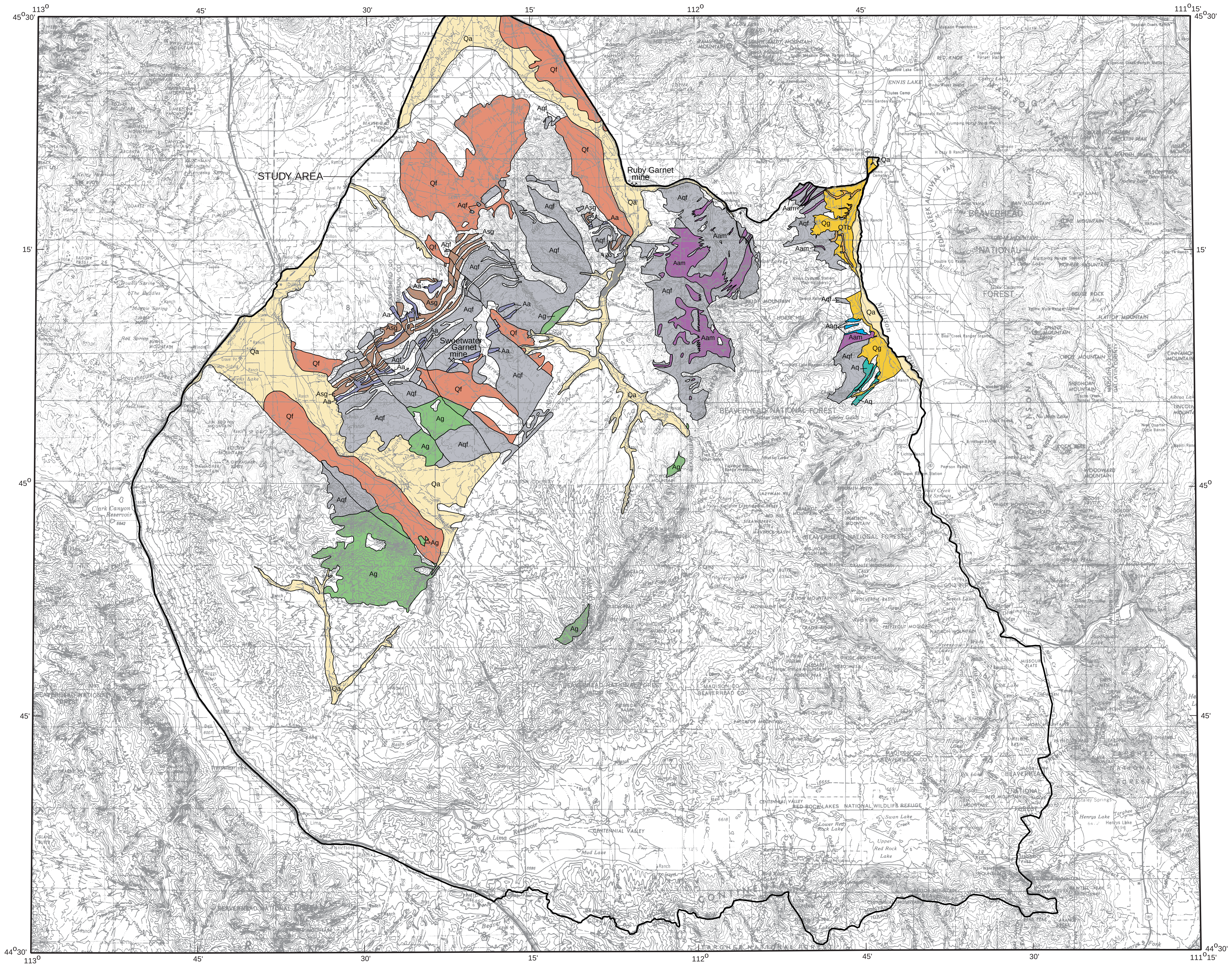


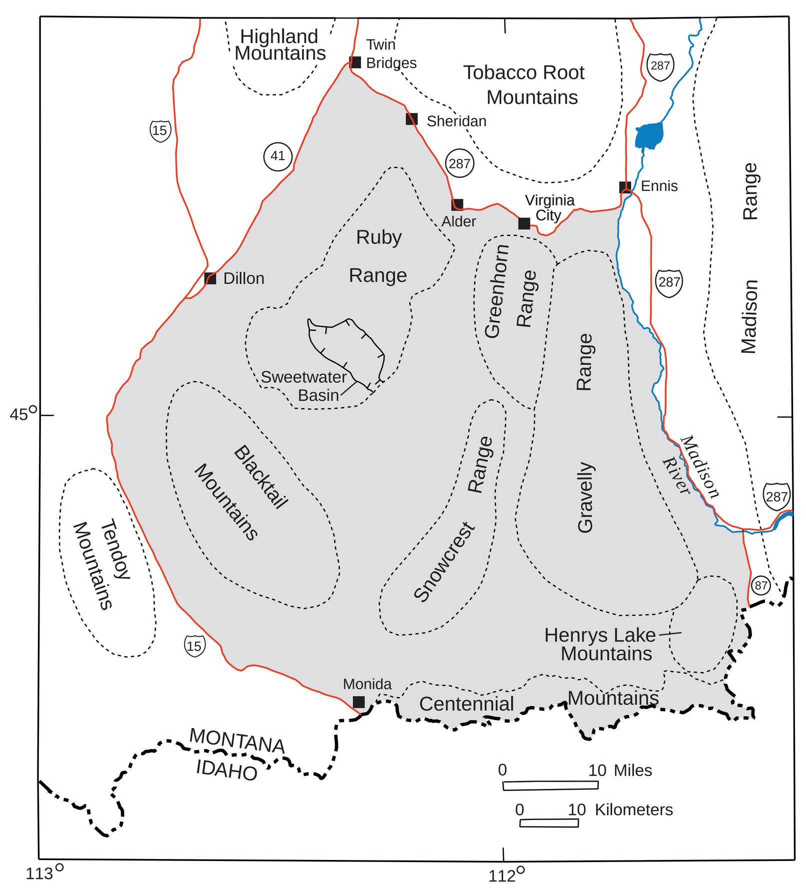
Base from U.S. Geological Survey, 1:250,000,
Ashton, 1972; Bozeman, 1972; Dillon, 1977; Dubois, 1978.
1927 North American Datum.
Projection: Transverse Mercator.

SCALE 1:250 000

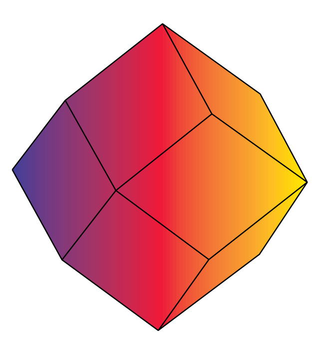
5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

CONTOUR INTERVAL 200 FEET
SUPPLEMENTARY CONTOUR INTERVAL 100 FEET IN DUBOIS QUADRANGLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929

