Sapphires in the Southwestern Part of the Rock Creek Sapphire District, Granite County, Montana

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Bulletin 135
2014

Montana Bureau of Mines and Geology

Cover Photo: Assortment of natural (no heat treatment) sapphires from the Rock Creek sapphire district selected to show the variety of colors. Largest sapphire 10 mm and most sapphires between 2 and 3 carats. Sapphires provided by Catherine McDonald and photographed by Pete Knudsen.

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ABSTRACT

The Rock Creek sapphire district was discovered in 1892, and between 1903 and the 1930s produced an estimated 65 tonnes of sapphires, mainly for the watch-bearing market. With the introduction of synthetic sapphires, this market was lost; now sapphires are mined for the gem market.

A local bedrock source is indicated for these sapphires because of their unusual concentration in an area of only 11 km^2 (4 square miles) and also by the preservation of delicate surface features on the sapphires, suggesting limited stream transport. Bedrock in this area consists of Precambrian metasedimentary rocks of the Belt Supergroup overlain by Tertiary rhyolite lava, volcaniclastic beds, tuff, and sedimentary beds. A single $^{40}Ar/^{39}Ar$ age on biotite from the rhyolite lava is 50.2 ± 0.4 million years. Rare sapphires with adhering rhyolite indicate that these sapphires were liberated from a rhyolite host by extended weathering. Rhyolitic magma is inferred to have been the transport medium that brought these sapphires to the surface from a metamorphic source. A metamorphic source is inferred for these sapphires by $\delta^{18}O$ values that range between 2.6 and 3.4‰, which is within the range of published analyses for metamorphic sapphires. Mineral inclusions identified in sapphires in order of decreasing abundance are rutile (both very small exsolved grains and larger individual grains), garnet, zircon, sillimanite, ilmenite(?), and allanite(?).

Sapphires have been recovered from colluvium that consists mainly of rhyolite granules. A combination of erosion of colluvium and stream action concentrated sapphires in three major gulches that have been extensively mined, with reported grades exceeding 100 carats per bank cubic yard.

CHAPTER 1

INTRODUCTION

This report is part of a continuing investigation of the alluvial sapphire deposits in western Montana. Previous publications resulting from these investigations include reports on sapphires in the Butte–Deer Lodge area (Berg, 2007), an alluvial sapphire deposit west of Butte (Berger and Berg, 2006), surface features of sapphires from the Rock Creek sapphire district (Berg and Cooney, 2006), and an overview of Montana sapphire deposits (Berg, 2009). The results of an investigation of the sapphire deposits along the Missouri River near Helena begun in 2012 will be published by the Montana Bureau of Mines and Geology.

In an effort to make it easy for the reader to find a particular topic of interest, this report is divided into six chapters: history, geology, placer deposits, sapphire descriptions, conclusions, and topics for future research. Analytical procedures, chemical analyses, oxygen isotope analyses, and descriptions of other sapphire deposits in the Sapphire Range are included in the appendices. Sapphire production was reported in avoirdupois ounces and grade in both carats and grams per bank cubic yard (bcy). For the sake of uniformity, production values have been converted to grams, kilograms, and tonnes. See appendix 1 for conversion factors. Where there were inconsistencies in the spelling of gulch or placer names, an attempt was made to use the spelling of the name of the individual for whom the feature was presumably named.

The Rock Creek sapphire district is situated approximately 16 mi (25 km) southwest of Philipsburg on the eastern flank of the Sapphire Range in southwestern Montana (fig.1.1).

It is bounded on the north and east by Rock Creek, and by West Fork Rock Creek on the south (fig. 1.2). The southwestern part of the large Rock Creek sapphire district (fig. 1.3) was studied in detail, because most of the production for which historic records are available was from this area. Additionally, recent construction of roads for logging provides easy access and new exposures. Sapphires have also been mined from placer deposits on Stony Creek and Quartz, Basin, and Cornish Gulches that flow into Rock Creek to the north (fig. 1.2). In addition to sapphires, the placers on these north-flowing gulches have yielded gold, whereas gold is exceedingly rare in the south-draining gulches that discharge into West Fork Rock Creek. Exploratory drilling for a bedrock gold deposit has been conducted in the vicinity of Basin Gulch. However, there does not seem to be a genetic relationship between the gold mineralization and sapphire deposits. Sapphires have also been mined from placer deposits on Montgomery Gulch, which flows northeast to Rock Creek. Other reported sapphire occurrences in the Sapphire Range are described in appendix 2.

Previous geologic mapping of this area is available from the Philipsburg 30' x 60' quadrangle map at a scale of 1:100,000 (Lonn and others, 2003), incorporating some previous geologic mapping at a scale of 1:250,000 (Wallace, 1987). In her extensive work on sapphires, Garland (2002) included a geologic map of the Rock Creek sapphire district at a scale of 1:36,000. Clabaugh (1952) provided a description of the geology, mining, and sapphires in his comprehensive publication on corundum in Montana.

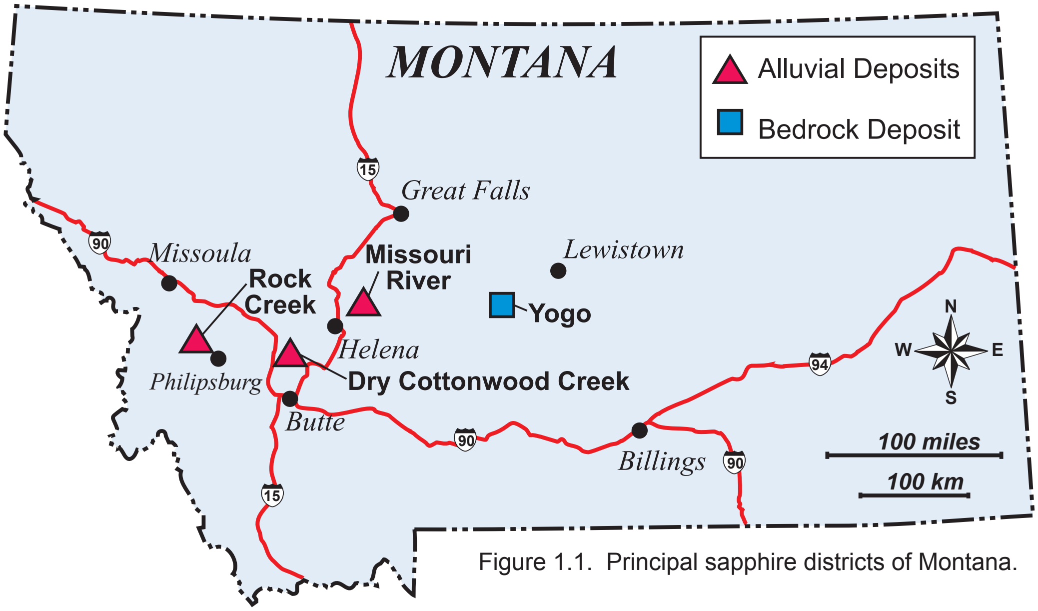


Figure 1.1. Principal sapphire districts of Montana.

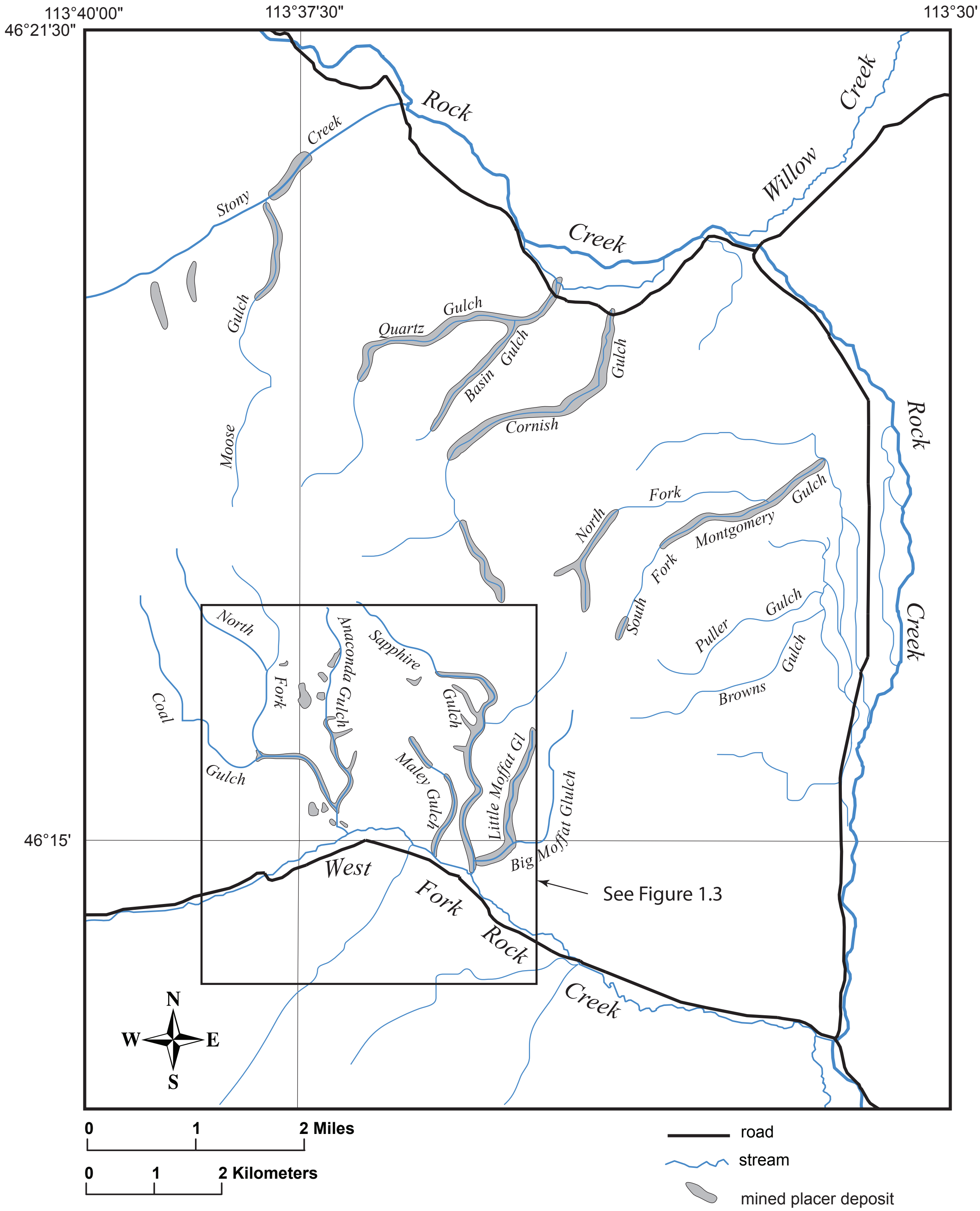
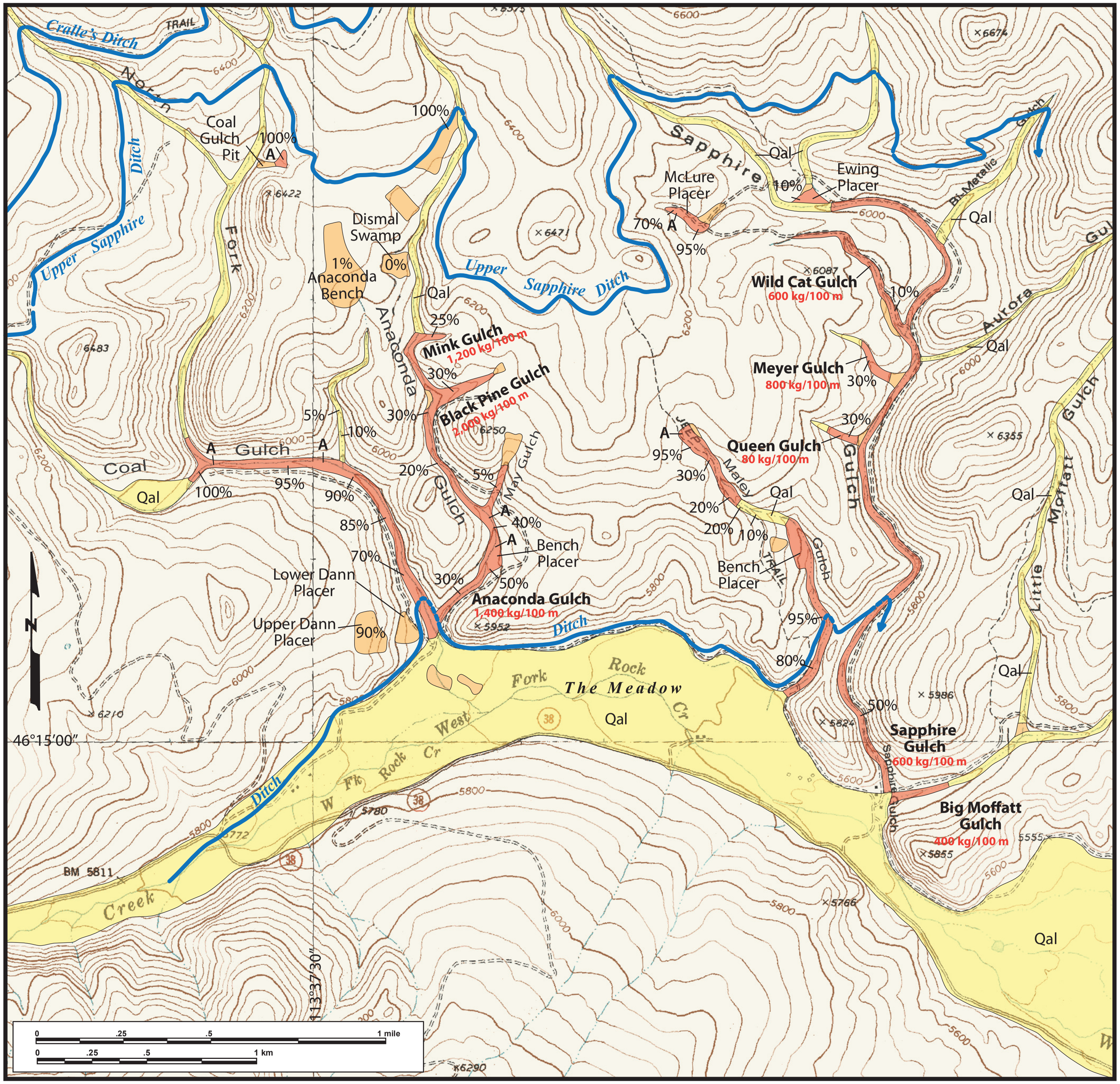


Figure 1.2. Gulches in the Rock Creek sapphire district from which sapphires have been recovered. With the exception of the southwestern part of the Rock Creek sapphire district, extent of placer mining from Robin McCulloch (oral commun., 2010.) See figure 1.3 for a more detailed map of the placer mining in the southwestern part of the Rock Creek sapphire district.



Explanation

Qal — Unmined alluvium along active creeks and rivers

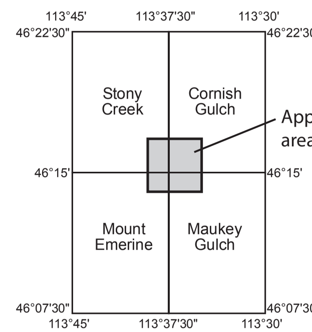
Area of recent (since circa 1940) and active sapphire mining

Area of early sapphire mining from circa 1900 to 1940

1400 kg/100 m — Estimated sapphire production per 100 m of gulch (name in bold type) from historic records (Table 1.1)

30% — Estimated percent quartzite cobbles and boulders piled in windrows during placer mining. The other cobbles and boulders are rhyolite and metasedimentary rock from the Piegan Group.

A — Alaskitic monzogranite boulder or cobble.



Base from enlarged parts of four U.S. Geological Survey 7.5' topographic quadrangles

Figure 1.3. Extent of mining of alluvial sapphire deposits in the southwestern part of the Rock Creek sapphire district.

HISTORY

Historic production of sapphires from the Rock Creek sapphire district exceeds that of all other Montana sapphire districts combined (fig. 1.4). Unlike the Missouri River or Dry Cottonwood Creek deposits where the recovery of gold was important to their economic success, the placers in the southwestern part of the Rock Creek district contained a sufficiently high concentration of sapphires to be mined only for sapphires. The following historical summary is mainly gleaned from the Montana Historical Society Archives (MHSA), a book on the history of Granite County (Domine, 2009), and MHSA files that deal with the early sapphire mining in this district (MC 310, American Gem Mining Syndicate Records). The MHSA records include correspondence, production records, financial records, and legal documents. In addition, information from individuals familiar with the district is included. Although an effort has been made to include only information that appears to be substantiated in different historical sources, it is recognized that there are inconsistencies in the dates and production figures and that some of the information reported here may be in error.

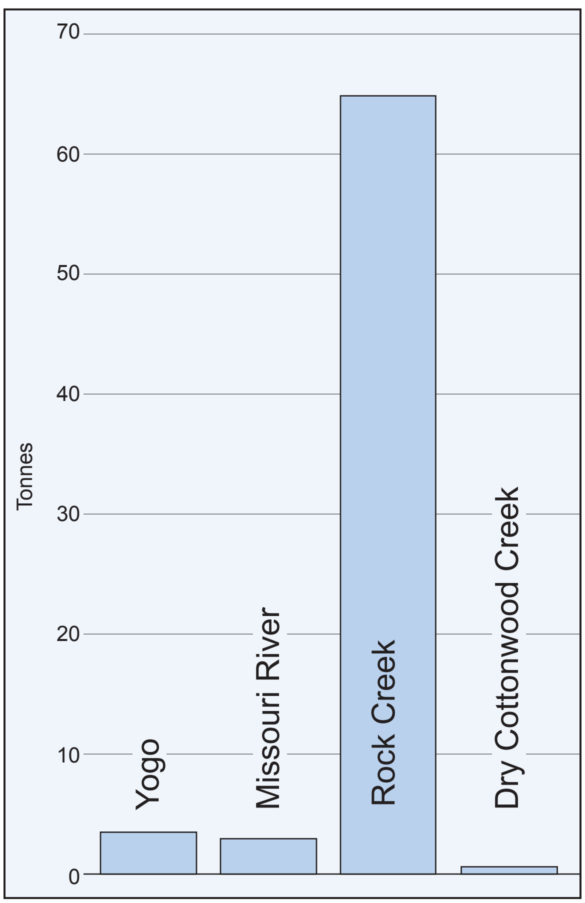


Figure 1.4. Estimated historic production of sapphires for all markets mined from Montana sapphire deposits.

Discovery and Early Production

1892—Discovery

The first reports of 'Missoula' (now Granite) County come from an 1893 report (Kunz, 1893, p. 762):

> "During the past year sapphires have also been found in Missoula County, 30 miles west of Philipsburg, on the west fork of Rock Creek, and 70 miles from the Missouri River locality. The sapphires obtained here are of yellow, blue, green and other colors, associated with garnets, pyropes, etc. occurring in a gravel bed which is 4 feet in depth down to the bed rock and is overlaid by 3 feet of loam. The sapphires are all found in this bed, and appear to be exceedingly plentiful, from ten to twenty being found in every pan of the gravel. The colors are steely blue, green, yellow, and a few pink or reddish brown."

It should be noted that the blue sapphires reported here were probably not the highly saturated blue sapphires typical of the Yogo district.

1894

First production of sapphires in this area was from Sapphire and/or Anaconda Gulches (fig. 1.3) in 1894 (tables 1.1, 1.2). These were the only gulches with reported production until 1910 when sapphires were produced from Meyer Gulch, a tributary of Sapphire Gulch.

August 1, 1901

Articles of Incorporation were filed by the American Gem Mining Syndicate. The principals were Paul A. Fusz, Moses Rumsey, Charles D. McLure, L.S. McLure, David Jankower, and W.E. Knuth [MHSA, American Gem Mining Syndicate (AGMS file)].

May 19, 1902

First placer claims to be patented (table 1.3). The first three claims patented were the Ruby (upper part of Sapphire Gulch) and Anaconda Gulch (upper Anaconda Gulch), and Star placer (lower Sapphire Gulch) (table 1.3). Additional placer claims were patented through 1915.

Ditches and Flumes

The construction of flumes and ditches was necessary for mining because there is normally insufficient water in these gulches for placer mining. There were at least three ditches that also incorporated flumes for part of their lengths. These ditches are, from upper to lower, Cralle's Ditch, Upper Sapphire Ditch, and an unnamed ditch from West Fork Rock Creek (fig. 1.3). There is contradictory information on

Table 1.1. Historic sapphire production from the southwestern part of the Rock Creek sapphire district, 1894–1928.

Gulch or Placer Claim	Ounces Avoirdupois	Tonnes	Years Mined
Sapphire and Anaconda	45,338	1.3	1894, 1899, 1900, 1903
Anaconda	776,422	22.0	1906, 1907, 1910, 1911, 1912, 1913, 1916, 1917, 1918, 1921, 1926, 1927, 1928
Sapphire	770,745	21.8	1906, 1907, 1910, 1911, 1912, 1913, 1916, 1917, 1918, 1921, 1926, 1927, 1928
Black Pine	258,790	6.5	1916, 1917, 1918, 1919
Wild Cat	152,792	4.3	1911, 1912, 1921, 1922, 1923
Half Moon	60,730	1.7	1916, 1917, 1920
Ewing	59,280	1.7	1923, 1924
Meyer	42,374	1.2	1910, 1920, 1921
Rumsey	42,256	1.2	1923, 1924, 1925
Jack Pine	37,704	1.1	1916, 1919
Mink	33,154	0.9	1917, 1918
Jasper	32,742	0.9	1919
Moffatt	32,208	0.9	1925, 1926
Coal Cr. Bar	9,032	0.2	1921
Queen	3,371	0.1	1923
Total	2,326,938	65.8	

Note. From Marc Bielenberg (written commun., 2006). Production from Maley Gulch is not included, but on the basis of observed windrows of cobbles it appears to be substantial. The Half Moon placer included the North Fork of Coal Gulch (unmined) and Coal Gulch downstream from its confluence with the North Fork, an area that was heavily mined, suggesting that total production was more than shown here. The Jasper claim is not shown on the 1908 claim maps (figs. 1.5, 1.6). For ease of comparison, production figures have been converted to metric units.

the dates these ditches and flumes were constructed, but it appears reasonably certain that Cralle's Ditch was the first.

1904—Cralle's Ditch

The uppermost ditch is shown on the 1908 map (fig. 1.5) as Cralle's Ditch to Basin Gulch. This flume and ditch brought water east from Stony Lake to serve the McLure placer and was reported to be 25 km (16 mi) long (Domine, 2009, p. 336). This earliest ditch was probably constructed around 1904. Attempts by Domine to verify this information were unsuccessful. Cralle's Ditch provided water for mining Anaconda, Sapphire, and Wildcat Gulches as well as Meyer Gulch before the construction of the Upper Sapphire Ditch in 1912. (Note: this ditch and other later claims appear on the 1908 map, which appears to have been updated later.) Reported production from Sapphire and Anaconda Gulches was greatest in the years 1906 and 1907, evidently using water from Cralle's Ditch (table 1.2). The remains of Cralle's Ditch can be clearly seen above the Upper Sapphire Ditch uphill from the North Fork Coal Gulch and also at the head of Anaconda Gulch.

1911—Upper Sapphire Ditch Surveyed

1912—Upper Sapphire Ditch Constructed

Correspondence in the MHSA files indicates construction of a flume and ditch from the North Fork of West Fork Rock Creek during July, August, September, and October 1912. Apparently this was the Upper Sapphire Ditch, which is clearly visible just a short distance below Cralle's Ditch near the head of North Fork Coal Gulch and also near the head of Anaconda Gulch. (Note: as mentioned above, this

Table 1.2. Historic sapphire production from the southwestern part of the Rock Creek sapphire district, arranged by year for the years 1903–1928.

Year	Ounces	Tonnes	Gulch or Placer Claim
1903	41,320	1.17	Anaconda, Sapphire
1904			Anaconda, Sapphire
1905			Anaconda, Sapphire
1906	228,652	6.47	Anaconda, Sapphire
1907	234,214	6.64	Anaconda, Sapphire
1908			
1909			
1910	162,704	4.61	Anaconda, Sapphire, Meyer
1911	105,600	2.99	Anaconda, Sapphire, Wild Cat
1912	128,896	3.65	Anaconda, Sapphire, Wild Cat
1913	154,190	4.37	Anaconda, Sapphire
1914			
1915			
1916	94,498	2.67	Anaconda, Sapphire, Jack Pine, Black Pine, Halfmoon
1917	53,554	1.52	Anaconda, Sapphire, Black Pine, Halfmoon, Mink
1918	83,822	2.37	Anaconda, Sapphire, Black Pine, Mink
1919	8,800	0.27	Sapphire, Black Pine, Jack Pine, Jasper
1920	8,240	0.27	Sapphire, Half Moon, Meyer
1921	20,148	0.57	Anaconda, Sapphire, Meyer, Coal Cr. Bar
1922	40,400	1.14	Sapphire, Wild Cat
1923	22,075	0.62	Sapphire, Rumsey, Ewing, Queen, Wild Cat
1924	57,216	1.62	Rumsey, Ewing
1925	30,152	0.85	Sapphire, Rumsey
1926	32,496	0.92	Anaconda, Sapphire, Moffatt
1927	64,305	1.8	Anaconda, Sapphire, Moffatt
1928	66,784	1.9	Anaconda, Sapphire, Moffatt
Total	1,638,066	46.4	

Note. From Marc Bielenberg (written commun., 2006). Although not stated, it was assumed that avoirdupois ounces were used when converting production into tonnes. Although there are inconsistencies in total production as reported in tables 1.1 and 1.2, no attempt was made to reconcile the values.

ditch does appear in the 1908 map in figure 1.5, but it seems to have been added to the old map sometime after construction). The Upper Sapphire Ditch also goes through a shallow cut in the rhyolite dike north of Sapphire Gulch between Meyer Gulch and Bi-Metallic Gulch. One of the sources of water for this ditch was probably Fusz Creek, which flows from Fusz Lake. Fusz Lake is incorrectly labeled as Fuse Lake on modern topographic maps. It was named for Paul A. Fusz, one of the original owners of the American Gem Mining Syndicate (AGMS).

The construction of the Upper Sapphire Ditch, when there was an existing ditch just uphill from it, is peculiar. On the historic map (fig. 1.6) it is shown as the Basin Ditch, indicating that it brought water for mining on Basin Gulch to the north. A possible explanation is that one group had constructed this ditch and flume for placer mining on Basin Gulch. When water was needed by another group for mining along Sapphire and Anaconda Gulches, this second ditch and flume were constructed.

19??—Unnamed lowest ditch

The lowest ditch and flume shown on the historic 1908 claim maps (figs. 1.5, 1.6) is situated just a short distance above West Fork Rock Creek, where it is still visible. This ditch took water from West Fork Rock Creek, approximately 1,200 m (4,000 ft) west of Coal Gulch, and brought it as far east as Sapphire Gulch.

Table 1.3. Patented placer claims as shown on historic maps (figs.1.5, 1.6).

Claim Name	Patent Date	Mineral Survey No.	Location
Ruby Placer	May 19, 1902	6154	Upper Sapphire Gulch
Anaconda Placer	May 19, 1902	6155	Anaconda Gulch and tributaries
Star Placer	May 19, 1902	6156	Lower Sapphire Gulch
Kruger Placer	January 31, 1905	6157	Maley Gulch
May Placer	January 31, 1905	6420	Between Maley and Anaconda Gulches
Yellow Dog Placer	March 1, 1905	6643	West Fork of Rock Creek “Meadow”
Half Moon Placer	April 3, 1905	6419	North Fork Coal Gulch and Lower Coal Gulch
Amended Bald Eagle Placer	June 8, 1908	8102	Head of Anaconda Gulch
Coal Gulch	November 27, 1908	8100	West of confluence with North Fork of Coal Gulch
Amended Rocky Bar Placer	April 2, 1913	8101	“Meadow” along West Fork of Rock Creek
Amended Bi-Metallic Placer	September 24, 1914	9150	Tributary to Sapphire Gulch from the east
Amended Aurora Placer	September 24, 1914	9185	Tributary to Sapphire Gulch from the east
Amended Moffatt Place	October 5, 1915	915	Along Moffatt Gulch (spelled Moffett on 1908 map, but correct spelling for this gulch is Moffatt, named after one of the early miners)
McLure Amended Placer	January 18, 1916	7444	West of Upper Sapphire Gulch and head of Sapphire Gulch

Historic Production and Ownership Changes

1906, 1907

These were the two years of maximum reported production, with 228,652 avoirdupois ounces (6,482.3 kg) produced in 1907 and 234,214 avoirdupois ounces (6,639.9 kg) in 1908; during these years production was reported only from Anaconda and Sapphire Gulches (table 1.2). In 1907, average production, presumably during the peak of mining, was 1,000 lbs (455 kg) a week (Emmett and Douthit, 1993, p. 252). These production figures are presumably for total production and include culls. The major market for these sapphires was watch bearings; the smaller sizes were most desirable, as they required less machining to produce bearings, some of which were only approximately 1 mm in diameter (fig. 1.7).When there was sufficient water, mining was accomplished both day and night. An indication of the extent of 24-hour mining is given in a request dated March 4, 1913 for a quote on the price of two tons of carbide for carbide lamps (MHSA, AGMS). Placer mining employed both ground sluicing and hydraulic mining (fig. 1.8). Production generally declined into the late 1920s. See the Production and Grade section for more detailed information on production from specific gulches and sizes of sapphires shipped.

1914—Indication of impending market change

In a letter dated April 3, 1914, Eug. Deshusses of Switzerland in effect states that the AGMS should provide better goods, ending with the following statement: “Scientific Ruby is getting cheaper every day and soon will be as cheap as rock creek. Large amounts are already utilized for watch jewels and meter jewels and if we let customers without the size goods that suits better for their work they might start with scientific and continue to use it.” By scientific ruby, Deshusses means man-made ruby and sapphire.

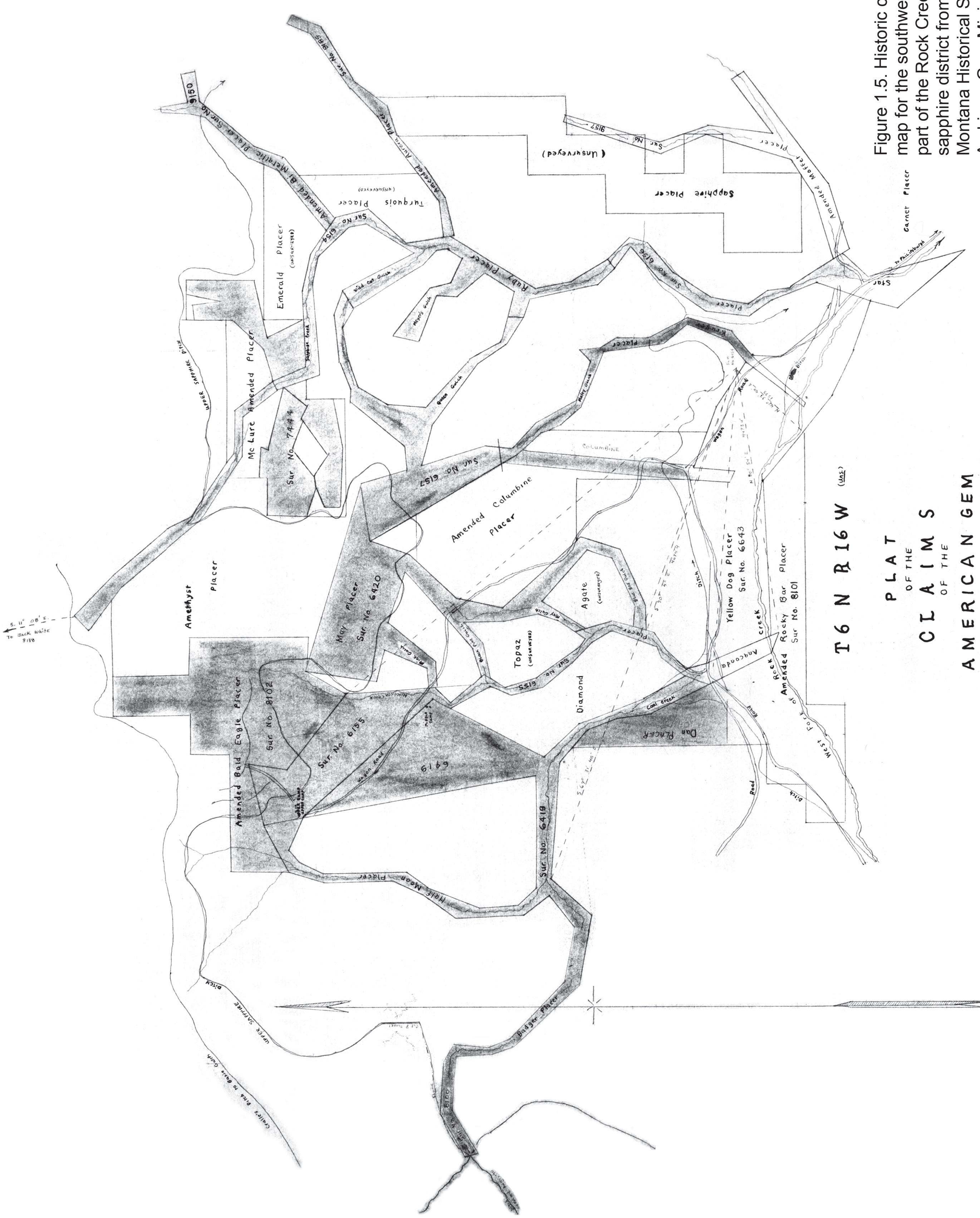


Figure 1.5. Historic claim map for the southwestern part of the Rock Creek sapphire district from the Montana Historical Society's Archives, Gem Mining Syndicate files map A-457.

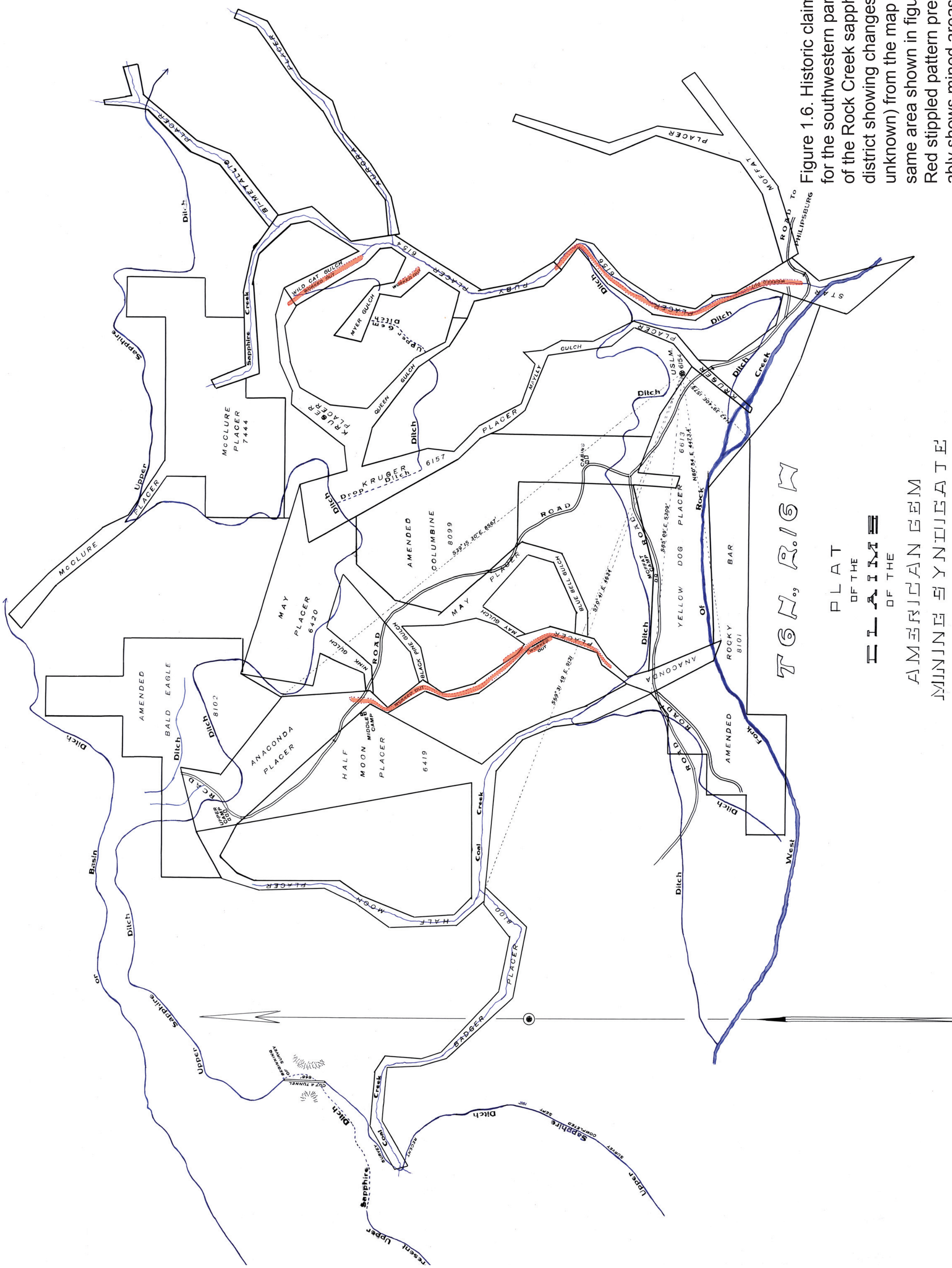


Figure 1.6. Historic claim map for the southwestern part of the Rock Creek sapphire district showing changes (date unknown) from the map for the same area shown in figure 1.5. Red stippled pattern presumably shows mined areas. Map provided by Ted Antonioli.

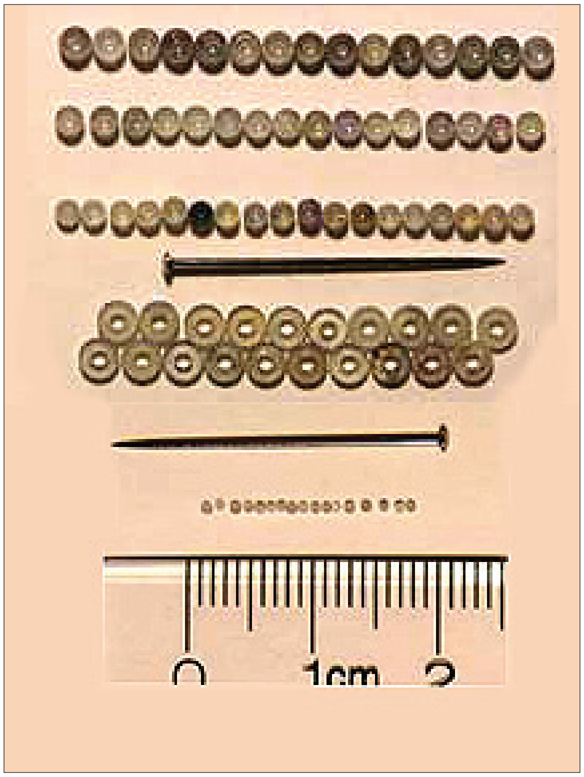


Figure 1.7. Watch or instrument bearings machined from sapphires mined from the Rock Creek sapphire district. Photo provided by Pete Antonioli.

Figure 1.8. Sonny Werning mining sapphires with a hydraulic in 1937. Judging from the date and the thickness of the gravel, this may have been Coal Gulch. Photo provided by Chris Cooney.

