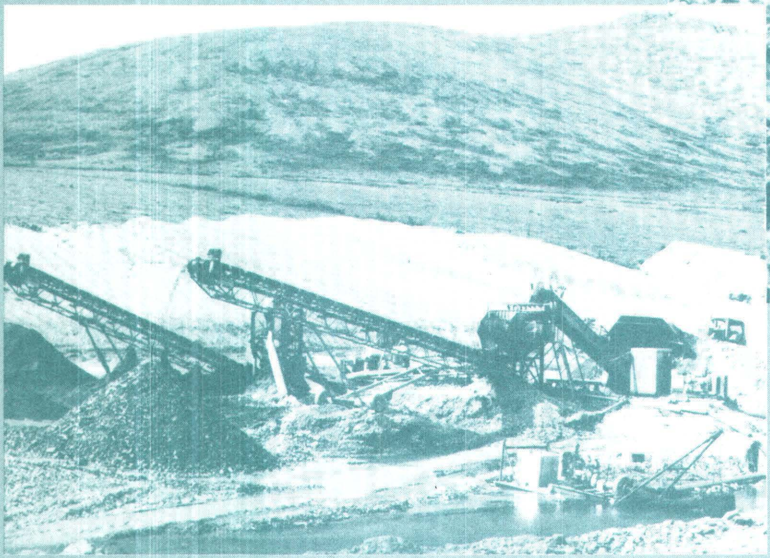
GOLD PLACERS OF THE CIRCLE DISTRICT, ALASKA — Past, Present, and Future



U. S. GEOLOGICAL SURVEY BULLETIN 1943

Cover photographs:

Upper left

Hydraulic mining of North Fork of Harrison Creek, 1980. This was the last hydraulic mining operation in the Circle district.

Lower left

Placer mining on Eagle Creek in July 1988.

Right

Panning for heavy minerals along Ketchem Creek.

CORRECTION FOR
GPO JACKET (FY91) 585-040 (PRINT ORDER 30035)
U.S. GEOLOGICAL SURVEY BULLETIN 1943

SUP. DOCS.: This page is to be distributed according to the standard IGS mailing list for USGS bulletins.

USER: An error during printing of plate 1 resulted in the dark screened pattern for unit TKg that appears in the boxes for both the "List of Map Units" and "Correlation of Map Units." This screened pattern is wrong. The pattern in these two boxes should be that pattern used within the map area for unit TKg.

Gold Placers of the Circle District, Alaska—Past, Present, and Future

By WARREN YEEND

U.S. GEOLOGICAL SURVEY BULLETIN 1943

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

Any use of trade, product, or firm names
in this publication is for descriptive purposes only
and does not imply endorsement by the U.S. Government

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1991

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Yeend, Warren E., 1936-
Gold placers of the Circle district, Alaska / by Warren Yeend.
p. cm. — (U.S. Geological Survey bulletin ; 1943)
Includes bibliographical references (p.).
1. Geology—Alaska. 2. Gold ores—Alaska. 3. Placer deposits—Alaska. I. Title. II. Title: Circle district, Alaska. III. Series.
QE75.B9 no. 1943
[QE83]
557.3 s—dc20 90-3932
[553.4'1'09798] CIP

CONTENTS

PLATE

FIGURES

TABLE

Gold Placers of the Circle District, Alaska—Past, Present, and Future

By Warren Yeend

ABSTRACT

The Circle mining district in east-central Alaska is one of the richest placer gold districts in the State, with an estimated total production of 1 million troy ounces since placer mining began in the district. Although many of the rich deposits have been mined, there still exist areas that can be profitably mined if the price of gold is $400 per troy ounce. These areas are identified on a geologic map that outlines mined and unmined gold-bearing creek gravel.

Placer gold has been mined in the Circle district almost continuously since its discovery in 1893. Sluicebox mining was one of the earliest methods used in the district; later hydraulicking, dredging, and draglining were used. During the 1980's, bulldozers, trommels, and sophisticated jigs were used. The rich mining lore of the district is, in part, associated with events of the nearby world-famous Klondike district. Bedrock and placer geology and mining history of individual gold-rich creeks are herein updated.

The area contains granite, quartzite, quartzite schist, and mafic schist overlain by colluvium, gravel, fan deposits, silt, organic material, and several ages of gold-bearing gravel. A correlation between the presence of mafic schist and the distribution of gold-bearing gravel strongly suggests that the schist is the bedrock source of the gold.

