

Figure 1. Location of the study area. The study area includes the eastern part of Beaverhead County, Montana, and the western part of Madison County, Montana. The study area is defined as the "Gravelly Landscape Analysis Unit" by the regional land management plan of the BLM and USFS, designated as follows: (1) The western boundary is U.S. Interstate Highway 15 from Mondak in Dillon, and State Highway 41 from Dillon to Twin Bridges; (2) The northern boundary is State Highway 287 from Twin Bridges to Ennis; (3) The eastern boundary is the Madison River from Ennis to Raymond Pass and State Highway 87 from Raymond Pass south to the Montana-Idaho border; and (4) The southern boundary is the Montana-Idaho border the Continental Divide between State Highway 87 and Mondak. This study area includes rugged mountains of the Blacktail, Centennial, and Henrys Lake Mountains and the Gravelly, Greenhorn, Ruby and Snowcrest Ranges, as well as the intervening basins.

In response to requests from the Bureau of Land Management (BLM) and the U.S. Forest Service (USFS), the U.S. Geological Survey (USGS) conducted a mineral resource assessment in the Dillon BLM Resource Area in Beaverhead and Madison Counties, southwestern Montana. These agencies use mineral resource data in creating and updating land-use management plans for federal lands for the recreational future. Mineral resources that have not been developed in the past may be developed in the future, based on changing economic demands and market conditions. Therefore, federal land managers need geologic information on known mineral occurrences as well as on areas that are permissive for the occurrence of undiscovered potential resources. This map was prepared to provide this type of geologic information for mineral deposits that can be associated with ultramafic rocks. Areas of exposed Precambrian ultramafic rocks are labeled with uppercase letters (A-F). Sources of geologic maps used to compile this map are shown on the smaller index map (Index to Geologic Mapping); lowercase letters (a-m) on the index map are keyed to the reference list.

Location of the study area

The study area includes the eastern part of Beaverhead County, Montana, and the western part of Madison County, Montana. The study area is defined as the "Gravelly Landscape Analysis Unit" by the regional land management plan of the BLM and USFS, designated as follows: (1) The western boundary is U.S. Interstate Highway 15 from Mondak in Dillon, and State Highway 41 from Dillon to Twin Bridges; (2) The northern boundary is State Highway 287 from Twin Bridges to Ennis; (3) The eastern boundary is the Madison River from Ennis to Raymond Pass and State Highway 87 from Raymond Pass south to the Montana-Idaho border; and (4) The southern boundary is the Montana-Idaho border the Continental Divide between State Highway 87 and Mondak. This study area includes rugged mountains of the Blacktail, Centennial, and Henrys Lake Mountains and the Gravelly, Greenhorn, Ruby and Snowcrest Ranges, as well as the intervening basins.

Mineral deposit types that can be associated with ultramafic and mafic rocks

Metallic minerals

Ultramafic rocks are igneous rocks that are distinctly dark in color and include pyroxenites, peridotites, and a host of specialized rock types named on the basis of their mineralogy. Ultramafic rocks lack quartz and albite feldspar and are essentially composed of ferromagnesian silicate minerals, sulfide and metallic oxide minerals. Mafic igneous rocks include, among others, gabbros and their extrusive equivalents, basalts. They have a relatively low silica content (about 45 to 52 weight percent), and are comprised of dense minerals such as pyroxene, amphibole, olivine, plagioclase, and dark rocks with little or no quartz. In some ultramafic and mafic rocks, metallic ore minerals are present in sufficient concentrations to form ore deposits that are mined for copper, nickel, chromium, cobalt, gold, iron, titanium, vanadium, and (of) platinum-group elements (PGE). Copper, nickel, chromium, and PGE have been mined from mafic and ultramafic rocks in Montana, most notably from mines developed in the Stillwater Complex near Nye, Montana, in the Beeshoof uplift area. The Stillwater Complex is a late Archaean (2.700 Ma) ultramafic to mafic layered igneous intrusion that hosts essentially all of the identified local resources of PGE and more than half of the identified chromium resources of the U.S., along with copper, nickel and other metals (Zientek, 1993, and references therein). Many layered intrusions consist of gabbro units of different ultramafic rock types, such as peridotite, gabbro, and anorthositic, layers enriched in disseminated sulfide minerals or chromite can be present throughout the intrusion. In addition to the very rare large layered intrusions such as the Stillwater Complex that were emplaced in tectonically stable areas, metallogenic mineral deposits can also be associated with smaller typically podiform or lense-shaped bodies of ultramafic and mafic rocks emplaced in tectonically unstable areas for example, see Albers, 1986, and Page, 1986). The igneous fabric of these smaller bodies is typically obscured by metamorphism, and olivine and pyroxene can be partially or completely replaced by serpentine and anthophyllite.