1928

This is the last year of almost continuous production with the exception of the years for which no production was reported: 1904, 1905, 1908, 1909, 1914, and 1915. Either sapphires were not mined during those years or for some reason production figures have been lost. According to a hearsay family story, in the late 1930s, a seven-ton shipment of sapphires destined for the watch-bearing market was returned from Switzerland because synthetic sapphire had replaced natural sapphire in this market (Ted Antonioli, oral commun., 2011).

1936 or 1937

Charles Carpp, Jr. and J. Walter Kaiser bought the most productive part of the district from the American Gem Mining Syndicate for a reported $6,000 (Dale Siegford, oral commun. 2011; Domine, 2009, p. 373). This included Coal, Anaconda, Maley, and Sapphire Gulches. Carpp subsequently mined the placer near the head of Anaconda Gulch just below the Upper Sapphire Ditch and possibly also the lower part of Coal Gulch. An attempt to sell these sapphires as gemstones was unsuccessful because of their pale colors (Marc Bielenberg, oral commun., 2009). The failed entry into the gemstone market occurred before the color of sapphires from the Rock Creek district was routinely enhanced by heat treatment. Total production of sapphires for the years 1936 through 1943 was estimated to be 98,000 ounces (Clabaugh, 1952, p. 51). It is not stated whether these are troy or avoirdupois ounces. The last year of production by Carpp and Kaiser was 1943, when these sapphires were sold for industrial use. The 1942 production was sold to the U.S. Government and stockpiled for instrument bearings (Clabaugh, 1952, p. 51).

Circa 1943

Carpp and Kaiser sold their holdings to Sally and Bill Eaton, who conducted a fee digging operation.

1966

The Eatons split the southwestern part of the Rock Creek sapphire district into the gulches (Mountain) and upland (Meadow along West Fork Rock Creek). They sold part of the “Meadow” to Marc Bielenberg for a reported $60,000 and the “Mountain” part of the district to Wilfred Chaussee for a reported $100,000 (Yvette Clevish, oral commun., 2013). Wilfred Chaussee formed the Chaussee Sapphire Corporation.

1970

Wilfred Chaussee constructed a facility at the mouth of Sapphire Gulch where the public could screen gravel for sapphires.

1971

The Chaussee mine was opened to the public.

1972

Kenneth and Yvette (Wilfred's daughter) Clevish purchased the stock of the Chaussee Sapphire Corporation and its assets and continued to run a tourist operation through 1979.

1980

The Chaussee Sapphire Corporation sold the mine property to Ted Smith for $1,000,000. The transaction included a partial exchange of real estate in Massachusetts. Ted Smith renamed the company as the Gem Mountain Sapphire Corporation.

Early 1970s?

Skalkaho Grazing, Inc. acquired the Meadow.

1974–1976

Day Mines systematically sampled the western part of the Meadow along West Fork Rock Creek close to the point where Anaconda Gulch empties into West Fork Rock Creek. In 1974, they sampled this area with a 6- to 8-in Becker drill followed in 1975 by 7-ft-diameter prospect pits. In 1976, the company constructed a small wash plant and completed bulk sampling. A 3,700-cubic-yard sample yielded an average sapphire grade of 47 carats/yard (9.4 g/bcy). Despite favorable sampling results, Day Mines found they could not sell these pale-colored sapphires into the gemstone market (Jim Brown, oral commun., 2001). A conservative estimate indicates 25 million carats (5 tonnes) of sapphires in this sampled area (Emmett and Douthit, 1993, p. 252).

1980

The Gem Mountain Sapphire Corporation began a fee digging and screening operation at the facility built by Wilfred Chaussee.

1982

Skalkaho Grazing, Inc. constructed a floating wash plant (fig. 1.9) and began mining sapphires near the west end of the Meadow where Coal and Anaconda Gulches join West Fork Rock Creek (fig. 1.3; Emmett and Douthit, 1993, p. 258). This was the area previously sampled by Day Mines.

Early 1980s

Mr. McCarty of Helena was the first individual in Montana to enhance the color of Montana sapphires by heat treatment (Dale Siegford, personal commun., 2010).

Figure 1.9. Floating washing plant in pond in 'the Meadow' constructed by Skalkaho Grazing, Inc.

1989

Rob Towner, working for Skalkaho Grazing, Inc., washed the stockpile of gravel recovered by Day Mines from the Meadow during their sampling program.

1989 and 1991

In each year, more than 80 kg of sapphires was recovered from material previously excavated by Day Mines from the Meadow (Shirley Beck, written commun., 2012).

1993

An extensive study of over 75,000 sapphires mined by Skalkaho Grazing, Inc. in the Meadow showed that the color of approximately 65–70 percent of these sapphires could be improved under carefully controlled heating (Emmett and Douthit, 1993, p. 250). The very pale green and pale blue sapphires could be changed to well-saturated blue and yellow sapphires.

1994

Gem Mountain Sapphire Corporation sold their holdings to American Gem (not to be confused with the earlier owner American Gem Mining Syndicate) for a reported $4,000,000 (Domine, 2009, p. 375). American Gem continued to operate a fee screening operation as well as mining gemstones for the retail market.

1994–2001

American Gem Corporation mined more than 4 million carats (800 kg) of gem-quality sapphires from Anaconda Bench and Dann Placer during the years 1994–1996 (Kane, 2003, p. 4).

2001 to Present

Gem Mountain acquired patented claims along Anaconda Gulch, North Fork Coal Gulch, and on some of the land between these two gulches. RY Timber acquired the other patented claims north of the Meadow. Gem Mountain mined sapphires from Anaconda Bench and an area near the head of Anaconda Gulch (fig. 1.10). Sapphire concentrate produced from this gravel is sold to the public, who recover sapphires by sieving.

Figure 1.10. Mining sapphire-bearing alluvium from Anaconda Bench by Gem Mountain, August 2009.

Production and Grade

Avoirdupois, troy, and metric (kg) units have been used in the historic production records. Where these records are reproduced, the original units are shown first and in some cases converted to kg or tonnes for ease of comparison. An avoirdupois ounce is 28.3 g, a troy ounce is 31.1 g, and a carat is 0.2 g. Five million carats equals 1 metric tonne.

Historic sapphire production from the gulches in the southwestern part of the Rock Creek sapphire district is given in tables 1.1 and 1.2. The total reported production in table 1.1, where production is arranged by gulch, is 65.9 metric tonnes, whereas table 1.2, arranged by year, shows 46 tonnes for approximately the same years. This comparison assumes that the units in table 1.2 are avoirdupois ounces like those listed in table 1.1. Production was not reported in 1904, 1905, 1908, 1909, 1914, and 1915. When considering the production numbers, it must be remembered that these figures include small sapphires probably only a little over 1 mm that were suitable for small watch and instrument bearings (fig. 1.7). Also, these production figures must include culls that were not suitable for bearing manufacture. In a letter dated April 3, 1914, Eug. Deshusses, the purchaser of sapphires in Switzerland, complained: “In the same shipment, there was also sacks containing only garnets, iron ore, etc. and not even one ounce of sapphire [sic] per sack.” (MHSA, AGMS files). If there is any truth to this statement, the reported production includes significant contaminants.

A comparison between production figures for the years 1911, 1912, and 1913 between those shown in table 1.4 and annual reports of the AGMS for these same 3 years (the only years for which the annual reports are available) shows significant inconsistencies (table 1.4). Production figures (with no stated units) from the AGMS log books (fig. 1.11) show yet a different value for the total production from Sapphire and Anaconda Gulches. Thus the production figures summarized in this report should be considered only an approximation of the actual sapphire production, which for the southwestern part of the Rock Creek sapphire district certainly exceeds 50 tonnes, and probably exceeds 60 tonnes.

Unfortunately, production from Maley and Coal Gulches was not included in the available information. Both of these gulches show evidence of significant placer mining. The lack of reported production in 1914 and 1915, and the diminished production in the following years, may be attributed to the introduction of synthetic sapphires that ultimately replaced natural sapphires in the instrument and watch bearing markets (fig. 1.12).

A comparison of mining costs for Anaconda and Sapphire Gulches for 1911 and 1913 shows that costs were higher for Sapphire Gulch for these 2 years (table 1.5). Total reported production from each gulch was approximately the same, 776,422 avoirdupois ounces (22.0 tonnes) for Anaconda Gulch and 770,745 avoirdupois ounces (21.8 tonnes) for Sapphire Gulch, excluding those years for which production from these two gulches was combined, which amounted to 1.28 tonnes. This difference may be attributed to significantly higher grade for Anaconda Gulch as compared to Sapphire Gulch. Reported sapphire grades of >100 carats/bcy (>20 g/bcy) are evidently common. Bcy, bank cubic yard, is the volume of undisturbed gravel before mining. Garland (2002, p. 2–48) reported consistent grades greater than 20 g/bcy (100 carats/bcy) for an area that encompasses Dann Placer, Anaconda Bench, and Black Pine Gulch. As pointed out in the discussion of individual placer deposits (Chapter 3), the relatively short Black Pine Gulch is unusually rich, with total production over 4 years reported to be 6,486 kg (table 1.1). A sample from Moffatt Gulch (presumably Big Moffatt Gulch,

Table 1.4. Comparison between production figures given in table 1.2 and those in the American Gem Mining Syndicate annual reports for the years 1911, 1912, and 1913, the only years for which these reports were available at the MHSA.

Date	Gulch	Table 1.2	Annual Report	AGMS Log
1911	Anaconda, Sapphire, and Wildcat Gulches	105,600*	129,471 t oz	
1912	Anaconda, Sapphire, and Wildcat Gulches	128,896*	97,114 t oz	
1913	Anaconda and Sapphire Gulches	154,190*	108,480 t oz	157,190*

Note. Production figures in the annual reports are given in both troy and avoirdupois units.
*Units were not stated for these figures. However, even if it is assumed that they used avoirdupois ounces, a conversion to troy ounces still leaves significant inconsistencies.

Anaconda Gulch Gross Production

Year.	O	A	B.	B	C-	C+	D.	E	F	Specials
1906	11984	15824	26040		21592		12432	8448	6320	448
1907	6176	23690	28624		20864		13232	8720	4992	384
1908	5936	14448	18000		14960		8976	6880	5568	76
1911	4240	17216	20688		17520		12288	7456	5344	248
1912	3504	17088	26080		22640		14832	9808	8640	384
1913	2800	13712	15712		16336		11456	7136	5754	352
1916	3344	6920	10208		2976	5024	7040	3696	3040	168
1917	160	13488	864		1728	3712	4352	1872	1648	64
1918	5408	14060	16624		4480	8896	10704	4960	4512	212
1921	128	968	866		704	704	1088	576	730	24
Totals	43680	137214	163706		123800	18336	96400	59572	46554	2360

Horizontal Ruled Form.
John C. Moore Corporation, Rochester, N.Y. Binder and holes in leaves, each Patented 1906.

Sapphire Gulch Gross Production

	O	A	B-	B+	C-	C+	D	E	F	Specials
1906	22848	20816	27536		21872		13072	9712	8864	844
1907	14320	28288	28512		22560		14700	11072	6912	1168
1910	9840	14688	18896		15264		10960	9088	8192	932
1911	2208	4240	3424		3200		2672	2224	2416	216
1912	1504	5200	6032		4720		3152	2400	2672	240
1913	7632	18896	18288	1836	18456		10000	6304	6960	560
1916	6976	12000	11808		2730	4208	6848	3536	3616	360
1917	528	122[illegible]4	978		1296	2928	3776	1936	1808	192
1918	1488	1104	2440		978	1840	2624	1520	1968	84
1919	656	1584	1808		688	832	1280	832	1040	80
1920	640	1616	1600		560	800	1360	704	864	96
1921	528	3248	2480		1760	1680	2048	1216	1488	112
1922	1760	10304	7728		3264	4672	5792	3072	3472	336
1923	960	4320	411	2256	1392	3240	3600	3056	2704	136
Totals	71888	138528	131941	4092	93740	26200	81884	56672	52976	5356

Figure 1.11. Pages copied from the American Gem Mining Syndicate's log book showing production of different sizes of sapphires for the years 1906–1921 for Anaconda Gulch and 1906–1924 for Sapphire Gulch (Marc Bielenberg, written commun., 2006). Production is given in carats. Size D is approximately 1 carat, size E approximately 1.5 carats, and size F approximately 2.5 carats.

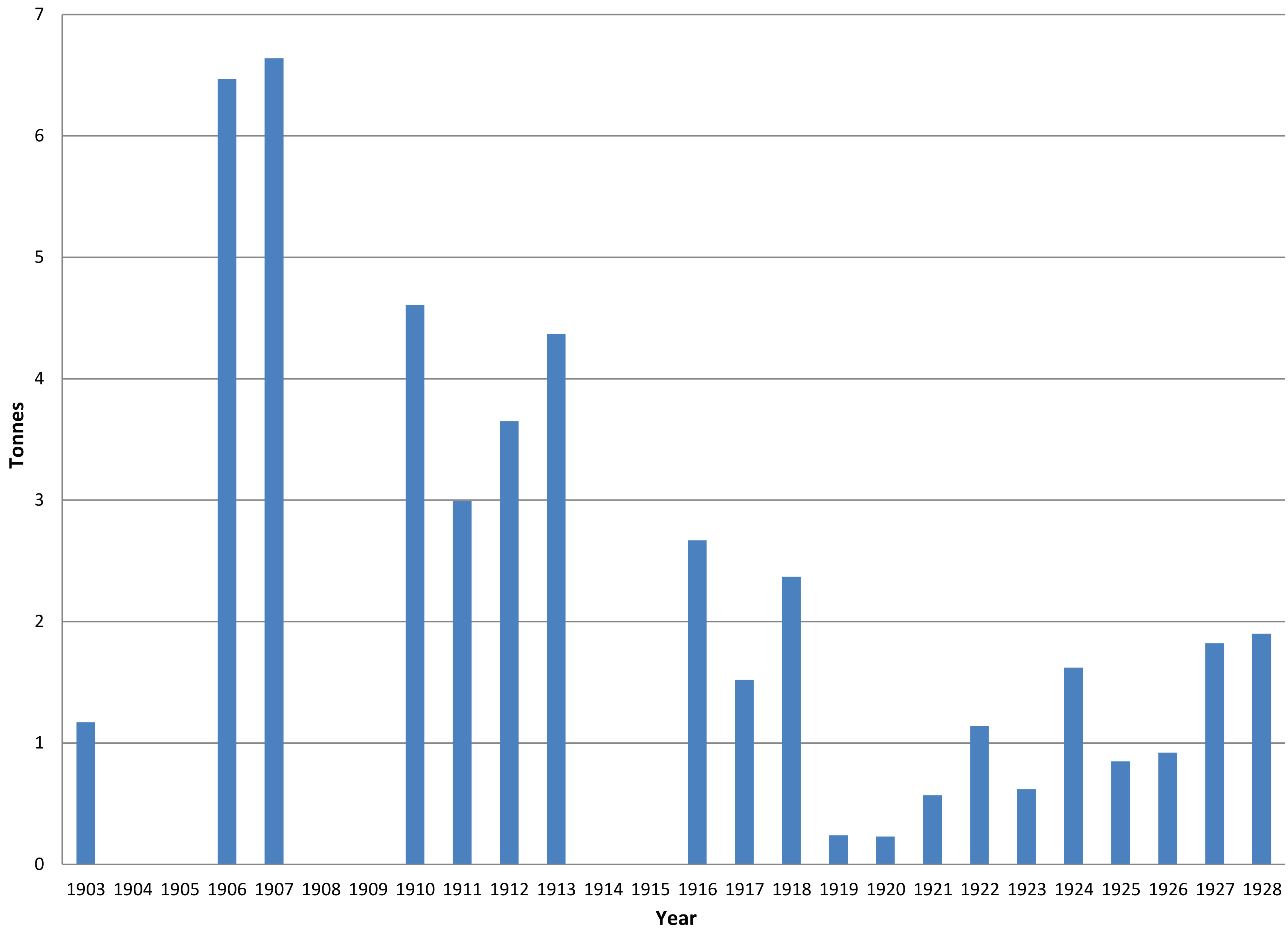


Figure 1.12. Production of sapphires from the southwestern part of the Rock Creek sapphire district as given in table 1.2. In the conversion of ounces to tonnes it was assumed that production was reported in avoirdupois ounces.

Table 1.5. Comparative production costs for sapphires mined from Anaconda and Sapphire gulches per pound avoirdupois as reported in the Annual Reports of the American Gem Mining Syndicate.

	Anaconda Gulch	Sapphire Gulch
1911	$1.08 ($2.38)	$2.23 ($4.93)
1913	$1.98 ($4.34)	$3.04 ($6.72)

Note. From MHSA, AGMS files. These figures were converted to costs per kilogram, shown in parentheses.

which was mined in 1925 and 1926; table 1.1) was reported to contain 178 carats/bcy (35.6 g/bcy; American Gem Mining Syndicate log book provided by Marc Bielenberg). Another test sample from the Coal Creek Bar at the mouth of Coal and Anaconda Gulches was reported to contain 104 carats/bcy (20.8 g/bcy; American Gem Mining Syndicate log book provided by Marc Bielenberg).

Figure 1.3 shows the extent of sapphire mining from 1894 through 1928. The extent of placer mining was determined by walking the major gulches and their tributaries, and noting evidence of mining. In an attempt to show the relative concentration of sapphires in these gulches, the reported production (table 1.1) was used to calculate sapphires recovered per 100 meters of gulch mined. Although these calculations provide interesting comparisons, they must be considered as only crude approximations. This evaluation assumes a uniform concentration of sapphires over the extent of mining in a particular gulch, which is rarely if ever found in placer deposits. Also, the production figures do not take into account the purity of the material recovered or the cross-sectional area of the gulch mined.

CHAPTER 2

GEOLOGY

Geologic Setting

The Rock Creek sapphire district is situated in the Sapphire Range, where metasedimentary rocks of the upper part of the Missoula Group of the Mesoproterozoic Belt Supergroup are the dominant bedrock. East-directed thrust faults and northerly trending high-angle faults displaced these metasedimentary rocks (Lonn and others, 2003). Cretaceous granodioritic plutons have intruded rocks of the Belt Supergroup west of the Rock Creek sapphire district. Much of the sapphire district is underlain by Eocene rhyolitic lava flows and associated volcanic rocks, with Tertiary sedimentary rocks generally exposed at lower elevations in the surrounding area. Paleozoic and Mesozoic sedimentary rocks are not exposed in the district. Glaciers in the high mountains south of West Fork Rock Creek left till and kame deposits.

Geologic Units

Belt Supergroup

The oldest formations exposed in the Rock Creek sapphire district are metasedimentary units of the Mesoproterozic Belt Supergroup, a sequence that is widespread in western Montana. Tan-weathering argillaceous limestone and dolomite with maroon argillite and quartzite beds of the Piegan Group (Lonn and others, 2003) are exposed along the lower part of Maley and Sapphire Gulches. The overlying Snowslip Formation is exposed to the west of the Piegan Group and also in the northern part of the area, as shown in figure 2.1. Beds in the Piegan Group are described by Lonn and others (2003) as characterized by green and red dolomitic siltite-argillite laminae and quartzite beds. The Mount Shields Formation informal members 2 and 3 are also recognized in this area. Mount Shields member 2 is described as fine- to medium-grained quartzite that contains tan-weathering dolomitic blebs. Mount Shields member 3 consists of red siltite and argillite.

Tertiary Sedimentary Beds

Sedimentary beds that appear to have been slightly metamorphosed by a poorly exposed adjacent rhyolite intrusive and also a rhyolite sill are exposed along a spur road on the southwest side of the ridge between Coal and Anaconda Gulches (locality 1, fig. 2.1). Chemical analyses of sample GM 157 of the rhyolite intrusive and rhyolite sill (sample GM 101) are given in appendix 3, table 1.

The following descriptions apply to the road cut shown in fig. 2.2:

GM 101—Rhyolite containing abundant, generally euhedral plagioclase phenocrysts and less abundant euhedral biotite phenocrysts in a fine-grained groundmass composed mainly of plagioclase microlites that shows pronounced trachytic texture.

GM 102—Black, flaky siltstone that contains quartz and rare plagioclase grains in a fine-grained matrix.

GM 160—Well-indurated or slightly metamorphosed tan siltstone that contains rare quartz grains in a fine-grained groundmass that may contain partly devitrified volcanic glass.

GM 159—Crystal-rich tuff consisting of angular quartz, plagioclase, and K-feldspar grains (in order of decreasing abundance). The fine-grained matrix is estimated to constitute 25 percent of this rock and contains glass shards, some slightly devitrified.

GM 103—Tan, tuffaceous rock with rare angular quartz grains and fossil leaf impressions (fig. 2.3).

The Tertiary sedimentary rocks in the southeastern part of the area shown in figure 2.1 were not examined. The extent of these beds is from Lonn and others (2003), who described them as both coarse- and fine-grained sedimentary rocks.

Igneous Rocks

Rhyolite lava flows

<u>Field observations.</u> Rhyolite lava flows in the southwestern part of the Rock Creek sapphire district are exposed on knobs and ridges between the major south-flowing drainages (figs. 2.1, 2.4). The general northerly trend of many of these linear ridges may indicate that magma was extruded from fissures in the underlying metasedimentary rocks of the Belt Supergroup. In hand specimens, the rhyolite is characterized by prominent plagioclase phenocrysts. Glassy quartz grains are rare, but small euhedral biotite phenocrysts are prominent in all of these flows. At some localities phenocrysts are sparse and set in a fine-grained groundmass. Outcrops of the fine-grained rhyolite typically have irregular, usually curving surfaces that consist of a thin layer (<1 mm thick) of very fine-grained rhyolite (fig. 2.5). Planar flow banding was observed at only a few localities (fig. 2.6).

A small exposure of a rhyolite flow along a logging road on the east side of the North Fork Coal Gulch contains subrounded xenoliths of a volcanic rock that, except for its brown color, resembles typical rhyolite from this area (fig. 2.7, locality 2 in fig. 2.1).

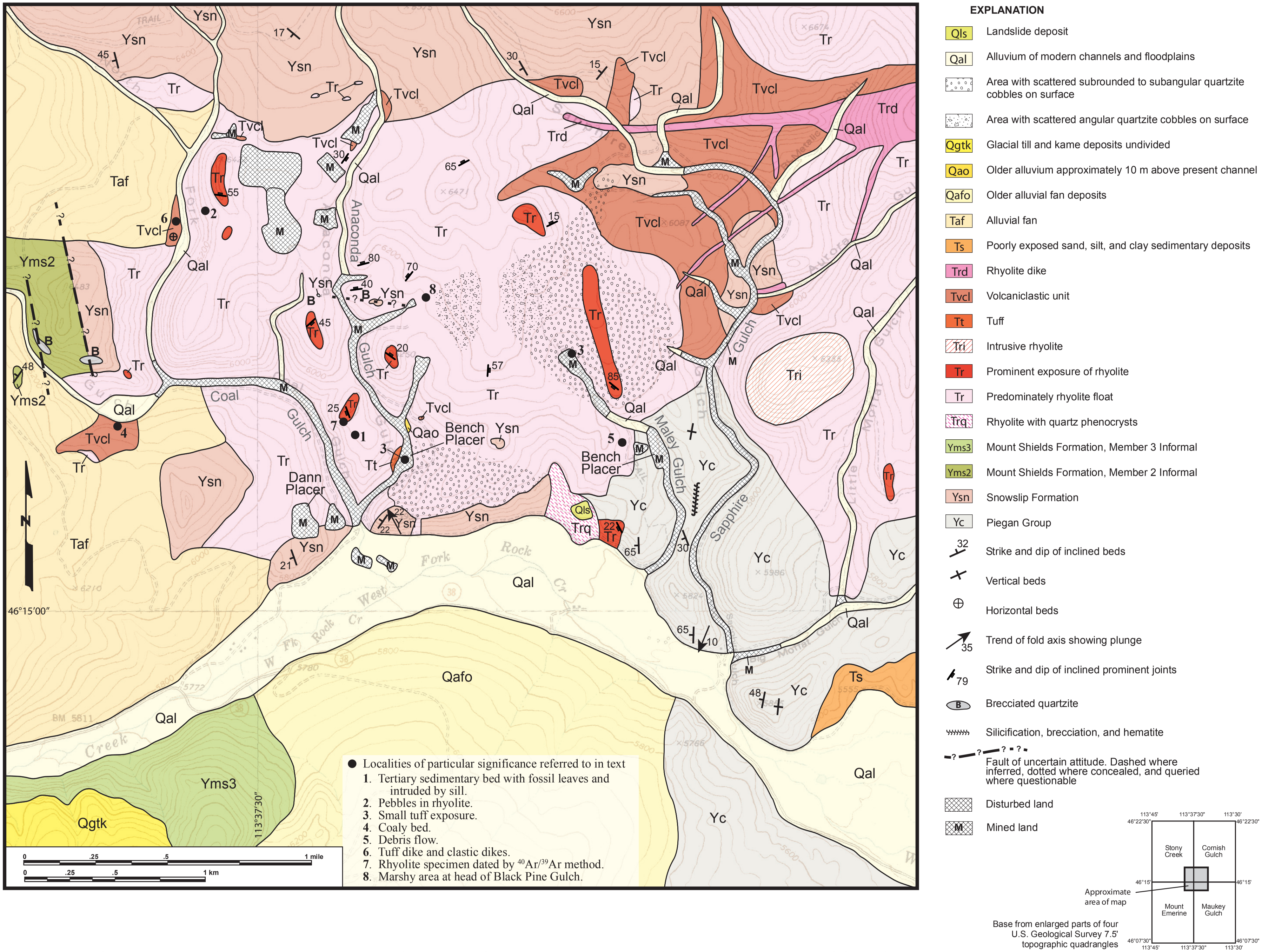


Figure 2.1. Geologic map of the southwestern part of the Rock Creek sapphire district. Geology of area west of Coal Gulch and south of Rock Creek from Lonn and others, 2010.

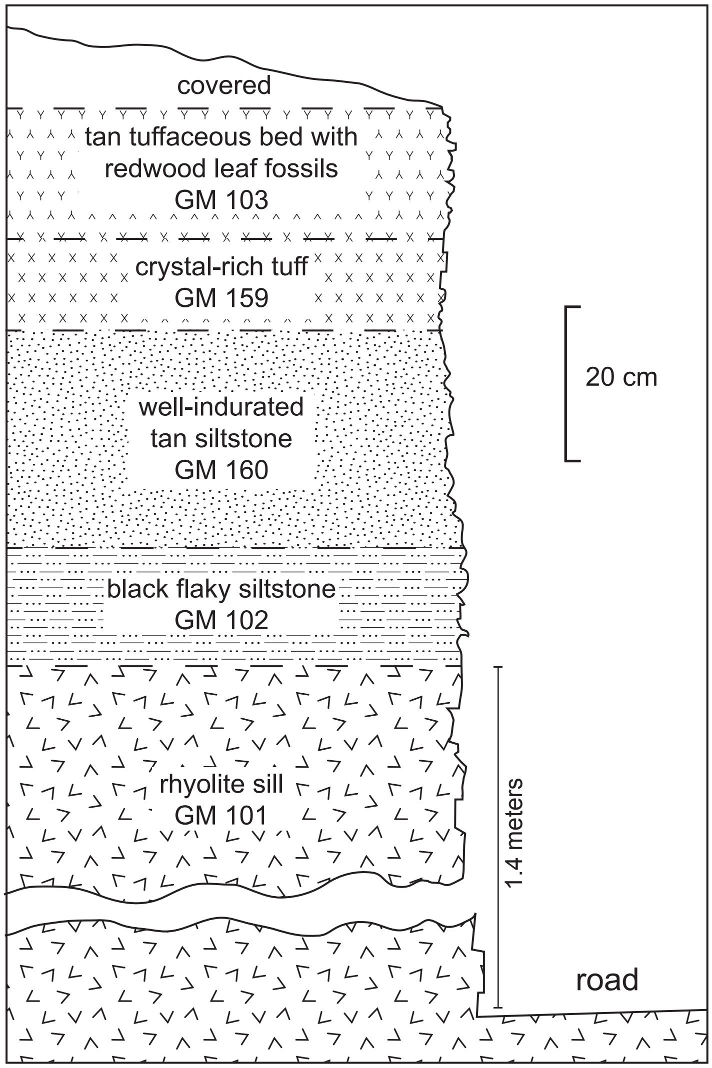


Figure 2.2. Tertiary sedimentary beds and rhyolite sill exposed in road cut in the extreme NW ¼ SW¼, sec. 21, T. 6 N., R. 16 W. Locality 1, fig 2.1. See fig. 2.3 for leaf fossil.

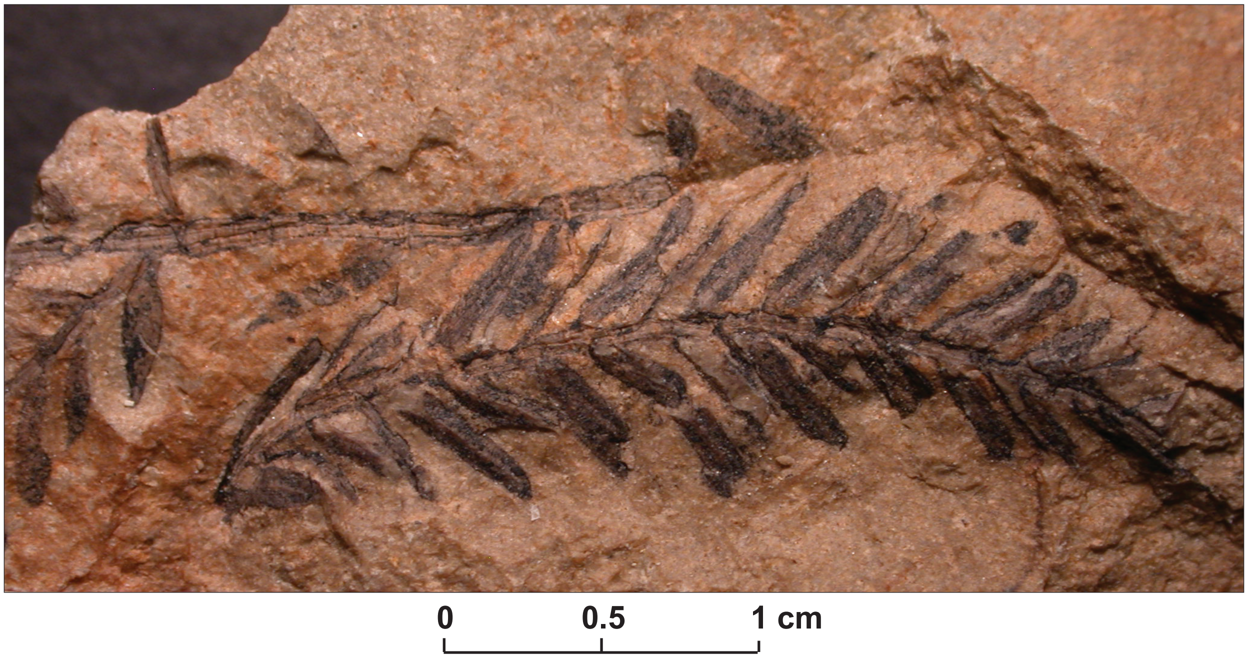


Figure 2.3. Fossil leaves from the tuffaceous bed shown in fig. 2.2. Stephen Manchester, Curator of Paleobotany at the Florida Museum of Natural History (written commun., 2008), identified these leaf impressions as belonging to the redwood family, but was unable to put a specific age on them except that they are most likely of Tertiary age.

Figure 2.4. Exposure of rhyolite lava flow on ridge between North Fork Coal Gulch and Anaconda Gulch.

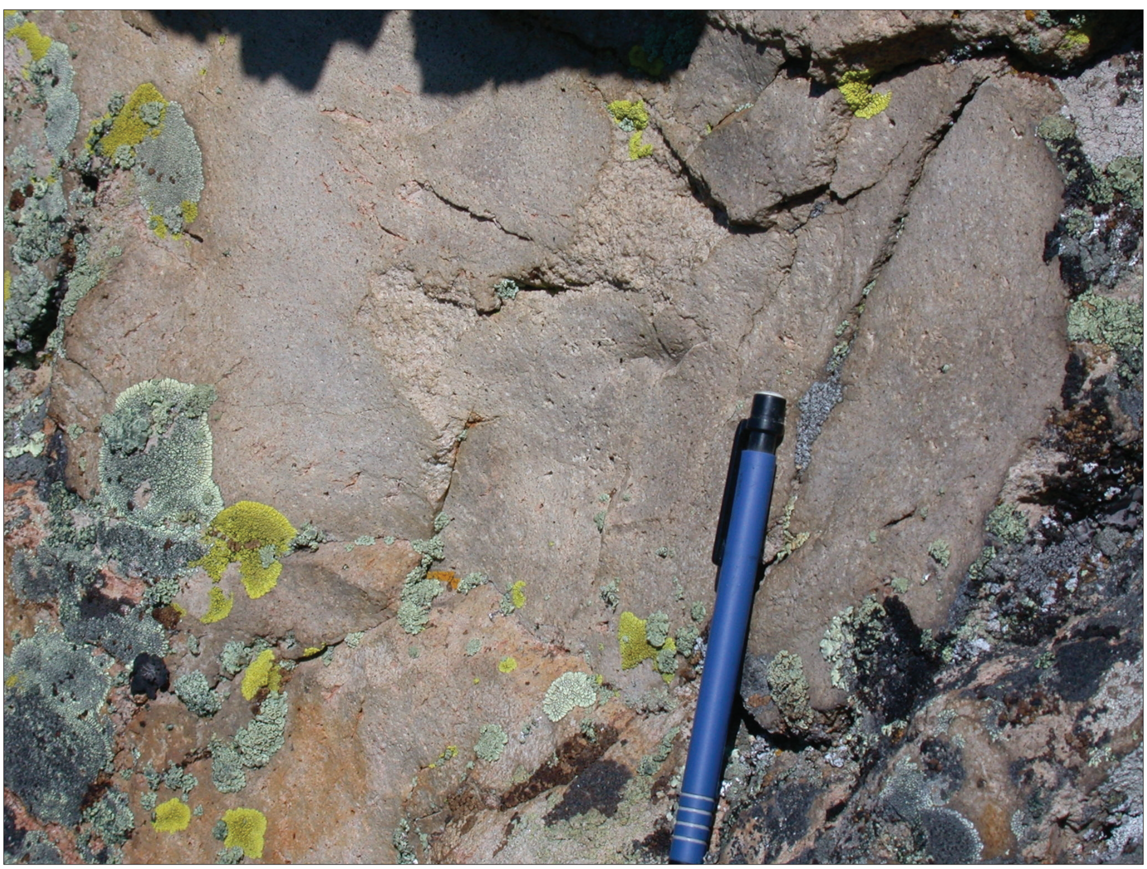


Figure 2.5. Fine-grained layer that occurs on some fracture surfaces in the rhyolite that may indicate post-extrusion fumarole activity.

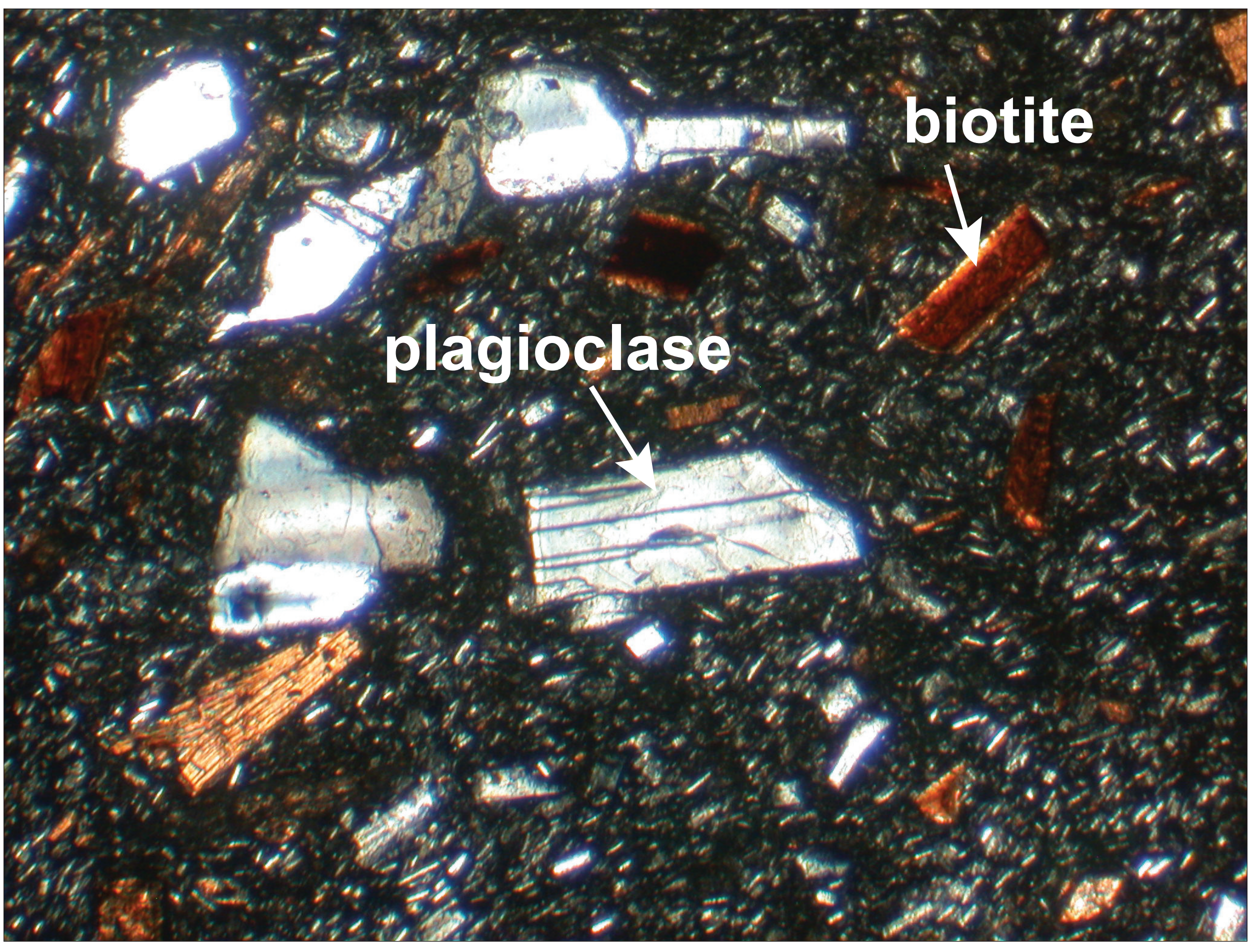
Figure 2.6. Flow banding in rhyolite.

Figure 2.7. Xenoliths of volcanic rock in rhyolite exposed on the west side of the ridge between Anaconda Bench and North Fork Coal Gulch.

These xenoliths consist of plagioclase and biotite phenocrysts in a fine-grained matrix with prominent plagioclase microlites. At this locality there are abundant inclusions of angular-to-subrounded pebbles, up to 2 cm in diameter, of gray sandstone that consist of angular grains of quartz, K-feldspar, plagioclase, and muscovite. These pebbles are interpreted to be fragments of Tertiary sandstone similar to that exposed with other Tertiary sedimentary beds to the south. This rhyolite flow may have incorporated fragments from an older flow as well as pebbles from an erosion surface developed on Tertiary sandstone.

Petrography. Plagioclase phenocrysts range from 0.2 to 2.0 mm in length and are usually broken and complexly zoned. Index of refraction determinations indicate a compositional range from approximately An_{28} to An_{35} (fig. 2.8). Plagioclase microphenocrysts with rectangular crystal outlines are estimated to be of the same composition as the larger phenocrysts based on extinction angles. Small prismatic inclusions within the plagioclase phenocrysts are tentatively identified as rutile. Euhedral biotite phenocrysts are pleochroic, from dark brown to light brown or reddish brown to lighter brown, and range in size from 0.15 to 0.45 mm. Dark brown hornblende occurs in several specimens. Quartz phenocrysts were identified in only 1 of 14 thin sections. Specimens with abundant plagioclase microlites in the groundmass typically exhibit trachytic texture with foliation wrapping around plagioclase and biotite phenocrysts. Some specimens lack plagioclase microlites, and in these specimens the groundmass has a fine-grained granular mosaic texture. Potassium feldspar was not recognized in thin sections stained for potassium.