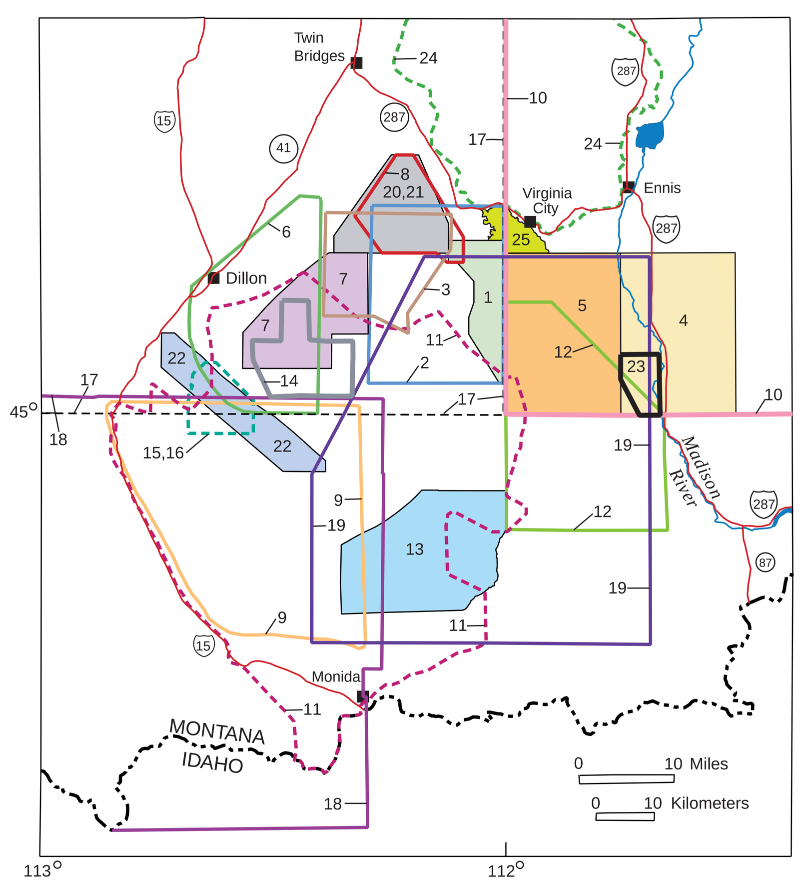


Index map showing the study area (stippled)



Garnet crystal, variety almandine

Idealized chemical composition: $Fe_3Al_2Si_3O_{12}$



Index to Geologic Mapping
(Refer to list of "References Cited and References to Geologic Mapping")

Map showing areas with potential for garnet resources in bedrock and placer in the Blacktail Mountains and the Gravelly, Greenhorn, Ruby, and Snowcrest Ranges of southwestern Montana

by

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EXPLANATION AND DESCRIPTION OF MAP UNITS

[**Note:** Areas within the study area without color have minimal or no potential for garnet in bedrock or placer. These areas consist of Archean marbles or ultramafic rocks or a variety of younger volcanic and sedimentary rocks.]

Alluvial deposits with potential for garnet placer resources

Qa — **Alluvium (Holocene)**—Silt, sand, gravel, and boulders in channels and modern flood plains of major rivers and streams. Deposits consist of moderately rounded to well-rounded material that is moderately well sorted to well-sorted. Mapped unit may include some alluvial deposits of Pleistocene age. Maximum thickness more than 5 m

Qf — **Alluvial-fan deposits (Holocene and upper Pleistocene)**—Poorly sorted to moderately well sorted, silty sand and pebble- to boulder-size gravel in fan-shaped deposits along valley margins at the base of mountain fronts. Includes pedimont-slope deposits, gravel veneer, and debris-flow deposits

Qg — **Terrace-gravel deposits (upper Pleistocene)**—Moderately well sorted, moderately rounded to well-rounded sand and gravel on the east flank of the Gravelly Range (Kellogg and Williams, 1997). Underlies about 12 terrace surfaces recognized in the Madison Valley. Highest terrace-gravel deposits may correlate with similar deposits of the Cameron bench, east of the Madison River. Mostly less than 10 m thick

QTb — **Basin-fill deposits (Pleistocene and Pliocene?)**—Moderately well sorted deposits of interbedded silt, sand, and well rounded cobble-size gravels exposed in slopes below terrace surfaces on the east flank of the Gravelly Range (Kellogg and Williams, 1997). A mostly unconsolidated unit with massive to lensoidal bedding. Exposed basin-fill deposits are presumed to be no older than Pliocene, although they overlie deeply buried basin-fill deposits that may be as old as Eocene in the Madison Valley (Rasmussen and Fields, 1983)

Archean metamorphic bedrock units within the study area that commonly contain garnet concentrations

[These rock sequences are probably Late to Middle Archean in age, but age relations between units are uncertain.]

