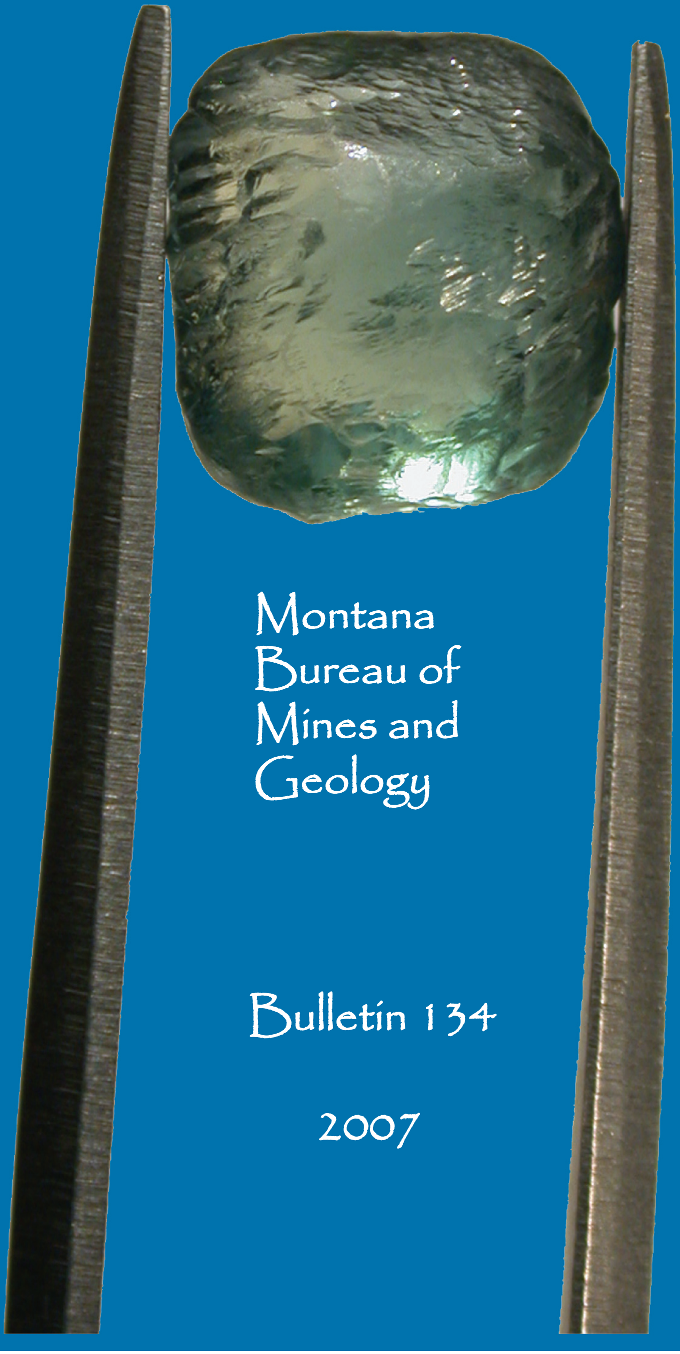
Sapphires in the Butte–Deer Lodge Area, Montana

Richard B. Berg



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Cover photo:

Sapphire from the South Fork of Dry Cottonwood Creek. Sapphire weighs 3.37 carats and is 7 mm across. Photo by R.B. Berg; sapphire provided by Mr. Marc Bielenberg.

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INTRODUCTION

Summary of Montana Sapphire Deposits

Montana has a long history of sapphire mining, beginning with the discovery of sapphires in gravels along the Missouri River northeast of Helena in 1865 (fig. 1). The most famous Montana sapphires come from the Yogo deposit in central Montana. These sapphires are characterized by scarcity of mineral inclusions and a generally uniform blue color, referred to as cornflower blue. Sapphires at the Yogo deposit are mined from dikes and surrounding alluvium. At all other Montana deposits, sapphires are mined from gravel. However, in addition to the Yogo dike, there are two other known bedrock occurrences of sapphires. Sapphires are found sparsely in the French Bar dike situated along the Missouri River near Helena (Berg and Dahy, 2002) and have been recovered from altered tuff at the Silver Bow location 6 miles west of Butte (Berger and Berg, 2006). Corundum, but not the gem variety sapphire, occurs in metamorphic rocks at several localities in southwestern Montana (Clabaugh, 1952). See Kane (2003) for a well-illustrated summary of sapphire deposits in Montana, with photographs of faceted sapphires from these deposits.

Along the Missouri River northeast of Helena sapphires and gold have been mined from terraces that extend for at least 13 miles along the river. These deposits are referred to as bars, the largest of which is Eldorado bar. Farther southwest, sapphires have been mined from alluvial deposits along Lowland Creek north of Butte and the South Fork of Dry Cottonwood Creek northwest of Butte (fig. 2). The largest concentration of sapphires in Montana is in the Rock Creek (Gem Mountain) district in the Sapphire Range southeast of Missoula (fig. 1), where sapphires have been mined from alluvium in numerous gulches within an area slightly larger than 3 miles by 3 miles. The greatest production of sapphires from all Montana deposits was from about 1906 to the 1920s, when sapphires were used for watch and instrument bearings. During this time, the larger and more highly colored sapphires were sold to the gemstone market. Currently, all Montana production is for the gemstone market.

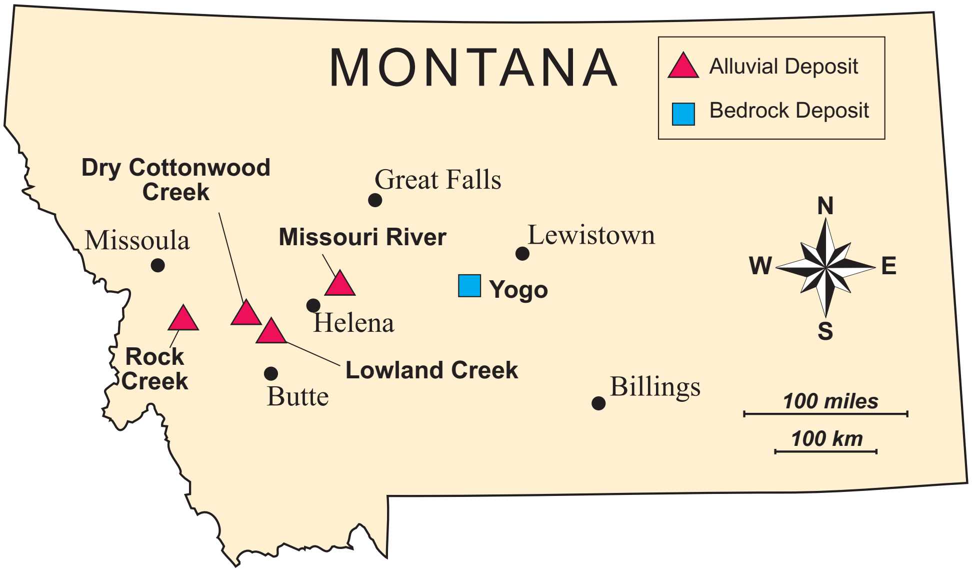


Figure 1. Principal sapphire deposits in Montana.

The introduction of synthetic sapphire largely eliminated the market for watch and instrument bearings for natural sapphires after the 1920s, with a brief exception during World War II. In the 1970s, heat treatment of Montana sapphires began. By carefully controlling the temperature and atmosphere, the pale colors typical of most sapphires from the alluvial deposits in western Montana can be intensified. Most sapphires destined for the gem market worldwide are enhanced by heat treatment. However, because of their natural blue color, sapphires from the Yogo deposit are not heat-treated.

Total past production of sapphires from the alluvial deposits in southwestern Montana exceeds 55 tons. In spite of over 100 years of searching, the bedrock sources of most of these sapphires have not been recognized. The goal of the present work was to investigate possible sources for some of these alluvial deposits as well as to provide new information on previously unreported deposits and occurrences.

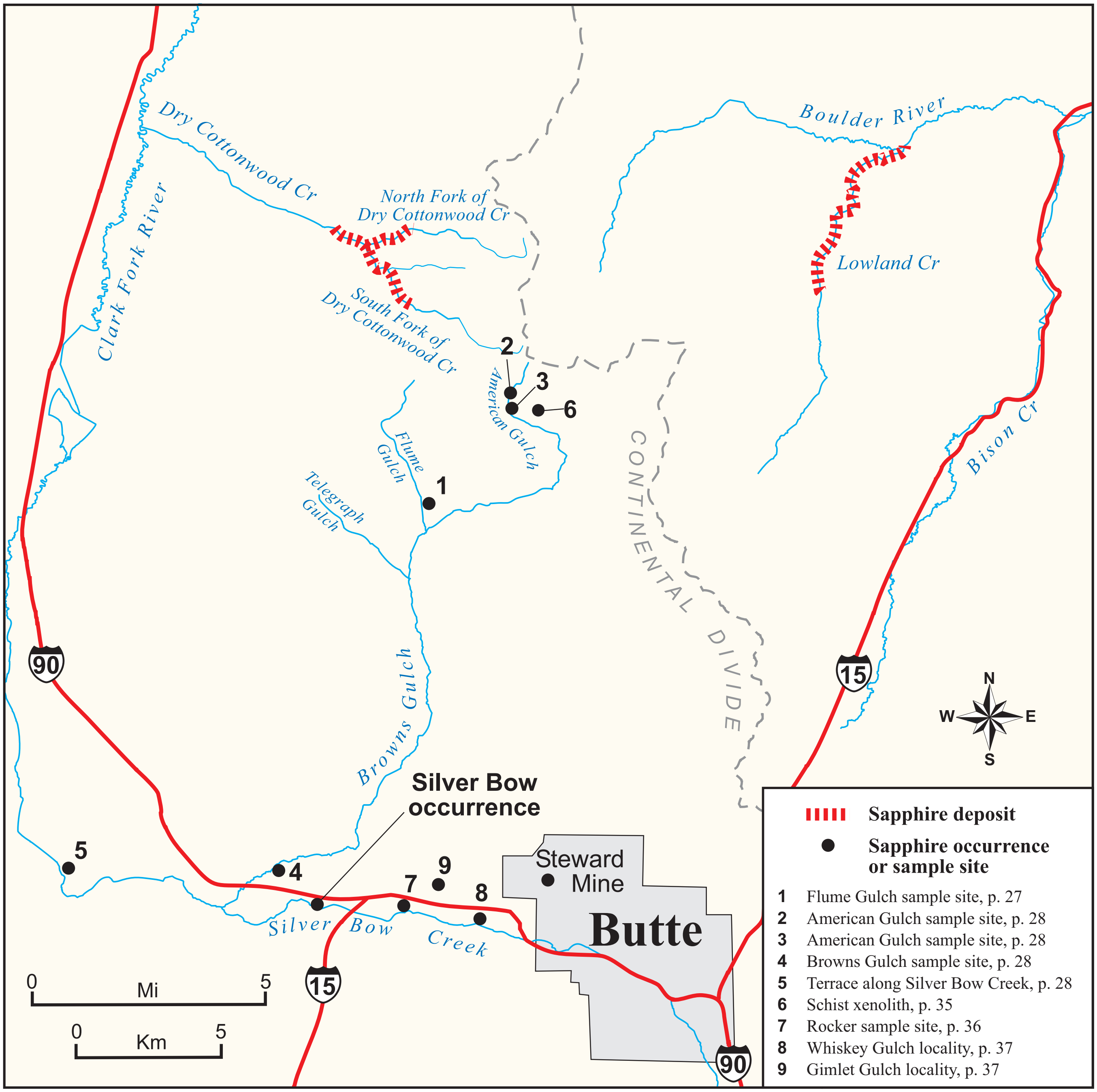


Figure 2. Known sapphire occurrences and deposits in the area north and west of Butte.

Previous Work

The most comprehensive publication on corundum in Montana (including the major sapphire deposits) is by Clabaugh (1952). He described the deposit along the South Fork of Dry Cottonwood Creek and mentioned a reported occurrence in Browns Gulch, but did not include descriptions of other occurrences in the area north and west of Butte. More recently, Garland (2002) provided information on the alluvial deposits in southwestern Montana in her Ph.D. dissertation completed at the University of Toronto. She provided information on the chemistry, mineral inclusions, and stratigraphy of the Rock Creek and South Fork of Dry Cottonwood Creek deposits. In addition, Garland presented detailed information on the chemistry of sapphires from major world deposits. Emmett and Douthit (1993) provided the results of an extensive study of heat treatment of more than 75,000 sapphires from the Rock Creek district. They also discussed the history of mining of this very significant sapphire deposit. Berg (2004) discussed evidence for a local bedrock source for the sapphires in the South Fork of Dry Cottonwood Creek; Berger and Berg (2006) described the occurrence of sapphires in altered tuff at the Silver Bow occurrence. The bedrock geology of the area north and west of Butte is shown on geologic maps by Derkey and Bartholomew (1988); Hargrave (1990); Smedes (1968); and Smedes and others (1962).

Present Work

Sapphire deposits and occurrences in the area north and west of Butte, generally in the area between Butte and Deer Lodge, are described here. Sapphires were first examined using the binocular microscope and petrographic microscope. Surface textures of selected sapphires were examined and photographed using the scanning electron microscope. Mineral inclusions in individual sapphires were identified using the petrographic microscope and energy-dispersive x-ray analysis (EDX). Heavy minerals associated with sapphires were also identified using the same techniques. Detailed information on laboratory procedures is given in the appendix. The exposed bedrock at the head of the South Fork of Dry Cottonwood Creek was mapped by the author, and Berger mapped the geology in the vicinity of the Silver Bow sapphire occurrence (Berger and Berg, 2006).

Gravel from several gulches west and northwest of Butte and in the Lowland Creek drainage basin was tested for sapphires. Generally, the 1- to 7-mm-size fraction was sieved to recover sapphires and other heavy minerals. In addition the <1-mm fraction was panned and examined using the petrographic microscope. The results of this sampling are reported in the appropriate sections. With the exceptions of an unusual occurrence of microscopic sapphires in the Steward mine in Butte and the altered tuff at the Silver Bow occurrence, all deposits and occurrences described here are alluvial. Fieldwork is planned in the Rock Creek (Gem Mountain) district in summer 2006 and will be published in a separate report.

Sapphires described here, as well as those provided from other Montana localities, have been accessioned into the collection of the Mineral Museum of Montana Tech of The University of Montana.

Figure 3. Sapphires of 0.25, 0.5, 1.0, 2.0, 3.0, and 4.0 carat weight. Photo by R.B. Berg.

Corundum

Sapphire and ruby are the gem varieties of the mineral corundum (Al_2O_3). Chromium in trace concentrations gives ruby its red color and in lesser concentrations gives sapphire a pink color. Trace concentrations of iron and titanium are responsible for the blue color in some sapphires and iron causes a yellow color. Sapphires with very low concentrations of foreign elements are colorless. However, the cause of color in sapphires is not really this simple. Colors are caused by the interaction of pairs of foreign atoms as well as the presence of imperfections or defects in the arrangement of atoms in each crystal's structure. See Emmett and Douthit (1993) for a detailed discussion of colors in sapphires.

Corundum is next to diamond in hardness, making sapphire a very durable gemstone. On a scale of mineral hardness (Mohs scale of hardness) in which minerals range from 1 (talc) to 10 (diamond), sapphire is 9. Typically, hard minerals have a high index of refraction and high density; this is true for corundum. The indices of refraction of corundum (1.760–1.772) are significantly higher than those of common minerals such as quartz (1.544–1.553). These high indices of refraction contribute to the brilliance of a faceted sapphire by causing the facets to reflect light, which enters the stone more efficiently than in a mineral with lower indices of refraction. Also, light is reflected more efficiently from the polished surfaces of the stone. The specific gravity of pure corundum is 4.02, considerably higher than quartz (2.65) and most other common minerals, and even than diamond, which is 3.5. Because of its greater specific gravity, a 1-carat sapphire is slightly smaller than a 1-carat diamond. One carat is equal to 0.2 gm. Because of the irregular shape of most sapphires, those shown in figure 3 are only approximations of sapphires of these weights.

Worldwide, most sapphires are mined from alluvial deposits. Sapphires are naturally concentrated in alluvial deposits because of several characteristics. They are chemically stable in the surface environment and do not alter to other minerals during weathering. They are physically durable because of their unusually high hardness and, although they break along parting planes, they do not separate along planes as readily as some minerals such as calcite, which has well-developed cleavage. Also, their high specific gravity causes them to be concentrated in certain alluvial deposits and makes it possible to separate sapphires from other minerals by gravity-separation techniques.

Corundum crystallizes to form hexagonal prisms, very often somewhat tapered, forming barrel-shaped crystals (fig. 4). Parting, the ability to part or break along definite crystallographic planes, is prominent in corundum. These planes are described as rhombohedral parting planes (fig. 5A) and basal parting planes (fig. 5B). The occurrence of hexagonal tablets in alluvial sapphire deposits can be explained by separation along these basal parting planes (fig. 6). Grooves developed on the surfaces of some sapphires from the South Fork of Dry Cottonwood Creek and Lowland Creek are an external indication of these basal and rhombohedral parting planes (fig. 7).

Figure 4. Corundum crystals in gneiss from the Elk Creek deposit southwest of Bozeman, Montana, from the William Heierman Collection. The largest crystal is 5.5 cm long. Photo by R.B. Berg.

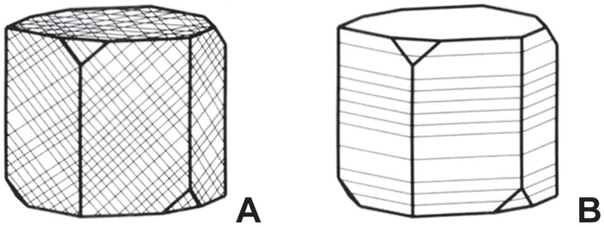


Figure 5. Parting planes in corundum. For clarity rhombohedral parting is shown in A, and basal parting in B. From Hughes, 1997, with permission from RWH Publishing.

Figure 6. Tabular sapphires from the South Fork of Dry Cottonwood Creek, some of which show remnants of hexagonal crystal form. Sapphire at upper left is 10 mm long. Photo by R.B. Berg.

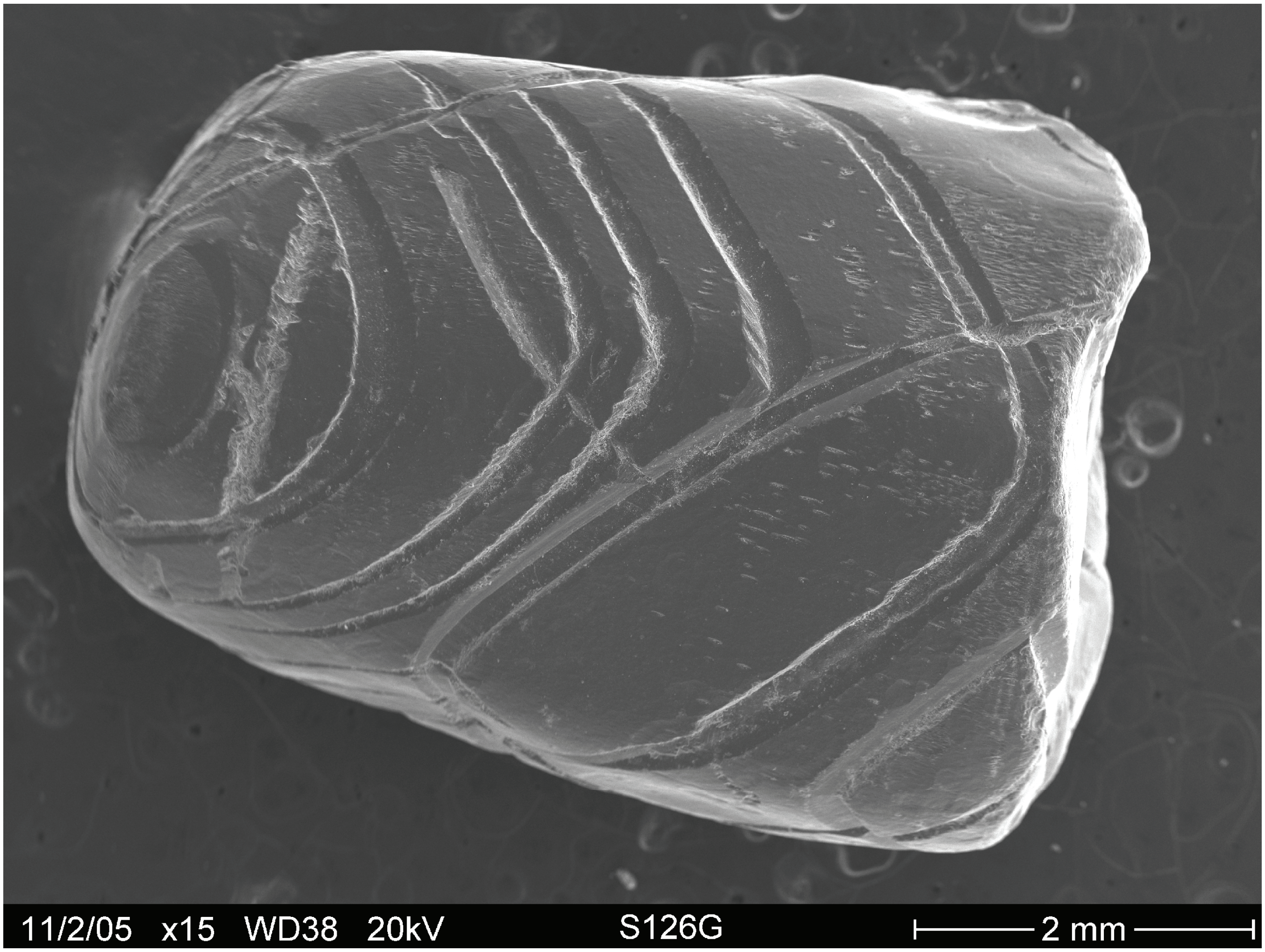


Figure 7. Sapphire from the South Fork of Dry Cottonwood Creek with prominent grooves developed along rhombohedral parting planes. Single groove at the left of the photo is along the basal parting plane. Small, barely visible elongate pits aligned parallel to the length of the sapphire are found rarely on sapphires from this locality. Sapphire provided by Marc Bielenberg. Scanning electron micrograph by Nancy Equall.

Recovery of Sapphires from Alluvial Material

A gold pan, rocker, or small sluice box can be used by an individual handling a small amount of sapphire-bearing gravel. More commonly, sieves are used in the recovery of sapphires and garnets, where small amounts of material are handled. A coarse sieve used to separate the coarser gravel may have a mesh size of 11 mm (15/32 in) and a fine sieve 1.3 mm (3/64 in). These dimensions will allow an approximately equidimensional sapphire of 7 carats to pass through the coarser sieve. During the recovery of sapphires, just as in the use of a gold pan, it is important that both sieves be completely underwater, so the fine material (silt and clay) can be washed from the gravel. Once the coarse material is separated, the upper sieve can be removed, and the material remaining on the finer sieve can be further concentrated. This is done by a combination of a rocking movement and vertical movement or jigging. The sieve is moved back and forth in one direction and then shifted and moved back and forth at 90 degrees to the first direction. By this action the gravel is concentrated in the middle of the screen, forming a low pile. Then the sieve is quickly flipped over onto a table. If the sieving was done correctly, there should be a small pile of gravel with a concentration of black heavy minerals such as magnetite and hematite in the middle of the sieve along with garnets and any sapphires. In bright sunlight, the wet sapphires are easily recognizable.

In commercial operations sapphires are recovered using gravity-separation methods normally employed in the recovery of placer gold. Washing plants with trommels or screen decks with sluices are typically used in operations where a large quantity of gravel is processed. However, because sapphires have a lower specific gravity than gold (4.02 for sapphire and 15.0–19.3 for gold), jigs are typically used for the final concentration of sapphires. A jig consists of a metal tank (hutch) filled with water topped by a screen. Movement of a diaphragm on the side of the tank causes water to pulse up through the screen. Small high-density balls (ragging) form a bed on top of the screen. Water carrying the sapphire-bearing material is fed onto the top of the screen. Each upward pulse causes the light material to be carried by the water above the screen and each downward pulse causes the sapphires and other heavy minerals to settle in the ragging. When there is sufficient accumulation of heavy minerals on the ragging, the flow of water is stopped and the hutch is cleaned.

Recognition of Sapphires

Sapphires can generally be recognized in a heavy mineral concentrate by several characteristics. Most sapphires from the Butte–Deer Lodge area are very pale green or very pale greenish blue to colorless. Only rarely are sapphires from this area darker shades of green, blue, pink, or yellowish orange. Quartz is commonly confused with sapphire. Color is an indicator; most quartz is water clear or milky white, compared to the very pale colors of sapphires. Also, quartz grains typically exhibit very glassy surfaces, whereas in sapphires glassy fractures are much less abundant (fig. 8). Feldspars can also be confused with sapphires but are often white or pale salmon and generally not as transparent as sapphires. In addition, the cleavage directions in feldspars are close to being perpendicular to each other and produce rectangular-shaped fragments. Most sapphires from the Butte–Deer Lodge area have a frosted surface that causes them to almost glow in bright light. The smooth crystal face on a quartz crystal can be easily scratched by the sharp edge of a sapphire, but the harder sapphire cannot be scratched by quartz. Alluvial sapphires exhibit a variety of shapes. In order of decreasing abundance, these are irregular, rounded, flat tablets, and hexagonal prisms (fig. 6). The identifying features of minerals commonly associated with sapphires in the Butte–Deer Lodge area are given in table 1. It should be noted that other minerals not listed here might be associated with sapphire occurrences in other areas. These minerals can generally be identified by their colors or shapes.