Age of rhyolite. Biotite separated from a specimen of typical rhyolite (sample GM 157) was analyzed by the $^{40}Ar/^{39}Ar$ step heating method. This specimen is from a road cut along a logging road between the lower part of Anaconda Gulch and Coal Gulch (locality 7, fig. 2.1). The analysis was performed at the Nevada Geochronology Laboratory at the University of Nevada, Las Vegas. The plateau age (fig. 2.9) of 50.2 ± 0.4 Ma is considered the “most reliable indicator” of the age of this specimen (Terry Spell, written com-



0.5 mm

Figure 2.8. Photomicrograph with crossed polars of rhyolite specimen GM-2 showing plagioclase and biotite phenocrysts surrounded by fine-grained groundmass. See appendix table 3.1 for chemical analysis.

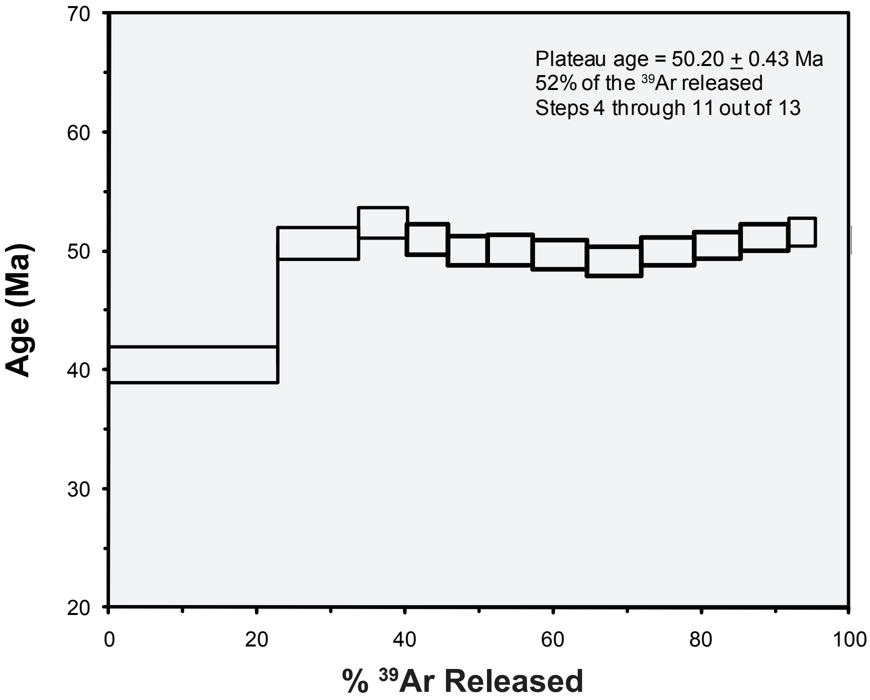


Figure 2.9. Plot of ^{39}Ar released showing plateau age of 50.20 ± 0.43 Ma.

mun., 2010). See appendix 4 for analytical data and procedures.

Alteration of rhyolite. Kaolinitic alteration occurs in rhyolite exposed near the head of Anaconda Gulch, at the northern end of the ridge between North Fork Coal Gulch and Anaconda Bench, and also in a road cut along Anaconda Gulch 150 m (500 ft) south of the remains of the Middle Camp that is on the west side of Anaconda Gulch opposite Mink Gulch. Thin sections of specimens from these localities contain many holes that were produced during thin section preparation by plucking and removal of altered plagioclase phenocrysts. Some plagioclase phenocrysts have been completely replaced by vermiform kaolinite as confirmed by x-ray diffraction analysis (fig. 2.10). Rhyolite specimens from other exposures in the Coal Gulch/Anaconda Gulch area do not contain recognizable kaolinite, but the cores and specific zones of plagioclase phenocrysts have been altered to an unidentified fine-grained mineral aggregate.

Rhyolite dome

Field observations. Previous geologic mapping has shown the prominent knob between Sapphire

Figure 2.10. Photomicrograph of feldspar (K-feldspar?) phenocryst in rhyolite that has been replaced by kaolinite. Kaolinite surrounded by blue impregnating medium. Crossed polars. Specimen GM 108.

Gulch and Little Moffatt Gulch to consist of intrusive rhyolite (Lonn and others, 2003). This light gray rhyolite consists of fine-grained layers containing scattered small plagioclase phenocrysts and millimeter- to several millimeter-thick layers of vesicular material that exhibit steeply inclined flow banding.

Petrography. Plagioclase phenocrysts are generally euhedral to subhedral, between 1 and 2 mm, exhibit oscillatory zoning, and have cores that show very slight alteration with small inclusions of fine-grained material, possibly devitrified glass (fig. 2.11). Euhedral biotite phenocrysts are pleochroic from light tan to very dark brown. Abundant plagioclase microlites in the groundmass exhibit a prominent trachytic texture. Hornblende is a minor constituent of one specimen that also contains one irregular quartz grain, probably xenocrystic.

Rhyolite with quartz phenocrysts

Field observations. Rhyolite exposed along the road on the north side of West Fork Rock Creek west of Maley Gulch is distinguished from the area's typical rhyolite by the abundance of prominent euhedral, 15 mm potassium feldspar phenocrysts and anhedral, 5–10 mm quartz megacrysts. Small euhedral biotite phenocrysts are scattered throughout the chalky white groundmass.

Petrography. Quartz occurs both as subrounded megacrysts and angular fragments of these grains (fig. 2.12). Except for a few euhedral phenocrysts, K-feldspar occurs as phenocryst fragments. Subhedral to euhedral plagioclase phenocrysts are generally fractured and have sericite(?) along the fractures. Pleochroism of biotite is from brown to very dark brown. Fine-grained quartz partly rims some of the quartz megacrysts and fragments, and feldspar phenocrysts, and also forms irregular, wispy veinlets and patches up to 0.2 mm across.

Dikes and volcanic rocks north and east of Sapphire Gulch

Field observations. A prominent east–west-trending rhyolite dike forms a ridge north of the upper part of Sapphire Gulch and branches into several thinner

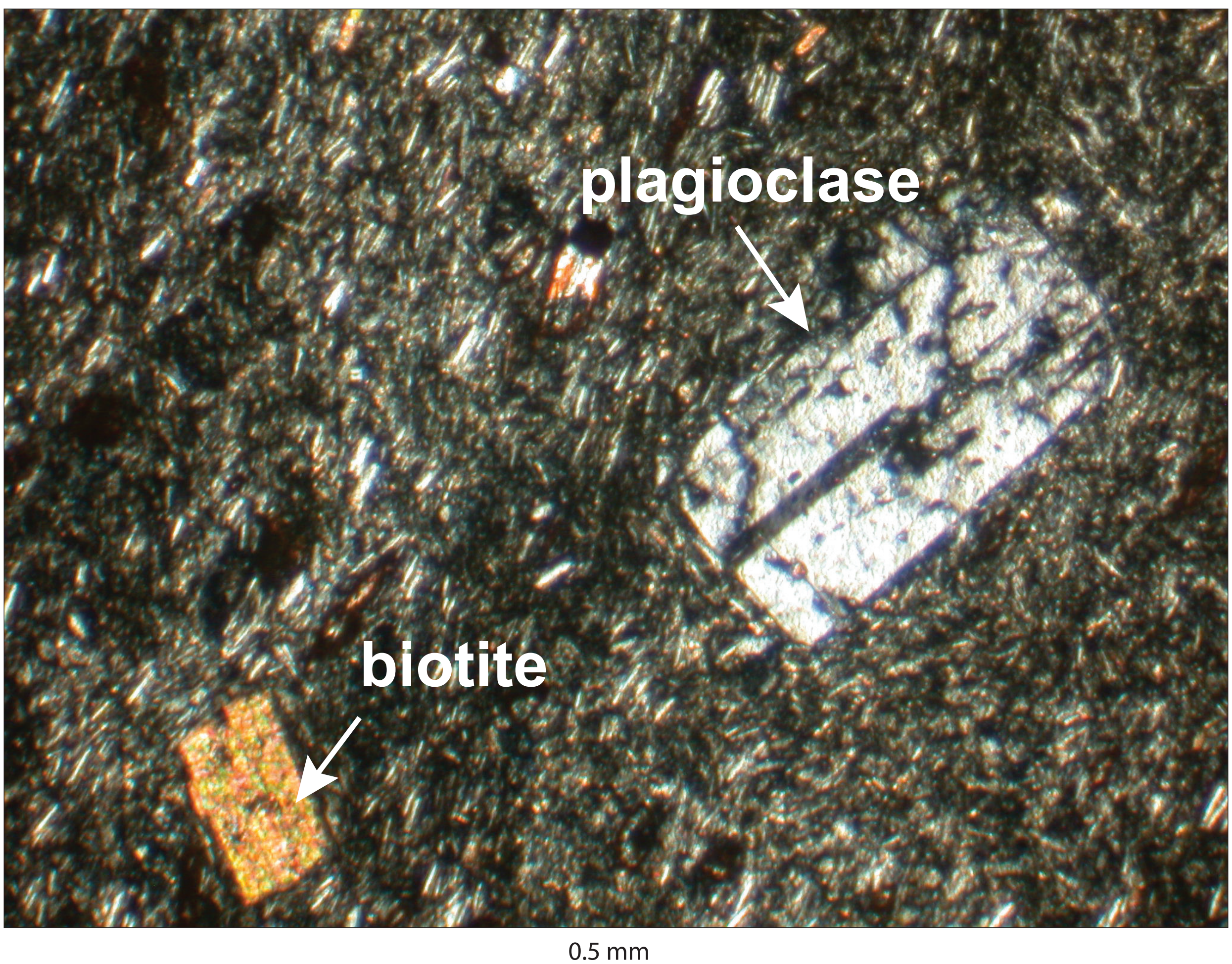


Figure 2.11. Photomicrograph with crossed polars of specimen GM 323 from rhyolite dome with plagioclase and biotite phenocrysts. See appendix table 3.2 for chemical analysis.

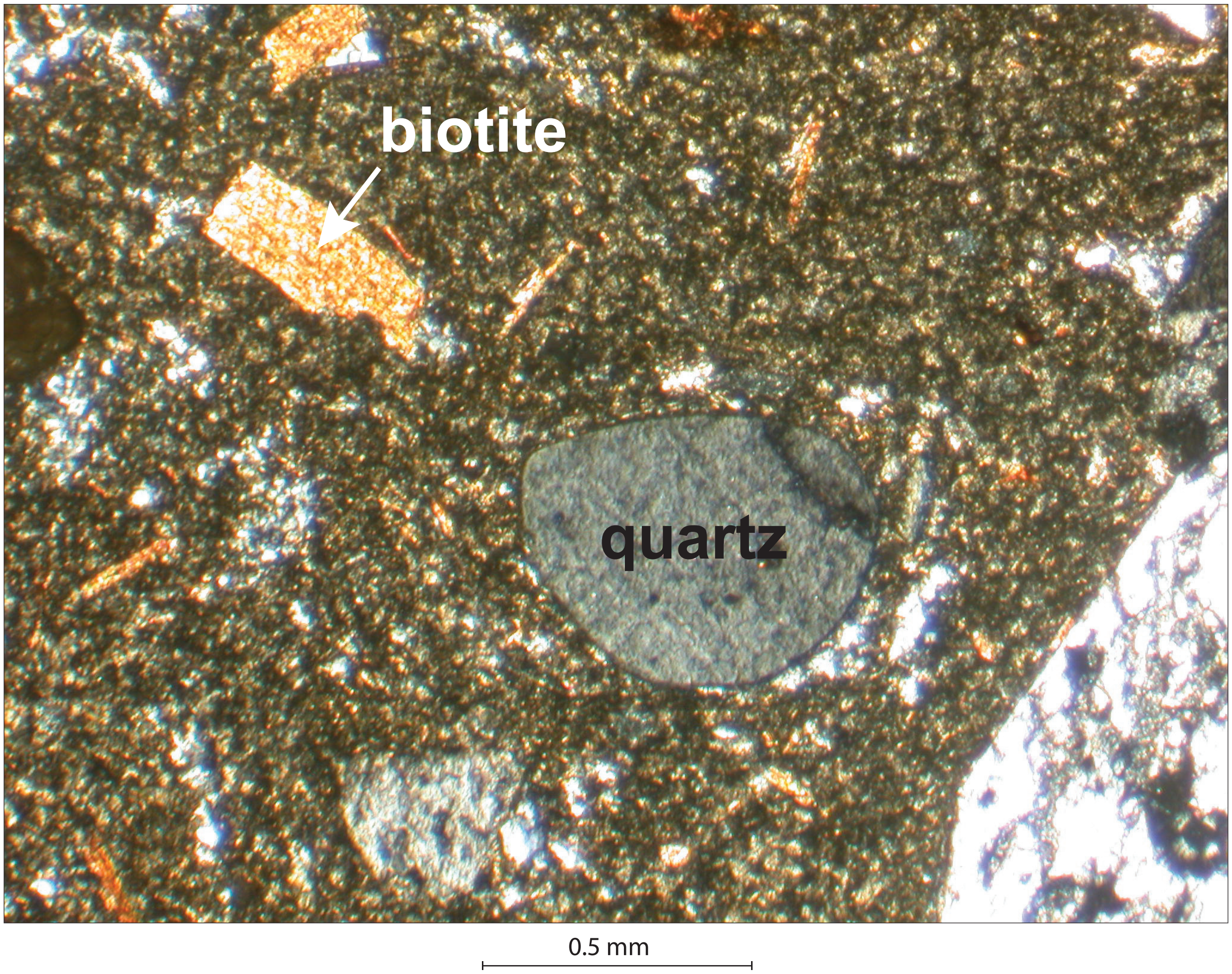


Figure 2.12. Photomicrograph with crossed polars of quartz megacryst and biotite phenocryst in rhyolite stained for potassium. Specimen GM 242.

dikes that extend southwest (fig. 2.1). These dikes that intruded both the volcaniclastic unit and rhyolite flows are more highly porphyritic than the rhyolite flows and contain prominent plagioclase megacrysts as large as 6 mm.

Petrography. Some of the abundant euhedral to subhedral plagioclase megacrysts are partly surrounded by very fine-grained material in which individual minerals are not recognizable. Oscillatory zoning is prominent in most plagioclase megacrysts that have an average composition of approximately An_{30} based on index of refraction measurements. Biotite forms euhedral phenocrysts that range from 20 to 400 μm, with light tan to very dark brown pleochroism. Quartz occurs in low concentrations and forms round to irregular grains that range up to 1.6 mm. Small, approximately 0.5 mm radial clusters of what appear to be plagioclase crystals are found in all thin sections (fig. 2.13). Plagioclase microlites dominate the groundmass of most specimens where they exhibit a well-developed trachytic texture. Specimens that contain less abundant microlites have a granular texture.

Tuff

Field observations. Remnants of what may have been a widespread tuff bed were recognized at three localities. The best exposure is in a road cut along the east side of lower Anaconda Gulch just below the bench placer (fig. 2.1). The other two occurrences are too small to show in figure 2.1. Fragments of tuff were found along a logging road on the west side of lower Anaconda Gulch opposite the bench placer shown on the east side of Anaconda Gulch. Tuff is also exposed in the area of placer mining along Maley Gulch (see description of Maley Gulch placer). The thickness of exposed tuff at all of these localities is less than a meter.

Petrography. The tuff consists of glass shards, both fresh and partly devitrified, with sparse feldspar and quartz grains. The index of refraction of the glass shards is <1.53. X-ray diffraction analyses of specimens from the bench placer on lower Anaconda Gulch showed the likely presence of a zeolite, but it was not possible to determine the specific mineral.

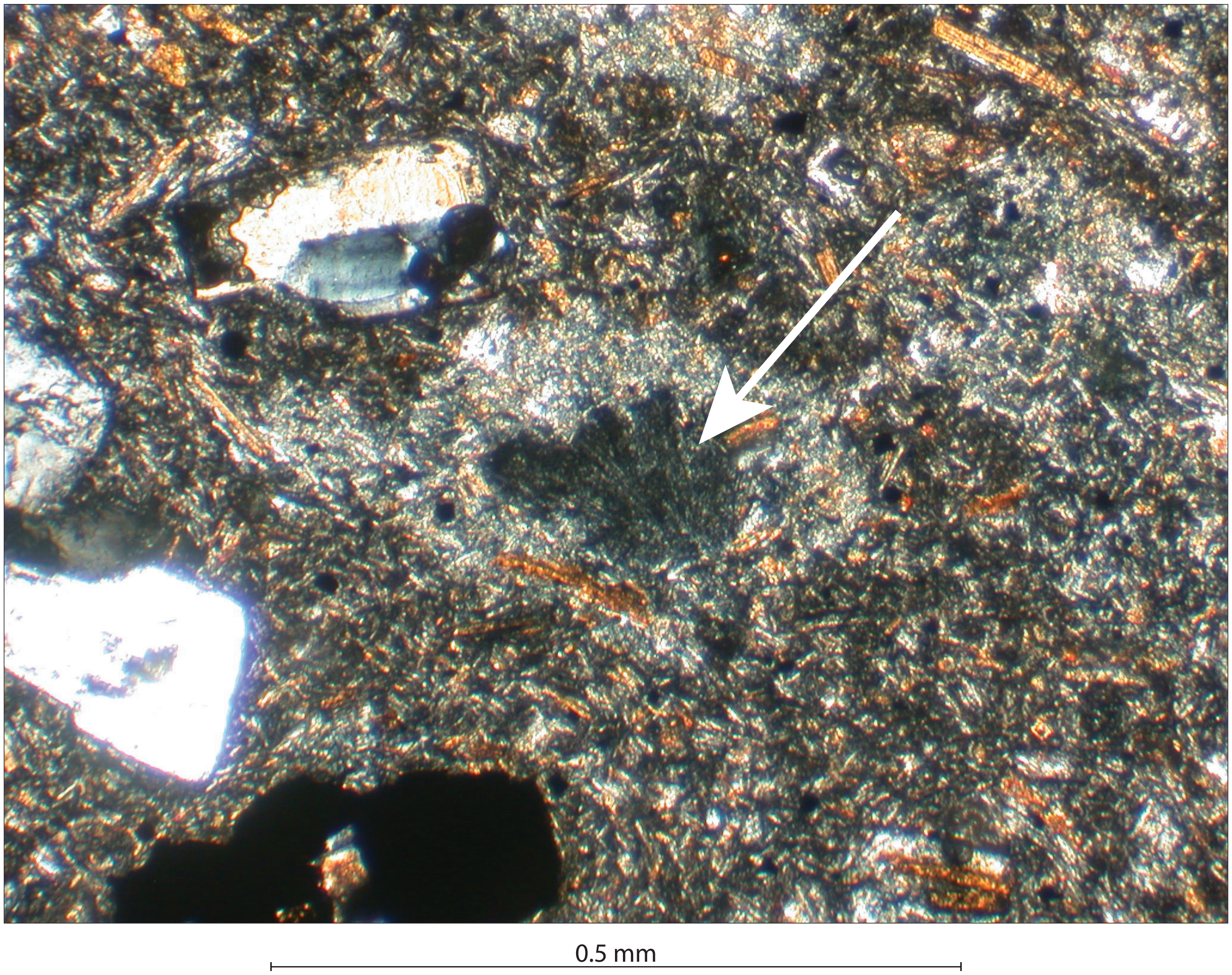


Figure 2.13. Photomicrograph with crossed polars of specimen GM 274 from dike showing radial cluster of plagioclase crystals.

Volcaniclastic unit

Field observations. The volcaniclastic unit does not form the prominent exposures typical of rhyolite lava flows because it is more easily eroded. The best exposures are in the pit near the head of North Fork Coal Gulch, in a road cut along the road to this pit, along Coal Gulch, and along the Upper Sapphire Ditch near the head of Anaconda Gulch. Bedding is poorly developed, but is generally horizontal where recognizable. The lithology of pebbles in this unit varies in proportion and is rhyolite, sandstone, quartzite, siltite, and lapilli. The rhyolite pebbles are derived from nearby rhyolite flows, and consist of plagioclase and biotite phenocrysts in a fine-grained groundmass. Both quartzite and siltite pebbles are typical of metasedimentary rocks of the Belt Supergroup. Rhyolite cobbles are prominent in the exposures in the pit wall near the head of North Fork Coal Gulch. Although poorly exposed, the volcaniclastic unit is inferred on the basis of float to cover a large area north and west of Sapphire Gulch. Two exposures are worthy of special note. A horizontal coaly bed approximately 5 cm thick is exposed in a prominent exposure on the south side of Coal Gulch upstream from its confluence with North Fork Coal Gulch (locality 4, fig. 2.1). A debris flow that incorporated rhyolite and quartzite clasts, some of boulder size, is exposed along the road on the west side of Maley Gulch (locality 5, figs. 2.1, 2.14). This is the only exposure of what is clearly a debris flow within this area.

Petrography. The volcaniclastic unit is characterized by angular to subrounded grains (<5 mm) of rhyolite, quartzite, and siltite in a fine-grained matrix composed chiefly of fragments of zoned plagioclase and biotite accompanied by K-feldspar and quartz in low concentration. The volcaniclastic beds exposed along the Upper Sapphire Ditch near the head of Anaconda Gulch east of the Carpp Mine contain round pebbles as large as 6 mm. The pebbles consist of a fine-grained sandy core surrounded by a rim of very fine-grained material that has a concentric fabric, as if the grains had been rolled in fine-grained material before incorporation in the volcaniclastic bed (fig. 2.15). A rhyolite pebble from this same exposure

Figure 2.14. Exposure of debris flow with large rhyolite boulders in road cut on the west side of Maley Gulch.

is also surrounded by fine-grained material that shows a concentric texture.

Tuff dike and clastic dikes

Adjacent volcaniclastic beds. A tuff dike and two clastic dikes are exposed along an abandoned road on the west side of North Fork Coal Gulch (locality 6, fig. 2.1). All three dikes are of approximately the same orientation (N 75º W, 60–65º SW) and intruded a poorly sorted volcaniclastic rock that contains prominent discoid pebbles of medium-grained maroon quartzite, presumably from the Belt Supergroup. Bedding of the volcaniclastic rock is approximately horizontal.

Petrography of adjacent volcaniclastic beds. The intruded volcaniclastic rock consists of subrounded granules of sandstone and pyroclastic flow fragments in a fine-grained matrix. The sandstone granules resemble the Tertiary sandstone exposed at locality 1, figure 2.1, where it is fine-grained and consists mainly of angular quartz grains enclosed in a fine-grained clay matrix. The granules of a pyroclastic flow contain zoned euhedral plagioclase phenocrysts and fragments of euhedral grains. Biotite grains, pleochroic from tan to brown, show weak alignment. The matrix within these pyroclastic flow granules consists of devitrified glass, either from pumice lapilli or glass shards.

The matrix of this volcaniclastic rock is a mixture of plagioclase and quartz grains. Less abundant biotite (pleochroism tan to dark brown) and a trace of K-feldspar also occur in the matrix of this rock. The plagioclase is typically zoned and euhedral, whereas the quartz is subhedral to angular. Most quartz and plagioclase grains are between 50 and 130 µm.

Tuff dike. The most prominent dike at this locality is a tuff dike 0.6 m thick, fine-grained and very light tan with closely spaced fractures (locality 6, figs. 2.1, 2.16). Approximately the southern one-third (left in fig. 2.16) of this dike is massive, very fine-grained, and breaks with a conchoidal fracture. This part of the dike consists of small (<50 µm) fragments of volcanic ash with index of refraction <1.53. Rare angular quartz grains range up to 150 µm. Other constituents are too small to identify optically. The northern two-thirds of the dike is characterized by delicate layering, with the slightly darker layers 1–2 mm thick and parallel to the contact with the surrounding volcaniclastic rock. This part of the dike consists essentially of glass shards with index of refraction <1.53. The lighter layers are

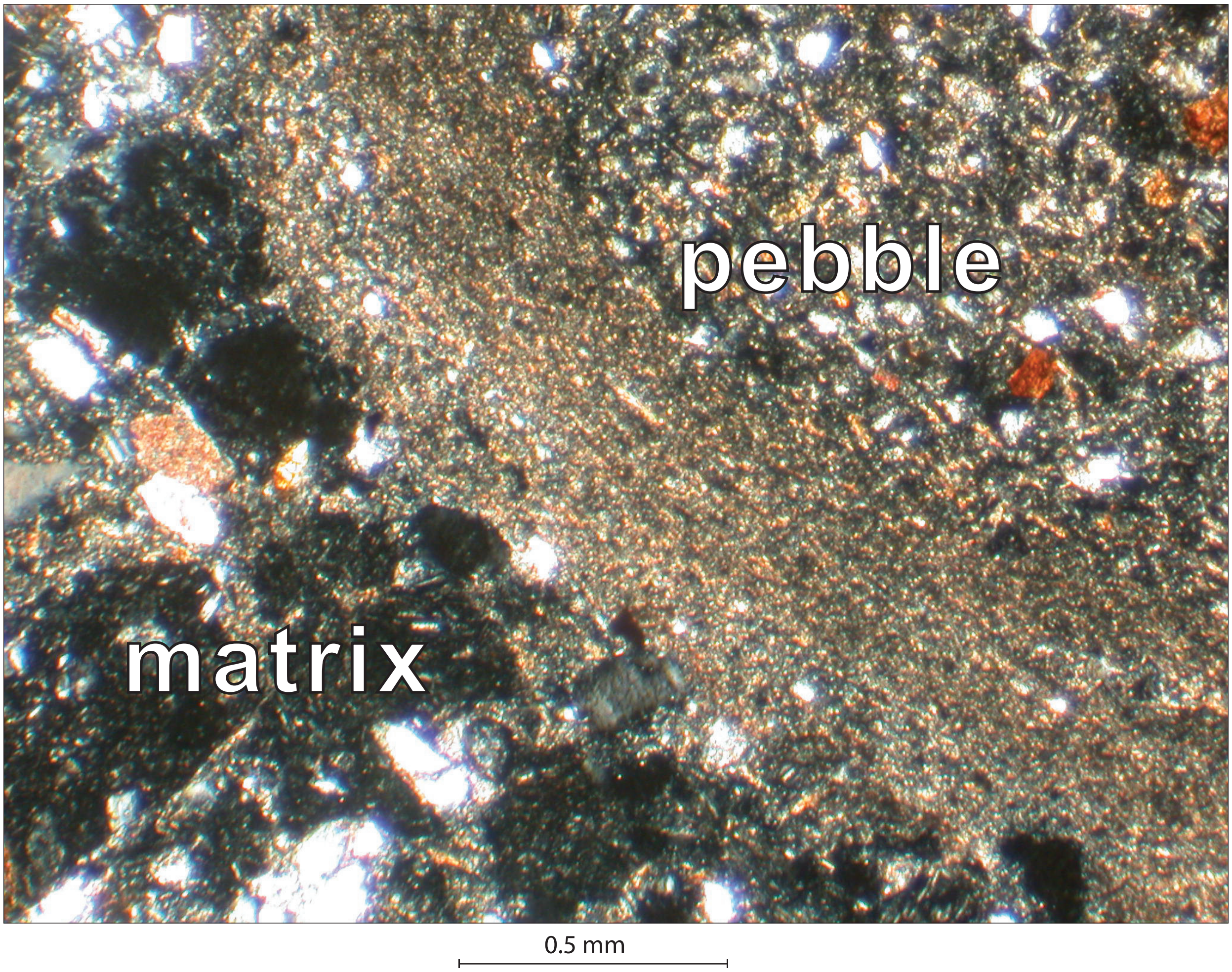


Figure 2.15. Photomicrograph with crossed polars of a sandstone pebble rimmed by fine-grained material in volcaniclastic rock exposed near the head of Anaconda Gulch along the Upper Sapphire Ditch. Specimen GM 111.

at least 90 percent glass shards, with some quartz and feldspar grains in the 40 to 60 µm size range (fig. 2.17). Shreds of biotite and colorless mica are scattered through these layers. The thin darker layers consist essentially of very small glass shards.

Clastic dikes. Two clastic dikes that parallel the tuff dike are exposed in the same road cut. The thicker and better exposed of these two dikes is about 0.5 m thick; the other poorly exposed dike is only about 10 cm thick. Quartzite pebbles are much more abundant in the two clastic dikes than in the intruded volcaniclastic (fig. 2.18). In addition to quartzite pebbles, these dikes contain pebbles that consist mainly of angular quartz grains in a fine-grained clay matrix, similar to that described in the adjacent volcaniclastic rock. Included fragments of a pyroclastic flow are also similar to those described in the adjacent volcaniclastic rock and consist of plagioclase fragments and shredded biotite grains in a fine-grained matrix that is interpreted to be partly devitrified glass. The other pebble type, not recognized in the adjacent volcaniclastic rock, is from a lava flow. These pebbles consist of unzoned euhedral plagioclase and biotite phenocrysts in a fine-grained groundmass with abundant plagioclase microlites.

Conjecture about dikes. The occurrence of volcanic ash or partly altered volcanic ash in both the tuff dike and the clastic dikes may indicate that volcanic ash was being vented along a fissure in the volcaniclastic beds. In its path to the surface, the volcanic ash incorporated quartzite pebbles in the clastic dikes, either derived from an underlying quartzite bed or from a quartzite gravel layer. Ash that formed the tuff dike simply did not come in contact with quartzite bedrock or quartzite gravel, and thus the dike consists essentially of volcanic ash.

Chemical composition of volcanic rocks

Nineteen whole-rock analyses plot either within the rhyolite field or very close to the rhyolite field on a total alkali vs. silica diagram (fig. 2.19). Chemical analyses were normalized to 100 percent after first subtracting loss on ignition (L.O.I.). Although three

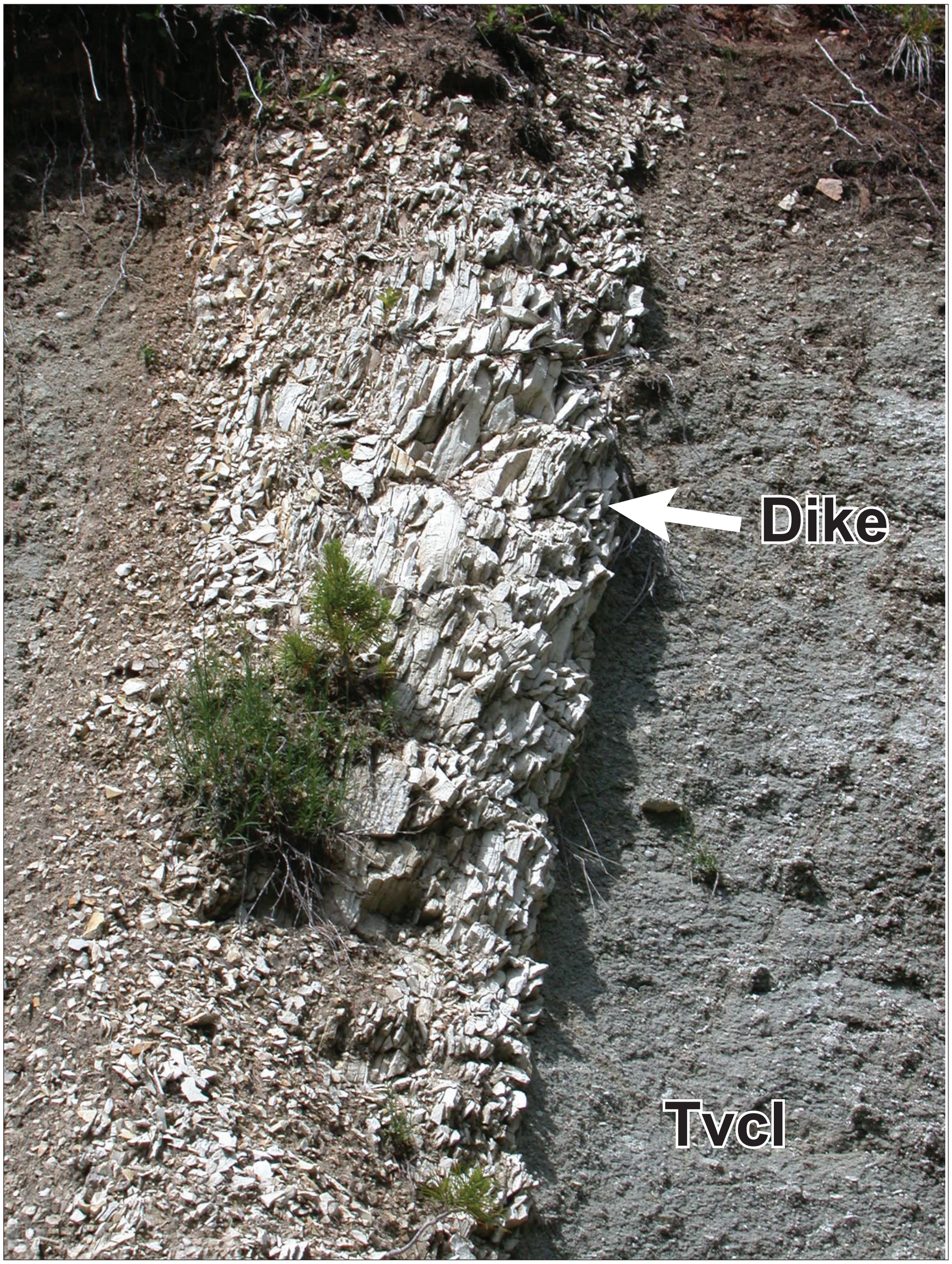


Figure 2.16. Tuff dike exposed in road cut on the west side of North Fork Coal Gulch. Dike is approximately 0.6 m thick above the little tree.

analyses of tuff were plotted, their positions should be viewed with suspicion because of the very high L.O. I., between 4.21 and 9.17 percent, that is attributed to zeolitic alteration. These chemical analyses are given in appendix 3.

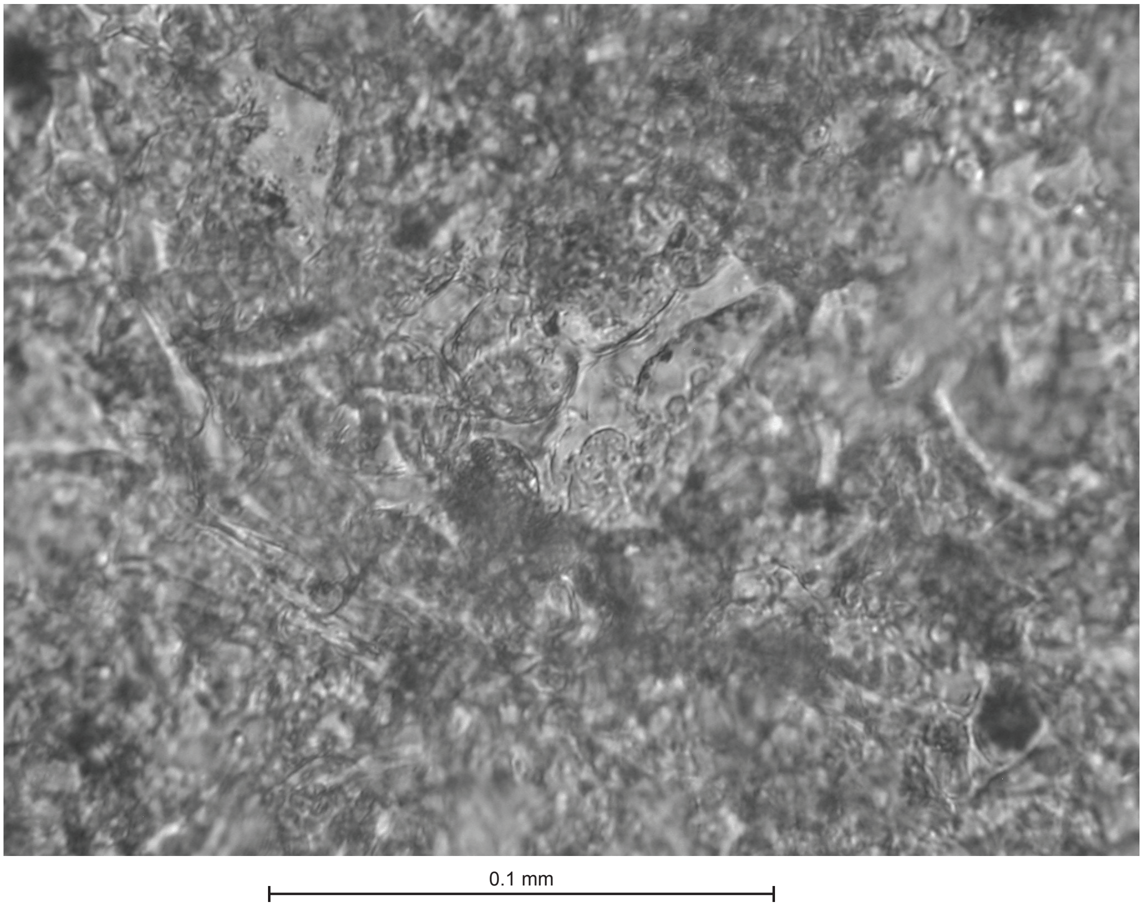


Figure 2.17. Photomicrograph of specimen from tuff dike showing glass shards.

Figure 2.18. Clastic dike exposed in road cut along the North Fork of Coal Gulch with angular to subrounded quartzite pebbles.

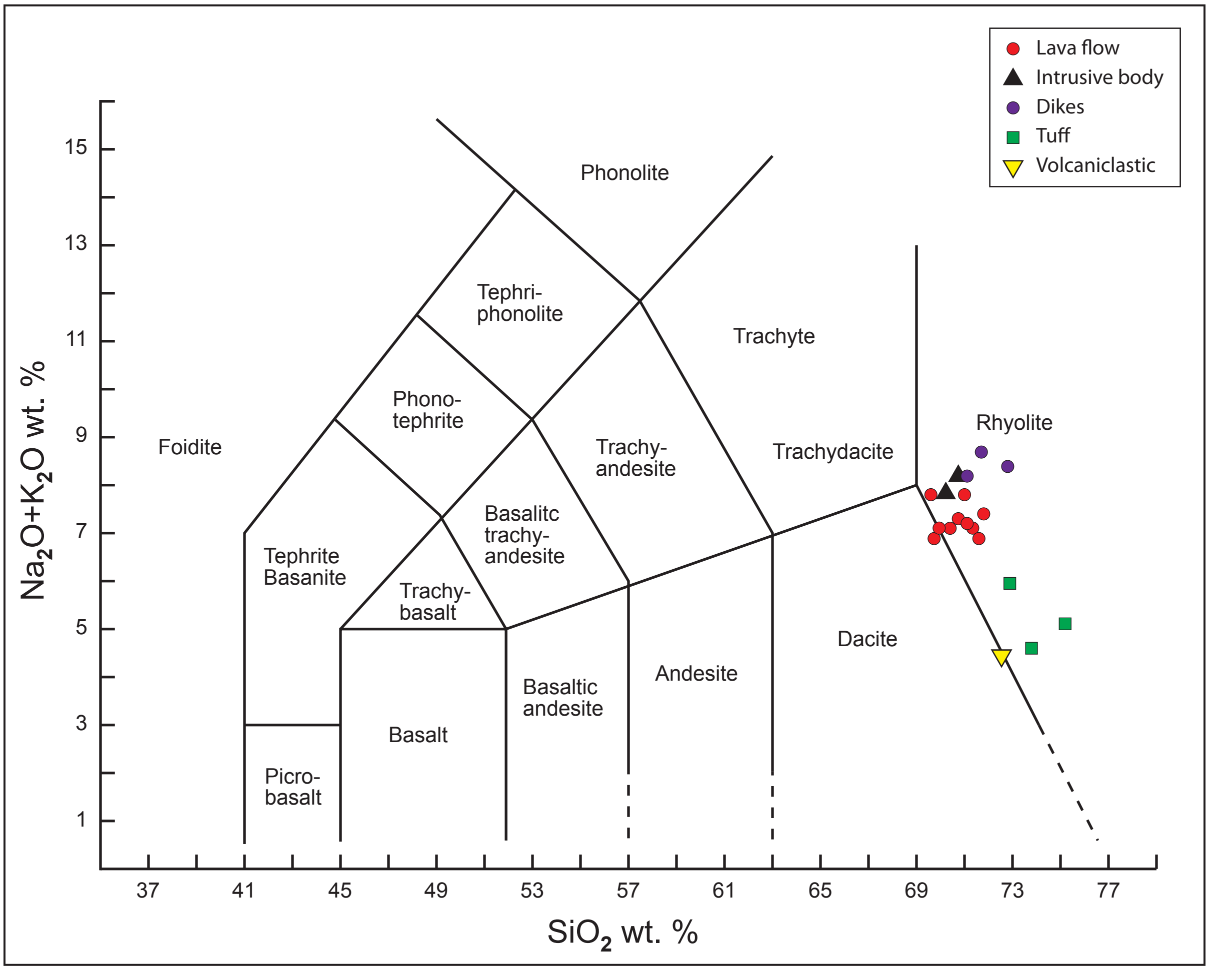


Figure 2.19. Plot of chemical analyses of volcanic rocks on an alkali-silica diagram after LeBas and others, 1986. Chemical analyses in tables 1 and 2, appendix 3.