The Tintina fault zone, which crosses the northeast edge of the study area, is a dominant structure in the area and it has played a major role in the recent geologic history. The zone contains at least three ages of superimposed fan gravel—late Tertiary(?), late Pleistocene, and Holocene. The Holocene fan gravel is the most gold rich, with values of $1 to $10 per cubic yard (at $400/ troy ounce). The late Tertiary(?) gravel possesses gold values of only $0.10 to $0.50 per cubic yard; however, the volume of this gravel is very high. The late Tertiary(?) gravel, where exposed, is intensely altered to a deep orange-brown near the Hot Springs fault, the southern boundary of the Tintina fault zone. Hot water associated with the fault may have caused the alteration. The Tintina fault trench was filled with successive layers of fan gravel from the surrounding highlands. Such infilling also occurred in other areas of Alaska that have subsequently been fragmented by faulting so only isolated remnants of the fan gravel remain.

Heavy-mineral-concentrate samples show that streams cutting through quartzite and schist are rich in garnet, whereas streams eroding granitic rocks contain ilmenite, magnetite, and some are rich in amphibole. Gold is most prevalent in the creeks whose drainage basins are in mafic schist. Gold from the Circle district is moderately high in silver (average 16.1 percent) and all samples contain antimony, which distinguishes it from the gold of many other areas in Alaska that does not contain antimony. Fineness varies from 714 to 984; however, it is difficult to attach geologic meaning to the fineness data.

Most placer gold in the Circle district is recovered at, or near, the gravel-bedrock contact. The lower 1 meter of gravel and the upper 0.5 meter of bedrock likely contains as much as 80 to 90 percent of the gold that is ultimately recovered. Gold nuggets are rare, and most of the gold recovered is in the form of flattened fragments less than 5 millimeters in greatest dimension.

The gravel in Mastodon Creek, the richest in the district, has produced between 150,000 to 200,000 troy ounces of gold and has been thoroughly mined. Deadwood Creek may be the most mined-out creek in the district, although some gold-bearing bench gravel remains unmined, as do the vast deposits of low-value fan gravel north of the Hot Springs fault. The gravel in Crooked Creek seems to be richest north of the Hot Springs fault, and little, if any, mining has been done on the south side of the fault in Crooked Creek. The North Fork of Harrison Creek has produced a great deal of gold from mining in the 1980's. Colluvium adjacent to streambeds in some steep-sided valleys contains sufficient gold to warrant mining; these valleys are Portage, Eagle, Miller, Mastodon, and Mammoth Creeks. The largest gold resource remaining in the Circle district is probably in the lower reaches of Crooked Creek and in the alluvial fill within the Tintina fault zone.

Although most current mining in the Circle district is done with expensive, sophisticated equipment, smaller, low-budget mining operations still have a place. A modest living can be made by two to three people mining in localities that would not support a large operation and, for some people, small-scale mining provides a great hobby. Environmental restrictions imposed by Federal and State agencies have slowed, but not stopped, placer mining in the Circle district. A significant rise in the price of gold (to more than $400 per ounce) would result in increasingly more mining.

Manuscript approved for publication, May 22, 1990.

INTRODUCTION

The Circle mining district in east-central Alaska is one of the richest placer gold districts within the State, with estimated production of 1 million troy ounces (oz) since 1893. Although many of the richest deposits in the district have been mined, economically marginal areas can now be profitably mined because of the recent gold price increase. The purposes of this study are to update the extensive mining history of the district, which has not received attention since Mertie (1938), to present the first detailed map of the gold-bearing placers of the Circle mining district and to offer a new hypothesis for the bedrock origin of the placer gold. Herein, all values of gravels are given for a gold price of $400/troy ounce.

Methods of Investigation

Fieldwork was carried on during parts of June 1980, July 1981, and June and July 1986, 1987, and 1988. Jeff Kline of the Alaska State Division of Mines and Geology worked with me in the field for several weeks in 1986. The geology was mapped directly on NASA (National Aeronautics and Space Administration) color aerial photographs at a scale of 1:63,000, (1980, 1981, 1984) and contacts were transferred to topographic quadrangle maps (1:63,360).

Lithologies and textures of creek gravels and dimensions of mined and unmined gravel were observed in the field. Fieldwork included summarizing current mining operations; sketching plan and cross sections at mine sites and at locations where critical field relations of geologic units were evident; discussing with miners all aspects of geology, gold values, and mining characteristics; and describing in detail the stratigraphy of selected areas including ice content. Stream-sediment samples collected from 144 sites were screened (with a minus-10-mesh screen) and panned in the field and the panned concentrates were dried for mineral identification and detailed study.

