Creek, a linear distance of about 1,900 m, average outcrop width 33 mm, and average dip 70° W.; (2) the west flank, from the east-west centerline of sec. 1 southward to the first crossfault in sec. 12, a linear distance of about 1,130 m, average outcrop width 33 m, and average dip 45° E. (the dip reversal reflects the Copper Mountain crossfold); and (3) the east flank, from just north of the center of sec. 36 southward to the termination of the belt north of Copper Mountain, a strike distance of roughly 1,400 m, outcrop width (highly approximate) of 60 m, and average dip 70° W. Ignoring topographic effects and other variables, the tonnage of each segment to a vertical depth of 100 m (a probably practical limit for open-pit mining) is as follows (values rounded to nearest million):

Segment	*Amount, in metric tons*
West flank, north	21,000,000
West flank, south	13,000,000
East flank	29,000,000
Total	63,000,000

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