STRUCTURE

Folds

The only structural folds recognized in this area are in the Snowslip Formation and in beds of the Piegan Group, where exposed along the north side of West Fork Rock Creek. Observed variation in platy jointing and foliation of the rhyolite is attributed to the viscous magma and internal deformation of the magma, not tectonic origin.

Faults

Brecciation of quartzite in the Snowslip Formation was recognized in two isolated exposures surrounded by rhyolite lava on both sides of Anaconda Gulch (fig. 2.1). A westerly trending fault in the pre-volcanic quartzite of the Belt Supergroup is indicated by these exposures. Northerly trending faults are inferred in the area west of North Fork Coal Gulch in the Snowslip and Mount Shields 2 member (?). A north–south-trending fault is shown by a zone of brecciation, silicification, and hematite in beds of the Piegan Group along the ridge between Maley and Sapphire Gulches. Physical evidence of faulting was not recognized in either the rhyolite or volcaniclastic rock.

SURFICIAL GEOLOGY

Colluvium

Sapphires have been recovered from both colluvium and alluvium. The distinction between colluvium and alluvium is based on the relative importance of stream transport (alluvium) as compared to downslope movement by soil creep and sheetwash (colluvium) and is somewhat arbitrary. Recent mining near the head of North Fork Coal Gulch, near the head of Anaconda Gulch, on the slope west of Maley Gulch, and next to the previously mined McLure Placer is in mainly colluvial deposits that are situated above previously mined alluvium (fig. 1.3). The thickness of sapphire-bearing colluvium at these localities is typically less than 3 m (10 ft) and consists mainly of sandy detritus derived by weathering of rhyolite.

Some of the colluvium, consisting mainly of rhyolite granules, has the texture of mortar (fig. 2.20). See the discussion of sapphire mining near the head of North Fork Coal Gulch (Chapter 3) for a description of the mineralogy of the colluvium at that locality.

Alluvium

Essentially all mining during the years of maximum production from 1903 into the 1930s was in the alluvium in the gulches (fig. 1.3). The extent of historic placer mining was determined by simply walking the gulches and noting windrows of gravel. In addition, the relative abundance of cobbles and boulders (but not pebbles) of different lithologies was estimated (fig. 1.3).The gravel in two mined areas, one just east of North Fork Coal Gulch and the other at the head of Anaconda Gulch, consists exclusively of quartzite cobbles derived from the metasedimentary rocks of the Belt Supergroup. In contrast, just to the south on Anaconda Bench and east of that bench in the “Dismal Swamp,” almost all cobbles are rhyolite. The alluvium in other mined areas is a mixture of cobbles of metasedimentary rocks of the Belt Supergroup (mainly quartzite) and rhyolite, typically from the immediate vicinity of the gulch.

Descriptions of Lithologies of Cobbles and Boulders

Rhyolite

Rhyolite cobbles are typically more angular than quartzite cobbles and covered to a greater extent by lichens. Cobbles in the Ewing Placer and Wildcat Gulch along the upper part of Sapphire Gulch are mainly rhyolite derived from the rhyolite dikes just uphill to the north.

Metasedimentary rocks from the Belt Supergroup

Boulders and cobbles of metasedimentary rocks of the Belt Supergroup are of two types. The most distinctive and most useful type in deciphering the paleodrainage is pink to white hard quartzite with black laminae. The pink color, black lamina, and very hard quartzite is typical of the Bonner Formation, which is exposed about 4 km (2.5 mi) west of Lower Coal Gulch and a like distance to the south (Lonn and others, 2003) and is considered the most likely source. These boulders and cobbles are subrounded to rounded, although some have fresh fractures that formed after rounding (fig. 2.21). The larger boulders, some more than 1 m in maximum dimension, are

Figure 2.20. Colluvium produced by weathering of rhyolite showing mortar-like consistency. Photo of exposure along small tributary that enters lowermost Coal Gulch from the west.

more highly rounded than the smaller boulders and cobbles. The Tertiary alluvial fan in the western part of the area (fig. 2.1) also contains similarly rounded quartzite boulders and cobbles. The gravels contain a second quartzite that is somewhat softer, generally forms angular cobbles and rarely boulders, and is tan, pink, or gray (fig. 2.21). The source of this quartzite is inferred to be the Snowslip Formation of the Belt Supergroup, which is exposed uphill to the north of these gulches (fig. 2.1).

Gravel piled from placer mining in the lower part of Coal Gulch consists mainly of the pink Bonner Formation quartzite cobbles and boulders, whereas the windrows of gravel at the placer mine near the head of Maley Gulch consist mainly of quartzite from the Snowslip Formation. Gravel in placers close to the heads of gulches and thus closer to exposures of the Snowslip Formation has the highest concentration of quartzite from this formation, as would be expected.

Alaskite (monzogranite)

Distinctive, well-rounded cobbles identified in the field as alaskite are found in many of the mined areas, but account for much less than 1 percent of all cobbles (fig. 2.21). Localities where these cobbles are found are shown in figure 1.3. Modal analysis of one of these cobbles from the mined area just east of North Fork Coal Gulch shows 24 percent quartz, 43 percent K-feldspar, 32 percent plagioclase, and <1 percent mica (both biotite and muscovite). This nonfoliated monzogranite (LeBas and Streckeisen, 1991) is similar to a two-mica granodiorite pluton of Tertiary or Cretaceous age exposed about 25 km (15 mi) west of Coal Gulch (Lonn and others, 2003) and is considered a likely source. It should be noted that the Bonner Formation is exposed between this pluton and the southwestern part of the Rock Creek sapphire district.

Paleodrainage

It is proposed that the Tertiary alluvial fan shown west of Coal Gulch extended east into the area in which rhyolite is now exposed. Rhyolite flows covered this gravel, which was later exposed by erosion of the present gulches. Local exposures of rhyolite, alluvial fan deposits, younger dikes, and metasedimentary rocks of the Belt Supergroup contributed various rock

Figure 2.21. Gravel from placer mining on Maley Gulch containing angular and subrounded cobbles of quartzite (1) derived from metasedimentary rocks of the Belt Supergroup and (2) round cobbles of alaskitic monzogranite.

types to the present gulches. Although conclusive evidence was not observed, the following observations support this hypothesis.

1. Large (>1 m) rounded quartzite boulders are found only in the gulches. Although cobbles were found on the surface between Anaconda and Sapphire Gulches, large quartzite boulders were not found. If this alluvial fan gravel had been deposited on the rhyolite, it is likely that some large quartzite boulders would remain on this low-relief surface.

2. At least some of the quartzite cobbles had been deposited in this area before the rhyolite lava flows. This is shown by quartzite cobbles found in the pit near the head of North Fork Coal Gulch that have adhering rhyolite. Garland (2002) photographed quartzite cobbles in the rhyolite exposed on the ridge between North Fork Coal Gulch and Anaconda Bench; however, the site was not found during the current investigation.

3. The ridge of metasedimentary rocks of the Belt Supergroup just north of West Fork Rock Creek is best explained by former drainage to the north of this ridge that was later diverted to the south by a rhyolite flow (fig. 2.1).

4. Tertiary conglomerate is exposed in cliffs on both sides of West Fork Rock Creek about 3 km (2 mi) east of the confluence of Sapphire Gulch and West Fork Rock Creek. This well-cemented, clast-supported conglomerate consists of round cobbles and pebbles of quartzite and siltite derived from Belt Supergroup formations, but no rhyolite clasts. It is speculated that this conglomerate was part of the same depositional system that deposited the quartzite gravel underlying the rhyolite to the west.

5. The boulders and cobbles derived from bedrock sources to the west were mixed with material from local bedrock sources during the development of the present drainage system. Quartzite from the Snowslip Formation, rhyolite flows, and igneous dikes all contributed detritus to the gravel in these gulches.

CHAPTER 3

PLACER DEPOSITS

Introduction

Descriptions of placers that have been mined in the southwestern part of the Rock Creek sapphire district are arranged starting with Sapphire Gulch and its tributaries and then proceeding west to Maley Gulch, Anaconda Gulch, Anaconda Bench, and then Coal Gulch. Historic information on these specific placer deposits is included.

Two figures may be particularly useful to the reader. Figure 1.3 shows the gulches and the extent of mining, both historic and more recent. Reference to figure 3.1 will be helpful where a site is identified by section, township, and range. Production figures have been converted to grams for ease of comparison.
In an attempt to show the relative richness of mined gulches, the historic production of sapphires for a specific gulch was divided by the length of gulch mined to arrive at kg/100 m of gulch length mined. This figure must not be confused with actual grade that is given in carats or grams/bcy. The extent of mining in the gulches was determined by walking the gulches and observing evidence of historic placer mining. The percent of quartzite or quartzitic cobbles and boulders derived from the Belt Supergroup was estimated. Unless specifically stated, the remainder of cobbles and boulders are of the rhyolite lava.

Sapphire Gulch and Tributaries

Introduction

Sapphire Gulch is the easternmost of the major gulches that have been mined in this part of the Rock Creek sapphire district (fig. 1.3). For the period from 1906 through 1928, a crude indication of the richness of Sapphire Gulch is given by the historic production of 600 kg/100 m of gulch mined as compared to 1,400 kg/100 m for Anaconda Gulch for the same years of reported production. Tributary gulches to Sapphire Gulch from the west typically were less productive (from 80 to 800 kg/100 m) than those that enter Anaconda Gulch from the east (production ranging from 1,200 to 2,800 kg/100 m; fig. 1.3). Aurora and Bi-Metallic Gulches, which enter Sapphire Gulch from the east, have not been mined even though water was available from the Upper Sapphire Ditch, which suggests that the grade of sapphire-bearing gravel was too low to justify mining as compared to the other gulches. It has been reported that Sapphire Gulch is known for larger sapphires than other areas mined in recent years (Dale Siegford, oral commun., 2011).

McLure Placer

Location. McLure Placer is situated on a short tributary that joins Sapphire Gulch west of the Ewing Placer (fig. 1.3). The placer is also known as the Rumsey Placer, named for Moses Rumsey, who was a director of the American Gem Mining Syndicate (Domine, 2009, p. 330).

History. Production information was not found, but presumably the original mining was during the same time as the adjacent placers, Ewing and Wildcat, sometime between the years 1911 and 1924. During the summer of 2008, Robert Glenn mined sapphires from colluvium next to the lower part of this placer, just above the logging road. The area of this recent mining has been reclaimed.

Description. Evidence of past mining is shown by piles of boulders and cobbles that extend up the gulch for about 400 m (1,300 ft); these piles are about 50 m (150 ft) wide near the upper limit of mining. No side ditches were recognized, but a section of fire hose was found, indicating at least some hydraulic mining. An estimated 95 percent of the boulders and cobbles in the lower part of the gulch are quartzite of the Belt Supergroup and are generally subrounded. The largest quartzite boulder was approximately 1 m across. One rounded alaskite (monzogranite) cobble was found. The rest of the boulders and cobbles are rhyolite. Near the upper limit of mining, an estimated 70 percent of the boulders and cobbles are quartzite, with the remainder rhyolite. Volcaniclastic rock is exposed on the banks next to mined areas that were in alluvium (fig. 3.2).

Ewing Placer

Location. Ewing Placer is situated along Sapphire Gulch where a small tributary enters from the north (fig. 1.3). This placer was probably named for C.G. Ewing, from St. Louis, Missouri, who was involved with the sapphire deposits (Domine, 2009, p. 335). Although the patented claim extends north along this tributary, the only evidence of past mining was at the mouth of the tributary between Sapphire Gulch and the present road north of Sapphire Gulch.

History. Reported production from the Ewing Placer was 59,280 avoirdupois ounces (1,680 kg), mined during 1923 and 1924 (table 1.1). Three cuts perpendicular to the road just west of the area of old placer mining appear to be a recent effort to evaluate this deposit.

Description. The area mined, exclusive of the newer cuts, is estimated to be approximately 200 m (650 ft) in an east–west direction and extends to within 50 m (160 ft) of Sapphire Gulch near its

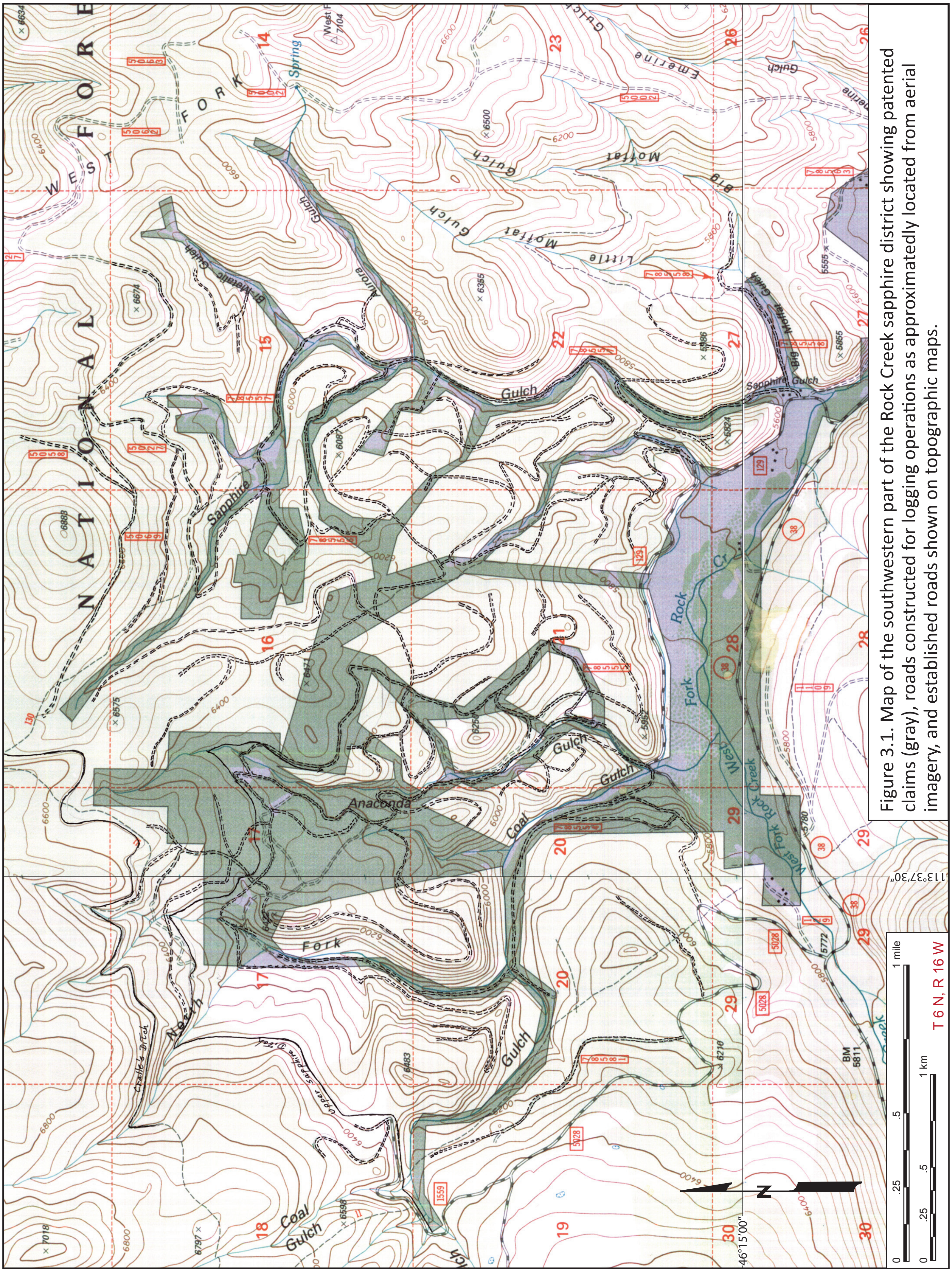


Figure 3.1. Map of the southwestern part of the Rock Creek sapphire district showing patented claims (gray), roads constructed for logging operations as approximately located from aerial imagery, and established roads shown on topographic maps.

Figure 3.2. Volcaniclastic sediment exposed in bank next to mined gulch at McLure Placer.

western extent. At the eastern limit of mining, cuts extend down to Sapphire Gulch and trend about S 40^0 E. Four small remnants of unmined material (similar to those observed at Maley Gulch) were left between the windrows of boulders and cobbles. The material mined was gray sandy alluvium containing scattered boulders and cobbles. Ninety percent of the boulders are angular rhyolite like that of the dike on the ridge to the north (fig. 3.3). Most of the smaller cobbles and pebbles are quartzite derived from the Belt Supergroup.

Wildcat Gulch

Location. Wildcat Gulch is a tributary that joins Sapphire Gulch from the west (fig. 1.3).

History. Wildcat Gulch was mined in 1911–1912, and 1921–1923, with a total reported production of 152,792 avoirdupois ounces (4,330 kg) of sapphires (table 1.1).

Description. This gulch was mined almost throughout its entire length (fig. 1.3). In the lower part, south of the main gulch, gray colluvium (fig. 3.4) was mined over a large area extending almost to Sapphire Gulch. Mining of the colluvium appears to be more recent than that farther up the gulch, where evidence of mining extends for 800 m (2,500 ft) and scattered piles of boulders consist of a mixture of subangular to subrounded gray and pink quartzite from the Belt Supergroup and more angular boulders of rhyolite. Downstream from the dike, exposed between Wildcat and Sapphire Gulches (fig. 2.1), 90 percent of the cobbles are rhyolite, with the remainder quartzite. Two ditches situated just north of Wildcat Gulch, one of which is close to the upper limit of mining in this gulch, may have brought water from the Upper Sapphire Ditch.

Meyer Gulch

Location. Meyer Gulch is a tributary to Sapphire Gulch from the northwest (fig. 1.3). This gulch was probably named for Emil Meyer, who is credited with discovering sapphires in this district in 1892 (Domine, 2009, p. 329).

History. Meyer Gulch was mined in 1910, 1920, and 1921, but production records are not available. The lower part of the gulch has been mined more recently, with a large area along the gulch reclaimed.

Description. Gray colluvium containing boulders and cobbles of quartzite was mined in the lower part of this placer (fig. 3.5). Thickness of colluvium is judged to be 2–3 m (6–10 ft). There are no well-

Figure 3.3. Angular rhyolite boulders and cobbles piled during mining of Ewing Placer.

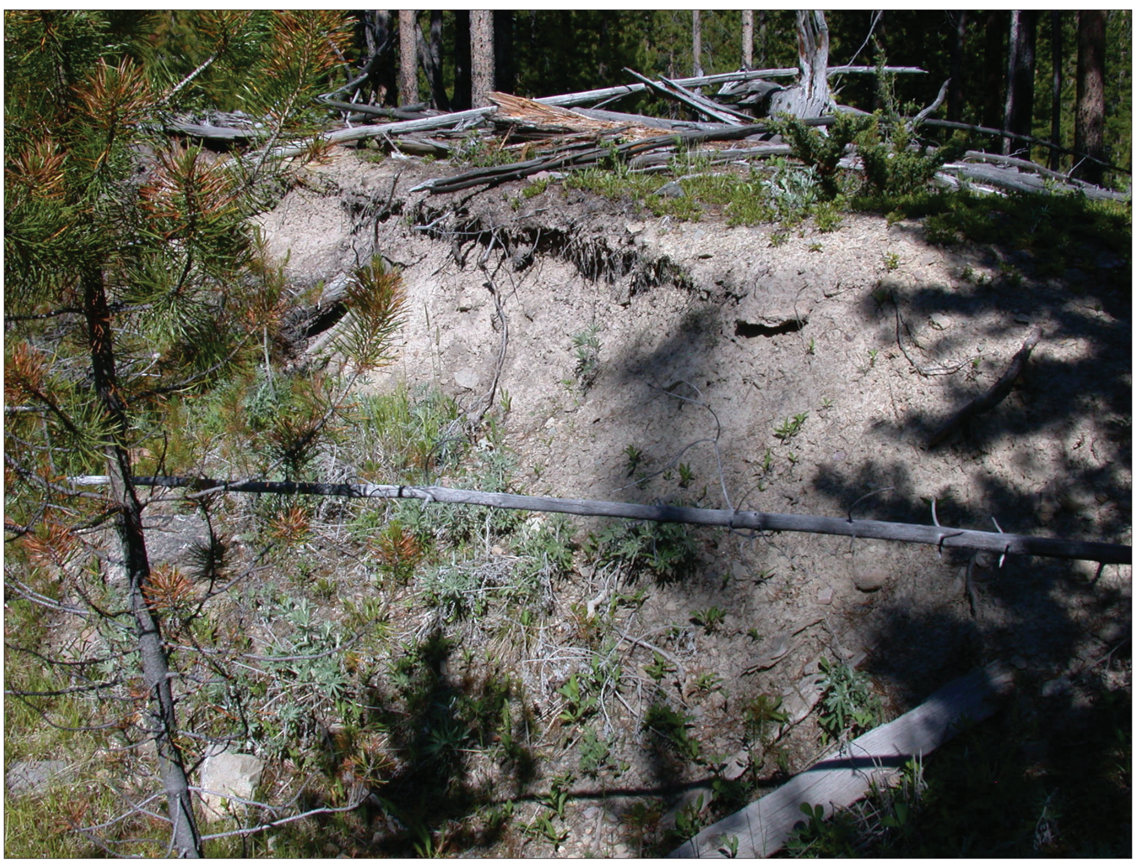


Figure 3.4. Exposure of colluvium mined in the lower part of Wildcat Gulch.

defined windrows of boulders and cobbles in Meyer Gulch, but there are isolated piles of the oversize gravel. An estimated 30 percent of the boulders are subangular to subrounded quartzite of the Belt Supergroup, with the remainder rhyolite, limestone, and dolomite. The most likely source of the limestone and dolomite is the Piegan Group, which has not been recognized close to this gulch.

Figure 3.5. Gray colluvium that was mined in the lower part of Meyer Gulch. Quartzite cobbles in the colluvium shown by arrows.

Queen Gulch

Location. This is the southernmost of three gulches that enter Sapphire Gulch from the west (fig. 1.3).

History. Reported production is 3,371 avoirdupois ounces (95.5 kg) in 1923 (table 1.1).

Description. This short, narrow gulch was mined within approximately 45 m (15 ft) of an old road that crossed the gulch 38 m (100 ft) in elevation above the main course of Sapphire Gulch. Although there was some placer mining below the road, most mining was above the road, where there is a windrow of cobbles in the middle of this narrow gulch (fig. 3.6). Gray colluvium is exposed on both sides of the mined gulch. It is estimated that 30 percent of the cobbles piled in the windrow are pink quartzite of the Belt Supergroup.

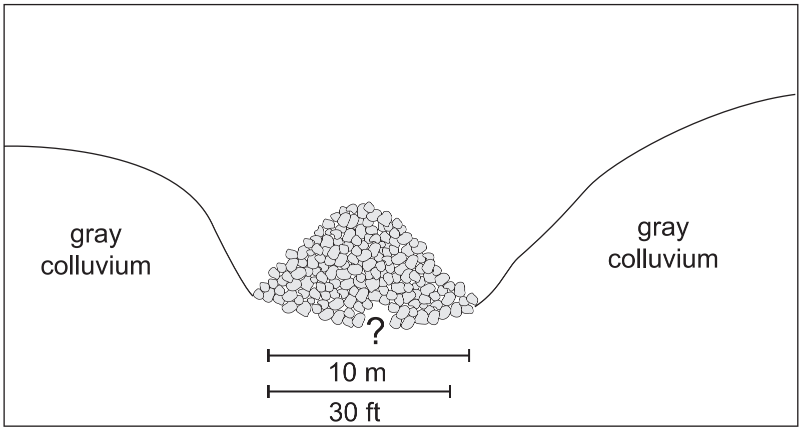


Figure 3.6. Cross section of Queen Gulch showing windrow of cobbles piled in the middle of the gulch surrounded by banks of colluvium.

Bi-Metallic Gulch

Location. Bi-Metallic Gulch is a tributary to Sapphire Gulch from the northeast (fig. 1.3).

History. Information on past mining was not found.

Description. Other than a test pit near the mouth of this gulch, no evidence of additional testing or mining was found.

Aurora Gulch

Location. Aurora Gulch is a tributary to Sapphire Gulch from the northeast (fig. 1.3).

History. Information on past mining was not found.

Description. A shallow test pit about 100 m (300 ft) above the main road up Sapphire Gulch is the only evidence of mining or prospecting activity.

Little Moffatt Gulch

Location. Little Moffatt Gulch joins Big Moffatt from the north (fig. 1.3).

History. Little Moffatt and Big Moffatt gulches were undoubtedly named for L.H. Moffatt, who was involved in mining sapphires in this district before September 1, 1899 (Domine, 2009, p. 329). Note that Moffatt was mistakenly spelled Moffit on the 1908 claim map (fig. 1.5).

Description. Scattered gravel piles indicate limited mining along this gulch. A small amount of gravel was mined at the confluence of Little Moffatt and Big Moffatt gulches, where in 2010 there was a small washing plant with a trommel and a settling pond.

Big Moffatt Gulch

Location. Big Moffatt Gulch joins Sapphire Gulch just above its confluence with West Fork Rock Creek (fig. 1.3).

History. Both Little Moffatt Gulch and Big Moffatt Gulch were named for L.H. Moffatt.

Description. The lower 0.3 km (0.2 mi) of this gulch was mined. Bedrock is not exposed.

Maley Gulch

Location. Maley Gulch is situated between Anaconda and Sapphire Gulches (fig. 1.3) and was named for Al Maley, a rancher and trapper from West Fork Rock Creek (Domine, 2009, p. 433).

History. Historic production records are not available, but it is reported that Carpp and Kaiser mined this gulch during the summer of 1938 (Smith, 1964, p. 184).

Description. Maley Gulch has been mined along most of its extent (fig. 1.3). Judging from the lack of windrows of boulders and cobbles in lower Maley Gulch, mining was either not as extensive as in the upper part of the gulch or this area has been completely reclaimed.

The following description is of the area of extensive mining near the head of the gulch shown in the SW¼SE¼ sec. 16, T. 6 N., R. 16 W. (fig. 3.7). Remnants of small ditches used in ground sluicing can be seen on both sides of the mined gulch, and several short lengths of canvas fire hose used in hydraulic mining remain in the mined area. Presumably water came from the Upper Sapphire Ditch 0.7 km (0.45 mi) uphill. Several ridges of unmined alluvium are surrounded by windrows of cobbles and boulders. Apparently the grade was simply too low to justify mining these areas even though water was available. Boulders and cobbles left in windrows are mainly angular to slightly rounded pink quartzite derived from the Belt Supergroup (fig. 2.21). Angular rhyolite cobbles are rare, as are rounded monzogranite cobbles. Tuff is exposed between windrows in the bottom of the gulch, and volcaniclastic rock is exposed in the eastern part of the mined area. This volcaniclastic rock contains pebbles and granules of quartzite, siltite, and rhyolite in a matrix of plagioclase fragments, biotite, K-feldspar, and quartz in extremely fine-grained material. The alluvium exposed in the bank, in addition to rare quartzite and altered tuff pebbles, consists mainly of fine sand and silt. The sand-size fraction of this material contains, in order of decreasing abundance: glassy quartz, milky quartz, rhyolite, plagioclase, and rare euhedral zircons. It is likely that this mined area consisted of several gulches that coalesced downstream between the remaining unmined ridges. The windrows left from placer mining contain abundant cobbles, whereas only pebbles were seen in the banks of unmined material, suggesting that sapphires were more abundant in the coarse gravel.

A bench placer was mined on the west bank of Maley Gulch in the NW¼SW¼ sec. 22, T. 6 N., R. 16 W. The placer is situated 12 m (38 ft) above the bottom of the gulch on bedrock of the Piegan Group and occupies an area 37 m (120 ft) wide by about 150 m (500 ft) parallel to the gulch. The gravel mined here is similar to that of the previously described mine farther up the gulch and is estimated to consist of 95 percent quartzite and 5 percent rhyolite. More recent mining by Ken Lutz farther up the bank west of this bench placer reportedly recovered sapphires down to a depth of about 2 m (6 ft) in the colluvium. This area has been reclaimed.

Anaconda Gulch and Tributaries

Introduction

Anaconda Gulch was the richer of the two major gulches (Sapphire and Anaconda) for which historical production figures are available (table 1.1). Total re-

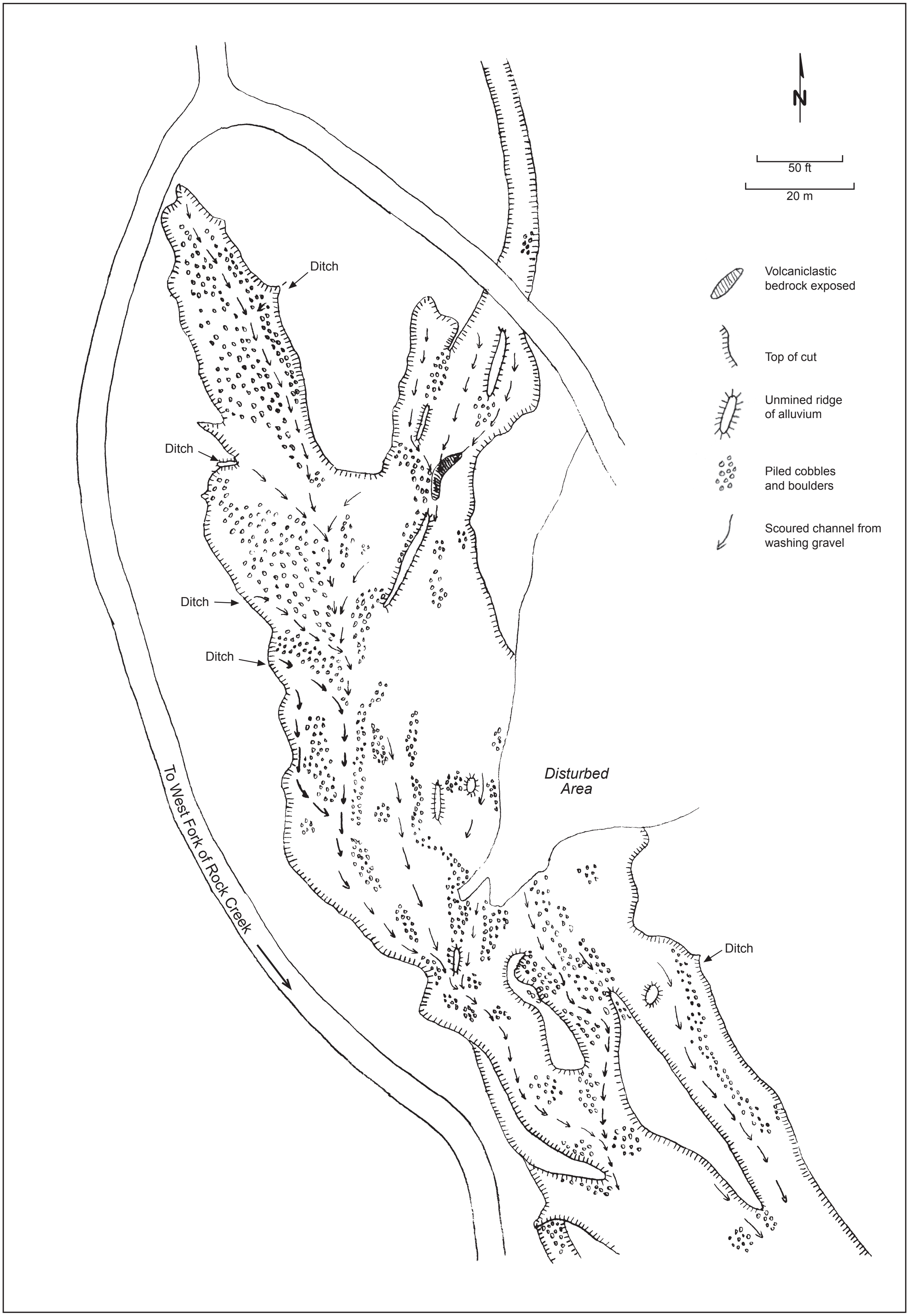


Figure 3.7. Area of extensive mining in the SW¼ SE¼ sec. 16, T. 6 N., R. 16 W. near the head of Maley Gulch. Tape and compass map by R.B. Berg, September 2009.

ported production for Anaconda Gulch was 22,010 kg for the years 1906 through 1928, for an average yield of 1,400 kg/100 m for the mined portion of this gulch (table 1.1, fig. 1.3). This figure does not include production from tributary gulches (Mink and Black Pine), which is given separately, nor Carpp's mine and other more recent mining near the head of Anaconda Gulch. There is no evidence of significant mining in the narrow stretch from Mink Gulch to the vicinity of Carpp's mine at the head of the gulch. Below this stretch, Anaconda Gulch widens and has been mined extensively, as judged from the piled cobbles and rare boulders.

Carpp's Mine

Location. Situated just below the Upper Sapphire Ditch on the west side of uppermost Anaconda Gulch (fig. 1.3).

History. It was reported that in 1937 the American Gem Syndicate sold their sapphire claims to Charles Carpp, Jr. and J. Walter Kaiser (Domine, 2009, p. 373). Carpp, who had been foreman of the previous sapphire mine, mined this deposit in 1939, 1940, and 1941 (Marc Bielenberg, oral commun., 2006). Carpp attempted to sell these sapphires to the gemstone market, but was unsuccessful because of their pale color, which at this time was not routinely enhanced by heat treatment (Marc Bielenberg, oral commun., 2006).

Description. Windrows of generally angular quartzite cobbles remained from Carpp's mining until 2009, when they were obliterated by recent mining. Sapphires were apparently recovered by individuals digging shallow (<2 m) pits in colluvium just west of these windrows. The inference from the distribution of windrows and disturbed material is that mining was confined to a depth of only a little more than a meter. Colluvium formed from weathered rhyolite contained quartzite cobbles largely derived from the Snowslip Formation just uphill. Sapphires mined by Carpp were reported to be covered with a coating of rhyolite (Marc Bielenberg, oral commun., 2007) or clay (Buss Hess, oral commun., 2009). It seems more likely the coating was clay, specifically kaolinite, as was observed on some sapphires from Anaconda Bench and the pit near the head of North Fork Coal Gulch (see Chapter 4 for detailed description of this coating). Poorly exposed rhyolite above the area of mining shows alteration of plagioclase to kaolinite.

Anaconda Bench

Location. Anaconda Bench is a large anomalous flat area between the rhyolite ridge located just east of Coal Gulch and low rhyolite exposures west of Anaconda Gulch (fig. 1.3).

History. American Gem Corporation mined more than 4 million carats (800 kg) for the gemstone market from Anaconda Bench and from Dann Placer during 1994–1996 (Kane, 2003). American Gem Corporation is an entirely different company than the American Gem Mining Syndicate that was involved in the early days of mining in this district. In 2001 Gem Mountain acquired the holdings of American Gem Corporation and since then has mined sapphires from Anaconda Bench for the sapphire concentrate they sell to the public, who recover sapphires by screening (fig. 1.10).

Description. Anaconda Bench differs in several ways from other deposits in the southwestern part of the Rock Creek sapphire district. Unlike the gulch placers or the small deposits in colluvium that were mined near the heads of gulches, it is of large areal extent. Also unlike most of the alluvial deposits where quartzite cobbles are abundant, greater than 99 percent of the cobbles on Anaconda Bench are rhyolite. The bedrock geology is obscured because of extensive mining, reclamation, settling ponds, washing plant, shop, and stockpiles. The most detailed information is provided by Garland (2002), who showed sketches of trenches in the southern part of the bench. The following observations are from these three sketches.

The bedrock at a depth of 1–3 m (4–9 ft) is volcaniclastic sediment characterized by clay that contains organic material and sapphires along fractures between blocks. The overlying beds are fine sand, coarse sand, clayey sand, and a mixture of silty sand with clay and some gravel. Figure 3.8 shows beds exposed in the southern part of Anaconda Bench during mining in 2009. Moderately well-sorted pebble beds alternate with granule and sand beds. A pebble bed consists of angular rhyolite and tan to pink quartzite pebbles. The quartzite pebbles are similar to the quartzite cobbles encountered during mining at Carpp's Mine and east of the head of North Fork Coal Gulch that were attributed to the Snowslip Formation exposed to the north. The sand beds described by Garland and the beds shown in figure 3.8 indicate that this material was water-sorted, perhaps by sheetwash. Rhyolite cobbles in mined material on Anaconda Bench were probably derived from the rhyolite ridge just west of the bench. Quartzite pebbles from metasedimentary rocks of the Belt Supergroup exposed north of the bench indicate transport to the south. If the hypothesis that a bedrock source of sapphires was rhyolite exposed just above the Upper Sapphire Ditch is correct, sapphires were carried onto the bench along with the quartzite pebbles (see discussion of bedrock source of sapphires in Chapter

Figure 3.8. Granule and pebble layers exposed in cut in sapphire-bearing alluvium on Anaconda Bench.

5). Sapphire grade in the Anaconda Bench deposit is reported to be highly variable. Sampling conducted by American Gem Corporation on Anaconda Bench showed samples with 10 g/bcy and one with 20 g/bcy of sapphires (Garland, 2002).

"Dismal Swamp"

Location. The small depression between Anaconda Bench and Anaconda Gulch has been called the "Dismal Swamp," even though it is not very swampy (fig. 1.3).

History. This area has been mined on a relatively small scale by individuals over the past 20 years and also by past operators who sold buckets of sapphire-bearing gravel to the public.

Description. The Dismal Swamp apparently served as a trap for sapphires eroded from Anaconda Bench before being transported down Anaconda Gulch. There is no evidence of significant placer mining in the narrow stretch of Anaconda Gulch east of the Dismal Swamp. It is reported that the Dismal Swamp is known for the high concentration of sapphires in a relatively small area.

Mink Gulch

Location. Mink Gulch is the northernmost of three mined gulches that enter Anaconda Gulch from the east (fig. 1.3).

History. Reported production for the years 1916–1917 is 1,031 kg, which gives a rate of 1,200 kg/100 m of gulch for the less than 100 m of gulch mined (fig. 1.3).