Aa — **Amphibolite (Archean)**—Usually foliated, lenticular bodies of dark-gray to greenish-black, medium- to coarse-grained gneiss composed mostly of hornblende and plagioclase (Ruppel and others, 1993; James, 1990). Amphibolite bodies range from less than 1 m to over 500 m in thickness (Ruppel and others, 1993). James (1990) suggests the protolith was "mostly mafic sills initially, of two or more ages" and "some small bodies may be metavolcanic or derived from metasedimentary diopside gneiss by retrograde metamorphism"

Aam — **Amphibolite assemblage (Archean)**—Predominant rock type of this unit is gray to black, medium-grained, weakly- to well-foliated gneiss composed mainly of hornblende grains interspersed with plagioclase. Assemblage also includes minor amounts of relatively thin (less than 5 m thick) hornblende gneiss, metagabbro, garnet-quartz-feldspar gneiss, biotite gneiss, anthophyllite gneiss, garnet-pyroxene granulite, quartzite and sillimanite schist (Hadley, 1969a-b; Berg, 1979; Kellogg and Williams, 1997)

Aq — **Quartzite and quartz-mica schist (Archean)**—White, medium- to coarse-grained, inequigranular, moderately foliated to massive quartzite and interbedded quartz-mica schist. Typically, rock consists entirely of anhedral quartz grains. Unit contains minor lenticular bodies of garnet-mica schist, anthophyllite schist, and granitic pegmatite (Hadley, 1969a-b; Kellogg and Williams, 1997)

Aag — **Aluminous gneiss and schist (Archean)**—Gray to dark-brownish-gray, medium-grained, inequigranular, generally well-foliated gneiss and schist, which are often micaceous and contain trace amounts to 15 percent aluminosilicate minerals (mostly sillimanite and rarer kyanite) (Kellogg and Williams, 1997). Unit is often rich in anhedral quartz (as much as 90 percent) and can grade into quartzite composition. Several kyanite prospects in the unit occur in section 6, T.8S., R.1W., on the east side of the Gravelly Range (Nordstrom, 1947)

Asg — **Interlayered schist and gneiss (Archean)**—Unit includes metamorphosed sedimentary rocks of quartz-mica schist; sillimanite schist; tremolite, phlogopite, and anthophyllite schist; quartz-feldspar-biotite gneiss; diopside and epidote gneiss; and small lenticular bodies of metaigneous amphibolite and granitic gneiss (Ruppel and others, 1993; James, 1990)

Aqf — **Quartzofeldspathic gneiss (Archean)**—Heterogeneous rocks of interlayered granitic to tonalitic, light- to medium-gray biotite-quartz-feldspar gneiss, quartz-feldspar gneiss, hornblende-quartz-feldspar gneiss, migmatite, and metamorphic pegmatite, in order of general decreasing abundance (Hadley, 1969a-b; Berg, 1979; Vitaliano and Cordua, 1979; Kellogg and Williams, 1997). Locally contains thin lenticular layers of amphibolite and schist. Unit envelops thick wedges of metasedimentary strata, especially dolomitic marble, due to multiple isoclinal folding (James, 1990). The protoliths for these metamorphic rocks are interpreted to be mostly sedimentary, and in part igneous (Hadley, 1969a-b; Karasevich and others, 1981; Wilson, 1981a-b; James, 1990). Rocks from this unit within the Ruby Range were dated at 2.76 Ga using the Rb-Sr method (James and Hedge, 1980)

Ag — **Older gneiss and schist (Archean)**—Well-foliated, medium- to dark-gray biotite-hornblende-garnet gneiss, migmatite, augen gneiss, hornblende gneiss, amphibolite, and aluminous schist (Heinrich and Rabbitt, 1960; James, 1990; Ruppel and others, 1993). Corundum-bearing schist and anthophyllite schist crop out in section 20, T.8S., R.6W. (James, 1990). Age of this sequence is unknown, but the group is apparently the lowest sequence of the area and presumably older than the quartzofeldspathic gneiss unit (Karasevich and others, 1981; James, 1990)

Introduction

Garnet crystals, some of gem quality, have been sought by rock hounds for many years in the alluvial deposits of the Alder Gulch-Ruby River area. Since 1995, garnet has been extracted from these gravels for industrial products at two separately owned placer mines in the region: (1) at Cominco American's "Ruby Garnet" operation at Alder, Montana, and (2) at the "Sweetwater Garnet" operation in the Sweetwater Basin of the Ruby Range. The two placer mines excavate different types of garnetiferous deposits, but both produce sized concentrates of almandine garnet derived from similar source rocks.