Figure 8. Quartz, feldspar, garnet, and sapphire recovered from alluvial deposits in the Butte–Deer Lodge area. Pale green sapphire is 11 mm across. Photo by R.B. Berg.

1. Garnet—Dark red variety
2. Sapphire—Sparkly surface found on some sapphires
3. Sapphire—Faint sheen and barely discernible remnant of hexagonal form
4. Sapphire—Faint sheen and rounded shape
5. Quartz—Typical glassy appearance
6. Feldspar—Very pale salmon color and straight edges
7. Sapphire—Faint sheen and remnant of hexagonal outline
8. Garnet—Pale pink variety
9. Sapphire—Sheen and pale green color
10. Quartz—Milky variety with irregular shape
11. Quartz—Typical glassy appearance

Table 1. Minerals associated with sapphires in alluvial deposits in the Butte–Deer Lodge area

Mineral	Specific Gravity	Identifying Characteristics
Quartz	2.65	Glassy, typically either clear or milky with irregular shape and glassy conchoidal fractures. Bipyramidal clear quartz is abundant in some sapphire occurrences.
Feldspars	2.57–2.76	Most are transparent and colorless, but some are chalky or pale salmon. May have a rectangular shape where surfaces intersect at almost right angles, due to breakage along cleavage planes.
Spinel	3.6–4.0	Small, light green to very dark green, almost black grains that range in shape from octahedral to rounded. Spinel grains from this area are generally less than 1 mm in size.
Corundum	4.02	Generally very pale green or very pale bluish green (sapphire) grains that because of their usual frosted surface or surface with small irregularities seem to glow in bright light.
Rutile	4.18–4.25	Small, very dark red to black prismatic grains.
Garnet	3.5–4.3	Three varieties of garnet are abundant in these alluvial deposits. These are pale pink, orangish red, and dark red. Dark red garnets are much less abundant than the other two varieties. Garnets are typically nearly equidimensional with fractured surfaces. Because the specific gravity of garnets is close to that of sapphires, garnets should be concentrated near the center of the hill of gravel when gravel is correctly sieved for sapphires. Garnets are much more abundant than sapphires in the South Fork of Dry Cottonwood Creek and Lowland Creek.
Zircon	4.68	Very small, clear, prismatic grains usually with shiny crystal faces. Most are smaller than 1 mm in maximum dimension.
Magnetite	5.18	Black, nearly equidimensional grains that range from octahedral to irregular in shape. Most grains are smaller than 1 mm. Magnetite is the only strongly magnetic mineral associated with sapphires.
Goethite, hematite, and limonite	3.6–5.26	These three iron-bearing minerals may be intergrown and are difficult to distinguish. They vary in color from shiny black (some hematite) to dull yellowish brown to reddish brown (hematite and limonite). The concentration of these black and brown minerals near the center of the hill of gravel after the gravel is sieved is an indication that the heavy minerals were concentrated during the sieving process and that the sapphires should be near the center of the pile of gravel also.
Ilmenite	4.7	Shiny black in irregular grains and may be slightly magnetic. Sometimes intergrown with magnetite.
Gold	15.0–19.3	Golden yellow and varies from flat flakes to grains that may retain remnants of crystal faces. Gold particles can be easily scratched with a needle.

DESCRIPTIONS OF OCCURRENCES

South Fork of Dry Cottonwood Creek

Introduction

Dry Cottonwood Creek flows northwest from the Continental Divide to join the Clark Fork River about 10 miles south of Deer Lodge (fig. 2). Although Dry Cottonwood Creek has several forks, sapphires have only been found in the gravels of the South Fork; they have been mined from the upper 2¼ miles of this tributary and have been found in soil and alluvium upstream from the area of placer mining (figs. 9 and 10). Records of production from the South Fork of Dry Cottonwood Creek are not available, but total production is certainly less than that in the major sapphire deposits in Montana [Yogo, Missouri River, and Rock Creek (Gem Mountain)].

History

Sapphires were first found in Dry Cottonwood Creek about 1889, presumably by prospectors in search of gold (Kunz, 1904, p. 829). Shortly after their discovery, Kunz (1894) reported "about 30 stones to the pan at Bed Rock on Cottonwood creek." The earliest production of sapphires was evidently by the Northwest Sapphire Company of Butte, who used hydraulic mining (Struthers and Fisher, 1903, p. 250). Two dredges subsequently operated on the South Fork of Dry Cottonwood Creek recovering both gold and sapphires. The following information is mainly from Mr. Marc Bielenberg's 1988 interview with Mr. Dean Dodd, who owned and operated the first dredge (personal communication, 2004). The Variegated Sapphire

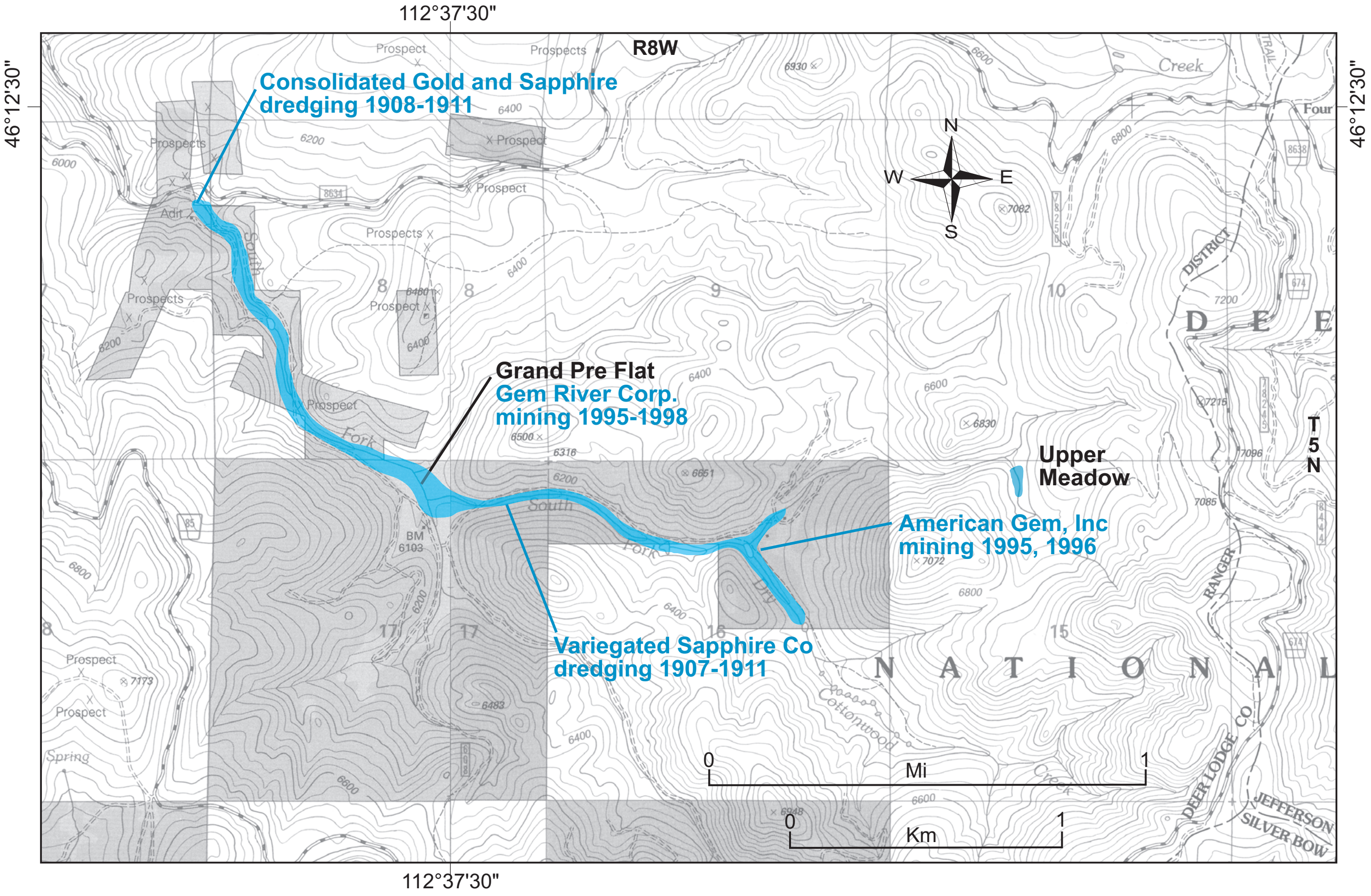


Figure 9. The known extent of sapphires in the South Fork of Dry Cottonwood Creek with companies and dates of mining. Map from USGS Orofino Mountain and Lockhart Meadows 7.5-minute quadrangles with contour interval of 40 ft. Upper extent of sapphires in section 16 is from testing by Watts, Griffis, and McQuat reported by Garland, 2002.

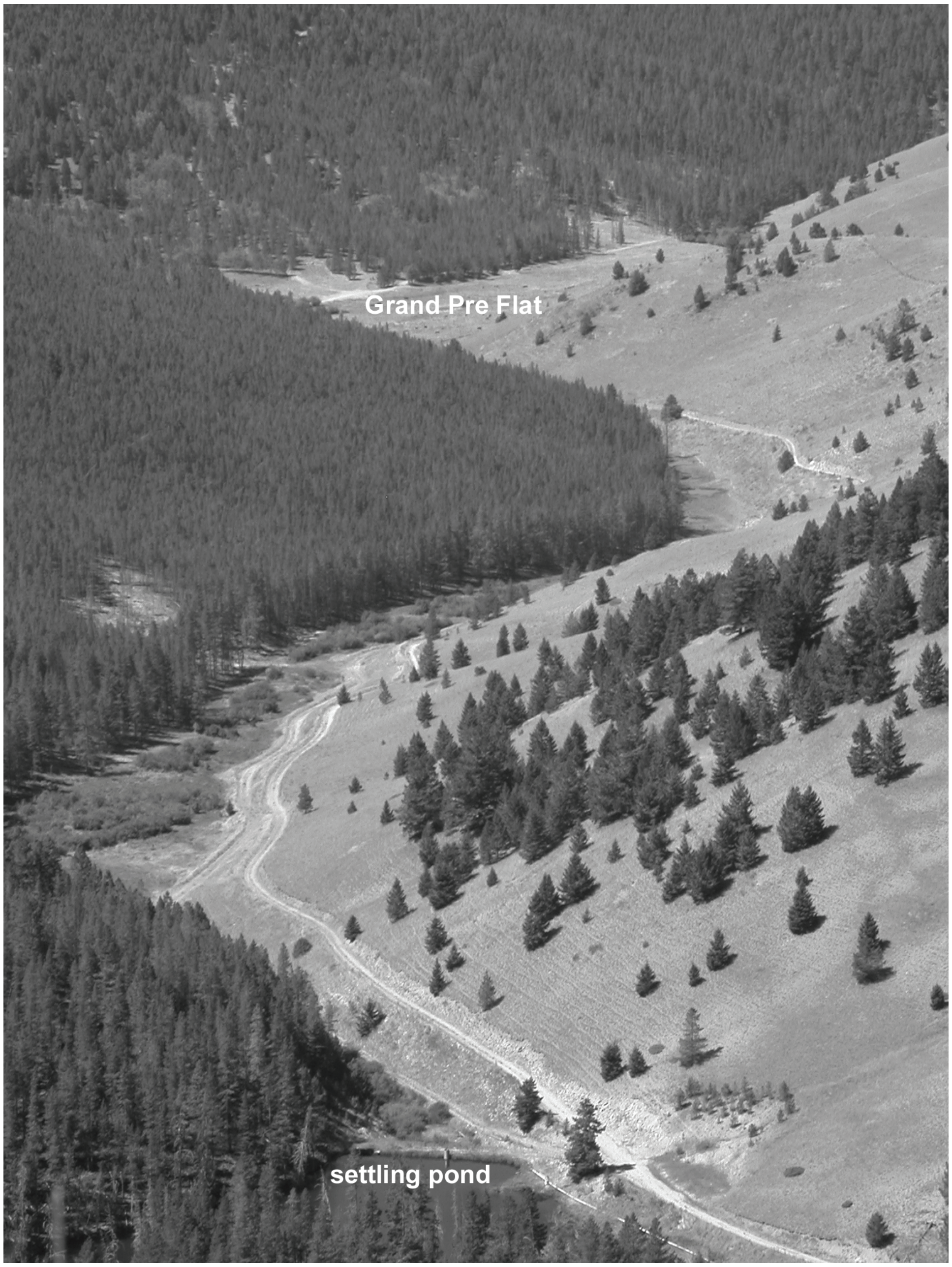


Figure 10. View looking downstream from a vantage point near the head of the South Fork of Dry Cottonwood Creek showing area mined by American Gem, Inc. downstream from the settling pond to the left of the road. Gem River Corp. mined Grand Pre Flat, in the background. Both of these mined areas have been reclaimed. Photo by R.B. Berg.

Company operated a bucket-line dredge with 1-cubic-foot buckets just above Grand Pre Flat (fig. 11). Construction of this dredge by members of the Dodd family began in 1905 and was completed and put into operation in 1907. It operated until 1911 and then was briefly operated by Mr. Nat Simon in 1914. Most of the gold and sapphires were on bedrock described as soft, yellow quartz rhyolite porphyry. The dredge worked a width of 80 to 100 ft and 1000 ft upstream from Grand Pre Flat and washed 12 yards of gravel per day. The sluices were cleaned every 2 weeks. It is reported that a 2-week cleanup would produce a wash tub ¾ full of sapphire concentrate, of which about ¼ was gravel and the remainder was sapphire. Six thousand troy ounces of bearing-grade sapphires recovered by this dredge were offered to the American Gem Mining Syndicate, which was mining sapphires in the Rock Creek district and selling them for watch bearings. Mr. Dean Dodd estimated that there was possibly over 100 troy pounds (121 avoirdupois pounds) of larger gem-quality stones recovered by this dredge. Most of the sapphires were sold to the watch and instrument bearing market, and the more highly colored sapphires were sold to be cut into gemstones. Judging from sapphires mined more recently from the South Fork of Dry Cottonwood Creek, sapphires with attractive colors are sparse. Operation of the dredge was terminated simply because there were not enough high-quality sapphires suitable for gemstones or enough gold to make it economical to mine these gravels.

The Consolidated Gold and Sapphire Mining Company of Butte operated a Ridison dredge with 3¾-cubic-foot buckets about 1 mile downstream from Grand Pre Flat near the confluence of a tributary with the South Fork of Dry Cottonwood

Figure 11. One-cubic-foot bucket-line dredge of the Variegated Sapphire Company, built and operated by members of the Dodd family on the South Fork of Dry Cottonwood Creek above Grand Pre Flat. Photo by Douglas B. Sterrett, U.S. Geological Survey, June, 1910.

Figure 12. Bucket-line dredge, (3¾ ft^3) operated by the Consolidated Gold and Sapphire Mining Company on the South Fork of Dry Cottonwood Creek below Grand Pre Flat. Photo by Douglas B. Sterrett, U.S. Geological Survey, June, 1910.

Creek (fig. 12). Some of the timbers of this dredge are still visible at this site (fig. 13). It is reported that this dredge was moved in 1908 from the Chinese diggings near Boulder, Montana to the South Fork of Dry Cottonwood Creek at a cost of $100,000 (personal communication from Mr. Marc Bielenberg, 2005). An area of hard bedrock at a depth of only 6 ft prevented the dredge from continuing its operation. This dredge also operated in 1911 (Clabaugh, 1952), but whether it operated continually during the summers of 1909 and 1910 is not reported. With the introduction of synthetic sapphire in the early 1920s, the watch and instrument bearing market for sapphires essentially disappeared, except for temporary demand during World War II.

In 1994 and 1995, the consulting firm of Watts, Griffis, and McQuat (WGM), on contract to American Gem Inc., trenched and tested sapphire-bearing gravel along the South Fork of Dry Cottonwood Creek upstream from Grand Pre Flat, presumably upstream from that area mined by the Variegated Sapphire Company close to 100 years earlier (Garland, 2002). In 1995, American Gem Inc. began mining sapphires for the gemstone market from gravel about 900 ft upstream from Grand Pre Flat. By 1996, American Gem discontinued their mining of sapphires along the South Fork of Dry Cottonwood Creek in favor of mining their property in the Rock Creek (Gem Mountain) district. In 1996, Gem River Corp. began mining sapphires for the gem market from Grand Pre Flat, known at that time as the Simon Meadow. Prior to mining, the meadow was sampled in test pits spaced 50 ft apart across the drainage and 100 ft apart in a downstream direction. The test pits encountered volcanic bedrock at depths of 12–15 ft. In an excellent example of a well-planned placer operation, the creek was diverted into a pipe and

Figure 13. Timbers remaining from the Consolidated Gold and Sapphire Mining Company's dredge on the South Fork of Dry Cottonwood Creek. Photo by R.B. Berg.

the gravel from the wash plant was returned to the meadow and covered with topsoil and sod. After washing in a trommel, the material smaller than ½ inch was fed to jigs, where the sapphires were separated. Sapphires from this mine were heat-treated for the gem market. The mine was closed in 1998. During the summer of 2000 Jim and John Rex mined sapphires on a limited basis from gravel stockpiled by American Gem Inc. at this locality.

Figure 14. View southeast across the uppermost drainage of the South Fork of Dry Cottonwood Creek showing dense timber and upper meadow described in text. Photo by R.B. Berg.

Geology

Volcanic rocks of the Lowland Creek Volcanics of Eocene age are exposed in the upper part of the drainage basin of the South Fork of Dry Cottonwood Creek and extend downstream where they are in contact with Cretaceous granitic rocks of the Boulder batholith (Smedes, 1962; Smedes and Thomas, 1965). This contact crosses the South Fork of Dry Cottonwood Creek near the western boundary of Grand Pre Flat. The area at the head of the South Fork of Dry Cottonwood Creek is thickly timbered and exposures of bedrock are scarce, except at the head of the drainage along the Continental Divide and in road cuts (fig. 14). Welded tuff and lava flows, the dominant rock types, are predominantly of dacitic composition (fig. 15). This gray rock consists of glassy quartz, white plagioclase, and lesser potassium feldspar and biotite phenocrysts within a fine-grained groundmass. Locally the dacite has been partly altered to kaolinite with thin quartz veinlets. This soft white rock is exposed at the first switchback along the trail from the road along the Continental Divide down to the meadow. Altered rock is also exposed at locality

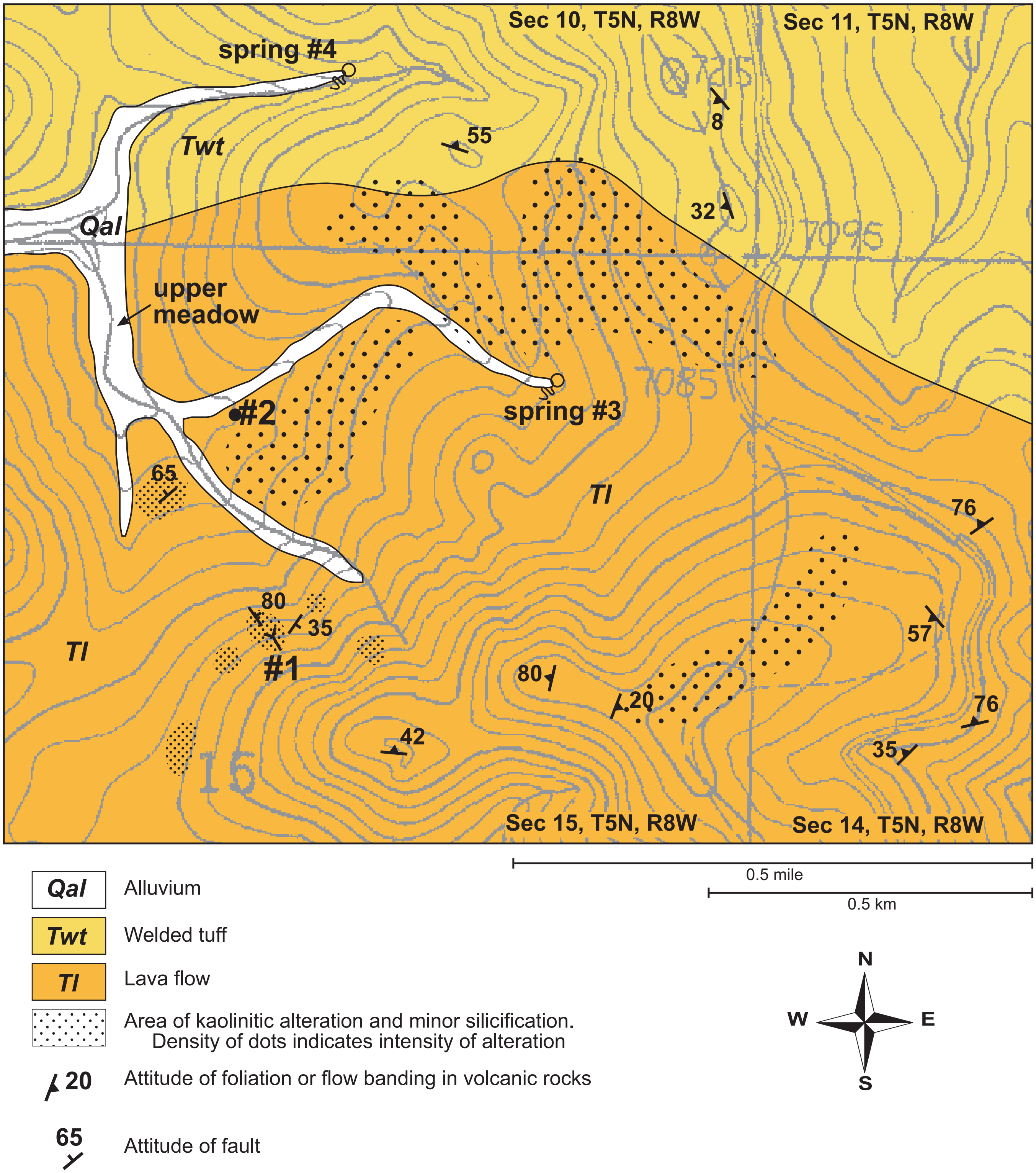


Figure 15. Geologic map of the area at the head of the South Fork of Dry Cottonwood Creek. Base map is USGS Lockhart Meadows 7.5-minute quadrangle with contour interval of 40 ft. Spring 3 is shown in figure 16. Sample of sapphire-bearing colluvium analyzed by Bureau of Land Management and U.S. Forest Service geologists was obtained at locality 2 and collapsed adit in area of kaolinitic alteration is locality 1. There is no evidence of past mining at the spring at locality 4.

1 (fig. 15) in an area barren of vegetation where an adit (now caved) and pits have been excavated. Sterrett (1911) reported that sapphires were not found in panning two buckets of this altered rock that was slaked in water. However, he did recover a few garnet fragments and glassy quartz crystals.

Although many have searched, sapphires have not been identified in bedrock in this drainage basin. Kunz (1904, p. 829) reported the following discovery made by Mr. J.M. Jamieson in June 1902. "He does not state the character of the rock, which is doubtless an igneous dike, but says that it is a ledge some 200 ft wide, traceable for 3,000 ft, and contains sapphires and garnets." Clabaugh (1952) stated that the source described by Jamieson had not been verified. Although sparse red garnets occur in some of the volcanic rocks, I did not find a garnet–sapphire-bearing ledge.

Distribution of Sapphires

Sapphires appear to be concentrated in the alluvium for about 2 miles along the South Fork of Dry Cottonwood Creek (fig. 9). However, they are undoubtedly found in lower concentrations downstream and possibly also upstream for some distance. Sampling of the alluvium upstream from Grand Pre Flat by WGM for American Gem, Inc. showed the highest grades along the South Fork of Dry Cottonwood Creek in the NW¼ sec. 16, T. 5 N., R. 8 W. Grades were as high as 150 carat (ct)/bank cubic yard (bcy) (Garland, 2002). Upstream from the point where the South Fork of Dry Cottonwood branches in the NE¼ sec. 16, T. 5 N., R. 8 W., grades are in the range of 15 to 45 ct/bcy. The greatest concentration of sapphires occurs where the channel widens downstream from a constriction (Garland, 2002). For detailed information on the size, distribution, and colors of sapphires recovered from test trenches, see Garland (2002).

Sapphires are also found in the alluvium in a small meadow close to the head of the South Fork of Dry Cottonwood Creek in the NW¼ sec. 15, T. 5 N., R. 8 W. (figs. 14 and 15).

This meadow is an old placer claim of 40 acres that has been acquired by the U.S. Forest Service. Because it is acquired land, it is not open to claim staking but is available for individuals to dig for sapphires. Individuals are encouraged to check with the Beaverhead–Deerlodge National Forest before digging in this area. Sapphires and garnets can be recovered from tan, clayey alluvium here. Several hours spent sieving this alluvium and retaining the 1- to 7-mm size fraction resulted in the recovery of 14 small (2–5 mm) colorless to very pale green sapphires with surface morphology typical of sapphires from the South Fork of Dry Cottonwood Creek. The total weight of sapphires recovered was 0.72 gm (3.6 ct). In addition, 3.97 gm of pale pink, dark red, and orangish red garnets were recovered.

In 1988, geologists with the U.S. Forest Service and Bureau of Land Management sampled a prospect pit in colluvium near the east edge of the meadow as part of a mineral examination in connection with a preference right-lease application (Anonymous, 1988). The approximate location of this pit is locality 2, figure 15. The results of this sampling are summarized as follows.