Description. There was only limited mining of this short gulch.

Black Pine Gulch

Location. Black Pine Gulch is a short gulch that joins Anaconda Gulch from the east just downstream from Mink Gulch (fig. 1.3).

History. Production from Black Pine Gulch is reported to be 228,790 avoirdupois ounces (6,475 kg or 1.3 tonnes) during the years 1916–1919 (table 1.1).

Description. This gulch was considerably richer than other gulches mined during the same years of peak production. Approximate calculations show that Black Pine Gulch yielded an average 2,800 kg of sapphires/100 m of gulch mined as compared to the average for Anaconda Gulch of 1,400 kg /100 m of gulch mined. Although these figures do not actually indicate grade of the gravel mined, they do offer an indication that Black Pine Gulch was a rich gulch. There are several factors that may have contributed to the gulch's relative richness: it was wider than most other gulches or sapphires were recovered more efficiently than in other gulches.

Examination of black and white aerial photos and color infrared images show a roughly circular feature about 70 m (230 ft) in diameter close to the head of Black Pine Gulch in the NW¼NE¼NW¼ sec. 21, T. 6 N., R. 16 W. (fig. 3.1 and locality 8, fig. 2.1) above the area mined. This area is devoid of trees, is marshy, and contains standing water. Under about 10 cm of mud there is well-consolidated detritus, similar to the material found in a prospect pit near the head of North Fork Coal Gulch, produced by *in situ* weathering of the surrounding rhyolite. Sapphires were not recovered by sieving the >1 mm fraction of a sample of this material from the marshy area nor were sapphires identified in panning the <1 mm fraction. The origin of the circular marshy area remains unexplained, but there is no evidence that it was excavated in an effort to find the bedrock source of the Black Pine Gulch sapphires. The intriguing possibility is that this feature is a sapphire-bearing volcanic pipe that contributed sapphires to Black Pine Gulch.

May Gulch

<u>Location.</u> May Gulch is the southernmost tributary to Anaconda Gulch that has been mined (fig. 1.3).

<u>History.</u> No record of past mining.

<u>Description.</u> The lower part of this gulch appears to have been mined during the early days of mining. Only 5 percent of the cobbles piled aside during this mining are quartzite, with rhyolite accounting for the rest. An area of more recent mining in the upper part of the gulch where it widens out has been reclaimed.

Bench Placer on Lower Anaconda Gulch

<u>Location.</u> This bench placer is on the east side of lower Anaconda Gulch (fig. 1.3).

<u>History.</u> Judging from the size of the trees that have grown on this placer, it was mined during the period of extensive sapphire mining about the same time as Anaconda Gulch was mined.

<u>Description.</u> The lowest part of this bench is approximately 13 m (38 ft) above Anaconda Gulch, and the mined area extends for approximately 170 m (500 ft) along the east side of Anaconda Gulch. Tuff is exposed along the main road to the Anaconda Bench just below the mined area and also in one small exposure within the mined area. An estimated 50 percent of the cobbles are quartzite, with the remainder being rhyolite, although rare monzogranite cobbles are also found. Some of the quartzite cobbles have remnants of an opal coating. A ditch above this placer has been largely obscured by the new road, but was the source of water for placer mining. Freshly broken rhyolite just above the road to the Anaconda Bench was either ripped from bedrock or dumped here.

Coal Gulch Area

Introduction

Five areas of sapphire mining are included in the Coal Gulch area. These are a small area of early mining just below the Upper Sapphire Ditch, an area of recent mining just to the west, lower Coal Gulch, Dann Placer just west of Coal Gulch, and mining along West Fork Rock Creek in an area known as the Meadow.

Mined area just below Upper Sapphire Ditch

<u>Location.</u> Colluvium just below the Upper Sapphire Ditch and above the road from the Anaconda Bench to North Fork Coal Gulch has been mined in two small areas, probably during the peak of sapphire mining activity (fig. 1.3).

<u>History.</u> No information is available on the mining of these two small areas. The western and larger area was mined by ground sluicing with water from the Upper Sapphire Ditch.

<u>Description.</u> A shallow gulch with exposed colluvium extends from the road between the Anaconda Bench and North Fork Coal Gulch down to a recent pit where both colluvium and volcaniclastic sediment were mined. The colluvium is best exposed in a small prospect pit in this shallow gulch (fig. 3.9) and consists of gray clayey material composed mainly of weathered rhyolite fragments and a few angular to subangular pebbles of tan, pink, and gray quartzite pebbles. Except for the concentration of quartzite pebbles in one discontinuous layer a few centimeters thick (fig. 3.10), no evidence of sorting or bedding was recognized. All of the sapphires recovered from this prospect pit are reported to have a tan coating, probably kaolinite. Mineralogy of the sand-size fraction from this pit is as follows: biotite, silver-colored mica (altered biotite), plagioclase, glassy bipyramidal quartz, fragments of concentrically banded kaolinite, unaltered glass shards, some of which have an index of refraction >1.53, other shards that have an index of refraction <1.53, nonmagnetic opaque mineral, euhedral elongate zircons, and stubby rounded zircons.

Figure 3.9. Prospect pit in sapphire-bearing colluvium situated east of the head of the North Fork of Coal Gulch. Black lines on shovel handle 5 cm apart.

Coal Gulch Pit

Location. This pit is located east of North Fork Coal Gulch (fig. 1.3).

History. Gem Mountain mined sapphires here shortly after their acquisition of this area in 2001.

Description. Sapphires were mined from both volcaniclastic sediment and colluvium. The volcaniclastic sediment contains scattered pumice lapilli and quartzite cobbles similar to quartzite in the Snowslip Formation. Clay seams along fractures in the volcaniclastic sediment are interpreted to indicate extended weathering before deposition of sapphire-bearing colluvium (fig. 3.11). Clay along fractures in the volcaniclastic sediment resembles that described by Garland (2002) as clay that contains organic material and sapphires between blocks of the sediment on the Anaconda Bench. X-ray diffraction analysis of clay separated from the colluvium in the pit on North Fork Coal Gulch showed it to consist of smectite, a 10Å mineral (probably biotite), and kaolinite. The volcaniclastic sediment is overlain by colluvium that contains rhyolite and quartzite pebbles, and cobbles. Remnants of rhyolite adhering to some of the quartzite cobbles indicate that they were incorporated in the rhyolite lava flow.

Figure 3.10. Concentration of quartzite pebbles and granules in lens in colluvium exposed in prospect pit shown in figure 3.9.

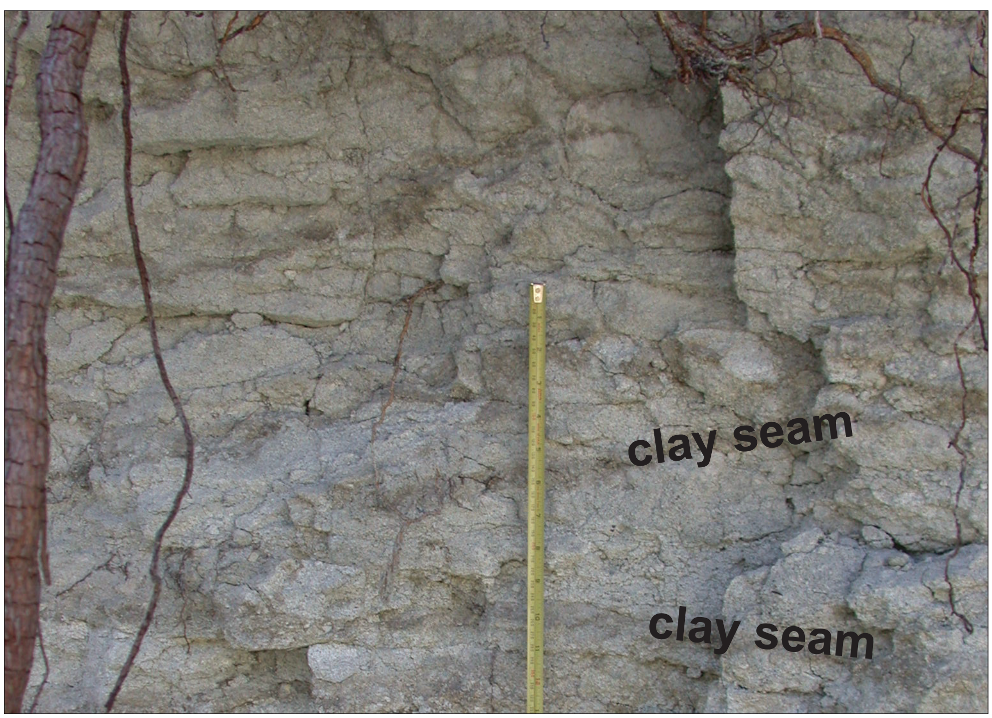


Figure 3.11. Volcaniclastic sediment exposed in Coal Gulch pit showing clay-rich seams along fractures. Tape is extended one-third meter.

Lower Coal Gulch

Location. Coal Gulch is the westernmost of the four major gulches (Coal, Anaconda, Maley, and Sapphire) that flow into West Fork Rock Creek and have been mined for sapphires (fig. 1.3). This gulch was evidently named for the thin bed of coaly material exposed on its south side (fig. 2.1, locality 4).

History. During 1916, 1917, and 1920, reported sapphire production from the Half Moon Placer was 1,888.7 kg (table 1.1). The extent of the Half Moon Placer is unclear from the historic claim maps (figs. 1.5, 1.6) but may include part of Coal Gulch. On the basis of the extent of the piles of cobbles on the lower part of Coal Gulch, actual production of sapphires must have greatly exceeded this figure.

Description. Evidence of mining along Coal Gulch stops abruptly a short distance west of its confluence with North Fork Coal Gulch and also extends only a short distance up North Fork Coal Gulch. Several shallow prospect pits along Coal Gulch west of the mined area indicate that the alluvium was tested and was apparently of insufficient grade to be profitably mined. The reason for the abrupt termination of mining on North Fork Coal Gulch is unclear. It may be that mining ceased at the time that the introduction of synthetic sapphires abruptly ended the market for natural sapphires for watch bearings. An interesting observation that may have some bearing on the abrupt termination of mining on North Fork Coal Gulch is the difference in lithology of cobbles in the alluvium. At the confluence of Coal Gulch and North Fork Coal Gulch, essentially all of the cobbles are quartzite, whereas to the north along North Fork Coal Gulch it is estimated that only 5 percent of the cobbles are quartzite, with the remainder rhyolite. The lithologic difference raises the possibility that the sapphires were transported with the quartzite cobbles, and thus where there are mainly rhyolite cobbles, there are few sapphires. Samples collected by the American Gem Corporation along North Fork Coal Gulch show grades of 10 g/bcy (Garland, 2002).

Dann Placer

Location. Dann Placer consists of an upper placer close to and on top of a ridge and a lower placer downslope to the east next to Coal Gulch (figs. 1.3, 3.12).

History. This deposit was not mined during the early days of intense mining in this area, presumably because of the lack of water. It is situated more than 1.5 km (1 mi) from the Upper Sapphire Ditch and close to but above the lower ditch. Between 1994 and 1996 the American Gem Corporation reportedly mined 4 million carats (800 kg) of sapphires from the Anaconda Bench and from Dann Placer (Kane, 2003). After Gem Mountain acquired the holdings of American Gem Corporation in 2001, they offered fee digging to the public at Dann Placer for several years. Robert Glenn mined sapphires from upper Dann Placer at about the same time. Both upper Dann Placer and lower Dann Placer have been reclaimed. Dann Placer is reported to be very rich according to Buss Hess, who mined sapphires in the southwestern part of the Rock Creek district for 15 years (Buss Hess, oral commun., August 2007).

Description. Alluvium mined to a depth of 2 m (6 ft) at the upper Dann Placer consists of angular and subrounded quartzite pebbles and cobbles in a clayey matrix largely composed of rhyolite granules, similar to the material mined in the area east of North Fork Coal Gulch. The Tertiary alluvial fan to the southwest is the most likely source of the quartzite; rhyolite granules are detritus from weathering of rhyolite to the west. Sapphires have been mined from colluvium from the surface to a depth of 0.5 m (1.5 ft; fig. 3.13) on the east side of the ridge on upper Dann Placer. The >1 mm size fraction from the sandy layers consists mainly of quartzite and rhyolite granules, whereas the finer fraction consists of quartz, potassium feldspar, rhyolite fragments, and plagioclase. Trace constituents are zircon, biotite, and glass with an index <1.53. Between the upper and lower Dann Placers, sapphires have been recovered along the road above the trees from colluvium between horizontal ledges of quartzite of the Belt Supergroup (fig. 3.11). Lower Dann Placer has been reclaimed.

Area along the West Fork of Rock Creek (the Meadow)

Location. The Meadow is the broad area of alluvium along West Fork Rock Creek mainly between the mouth of Coal Gulch and the mouth of Sapphire Gulch (fig. 3.14).

History. The following information is from Jim Brown, who worked for Day Mines when they sampled gravel in the Meadow near the mouth of Coal Gulch where both Coal and Anaconda Gulches join the Meadow (Jim Brown, oral commun., February 2001).

1974—Sampled the gravel using a Becker drill that drilled a hole of 6–8 in. in diameter. Samples were taken at 4-ft intervals in glacial deposits and then at 2-ft intervals in the river gravels. Garnets were much rarer than sapphires and there was some magnetite and hematite.

1975—Dug three 7-ft-diameter holes using cais-

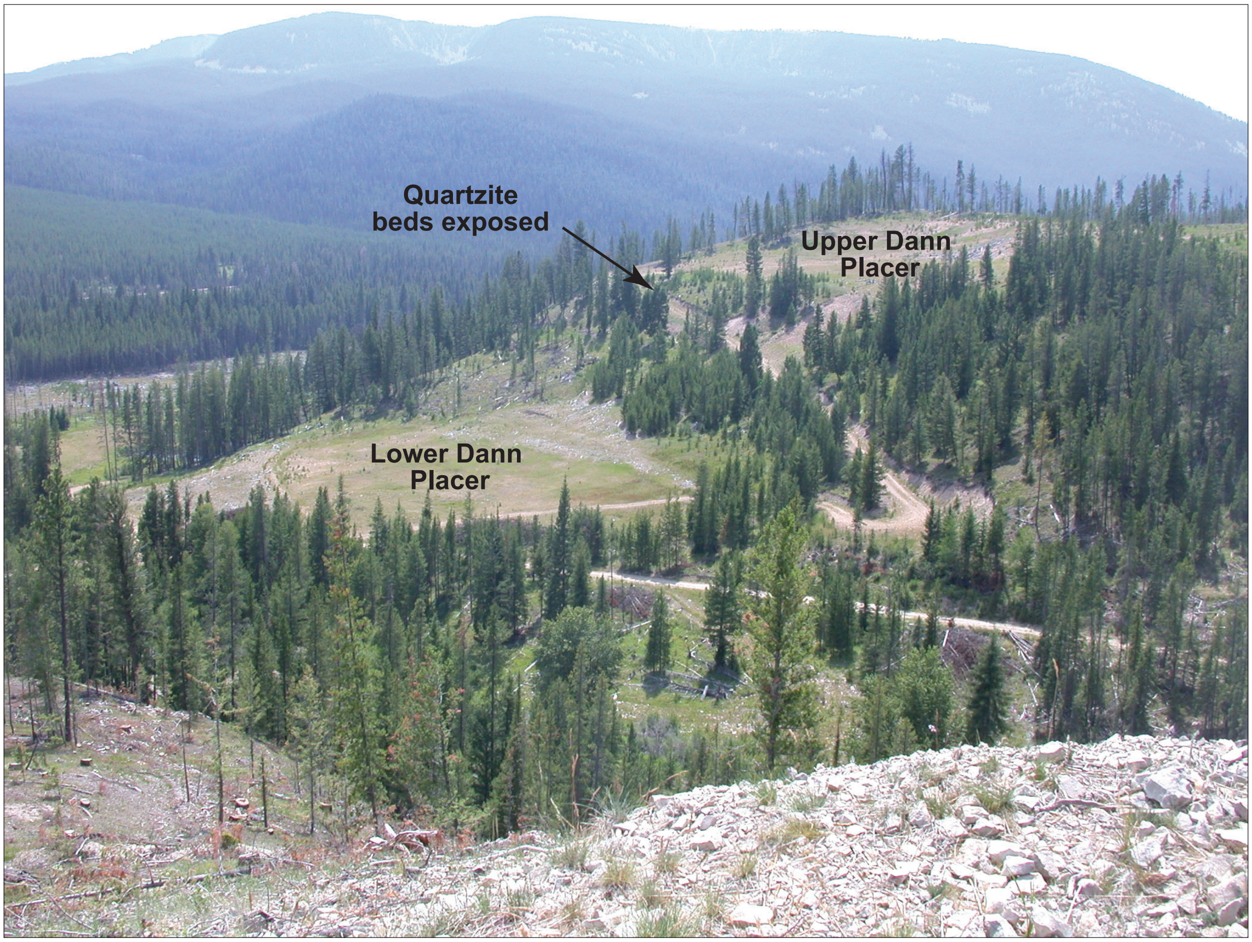


Figure 3.12. Photo looking across Coal Gulch to Dann Placer. Ledges of quartzite of the Snowslip Formation exposed along the road between Upper and Lower Dann Placer.

sons and small clam shell. The results of this sampling agreed remarkably well with the Becker drill results. The highest grades were on bedrock of the Belt Supergroup.

1976—Constructed a small washing plant and jigs and did bulk sampling. After investigating the market they found that although the sapphires showed pretty colors and were considered fancies, they had no market. The bulk sampling was done before sapphires from the Rock Creek district were routinely heat treated. This sampling showed the presence of approximately 5 tonnes of sapphires in what was considered a mineable deposit (Emmett and Douthit, 1994).

A few years later in 1989, 1990, and 1992, Skalkaho Grazing mined sapphires near the west end of the Meadow in the area that Day Mines had sampled, and processed this material in the floating washing plant shown in figure 1.9. By this time the pale colors in Montana's alluvial sapphires were routinely enhanced by heat treatment. An exhaustive study by Emmett and Douthit (1994) of 70,000 sapphires mined by Skalkaho Grazing showed that the color of approximately 65 to 70 percent of these sapphires could be significantly enhanced by heating under carefully controlled conditions.

Description. The area sampled by Day Mines is only that part of the Meadow below Coal and Anaconda Gulches and does not include those areas that received sapphires from Maley and Sapphire Gulches. It is reasonable to assume that the total sapphire reserves of the Meadow significantly exceed the approximately 5 tonnes of sapphires identified by Day Mines.

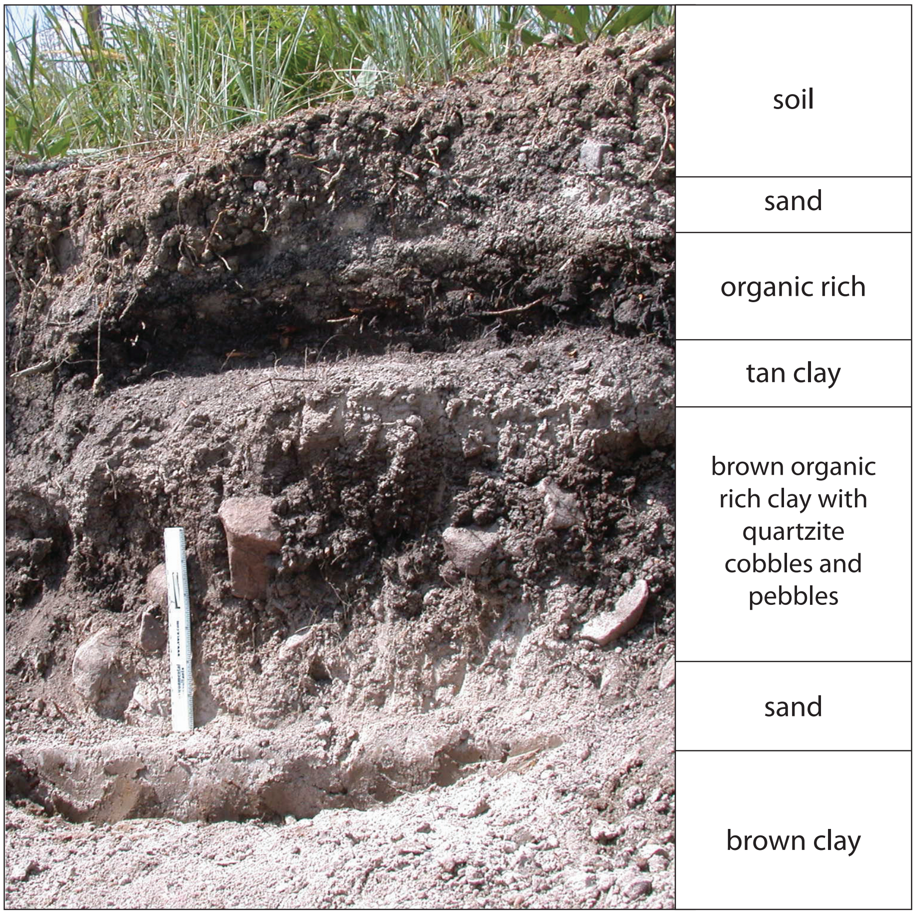


Figure 3.13. Sapphire-bearing colluvium near the top of the ridge on Upper Dann Placer. Ruler 6 inches (15 cm long).

Figure 3.14. The Meadow looking toward the mouth of Coal Gulch with reclaimed Lower Dann Placer in the background.

CHAPTER 4

DESCRIPTIONS OF SAPPHIRES

Introduction

This chapter is devoted entirely to the physical properties of the sapphires from the Rock Creek sapphire district. These include color, size, shape, surface morphology, adhering material, and mineral inclusions. A significant part of this chapter is devoted to surface morphology illustrated with scanning electron micrographs. Oxygen isotope analyses are presented in appendix 4.

Color

Sapphires from the southwestern part of the Rock Creek sapphire district come in a variety of colors, but the majority are pale green (fig. 4.1). Blue sapphires and sapphires in many shades of pink are also found in this district, as are extremely rare rubies. Some of the pink sapphires weakly fluoresce 'orangish'-red under long-wavelength ultraviolet light. Because of their pale colors, most sapphires from the district are heated to enhance their colors for the gemstone market.

Sapphires from the Rock Creek district are the most receptive to heat treating of all the sapphires from Montana (Don Baide, written commun., 2013). Heat treating can also eliminate very small exsolved rutile crystals that produce a silken appearance and are referred to as "silk" by gemologists (see the discussion of exsolved rutile in the section on mineral inclusions). Heat treatment was introduced into the Montana sapphire industry in the 1980s. An extensive study into the heat treatment of 75,000 Rock Creek sapphires recovered from the meadow along West Fork Rock Creek showed that 65–70 percent of these sapphires changed to blue or yellowish-orange depending on the conditions of heating (Emmett and Douthit, 1993). Pale-colored sapphires heated in an oxidizing environment become yellow to orange. Those heated in a reducing atmosphere turn blue (fig. 4.2). During this treatment, the sapphire rough is slowly heated to a temperature between 1,400^{o} and 1,700^{o}C. Heat treatment, as generally employed in the United States, produces colors that are just as stable as the natural colors of sapphires. Only those sapphires without large mineral inclusions or fractures can be subjected to heat treatment without shattering.

Figure 4.1. Sapphires from the southwestern part of the Rock Creek sapphire district. Average size approximately 3 mm. Because of their small size, colors of these sapphires appear less intense than the larger sapphires from this district. Photo by R.B.B.

Figure 4.2. Sapphires from the Rock Creek district that have been heated to enhance their colors. Size approximately 3 to 7 mm. Photo © Tino Hammid, used with permission.

Size

The size distribution of sapphires from the southwestern part of the Rock Creek district is shown in figure 4.3—small sapphires are abundant. A total of 70.4 percent of the total weight of sapphires mined from Anaconda Gulch during the years 1906–1921 and 70.0 percent of those mined from Sapphire Gulch are less than 1 carat. The smallest sapphire positively identified by the author from the southwestern part of the Rock Creek sapphire district was 1.27 mm in maximum dimension. The largest sapphire mined in recent years was recovered near the head of Anaconda Gulch during the summer of 2008 (fig. 4.4). This pale green sapphire weighs 39.14 carats, but is not suitable for faceting because of inclusions. The largest sapphire ever reported from the district was a 45-carat sapphire recovered during the early days of mining (Dale Siegford, oral commun., 2013).

Shape

Most Rock Creek sapphires from this area are roughly equidimensional, but a few are tabular (sometimes called tablets) and have a crude hexagonal outline (fig. 4.5). Although rare, tablets seem to be more abundant in the large sizes (compare the sapphires shown in fig. 4.1 with those shown in fig. 4.5). Tablets may have formed by separation along the basal parting plane. Even rarer than tablets are sapphires that retain the hexagonal prism form of corundum as shown in fig. 4.4. Some small sapphires with frosted surfaces are subrounded (fig. 4.1). Based on comparison using scanning electron microscopy (figs. 22 to 24 in Berg, 2007) of Rock Creek specimens with stream-rounded corundum from Alder Gulch near Virginia City, Montana, as well as rounded sapphires from the South Fork of Dry Cottonwood Creek, rounding of Rock Creek sapphires is attributed to resorption during magmatic transport rather than abrasion during stream transport. The round pebble of corundum from Alder Gulch shows flat fracture surfaces, presumably along parting planes, whereas the round sapphire from the South Fork of Dry Cottonwood Creek shows an entirely different surface with small oriented pits.

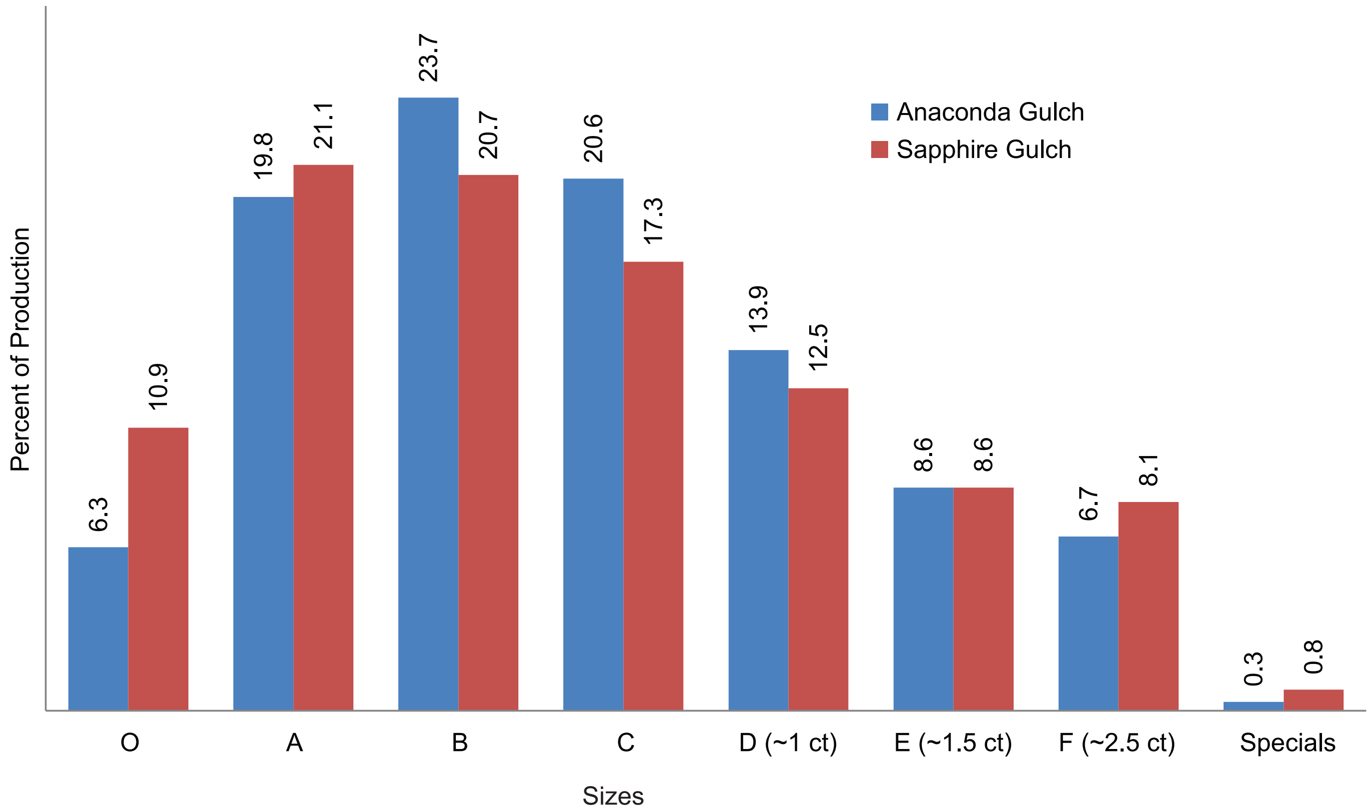


Figure 4.3. Histograms of the size distribution of sapphires from Anaconda and Sapphire Gulches derived from production figures in the log books of the American Gem Mining Syndicate (fig. 1.11). Reported production is for the years 1906–1921 with the exception of the years 1909, 1910, 1914, and 1915, for which no production figures are available. The letter designations are those used in the log books. If it is assumed that these figures are in troy ounces, as it was for other production reported by the American Gem Mining Syndicate, the total reported production for these two gulches is 41.9 tonnes.

SURFACE MORPHOLOGY

Introduction

Like sapphires from other alluvial deposits in Montana, the surface morphology of sapphires from the Rock Creek deposit is the result of three processes: primary growth features, resorption during magmatic transport, and abrasion during fluvial transport or recovery in a washing plant. The observations and interpretations presented here are based mainly on initial optical microscope examination of many sapphires followed by examination of selected sapphires by scanning electron microscopy (SEM) as photographed by Nancy Equall at the Instrument and Chemical Analysis Laboratory (ICAL) at Montana State University. After a cleaning in acetone, the sapphires were coated with graphite or iridium and scanned using a JEOL instrument operated at 20 kv. Sapphires examined were from the following deposits in the southwestern part of the Rock Creek sapphire district: Dann Placer, the Meadow, Anaconda Bench, Dismal Swamp, head of North Fork Coal Gulch, near the head of Anaconda Gulch, and McLure (Rumsey) Placer (fig. 1.3). Notably lacking are sapphires specifically from Sapphire Gulch, which were not available for study. Most of the sapphires examined were culls that would not be considered suitable for heat treatment and faceting because of fractures or mineral inclusions. Only the predominant surface features are described.

Because of the difficulty in separating growth features from solution or resorption features in crystals, some features are described without interpretation. Many of the examined sapphires show a combination of surfaces. For instance, a sapphire may be frosted over much of its surface, but have an irregular surface that covers other areas. I have speculated about the origin of some of these surfaces, but in other cases I have no reasonable explanation for their formation.

Basal Surfaces

Observations

The most distinctive feature of sapphires from the southwestern part of the Rock Creek district are irregular hillocks, small “mesas,” and intervening flat areas found on basal surfaces (figs. 4.6A–F).

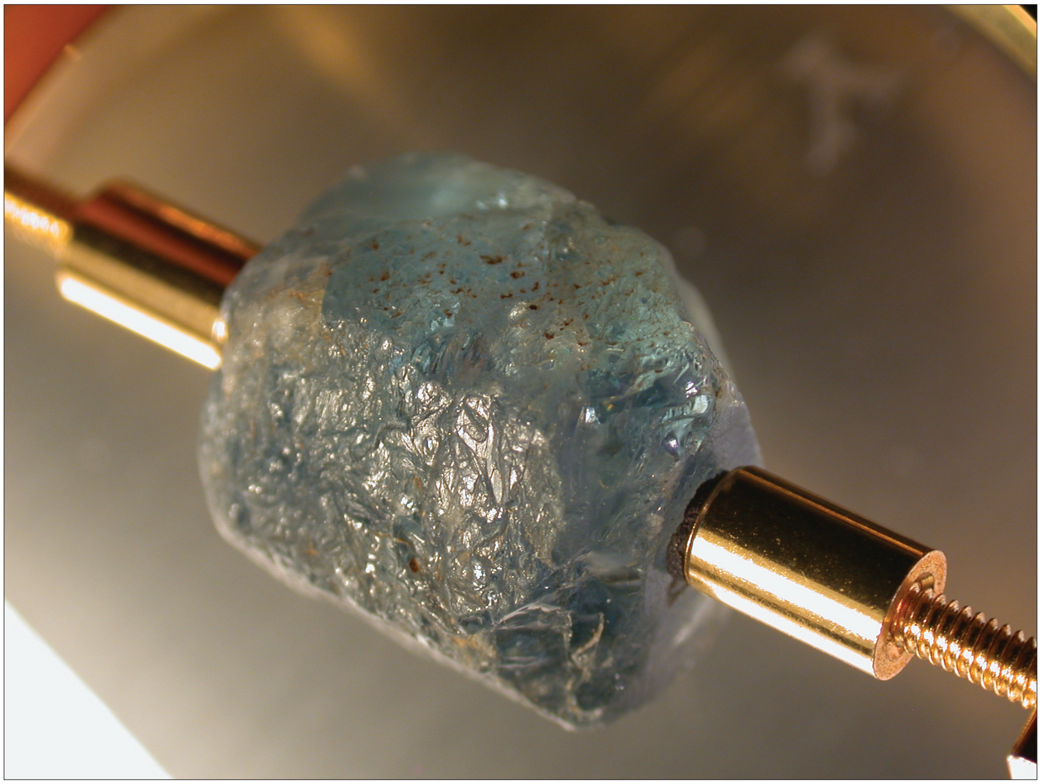


Figure 4.4. Gem Mountain recovered this 39.14-carat sapphire during mining near the head of Anaconda Gulch in 2008. Note the relict hexagonal prismatic form and intricate surface on the prism face. Photo by R.B.B.

Figure 4.5. Assortment of generally equidimensional sapphires with rare tabular sapphires. These sapphires are culls probably mined during the peak of production when the main markets were watch and instrument bearings. Sapphires provided by Jerry Gyldenvand. Photo by R.B.B.

Although the tops of the hillocks often show evidence of abrasion, other features such as the steps on the sides of the mesas show no evidence of abrasion (figs. 4.6D,E). Figure 4.7 shows a triangular pit on the basal surface of this same sapphire. Shallow, parallel grooves occur on some of the flat areas between the mesas and may represent the intersection of rhombohedral parting planes and the basal planes. Microscopic examination of 144 sapphires from the pit near the head of North Fork Coal Gulch showed that 57 percent of these sapphires had small mesas surrounded by flat surfaces on the basal surface. Only 20 percent of 30 sapphires from Dann Placer exhibited similar features; 61 percent of 77 sapphires examined from the McLure Placer had these features. Similar features were not observed on basal surfaces of sapphires from the South Fork of Dry Cottonwood Creek or Lowland Creek in the Butte–Deer Lodge area (Berg, 2007). Sapphires from deposits along the Missouri River near Helena generally lack these hillocks and intervening flat areas (Berg and Equall, 2013).

Interpretation

The mesas and flat areas are thought to be caused by fracturing along the basal parting of the sapphire.

Irregular Surfaces

Observations

Most sapphires from this area have a surface that at least in part can best be described as irregular. The sapphire in fig. 4.8, from Anaconda Bench, is covered with irregular curving planar surfaces punctuated by small pits.

Interpretation

No evidence was recognized that indicates whether this surface is the result of crystal growth or resorption.

Frosted Surfaces

Observations

Frosted surfaces are common on many of the sapphires. In particular, many of the small rounded sapphires are partly covered with a frosted surface. Also, some larger sapphires that have a remnant of the hexagonal prism crystal form of corundum are completely covered with a frosted surface. Figure 4.9A shows the typical “frosted” surface of a subrounded sapphire and figures 4.9B and 4.9C show peculiar pits and irregular projections frequently seen on frosted sapphires.

Interpretation

As discussed in the report on sapphires from the Butte–Deer Lodge area (Berg, 2007), frosted surfaces are attributed to resorption during magmatic transport and not abrasion during fluvial transport. Small, spherical sapphires may be the result of significant resorption in the magma resulting in their spherical shapes, small sizes, and frosted surfaces. The presence of pits together with irregular features on some frosted sapphires is not easily explained, nor is the occurrence of an irregular surface on one part of the sapphire and a frosted surface on its other side.

Abrasion

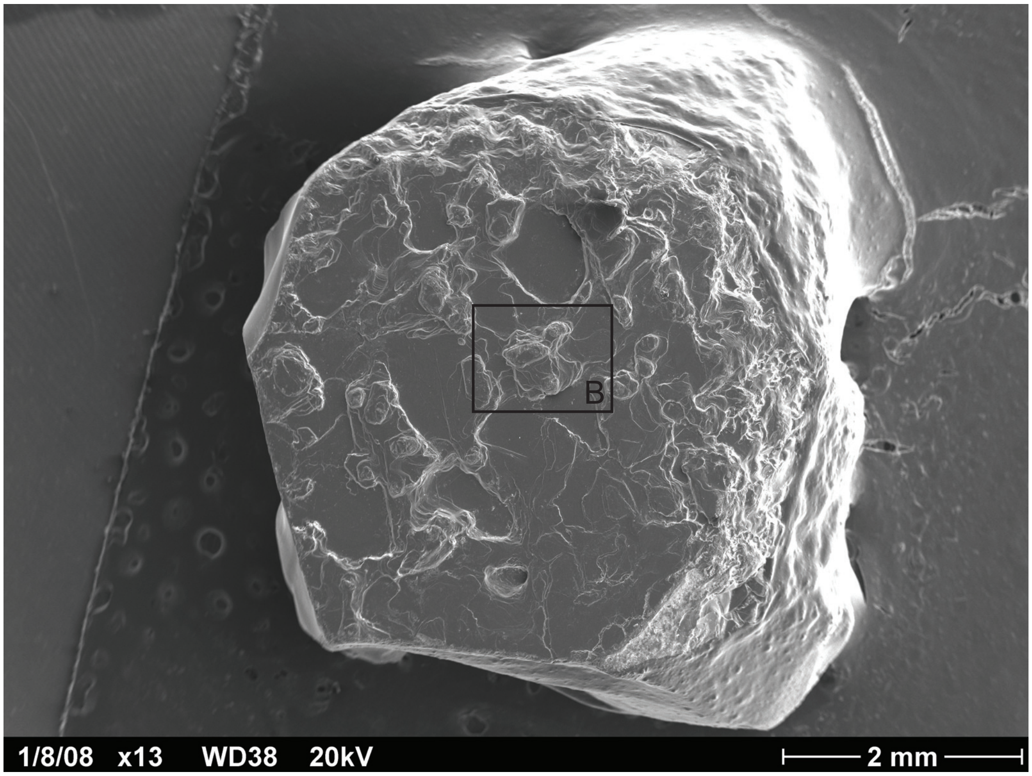
The preservation of delicate surface features on the alluvial sapphires from this district is surprising. However, most of these sapphires, when examined carefully under the binocular microscope, show the effects of abrasion and fracturing that are interpreted as having formed during fluvial transport. Typically projections on the sapphire are chipped, whereas the protected areas show no evidence of abrasion (fig. 4.10).

Some sapphires, particularly the larger ones, exhibit large, glassy conchoidal fractures that presumably formed when they were caught between cobbles during fluvial transport or during processing in the trommel. See the section below on adhering kaolinite for a discussion of the unusual sapphires recovered near the head of North Fork Coal Gulch that are covered with conchoidal fractures.