Early History

Beginning in the 1860's, there persisted a rumor that gold had been found on Preacher Creek, a major drainage northwest of the Circle district. However, it was not until 30 years later that the presence of gold in the region was confirmed. Gold had been found at several locations in Alaska by the early 1890's, yet the most famous rush to the Canadian Klondike was still several years away. Word that Pitka and Cherosky had found gold on Birch Creek during the summer of 1892 prompted a prospecting trip by several gold miners from the Fortymile gold mining area approximately 200 km to the southeast. Henry Lewis, John McLeod, and Gus Williams came over in July 1893 from the Fortymile and made a discovery August 10 of that same year on Birch Creek, at a place known as Pitka's Bar (Dunham, 1898). Numerous miners in the Fortymile were eager to try their luck in this new area, and through the generosity of Mr. L.N. (Jack) McQuesten (fig. 1), who offered them supplies from his warehouse, all who cared to take a chance in the new district did (Spurr, 1898). Approximately 30 men came over from the Fortymile and the richness of the new district was soon realized. In June 1898 gold was discovered on Mastodon Creek by Pat J. Kinnaley and John Gregor, and on June 22 of the same year gold was discovered on Independence Creek. Mastodon Creek was to become the richest creek in the district and for several years was known as the best creek in Alaska. There exist various versions of finding gold in the Circle district. A detailed and romantic account is presented in Wharton's book, "The Alaska Gold Rush" (1972).

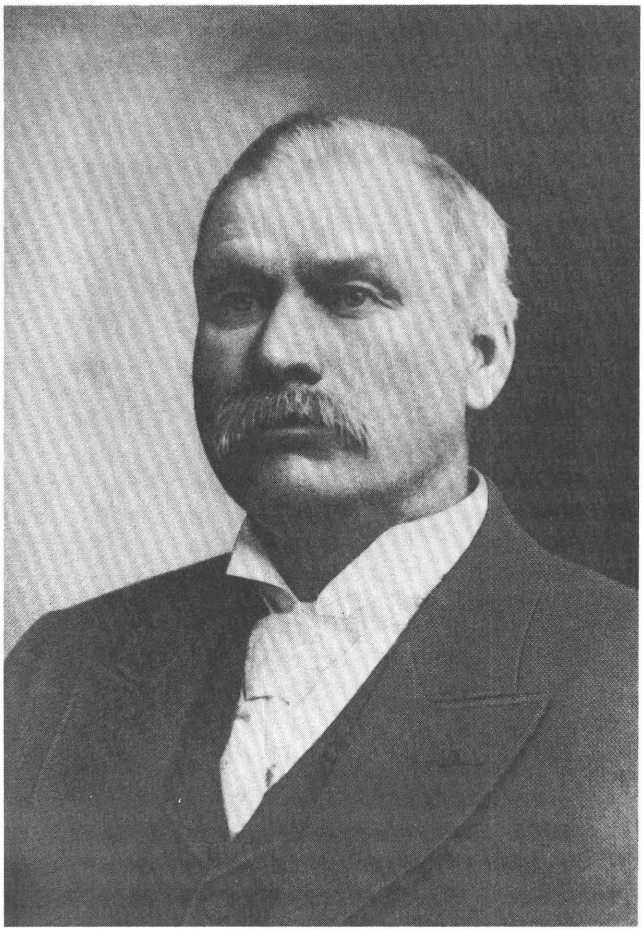


Figure 1. L.S. (Jack) McQuesten, called "father of the Yukon" because of his benevolence to early miners in Yukon and Circle districts.

Circle City became the supply distribution center for the Birch Creek mines, as they were originally termed, which became the most extensive placer diggings in Alaska. Circle City was known as the best built town on the Yukon, with 300 comfortable cabins and several two-story buildings. In the fall of 1894, McQuesten established a trading post in Circle City and, because of his interest in and kindness to the miners, he was called "Father of the Yukon" by them (Dunham, 1898). Much of the development of the Yukon gold fields is attributed to McQuesten's farsightedness through his faith in the miners.

Prior to the Klondike discovery in 1897 there was a population of about 1,000 in Circle City, including the nearby Birch Creek district, and the town was considered prosperous. Known as "the Paris of Alaska," Circle had five general stores, two jewelers, two physicians, two dentists, a hospital, a music hall, two theaters, eight dance halls, and 28 saloons (Berton, 1958; Wharton, 1972). Sam Dunham was the editor of the local newspaper, the Yukon Press. He had help from visiting Joaquin Miller, who had been sent to the Yukon by the San Francisco Examiner (Wharton, 1972). When news of the Klondike gold strike reached Circle City, 800 to 900 men left immediately for Dawson and by late spring of 1897 there were not more than 50 people, mostly women and children, left in town. Most of the mining claims in the Birch Creek district were relocated and had to be restaked when the miners returned from the Klondike in the fall of 1898.