Chromite deposits can be present in layered intrusions that formed in relatively stable tectonic environments, such as the Stillwater Complex, or in podiform deposits in ultramafic parts of ophiolite complexes that formed in unstable tectonic environments (Albers, 1986; Page, 1986). Podiform ultramafic bodies are typically composed of peridotite and pyroxenite and their hydrated equivalents, serpentine. In the past, chromite was produced from a number of small, highly altered and tectonically disrupted ultramafic bodies near Red Lodge, Montana; both streamflow and podiform origins have been postulated for these deposits. Most of these were mined out or have been inactive since the 1940's, and were developed with government subsidies to stockpile strategic minerals during periods of war (as were the chromite deposits in the Stillwater Complex). Montana is the only state that produced primary platinum and palladium in 1999 (U.S. Geological Survey, 1997). Chromite ore is not currently produced in the United States, but the Stillwater Complex represents the largest U.S. chromium resource (Zientek, 1993). All mining, and essentially all exploration, for PGE is confined to the Stillwater Complex.

Pearson and others (1990) evaluated nickel and chromium resources as part of their assessment of the mineral resources of the Dillon 1° x 2° quadrangle, Idaho and Montana (Pearson and others, 1992). Pearson and others (1990) concluded that "the potential for nickel deposits in the quadrangle is low" and "the prospect for finding significant chromium deposits is poor, and the potential for undiscovered resources is low".

Industrial minerals

Low-temperature metamorphism of minerals that comprise mafic and ultramafic rocks (dark mica, pyroxene, serpentine) can form vermiculite, a hydrated sheet silicate mineral that is mined for industrial uses in horticulture, waste treatment, and lightweight aggregate. Bush (1976) recognized three types of vermiculite deposits: (1) hydrothermal deposits formed in large ultramafic intrusions bodies cut by dykes, such as granites; (2) hydrothermal deposits associated with smaller ultramafic bodies, such as peridotite or pyroxenite, and cut by granitic rocks; (3) deposits formed by weathering of metamafic rocks. Vermiculite was produced from biotite-rich, hydrothermally altered ultramafic rocks at a mine near Libby, Montana from 1925 until 1990, when the mine was closed due to concerns over potential environmental problems associated with fibrous minerals such as tremolite (Harben and Kuwari, 1996; Berg, 1997). At one time, the now-reclaimed deposit at Libby (an example of a type (1) deposit), also represented the world's largest single source of vermiculite (Harben and Bates, 1990). Berg (1990) described four other vermiculite deposits in Montana, including the Elk Creek deposit in the study area (see map area B, site number 13 on the map), which was discovered in the 1970's. In 1990 and 1991, a small amount of vermiculite was produced from the Elk Creek deposit at the operation Mondak mine (McCulloch, 1992, p. 70; Berg, 1997). Berg (1990) noted similarities between the Elk Creek deposit and the type 2 hydrothermal vermiculite deposits in the Blue Ridge Mountains of North Carolina. The other known vermiculite deposits in Montana all lie north of the study area and are undeveloped. In 1997, a vermiculite deposit in the Tobacco Root Mountains near Pony, Montana, was drilled (McCulloch, 1998).

Ultramafic rocks in the study area

Small bodies of ultramafic and mafic rocks are scattered throughout the Archaean gneisses in the study area. This map shows areas of exposed ultramafic rocks that are large enough to show at a scale of 1:250,000. None of these rocks were prospected for nickel and chromium before 1920, but no metal mining or recent exploration has been reported. The only vermiculite occurrence known within the study area is associated with the ultramafic rocks of the southern Ruby Range (map area B on the large map). The following descriptions of the ultramafic rocks are based on the references cited in the map explanation. The origin of these bodies is uncertain because of their complex metamorphic history; they may have been emplaced as igneous intrusions, or they may have been emplaced during tectonism as already metamorphosed, cold, ultramafic bodies. Many of the bodies are sill-like, or parallel to the foliation of the enclosing gneiss. Most of the prospects (table 1) and the most detailed studies have focused on the ultramafic rocks of the Ruby Range. Geochemical data for mafic and ultramafic rocks in map areas B (Wolf Creek pluton) and F (Virginia City mining district) were sampled for this study (table 2; see Hammarstrom and Van Gosen (1998) for exact sample locations and analytical techniques). Existing aeromagnetic and gravity data (McCafferty and others, 1998) suggest that the ultramafic bodies are too small to produce geophysical anomalies at this regional scale, and also are of limited extent in the shallow subsurface. Most of them contain magnetite and should be detectable as magnetic highs relative to the surrounding quartzofeldspathic gneisses, if they are present in sufficient quantities. The ultramafic rocks are also more dense than the surrounding gneiss, and should, similarly, produce low gravity anomalies where measurements were made over the bodies if they are of significant volume.