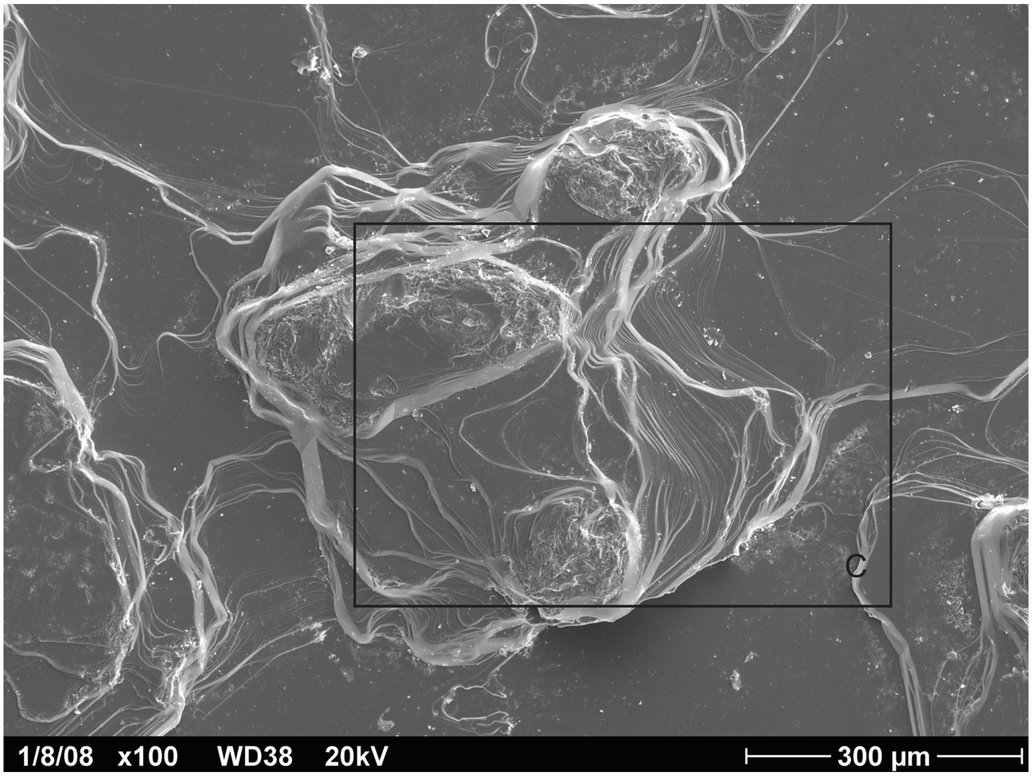
A systematic comparison was not made of the amount of abrasion on sapphires from different localities in this part of the Rock Creek sapphire district, but might provide evidence of differences in distance of fluvial transport.

Conclusions and Speculation

Examination of the surface morphology of sapphires, typically using a binocular microscope, can aid in differentiating between sapphires from different deposits. Many of the sapphires from the southwestern part of the Rock Creek district show distinctive projections, mesas, and small steps on basal surfaces. These features were not seen on any sapphires examined from the South Fork of Dry Cottonwood Creek or Lowland Creek in the Butte–Deer Lodge area. Sapphires from these two alluvial deposits have grooves along the basal and rhombohedral partings, attributed to resorption (Berg, 2007). However, there seems to be a greater variety of surface features on the sapphires from the southwestern part of the Rock Creek district than

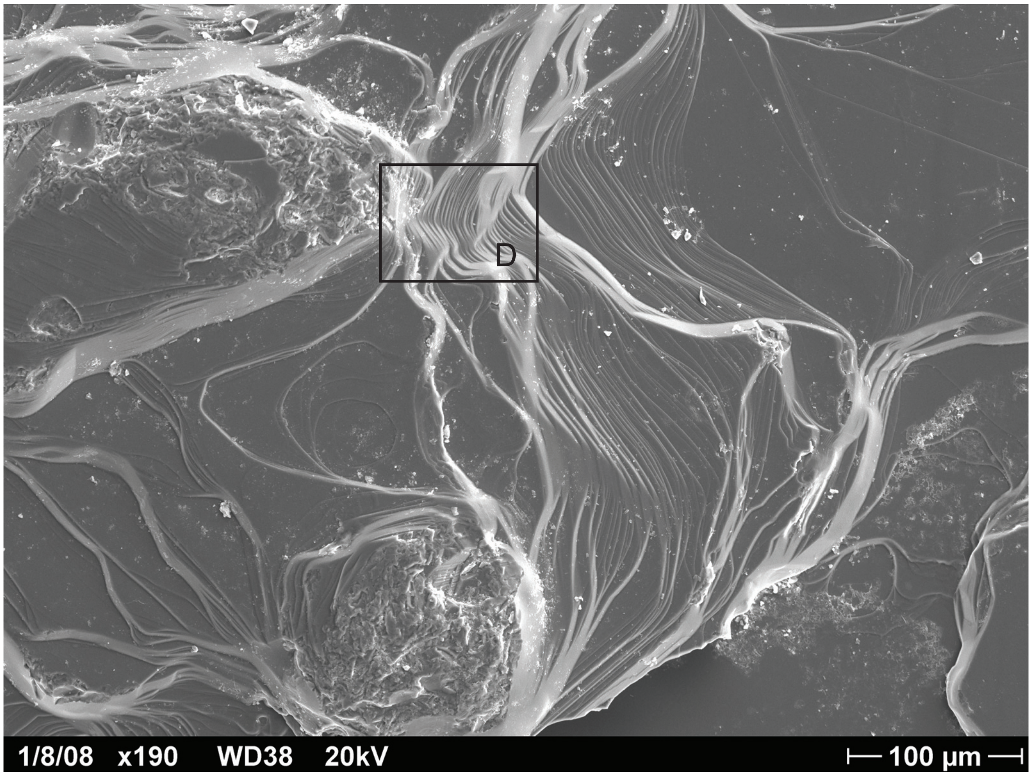


A. Basal surface of sapphire showing irregular hillocks and surrounding flat areas.

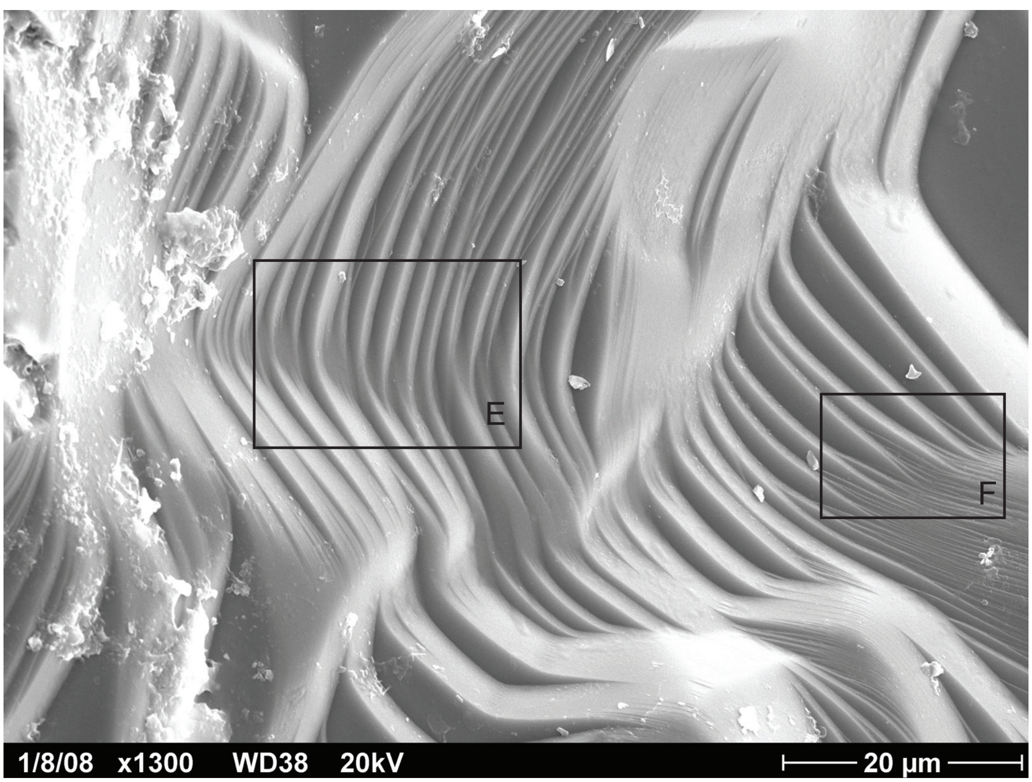


B. Enlargement of hillocks shown in A. Note evidence of abrasion on hillocks.

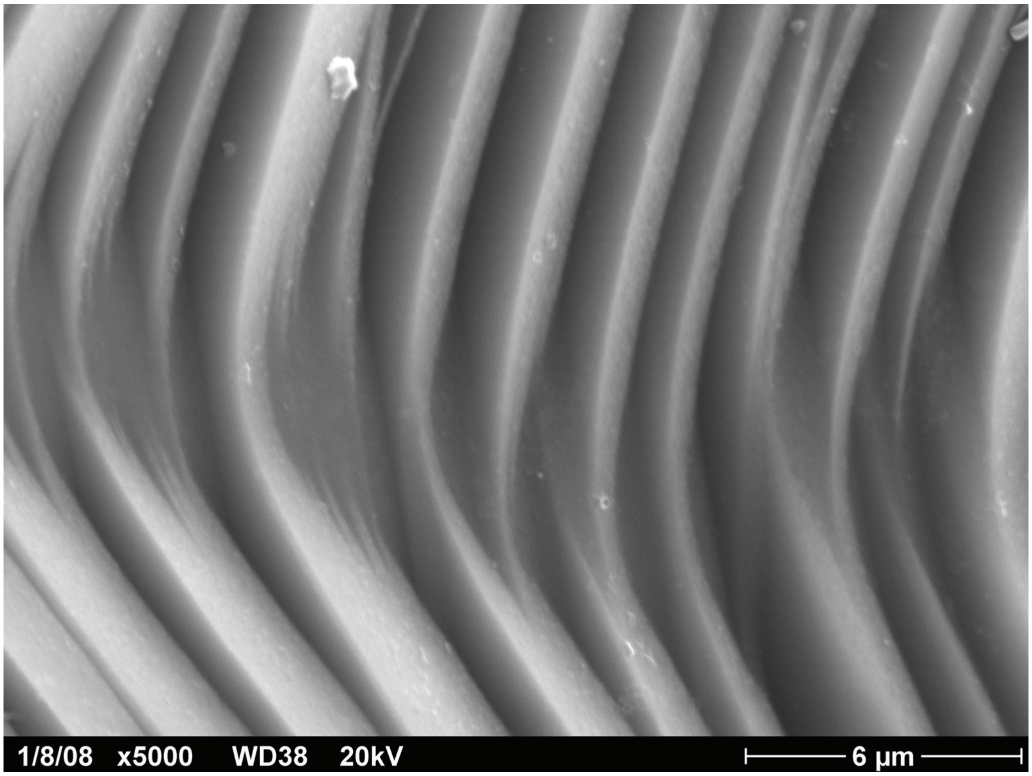
Figure 4.6 (A,B,C,D,E,F). SEM photos of sapphires from Anaconda Bench showing basal surface typical of many sapphires from this district. Photos by Nancy Equall.



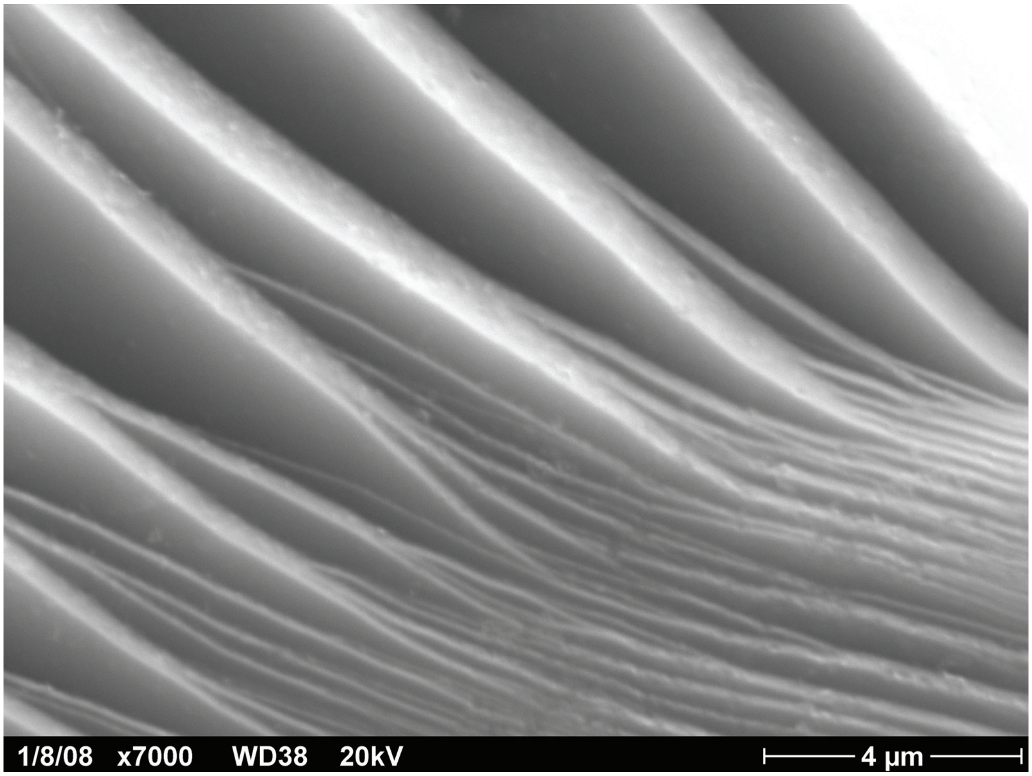
C. Enlargement of small area in B showing steps.



D. Further enlargement of steps.



E. Area of branching steps or ridges.



F. Area of very small ridges.

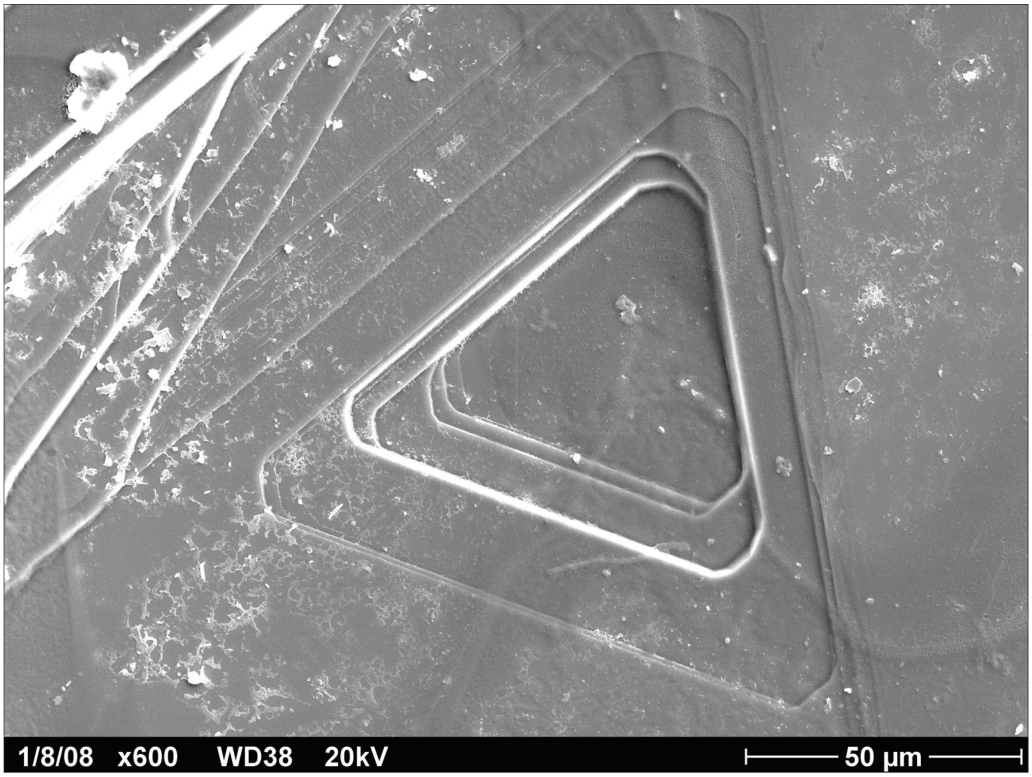


Figure 4.7. SEM photo of triangular pit on the basal surface of the same sapphire shown in fig. 4.6. Photo by Nancy Equall.

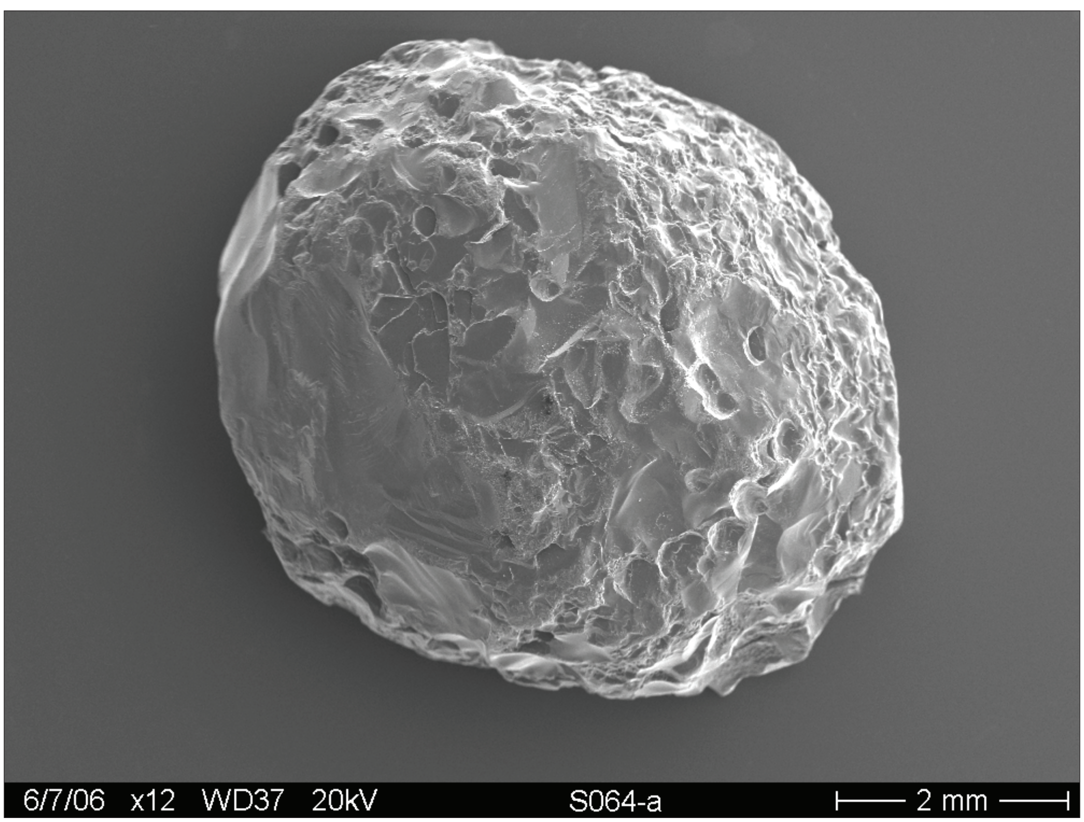
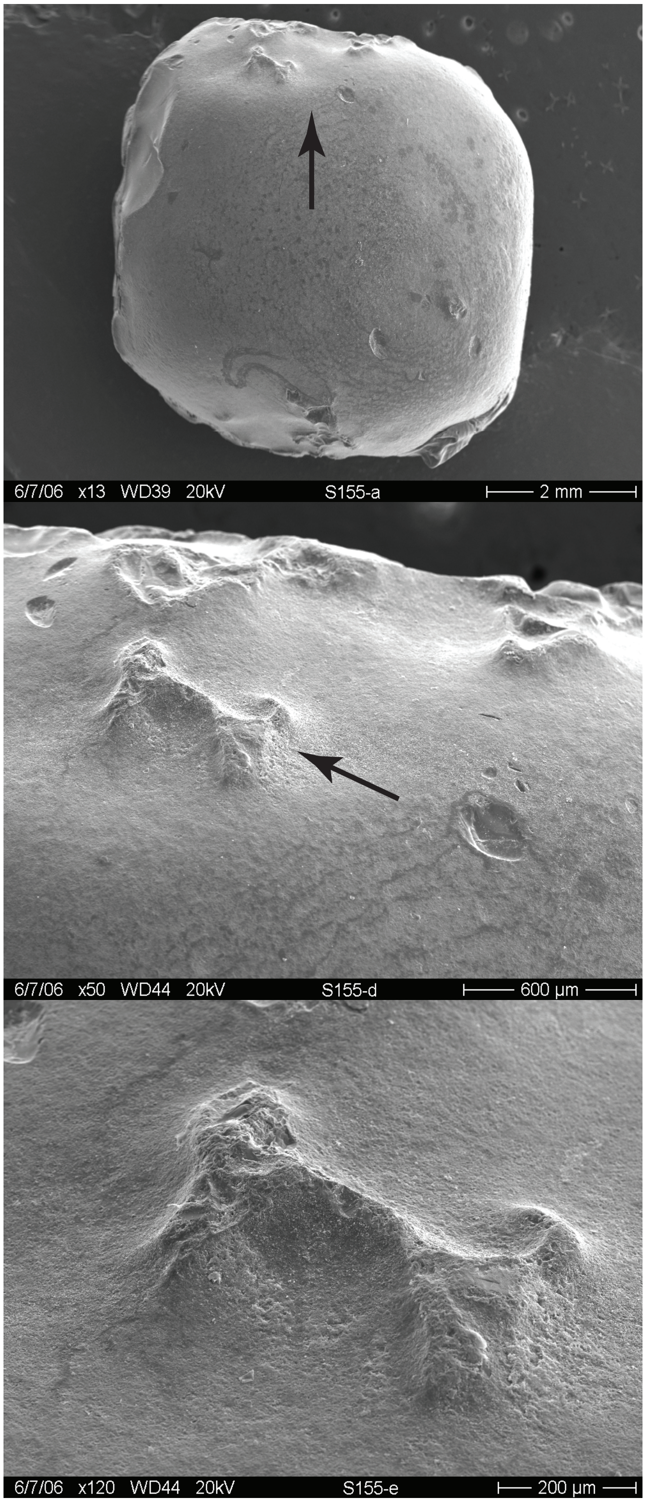


Figure 4.8. SEM photo of sapphire from Anaconda Bench with irregular surface covered with small pits and irregular curving planar surfaces. Photo by Nancy Equall.



A

B

C

Figure 4.9 (A,B,C). SEM photos of sapphire from North Fork Coal Gulch with frosted surface. (A) Frosted surface of sapphire with irregular projections. (B) Enlargement of area with pits and projections. (C) Further enlargement of projection. Photos by Nancy Equall.

for those studied from the Butte–Deer Lodge area. Current study of sapphires from the deposits along the Missouri River east of Helena show yet different surface morphologies (Berg and Equall, 2013).

The cause of the various morphologies of sapphires from several Montana districts is not understood. It is likely that many of the observed features are the result of resorption during the sapphire's transport in magma from its source to the Earth's surface. There are at least three possible causes for the morphological differences. Internally, there may be differences in trace-element chemistry of the sapphires or some other internal feature such as abundance of lattice defects that caused differential resorption rates. Two other possibilities related to the magma include its chemical composition or length of time the sapphires resided in the magma. This is an interesting area for further research. For a comparison to the surface features found on diamonds attributed to resorption, see Tappert and Tappert (2011).

Adhering Material

Volcanic Rock

Although extremely rare, sapphires that have adhering volcanic rock have been recovered (fig. 4.11). In this image, the crude alignment of biotite phenocrysts parallel to the surface of the sapphire is interpreted to indicate that this sapphire was a xenocryst in the volcanic rock. Just as plagioclase microlites are oriented parallel to the surface of plagioclase phenocrysts in the rhyolite (fig. 2.8), biotite phenocrysts are oriented parallel to the surface of the sapphire (fig. 4.11). A SEM photo of a basal surface of a sapphire shows a remnant of volcanic rock with a euhedral biotite phenocryst adhering to the sapphire (fig. 4.12). A sapphire recovered by a customer at Gem Mountain was partly enclosed by what is interpreted to be volcaniclastic rock. This sapphire was from material mined either from the Anaconda Bench or near the head of Anaconda Gulch. The enclosing material contains fragments of plagioclase crystals and biotite grains in a very fine-grained matrix that consists of concentrations of plagioclase microlites interspersed with glass.

Kaolinite

Observations

Many of the sapphires mined from colluvium near the head of North Fork Coal Gulch and Anaconda Bench are coated with kaolinite (fig. 4.13) as identified by x-ray diffraction analysis. All of the sapphires recovered from a small prospect pit east of the head of North Fork Coal Gulch (figs. 3.9, 3.10) are coated

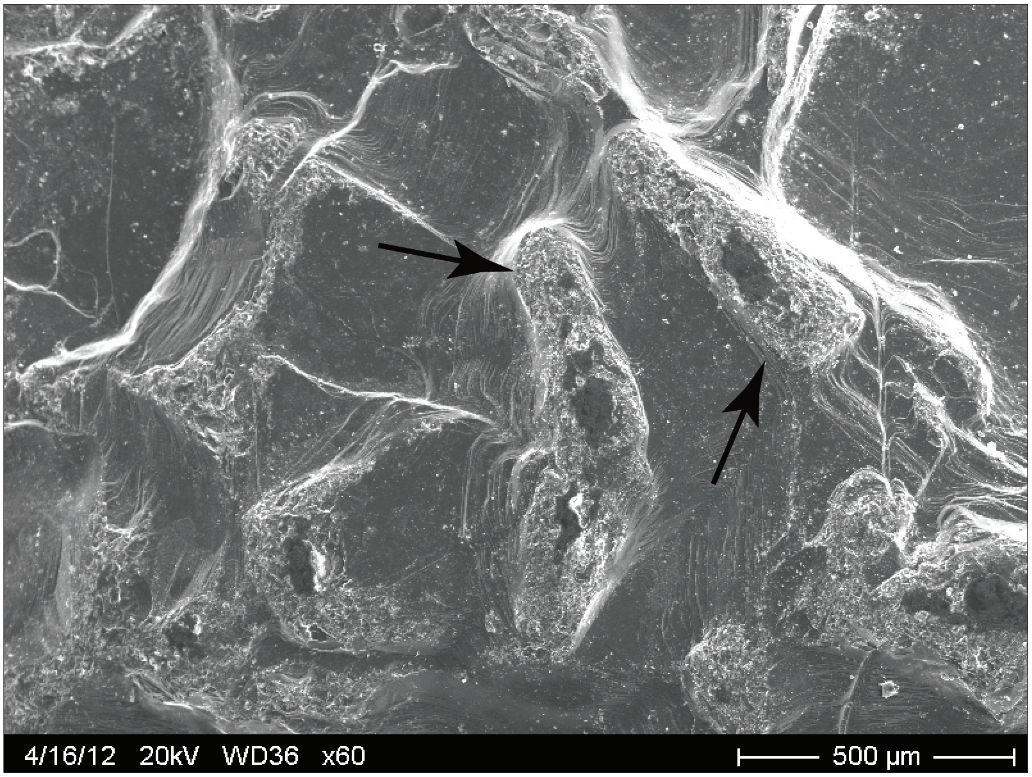


Figure 4.10. SEM photo of a sapphire from the pit near the head of North Fork Coal Gulch showing comparison between abraded projections shown by arrows and the pristine basal surface. Photo by Nancy Equall.

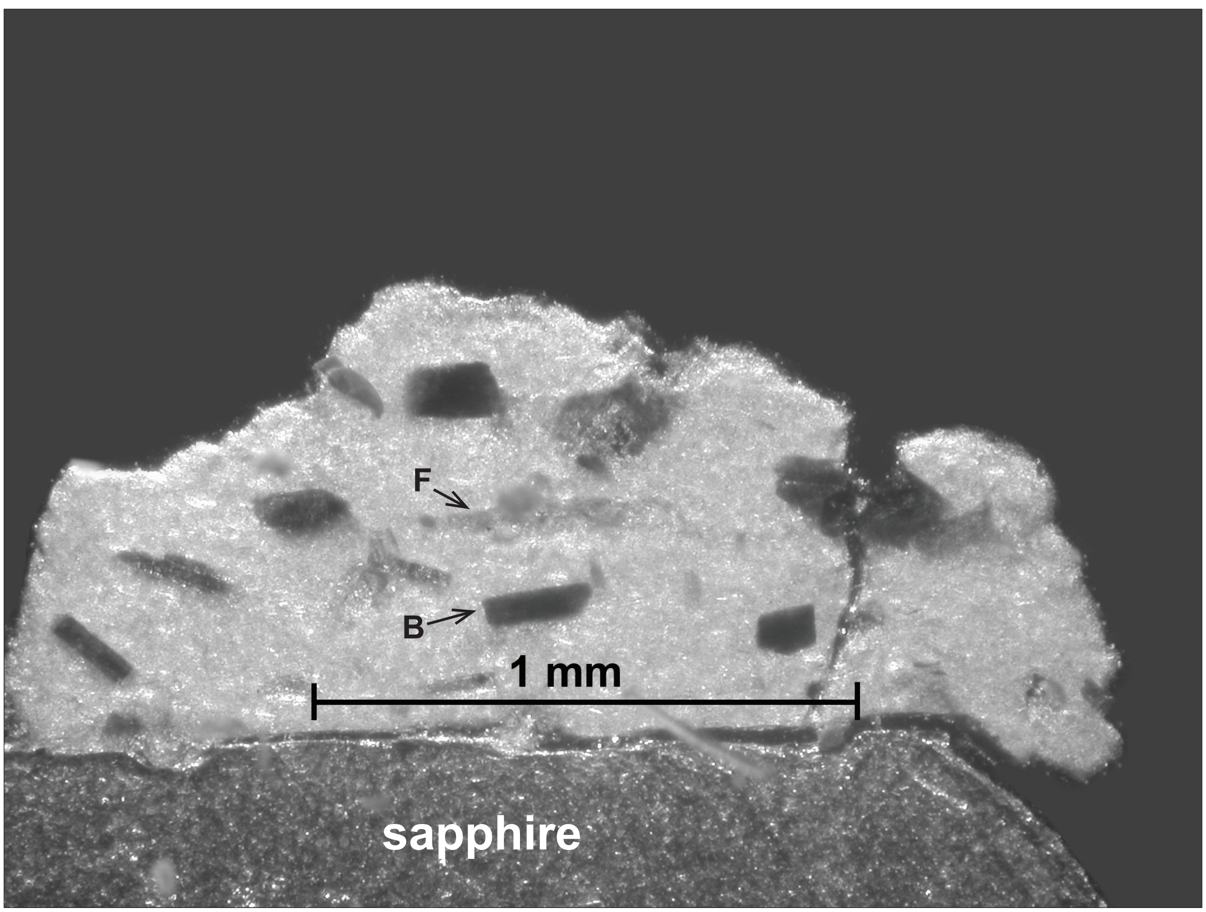


Figure 4.11. Photomicrograph of a thin section of a sapphire from Dann Placer with adhering volcanic rock. Photographed in plane polarized light. The volcanic rock has pulled away from the sapphire slightly during preparation of the thin section. B, biotite; F, feldspar.

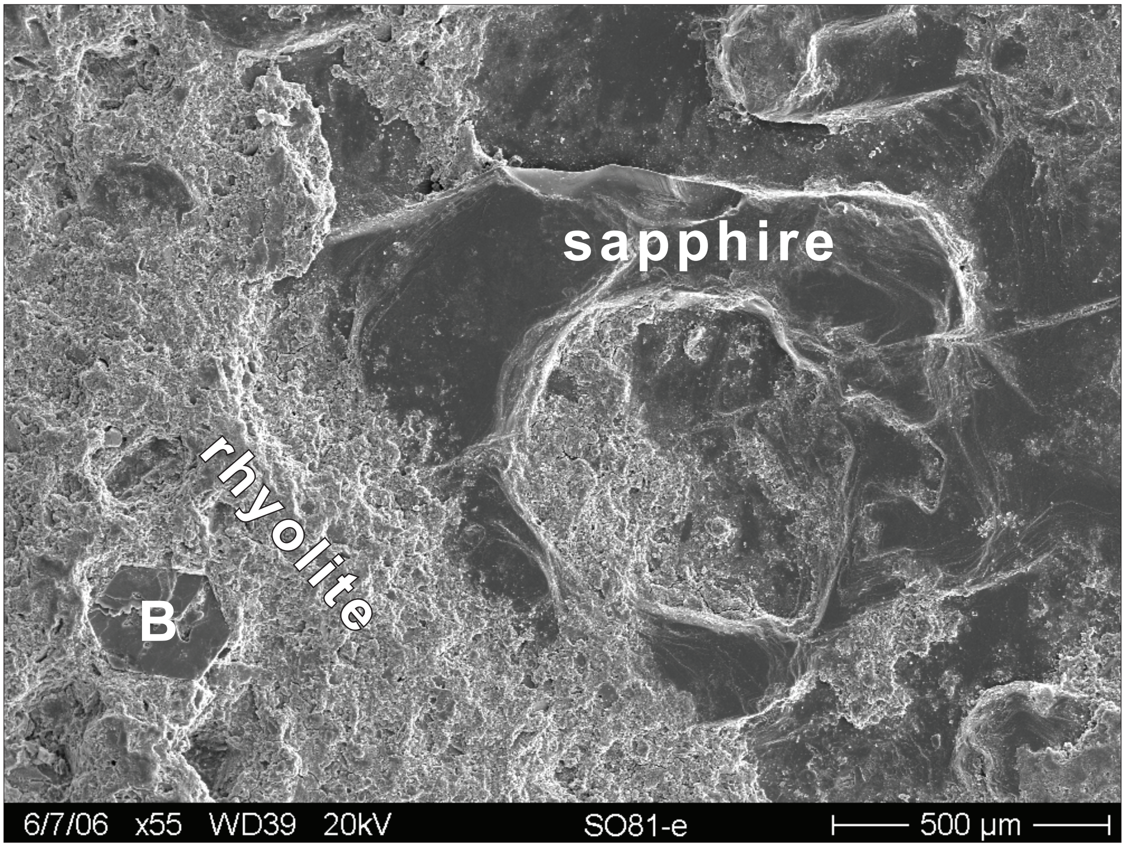


Figure 4.12. SEM photo of the basal surface of a sapphire from Anaconda Bench with adhering volcanic rock (irregular, light gray pattern in photo) and euhedral biotite (B) phenocryst. Photo by Nancy Equall.

with kaolinite. It was reported that the sapphires mined from the head of Anaconda Gulch by Carpp and Kaiser in the 1930s were coated with rhyolite that could only be removed with difficulty (Marc Bielenberg, oral commun., 2007). However, Buss Hess (oral commun., 2006) reported that clay coated these sapphires. It is likely that the clay coating was kaolinite as found in other sapphires from this area. Kaolinite coatings were not observed on sapphires from Dann and McLure Placers, the only other localities from which sapphires were available for study.

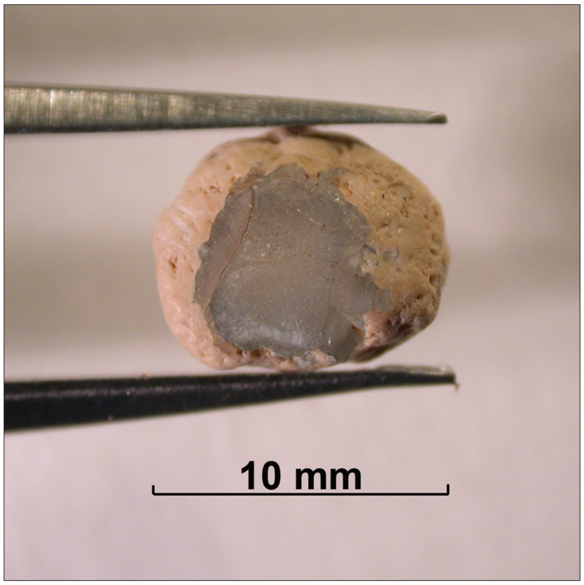


Figure 4.13. Sapphire from pit near the head of the North Fork of Coal Gulch with kaolinite coating. Photo by R.B.B.