At Cominco American's Ruby Garnet placer mine, the garnet is removed from 1920's gold dredge tailings, up to 15 m thick, in Alder Gulch near Alder. The dredged alluvial material at Alder typically contains from about 4 to 10 percent garnet, mainly the almandine variety. The Ruby Garnet operation separates on site the free grains of garnet from the tailings using a series of gravity separation processes. The garnet concentrates are separated into several size fractions and sold accordingly for use in light grinding, sand blasting, abrasive water- jet cutting, and filter bed material in water purification plants. This placer mine received its permit to operate in 1993.

The placer tailings reworked at the Ruby Garnet operation were created by a succession of gold dredges that began working the gulch near Ruby in 1899. Dredges began operation in Alder Gulch just downstream of Virginia City in 1896. Alder Gulch extends 21 km from the foot of Baldy Mountain, south of Virginia City, to its confluence with the Ruby River near Laurin, about 3 km downstream of Alder. Alder Gulch became the largest gold placer deposit in the history of Montana (Lyden, 1987). The gulch was worked until 1922 by dredges, including some of the largest floating dredges of the time in the world (Anonymous, 1911; Bushnell, 1911; Hutchins, 1907a, 1907b; Janin, 1918; Jennings, 1912, 1916a, 1916b; Lyden, 1987; Scott, 1910; Spence, 1989). Dry land dredges (draglines) worked the gulch in 1935-37 and 1940-41 (Corry, 1936; Gardner and Allsman, 1938; Lyden, 1987). The dredging activity in the gulch reached its high point in 1915, when "four dredges treated 6,000,000 yd^3 [about 4,600,000 m^3] of gravel and recovered more than $800,000 in gold" (Lyden, 1987). It is likely that the bulk of the rich gold placer deposits in the gulch, upstream of Alder, have been found and processed at least twice, excepting small scattered pockets. However, considerable amounts of garnet are left in the dredge and dragline workings.

In 1996 the Sweetwater Garnet placer mine began production in the central Ruby Range. This mine recovers almandine garnet from alluvial deposits located about 0.8 km north of the main road in the Sweetwater Basin, about 22 km east-southeast of Dillon, Montana (section 17, T.8S., R.6W.). The processing plant for the operation is located at the Barretts exit of interstate highway 15, about 10.5 km southwest of Dillon. The garnetiferous sediments excavated by this placer mine are thin deposits of stream-worked material derived from the surrounding bedrock of Archean quartzofeldspathic gneiss. This garnet-bearing alluvium fills the narrow stream beds that drain into the Sweetwater Basin; these strips of alluvium are too small in extent to show at the scale of this map (the most detailed geologic map of this area is provided by James (1990)). Alluvial fans and eluvial deposits throughout the Sweetwater Basin are prospective for garnet concentrations. Heinrich and Rabbit (1960, p. 33) reported eluvial deposits of deep-red garnets (almandine) averaging a quarter inch in diameter, which lie to the north of the Sweetwater Basin road, a few kilometers east of the current mine.

The virgin alluvial gravels of the Ruby River valley and alluvial fans along the mountain fronts also hold plentiful deposits of garnet. For many years, mineral collectors have retrieved garnets from the gravels in Barton Gulch, which drains into Ruby Reservoir from the northwestern part of the Greenhorn Range.