A regional magnetic high is associated with the metamorphic rocks of the Ruby and Blacktail Ranges, and superposed high and low anomalies reflect the diverse magnetic content of local bodies within the ranges. A simple magnetic high occurs over the Henrys Lake Mountains. The gravity values over the Ruby and Blacktail Ranges are generally high, but variable, and there is no well-defined anomaly associated with the Henrys Lake Mountains.

Aeromagnetic flight lines passed near or over several of the exposed ultramafic bodies, and some are associated with local anomalies, but no consistent relationship occurs. Outcrops of ultramafic rocks at map area A (Blacktail Mountains) occur at the base of a more extensive magnetic high, while the rocks at map area B (southern Ruby Range) occur on the flanks of a magnetic low incursion into a more extensive magnetic high associated with peridotites of the Wolf Creek Pluton. A magnetic high that exceeds others in the Ruby and Blacktail Ranges by over 200 nT (nanotesla) is associated with ultramafic rocks at area C (northern Ruby Range). The anomaly is similar to those interpreted to be caused by varying amounts of magnetite in local bodies throughout the Ranges, and the anomaly may be augmented by ultramafic rocks at this location, but it is more likely that the high values arise from iron formation which is also present. In the Greenhorn Range and Virginia City mining district, area D lies on a magnetic gradient, area E is associated with a broad, high, north, and area F with a narrow, low, one. Map areas A, B, and C all occur at culminating points of the regional gravity highs that define the Blacktail and Ruby Ranges. No gravity measurements were obtained near area D; however, those obtained on outcrops of ultramafic rocks at areas D and F did not produce high anomalies, suggesting that the volume of ultramafic rocks in these locations is insignificant, of minimal density contrast, or both. If all ultramafic rocks of the Blacktail and Ruby Ranges are considered to be of similar density, we may infer that the high gravity culminations at A, B, and C are related to the thickness of the metamorphic rocks of the uplifts contrasted with low density fill in the surrounding basins, rather than to buried ultramafic bodies of significant extent. Two bodies of ultramafic rocks crop out in the Henrys Lake Mountains, and also have prominent gravity and magnetic expressions. The northeastern body is associated with a magnetic low of 15 nT, and a minor gravity high, while the southwestern body is associated with a magnetic gradient and a minor gravity low. The differing responses suggest that there is no ultramafic rock, and thus the geophysical data cannot be used to infer any subsurface extent of these bodies.

Regional-scale structural data considered to be a result of the National Uranium Resource Evaluation (NURE) program are available for the study area from Smith (1998). The data for 3,680 samples collected in and adjacent to the study area were examined for chemical signatures indicative of ultramafic and mafic rocks and any associated mineral occurrences. The relatively wide spacing of sampled sites is well suited to characterizing the small ultramafic and mafic bodies exposed in the study area. In addition, the non-absolute analytical methods used on these samples provided element detection levels with limited usefulness for mineral resource evaluation. Low-level geochemical signatures in NURE streamflow data are examined in an examination for general mineral resources associated with ultramafic and mafic rocks (for example, no PGE analyses). No highly anomalous chemical signatures for ultramafic and mafic rocks and their associated mineral deposit types were detected. Low-level geochemical signatures in NURE stream sediments from this area include iron, chromium, nickel, titanium, vanadium, and cobalt.

Ultramafic rocks adjacent to the study area

Scattered pods of complexly metamorphosed mafic and ultramafic rocks are mapped throughout areas of Archean gneiss in southwestern Montana. Vitiliano and Corbett (1979) described the meta-ultramafic rocks of the southern Tobacco Root Mountains, just north of the study area (see index map), as small lenses, pods, and stock-like bodies of metamorphosed and intensely altered harzburgite, hercynite, and peridotite that may have been emplaced in their present setting as solid bodies rather than as magmas. Samples of small pods and lenses of ultramafic rocks from the northern part of the Ruby Mountains were analyzed as part of a study of the Middle Mountain-Tobacco Root Roadless Area and they showed no significant concentrations of cobalt, copper, nickel, chromium or platinum-group elements (O'Neill and others, 1983, p. 8). "Platinum-group elements are known to occur in the Elk Creek Pluton, a 1 km wide by 2 km long, layered mafic intrusion in the southern part of the Tobacco Root Range (Horn and others, 1991, 1992). The mafic rocks of the Lake Complex, estimated to be about 1,000 Ma, intruded Archean quartzofeldspathic gneiss and is cut by the late Cretaceous Tobacco Root batholith (Horn and others, 1992). Its composition ranges from mafic north and to granophyre. Precious metal concentrations of up to 1,300 ppb (gold + platinum + palladium) are reported in sulfide-rich zones of the complex (Horn and others, 1991).

In the southern Highland Mountains (see index map), O'Neill and others (1996) mapped irregularly shaped pods and lenses of coarse-grained, Early Proterozoic ultramafic rocks composed of orthopyroxene, olivine, spinel, hornblende and magnetite. These ultramafic rocks bodies are typically narrow (<30 m wide), but can be exposed over lengths of more than a kilometer. No mines, prospects, or mineral occurrences for chromium, nickel, PGE, or vermiculite are known to be associated with these rocks.