The kaolinite coating is sufficiently durable that it has survived passage through the trommel and jigs during sapphire recovery. Examination of a thin section of this coating on a sapphire from the pit near the head of North Fork Coal Gulch shows that the coating consists of fragments of vermiform kaolinite in fine-grained kaolinite. When the kaolinite coating was removed by soaking the sapphire in HF overnight, angular sapphire chips were found in the bottom of the beaker (fig. 4.14). After removal of the adhering kaolinite, the sapphire is seen to be covered with conchoidal fractures (figs. 4.15A,B). Internal fractures are inferred to also be coated with kaolinite on the basis of similarity in chemical composition to the external kaolinite coating. The Al:Si ratio of the kaolinite coat-

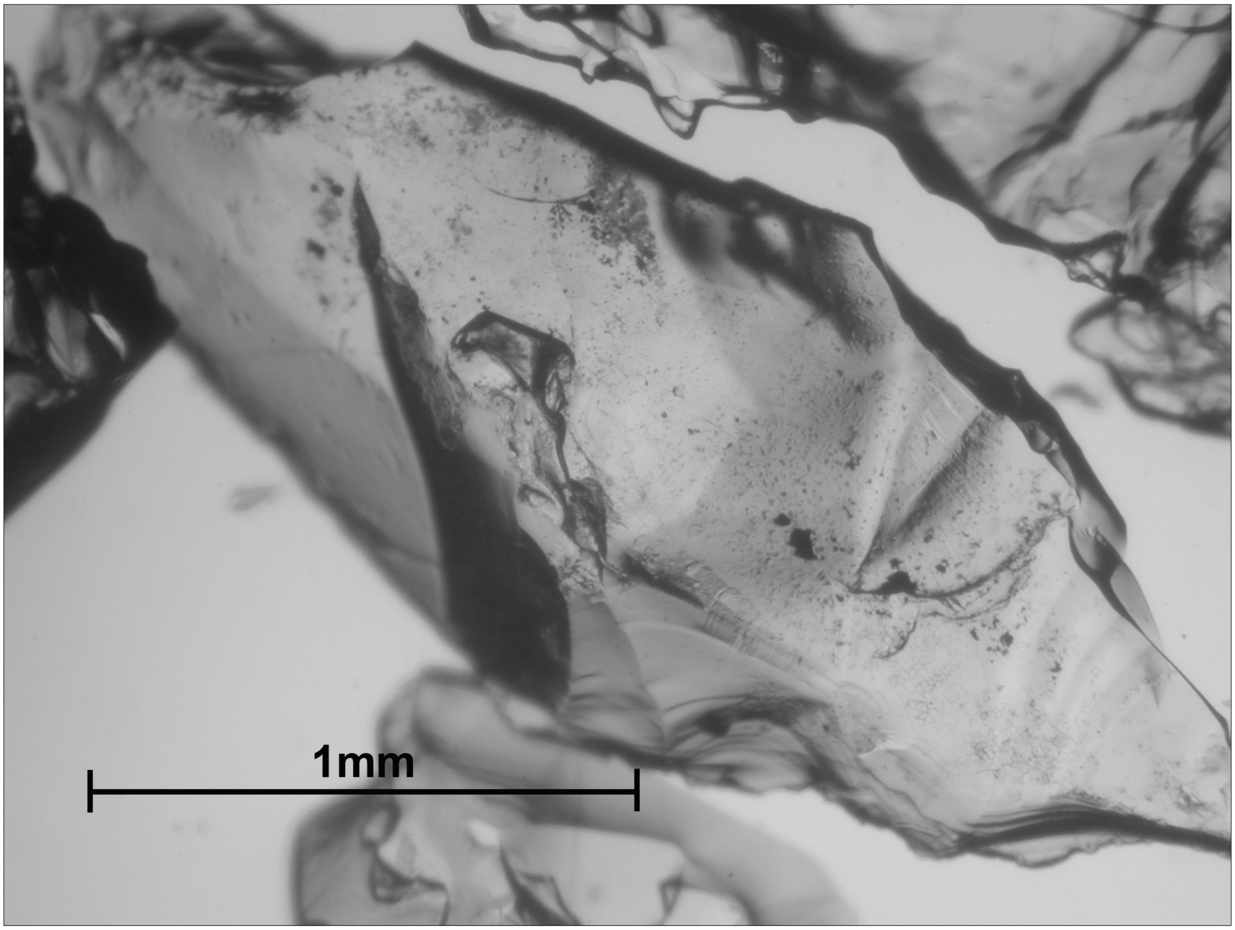
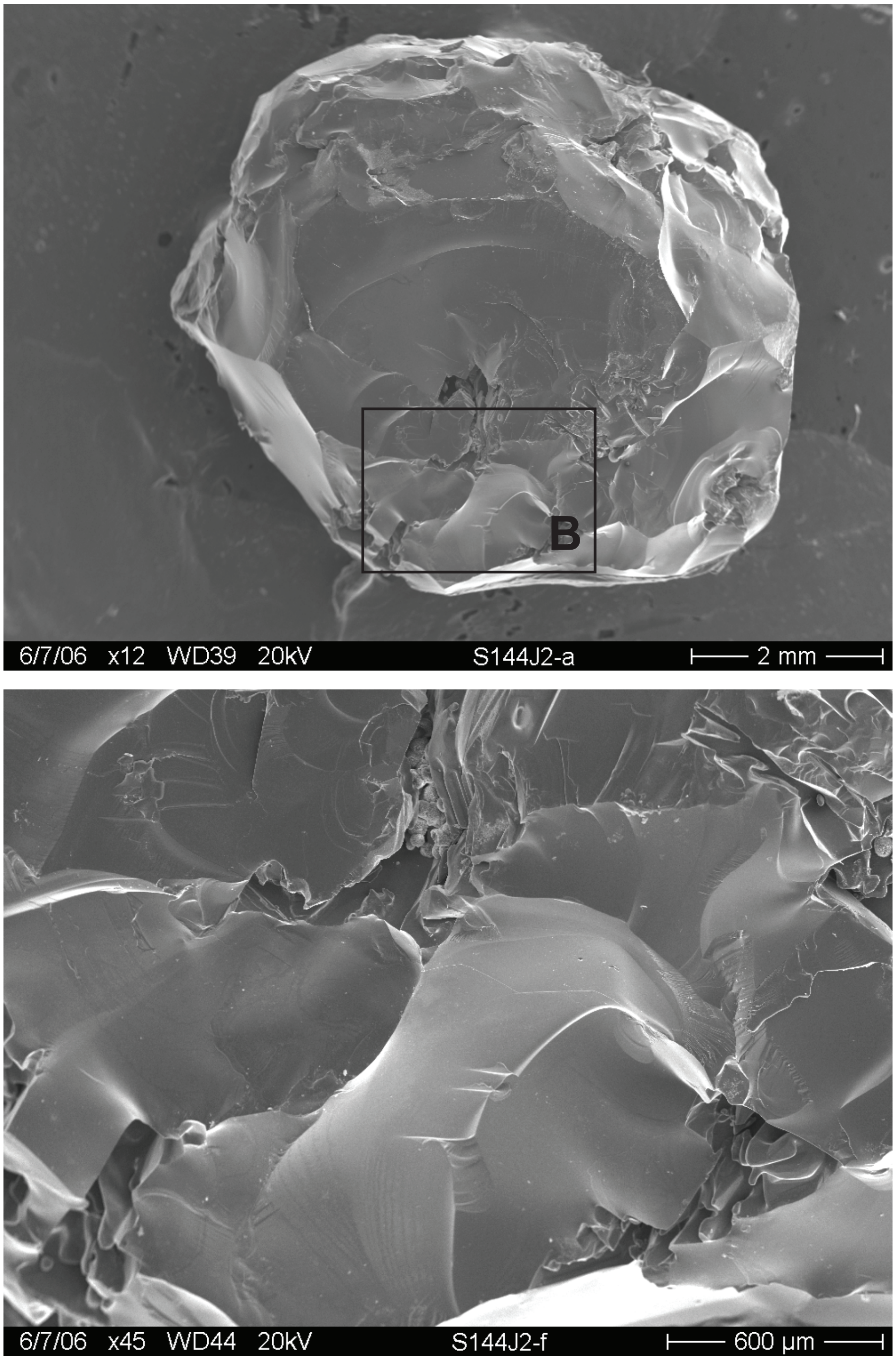


Figure 4.14. Photomicrograph of one of the sapphire chips recovered after dissolving adhering kaolinite in HF from a sapphire recovered from the pit near the head of the North Fork of Coal Gulch. Photographed in liquid with index of refraction of 1.53. Photo by R.B.B.

ing a sapphire as determined by semi-quantitative energy dispersive x-ray analysis was approximately 1:1.3, and that of the coating on the internal fracture was approximately 1:1.1 and 1:1.5. A thin section of one of the sapphires with a kaolinite coating shows that it fills embayments into the sapphire and completely encloses numerous sapphire chips (fig. 4.16). Some sapphires without a kaolinite coating exhibit several conchoidal fractures, but no sapphire is completely covered with conchoidal fractures like the kaolinite-coated sapphires.

Interpretation and inference

The association of kaolinite coating with sapphires completely covered with conchoidal fractures requires an explanation that includes both features. The occurrence of kaolinite(?) coating internal fractures and completely enclosing angular sapphire chips indicates that kaolinite was deposited before the sapphire was in the alluvial environment, presumably while it was in a bedrock source. Replacement of plagioclase by kaolinite has been recognized in rhyolite from the head of Anaconda Gulch and also in the rhyolite exposed on the ridge between North Fork Coal Gulch and the Anaconda Bench (fig. 2.9). A likely possibility is that these sapphires were fragmented by some unrecognized process while in the rhyolitic magma and subsequently enclosed by kaolinite that included small fragments of the sapphire. Furthermore, the lack of kaolinite coating on sapphires from Dann and McLure Placers, in comparison to an abundance of sapphires with this coating from the head of North Fork Coal Gulch, the head of Anaconda Gulch, and the Anaconda Bench, suggests that this coating is a local phenomenon related to kaolinitic alteration of a rhyolite source. It should be pointed out that vermiform kaolinite grains occur with rhyolite fragments in the colluvium east of the head of North Fork Coal Gulch. When the rhyolite disintegrated during extended weathering to form colluvium, kaolinite in the rhyolite as shown in fig. 2.10 was released. If these interpretations are correct, they have significant implications for the bedrock source of the kaolinite-coated sapphires (see Chapter 5, Conclusions).



A

B

Figure 4.15. (A) SEM photo of sapphire from the pit near the head of the North Fork of Coal Gulch that has been soaked in HF to remove kaolinite coating. (B) Enlargement of image of sapphire in A. The small fuzzy crystals in the cavity near the top of the photo are CaF_2 produced by reaction of the HF with a Ca-bearing mineral in the kaolinite coating, probably calcite. Photos by Nancy Equall.

Black Material

Observations

Several sapphires from the southwestern part of the Rock Creek district, but with no specific locality, have irregular adhering masses of black material. Semi-quantitative, energy-dispersive x-ray analysis of one of these masses shows it to contain 9 atomic percent Mn, 0.8 atomic percent Ba, 0.4 atomic percent Na, 2.7 atomic percent Al, 8.4 atomic percent Si, 0.5 atomic percent S, and 0.9 atomic percent K.

Interpretation

This black material is a mixture of several minerals, perhaps including one of the manganese oxides such as romanechite [$(Ba,H_2O)_2Mn_5O_{10}$] that contains barium. This material presumably was deposited on the sapphire in the weathering environment.

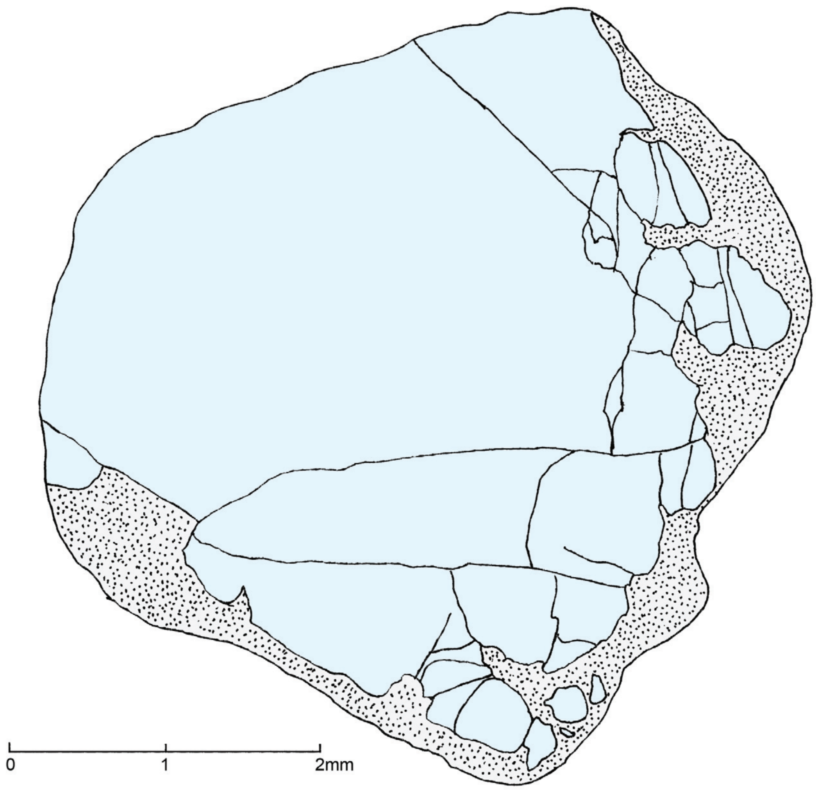


Figure 4.16. Tracing made from a photomicrograph of a thin section of a sapphire from the pit near the head of the North Fork of Coal Gulch. Stippled pattern is kaolinite and unpatterned area is sapphire with fractures shown.

MINERAL INCLUSIONS

Introduction

Mineral inclusions in sapphires from the southwestern part of the Rock Creek sapphire district were identified to help provide information on the ultimate origin of these sapphires—magmatic or metamorphic. Although not an exhaustive study of mineral inclusions, more than several hundred sapphires were examined for mineral inclusions using the binocular microscope.

Procedure

Sapphire rough was examined under a binocular microscope with both substage and incident illumination. Sapphires containing recognizable inclusions were mounted on a glass slide with cement such as Duco™ that is soluble in acetone. After the sapphire was ground on a thin section machine to almost expose the inclusions, the cement was dissolved. The sapphire was then mounted with the ground side down on a glass slide and then ground to expose the mineral inclusion for analysis. Some of these sections were ground to standard thin section thickness of 30 µm, whereas others were left thicker. More than 90 thin sections were made of individual sapphires. After removal of the sapphire from the glass slide with acetone, it could be examined with the petrographic microscope and then mounted on the sample holder for instrumental analysis.

Analyses by scanning electron microscopy (SEM), back-scattered electron imaging (BSE), and energy dispersive x-ray analysis (EDX) were performed by Nancy Equall using a JEOL instrument in the Instrument and Chemical Analysis Laboratory at Montana State University, Bozeman. The instrument was operated at 20 kv and most specimens were iridium coated.

Primary Mineral Inclusions

Rutile

Rutile, the most abundant mineral inclusion, occurs as individual irregular grains and more rarely as prismatic grains. It is dark reddish brown to yellowish brown when examined with crossed polars and ranges in size from approximately 150 to 300 µm (fig. 4.17). Typically, rutile occurs in clusters of grains, and in some instances many individual inclusions are seen in one thin section. Rutile was identified petrographically in thin sections of 13 individual sapphires and confirmed by Raman spectroscopy in one sapphire (Bryan Ray, written commun., 2008). Multiple grains in 6 additional sapphires were determined by EDX to contain Ti and O and inferred also to be rutile.

In addition to the relatively large individual rutile inclusions, this mineral also occurs in small acicular grains concentrated in growth zones, as shown in thin sections cut perpendicular to the C crystallographic axis (fig. 4.18). The concentration of these small grains (8–15 µm with rare grains as long as 45 µm) is sufficiently great in some sapphires to give them a dark brown appearance. When viewed in a thin section cut perpendicular to the C axis, the rutile needles show a preferred alignment that intersects at 60 degrees. Some of these grains look like miniature hockey sticks with the 'knee-shaped' twins typical of rutile.

Interpretation

Large individual rutile grains were simply incorporated in the sapphire (corundum) during growth. Very small rutile grains, zonally arranged in some sap-

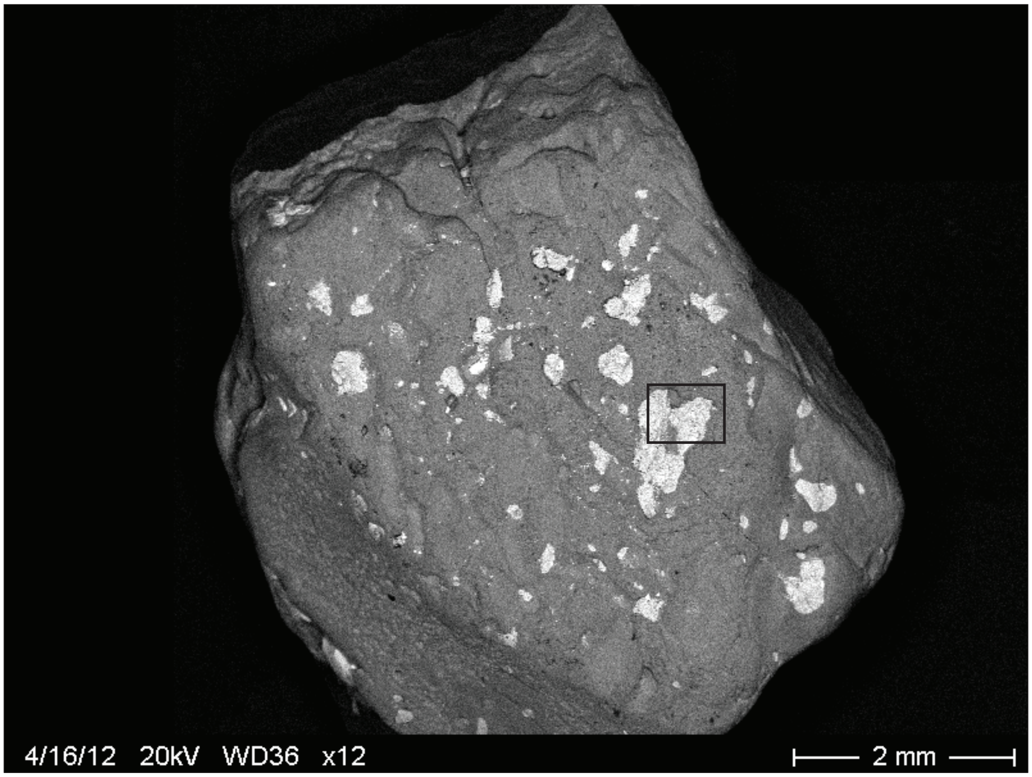


Figure 4.17. BSE image of sapphire from the southwestern part of the Rock Creek sapphire district showing included irregular rutile grains. Box shows the enlarged area in Fig. 4.20. Photo by Nancy Equall.

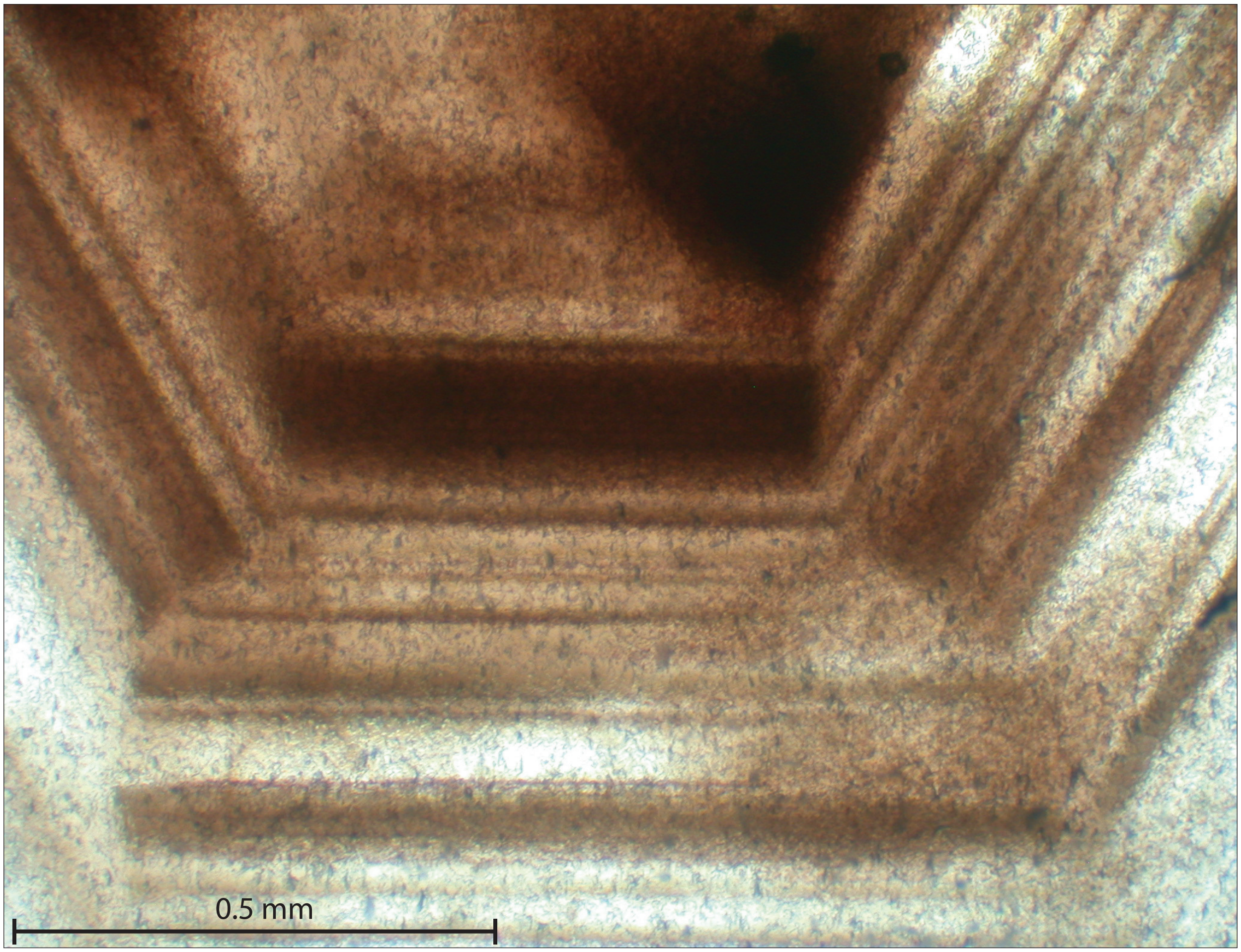


Figure 4.18. Photomicrograph in plane polarized light of a sapphire from Anaconda Bench cut perpendicular to the C axis showing zonal arrangement of exsolved rutile.

phires, are inferred to be an indication of variation in titanium concentration in the corundum crystal during its growth. These zonally concentrated rutile grains are generally considered to be caused by exsolution of rutile. During the growth of the corundum crystal some zones contained more Ti in the crystal lattice than others that subsequently exsolved on cooling of the crystal. The crystallographic alignment of these rutile needles supports this interpretation.

Garnet

Although much less abundant than rutile, garnet inclusions were recognized in seven sapphires. Unfortunately, thin sections of these sapphires were accidentally destroyed in preparation for chemical analyses. Garnets are of two colors, orangish-red and red. Unlike the South Fork of Dry Cottonwood Creek, where garnets greatly outnumber sapphires in the alluvium, sapphires greatly outnumber garnets in the southwestern part of the Rock Creek sapphire district.

Zircon

Zircon inclusions were identified in thin sections of two sapphires. One of the sapphires is from Dann Placer and the other is from an area near the head of Anaconda Gulch. Most zircons are subrounded and range in size from approximately 30 µm to 100 µm (fig. 4.19). In addition to the subrounded zircons, these sapphires contain elongate euhedral zircons within the same size range. Small zircons within rutile inclusions were identified in several sapphires when the rutile inclusions were examined using BSE (fig. 4.20). The zircons were identified using EDX analyses, which showed that the grains contain Zr, Si, and O in approximately the expected ratio for zircon. These small zircons were not recognized in examination of these sapphires with the petrographic microscope.

Interpretation of zircon inclusions in sapphires

If the assumption is made that the sapphires grew in a metamorphic rock, it can be inferred that

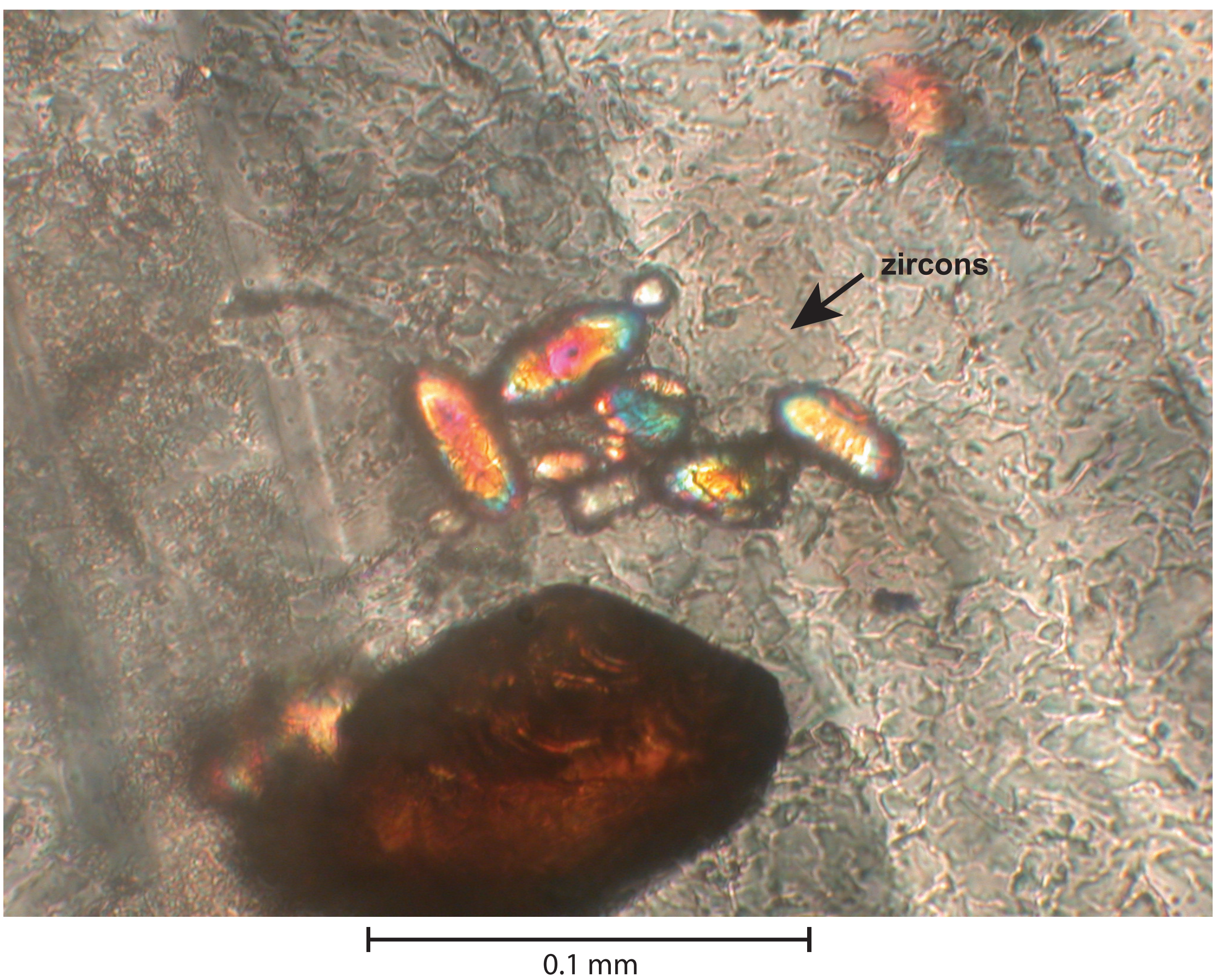


Figure 4.19. Photomicrograph with crossed polars of a cluster of zircons next to a rutile inclusion in a sapphire from Dann Placer.

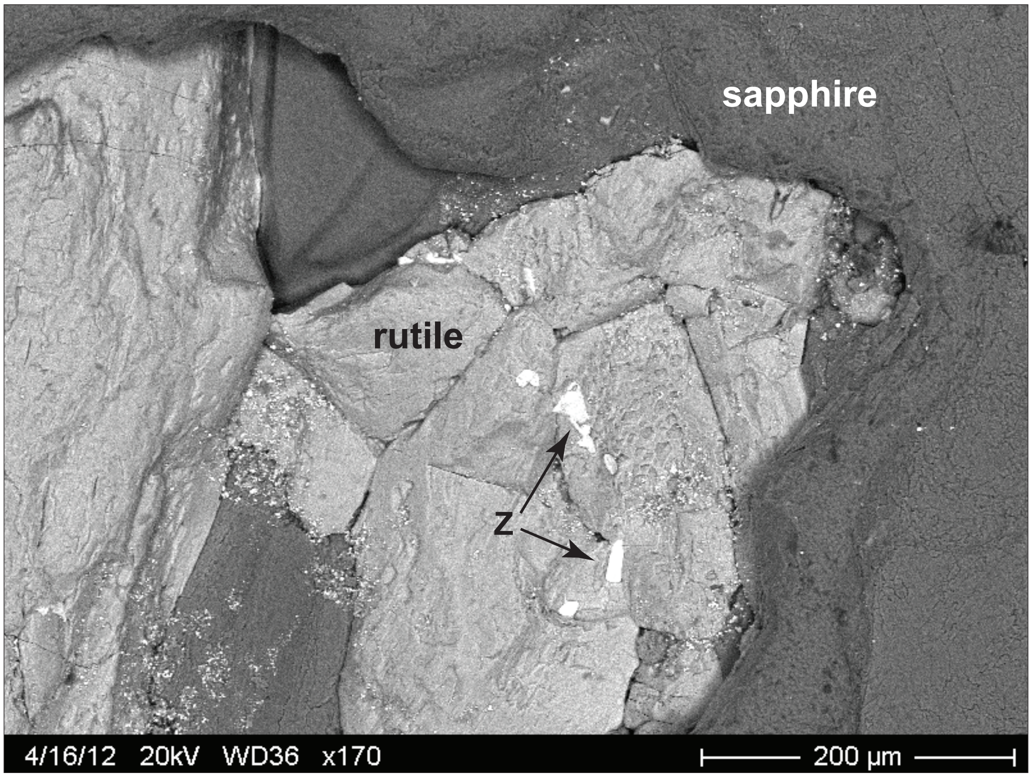


Figure 4.20. Back-scattered electron (BSE) image of rutile inclusion in sapphire from the southwestern part of the Rock Creek sapphire district. See fig. 4.17 for location of this rutile grain. Angular grains in rutile are zircon (Z). Photo by Nancy Equall.

the zircons were inherited from the protolith. Euhedral zircons are generally found in igneous rocks and rounded zircons are considered to indicate a sedimentary source as having been rounded during aqueous transport. A possible inference is that the rounded zircons indicate a sedimentary protolith that when metamorphosed formed an aluminous assemblage that contained corundum.

Interpretation of zircon inclusions in rutile

No attempt was made to explain the irregular zircon inclusions in the rutile grains.

Sillimanite

A sapphire from the pit near the head of North Fork Coal Gulch is partly rimmed with a fibrous mineral identified as the fibrolite variety of sillimanite on the basis of petrographic examination. Semi-quantitative analysis of this mineral by EDX verified this identification. The average of two analyses was 9.3 atomic percent Al and 4.6 atomic percent Si, close to that represented by the sillimanite formula of Al_2SiO_5. Equant feldspar grains adjacent to and intergrown with the sillimanite were also analyzed by EDX. The average of seven analyses of individual grains yielded a Na:Ca atomic ratio of approximately 3:1, indicating a composition in the oligoclase range.

Interpretation

The intergrowth of sillimanite in sapphire strongly suggests that the sillimanite and corundum grew in a metamorphic environment.

Unidentified Aluminosilicate

A sapphire from the McLure Placer contains five small (100–150 µm) grains that were analyzed by semi-quantitative EDX. The average atomic Si:Al ratio for these five grains was approximately 1:2. The average Fe content is approximately 1 atomic percent. These grains were irregular in shape and could not be located on the thin section. This sapphire also contains rutile and zircon inclusions.

Ilmenite(?)

Small (50 µm) irregular inclusions within a rutile inclusion in a sapphire were recognized by BSE and inferred to be ilmenite on the basis of EDX analyses that showed an atomic ratio of Ti:Fe of approximately 1:1.

Allanite(?)

Several small, irregular inclusions in a sapphire were inferred to be allanite on the basis of the following average of two semi-quantitative EDX analyses shown in atomic percent: Ca 8.9%, Fe 5.6%, La 5.2%, Ce 7.5%, Mg 0.5%, Al 10.1%, Si 12.0%, and P 0.9%.

The phosphorus might be explained by monazite included in the inferred allanite.

Secondary mineral inclusions

Barite(?). Small grains along the edges of a rutile inclusion in a sapphire from the southwestern part of the Rock Creek district, but with no specific gulch known, is tentatively identified to be barite on the basis of an EDX analysis that shows Ba and S.

Hematite. Hematite was visually identified along small fractures in some sapphires. These sapphires are typically yellowish because of the hematite.

CONCLUSIONS

Only the most abundant inclusions have been identified in this study. There is room for much further work. Garland (2002) analyzed 356 mineral inclusions using Raman spectroscopy and identified 11 mineral species. She found labradorite to be the most abundant inclusion, with muscovite the second most abundant. Muscovite was associated with fluid inclusions and fractures. Other inclusions identified by Garland are clinozoisite, zoisite, calcite, rutile, ilmenite, hematite, hercynite, diaspore, and gibbsite.

CHAPTER 5

CONCLUSIONS AND SPECULATION

Bedrock Source of Sapphires

There has been significant discussion and debate concerning the bedrock source or sources of the alluvial sapphire deposits of southwestern Montana. Evidence for a volcanic bedrock source has been presented for both the South Fork of Dry Cottonwood Creek and the sapphire occurrence at Silver Bow west of Butte (Berg, 2007; Berger and Berg, 2006). The following evidence supports a similar, local volcanic-bedrock source for sapphires in the southwestern part of the Rock Creek sapphire district.

Evidence for a Local Bedrock Source

The unusual concentration of sapphires in a relatively small area within the Rock Creek sapphire district implies a local bedrock source. Historic production records indicate that at least 65 tonnes of sapphires were recovered from an 11 km^2 (4 mi^2) area in the southwestern part of the Rock Creek sapphire district (fig. 1.3). It would require an unusual coincidence of geologic processes to form such a rich deposit if the sapphires were transported from a distant source.

Sapphires from an area east of the head of North Fork Coal Gulch and some from the Anaconda Bench are covered with a layer of kaolinite (fig. 4.13). A clay mineral coating would certainly not survive transport in a fluvial system for any significant distance.

Delicate surface features found on many sapphires (figs. 4.6, 4.9) would not survive transport from a distant bedrock source.

Evidence for a Rhyolite Source

Sapphires with small amounts of adhering volcanic rock have been recovered from these deposits (figs. 4.11, 4.12). The adhering rock clearly shows that at least some of these sapphires were liberated by weathering from a volcanic rock, presumably one of the rhyolite flows.

A similar argument for a volcanic bedrock source can be made on the basis of the adhering kaolinite. Feldspar phenocrysts in rhyolite near the head of Anaconda Gulch have been replaced by kaolinite (fig. 2.10). Sapphire chips encased within the kaolinite coating indicate that the kaolinite formed while the sapphire was in a bedrock source and not in the weathering environment (see Chapter 4).

Evidence against a Rhyolite Bedrock Source

Sapphires have not been found in exposures of the rhyolite flows. Considering the large quantity of sapphires recovered from both colluvial and alluvial deposits, it would be reasonable, if it is the source, to find *in situ* sapphires in the rhyolite. There are two possible explanations for this apparent contradiction. One is that the concentration of sapphires in the rhyolite is very low, and for this reason they have not been recognized. This explanation has been suggested for the sapphire deposit on the South Fork of Dry Cottonwood Creek, northwest of Butte, where calculations showed that the sapphire concentration in the volcanic bedrock need only have been 1 carat in 48 cubic yards (Berg, 2007). Another possibility for the Rock Creek district is that most of the sapphires weathered from relatively soft tuffaceous beds within the volcanic sequence or some other volcaniclastic rock. Because the tuffaceous materials erode much more easily than rhyolite flows, these lithologies are not well exposed and may have not been generally recognized. Additionally, tuff would be more easily eroded than rhyolite from a sapphire, leaving no evidence as to bedrock source.

Evidence for Other Igneous Sources

Another possibility is that the bedrock source of some sapphires may be igneous pipes, although none have been recognized during geologic mapping. A circular marshy area at the head of Black Pine Gulch, an unusually rich tributary of Anaconda Gulch, might be just such a feature. This feature presents an intriguing alternative possibility for the bedrock source of some sapphires.

Further Speculation about Bedrock Source

If the assumption is made that the distribution of sapphires is indicated by the gulches mined for sapphires as well as the more recently mined areas between the head of Anaconda Gulch and North Fork Coal Gulch, two sources of sapphires are suggested. The sapphires mined at the head of Anaconda Gulch and east of North Fork Coal Gulch are coated with kaolinite that can be related to kaolinitic alteration in the rhyolite lava in this area (see Chapter 4 and fig. 4.13). Also, some of the sapphires from the Anaconda Bench are coated with kaolinite. None of the sapphires examined from McLure and Dann Placers were coated with kaolinite. It is reported that sapphires mined from colluvium along lower Maley Gulch were also free of kaolinite (Ken Lutz, oral commun., 2012). Unfortunately sapphires were not available from other gulches for examination.

The distribution of sapphires with a kaolinite coating indicates a source for these sapphires near the head of North Fork Coal Gulch and Anaconda Gulch (fig. 1.3).

Gulches that enter Sapphire Gulch from the west have been mined for sapphires, but those that enter Sapphire Gulch from the east have not been mined. Gulches that enter Anaconda Gulch from the east have been mined, and historic production records indicate rich placers (fig.1.3). Gulches do not enter Anaconda Gulch from the west. This distribution of sapphire-bearing gulches suggests a source or sources situated between Anaconda and Sapphire Gulches.

Bedrock Source Conclusion

Because the southwestern part of the Rock Creek sapphire district was not glaciated during the Pleistocene, rhyolite flows/tuffs have been subjected to a long weathering interval that allowed sapphire liberation. Evidence for long weathering periods can be seen in the small prospect pit near the head of North Fork Coal Gulch where sapphires have been recovered from colluvium, which consists mainly of rhyolite granules (analogous to gruss formed by weathering of granite in an arid climate). Sapphires have been recovered from similar colluvial deposits during recent mining at several localities including McLure Placer, the west side of Maley Gulch, and along several tributaries of Sapphire Gulch. As the colluvium eroded, sapphires were washed into the major gulches where they were concentrated by fluvial action into rich deposits that were mined during the era of major sapphire production.

Ultimate Origin of Sapphires

Although it is postulated that the sapphires mined in the southwestern part of the Rock Creek district weathered out of volcanic rocks, there is evidence that the sapphires are xenocrysts within those rocks. The oxygen isotopic composition ($\delta^{18}O$) was determined for four sapphires from this area. The $\delta^{18}O$ values are unusually low (appendix 5) and are indicative of a metamorphic origin based on published isotopic analyses (see appendix 5 and Berg and others, 2008). Sillimanite intergrown with a sapphire from this district is also indicative of a metamorphic source.

CHAPTER 6

INTERESTING TOPICS FOR FURTHER RESEARCH

- Sapphires and geology of the gulches generally north of the area described in this report (see fig. 1.2).
- Circular marshy area at head of Black Pine Gulch (see description of Black Pine Gulch in Chapter 3).
- Origin of fractures and kaolinite coating on sapphires from the head of North Fork Coal Gulch and Anaconda Gulch (see description of kaolinite coating in Chapter 4).
- Comparison of physical characteristics, trace element chemistry, and mineral inclusions for sapphires recovered from different gulches in the Rock Creek district.
- Process large sample (several tons) from rhyolite lava flows to determine if these flows are the bedrock sources for these sapphires.
- Determine element chemistry and identify mineral inclusions in corundum from the Archean metamorphic rocks in southwestern Montana to determine if there are similarities between this metamorphic corundum and the Rock Creek sapphires.
- When LIDAR imagery is available for this area it will undoubtedly show drainage patterns that were not recognized because of vegetative cover. Such an observation may lead to a new interpretation of the fluvial history of these deposits.

ACKNOWLEDGMENTS

Chris Cooney provided complete access to his property, shared his knowledge freely, provided sapphires, and was very helpful in all aspects of this investigation. Also R Y Timber allowed complete access to their land. Dale Siegford of Sapphire Gallery not only provided sapphires, but also contributed to my knowledge of this district and sapphires in general with many interesting discussions. The following individuals also provided sapphires for this study: Ben Duffey, Kyle Durrett, Dan Ekstrom, Robert Glenn, Jerry Gyldenvand, Russ Hage, Brad Somers, and Chris van Laer. Sapphires given to me for study have been accessioned into the collection of the Montana Tech Mineral Museum.

Reviews, in some instances of individual chapters, by the following individuals have improved this report:

Ted Antonioli (Consultant)

Don Baide (Gem Gallery)

Chris Cooney (Gem Mountain)

Edmond Deal (Retired Director, Montana Bureau of Mines and Geology)

Nancy Equall (Image and Chemical Analysis Laboratory, Montana State University)

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Brian Shovers (Montana Historical Society)

Dale Siegford (Sapphire Gallery)

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Edited by Susan Barth, Montana Bureau of Mines and Geology.