Sample H1: Sample extended down 2 ft below prominent limonite-stained layer. The sample weighed 423.5 lbs and contained four sapphires suitable for cutting that weighed 1.07, 1.34, 1.15, and 0.91 ct in addition to 8.8 mg of gold. If a bank cubic yard of this material is assumed to weigh 3000 lbs, this small sample indicates an inferred grade of 31 ct of cuttable sapphires/bcy.

Sample H2: Sample extended down 1.3 ft below the limonite-stained layer and weighed 297 lbs. This sample contained one sapphire suitable for cutting that weighed 1.45 ct, and 20.4 mg of gold.

Sample H3: This sample from the same pit as H2 weighed 149 lbs, and contained two sapphires suitable for cutting that weighed 1.76 and 0.91 ct, and 3.0 mg gold. Because of water in the pit, it was not possible to reach bedrock. All of the sapphires were reported to be pale in color. The approximate location of this pit is locality 2 in figure 15. Considering the small size of the samples, it is significant that this many sapphires were recovered from colluvium.

The most intriguing report of sapphires near the head of the South Fork of Dry Cottonwood Creek is that by Sterrett (1911), who reported that, "Sapphires have been found in placer mining to an

Figure 16. Spring near the head of the South Fork of Dry Cottonwood Creek showing evidence of past mining (spring 3 in fig. 15). Photo by R.B. Berg.

elevation of 6,800 ft and in a test panning as high as 6,950 ft, the elevation of the highest spring on this fork of the creek.” By “this fork of the creek,” it is likely he referred to the South Fork of Dry Cottonwood Creek. The spring to which Sterrett referred must be the one just south of the trail from the road to the meadow at an elevation of about 6850 ft (spring 3, figs. 15 and 16). Water flows during the summer in this tributary to the South Fork of Dry Cottonwood but the tributary to the south has only intermittent flow. There is evidence of placer mining and a small dam just above this spring at an elevation of 6,920 ft. It is also possible that the spring described by Sterrett is the spring on another tributary to the South Fork of Dry Cottonwood Creek in the SE¼ sec. 10, T. 5 N., R. 8 W. (spring 4, fig. 15). This spring, at an elevation of approximately 6,720 ft, is considerably lower than the one described by Sterrett, but evidence of past mining was not recognized.

Description of Sapphires

Size and shape

Systematic size analyses of sapphires recovered in the trenching of the South Fork of Dry Cottonwood Creek by WGM showed that sapphires from 3.5 to 6.5 mm are most abundant (Garland, 2002). A size distribution of sapphires from the same investigation where sapphires were separated into culls (non-gem material), blocky, and wafers or tabular shapes is shown in figure 17. This chart shows that the blocky sapphires in the 3.5- to 6.5-mm size range are the most abundant, with the percent of culls increasing in the larg-

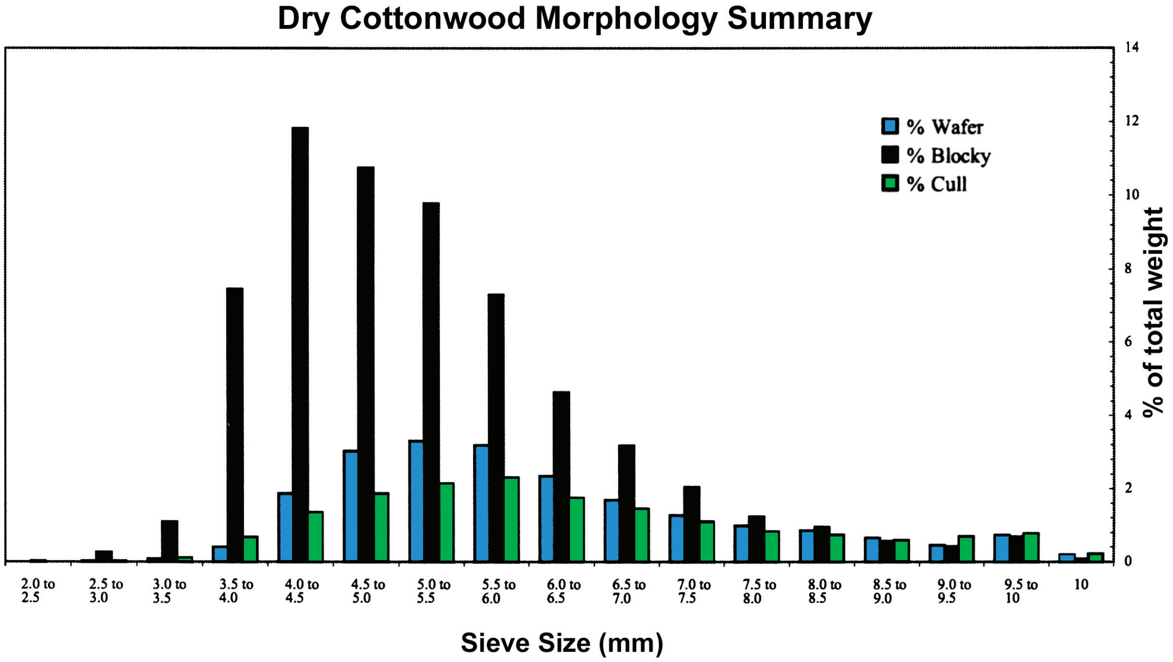


Figure 17. Size distribution by weight of culls, blocky, and tabular sapphires (wafers) from the South Fork of Dry Cottonwood Creek as determined by Crystal Research. Figure reproduced with permission from Garland, 2002. Note: smaller sapphires occur in the South Fork of Dry Cottonwood Creek, but are not shown here because they were not considered of economic importance.

er sizes. In addition to tabular and blocky or nearly equidimensional sapphires, a few sapphires have an elongate, somewhat rounded prismatic form that is a relict of the hexagonal prismatic habit of corundum (fig. 4). According to Mr. Marc Bielenberg, the largest sapphire recovered from the South Fork of Dry Cottonwood Creek was 22 ct, but it was 'flat' in shape and thus did not make a very large stone when cut (Bielenberg, personal communication, 2005).

Color

Most of the sapphires from the South Fork of Dry Cottonwood Creek are pale aquamarine to pale green to very pale blue to colorless (fig. 18). Pink, pale orange, and pale blue are rarer, and purplish pink or amethyst sapphires are even rarer. Smaller sapphires, because of their small size, appear very pale to colorless. A few sapphires are faintly dichroic from pale green to pale blue (fig. 19), and there are rare colorless or faintly colored sapphires that exhibit an orange center.

Although rare in sapphires recovered for gem use, blue sapphires appear to be relatively abundant in the <1-mm fraction. Sixteen bright blue to slightly purplish blue sapphires (fig. 20) were recovered from a heavy mineral concentrate provided by Mr. Marc Bielenberg from the North Fork of the South Fork of Dry Cottonwood Creek, probably from the NE¼ sec. 16, T. 5 N., R. 8 W. The

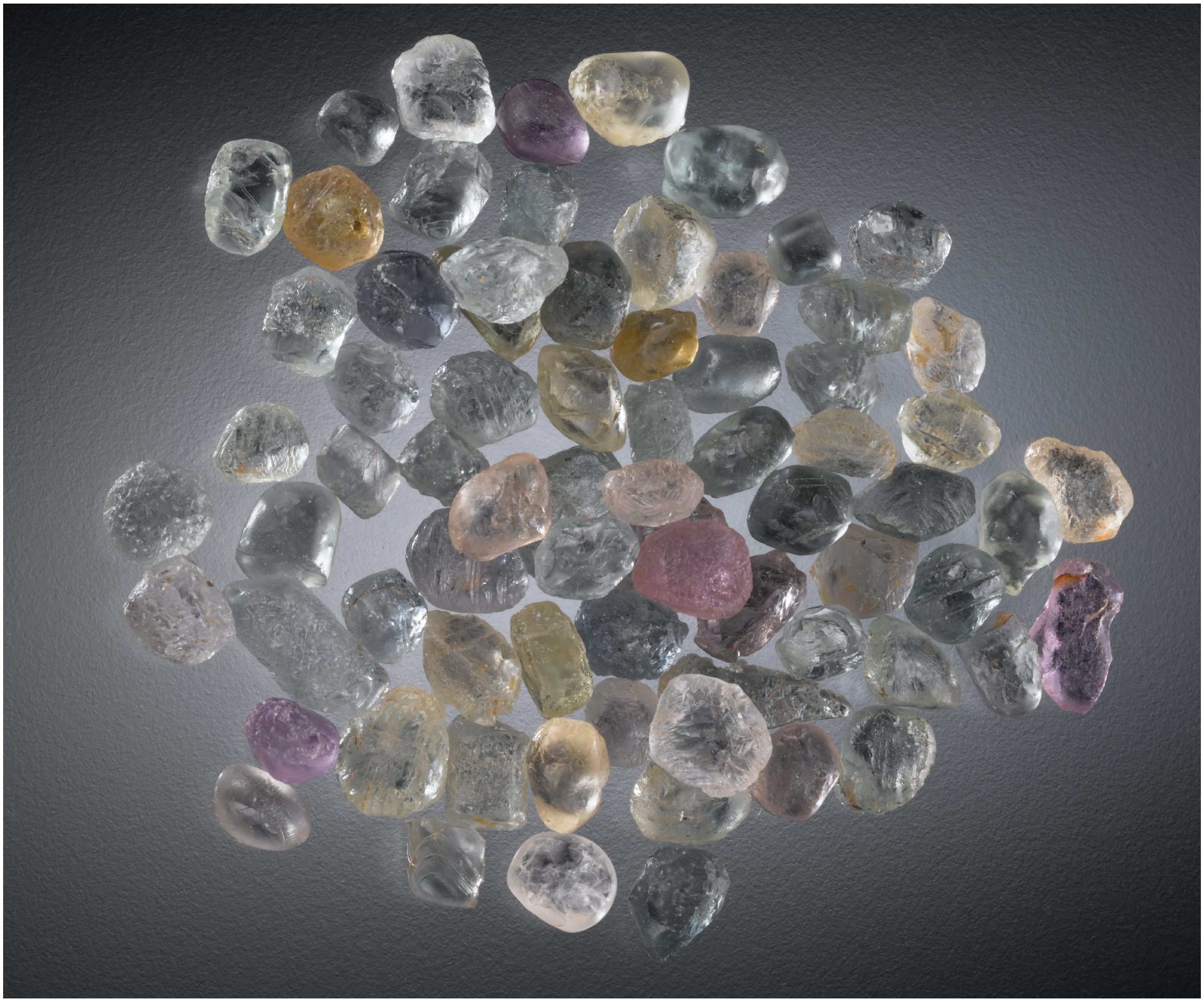


Figure 18. Assortment of sapphires from the South Fork of Dry Cottonwood Creek provided by Marc Bielenberg. Average size 5 mm. Photo © Tino Hammid.

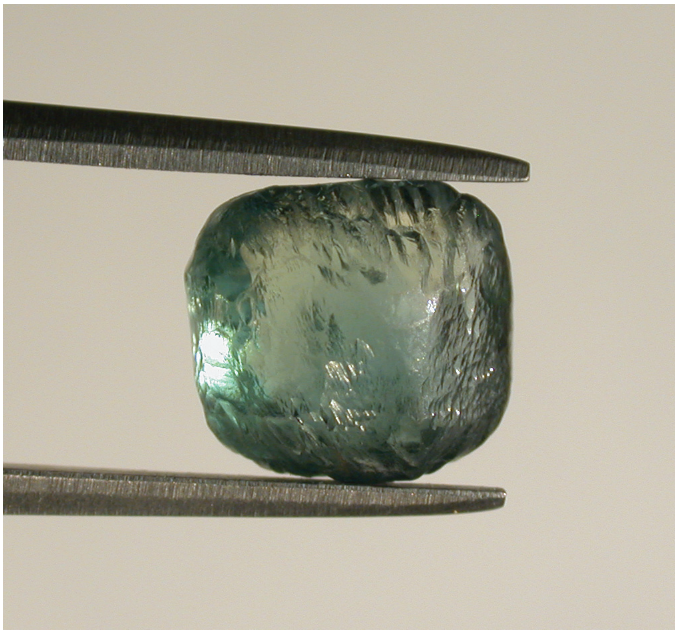


Figure 19. Pale green sapphire from the South Fork of Dry Cottonwood Creek. Sapphire weighs 3.37 ct and is 7 mm across. Sapphire from Marc Bielenberg. Photo by R.B. Berg.

identification of these small blue grains as corundum (sapphire) was verified by EDX analyses of four grains. These semi-quantitative analyses showed that three of these sapphires contained titanium and iron in trace concentrations, a common cause of the blue coloration in sapphires. The blue color of these sapphires was somewhat irregular in several grains, and one grain showed very strong dichroism when examined with the petrographic microscope. This elongate sapphire was dark blue parallel to its length and green perpendicular to its length. Just as unusual as the color of these very small sapphires were their shapes. Most of the very small colorless sapphires recovered from the South Fork of Dry Cottonwood Creek were rounded, some approaching a spherical form. However, the blue sapphires ranged from what can best be described as irregularly shaped to grains with well-defined hexagonal outlines (fig. 21). Careful examination under high magnification with the microscope showed that some had the triangular pits and grooves typical of many sapphires. Because these sapphires were different in both color and form from the larger sapphires from the South Fork of Dry Cottonwood Creek, it is suspected that they are from a different source rock or have a different origin than the other sapphires from the South Fork of Dry Cottonwood Creek. See the descriptions of sapphires from the Silver Bow occurrence for a further discussion of blue sapphires.

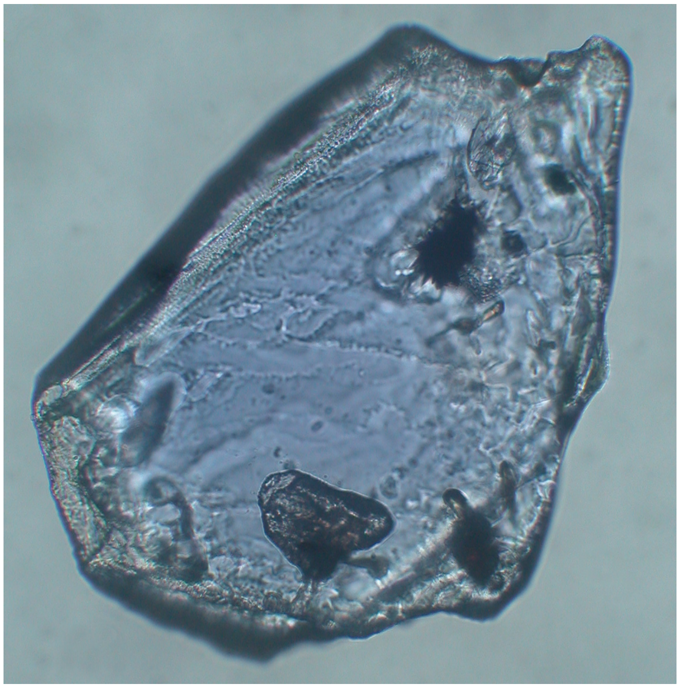


Figure 20. Photomicrograph of blue sapphire from the South Fork of Dry Cottonwood Creek with unidentified mineral inclusions. Length of sapphire is 0.5 mm. Photo by R.B. Berg.

Surface textures

Observations. Examination of the surfaces of sapphires from the South Fork of Dry Cottonwood Creek and from other alluvial deposits in Montana with the binocular microscope or with a 10-power hand lens shows a variety of fine surface features. The surface features of sapphires from the Rock Creek district differ from those in the South Fork of Dry Cottonwood Creek and also differ from those from the Missouri River deposits and the Silver Bow occurrence (Berg and Equall, 2004). Sapphires from the South Fork of Dry Cottonwood Creek exhibit surface textures similar to those recovered from Lowland Creek.

At first glance, it appears that some of the sapphires from the South Fork of Dry Cottonwood Creek, as well as other alluvial sapphires from southwestern Montana deposits, have been highly rounded by stream transport. However, examination at high magnification by scanning electron microscopy shows that these sapphires exhibit surface features that are

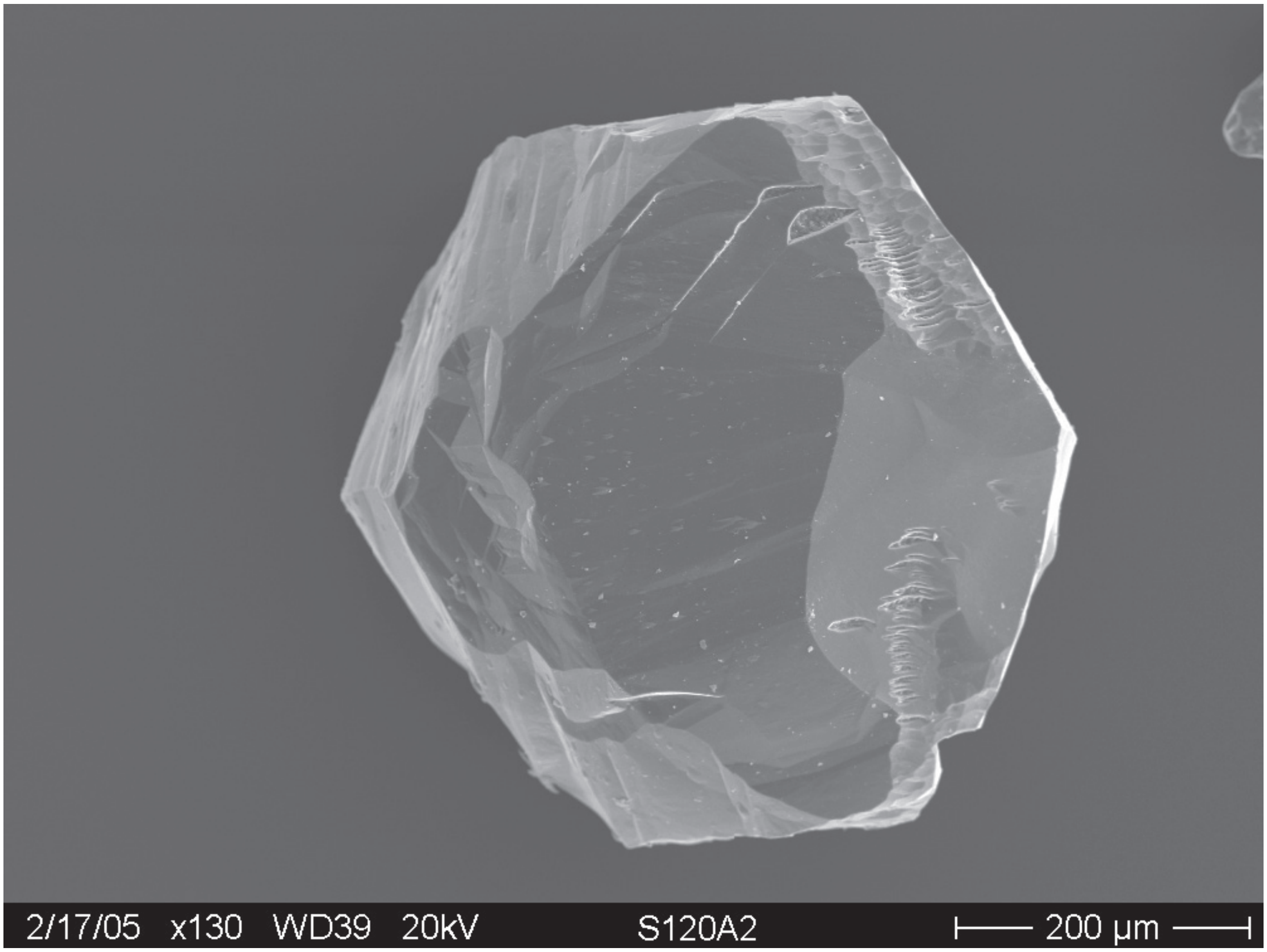


Figure 21. Scanning electron micrograph of blue sapphire from the South Fork of Dry Cottonwood Creek showing hexagonal outline. Photo by Nancy Equall.

unlike those produced by abrasion and are more likely attributed to other processes (see following discussion of interpretations). The nearly spherical sapphire in figures 22 and 23 shows a sculpted surface with very small uniform pits that are very different from the irregular surface of a stream-rounded corundum pebble (fig. 24). The rough and chipped surface of the stream-rounded pebble resulted from fractures caused by impact with other pebbles in the stream. Some of the flat surfaces resulted from fracture along parting planes, and others are simply conchoidal fractures. Almost all of the sapphires recovered from the South Fork of Dry Cottonwood Creek had conchoidal fractures, some so small that they are only recognizable with the microscope. These fractures are generally caused by stream transport and, probably to a much lesser extent, by abrasion incurred during recovery. Some sapphires showed only very small chips on the edges or projections of the sapphires. Figures 25 and 26 show the difference between the smooth conchoidal fracture and the ‘frosted’ surface. Many of the sapphires with ‘frosted’ surfaces have straight grooves that cut across the smooth surfaces (fig. 7). This abundance of straight grooves on the surface of the sapphires is the most distinctive feature of sapphires from the South Fork of Dry Cottonwood Creek. These grooves may be very shallow and only recognizable under the microscope or deep grooves easily recognizable with a hand lens. The sapphire shown in figure 7 is unusual because the grooves are of two crystallographic orientations, along both the rhombohedral and the basal parting planes. Most sapphires from this locality only have grooves of one orientation. Some grooves are recognizable on the basal parting surface as straight lines that look as if they have been inscribed on this flat surface. It is estimated that more than 10 percent, and perhaps as

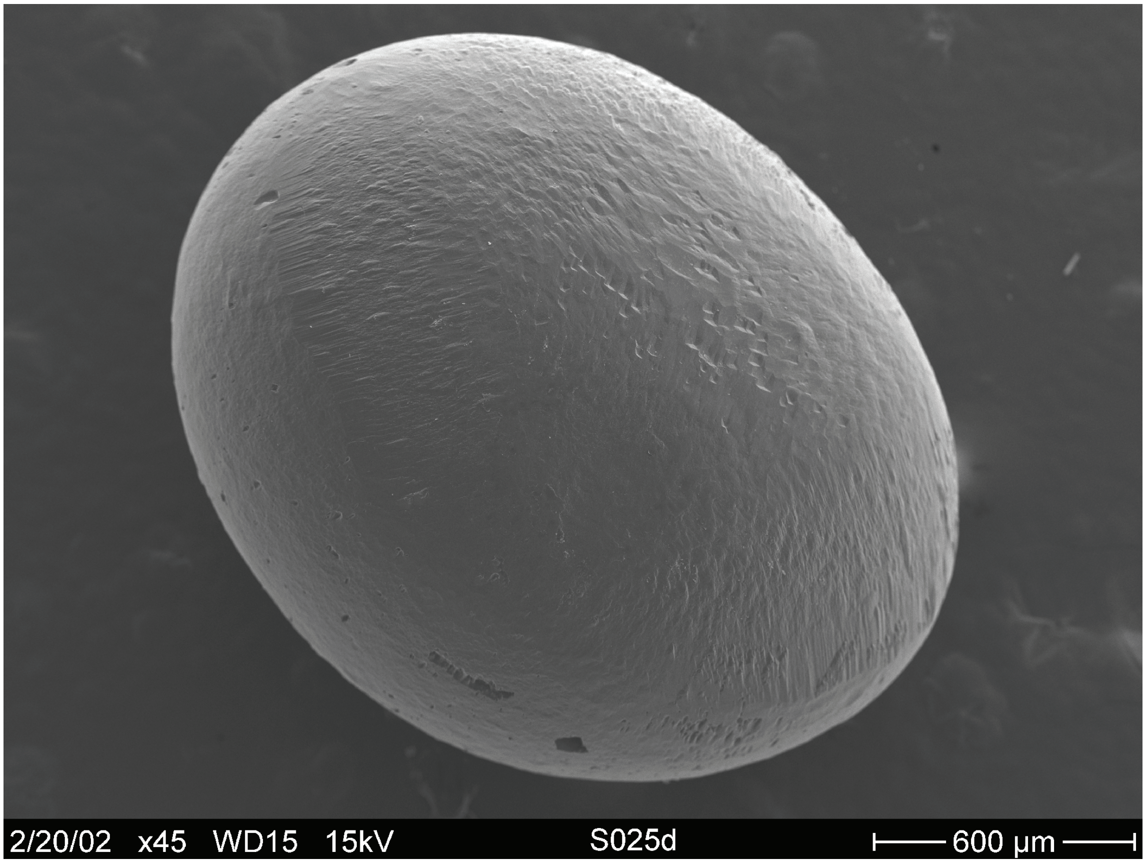


Figure 22. Scanning electron micrograph of an almost spherical sapphire from the South Fork of Dry Cottonwood Creek. Photo by Nancy Equall.