Meta-ultramafic rocks that include variably serpentinized olivine websterites, hercynite, and kelloite gabbros occur as small lenses, pods, and irregular masses in the Madison Range (Kellough, 1993; Kellough and Williams, 1997; Franchy and others, 1980). Representative samples of two such meta-ultramafic rocks have been analyzed for trace elements (see index map). The Madison Range ultramafic rocks are associated with the Dillon Resource Area. Nickel and platinum-group elements typically occur in lower concentrations than other trace elements (parts per billion) and are difficult to analyze. False positive bias in PGE and gold concentrations can result from Galileo's (inductively coupled plasma-optical spectrometry) technique following simple aqueous leach of inorganic samples due to inter-element interferences (Brown and Biggs, 1984). This result of PGE mineral occurrences should be carefully scrutinized. These inter-element interferences can be eliminated by more sophisticated analytical techniques. All of the ultramafic rocks we sampled contain very small amounts of PGE (table 2), but none are anomalous for these types of rocks, or comparable to the concentrations reported for the Lady of the Lake Complex in the Tobacco Root Mountains (Horn and others, 1991). PGE-enriched layers could be present within the ultramafic rocks, but detailed exploration by drilling and geochemical analysis would be required to document any occurrences, and general lack of sulfides and the small size of the bodies suggest that significant tonnages are unlikely. Chromium and nickel concentrations for ultramafic rock samples from the study area are not anomalous. Although these ultramafic bodies have not been fully evaluated for chromium and nickel, they are small and discontinuous and there is no indication that they contain significant tonnages of ore-grade metal concentrations (for example, >1% nickel, 40% chromium oxide, or parts per million levels of PGE).

The metabasites in the Henrys Lake Mountains have not been investigated for their resource potential. However, no prospects or mineral occurrences are reported near here and the area's stream sediment geochemical data do not suggest the presence of ultramafic-related mineral deposits.

U.S. production of vermiculite declined during the period 1990 to 1995. Should market trends change in the future, exploration for additional resources, and development of identified resources associated with the Wolf Creek pluton, could be expected in the study area. Weathering or hydrothermal alteration of biotite and phlogopite typically form the best vermiculite because of their large particle size. For commercial value, vermiculite particle size should be >0.25 mm, so any undiscovered deposits are likely to be shallow. Potential exploration guides for vermiculite deposits include: (1) contacts of ultramafic bodies with biotite-rich gneiss; (2) regional structural trends, because the bodies appear to be relatively continuous with foliations in the host gneiss; (3) geophysical data (magnetic anomalies) of appropriate scales to detect small bodies; and (4) stream sediment or soil geochemical surveys. In areas of weathered ultramafic rocks in South Carolina, for example, geochemical surveys have demonstrated that chromium, cobalt, copper, phosphorous and nickel can serve as pathfinders for vermiculite exploration (Maybin and Carpenter, 1990). This same suite of elements would also indicate potential mafic and ultramafic-hosted metal deposits.

Figure 2. Southern Ruby Range (map area B).

A number of small, mafic and ultramafic bodies of Archean age intrude Archean rocks of the Ruby Range metamorphic complex (Desmaris, 1978, 1981). Compositionally, the bodies include locally serpentinized metaperidotite (harzburgite) and metapyroxenite. The bodies tend to be aligned parallel to the regional metamorphic foliation (Kennerly, 1979). Multiple phases of ultramafic rocks have been described for the Ruby Range bodies, and primary cumulate textures may have been obscured by metamorphism. The Ruby Range ultramafic rocks have been prospected for nickel and copper (Sinker, 1942; Geach, 1972) and the contact zones have been explored for vermiculite (Berg, 1995, 1997).

The fash-bounded Wolf Creek pluton of Heinrich (1966) is a northeast-trending series of exposures of weathered peridotite bodies, also described by Sinker (1942) and Desmaris (1978, 1981). Heinrich (1966) interpreted the numerous, small ultramafic bodies in the area as one intrusion, out by faults. Desmaris (1978) and Berg (1995) interpret the small bodies as individual pods emplaced before Precambrian folding, although the nature of the emplacement (tectonic emplacement of peridotite or magmatic intrusion) is uncertain.