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APPENDIX 1

UNITS AND CONVERSIONS

1 carat = 0.2 g
1 ounce avoirdupois = 28.35 g = 141.75 carats
1 ounce Troy = 31.10 g = 155.5 carats
1000 kg = 1 tonne
1 tonne = 35,273.37 ounces avoirdupois = 5,000,000 carats
1 tonne = 1.10 short tons
bcy = bank cubic yard (the measure of undisturbed gravel before mining)
1 sq mile = 2.59 sq km

APPENDIX 2

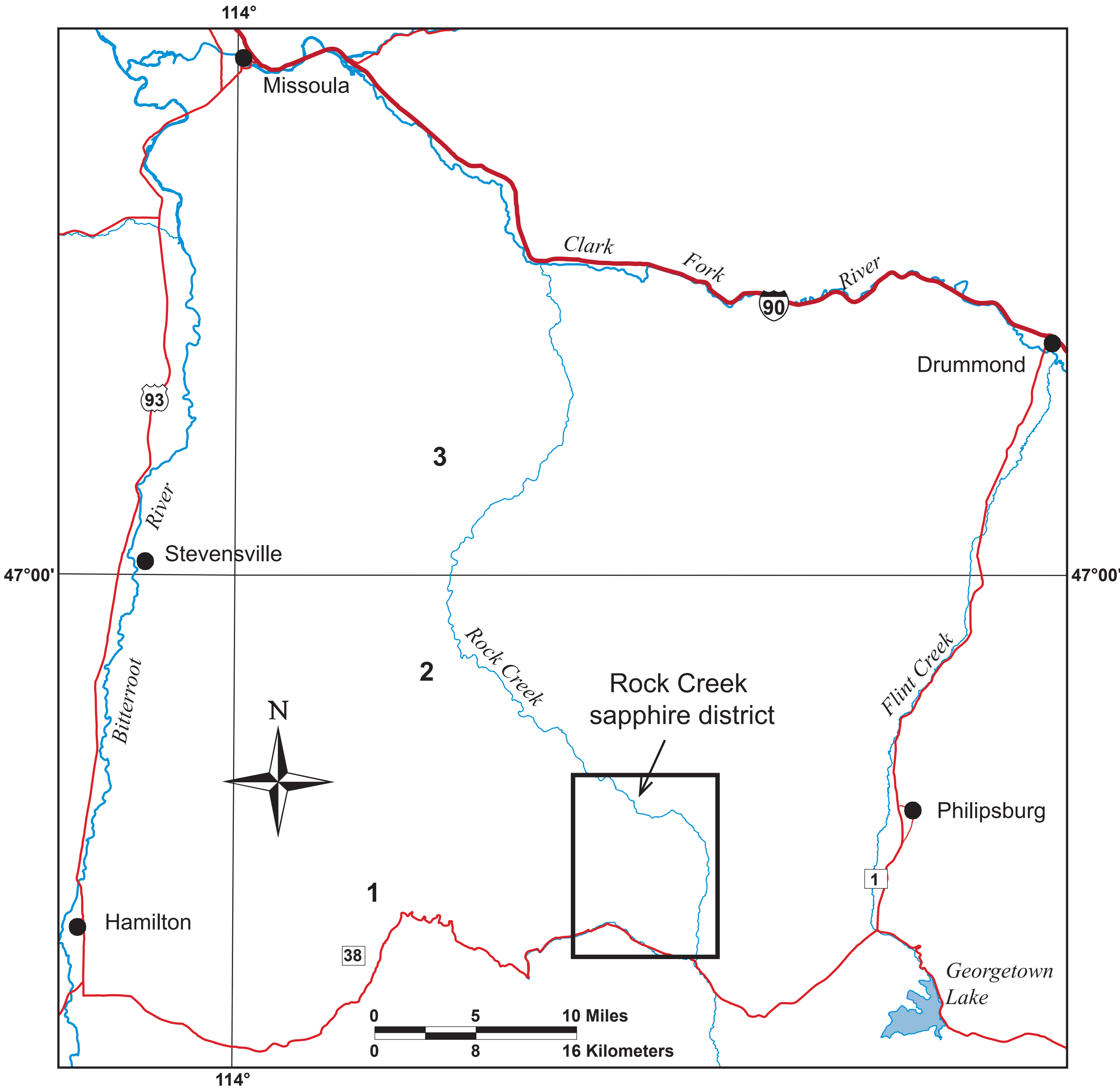
SAPPHIRE OCCURRENCES IN THE SAPPHIRE RANGE OUTSIDE OF THE ROCK CREEK SAPPHIRE DISTRICT

Skalkaho Falls Area

Sapphires have been recovered from the alluvium along Daly Creek below Skalkaho Falls (Larry Moody, oral commun., 2009). Skalkaho Falls is about 11 mi (18 km) west of Skalkaho Pass along the Skalkaho Road between Philipsburg and Hamilton (figs. A2.1, A2.2). Beds of the Piegan Group of the Belt Supergroup are exposed along Daly Creek (Lonn and others, 2003).

Big Spring Creek

Sapphires have been mined from a small meadow near the head of Big Spring Creek, a tributary of Rock Creek, approximately 12 mi (19 km) northwest from



1 Skalkaho Falls area
2 Big Spring Creek
3 Spartan Creek

Figure A2.1. Map showing sapphire deposits, occurrences, and reported occurrences in the Sapphire Range.

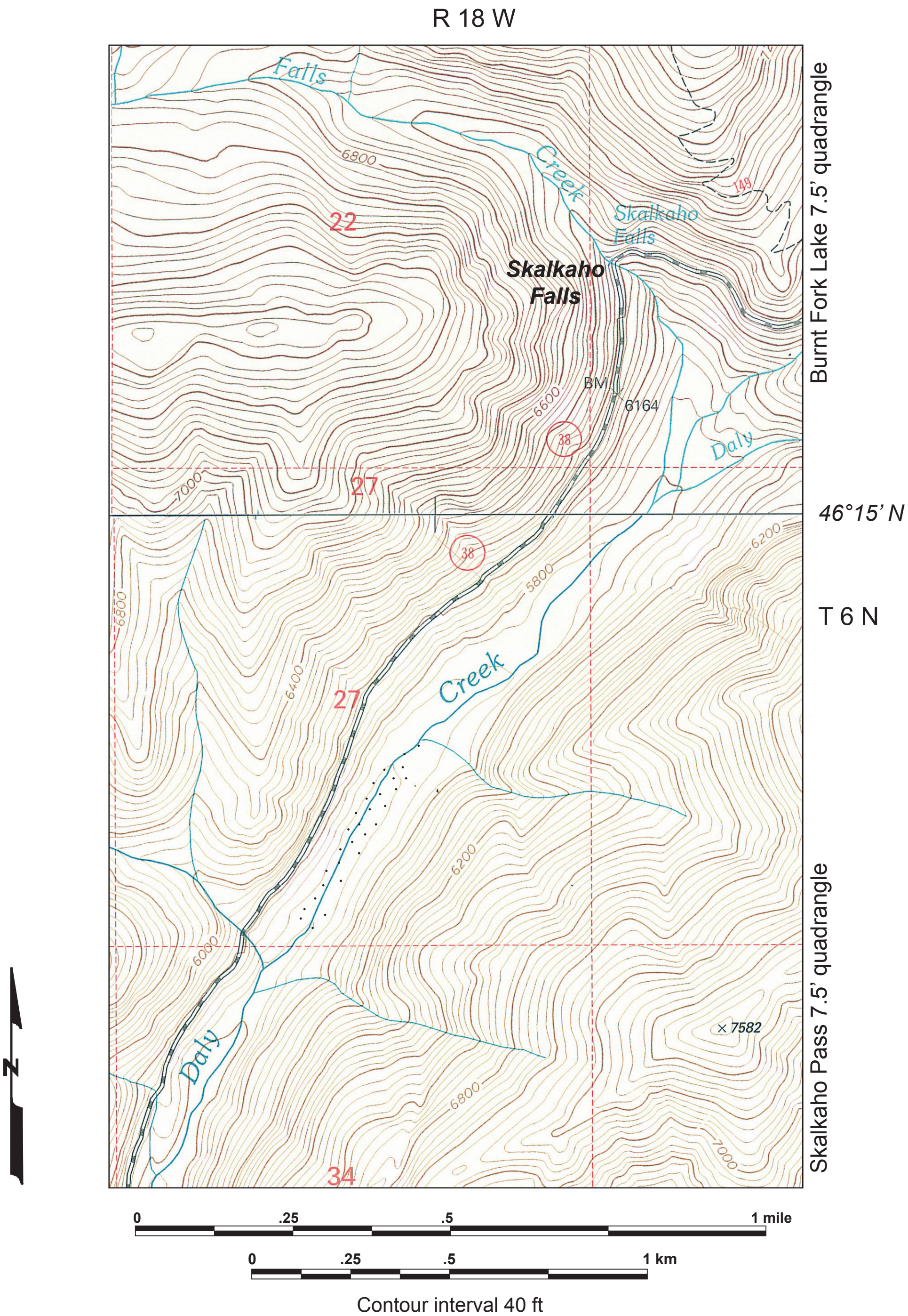


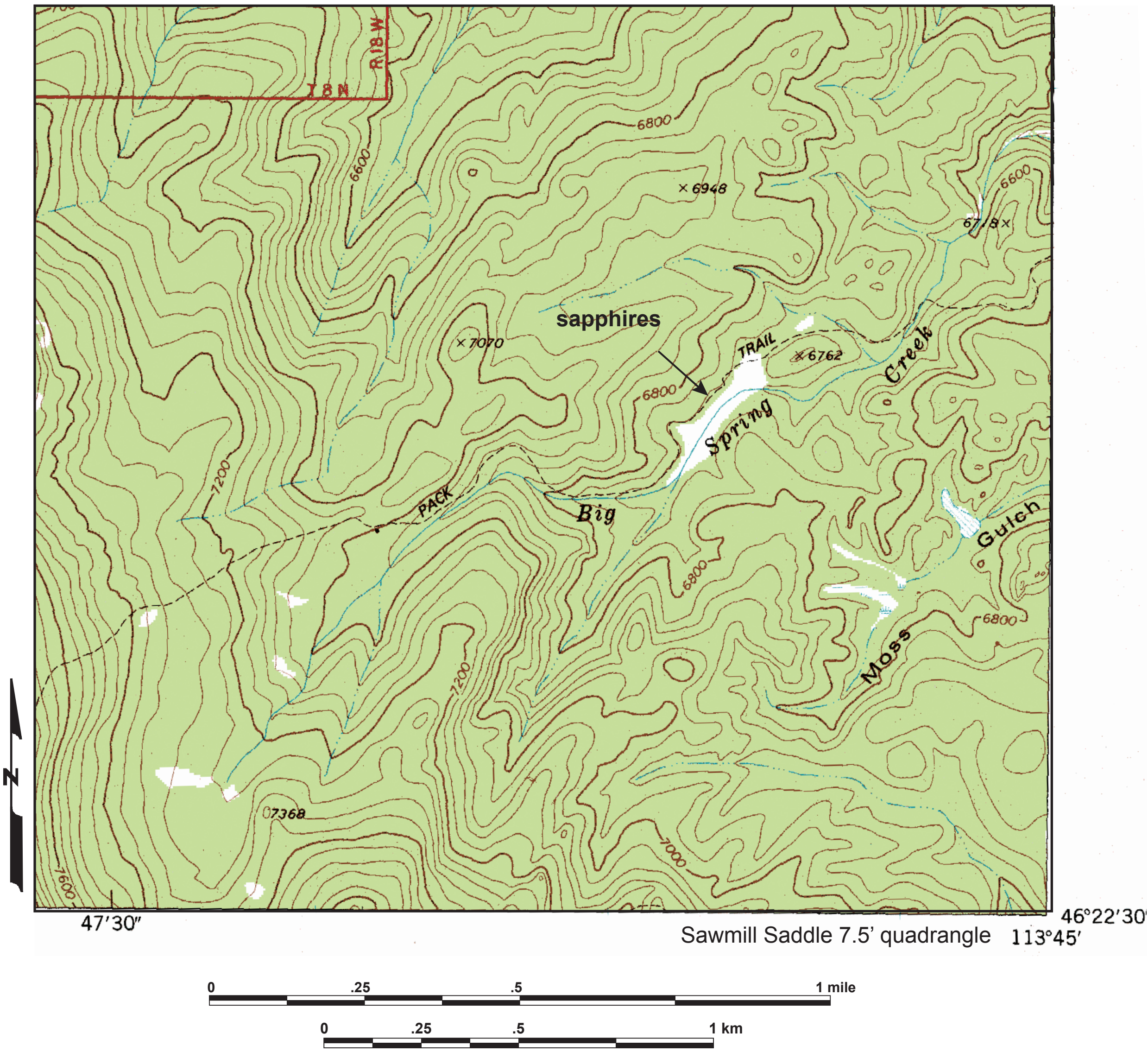
Figure A2.2. Map showing the sapphire occurrence (dotted area) along Daly Creek near Skalkaho Falls. Locality 1, fig. A2.1.

the southwestern part of the Rock Creek sapphire district (Dan Ekstrom, oral commun., 2013; figs. A2.1, A2.3). Mr. Ekstrom led pack trips into this deposit for individuals interested in recovering sapphires. It is reported that gold was also recovered from this placer deposit in the 1930s (Lester Zeihen, oral commun., 1985). The surrounding bedrock is shown on the geologic map to be either granodiorite or tonalite (Lonn and others, 2003).

Examination of an assortment of 99 sapphires with a total weight of 117.9 carats provided by Mr. Ekstrom showed the following range of colors: very pale green to colorless, 79; pale blue (blue coloration in some instances is only part of a colorless sapphire), 10; purple, 6; gray, 2; pink, 1; yellow, 1.

Most of these sapphires have an irregular surface, but some of the smaller subrounded sapphires have a frosted surface as described for Rock Creek sapphires. A few of the sapphires have flat surfaces with small mesas as also described for the basal surfaces of some Rock Creek sapphires.

Two large purple sapphires in this assortment con-



Contour interval 40 ft

Figure A2.3. Map showing sapphire deposit along Big Spring Creek. Locality 2, fig. A2.1.

tain elongate black inclusions, probably rutile. Monazite was identified in the heavy mineral concentrate from this deposit.

Spartan Creek

It has been reported, but not verified, that sapphires were recovered during placer mining of gold near the confluence of Spartan and Welcome Creeks 25 mi (41 km) northwest from the southwestern part of the Rock Creek sapphire district (figs. A2.1,A2.4). Reportedly sapphires have been found along the east bank of Spartan Creek just above a small dam across this creek. This locality is within the Welcome Creek Wilderness. The bedrock surrounding Spartan and Welcome Creeks upstream from this locality is the third member of the Mount Shields Formation of the Belt Supergroup (Lonn and others, 2003).

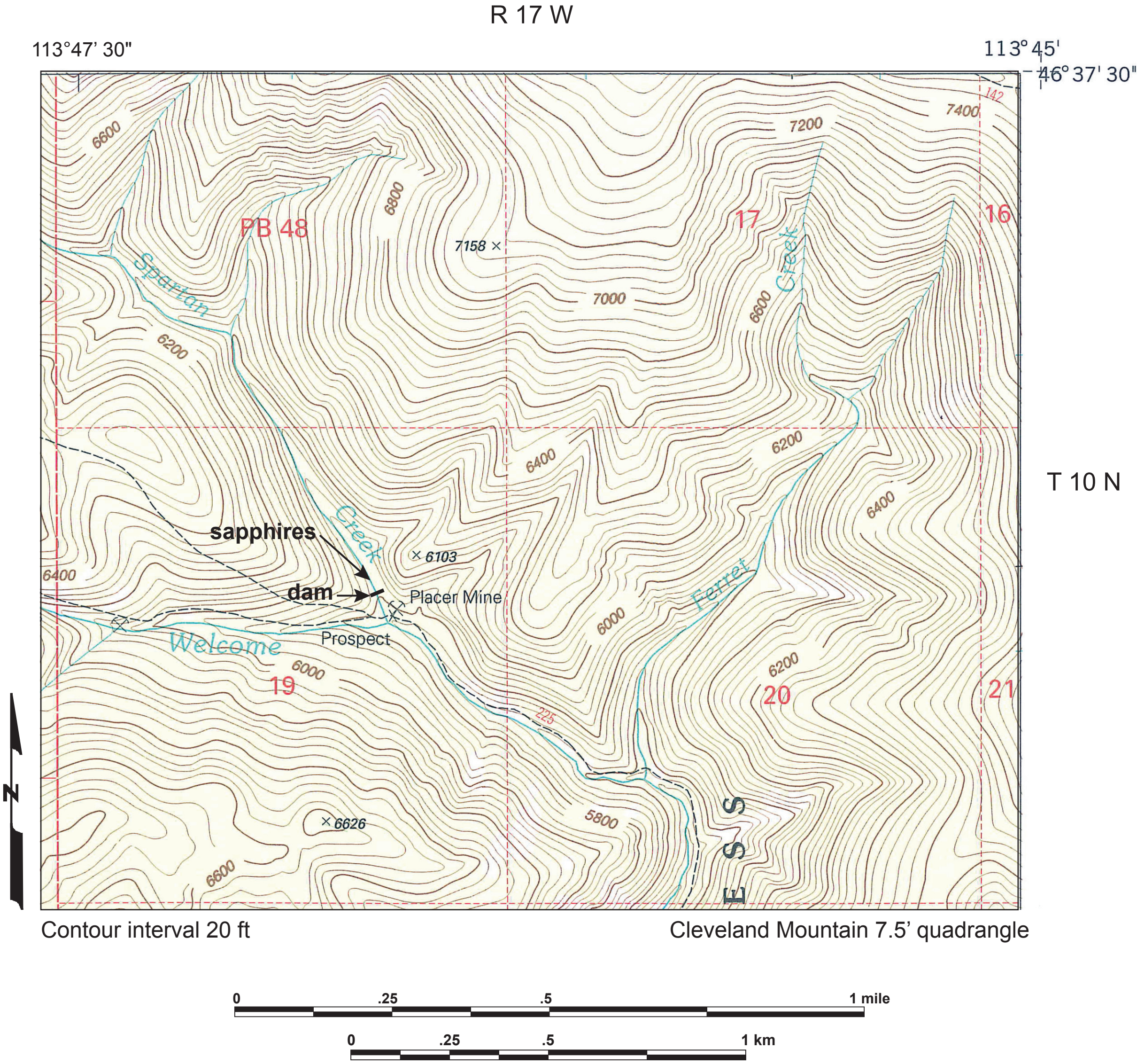


Figure A2.4. Map showing reported sapphire occurrence along Spartan Creek. Locality 3, fig. A2.1.

APPENDIX 3

CHEMICAL ANALYSES

Sample localities are shown in fig. 3.1 and chemical analyses are shown in tables 3.1 and 3.2. Because the analyses were performed using different analytical techniques they are shown in two tables. See fig. A3.1 for sample sites.

Table A3.1. Chemical analyses of volcanic rocks from the southwestern part of the Rock Creek sapphire district. Analyses performed by ALS Chemex using x-ray fluorescence techniques. Sample sites shown in figure A3.1.

	SIO_2	Al_2O_3	Fe_2O	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	L.O.I.	Total
GM 2	67.49	16.87	1.83	2.49	0.77	3.57	3.16	<0.01	0.38	0.03	0.086	0.06	0.11	2.75	99.60
GM 10	70.27	16.30	1.30	1.45	0.81	3.60	3.63	0.01	0.34	0.01	0.048	0.04	0.13	1.98	99.91
GM 94	69.33	16.28	1.44	2.00	0.78	3.77	3.27	0.01	0.36	0.01	0.101	0.06	0.13	1.69	99.23
GM 100	70.27	16.21	1.45	2.01	0.66	4.17	3.56	0.01	0.35	0.01	0.033	0.05	0.12	0.99	99.90
GM 101	67.65	15.94	1.93	2.32	1.25	3.23	4.32	0.01	0.32	0.03	0.089	0.05	0.10	2.64	99.88
GM 114	69.10	17.16	1.49	2.29	0.55	3.93	3.04	<0.01	0.36	0.01	0.090	0.06	0.12	1.56	99.76
GM 157	70.20	16.46	1.38	1.86	0.71	3.63	3.18	<0.01	0.35	0.01	0.101	0.06	0.12	1.68	99.74
GM 208	66.70	15.06	2.91	1.09	0.51	0.72	2.71	<0.01	0.43	0.02	0.037	0.02	0.14	9.17	99.52
GM 232	69.00	17.79	1.27	1.86	0.38	3.55	3.13	<0.01	0.41	0.01	0.041	0.05	0.12	2.27	99.89

Note. GM 2, lava flow; GM 10, lava flow; GM 94, lava flow; GM 100, lava flow; GM 101, sill; GM 114, lava flow; GM 157, lava flow; GM 208, tuff dike; GM 232, lava flow.

Table A3.2. Chemical analyses of volcanic rocks by Activation Laboratories using lithium metaborate/tetraborate fusion and induction coupled plasma techniques. Sample sites shown in figure A3.1.

Analyte Symbol	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	L.O.I .	Total	Ba	Sr	Y	Sc	Zr	Be	V
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Detection Limit	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	2	2	1	1	2	1	5
GM 165	69.55	13.15	2.29	0.021	0.25	1.23	0.89	3.94	0.104	0.03	6.92	98.36	1054	166	25	3	93	2	< 5
GM 201	66.39	14.85	2.65	0.022	0.61	1.5	0.59	3.49	0.315	0.1	7.84	98.36	1876	321	11	4	133	3	24
GM 262	69.52	16.56	1.57	0.002	0.16	0.47	1.83	3.81	0.367	0.09	4.21	98.61	668	132	6	3	161	2	27
GM 277	69.14	14.7	2.97	0.02	0.64	1.63	3.16	5.33	0.339	0.16	1.03	99.14	1235	312	9	3	184	3	36
GM 316	69.17	15.56	2.21	0.013	0.64	1.94	3.61	4.46	0.338	0.11	0.85	98.89	1299	423	9	3	185	3	29
GM 321	70.74	14.58	1.79	0.015	0.52	1.37	3.29	5.02	0.296	0.1	0.83	98.57	1151	264	6	3	166	3	23
GM 323	70.02	16.5	1.61	0.005	0.53	2.14	4.26	3.81	0.347	0.1	1.06	100.4	1150	524	6	5	144	2	34
GM 324	69.32	15.79	1.67	0.01	0.63	2.29	4.11	3.65	0.346	0.09	0.88	98.78	1105	517	6	4	146	2	65
GM 339	70.07	16.54	1.57	0.09	0.47	2.19	3.81	3.13	0.396	0.06	1.61	99.93	1080	482	7	5	124	2	37
GM 340	69.85	16.88	1.46	0.102	0.45	2.25	3.92	3.21	0.405	0.08	1.61	100.2	1155	493	7	5	124	2	38

Note. Analysis method, FUS-ICP. GM 165, tuff; GM 201, volcaniclastic; GM 262, tuff; GM 277, dike; GM 316, dike; GM 321, dike; GM 323, rhyolite dome; GM 324, rhyolite dome; GM 339, lava flow; GM 34, lava flow.

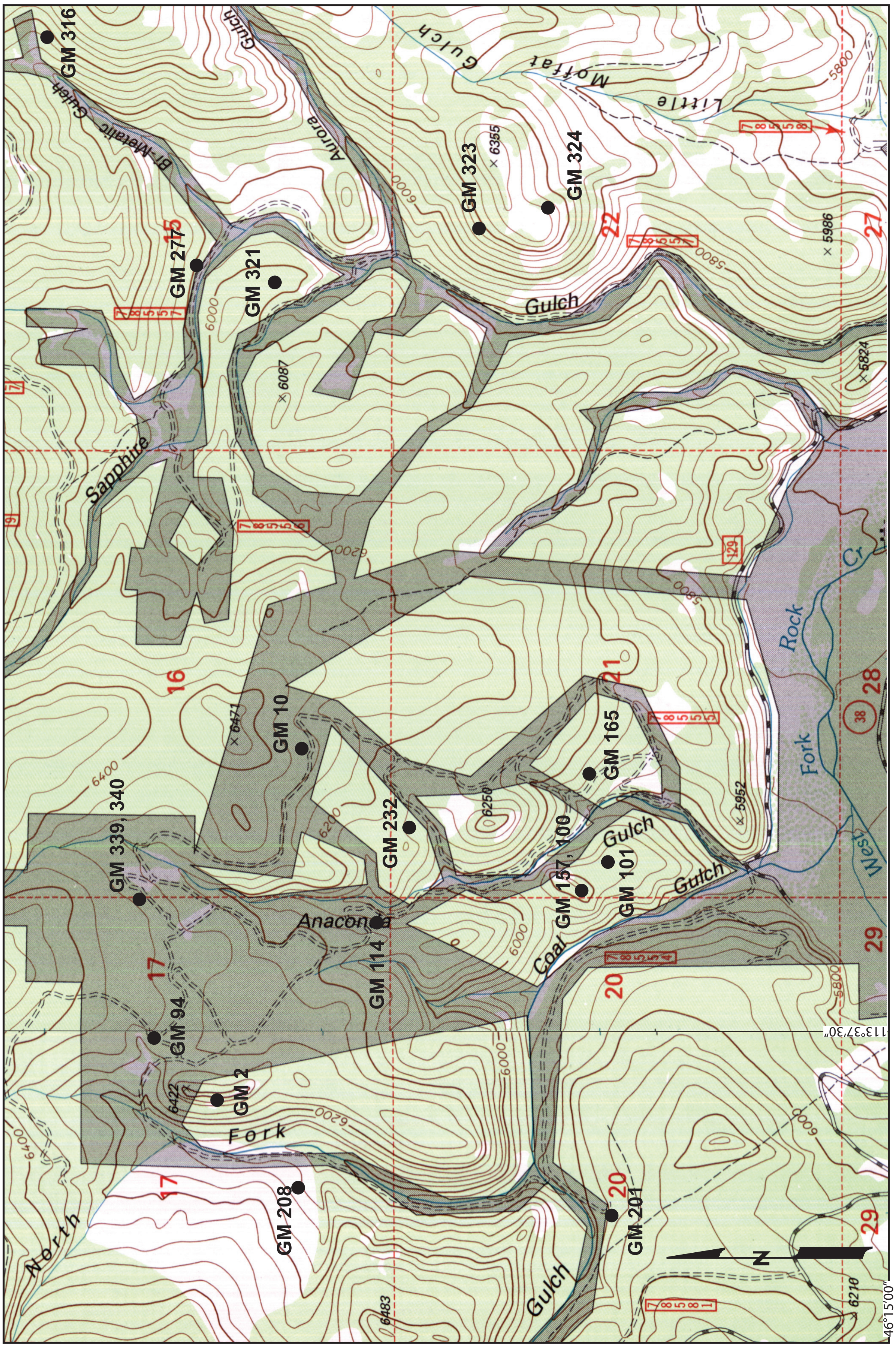


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Figure A3.1 Sample sites for samples whose chemical analyses are presented in tables A3.1 and A3.2. See figure 2.1 in the text for geology. Gray areas are patented claims.

APPENDIX 4

$^{40}Ar/^{39}Ar$ ANALYSES

Nevada Isotope Geochronology Laboratory—Description and Procedures

Samples analyzed by the $^{40}Ar/^{39}Ar$ method at the University of Nevada Las Vegas were wrapped in Al foil and stacked in 6-mm inside-diameter sealed fused silica tubes. Individual packets averaged 3 mm thick and neutron fluence monitors (FC-2, Fish Canyon Tuff sanidine) were placed every 5–10 mm along the tube. Synthetic K-glass and optical grade CaF_2 were included in the irradiation packages to monitor neutron-induced argon interferences from K and Ca. Loaded tubes were packed in an Al container for irradiation. Samples irradiated at the U.S. Geological Survey TRIGA Reactor, Denver, CO, were in-core for 7 h in the In-Core Irradiation Tube (ICIT) of the 1 MW TRIGA-type reactor. Correction factors for interfering neutron reactions on K and Ca were determined by repeated analysis of K-glass and CaF_2 fragments. Measured $(^{40}Ar/^{39}Ar)_K$ values were 1.74 (±67.07%) x 10^{-2}. Ca correction factors were $(^{36}Ar/^{37}Ar)_{Ca}$ = 2.16 (±8.78%) x 10^{-4} and $(^{39}Ar/^{37}Ar)_{Ca}$ = 6.70 (±1.60%) x 10^{-4}. J factors were determined by fusion of 4–8 individual crystals of neutron fluence monitors, which gave reproductions of 0.15% to 0.56% at each standard position. Variation in neutron fluence along the 100 mm length of the irradiation tubes was <4%. A Matlab curve fit was used to determine J and uncertainty in J at each standard position. No significant neutron fluence gradients were present within individual packets of crystals, as indicated by the excellent reproducibility of the single crystal fluence monitor fusions.

Irradiated FC-2 sanidine standards together with CaF_2 and K-glass fragments were placed in a Cu sample tray in a high-vacuum extraction line and were fused using a 20-W CO_2 laser. Sample viewing during laser fusion was by a video camera system and positioning was via a motorized sample stage. Samples analyzed by the furnace step-heating method utilized a double vacuum resistance furnace similar to the Staudacher and others (1978) design. Reactive gases were removed by three GP-50 SAES getters prior to being admitted to a MAP 215-50 mass spectrometer by expansion. The relative volumes of the extraction line and mass spectrometer allow 80 percent of the gas to be admitted to the mass spectrometer for laser fusion analyses and 76 percent for furnace heating analyses. Peak intensities were measured using a Balzers electron multiplier by peak hopping through 7 cycles; initial peak heights were determined by linear regression to the time of gas admission. Mass spectrometer discrimination and sensitivity were monitored by repeated analysis of atmospheric argon aliquots from an online pipette system. Measured $^{40}Ar/^{36}Ar$ ratios were 279.80 ±0.82% during this work; thus a discrimination correction of 1.0562 (4 AMU) was applied to measured isotope ratios. The sensitivity of the mass spectrometer was ~6 x 10^{-17} mol mV^{-1} with the multiplier operated at a gain of 36 over the Faraday. Line blanks averaged 27.65 mV for mass 40 and 0.11 mV for mass 36 for laser fusion analyses and 9.56 mV for mass 40 and 0.03 mV for mass 36 for furnace heating analyses. Discrimination, sensitivity, and blanks were relatively constant over the period of data collection. Computer-automated operation of the sample stage, laser, extraction line, and mass spectrometer as well as final data reduction and age calculations were done using LabSPEC software written by B. Idleman (Lehigh University). An age of 28.02 Ma (Renne and others, 1988) was used for the Fish Canyon Tuff sanidine fluence monitor in calculating ages for samples.

For $^{40}Ar/^{39}Ar$ analyses, a plateau segment consists of three or more contiguous gas fractions having analytically indistinguishable ages (i.e., all plateau steps overlap in age at $\pm 2\sigma$ analytical error) and constituting a significant portion of the total gas released (typically >50%). Total gas (integrated) ages are calculated by weighting by the amount of ^{39}Ar released, whereas plateau ages are weighted by the inverse of the variance. For each sample inverse isochron diagrams are examined to check for the effects of excess argon. Reliable isochrons are based on the MSWD criteria of Wendt and Carl (1991) and, as for plateaus, must constitute contiguous steps and a significant fraction of the total gas released. All analytical data are reported at the confidence level of 1σ (standard deviation).

This sample produced a discordant age spectrum, with a first step age of ~40.5 Ma followed by generally concordant ages of ~49–52 Ma for the remainder of the gas released (percent ^{39}Ar released). The total gas age, which is equivalent to a conventional K/Ar age, is 48.2 ± 0.3 Ma. Steps 4–11 (52% of the ^{39}Ar released) define an older plateau age of 50.2 ± 0.4 Ma. The same steps define a statistically valid isochron that yields a similar age of 51.0 ± 0.9 Ma, and an initial $^{40}Ar/^{36}Ar$ ratio of 277.0–20.5, indistinguishable from the atmospheric ratio. Ca/K ratios are generally consistent with degassing of a homogeneous biotite separate, and radiogenic yields (percent $^{40}Ar^*$) are generally high and do not suggest the biotite is altered significantly. Note that the isochron, although valid, is

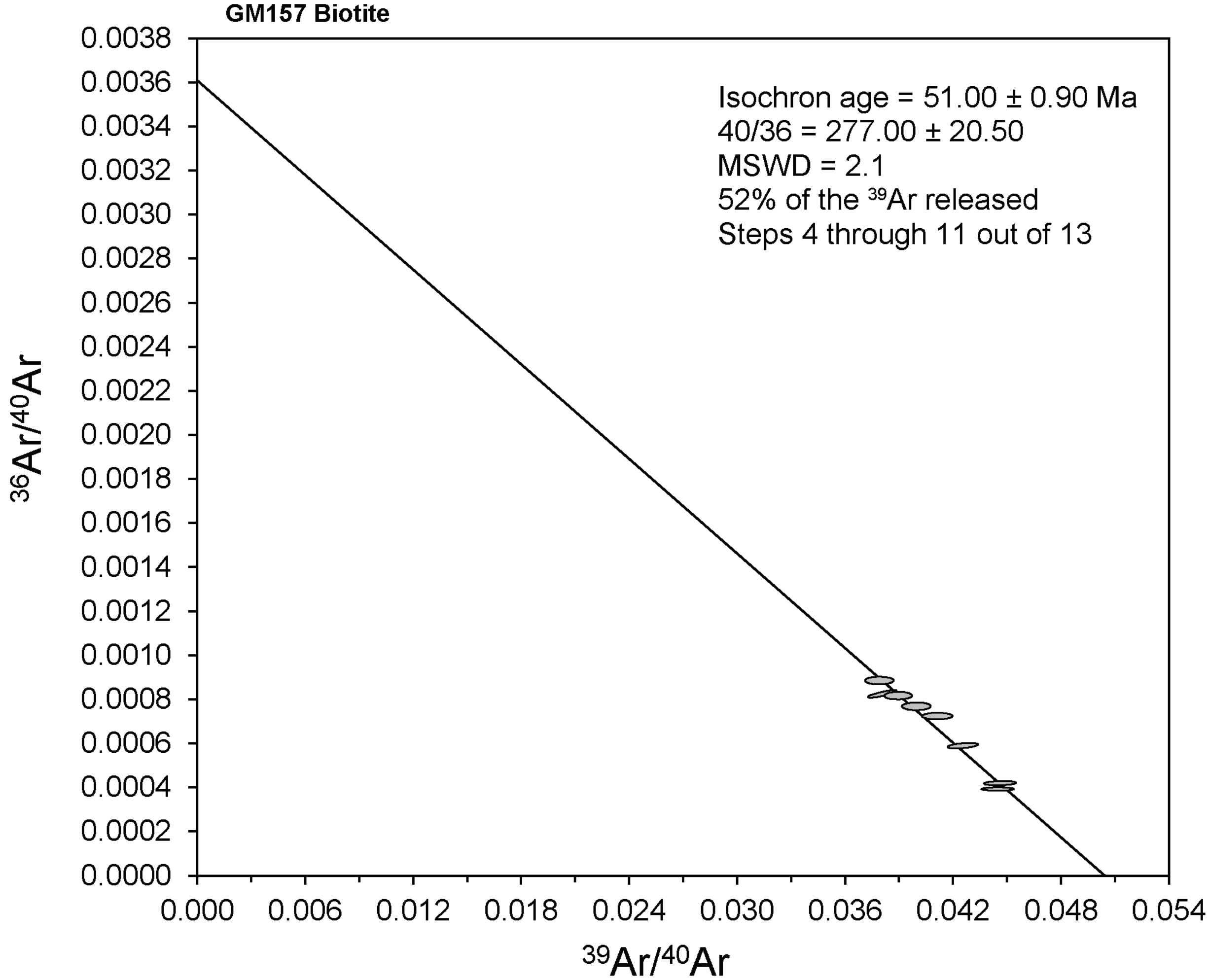

Figure A4.1 Isochron plot.

constrained by data that clusters near the center of the regressed line, thus yielding relatively poor precision on the x- and y-intercepts. The shape of the age spectrum and the isochron do not indicate excess argon is a problem for this sample. Accordingly, it is reasonable to use the plateau age as a reliable indicator of the age of this sample.

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APPENDIX 5

OXYGEN ISOTOPE ANALYSES

The information presented here is from Berg and others (2008). For information on the sources of these sapphires other than Rock Creek, see Mychaluk (1995) for Yogo; Berg (2007) for Lowland Creek; and Berger and Berg (2006) for Silver Bow.

Procedures

Sapphires were selected from suites of sapphires obtained directly from individuals who either were actively mining sapphires from these localities or had previously mined these specific sapphires. All isotopic analyses were done at the Nevada Stable Isotope Laboratory at the University of Nevada Reno using a laser-based extraction technique modified after the technique of Sharp (1990) using BrF_5 as the reagent. Samples were heated using a Merchantek EO CO_2 laser, and the liberated molecular O_2 was collected on silica gel for transfer to the mass spectrometer. The isotope analyses were performed using a Micromass IsoPrime stable isotope ratio mass spectrometer in dual inlet mode. Results are reported in units of permil in the usual delta notation vs. VSMOW, using a value of $\delta^{18}O$ = +9.6‰ for NBS28. Replicate analyses of sapphires and laboratory standards indicate an uncertainty of ±0.1‰.

Results

Analyses of Rock Creek sapphires form a tight cluster at 2.6 to 3.4‰, which are some of the lowest $\delta^{18}O$ values reported in the literature for sapphires worldwide. A comparison of $\delta^{18}O$ values for the Rock Creek sapphires to those analyzed by Guliani and others (2005; 2007) suggest that the Rock Creek sapphires are from a metamorphic source such as schist, gneiss, or amphibolite.

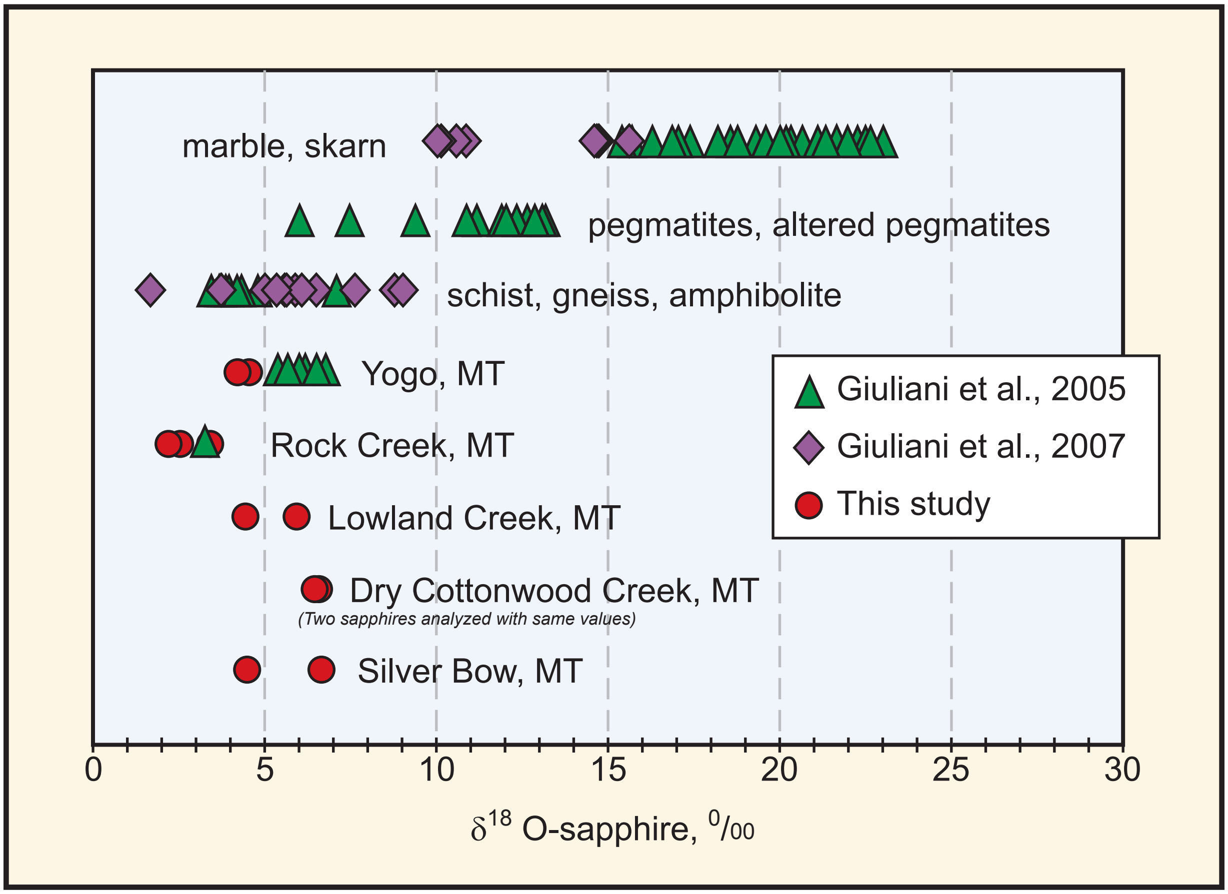

Figure A5.1. Oxygen isotope analyses.

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