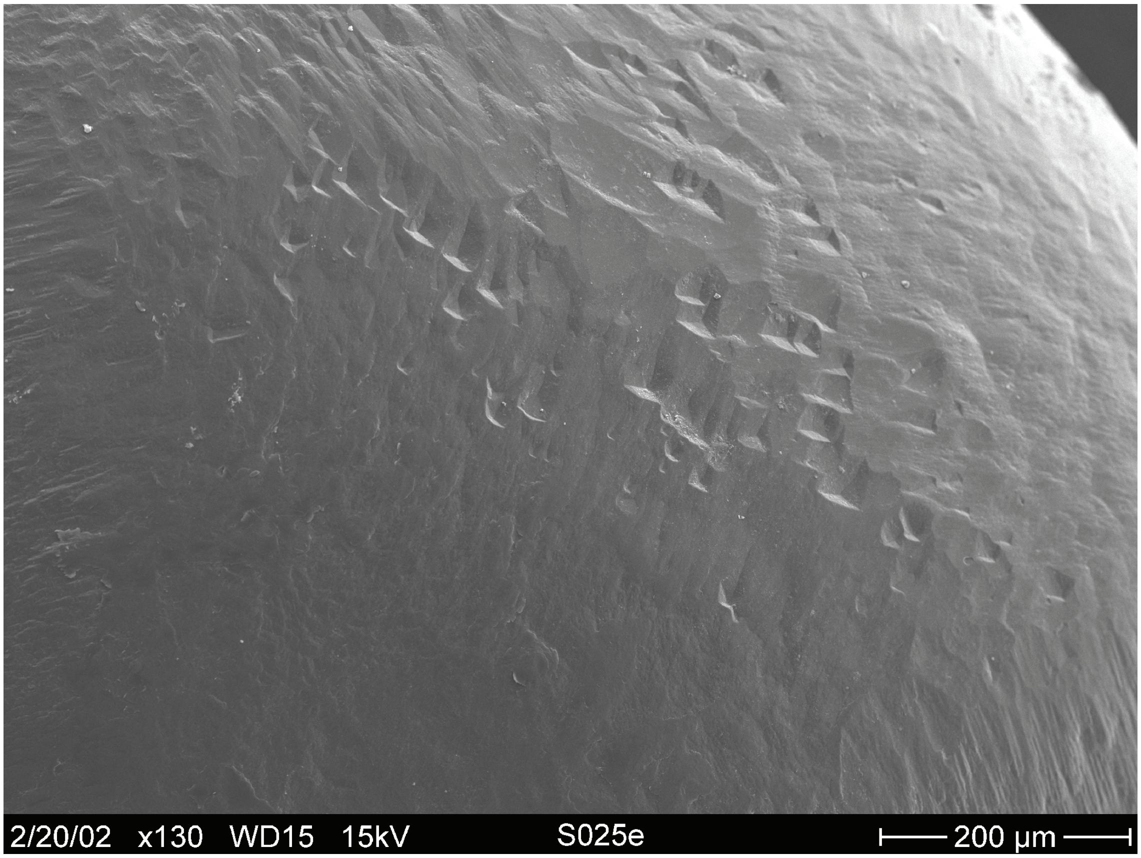


Figure 23. Enlargement of the image shown in figure 23 showing small uniform depressions. Photo by Nancy Equall.

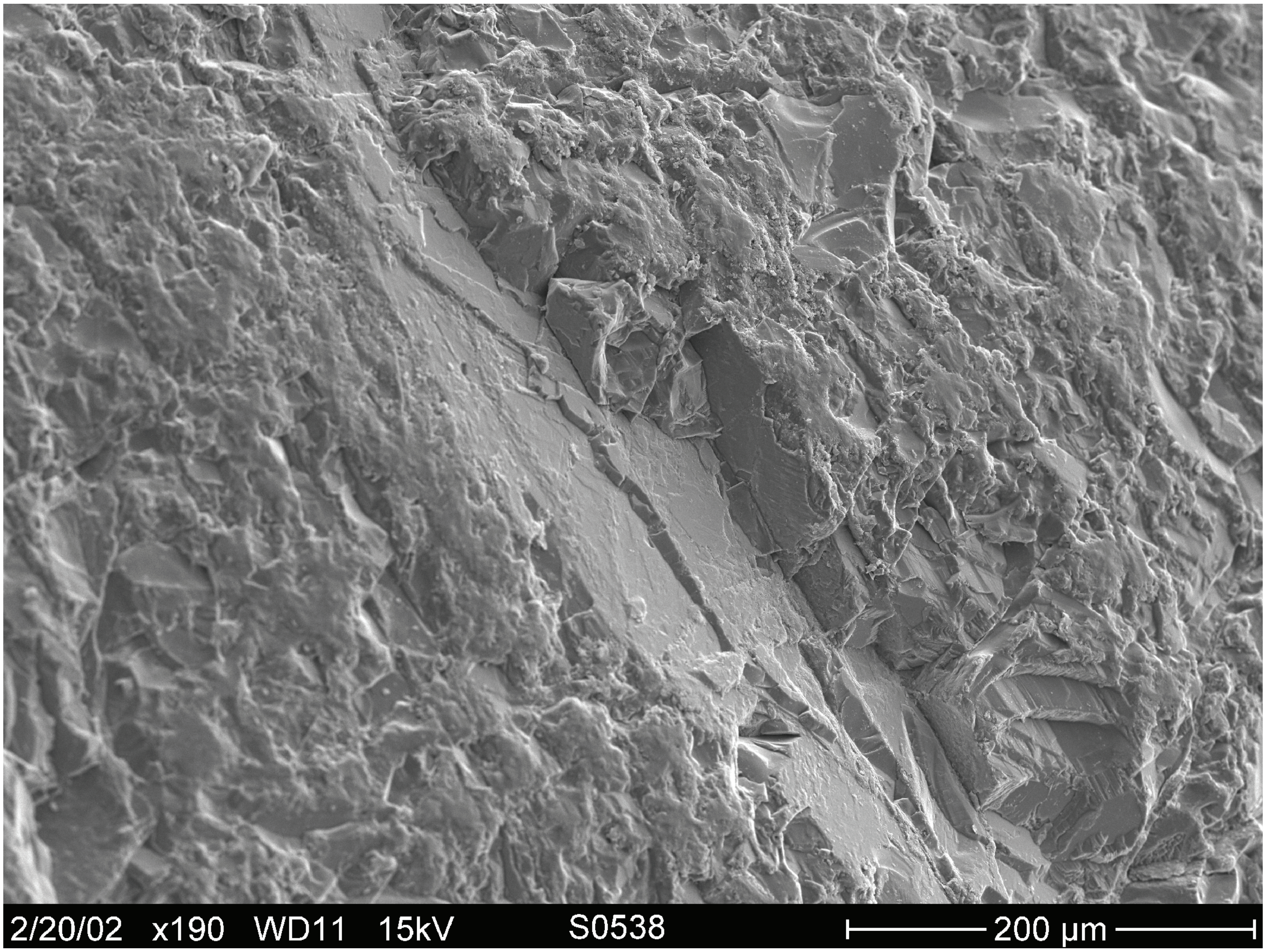


Figure 24. Scanning electron micrograph of a stream-rounded corundum pebble from Alder Gulch, Montana showing a surface produced by abrasion during stream transport. Alder Gulch is approximately 60 miles southeast of Butte. Photo by Nancy Equall.

many as 20 percent, of the sapphires from the South Fork of Dry Cottonwood Creek exhibit grooves, whereas they are only rarely found on sapphires from the Rock Creek or Missouri River deposits.

Although not as common as grooves, some sapphires that are generally somewhat rounded with an apparently smooth surface or finely frosted surface have bumps and pinnacles (fig. 27). Another interesting and inexplicable feature found on sapphires from this locality are irregular hillocks usually developed on a basal surface (fig. 28). It is surprising that that some of these delicate surface features have survived the stream transport of these sapphires recovered from alluvial deposits. For more scanning electron micrographs of Montana sapphires see Berg and Equall (2004).

Interpretations. Features on the surfaces of some crystals can be attributed to either growth of the crystal or partial solution of the crystal. Some of the surface features on sapphires from the South Fork of Dry Cottonwood Creek, as well as those on sapphires from the other localities described here, are interpreted to have formed by partial solution of these sapphires rather than growth features. The finely pitted or etched surfaces (fig. 25) and the straight grooves (fig. 7) can best be explained by some of the sapphire having been dissolved. The straight grooves have formed along definite crystallographic directions that are parallel to the basal parting and to the rhombohedral parting. It is reasonable to expect that solution can proceed more rapidly along parting planes than along the rest of the crystal. Parting is generally attributed to a misalignment of atoms along a definite crystallographic plane, thus allowing the crystal to fracture or part more easily along

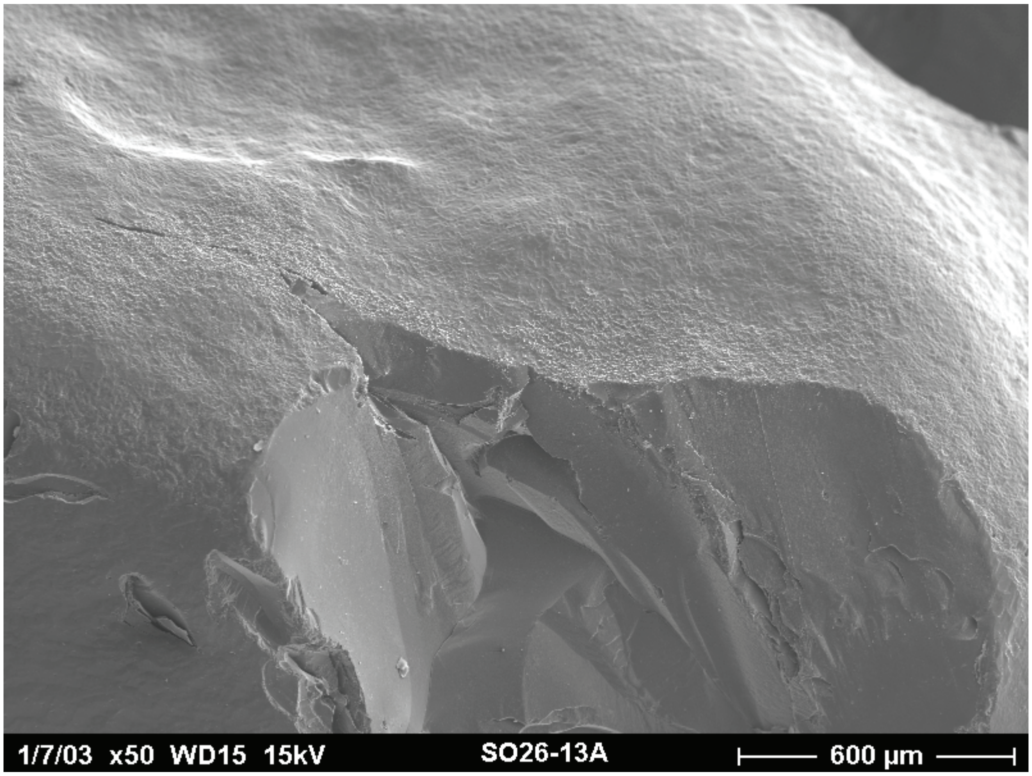


Figure 25. Scanning electron micrograph of a sapphire from the South Fork of Dry Cottonwood Creek showing ‘frosted’ surface and fresh conchoidal fracture. Photo by Nancy Equall.

this plane than in other directions. Any attempt to explain other features such as the bumps and hillocks found on some sapphires (figs. 27 and 28) would be rank conjecture.

Crystals can be partly dissolved during weathering to produce features such as the frosted or etched surfaces as seen on these sapphires. However, I suggest that formation of these features on these sapphires did not occur by weathering for the following reasons. The solubility of corundum in water under normal temperatures at the surface of the earth and the normal range of pH values is very low. At a pH of 7 (neutral solution, neither acid nor basic) the solubility of corundum is less than 1/30 that of quartz (Mason, 1958). It follows that if sapphires had been etched in the weathering environment, associated quartz should be much more extensively etched; this is not the case in the meadow at the head of the South Fork of Dry Cottonwood Creek (fig. 15). At this locality, shiny, small quartz crystals that show no evidence of

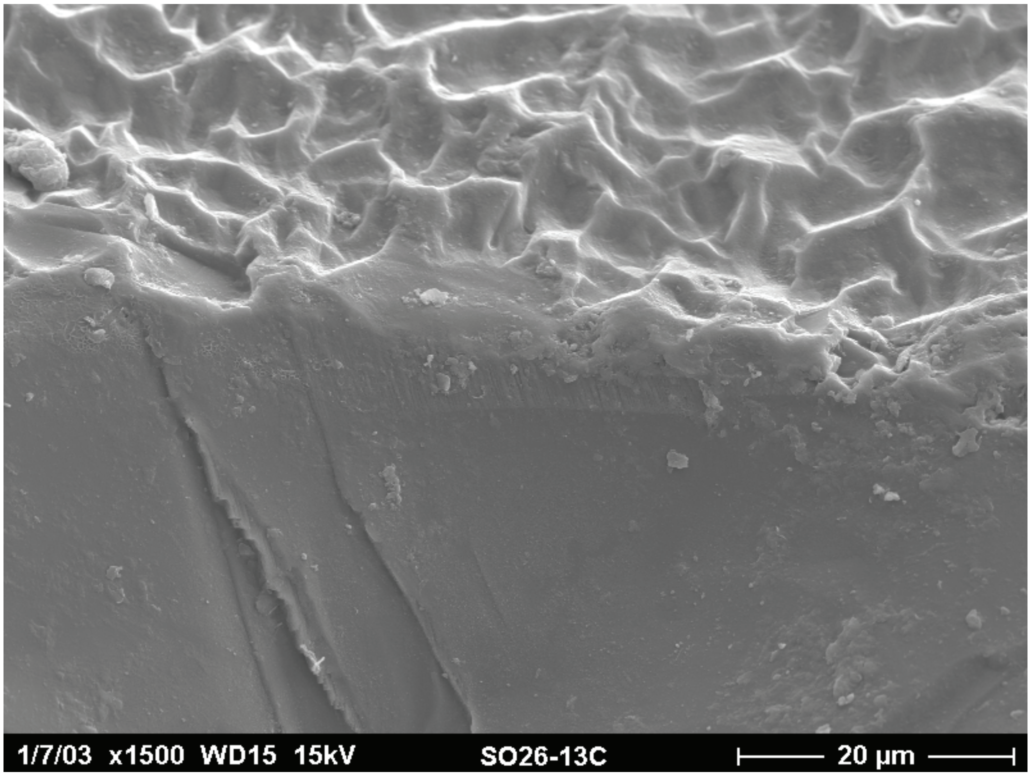


Figure 26. Enlargement of part of the area shown in figure 25 showing contrasting surface textures. Photo by Nancy Equall.

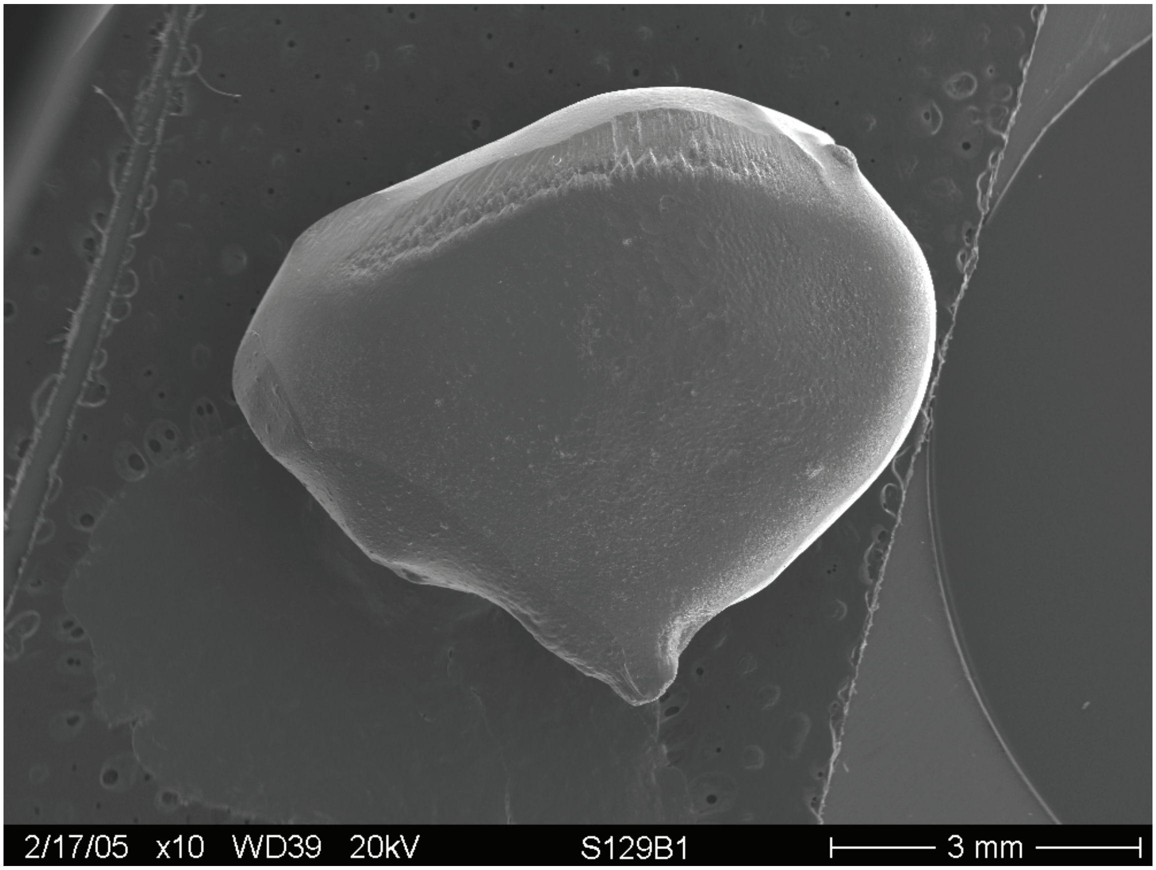


Figure 27. Scanning electron micrograph of a sapphire from the South Fork of Dry Cottonwood Creek showing ‘bumps’ found on some sapphires from this locality. Photo by Nancy Equall.

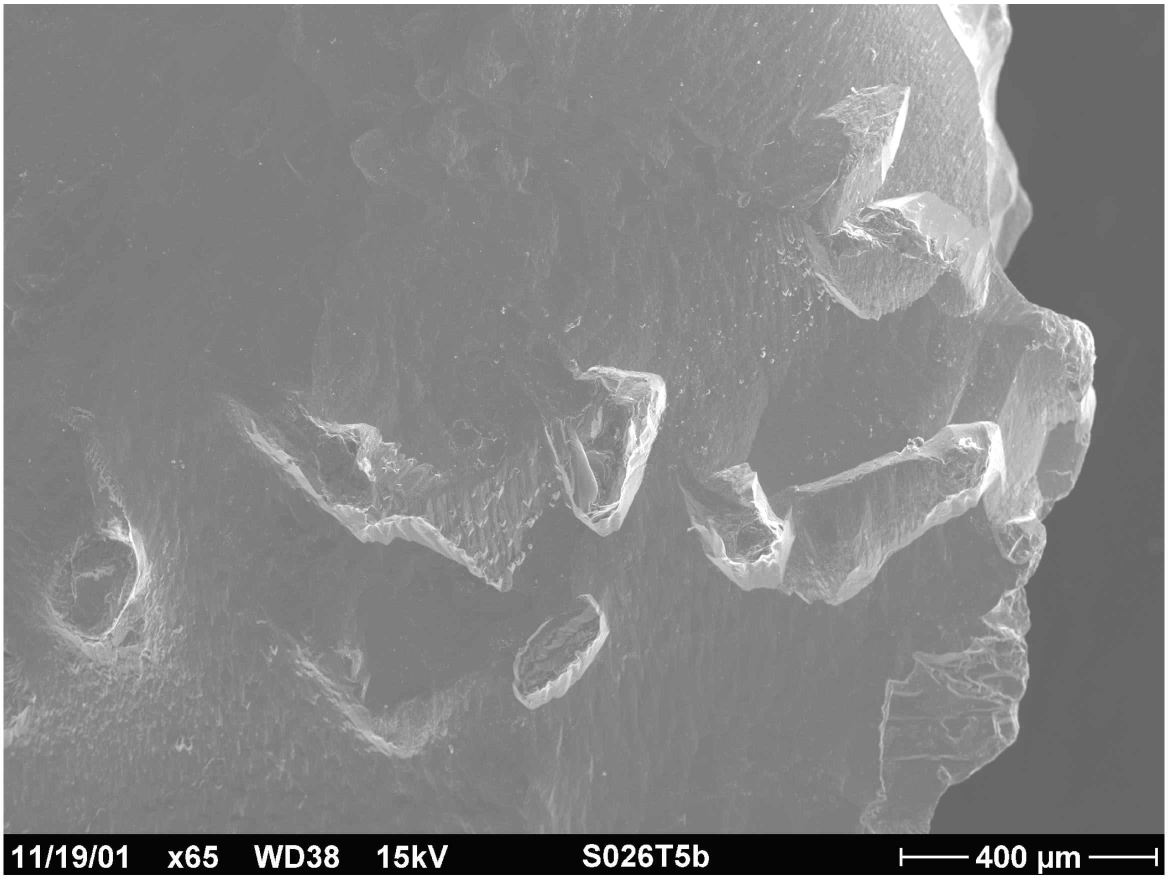


Figure 28. Scanning electron micrograph showing irregular hillocks on the basal surface of a sapphire from the South Fork of Dry Cottonwood Creek. Photo by Nancy Equall.

solution or etching are found in alluvium along with sapphires. Further evidence can be found at the French Bar 'dike' where sapphires occur sparsely in the dike (Berg and Dahy, 2002). A sapphire carefully removed from this igneous rock shows pitting on the surface that is attributed to solution (fig. 29). Because this sapphire has not been exposed to the atmosphere, these features must have formed while the sapphire was either in the magma that formed the dike, or even prior to that event.

If these sapphires were carried to the surface in magma that erupted to form lava flows as discussed under the heading bedrock source, it follows that resorption or solution occurred in this magma. It is impossible to estimate the length of time that these sapphires may have been exposed to this magma, but it

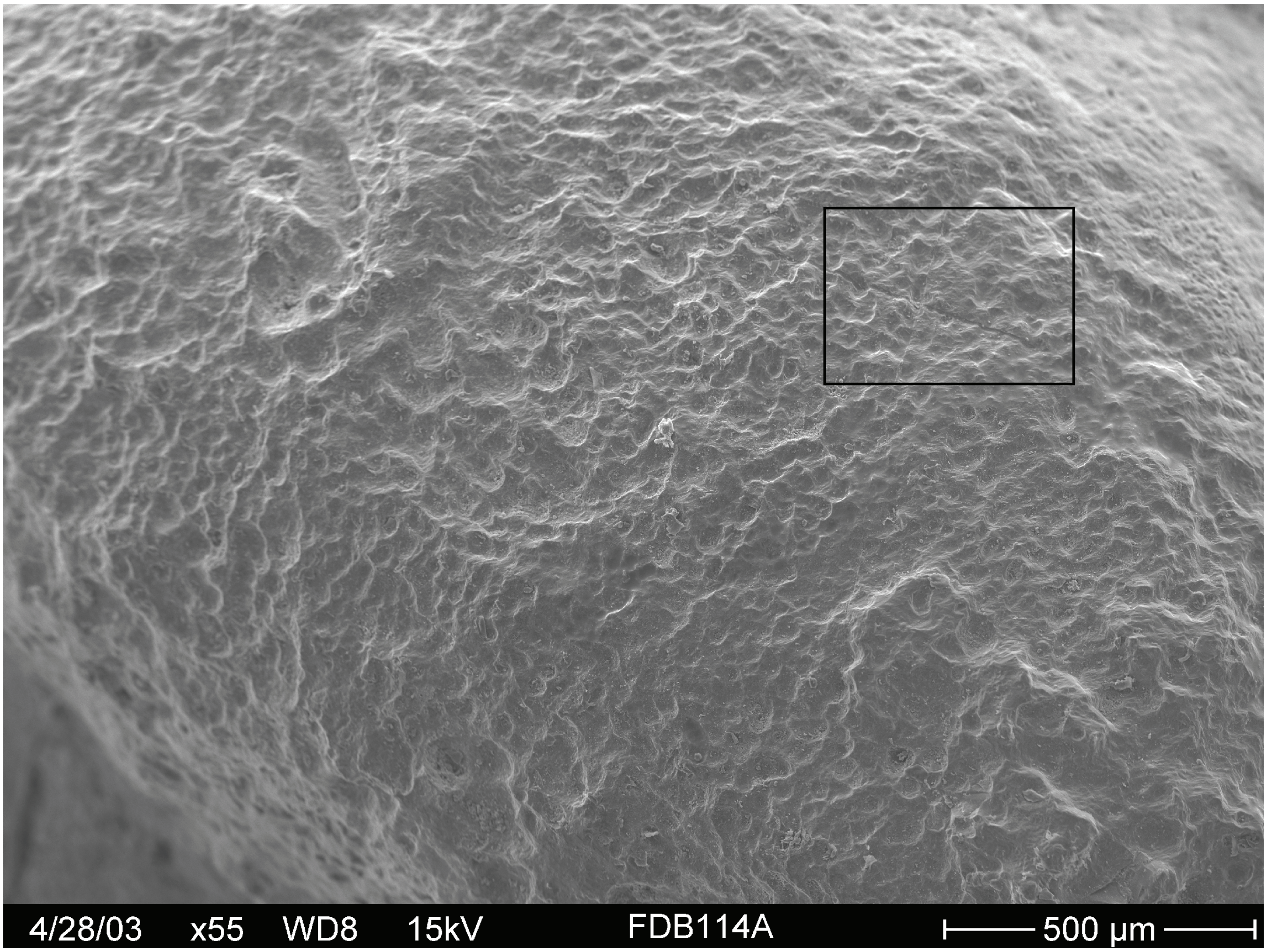


Figure 29A (above). Scanning electron micrograph of sapphire from the French bar 'dike' from which the surrounding igneous rock has been carefully removed to show the texture of the sapphire. Rectangle shows the area enlarged in figure 29B.