Sinker (1942) described the occurrence of nickel associated with the ultramafic body, which was later called the "Wolf Creek prospect" by Heinrich (1966), as the "Dillon nickel prospect", and suggested that it represented a source of low-grade nickel alloy-bearing rocks. The pluton was prospected on the basis of its similarity to the Jake Creek pluton to the south (map area A), and consequently, nickel was discovered at Wolf Creek in 1938. Heinrich (1966) showed a number of nickel and chromite prospects on his geologic map of the pluton (table 1, sites 1, 7, 9, 10, and 12), but none of these have ever been developed. Nickel is present in relatively small concentrations as the supergene nickel arsenate mineral, ankerbergite. No primary sulfide minerals have been recognized in the ultramafic rocks, but nickel is probably derived from olivine or other silicates. Sinker (1942) reported nickel concentrations of 0.002% Ni in gabbro, 0.10% in peridotite, and 0.4% in serpentine, and assay values up to 1.25% Ni in grab samples from the Nickel Mountain Claim Group (likely site 9 of table 1). The sulfide minerals reported are pyrrhotite, pyrite, chalcopirite and minor amounts of the nickel sulfide mineral pentlandite (along with the trace amounts of gabbro exposed at Ruby Nickel Claim No. 6 on the southeastern side of the ultramafic "body"). Heinrich (1966) mapped a northwest-trending dike-like, rather than a gabbro in this area, and the sulfide location appears to be in the area of the Nickel Lake Claims (table 1, site 9). Desmaris (1981) did not mention sulfide minerals in his detailed petrologic study of the Ruby Range ultramafic rocks, but did confirm the presence of nickel in silicate and oxide minerals (up to 0.5% NiO in olivine; also present in orthopyroxene, clinopyroxene, and spinel). Mineral occurrences such as the Dillon nickel prospect were not economic at the time of their discovery, and are unlikely to ever be sought as a source for nickel.

Berg (1995) reported gold (8 ppb) and silver (5 ppb), and palladium (at <2 ppb) values for four samples of ultramafic rocks from the Wolf Creek pluton in the area of the Elk Creek vermiculite deposit. Hammarstrom and Van Gosen (1998) reported on the major and trace element chemistry of two pyroxene-rich ultramafic rocks from the same area (table 2) as well as samples of biotite-rich schist and amphibolite that developed at the metamorphic reaction contact that localized the vermiculite deposit. Chromium concentrations are typical (about 2,000 ppm Cr) for ultramafic rocks, but nickel concentrations are relatively low (<1,000 ppm) for ultramafic rocks (Flaxner and Webb, 1982). Heinrich and Rabitt (1966) noted that anomalous chromium concentrations can be obtained for the Wolf Creek pluton even though no significant amounts of chromite are present, because a chromium spinel mineral occurs throughout the peridotite; chromite is present as an accessory mineral on a local scale. Low-level geochemical signatures in NURE stream sediments from this area include iron, chromium, nickel, titanium, vanadium, and cobalt.

Table 2. Chemical analyses of metaliferous rocks in the study area. Samples 95JH101 and 95JH102 are grab samples from two pyroxene-rich ultramafic bodies near the Elk Creek vermiculite deposit. Sample 96JH167 is a grab sample of a moderately serpentinized, pyroxene-rich ultramafic body mapped by Hadley (1969). Refer to Hammarstrom and Van Gosen (1998) for sample locations, analytical techniques, and complete analyses. [Total iron reported as Fe₂O₃; LOI, loss on ignition; N.D., not determined; ppm, parts per million; ppb, parts per billion]

Sample	Southern Ruby Range (map area B)		Virginia City area (map area F)
	95JH101	95JH102	
Major elements, in weight percent			
SiO ₂	48.1	51.7	40.0
TiO ₂	0.35	0.26	0.11
Al ₂ O ₃	10.4	5.0	2.3
FeO	11.3	10.7	10.7
MnO	0.17	0.16	0.13
MgO	23.0	26.7	35.1
CaO	5.6	3.4	1.1
Na ₂ O	0.67	0.15	0.04
K ₂ O	0.14	0.06	<0.01
P ₂ O ₅	0.03	0.05	0.02
LOI	0.8	0.6	9.2
Total	99.5	99.5	98.7
S	<0.003	<0.003	N.D.
Selected trace elements (units)			
Cr (ppm)	2,260	3,340	4,240
Ni (ppm)	815	926	1,735
Co (ppm)	85	93	117
Cu (ppm)	11	99	7
Zn (ppm)	7.6	12.2	13.4
Pd (ppb)	1.9	2.8	1.7
Rh (ppb)	1.1	1.7	2.4
Pt (ppb)	2.8	3.2	3.9
Total PGE	13.4	19.9	21.1
(ppb)			

References Cited and References to Geologic Mapping
([Referenced figures are indexed to the "Index to Geologic Mapping"])

Albers, J.P., 1986, Descriptive model of podiform chromite, in Cox, D.P. and Singer, D.A., eds., *Mineral deposit models*, U.S. Geological Survey Bulletin 1493, p. 34.

Berg, R.B., 1979, Precambrian geology of the west part of the Greenhorn Range, Madison County, Montana, Montana Bureau of Mines and Geology Open-File Report Map G, 2 sheets, scale 1:28,800, 12 p. pamphlet.