Purpose of the Study

In response to requests from the Bureau of Land Management (BLM) and the U.S. Forest Service (USFS), the U.S. Geological Survey conducted a mineral resource assessment of specified study areas in Beaverhead and Madison Counties of southwestern Montana. These agencies use mineral resource data in developing land-use management plans for the reasonably foreseeable future for federal lands in the region. The active mining of garnet in the area suggests that garnet resource exploration and development potential must be evaluated and considered in planning. This map is designed only to show potential rock sources for the garnets within the study area, as well as large areas that are likely to contain alluvial concentrations of garnet. Identification of specific targets for potential mines is beyond the scope of this study. Multiple economic and social considerations (for example, optimum garnet grade, mining and processing costs, proximity to markets, transportation costs, demand, prices, and environmental and reclamation issues and expenses) are factors that effect the economic viability of any future development.

SUMMARY OF GARNET PLACER RESOURCES

Deposit type: Garnet placer

Description: Alluvium (fans, stream channel and flood-plain deposits) proximal to garnetiferous source rocks in the areas of the Ruby River, Blacktail Deer Creek, and the northeastern part of the Gravelly Range.

Geologic criteria

Alluvium derived from garnetiferous source rocks. Source rocks are not considered to be mineral deposits. Upon weathering and erosion, these source rocks disaggregate and contribute garnet to nearby stream sediments and alluvium; mineral deposits may form if garnet is sufficiently concentrated. Source rocks include quartzofeldspathic gneisses that locally contain concentrations of garnet, interlayered with garnetiferous amphibolite, schist, and quartzite. These rocks include map units Aqf, Aa, Asg, and Ag on the geologic map of the Dillon 1° x 2° quadrangle (Ruppel and others, 1993) and map units p€cq, p€g, p€cg, and p€cb on Hadley's (1969a-b) maps of the Varney and Cameron quadrangles. The map includes alluvium, alluvial-fan, terrace-gravel and basin-fill deposits that may be proximal to garnet source rocks. The map excludes areas where source rocks for alluvial deposits are Paleozoic rocks. The map also excludes Tertiary sedimentary and volcanic rocks; although these rocks could contain heavy mineral concentrations, they generally contain no garnet or merely trace concentrations. Garnet erodes from some rocks of the Tertiary Bozeman Group, because the Bozeman Group is derived locally, in part, from Archean garnetiferous rocks. However, the rocks of the Bozeman Group are excluded from the map because the garnet grade in this unit is generally very low; there was considerable dilution from non-garnet-bearing units in the sediments that formed this rock group.

In the northern Greenhorn Range, garnetiferous quartzite locally contains as much as 40 percent garnet (Berg, 1979, p. 5-6). In the same area, anthophyllite gneiss locally contains garnet porphyroblasts, and where it weathers, the ground is covered with garnet. Garnet is abundant in the alluvium along Barton Gulch in the northern Greenhorn Range. In the area of the Elk Creek vermiculite deposit of the southern Ruby Range (Berg, 1995), the road is locally colored red by garnet.

Geochemical signature

Stream sediments: Stream sediment data coverage is lacking for much of the area. We are unaware of a geochemical signature in stream sediments that is indicative of elevated garnet concentrations.

Garnet placer mines

Active placer mines: Cominco American's "Ruby Garnet" operation at Alder produces high-purity garnet of different size fractions on site by reworking old dredge tailings from historic gold placer mining operations. These dredge tailings reportedly contain an average of 4.5% almandine (Austin, 1994). Their products are concentrates of 90% almandine separated into specific size fractions ranging from 6 mesh (3.4 mm) to 150 mesh (0.1 mm) (Berg, 1997). The mine opened in 1995 and expects to reach full production status in 1998.

The "Sweetwater Garnet" property began producing garnet from garnet-rich alluvial deposits in the Sweetwater Basin of the central Ruby Range in 1996. The property encompasses 1,860 acres of private land and is operated by Sweetwater Garnet, Inc. of Dillon, Montana, a wholly owned subsidiary of Absolut Resources Corporation. This deposit reportedly contains 8% almandine garnet. Their processing plant is located at the Barretts exit of interstate highway 15, about 10.5 km southwest of Dillon.