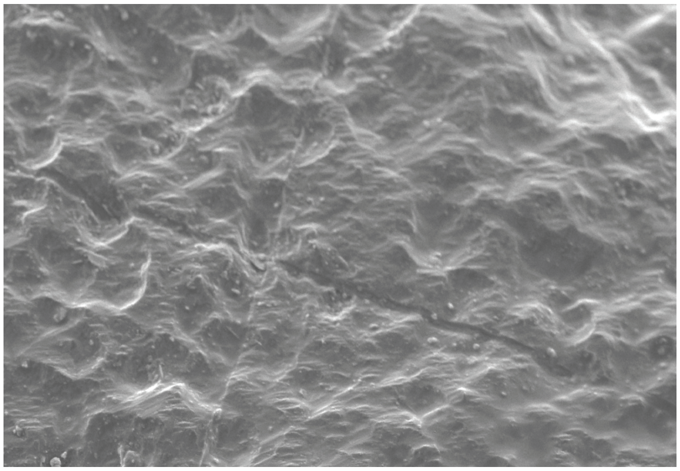


Figure 29B (right). Enlargement of part of above image to show grooves on the surface of the sapphire that resemble those developed by solution along parting planes (see fig. 7 for comparison).

Photos by Nancy Equall. For a discussion of sapphires in the French bar 'dike' situated along the Missouri River see Berg and Dahy, 2002.

could have conceivably been millions of years.

An unusual sapphire provided by Mr. Marc Bielenberg may be illustrative of this process of resorption (fig. 30). A reasonable interpretation is that the sapphire was partly enclosed in a xenolith and partly exposed to magma. That part of the sapphire sticking out of the xenolith and exposed to the magma (left end) was partly dissolved, with the development of grooves along rhombohedral parting planes and a frosted surface. Where the sapphire was protected from the magma by the enclosing xenolith, the original surface was preserved (right end). Impressions of small crystals that were in contact with the sapphire during growth are still evident.

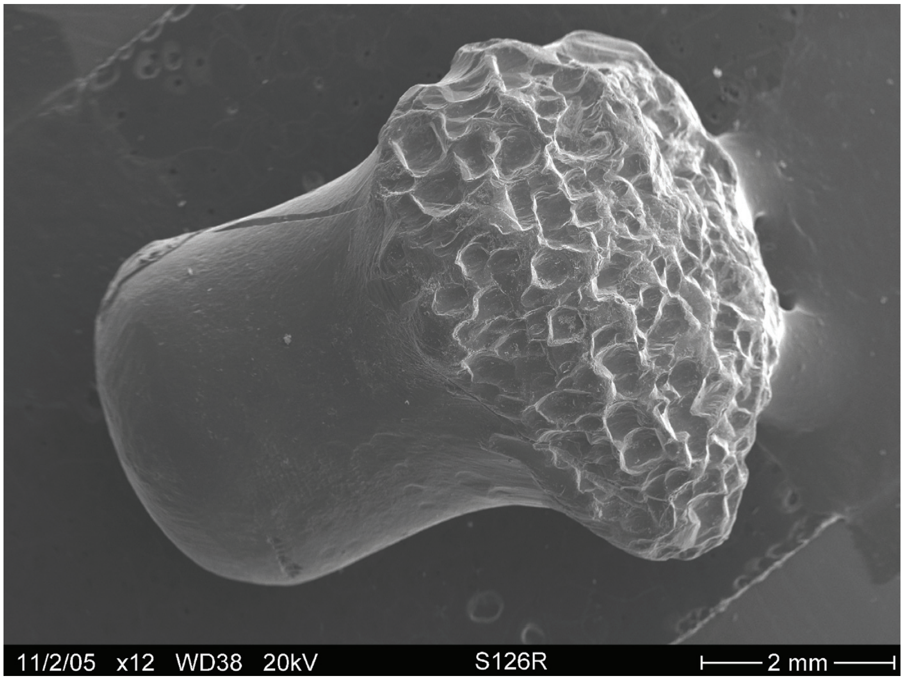


Figure 30. Scanning electron micrograph of sapphire from the South Fork of Dry Cottonwood Creek provided by Marc Bielenberg. Note grooves developed on smooth surface. See text for interpretation of surface features. Photo by Nancy Equall.

Internal Features

Mineral inclusions. Most of the sapphires from the South Fork of Dry Cottonwood Creek that were examined using the binocular microscope were free of recognizable mineral inclusions. However, typically sapphires with mineral inclusions have more than one inclusion, and some have many inclusions. Mineral inclusions in thin sections of 13 sapphires were identified by optical methods using the petrographic microscope and by semi-quantitative chemical analyses using EDX methods. See the appendix for detailed information on analytical methods. Biotite, apatite, zircon, pale pink garnet, kyanite, rutile, and andalusite(?) were identified. Rutile occurred as both relatively large discrete crystals and as very small grains concentrated in tan zones recognizable in thin section (fig. 31). Individual rutile needles in these zones were typically about 15 µm long. One sapphire contained eight biotite crystals all oriented with their c-axes parallel to the c crystallographic axis of the host sapphire, and all in the same plane. Apparently during the growth of this corundum crystal, biotite crystals grew on the basal pinacoid of the corundum and were subsequently covered by further growth of corundum. Pale pink garnet was identified in five sapphires from the South Fork of Dry Cottonwood Creek. In some instances, there were several garnets in one sapphire. These garnet inclusions were typically exposed at or near the surface of the sapphire. An included garnet was identified as almandine by x-ray diffraction analysis (Koivula and others, 1991). Garland (2002) reported muscovite and labradorite as the most abundant mineral inclusions in sapphires from the South Fork of Dry Cottonwood Creek. She also identified phlogopite, mariposite, orthoclase, analcime, epidote, clinozoisite, zoisite, garnet, apatite, rutile, rutile-zoned ilmenite, anatase, and magnetite by Raman spectroscopy. Calcite, anhydrite, and amorphous carbon found along fractures were considered to be secondary by Garland. The current investigation identified very small crystals of dark green spinel in a depression on the surface of one sapphire. These crystals did not appear to be inclusions, but the remnants of a coating of spinel. Also, small black crystals of galaxite (manganese spinel) adhering to the surface of one sapphire were identified by Mr. John Koivula of the Gemological Institute of

America (personal communication to Mr. Marc Bielenberg, November 16, 1992). This is not an exhaustive list of mineral inclusions, as several opaque or nearly opaque inclusions were not identified.

Healed fractures. Many of the studied sapphires exhibited peculiar patterns frequently found in sapphires and referred to as "fingerprints" (fig. 31). These patterns are interpreted to be partly healed fractures and sometimes surround a mineral inclusion. They can be explained by a difference in coefficient of thermal expansion between the host sapphire and the included mineral grain. Sapphire or corundum has a low coefficient of thermal expansion, whereas the included mineral may have a higher coefficient of thermal expansion. If the sapphire was heated during magmatic transport, the difference in thermal expansion may have caused local stress in the sapphire, forming the small fracture. Also, some sapphires contained small two-phase inclusions consisting of a liquid with a vapor bubble.

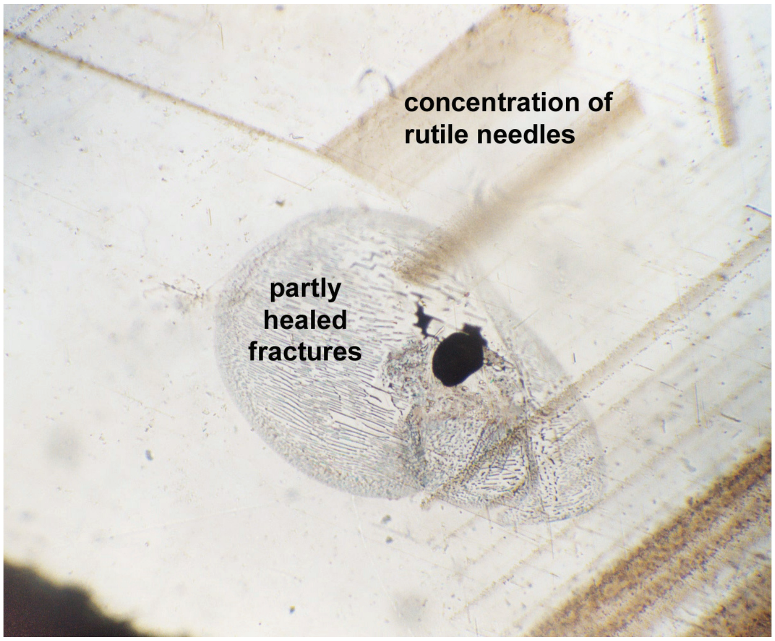


Figure 31. Photomicrograph of partly healed fractures (fingerprint) around unidentified mineral inclusion in sapphire from the South Fork of Dry Cottonwood Creek. Fingerprint is 2 mm across. Dark bands are concentration of very small rutile needles that illustrate the hexagonal form of this sapphire. Small rutile needles are visible near the lower right-hand corner of this photomicrograph. Sapphire provided by Marc Bielenberg. Photo by R.B. Berg.

Adhering rock

Rock adhering to alluvial sapphires provides an important clue as to the bedrock source of the sapphire. Dale Siegford of the Sapphire Gallery provided the author with three sapphires from the South Fork of Dry Cottonwood Creek that had adhering volcanic rock. The adhering rock on one specimen consisted of potassium feldspar and biotite phenocrysts in a fine-grained groundmass (fig. 32). Another specimen contained altered hornblende(?) phenocrysts in a fine-grained groundmass of plagioclase microlites, and a third specimen contained plagioclase, biotite, and quartz phenocrysts, also in a groundmass of very small plagioclase crystals. Because of the very small amount of adhering rock, it must be remembered that these samples provide only a glimpse of the possible volcanic bedrock source of these sapphires. The rock adhering to these sapphires is similar to the volcanic rock exposed at the head of the South Fork of Dry Cottonwood Creek.

Associated minerals

As might be expected, quartz and feldspar were the most abundant minerals found with the sapphires from the South Fork of Dry Cottonwood Creek. The feldspar tended to be white and sometimes chalky, and both potassium feldspar and plagioclase were identified. Most quartz grains were dull white and irregular in shape with conchoidal fractures. Glassy bipyramidal quartz crystals, such as those commonly found in volcanic rocks, are less abundant, and rarely small glassy prismatic quartz crystals derived from quartz veinlets were found.

The most abundant heavy mineral concentrated with the sapphires during panning or sieving was garnet. Garnets were 5.5 times more abundant by weight than sapphires in the sample from the upper meadow near the head of the South Fork of Dry Cottonwood Creek. Thus, the recovery of garnets can be an indication that sapphires are also present. The predominant colors of garnets from the South Fork of Dry Cottonwood Creek are pale pink, orangish red, and, more rarely, very dark red. A sample of 204 garnets from the upper meadow that were recovered with sapphires consisted of 55 percent orangish red, 40 percent pale pink, and 5 percent very dark red. See the discussion of Lowland Creek for a more detailed description of similar garnets associated with sapphires.

The following heavy minerals were identified from a heavy mineral concentrate provided by Mr. Marc Bielenberg, consisting of grains less than 1 mm in size from the north branch of the South Fork of Dry Cottonwood Creek. In addition to small blue sapphires, gold, garnet, cassiterite (stream tin), zircon, magnetite, calcite spheres, monazite, apatite, goethite after pyrite cubes, rutile, gahnite (zinc spinel), and cinnabar were identified. Rutile is a common constituent of the heavy mineral assemblage from the South Fork of Dry Cottonwood Creek, as are masses of secondary manganese minerals and hematite. Individual grains of kyanite and anthophyllite were also identified in sapphire concentrates from this deposit.

Bedrock Source of Sapphires

The bedrock source of alluvial sapphires has been a long-standing puzzle, not only in the South Fork of Dry Cottonwood Creek but also in other alluvial deposits in southwestern Montana. The following observations lead to the conclusion that the sapphires in the alluvium along the South Fork of Dry Cottonwood Creek were derived from a local source.

1. The distribution of sapphires is limited. They are found in the South Fork of Dry Cottonwood Creek, but not in either the North Fork or the unnamed fork between the South and North Forks.

2. A relatively short distance of stream transport is indicated by the preservation of delicate surface features and lack of indications of abrasion. See figure 28 for an example of these features.

3. Sapphires have been recovered very close to the head of this drainage, only about 250 ft in elevation below the drainage divide.

4. Although very rare, sapphires have been recovered with adhering volcanic rock similar to that exposed at the head of this drainage.

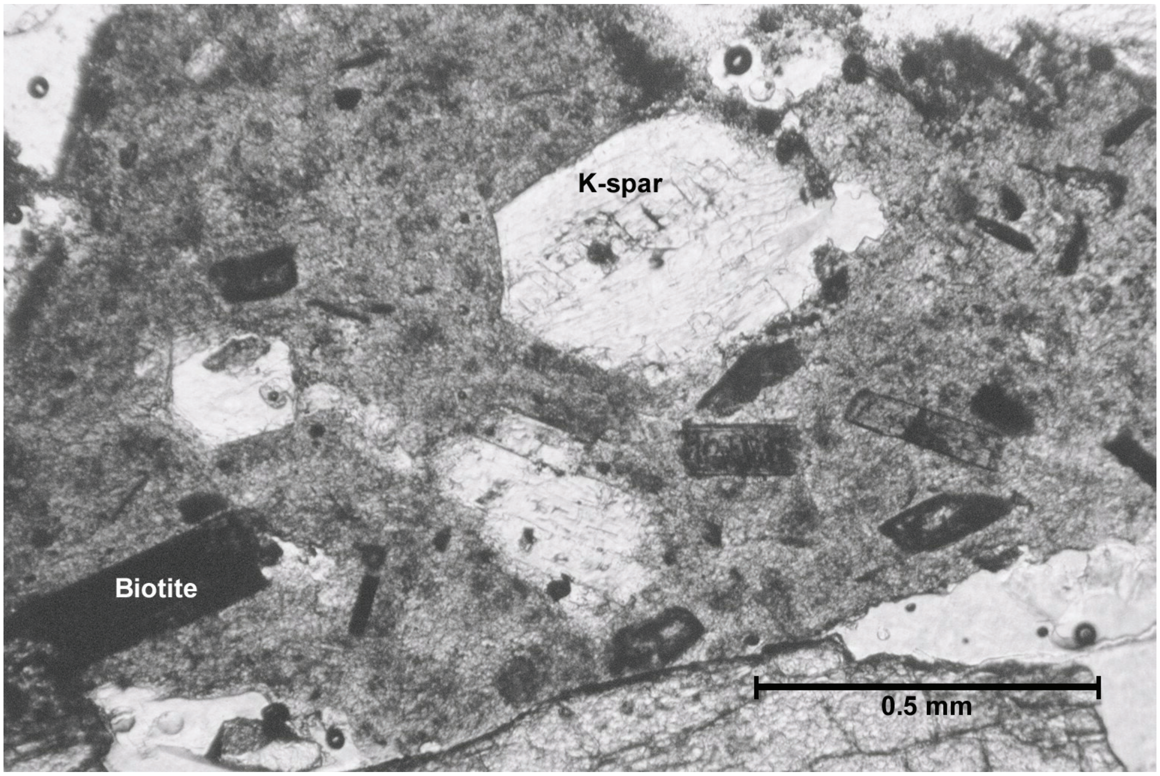


Figure 32. Photomicrograph of thin section of a sapphire with adhering volcanic rock. Sapphire from the South Fork of Dry Cottonwood Creek provided by Dale Siegford. Photo by R.B. Berg.

These observations support the hypothesis that sapphires in the alluvial deposit of the South Fork of Dry Cottonwood Creek were derived by weathering of the Lowland Creek Volcanics exposed in the upper part of this drainage basin. However, the rarity of adhering volcanic rock eludes easy explanation. If all of the sapphires weathered from the volcanic rocks exposed at the head of the South Fork of Dry Cottonwood Creek, there should be remnants of this rock preserved between some of the small projections present on some of the sapphires (for instance, those shown in figure 28). A possible explanation is that the volcanic rock rarely found adhering to the surfaces of these sapphires is not typical of the bedrock source, but rather most of the sapphires weathered from a less durable rock. This hypothesis is supported by the occurrence of volcanic rock that has been largely hydrothermally altered to kaolinite over a large area near the head of this drainage (fig. 15). This altered rock could be more easily weathered from the sapphire than fresh volcanic rock and not leave a clue as to the bedrock source. Another speculative possibility is that there is a bed of volcanic ash that is not exposed, but lies near the head of the South Fork of Dry Cottonwood Creek. Volcanic ash could very easily be removed by weathering. See the discussion of the Silver Bow occurrence for evidence of sapphires derived from altered volcanic ash. A faint indication of a bed of volcanic ash near the head of this drainage is provided by the occurrence of small grains of volcanic glass in the weathered material overlying bedrock at several localities.

Considering that prospectors have searched for 100 years for a bedrock source of the alluvial sapphires in this drainage, it seems strange that no one has discovered a sapphire in the outcrop. This dilemma may be attributable to a very low concentration of sapphires in the bedrock. A rough calculation was made using 100 times the weight of sapphires estimated to have been recovered in 1907–1908 and 1910–1911 (Clabaugh, 1952). This conservative estimate takes into account the sapphire production in recent years from the deposit and also the sapphires yet to be recovered. The volume of bedrock that has been removed by erosion at the head of the South Fork of Dry Cottonwood Creek was also calculated and the assumption was made, probably incorrectly, that sapphires were uniformly distributed throughout this rock mass. This crude calculation showed that the concentration of sapphires in this volume of volcanic rock would only have been 1 carat in 48 cubic yards of bedrock. Obviously, it would take a tremendous amount of searching to find a sapphire in such low concentration in bedrock.

Browns Gulch and Vicinity

Tributaries of Browns Gulch

The Browns Gulch drainage basin is just across the Continental Divide to the east from the head of the South Fork of Dry Cottonwood Creek (fig. 2). Thus if the sapphires in the South Fork of Dry Cottonwood Creek are locally derived from a source in the Lowland Creek Volcanics, it is reasonable to expect sapphires to also occur in the Browns Gulch drainage basin. Most of the Browns Gulch drainage basin is underlain by volcanic rocks of the Lowland Creek Volcanics with lesser granitic rock of the Boulder batholith.

Brief mention was made of sapphires in Browns Gulch by Ball (1943) when he stated, "Besides the two localities mentioned above, production could be obtained from Browns Gulch in Silver Bow County, Dry Cottonwood Creek in Powell County, and lode mines of Yogo Gulch." The two other localities that Ball refers to are the West Fork of Rock Creek and the Missouri River deposits. Although several landowners in Browns Gulch were asked about sapphire localities, the only sapphire occurrence they mentioned is that just north of Silver Bow near the confluence of Browns Gulch and Silver Bow Creek (fig. 2). This occurrence is described in detail at the end of this discussion of Browns Gulch. There is an unconfirmed report of sapphires near Telegraph Hill that is not shown on the Orofino Mountain 7.5-minute topographic map but presumably is next to Telegraph Gulch (fig. 2).

Alluvial sediments were sampled at four localities in the Browns Gulch drainage. A sample was collected from the alluvium on the east side of Flume Gulch in the SW¼ SW¼ NE¼ sec. 32, T. 5 N., R. 8 W., Orofino Mountain 7.5-minute quadrangle (locality 1, fig. 2). This sample, collected from the surface to a depth of 2 ft, weighed 142 lbs before screening. No sapphires or garnets were recovered from the 1- to 7-mm-size fraction. The <1-mm fraction was panned and also lacked sapphires or garnets. Zircon, hornblende, and a very pale pink garnet were identified in the nonmagnetic fraction of this concentrate of heavy minerals examined with the petrographic microscope. This sample did not seem to have as high a concentration of heavy minerals as most of the other samples that were examined for sapphires.

Samples were collected from three localities along American Gulch. One sample was collected in an open area just below the point where the road crosses American Gulch in the SW¼ NE¼ SE¼ sec. 22, T. 5 N., R. 8 W., Lockhart Meadows 7.5-minute quadrangle (locality 2, fig. 2). A sample of the <7-mm fraction was collected from an area approximately 3 ft by 4 ft in the active stream. The 1- to 7-mm fraction weighed 23 lbs when dry and the <1-mm fraction weighed 25 lbs when dry. No sapphires and only one orangish red garnet were recovered in sieving the <7-mm fraction. However, microscopic examination of the <1-mm fraction showed garnets, predominantly orangish red with lesser pink garnets. Also one small (0.24 mm) grain was tentatively identified to be a sapphire. Other heavy minerals were magnetite, zircon, apatite, hornblende, allanite?, and a nonmagnetic opaque mineral.

Two additional samples were collected along American Gulch in the SW¼ NE¼ NE¼ sec. 27, T. 5 N., R. 8 W., Lockhart Meadows 7.5-minute quadrangle (locality 3, fig. 2). One sample was collected about 150 ft upstream from the point where a jeep trail crosses American Gulch. One garnet, but no sapphires, was recovered from the <7-mm fraction of this 27-lb (wet) sample. A similar 57-lb sample collected several hundred feet upstream contained neither garnets nor sapphires. The <1-mm fraction of these samples was not examined.

Much farther downstream, a sample was collected from alluvial material in the Browns Gulch drainage that is exposed in a road cut on the Ueland ranch in the SE¼ SE¼ NE¼ sec. 14, T. 3 N., R. 9 W., Ramsay 7.5-minute quadrangle (locality 4, fig. 2). The sample of <11-mm material weighed 151 lbs as collected. Two sapphires, but no garnets, were recovered in sieving the 1- to 11-mm fraction. These sapphires were both about 5 mm across and very pale green. One of the sapphires had a small adhering remnant of white opal like that seen on some of the sapphires from the Silver Bow locality. Heavy minerals concentrated from the <1-mm fraction included magnetite, ilmenite?, zircon, apatite, hornblende, and one small pale pink garnet. Also, a very small, round sapphire that had been broken in half and was only 80 µm across was identified.

Sapphires have also been recovered from a terrace deposit along Silver Bow Creek in the SW¼ NW¼ sec. 12, T. 3 N., R. 10 W. about 5 miles downstream from the confluence of Browns Gulch and Silver Bow Creek (locality 5, fig. 2). Seven sapphires between 2.5 and 5.5 mm in size were recovered by Berger. The concentration of sapphires in the gravel just above bedrock is approximately 7 ct/loose cubic yard. Spinel adhered to one of the sapphires, and two garnets as well as a trace of gold were recovered.

Silver Bow Occurrence

Geology

Sapphires have long been known to occur just north of the settlement of Silver Bow between Silver Bow Creek and Interstate 90 (fig. 2). This may be the occurrence referred to by Ball (1943) when he stated that sapphires could be produced from Browns Gulch. Sapphires are most abundant on a small bench situated just north of Silver Bow Creek in the NE¼ SW¼ SE¼ sec. 24, T. 3 N., R. 9 W., Ramsay 7.5-minute quadrangle on the patented Bull Moose mining claim. The Bull Moose was apparently located for metalliferous veins in the granite northeast of the sapphire occurrence (fig. 33). This occurrence is on private land and is not open to the public; special permission was granted to Berger and the author to sample and study this occurrence. The following description is largely from Berger's study of this occurrence in 2003 and 2004 when he was a graduate student at Montana Tech. His investigation provided significant new information on the bedrock source of alluvial sapphires in southwestern Montana (Berger and Berg, 2006. See this article for a more detailed account of this sapphire occurrence).