1990, Montana's industrial minerals, in *Industrial rocks and minerals of the Pacific northwest*, Proceedings of the 25th Forum on the Geology of Industrial Minerals, April 30 to May 2, 1989, Portland, Oregon; Department of Geology and Mineral Industries, State of Oregon, p. 37-44.

1995, *Geology of the Elk Creek vermiculite deposit*, Madison and Beaverhead Counties, Montana, Montana Bureau of Mines and Geology Open-File Report 335, 9 p. pamphlet, 2 plates, scales 1:60,000 and 1:30,000.

1997, Montana's changing industrial minerals industry, in Jones, R.W., and Harris, R.E., eds., *Proceedings of the 32nd Annual Forum on the Geology of Industrial Minerals*, Laramie, Wyoming: Wyoming State Geological Survey, Public Information Circular No. 38, p. 167-175.

Brown, R.J., and Biggs, W.R., 1984, Determination of platinum and palladium in geologic samples by ion-exchange chromatography with inductively coupled plasma atomic emission spectrometric detection: *Analytical Chemistry*, v. 56, no. 6, p. 646-649.

Bush, A.L., 1976, Vermiculite in the United States, in *Eleventh Industrial Minerals Forum*, Montana Bureau of Mines and Geology Special Publication 74, p. 145-155.

Desmaris, N.R., 1978, Structural and petrologic study of Precambrian ultramafic rocks, Ruby Range, southwestern Montana, Montana Bureau of Mines and Geology Memoir 38, 40 p.

1981, Metamorphosed Precambrian ultramafic rocks in the Ruby Range, Montana: Precambrian Research, v. 16, p. 67-101.

Garhain, J.M., 1979, Geology and structure of the central Ruby Range, Madison County, Montana—Summary, Geological Society of America Bulletin, Part 1, v. 90, no. 4, p. 323-326.

Geach, R.D., 1972, Mines and mineral deposits (except fuels), in *Montana*, Montana Bureau of Mines and Geology Bulletin 85, 194 p.

C Hadley, J.B., 1969, Geologic map of the Ruby Range quadrangle, Madison County, Montana, U.S. Geological Survey Geologic Quadrangle Map GQ-814, scale 1:24,000.

Hammarstrom, J.M., and Van Gosen, B.S., 1998, Selected geochemical data for the Dillon BLM Resource Area (including the Virginia City mining district), Madison and Beaverhead Counties, southwest Montana—Mineral resource and mineral-environmental considerations, U.S. Geological Survey Open-File Report 98-224-C, 106 p.

Hammarstrom, J.M., Wilson, A.B., and Van Gosen, B.S., eds., in prep., Mineral and energy resource assessment of the central portion of the Dillon National Forest, including the Absarokee-Beeshoof study area in Gallatin, Madison, Meagher, Park, and Sweet Grass Counties, southern Montana: U.S. Geological Survey Professional Paper.

Harben, P.W., and Bates, R.L., 1990, Industrial minerals—geology and world deposits, London, Industrial Minerals Division, Metallus Pibic, p. 295-298.

Harben, P.W., and Kuwari, M.S., 1996, *Industrial minerals—A global geology*, London, Industrial Minerals Division, Metallus Pibic, p. 432-437.

Hawkes, H.E., and Webb, J.S., 1962, *Geochemistry in mineral exploration*, New York, Harper & Row, 415 p.

Heinrich, E.W., 1966, Geology of the Ruby Mountains, in *Pre-Belt geology of the Cherry Creek and Ruby Mountains areas, southwestern Montana*, Montana Bureau of Mines and Geology Memoir 38, p. 15-19.

1963, Paragenesis of chromite and associated minerals from Wolf Creek, Montana, The American Mineralogist, v. 48, p. 597-613.

Heinrich, E.W., and Rabitt, J.C., 1969, Pre-Belt geology of the Cherry Creek and Ruby Mountains areas, southwestern Montana, Montana Bureau of Mines and Geology Memoir 38, 40 p.

Horn, L., Conner, S., Mueller, P., Heatherington, A., and Mogk, D., 1991, The Lady of the Lake Complex: A newly discovered, layered mafic intrusion, Tobacco Root Mountains, southwestern Montana: *Geological Society of America Abstracts with Programs*, v. 23, no. 5, p. A329.

Horn, L., Mueller, P., Heatherington, A., and Mogk, D., 1992, Geochemistry of a layered mafic intrusion—The Lady of the Lake Complex, Tobacco Root Mountains, southwestern Montana: *Geological Society of America Abstracts with Programs*, v. 24, no. 7, p. A262.

Horn, L., Muller, P., Heatherington, A., and Mogk, D., 1992, Geochemistry of a layered mafic intrusion—The Lady of the Lake Complex, Tobacco Root Mountains, southwestern Montana: *Geological Society of America Abstracts with Programs*, v. 24, no. 7, p. A262.