Comments and outlook

Detailed exploration in favorable areas is necessary to evaluate the economic potential of a particular garnet deposit. This level of evaluation is beyond the scope of this study. There are places in the Archean bedrock of this area where one could recover garnet by hard-rock mining. However, it is unlikely that bedrock garnet will be mined in the foreseeable future, because placer garnet is much more economical to mine is this region. Fluvial processes have disaggregated the bedrock and concentrated garnet in the alluvial deposits, saving significant mining and processing effort and cost in retrieving the garnet.

Areas that have the highest potential for additional garnet deposits include: (1) the lower Ruby River around Ruby Reservoir and downstream to Alder; and (2) alluvial fan deposits in the Sweetwater Basin. These areas have high potential because Archean source rocks are present on both sides of these drainages. The eastern Gravelly Range area is less likely to contain rich garnet deposits than these two areas, because the extent of exposed garnetiferous source rocks in the eastern Gravelly Range is much less.

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 (see Index map), designated the "Gravelly's Landscape Analysis Unit" by the regional land managers of the BLM and USFS, is defined as follows: (1) The western boundary is U.S. Interstate Highway 15 from Monida to 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 Raynolds Pass (4 km west of Earthquake Lake) and State Highway 87 from Raynolds Pass south to the Montana-Idaho border; and (4) The southern boundary is the Montana-Idaho border (the Continental Divide) between Monida and State Highway 87. 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.

Garnet Characteristics and Rock Sources

The garnet mined from dredge tailings at the Ruby Garnet operation near Alder, as well as those mined from the Sweetwater Basin alluvial deposits at the Sweetwater Garnet placer mine, is naturally occurring almandine, which exhibits deep shades of violet-red and reddish-brown. The Ruby Range was named by early prospectors who thought that the abundant red garnets in the area were rubies. Almandine is the iron-rich species of the garnet group and the hardest of the garnets, and thus is well suited for abrasive (blasting) uses. According to garnet industry reports, almandine garnet has a number of characteristics beneficial for use in abrasive blasting. Favorable qualities include: (1) grains that are angular to subangular; (2) an inert nature (no silica or heavy metals are released); (3) a product that is reusable; (4) a minimum of dust production, which is a health, safety and cleanliness advantage; (5) a specific gravity of 3.95 and Mohs hardness of 8; and (6) a bulk density of the product of 120-160 pounds per cubic foot (1.9-2.6 grams per cubic cm).

The rocks in the region that contain garnet are metamorphic rocks of Archean age formed by regional metamorphism. Local concentrations of garnet occur in gneiss, amphibolite, schist, migmatite, quartzite, and granulite. The garnet-bearing gneiss is primarily quartzofeldspathic, with a variety of compositions, reflecting variable amounts of quartz, potassium feldspar, biotite, hornblende, and plagioclase. Biotite-quartz-feldspar gneiss appears to be the most abundant Archean rock type in the study area. Generally, amphibolite seems to contain the highest concentrations of garnet of all the rock types. In composition, the hornblende-quartz-plagioclase gneiss grades into amphibolite. Garnet-bearing schist is also highly variable in composition, consisting of different proportions of quartz, biotite, muscovite, sillimanite, cummingtonite, biotite, anthophyllite, and phlogopite. Detailed descriptions of the garnet-bearing rocks shown on the accompanying map, as well as interpretations of their geologic history, are provided in the geologic map data sources and references listed below, especially Berg (1979), Clark (1987), Dahl (1977, 1979), Garihan (1976, 1979), Garihan and Williams (1976), Heinrich and Rabbitt (1960), James (1990), Karasevich (1981), Karasevich and others (1981), Millholland (1976), Smith (1980), Tompson (1959, 1960), Vargo (1990), and Wilson (1981a-b).

Garnets eroded from the Archean metamorphic rocks, which are physically and chemically durable, are naturally concentrated by fluvial processes in the fans that drape the mountain fronts and in the sediments of the streams and rivers. The alluvial deposits shown on the map—alluvial fan, channel and floodplain, terrace-gravel, and basin-fill deposits—are likely to contain garnet as free grains, crystals, and most commonly, as aggregates of grains moderately to weakly cemented by silt and clay.

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