Sapphires occur in the very poorly sorted layer of sediment, 1 to 2 ft thick, which overlies light tan, silty mudstone of Tertiary age (fig. 34). This sapphire-bearing sediment is interpreted to consist of debris flows composed predominantly of pebbles and cobbles of volcanic rock and chalcedony slabs in a clay matrix (fig. 35). The clay is smectite

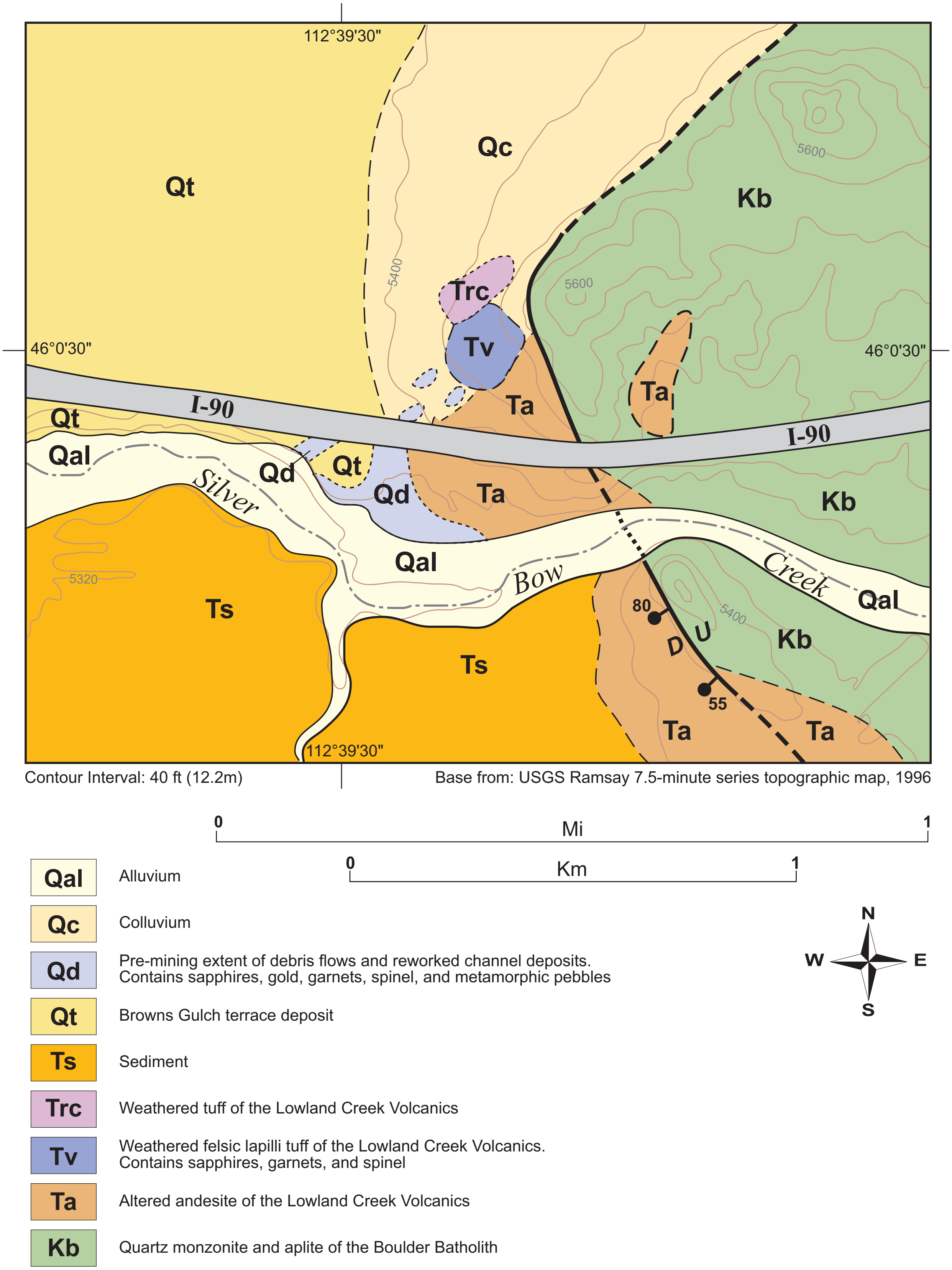
Figure 33. View of Silver Bow sapphire occurrence looking northeast across Interstate 90 showing granite of the Boulder Batholith, debris flow, and Tertiary sedimentary beds. Photo by R.B. Berg.

and contains small (<1 mm) grains of vesicular glass. Clinoptilolite is a zeolite commonly found in altered volcanic ash or tuff, and was identified by x-ray diffraction analysis. Sapphire concentrations in these clayey sediments is highly variable. A composite sample representing 17 loose cubic yards contained an average concentration of sapphires of 172 ct/loose cubic yard and 0.02 oz of gold/loose cubic yard. The clayey areas are generally elongate north–south and are on the order of 50 ft wide. Sapphires also occur in the more abundant gravelly material, which may represent channel deposits. The concentration of sapphires in this gravelly material is as high as 50 ct/loose cubic yard and the gold concentration is 0.15 oz/loose cubic yard. The source of these debris flows is an altered tuff situated adjacent to the granite exposure that forms a prominent hill north of Interstate 90 (figs. 33 and 35). The area in which sapphires are concentrated appears to be small. Sapphires were not found in a careful search of the surface of the ground about ½ mile west on the same apparent terrace level, reflecting the limited extent of these debris flows. Also, no sapphires were recovered in screening clayey sediment exposed in a road cut along the frontage road about 1000 ft west of the sapphire occurrence. One sapphire was found in an exposure of red clay below the frontage road just east of the sapphire occurrence.

Description of sapphires

The following observations are based on the examination of 444 sapphires recovered by Berger using a sluice box and washing 3.2 loose cubic yards of material. The concentrate of heavy minerals coarser than 2 mm was saved. Sapphires ranged in size from 3 to 6 mm with the exception of one tablet that measured 9 mm across. Most sapphires were in the 4-to 5-mm size range, and the average weight of

Figure 34. Cut in the Silver Bow sapphire occurrence showing brown sapphire-bearing layer overlying tan Tertiary sedimentary beds. Photo by R.B. Berg.



Contour Interval: 40 ft (12.2m)

Base from: USGS Ramsay 7.5-minute series topographic map, 1996

Figure 35. Geologic map of the Silver Bow sapphire occurrence by Aaron Berger (Berger and Berg, 2006).

sapphires in this sample was 0.5 ct. Sapphires had a nearly equidimensional, subrounded shape with rare hexagonal tablets and even rarer hexagonal prisms (fig. 36). In some instances, these more angular sapphires had irregular pitted surfaces with flat-bottomed pits. Finely sculpted surfaces with irregular ridges were very rare, as were grooves developed along parting planes. Sapphires from the Silver Bow locality generally lack the highly irregular and intricate surfaces found on some of the sapphires from the South Fork of Dry Cottonwood Creek.

Figure 36. Sapphires from the Silver Bow sapphire occurrence provided by Aaron Berger. Average size of sapphires is 5 mm. Photo © Tino Hammid.

Several sapphires in this sample showed impressions of crystals that are interpreted to have formed where the sapphire impinged on another crystal during its growth. The crystal has since disappeared during transport or weathering, leaving only its impression. Two of these impressions had a triangular form like that of an octahedral spinel crystal.

All of the sapphires in this sample showed some evidence of fracturing or abrasion during transport. Some sapphires showed large shiny conchoidal fractures, whereas others exhibited only small, almost microscopic chips, recognizable only with a hand lens or under the microscope. These small chips were in many instances along ridges or other projections. Also, the raised areas between pits on the surfaces of some sapphires had microscopic chips. Because these sapphires were recovered by the use of a sluice box, and thus were not subjected to the possible breakage in a trommel in a typical washing plant, all of the fractures are ‘natural.’

Almost all (96 percent) of the sapphires in this sample were colorless or very pale green (fig. 36). The remaining 4 percent were pale amethyst to a reddish purple and very rare small dark blue sapphires. Unlike most sapphires from this locality, dark blue sapphires typically exhibited prismatic crystal form.

Most of the sapphires were free from mineral inclusions as seen with the binocular microscope. However, a detailed study of selected sapphires in which inclusions were recognized under the binocular microscope showed phlogopite, albite, rutile, ilmenite, apatite, zircon, and tentatively chromium-iron spinel inclusions (Williams and Walters, 2004). These inclusions were identified by a combination of optical microscopy and scanning electron microscopy techniques. The amethyst and dark blue sapphires typically contained unidentified small black inclusions.

Some of the sapphires from the Silver Bow locality had remnants of very dark green to black spinel adhering to their surfaces. The dark green spinel, preserved in shallow depressions on the surfaces of these sapphires, was similar in appearance to that identified on some of the sapphires from Eldorado Bar and other localities in the Helena area.

Fine-grained white material adhering to the surfaces of some sapphires encloses microscopic quartz and potassium feldspar grains. On the basis of optical characteristics and a semi-quantitative analysis by EDX, this mineral was identified as opal. Very significantly, unlike the spinel that is usually only found in protected depressions, the opal occurred on unprotected locations on the sapphire surface. The opal coating partly covered fresh conchoidal fractures on several sapphires, indicating that the opal was deposited after fracturing. Clearly these sapphires were not significantly abraded after deposition of the opal or the opal would have been removed from these surfaces. In addition to opal, some sapphires had similar remnants of a brown coating that encloses very fine sand grains. This material was also identified as opal, but presumably a low concentration of limonite causes the brown color.

Associated rocks and minerals

Garnets occur with sapphires, but unlike the South Fork of Dry Cottonwood Creek and Lowland Creek, where garnets are much more abundant than sapphires, sapphires are more abundant than garnets at Silver Bow. In one sample of heavy minerals, only 10.5 percent of the grains were garnet and most of the remainder was sapphire. The distribution by color for a sample of 52 garnets from the Silver Bow locality was 71 percent orangish red, 25 percent very dark red, and 4 percent pale pink. Other heavy minerals recovered from the sapphire-bearing sediment included zircon, hornblende, gold, apatite, spinel, and ilmenite. The spinel forms dark green, almost equidimensional grains.

Pebbles recovered by Berger from the sediment that was richest in sapphires were examined in an effort to find a clue as to the bedrock source of the sapphires. Although the debris flow in which the sapphires were found consists predominantly of clay, silt, and sand (about 93 percent <3.3 mm in grain size), about 89 percent of the pebbles were volcanic rocks like those in the surrounding Lowland Creek Volcanics, 10 percent were chalcedony, and approximately 1 percent were aplite. Chalcedony is associated with fluorite veins in the granite uphill from the debris flow to the northeast (Ross, 1950). Aplite dikes have intruded this granite. Pebbles of volcanic rock ranged from angular, irregular fragments to subrounded pebbles. Although there were a variety of volcanic rock types, three dominated. Easily recognizable volcanic rocks were rhyolite, in which quartz and biotite phenocrysts are set in a chalky white to light gray groundmass. Other pebbles were rhyolitic but had a reddish brown groundmass with quartz and potassium feldspar phenocrysts, and no biotite. Although rare, basalt and andesite in which the feldspar has largely altered to epidote were also found.

Berger also recovered relatively rare pebbles of rock types not known to be exposed in the present Browns Gulch drainage basin. These included arkose sandstone, quartzite, and schist. Because these rock types are not exposed in the present drainage basin, they are inferred to be fragments of metamorphic rock that were incorporated in the magma that cooled to form the Lowland Creek Volcanics. Thirty-two schist pebbles were recovered from the sapphire-bearing sediment at the Silver Bow occurrence. The typical mineralogy of these pebbles was sillimanite, spinel, biotite, and either plagioclase or potassium feldspar. Two of the pebbles also contained corundum (fig. 37). Another pebble consisted of spinel, sillimanite, andalusite?, plagioclase, and biotite. Rutile was identified in another schist pebble.

An unusual pebble also recovered from the Silver Bow sapphire occurrence contained blue corundum (sapphire), albite, biotite, and small amounts of ilmenite and chromite (fig. 38). Because this pebble contained glass in contact with albite crystals that exhibited crystal faces, it was interpreted to be of igneous origin. This textural relationship can be explained by relatively slow cooling of the magma with the formation of the albite crystals followed by cooling so rapid that the remaining magma then solidified to form the glass. Perhaps the rare dark blue sapphires recovered from the Silver Bow occurrence were derived from such an igneous rock.

Bedrock source of sapphires

This occurrence of sapphires at Silver Bow provides significant evidence for the bedrock source of these sapphires as well as clues as to their ultimate origin. Berger's recovery of sapphires, garnet, and spinel from partly altered felsic tuff that is poorly exposed on the hill north of Interstate 90 indicates that this volcanic rock was the source of these sapphires. The distribution of the sapphire-bearing clayey sediment is indicative of deposition by a debris flow or, more likely, by several debris flows that flowed to the southwest from the altered tuff next to the granite hill north of Interstate 90. The

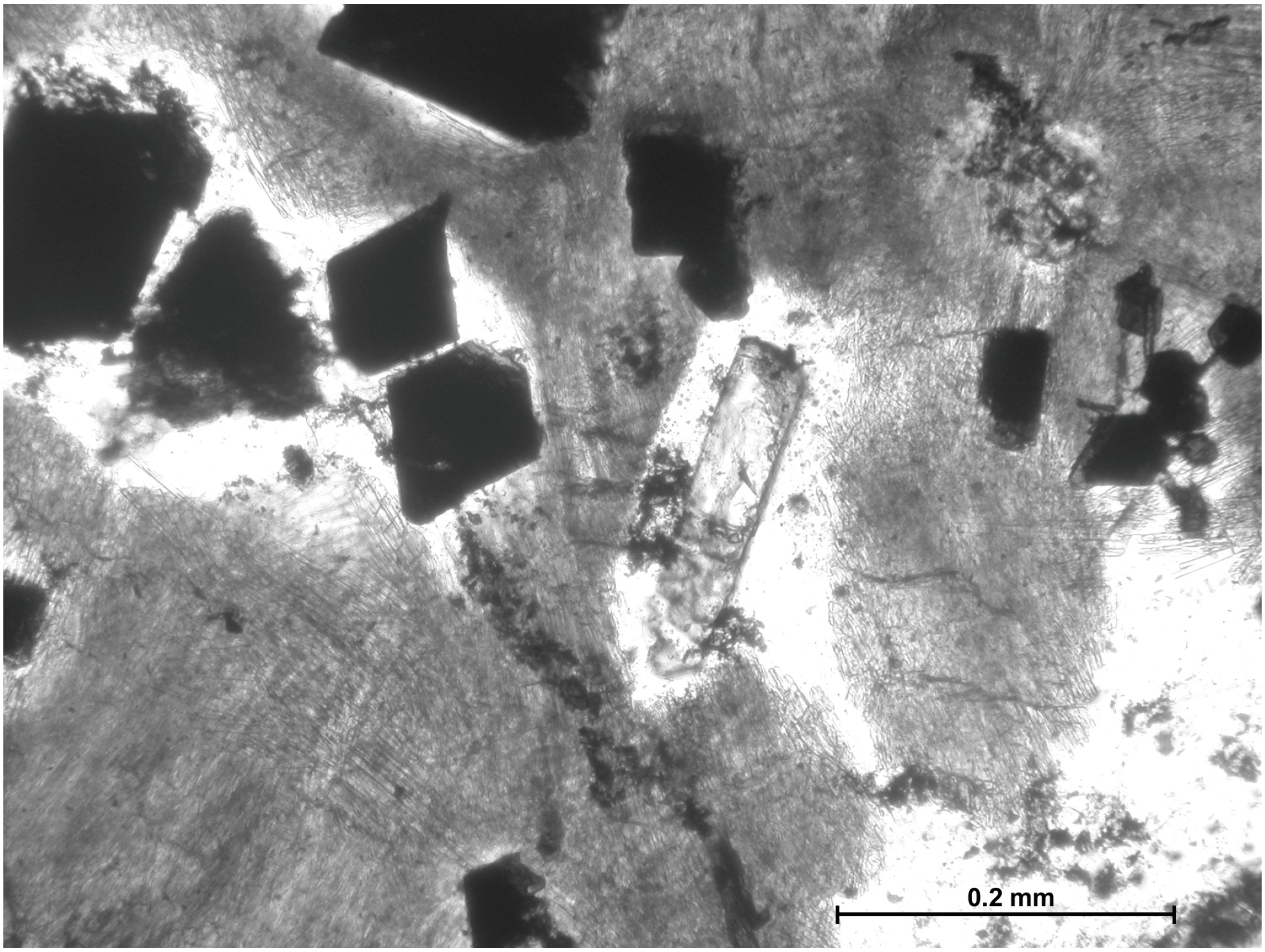


Figure 37. Photomicrograph of a thin section of a pebble of corundum-bearing metamorphic rock from the Silver Bow sapphire occurrence. Black grains are spinel and prismatic crystal is corundum. The corundum crystal is surrounded by plagioclase feldspar (white) and masses of small, prismatic sillimanite grains that appear gray. Specimen collected by Aaron Berger. Photo by R.B. Berg.

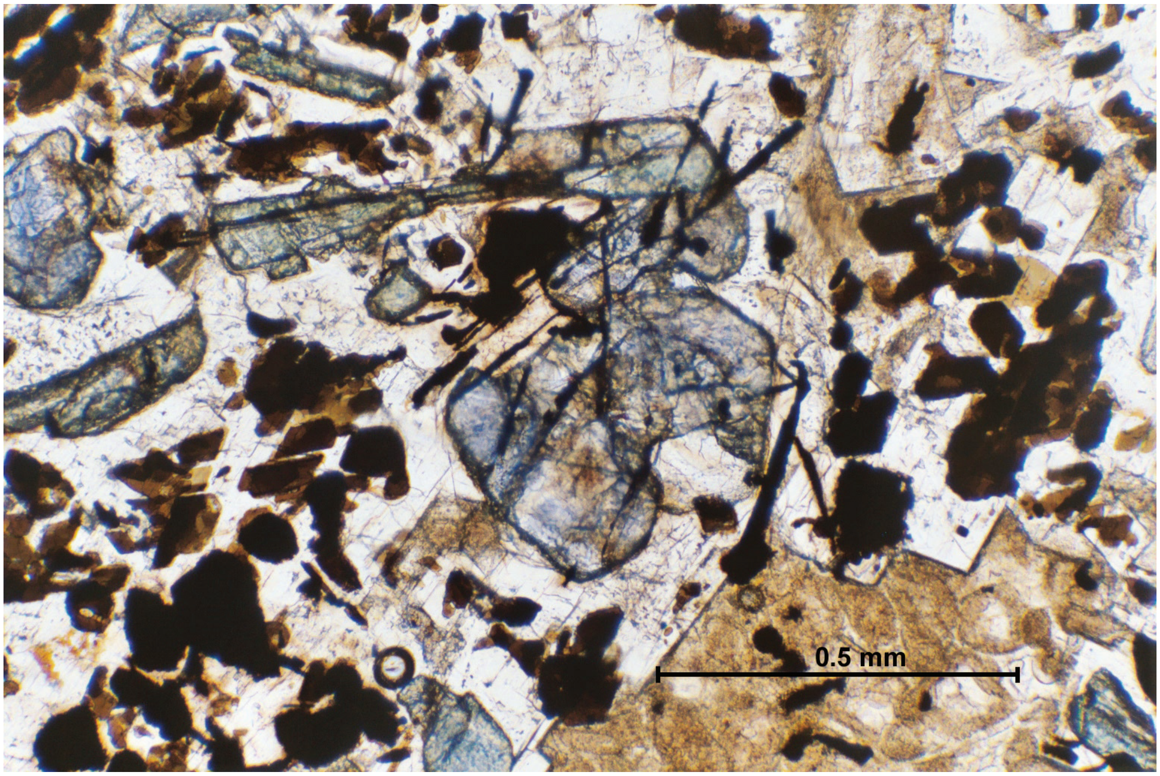


Figure 38. Photomicrograph of a thin section of a pebble of corundum-bearing igneous rock from the Silver Bow sapphire occurrence. Pale greenish blue grains are corundum and are surrounded by plagioclase feldspar (oligoclase) and very dark brown to black grains of biotite. Tan material in the lower right-hand corner of the photomicrograph is glass. Specimen collected by Aaron Berger. Photo by R.B. Berg.

abundance of smectite, clinoptilolite, and rare grains of vesicular glass all indicate a tuffaceous source for this sediment. Opal was identified adhering to the surfaces of some sapphires. Smectite, clinoptilolite, and opal are commonly formed by the alteration of volcanic ash. Thus, we conclude that sapphire, garnet, and spinel occurred in this tuff and were transported to the present site in a debris flow. The occurrence of two corundum-bearing schist pebbles and other schist pebbles that contain spinel and sillimanite give support to the hypothesis previously suggested for sapphires in alluvial deposits in southwestern Montana (Garland, 2002; Berg and Dahy, 2002), that the ultimate source of these sapphires is crustal metamorphic rock. As the magma oozed through fractures in the metamorphic rock at depth, fragments of metamorphic rock were incorporated in the magma. Because corundum, spinel, and garnet melt at higher temperatures than many other metamorphic minerals, or rocks composed of mixtures of other metamorphic minerals, these minerals survived transport in the magma without melting. Additionally, a similar schist xenolith was found in a lava flow of the Lowland Creek Volcanics east of American Gulch in the NW¼ NW¼ sec. 26, T. 5 N., R. 8 W., Lockhart Meadows 7.5-minute quadrangle (locality 6, fig. 2). Although this xenolith does not contain corundum, it consists of sillimanite, spinel, biotite, potassium feldspar, and plagioclase, a mineralogy similar to that of those pebbles from the Silver Bow sapphire occurrence that do contain corundum. This xenolith adds support to the hypothesis that corundum-bearing pebbles have been released from the tuff during weathering.

Area between Silver Bow and Butte

Corundum is reported to occur in the dry streambeds in Silver Bow Valley, presumably downstream from Rocker (McLaughlin, 1934). McLaughlin also stated that commercial gems occur in the placers north of Silver Bow, which may be our Silver Bow occurrence. Sapphires have also been reported on the west side of Big Butte and in Gimlet Gulch (fig. 39). Gravel was sampled just north of Rocker downstream from the confluence of Gimlet Gulch and two unnamed creeks that enter it from the west. The sample was collected from the dry creekbed in the SW¼ SE¼ SW¼ sec. 16, T. 3 N., R. 8 W., Butte North 7.5-minute quadrangle (locality 7, fig. 2 and locality 1, fig. 39). This sample, after first sieving to remove the >3-mm-size fraction, weighed 650 lbs. The sample represents approximately ⅓ cubic yard of this sediment on a loose basis. The 1- to 3-mm fraction was sieved, but neither sapphires nor garnets were recovered.

There are numerous reports of sapphires having been recovered from Whiskey Gulch during placer mining for gold. Whiskey Gulch, situated less

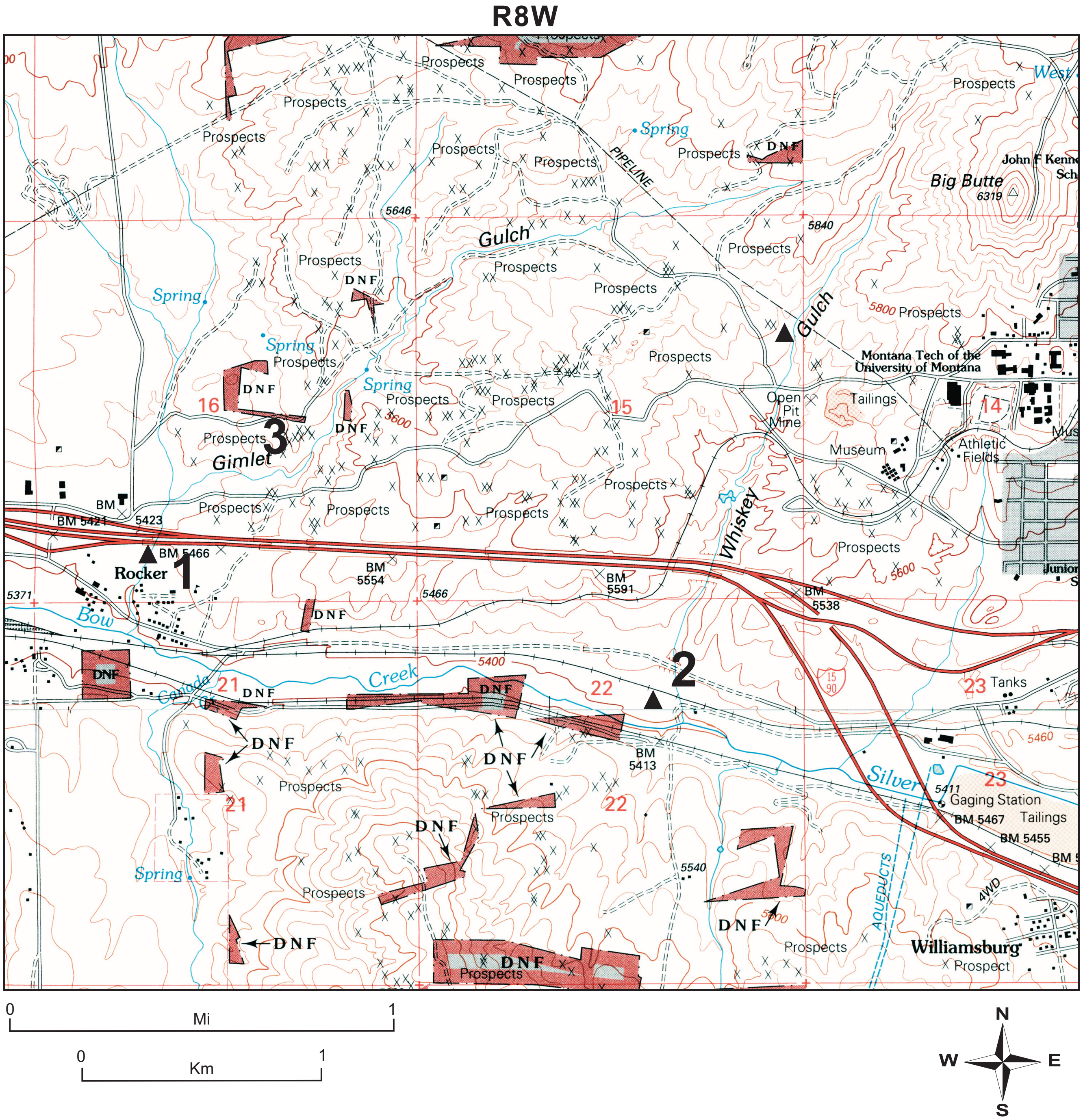


Figure 39. Map showing Whiskey and Gimlet Gulches in T. 3 N., R. 8 W. Base map from USGS Butte North and Butte South 7.5-minute quadrangles; 40-ft contour interval. Locality 1 is the site of sampled gravel, locality 2 is the site where 6.5 carat sapphire was recovered, and locality 3 is the site where sapphires were recovered by panning. Shaded areas indicate National Forest.