Horn, J.H., 1990, Precambrian geology and bedrock iron deposits of the southwestern Ruby Range, Montana: iron section on the Kelly iron deposit of the northeastern Ruby Range, U.S. Geological Survey Professional Paper 1495, 39 p., 2 plates.

Kaas, M.L., ed., 1996, *Index to U.S. Bureau of Mines mineral resources records*, U.S. Bureau of Mines Special Publication 96-2 (CD-ROM).

Karasewich, L.P., 1989, Geologic map of the northern Ruby Range, Madison County, Montana: Montana Bureau of Mines and Geology Geology Map 25, scale 1:24,000.

Kellough, R.G., 1993, Geologic map of the Ennis Lake quadrangle, Madison County, Montana, U.S. Geological Survey Geologic Quadrangle Map GQ-1729, scale 1:24,000.

Kellough, R.S., and Williams, V.S., 1997, Geologic map of the Ennis 30' x 60' quadrangle, Madison and Beaverhead Counties, Montana: U.S. Geological Survey Open-File Report 97-533, scale 1:100,000.

Mason, G.T., Jr., and Analt, R.E., 1996, *Mineral Resources Data System (MRDS)*: U.S. Geological Survey Digital Data Series DD-20, Release 1.

Maybin, B., A.H., and Zientek, M.L., 1998, Geochemistry—A new approach for vermiculite exploration in South Carolina, in Dupan, J.H.W., and Waplin, J.H., eds., *Proceedings, 24th Forum on the Geology of Industrial Minerals*, May 2-5, 1988, Greenville, South Carolina; South Carolina Geological Survey Special Report 1998-1, 13 p.

McCafferty, Anne, Barkley, V.L., and Brenner, K.C., 1998, Montana aeromagnetic and gravity maps and data, U.S. Geological Survey Open-File Report 98-333, version 1.00, WWW release only, URL: <http://gdweb2.cr.usgs.gov/pub/openfile-reports/ofr98333>

McCulloch, Robin, 1992, *Montana mining directory 1991*, Montana Bureau of Mines and Geology Bulletin 120, 135 p.

1998, *Montana mining and exploration in 1997*, Montana Bureau of Mines and Geology Open File Report 369, 15 p.

9 Olmua, A.F., 1992, Geology of the southwestern Ruby Range near Dillon, Montana: University Park, Pennsylvania: University Park, Ph.D. dissertation, 122 p.

O'Neill, J.M., Caher, Eric, and Linne, J.M., 1983, Mineral resource potential map of the Middle Mountain-Tobacco Root Roadless Area, U.S. Geological Survey Open-File Report 83-333, scale 1:100,000.

O'Neill, J.M., Klepper, M.R., Smoles, H.W., Hansman, D.L., Frazer, G.D., and Melhorn, H.H., 1996, Geologic map and cross sections of the central and southern Highland Mountains, southwestern Montana, U.S. Geological Survey Miscellaneous Investigations Series Map I-2525, scale 1:500,000.

Page, N.A., 1986, Descriptive model of synorogenic-synorogenic Ni-Cu, in Cox, D.P. and Singer, D.A., eds., *Mineral deposit models*, U.S. Geological Survey Bulletin 1493, p. 62-90, 2 sheets, scale 1:60,000.

Pearson, R.C., Hanna, W.F., James, H.L., Loen, J.S., Moll, S.H., Ruppel, E.T., and Trautwein, C.M., 1990, Map showing mineral resource assessment for silver, cobalt, and base metals in Proterozoic sedimentary rocks and for iron, chromium, nickel, and platinum group metals in the Archaean crystalline rocks, Dillon 1° x 2° quadrangle, Idaho and Montana, U.S. Geological Survey Miscellaneous Investigations Series Map I-1803-D, scale 1:250,000.

Pearson, R.C., Trautwein, C.M., Ruppel, E.T., Hanna, W.F., Rowan, L.C., Loen, J.S., and Berger, B.R., 1992, Mineral resource assessment of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Circular 1077, 15 p.

Packard, D.H., Hanna, W.F., Southern, H.A., and Larsen, C.E., 1980, Resource potential of the Bear Trap Canyon Instant Study Area, Madison County, Montana: U.S. Geological Survey Open-File Report 80-859, 32 p.

Sinker, Helen, 1942, Geology and ore deposits of the Dillon nickel prospect, southwestern Montana: *Economic Geology*, v. 37, no. 2, p. 136-152.

Smith, S.M., 1998, *National Geochemical Database—Reformatted data from the National Uranium Resource Evaluation (NURE) Hydrogeochimical and Stream Sediment Reconnaissance (HSSR) Program*, U.S. Geological Survey Open-File Report 97-492, version 1.00; WWW release only, URL: <http://geowood.cr.usgs.gov/pub/openfile-reports/ofr97492/>

9 Sanderberger, J.L., 1982, Geologic map of the central Madison Range, southwestern Montana, Beaverhead and Madison Counties, Montana, with a section on the Madison Valley thermal springs by G.J. Weathers: Montana Bureau of Mines and Geology Memoir 50, p. 363-383, sheet 1.