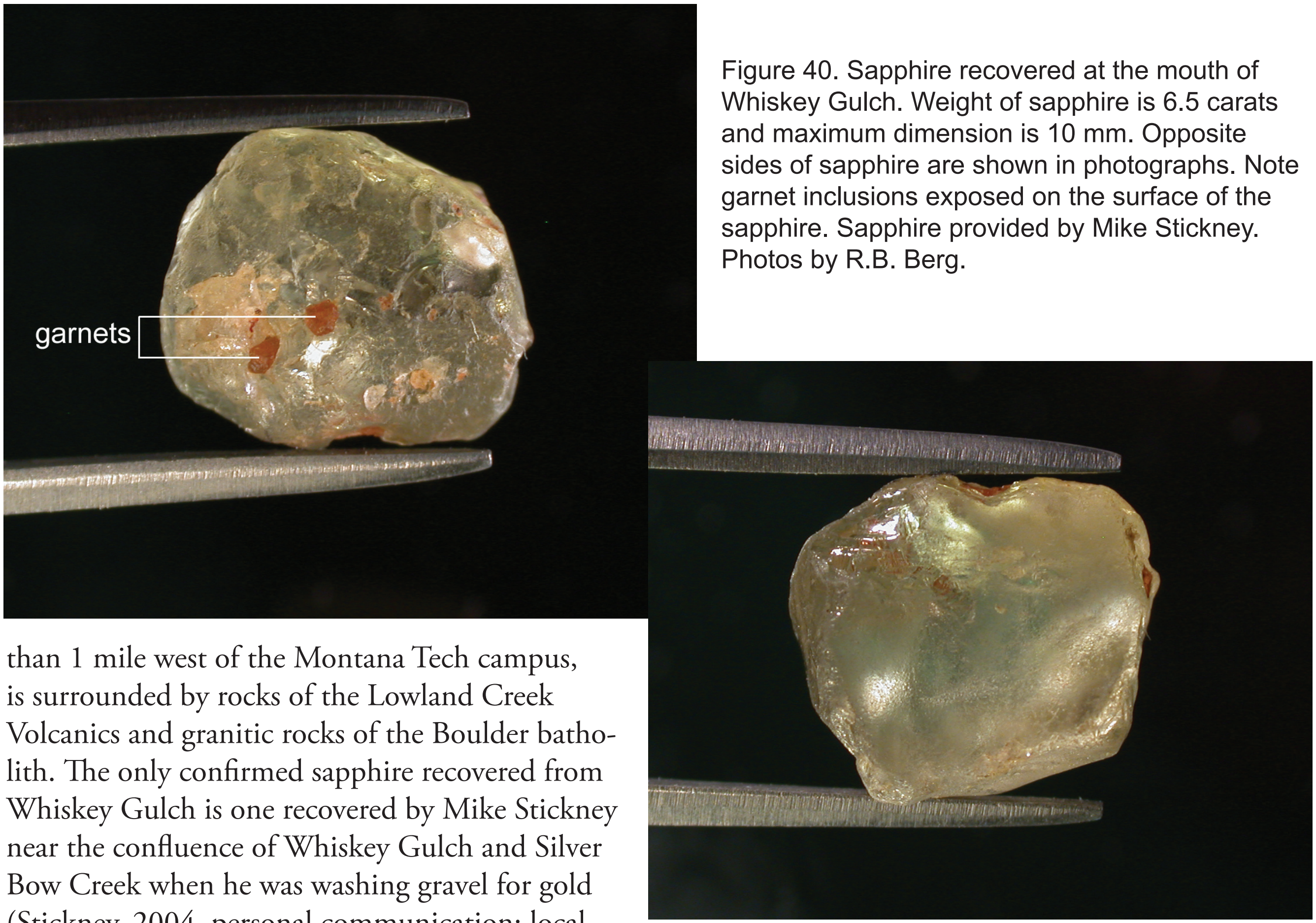


Figure 40. Sapphire recovered at the mouth of Whiskey Gulch. Weight of sapphire is 6.5 carats and maximum dimension is 10 mm. Opposite sides of sapphire are shown in photographs. Note garnet inclusions exposed on the surface of the sapphire. Sapphire provided by Mike Stickney. Photos by R.B. Berg.

than 1 mile west of the Montana Tech campus, is surrounded by rocks of the Lowland Creek Volcanics and granitic rocks of the Boulder batholith. The only confirmed sapphire recovered from Whiskey Gulch is one recovered by Mike Stickney near the confluence of Whiskey Gulch and Silver Bow Creek when he was washing gravel for gold (Stickney, 2004, personal communication; locality 8, fig. 2 and locality 2, fig. 39). This site is just south of the railroad tracks (formerly the Butte Anaconda and Pacific Railroad) in the NW¼ SW¼ NE¼ sec. 22, T. 3 N., R. 8 W., Butte North 7.5-minute quadrangle. Here gold-bearing gravel is overlain by a hard bed of silica-cemented gravel. The sapphire from this locality was very pale green, 10 mm across, and weighed 1.30 gm (6.5 ct) (fig. 40). Four pale red garnets were exposed at the surface, but the interior of this sapphire appeared free of inclusions.

Sapphires have been recovered by panning alluvium along Gimlet Gulch in the NW¼ NE¼ NW¼ sec. 15, T. 3 N., R. 8 W., Butte North 7.5-minute quadrangle (locality 9, fig. 2 and locality 3, fig. 39; John Little, personal communication, 2006). Examination of the nonmagnetic fraction of the heavy mineral concentrate showed it to contain sapphire, garnet, spinel, and zircon in addition to sparse gold. Five of the eight sapphires in this sample were colorless, two very pale green, and one pale purple. They ranged in size from 2 to 5 mm and in shape from a broken hexagonal tablet to irregular grains to an almost spherical grain. The eight spinel grains were less than 1 mm in size, pale green, and of somewhat rounded equidimensional form. In color and form, they resembled the spinel recovered from the Silver Bow sapphire occurrence. One of the garnets was pale pink, four orangish red, and six dark red. They were angular and ranged in size from 2 to 3 mm. Zircon was also a major constituent of this sample.

Steward Mine, Butte

Brimhall (1977) described the occurrence of corundum at Butte in low concentrations in the altered granite surrounding pre-Main Stage veins. Muscovite, andalusite, quartz, alkali feldspar, biotite, anhydrite, magnetite, calcite, pyrite, and chalcopyrite are also found in this altered granite.

Corundum was also identified by Anaconda Company geologists in a specimen collected on the 4600-ft level of the Steward mine, a copper mine in the Butte district (fig. 2). The corundum occurred in clusters up to 0.5 mm across, composed of small grains surrounded by white mica (fig. 41). The corundum must be a fairly dark blue, because even in a

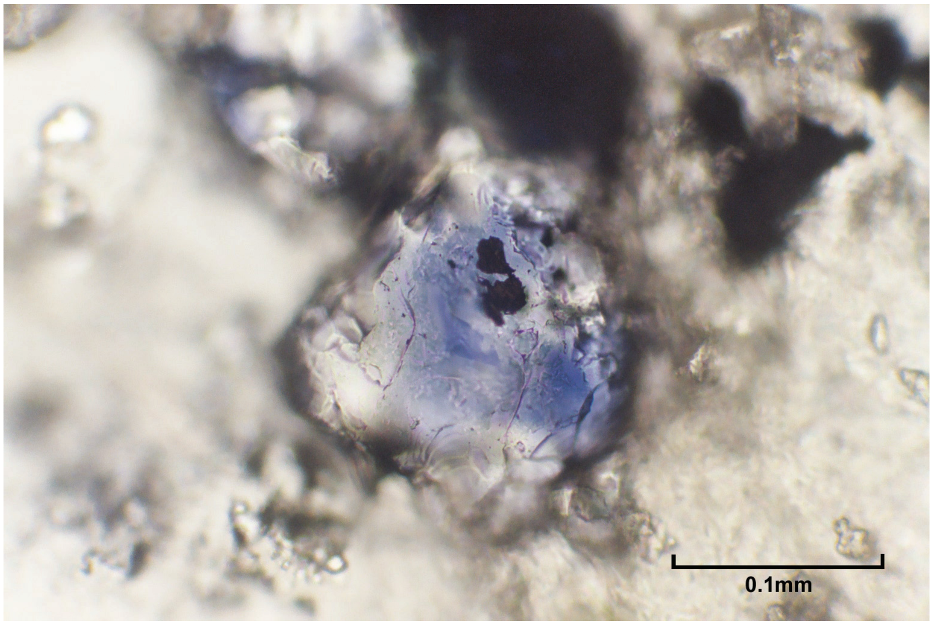


Figure 41. Photomicrograph of a thin section of a specimen from the 4600-ft level of the Steward mine, Butte, MT, showing corundum crystals surrounded by white mica and opaque pyrite grains (black in photo). Specimen 9111 in the Anaconda Research Collection. Photo by R.B. Berg.

thin section some of the grains appear blue. Concentration of corundum in this specimen was probably less than 1 percent. This specimen also contained biotite that is pleochroic from light to dark brownish green, pyrite, and minor chalcopyrite. A specimen similar in mineralogy, but lacking corundum, was collected from the 4200-ft level of the Steward mine (specimen 9975). These specimens may be from a large xenolith in the Butte quartz monzonite that has been hydrothermally altered. Both specimens, including thin sections and polished slabs, are in the Anaconda Research Collection (Reno Sales-Charles Meyer-Anaconda Memorial Collection) curated by the Montana Bureau of Mines and Geology in Butte.

Lowland Creek

Introduction

Lowland Creek, which is a tributary of the Boulder River, is about 16 miles northeast of Butte within the Sheepshead Mountain 7.5-minute quadrangle map (fig. 2). Placer deposits in the lower 3.7 miles of Lowland Creek were mined for gold (fig. 42). Although there are no records of the earliest placer mining, it is reported that gold was mined between 1933 and 1941 (Lyden, 1987, p. 33). Undoubtedly sapphires were encountered during this mining, but it is likely that they were not

Figure 42. View looking north along the lower part of Lowland Creek showing dredge tailings. Photo by R.B. Berg.

recovered because economic interest was focused on gold. Sapphires were recovered from Lowland Creek just upstream from its confluence with the South Fork of Dry Gulch during placer mining for gold in the 1970s (fig. 43). Placer mining for gold in Lowland Creek is limited to the area downstream from the Ruby mine (fig. 43), which is considered to be the source of this gold.

Geology

As with the other sapphire occurrences and deposits in the area north and west of Butte, the Lowland Creek Volcanics are the dominant rock sequence in the Lowland Creek drainage (Smedes and others, 1962). The major rock types exposed in the hills on both sides of Lowland Creek are welded tuff and a lava unit. However, sapphires have not

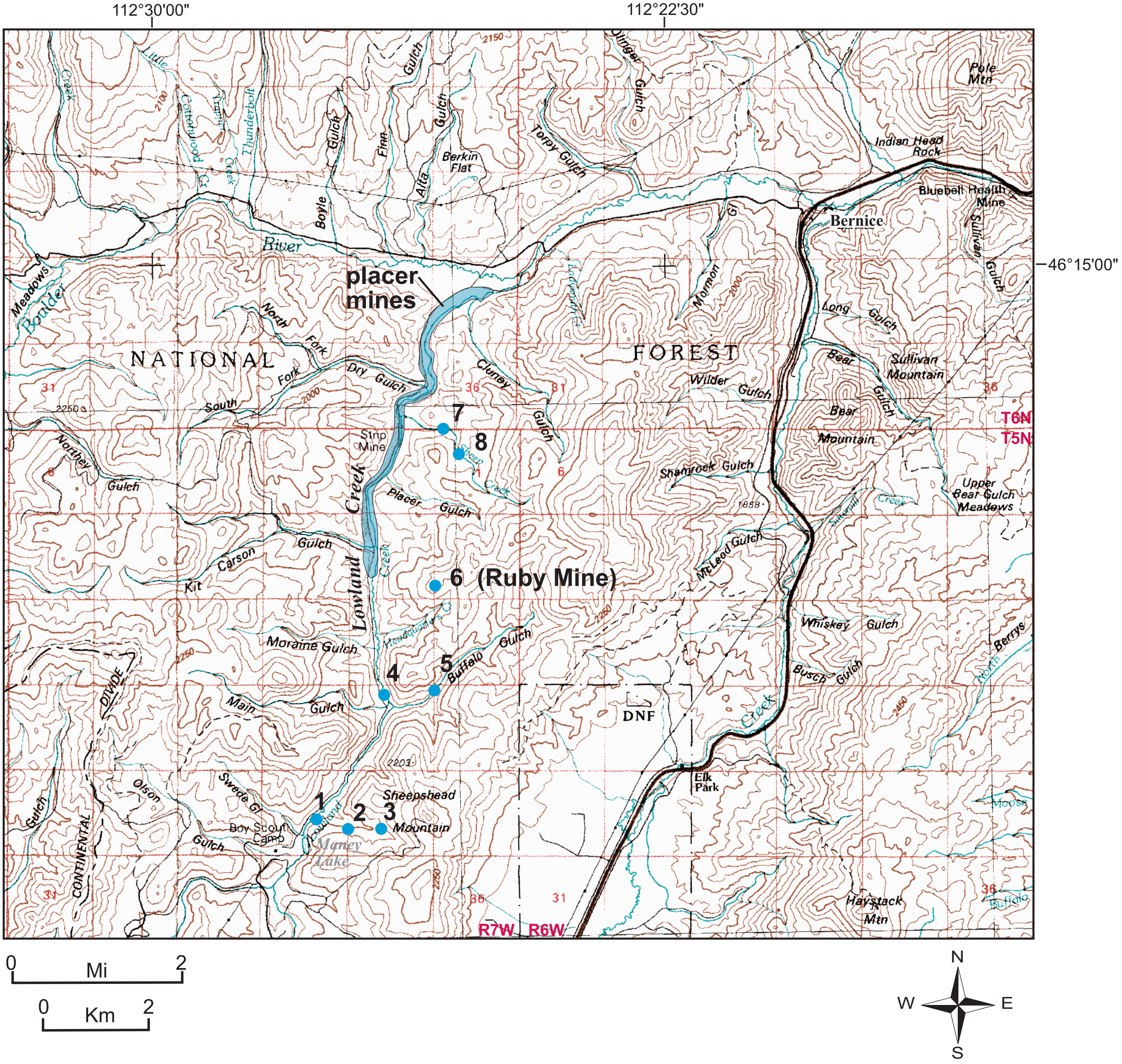


Figure 43. Map of the Lowland Creek area showing sample sites and area of placer mining. Base map is USGS Butte North 1:100,000 scale map; contour interval 50 meters. Numbered localities described in text (p. 42).

been described from any of the volcanic units in the Lowland Creek Volcanics. The only other rocks that have been mapped in the Lowland Creek drainage are granitic rocks of the Boulder batholith that are exposed upstream from the confluence of Olson Gulch and Lowland Creek (fig. 43).

Description of sapphires

Ninety-five sapphires recovered during placer mining in the 1970s, provided by Mr. William Carlson of Bernice, were examined. These sapphires ranged in size from 3 to 10 mm and were colorless to very faintly colored (fig. 44). Some were very pale blue-green and several were pale lavender to pink; shapes ranged from tablet to equidimensional forms. Surfaces of sapphires from Lowland Creek were similar to those from the South Fork of Dry Cottonwood Creek, but did not show the diversity of surface features typical of sapphires from that locality. Some sapphires had small bumpy ridges on nonbasal surfaces (fig. 45), and only one sapphire with a pinnacle was observed. Nearly spherical sapphires with frosted surfaces like

Figure 44. Sapphires from Lowland Creek provided by William Carlson. Average size about 5 mm. Photo © Tino Hammid.

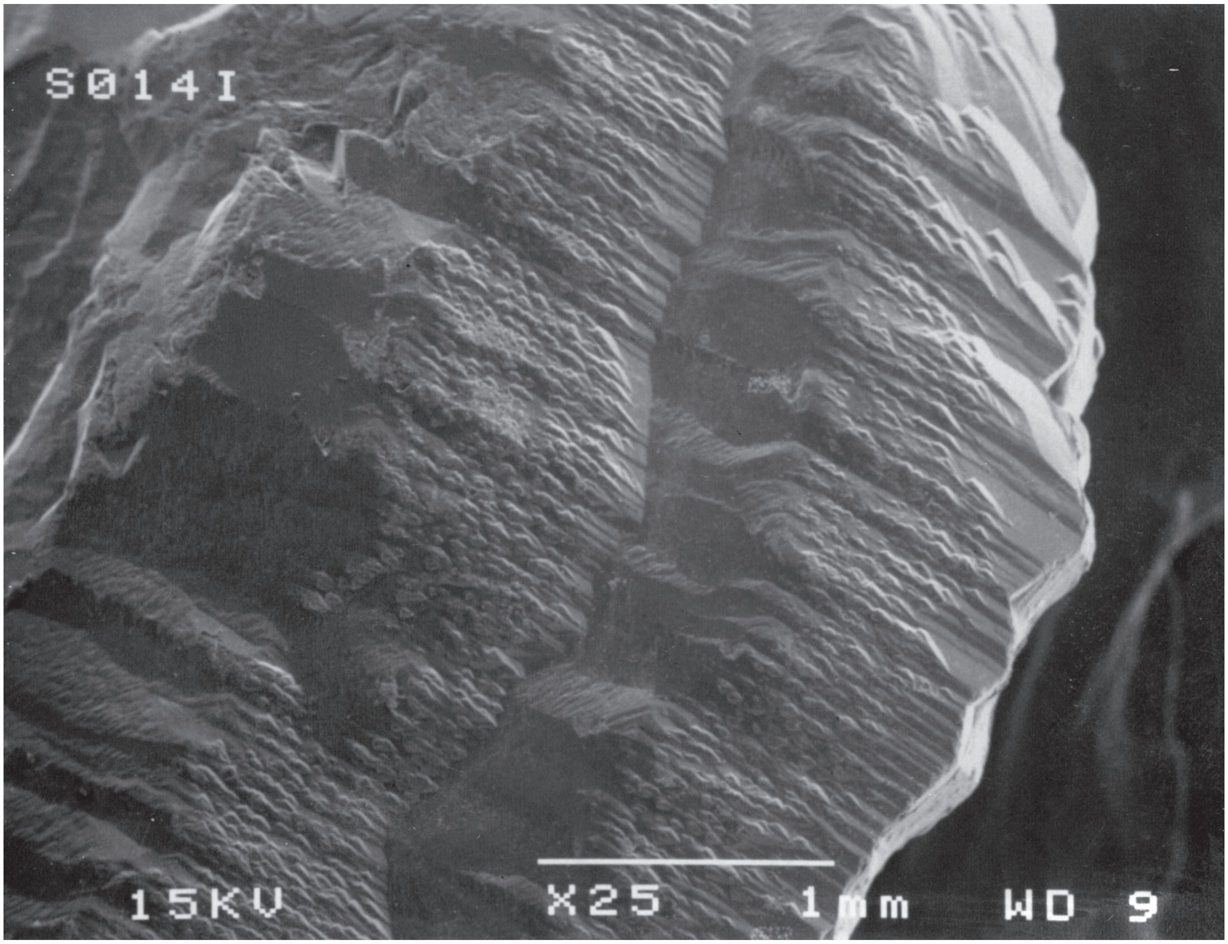


Figure 45. Scanning electron micrograph showing the surface developed on some sapphires from Lowland Creek. Photo by Nancy Equall.

some of the small sapphires from the South Fork of Dry Cottonwood Creek were not observed. All of the sapphires from Lowland Creek showed the development of smooth and shiny conchoidal fractures that ranged from just a single microscopic chip to some sapphires where much of the surface was characterized by fresh conchoidal fractures. Presumably most of these fractures were caused by stream transport, but possibly some may have been caused by abrasion in a trommel during their recovery.

Very small sapphires were recovered by careful panning (completed by "panning" in a watch glass) of a heavy mineral concentrate provided by Mr. Carlson. These colorless sapphires ranged in size from a hexagonal tablet 0.2 mm across to a 0.09 mm irregular grain.

Sapphires with mineral inclusions recognizable with the aid of the binocular microscope were examined in 14 thin sections made of individual sapphires. Biotite was the most abundant inclusion, and was identified in 4 thin sections. Grains ranged from 0.5 to 0.8 mm in size, were subrounded in outline, and were oriented with their c crystallographic axes approximately parallel to the c-axis of the host corundum. Apatite was identified in 5 thin sections (fig. 46) and ranged in size from 0.2 to 0.5 mm; most grains were spherical, but a few exhibited elongate prismatic form. A less abundant brown mineral shown to contain iron and oxygen by semi-quantitative EDX was inferred to be hematite. Small (30–60 µm) elongate zircons with rounded outlines were identified in two sapphires, where they occurred in clusters. Most of the sapphires examined in thin section contained only one or two mineral inclusions. Rutile was not identified in any of these sapphires.

Some sapphires contained planes of small elongate vapor or liquid inclusions that formed a pattern somewhat resembling a fingerprint. These planes typically were between 0.2 and 1 mm long, and some curved, but did not continue to the outer surface of the sapphire. See figure 31 for a similar feature in a sapphire from the South Fork of Dry Cottonwood Creek. Also, some sap-

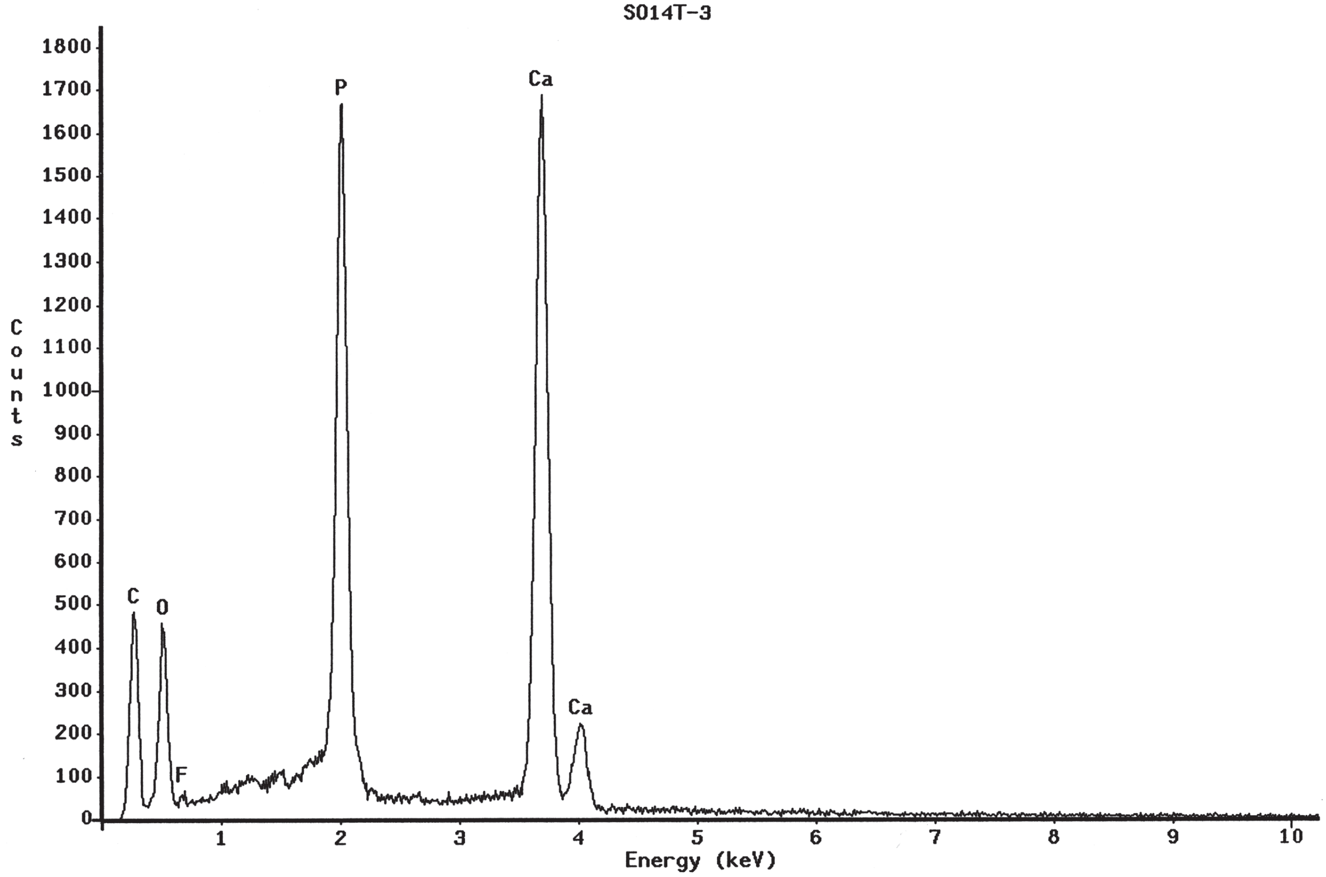


Figure 46. Energy dispersive x-ray analysis spectrum of apatite grain in a sapphire from Lowland Creek.

phires contained small, two-phase inclusions that consisted of a liquid with a vapor bubble. None of the sapphires from Lowland Creek were found to have adhering rock or minerals.

Associated heavy minerals

Garnet is an abundant heavy mineral associated with sapphires in Lowland Creek. Garnets in the Lowland Creek deposit were examined in detail because of the apparent association of garnets with sapphires. On the basis of color (and by inference chemical composition), there are two major groups of garnets from Lowland Creek: pale pink and darker red or orangish red. Garnets ranged from 1 to 3 mm and did not show crystal faces, but were fragments of crystals. Pale pink garnets were less abundant than the darker red or orangish red garnets and contained more inclusions, mainly rutile with lesser anthophyllite and rare zircon. Some of the darker garnets contained quartz inclusions. Both pale pink and darker red or orangish red garnets occur in some of the lava flows in the Lowland Creek Volcanics that are exposed along Lowland Creek. Garnets in the lava flows are typically 2 to 4 mm in size and surrounded by a thin rim of biotite.

In addition to garnet and sapphire, other heavy minerals were identified in the >0.3-mm-size fraction of a heavy mineral concentrate. The concentrate was provided by Mr. Carlson and was recovered from the lower section of Lowland Creek below Sheep Creek when Lowland Creek was placer mined for gold. The minerals, in order of decreasing abundance, are magnetite, hematite, zircon, allanite, apatite, pyrite cubes replaced by goethite, hornblende, titanite, and schorl. All of the zircons were colorless and ranged in shape from elongate to stubby crystal forms, as well as some that were subrounded. Many had shiny surfaces as if they had been polished.

Sampling in the Lowland Creek Drainage

In an effort to determine the bedrock source of the alluvial sapphires in Lowland Creek, alluvium was screened for sapphires at several localities. Bedrock was not reached at any of the sample sites. Alluvium was screened to obtain a 1- to 7-mm sample, and generally between 1 and 2 hours was spent screening at a specific site. No sapphires were found. Perhaps larger samples would have yielded sapphires, but the lack of recovery indicates that the concentration of sapphires at these localities is very low compared to that along the South Fork of Dry Cottonwood Creek or at the Silver Bow occurrence. Because garnets are much more abundant than sapphires in the sapphire-bearing concentrates of heavy minerals from Lowland Creek, it is significant that garnets were not recovered at most of these localities. Following are descriptions of these sample sites, shown in figure 43.

Locality 1. Sapphires have reportedly been recovered from Lowland Creek just below Maney Lake. Gravel along Lowland Creek was sampled in the SE¼ SW¼ NE¼ sec. 27, T. 5 N., R. 7 W., just upstream from the point where a tributary enters Lowland Creek from the southeast. No sapphires or garnets were recovered.

Locality 2. Gravel was sampled in the NW¼ NE¼ SE¼ sec. 27, T. 5 N., R. 7 W., along the intermittent stream that enters Lowland Creek from the southeast that was mentioned for locality 1. No sapphires or garnets were recovered.

Locality 3. Gravel was sampled farther upstream along this tributary in the SE¼ NW¼ SW¼ sec. 26, T. 5 N., R. 7 W. No sapphires or garnets were recovered.

Locality 4. Gravel along Lowland Creek was sampled just below the confluence of Buffalo Gulch in the SE¼ NE¼ NW¼ sec. 23, T. 5 N., R. 7 W. This is just upstream from the beaver ponds along Lowland Creek. No sapphires or garnets were recovered.

Locality 5. Gravel was sampled along Buffalo Gulch, also a tributary to Lowland Creek. The sample site is in the NE¼ NE¼ NE¼ sec. 23, T. 5 N., R. 7 W. No sapphires or garnets were recovered.

Locality 6. Because of the association of garnets with sapphires in the Lowland Creek placer, an attempt was made to recover sapphires from a heavy mineral concentrate made by panning garnet-bearing cuttings that were available from a mineral exploration drillhole located near the Ruby Mine. A panned concentrate of heavy minerals was provided by Peter Mejstrick. Heavy minerals were further concentrated from 10 samples by panning in the laboratory and then examined with the binocular microscope. All samples contained garnets, but no sapphires were recognized. Pale pink garnets were more abundant than the orangish red garnets and some of these pale pink garnets contained abundant small rutile needles.

Locality 7. Garnets are generally fairly sparse in the lava flows of the Lowland Creek Volcanics. In 15 minutes of searching an outcrop, one garnet might be found. However, a fine-grained altered felsic volcanic rock exposed in the Sheep Creek road at the first switchback in the NE¼ NW¼ NW¼ sec. 1, T. 5 N., R. 7 W., contained abundant garnets. One fist-sized rock (0.6 lbs, 286 gm) contained eight garnets, both pale pink and orangish red, exposed on the surface. Garnets in this specimen were small, less than 4 mm across, typically fractured, and surrounded by a thin rim of biotite that in some instances was altered to a fine-grained dark green mineral. More than 100 lbs of this rock was collected, but no sapphires were found exposed on the surfaces of the material.

Locality 8. Sandy material was sampled along the road up the Sheep Creek drainage in the NE¼ NE¼ SW¼ sec. 1, T. 5 N., R. 7 W. No sapphires or garnets were recovered.

Bedrock Source of Sapphires

The bedrock source of the sapphires recovered during placer mining along Lowland Creek has not been recognized. Volcanic rocks belonging to the Lowland Creek Volcanics of Eocene age are the dominant exposed bedrock in this drainage (Smedes and others, 1962; Smedes and Thomas, 1965). Unlike the South Fork of Dry Cottonwood Creek or the Silver Bow occurrence, where these volcanic rocks are indicated to be the bedrock source, there is no similar evidence for the Lowland Creek sapphires. The only inference that can be made is that the similarity of surface features of sapphires from Lowland Creek and from the South Fork of Dry Cottonwood Creek, and the abundance of associated pink and orangish red garnets, suggests they share a similar rock source. The bedrock exposed in both areas is predominantly volcanic rock of the Lowland Creek Volcanics and to a lesser extent granitic rocks of the Boulder batholith. Based on these considerations, it seems probable that the Lowland Creek Volcanics are the bedrock source of the sapphires recovered from Lowland Creek.

DISCUSSION

Sapphires occur in significant concentrations in three alluvial deposits in the Butte–Deer Lodge area: the South Fork of Dry Cottonwood Creek, Lowland Creek, and the Silver Bow occurrence. Sapphires have also been found at several other localities and there are unverified reports of sapphires in alluvium at other localitites. It is reasonable to speculate that if alluvium were sampled throughout the area north and west of Butte, additional sapphire occurrences would be discovered.

Various units of the Lowland Creek Volcanics are exposed in much of this area. On the basis of field observations of the deposit on the South Fork of Dry Cottonwood Creek and the occurrence of sapphire in slightly altered tuff at the Silver Bow occurrence, these volcanic rocks are the most likely bedrock source for sapphires in the Butte–Deer Lodge area. The ultimate source of these sapphires may be corundum-bearing metamorphic rock that was incorporated in this magma during its ascent to the surface. Corundum-bearing schist pebbles associated with sapphires at the Silver Bow occurrence, and the one schist xenolith of similar mineralogy but lacking corundum found in an exposure of the Lowland Creek Volcanics in the Browns Gulch drainage basin, add support to this hypothesis.

The investigation described here is essentially a field study aided by laboratory methods used in the identification of mineral inclusions and surface textures shown by scanning electron microscopy. There are many interesting studies that can provide significant information on these sapphires by using modern analytical techniques routinely applied to fluid inclusions, isotopic ratios of minerals, and trace element geochemistry. Currently (2007), Berger is studying fluid inclusions in sapphires from the Silver Bow occurrence. Sapphires from the deposits and occurrences described here are available on loan to those wishing to pursue further research.

ACKNOWLEDGMENTS

Many individuals have contributed to this investigation of sapphire deposits and occurrences in the area west of Butte, both directly by contributing specimens and through sharing information on alluvial sapphire deposits in Montana. Aaron Berger, formerly a graduate student at Montana Tech of The University of Montana, contributed very significantly to our understanding of these deposits by his investigation of the sapphire occurrence at Silver Bow. Dale Siegford of the Sapphire Gallery in Philipsburg contributed sapphires for this study and was a useful sounding board for my ideas about the origin and source bedrock of these sapphires. Mr. Marc Bielenberg, who has been involved with sapphires and gold in Montana for over 60 years, contributed very significant sapphire specimens from the South Fork of Dry Cottonwood Creek. Marc also shared historical information on this deposit.

Mr. Carlson of Bernice, Montana contributed a significant suite of sapphires and garnets from Lowland Creek. Jim and John Rex contributed an assortment of sapphires and garnets from their sapphire mining on the South Fork of Dry Cottonwood Creek. Many others contributed sapphires and information that, although not specifically from the area covered in this report, was nonetheless very helpful to my understanding of sapphires in Montana. Included in this list are Chris Cooney, Russ Hage, Ben Duffy, John Felde, Gene Hodge, Bill Dansie, and Chris van Laer. Special acknowledgments are due to Mary Garland, who freely shared ideas about the source and origin of alluvial sapphires in southwestern Montana while she was completing her dissertation.

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APPENDIX

LABORATORY PROCEDURES

Scanning Electron Micrography (SEM)

Scanning electron micrographs were taken at the Image and Chemical Analysis Laboratory (ICAL) at Montana State University in Bozeman by Nancy Equall of the laboratory staff. Sapphires were rinsed in acetone and then mounted. An attempt was made to remove loose dust by blowing nitrogen over the specimen. Specimens were then coated with either carbon or a palladium-gold alloy and scanned using a Jeol scanning electron microscope. Most images were recorded digitally.

Identification of Mineral Inclusions

Sapphires were examined using a binocular microscope with illumination from below a frosted glass plate. Some of the sapphires in which mineral inclusions could be recognized were selected for analysis. The selected sapphire was mounted on a frosted microscope slide with Duco or similar cement and ground using a diamond-impregnated grinding wheel to produce a flat surface. For a good bond between the Duco and the microscope slide it was necessary that the Duco cover much of the slide, a much larger area than that simply surrounding the sapphire. Grinding was done carefully so that the mineral inclusion of interest was only a few tens of microns below this surface.

The Duco was then dissolved by soaking the mounted grain in acetone to free the sapphire. The sapphire was then mounted with the flat side down on another microscope slide with 5-min epoxy. It was found that it was not necessary to frost these slides for good adhesion. Next the sapphire was ground down to expose the inclusions of interest. This was necessary because the analytical technique used here (EDX) requires that the mineral inclusion be exposed to the electron beam. It is desirable to try to attain a thickness of 30 µm, the standard thickness for petrographic thin sections. This was important in the determination of the optical parameters of the mineral inclusion. Occasionally the mineral inclusion was "plucked" out of the thin section and lost during this final grinding. Some thin sections were finished by hand lapping using 600-mesh grit. The thin section was then covered with microscope immersion oil and a cover slip was added for optical examination.

Before analysis by EDX, the oil was removed by rinsing the thin section in acetone. It was found that if the thin section was allowed to stand in acetone, the epoxy would slowly dissolve. This procedure worked well if the instrument used for the EDX analysis required that the thin section first be coated with carbon or a gold-palladium alloy. If the instrument was of the high-vacuum type, where the sample does not need to be coated first, immersion oil was not applied to the surface. It is not possible to remove all of the oil by rinsing the specimen in acetone, and oil left on the specimen can cause serious contamination problems in the instrument. Optical parameters of individual grains were determined by standard petrographic techniques.

Mineral inclusions easily recognizable in thin section can be almost impossible to locate when viewing the thin section by SEM. The best procedure is to circle the grains to be analyzed with black ink when they are examined under the petrographic microscope. These black ink lines are easily recognizable when viewing the thin section with SEM. It is even more helpful to take a photomicrograph that shows the circled grains. Careful designation of individual mineral grains saves time and money when the actual analyses are being performed. Most of the EDX analyses used in the identification of the mineral inclusions described here were performed in ICAL at Montana State University using the same instrument as that used for the SEM work. A few were done in the Department of Metallurgy and Mineral Processing at Montana Tech of the University of Montana by Dr. Vernon Griffiths. Although EDX analyses are semi-quantitative, they are extremely helpful in confirming a mineral determination based on optical parameters.

The following is an example of the usefulness of this technique. Apatite was identified in several sapphires from Lowland Creek on the basis of its optical parameters. EDX analyses showed these grains to contain calcium, phosphorus, and fluorine (fig. 46). The average of nine semi-quantitative analyses of similar inclusions in sapphires from Lowland Creek showed the following results: CaO 60%, P_2O_5 46%, F 3%, obviously not normalized to 100%. The results of these semi-quantitative analyses agree reasonably well with published chemical analyses for apatite and support the optical identification of these mineral inclusions.

Photomacrography

A Nikon Coolpix 995 was used for all photomacrographs taken by the author. Two 50-watt reflector bulbs were used for lighting and the camera was set for incandescent light, either weighted average or spot metering, and manual focus. A white or black paper background was used because even a lightly colored background altered the color of the very faintly colored sapphires. Individual sapphires were best photographed when held above the background or above a mirror that was tilted at about 40 degrees to avoid a reflection of the camera. Photographs used in this report were in some instances selected from more than 20 individual photographs.

GLOSSARY

GLOSSARY

Some definitions are modified from The Dictionary of Mining, Mineral and Related Terms (American Geological Institute, 1997) and The Glossary of Geology (Jackson, 1997). The definitions given here apply to the use of the term in this report and do not necessarily apply to all usage of the term.

Albite $NaAlSi_3O_8$ (Sodium aluminum silicate). Albite is a member of the plagioclase group of feldspars. (See **plagioclase.**)

Alkali feldspar Either potassium feldspar or albite.

Allanite A hydrous silicate that contains rare-earth elements and may contain calcium, sodium, aluminum, iron, manganese, beryllium, and magnesium. It is a member of the epidote group. Allanite occurs in low concentration in some igneous rocks and may be concentrated in placers because of its relatively high specific gravity (3.5–4.2).

Alluvium An unconsolidated mixture that may contain clay, silt, sand, and gravel that was deposited by running water.

Andalusite Al_2SiO_5 (Aluminum silicate). One of three minerals (kyanite, sillimanite, and andalusite) with the same chemical composition, but different crystal forms. Occurs in aluminous metamorphic rocks.

Anhydrite $CaSO_4$ (Calcium sulfate). A mineral found in some sedimentary deposits and more rarely with other minerals in veins.

Anthophyllite $(Mg,Fe^{2+})_7Si_8O_{22}(OH)_2$ (Hydrous magnesium, iron silicate). Occurs in metamorphic rocks and in some altered rocks.

Apatite $Ca_5(PO_4)_3F_2$ (Calcium fluorophosphate). Commonly occurs in low concentrations in igneous and metamorphic rocks. In spite of being relatively soft, it is a common constituent of placers because of its moderately high specific gravity (3.15–3.20) and widespread occurrence.

Avoirdupois pound The unit of weight commonly used in the United States (the common pound); not used for precious metals and gemstones. An avoirdupois pound consists of 16 avoirdupois ounces. For difference between an avoirdupois ounce and a troy ounce see **troy ounce**.

Bank cubic yard (bcy) A measurement of unconsolidated material, such as gravel, that is in place before excavation. Grade of a sapphire deposit is often shown as carats/bank cubic yard or ct/bcy, or may simply be shown as gm/bcy.

Bar A deposit of alluvial material that is above or below the water level of the present stream. As used here it refers to the sapphire-bearing gravels along the Missouri River near Helena that are situated above the river.

Basal parting Parting or breakage along planes of weakness perpendicular to the c crystallographic axis. The c crystallographic axis in corundum is the long axis of the hexagonal prismatic form of corundum.

Bedrock The solid rock that may be exposed or covered by soil and other loose material.

Biotite (Hydrous potassium aluminum silicate that also contains iron, magnesium, and generally titanium). This black mica is a common constituent of igneous and metamorphic rocks.

Bipyramidal A crystal form that consists of two pyramids with their bases joined. Synonymous with dipyramid. Quartz in volcanic rocks may have this form.

Calcite $CaCO_3$ (Calcium carbonate). A very common mineral in sedimentary and metamorphic rocks and the principal constituent of limestone.

Carat A unit of weight used in the weighing of gemstones; equal to 1/5 of a gram.

Chalcopyrite $CuFeS_2$ (Copper, iron sulfide). A common copper ore mineral.

Cinnabar HgS (Mercury sulfide). A mercury ore mineral that can be found in placers because of its high specific gravity (8.10).

Cleavage The breakage of a mineral along definite crystallographic planes. Cleavage is directly caused by the arrangement of atoms in the mineral, whereas parting may also occur along definite planes, but may be controlled by other factors.

Clinoptilolite A common member of the zeolite group of minerals that typically forms by the alteration of volcanic ash.

Coefficient of thermal expansion The relative increase in volume of a material that results from an increase in temperature. A mineral with a higher coefficient of thermal expansion will expand more with a given temperature increase than the same volume of mineral with a lower coefficient of thermal expansion.

Conchoidal fracture Smooth, curving fracture like that of broken glass.

Corundum Al_2O_3 (Aluminum oxide). The mineral name for ruby and sapphire. The red, transparent variety is ruby. Corundum of other colors, or even colorless, is considered sapphire if transparent.

Crystallographic axes Imaginary lines in a crystal that are useful in defining the crystal form and other physical properties. The c crystallographic axis in corundum is the long axis of the hexagonal prism.

Dacite An extrusive igneous rock that contains more plagioclase feldspar than potassium feldspar or quartz. Typically a dacite contains biotite and/or hornblende.

Dichroism See **pleochroism**.

Dike A tabular body of rock that formed by cooling molten rock or magma. Dikes cut across layers in the enclosing rock.

Dredge The dredge commonly used in the recovery of sapphires is a bucket ladder or bucket line dredge. Metal buckets are attached to a continuous chain and supported by a superstructure on a flat-bottomed boat to excavate gravel and convey it to the dredge where it is processed.

Energy-dispersive x-ray analysis (EDX) A type of x-ray analysis used to determine the approximate chemical composition of minerals.

Eocene A unit of geologic time that covers the interval from approximately 34 to 56 million years ago. During this time there was much volcanic activity in Montana.

Epidote $Ca_2(Al,Fe^{3+})_3(SiO_4)_3OH$ (Hydrous calcium, aluminum, iron silicate). A relatively common mineral in metamorphic rocks that also can form by the alteration of plagioclase feldspars.

Extrusive An igneous rock that formed when magma was extruded onto the surface of the earth; synonymous with volcanic.

Felsic A general term describing the composition of an extrusive igneous rock that consists mainly of light-colored minerals such as feldspar and quartz.

Gahnite $ZnAl_2O_4$ (Zinc, aluminum oxide). A relatively rare mineral that is the zinc-bearing member of the spinel group. (See **spinel.**)

Garnet A silicate mineral with various concentrations of aluminum, calcium, iron, magnesium, and manganese. Garnets vary in chemical composition between at least four end member chemical compositions. Because of their high specific gravity (3.5–4.3) and their physical and chemical durability, garnets are common in placers.

Goethite FeO(OH) (Hydrous iron oxide). A very common mineral formed by the weathering of iron-bearing minerals. Found in placers because of its high specific gravity (4.37) when in solid masses. Frequently found where it has replaced pyrite cubes.

Gram The basic unit of weight in the metric system. A two-inch paper clip weighs 1.2 grams. Usually abbreviated as gm.

Hornblende Hydrous aluminum silicate that contains variable concentrations of calcium, sodium, magnesium, and iron. A common mineral of a group of minerals called amphiboles.

Hydraulic mining A method used in placer mining where gravel in a bank is washed into a sluice box with a high pressure jet of water.

Ilmenite $FeTiO_3$ (Iron titanium oxide). May be slightly magnetic and found in many rocks. Because of its high specific gravity (4.7), it is concentrated in placers.

Inclusion A mineral grain, typically very small, that occurs within another mineral such as a sapphire.

Index of refraction The ratio of the velocity of light in a vacuum to the velocity of light in the mineral. In some minerals, including corundum, light traveling in different directions through the mineral travels with different velocities, and thus the mineral has two indices of refraction. Determination of these indices by optical methods is routinely used in the identification of minerals.

Jigging A process used in the concentration of heavy minerals, such as sapphires, where up and down pulses of water cause the heavy minerals to be concentrated and the lighter minerals to be washed away.

Kaolinite $Al_2Si_2O_5(OH)_4$ (Hydrous aluminum silicate). A relatively common clay mineral that forms by alteration of feldspar caused by weathering or other processes.

Kyanite Al_2SiO_5 (Aluminum silicate). One of three minerals (kyanite, sillimanite, and andalusite) with the same chemical composition, but different crystal forms. Occurs in some aluminous metamorphic rocks.

Loose cubic yard (lcy) A measurement of material such as gravel after it has been excavated. Because of the increase in void space caused by disturbance of the deposit, a loose cubic yard weighs less than a bank cubic yard (bcy).

Magma Molten rock. When magma solidifies it forms an igneous rock such as granite or rhyolite.

Magnetite Fe_3O_4 (Iron oxide). A common magnetic mineral that occurs in low concentrations in some rocks and is concentrated in placers because of its high specific gravity (5.18).

Microlite Small crystals in porphyritic igneous rocks that can only be recognized with the aid of a microscope.

Micron Also referred to as micrometer. 1/1000 of a millimeter, shown as µm. The diameter of a piece of human hair varies, but is around 70 µm.

Mohs hardness scale A scale that consists of ten minerals that are arranged in order of increasing hardness and can be used in the determination of the hardness of a mineral. These range from talc, the softest, to diamond, the hardest with a hardness of 10. Corundum has a hardness of 9 on this scale.

Monazite $(Ce, La, Y, Th)PO_4$ (Phosphate that contains rare-earth elements and thorium). A mineral that occurs in low concentrations in some rocks and is found in placers, where it is concentrated because of its high specific gravity (5.0–5.3).

Opal $SiO_2 \cdot nH_2O$ (Amorphous hydrated silicate with variable amounts of water). Occurs in a variety of rocks, where it has been deposited from silica-bearing water at low temperatures.

Petrographic microscope A microscope with specialized optics used in the study of thin sections and individual mineral grains.

Phenocryst A large conspicuous crystal that occurs in igneous rock.

Phlogopite $K_2(Mg, Fe^{2+})_6(Si_6Al_2)O_{20}(OH)_4$ Hydrous aluminum silicate that contains potassium and variable amounts of iron and magnesium. Lighter brown than biotite, which contains more iron and is very dark brown to black.

Pinacoid A term used in crystallography to describe two parallel faces of a crystal. A well-formed corundum crystal has two parallel faces at the ends of the prism, referred to as the basal pinacoid (see fig. 4).

Placer A deposit of unconsolidated clay, silt, sand, or gravel that contains heavy minerals of value. All placers discussed in this report are alluvial placers.

Plagioclase $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$ A series of feldspars that range in composition from the two end members, albite (sodium aluminum silicate) to anorthite (calcium aluminum silicate). Plagioclase feldspars are common constituents of igneous and metamorphic rocks.

Pleochroism The ability of a mineral to change in color generally when viewed with the petrographic microscope. Dichroism is applied when the mineral has only two principal directions of different color, whereas pleochroism is applied when the mineral has three principal directions of different color.

Porphyry An igneous rock with conspicuous large crystals in a finer-grained groundmass.

Potassium feldspar $KAlSi_3O_8$ (Potassium aluminum silicate). A very common mineral in igneous, metamorphic, and sedimentary rocks. Minerals with this composition are adularia, microcline, orthoclase, and sanidine.

Prism A crystal form that has three, four, six, eight, or twelve crystal faces whose intersections are parallel. The cross section of a prismatic crystal may be square, rectangular, or, as in the case of corundum, hexagonal.

Pyrite FeS_2 (Iron sulfide). A very common mineral in veins and also sometimes in placers, where it may be concentrated because of its high specific gravity (5.02).

Quartz latite An extrusive igneous rock that contains quartz, potassium feldspar, plagioclase, biotite, and/or hornblende.

Raman spectroscopy An analytical method frequently used in the identification of mineral inclusions in gemstones. Unlike energy-dispersive x-ray analysis, which provides information on the chemical composition of a mineral, Raman spectroscopy identifies the mineral. In this method the Raman spectrum of the unknown mineral is compared to spectra of known minerals.

Rhombohedral parting Parting or breakage along definite crystallographic planes that define a rhombohedron. Corundum shows rhombohedral parting.

Rhyolite An extrusive igneous rock that is dominated by potassium feldspar and quartz. These minerals commonly occur as larger crystals (phenocrysts) in a finer-grained groundmass.

Rutile TiO_2 (Titanium oxide). A mineral that commonly occurs in low concentrations in rocks and is concentrated in placers because of its high specific gravity (4.18–4.25).

Scanning electron microscope A type of electron microscope where the electron beam moves back and forth across the object to produce an image. Because an electron beam is used rather than a light beam, electron microscopes are capable of higher magnification than optical microscopes. Scanning electron microscope, or microscopy, is abbreviated SEM.

Schorl $NaFe^{2+}{}_3B_3(Al,Si_2O_9)_3(OH)_4$ (Complex hydrous aluminum silicate). The iron-rich member of the tourmaline group.

Sillimanite Al_2SiO_5 (Aluminum silicate). One of three minerals (kyanite, sillimanite, and andalusite) with the same chemical composition, but different crystal forms. Occurs in some aluminous-metamorphic rocks.

Smectite A hydrous magnesium aluminum silicate that may contain potassium, sodium, and calcium in various concentrations. A group of common clay minerals.

Specific gravity The ratio between the weight of a mineral and an equal volume of water. Quartz has a specific gravity of 2.65, meaning a cubic foot of quartz weighs 2.65 times the weight of a cubic foot of water.

Spinel Aluminum oxide with variable amounts of iron, magnesium, and chromium. Chromium spinel is chromite and iron spinel is magnetite. The name spinel is reserved for those minerals with variable concentrations of iron and magnesium.

Stratigraphy The study of the layers or strata of rocks and the relationships between different strata.

Terrace A relatively horizontal, flat surface of gravel or other unconsolidated material that may have developed when a river was at a higher elevation. This is the case for the terraces along the Missouri River near Helena, referred to as bars.

Thin section A slice of a rock so thin that light will pass through it when it is examined with an optical microscope. The normal thickness is 30 µm (microns).

Titanite $CaTiSiO_5$ (Calcium titanium silicate). A relatively common mineral that occurs in low concentration in igneous and metamorphic rocks and is concentrated in placers because of its moderate specific gravity (3.40–3.55). Formerly known as sphene.

Troy ounce Usually the weight of gemstones either individually or in batches is given in either metric units (grams or kilograms) or carats. Rarely, troy ounces are used in production figures. A troy ounce is 31.1 grams and an avoirdupois ounce is 28.3 grams. Thus a troy ounce is about one-tenth heavier than an avoirdupois ounce.

Troy pound Twelve troy ounces.

Tuff Consolidated or cemented volcanic ash.

Vesicular An adjective describing a volcanic rock that has cavities formed by entrapment of gas during solidification of the lava.

Welded tuff A volcanic rock formed by the welding or fusing together of small glass fragments. Welding is attributed to heat, weight of the overlying material, and the effect of trapped gases.

White mica A general term used when a colorless mica has not been identified as to mineral species.

Xenolith A fragment of a foreign rock in an igneous rock.

Zircon $ZrSiO_4$ (Zirconium silicate). Small grains commonly found in low concentration in most rocks and concentrated in placers because of their high specific gravity (4.68).

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