J Tysdal, R.G., 1988, Geologic map of the northeast bank of the Blacktail Mountains, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-2041, scale 1:24,000.

9 Tysdal, R.G., Lee, G.K., Hassenner, J.H., Hanna, W.F., and Schramm, S.W., 1987, Mineral resources of the Ruby Mountains Wilderness Study Area, Madison County, Montana, with a section on Lake by R.B. Berg: U.S. Geological Survey Bulletin 1724-A, p. A8 and plate 1.

U.S. Geological Survey, 1997, *The mineral industry of Montana*, in *Minerals Yearbook*, area reports—Domestic 1996, volume II, U.S. Geological Survey, p. 166-171.

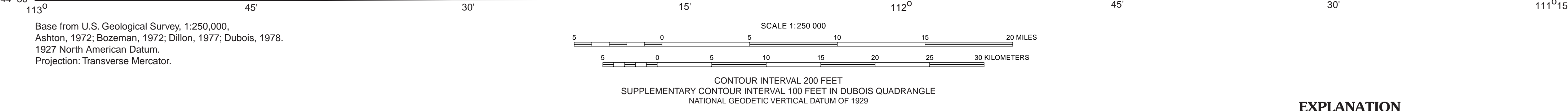
Vitaliano, C.J., and Corbett, W.S., 1979, Geologic map of southern Tobacco Root Mountains, Madison County, Montana: Geological Society of America Paper and Chart Series MC-31, scale 1:62,500, includes 8 p. pamphlet.

9 Wier, K.L., 1982, Maps showing geology and outcrops of part of the Virginia City and Alder quadrangles, Madison County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1490, 2 sheets, scales 1:120,000 and 1:47,500.

11 Winkler, L.J., 1972, Geologic map of the Henrys Lake quadrangle, Idaho and Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1070, scale 1:62,500, 2 sheets.

m Survey, 1996, Geologic map of the southern part of the Upper Red Rock Lake quadrangle, southwestern Montana and adjacent Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-1943, scale 1:62,500.

Zientek, M.L., 1993, Mineral resource appraisal for localite minerals—The Stillwater Complex (chapter F), in Hammarstrom, J.M., Zientek, M.L., and Elliott, J.E., eds., *Mineral resource assessment of the Absarokee-Beeshoof study area*, Center and Galatin National Forests, Montana: U.S. Geological Survey Open-File Report 95-207, p. F1-F83.



EXPLANATION

Prospect or mineral occurrence reporting chromium, nickel, or platinum-group elements—Number listed to Table 1 below.

Areas of exposed Precambrian ultramafic rocks located within the study area:

(A) "Jake Creek ultramafic body" in the center of the Blacktail Mountains—Described and mapped by Tysdal (1988) at a scale of 1:24,000; shown in SW¼ section 18, T. 10 S., R. 7 W., and SE¼ section 13, T. 10 S., R. 8 W. Character and petrology described by Sinker (1942, p. 137) and Heinrich and Rabitt (1966, p. 38). Four other bodies of exposed ultramafic rocks are shown by Tysdal (1988) in sections 6-8, T. 10 S., R. 7 W.

(B) Ultramafic rocks of the southern Ruby Range, including the "Wolf Creek pluton" and the "Elk Creek vermiculite deposit"—The exposed ultramafic rocks of this area were mapped and described by Heinrich and Rabitt (1966), Ozuma (1971), and James (1990). A description and detailed map (scale 1:60,000) of the Elk Creek vermiculite deposit (within the Wolf Creek pluton) is provided by Berg (1995). The Wolf Creek pluton is exposed in sections 1, 2 and 11, T. 9 S., R. 7 W.; section 6, T. 9 S., R. 6 W.; section 31, T. 8 S., R. 6 W.; and section 36, T. 8 S., R. 7 W. The petrology and mineralogy of this pluton is described by Sinker (1942), Heinrich (1966), and Desmaris (1978, 1981). James (1990) mapped the area at a scale of 1:24,000. He also shows a number of small exposed bodies of ultramafic rocks, which are too small to show at this scale (<1.600 ft long and <250 ft wide); these bodies outcrop throughout an area of about 35 square miles to the north and west of the Wolf Creek pluton.

(C) Ultramafic rocks exposed in the northern Ruby Range—Four small exposed bodies of ultramafic rocks, too small to show at the scale of this map (<750 ft across), occur in section 25, T. 6 S., R. 5 W., and sections 29 and 33, T. 6 S., R. 4 W. Mapped by Karasewich (1983) at a scale of 1:24,000, and described and mapped by Tysdal and others (1987) at a scale of 1:2