The Miners' Association was an institution in Circle City, whose primary purpose was relieving members in sickness and distress. In 1898, membership was 275 and the association's library contained 1,000 volumes. Resident miners felt U.S. mining laws were inadequate to their unique needs that resulted from isolation, short seasons, and severe climate. Therefore, an unwritten set of laws and customs prevailed over the Birch Creek district (Dunham, 1898).

Area of Study

The Circle mining district lies near the middle of the Circle 1:250,000-scale quadrangle and includes parts of the Circle B-2, B-3, B-4, C-2, C-3, and C-4 1:63,360 topographic quadrangles. The mapped area, which is bounded by Birch Creek on the south and west, Porcupine and Crooked Creeks on the north, and Portage Creek on the east (fig. 2), was selected for study because it contains the placer-rich creeks from which most placer gold in the Circle district was mined, and because it probably contains the largest unmined placer deposits within the Circle district.

Previous Work

Samuel Dunham (fig. 3), as a special investigator and statistical expert for the U.S. Department of Labor, went to Alaska in 1897. His official report (1898) on conditions in the Alaska gold fields is one of the classics of gold rush literature, but it is not well known. He was present during the formative period of the Circle mining district, and his report detailing the discovery and subsequent development of the district is as accurate as any published since. Dunham's report includes the first published geographic map of the district, then called the Birch Creek district (fig. 4). Much of the material in the "Early History" section of this report is taken from Dunham's original report.

Spurr (1898) included a short discussion of the Circle area in his report on the geology of the Yukon gold district. This report contains the first published geologic map of the district and it provides historical perspective. Short papers by early 20th century U.S. Geological Survey geologists were concerned primarily with the status of mining in the district—Brooks (1907, 1918), Ellsworth (1910, 1912), Ellsworth and Davenport (1913), Ellsworth and Parker (1911), and Johnson (1910). John Mertie visited the district in the 1930's (Mertie, 1982), and his subsequent publications (1932, 1938) are still the most detailed and definitive on the placer geology and mining. Likewise, his report on the bedrock geology in the Yukon-Tanana region (1937) is important and useful in understanding the placer geology.

More recently, Foster and others (1983) mapped the geology of Circle quadrangle at scale of 1:250,000. Simultaneously Menzie and others (1983) assessed the mineral resource potential of the quadrangle.

Acknowledgment

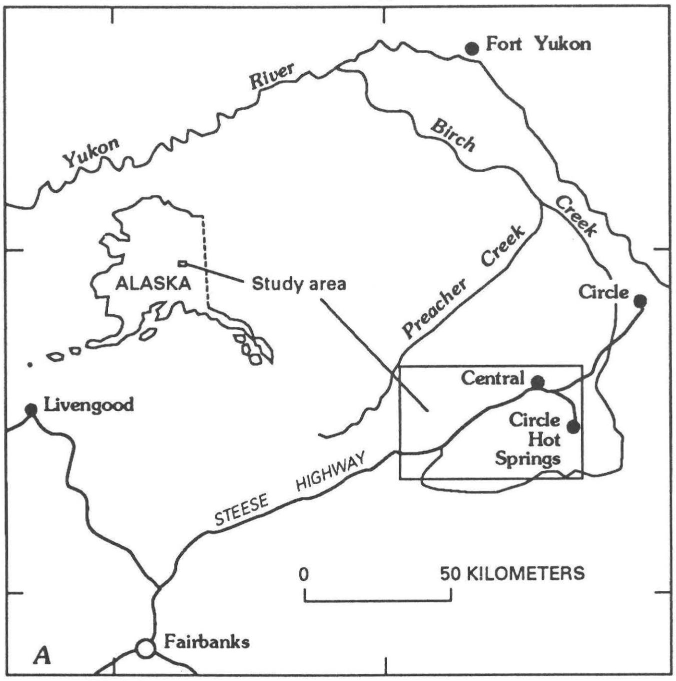
I am grateful to the numerous kind and courteous miners of the Circle district who permitted access to their properties, allowed samples to be collected, and cooperated in the various phases of the work done on their claims. Frank and Mary Warren of Central, Alaska, allowed Jeff Kline and I to stay on their property near Crooked Creek during the summer of 1986. During June and July of 1987, they again allowed me to stay there, and I am most thankful for their hospitality.

GEOLOGY

The boundaries of creeks containing gold placers together with the outlines of mined and unmined areas, are shown on plate 1. Bedrock and surficial deposits adjacent to the gold-bearing creek deposits are also shown on plate 1. Major faults such as the Hot Springs and Preacher Creek faults, part of the Tintina fault zone, are near the gold placers. Gold values, where given, are calculated at the $400/troy ounce (oz) rate.

Bedrock

The Circle mining district lies at the fragmented northern margin of the North American craton. The Tintina fault zone trends northwest across the northern part



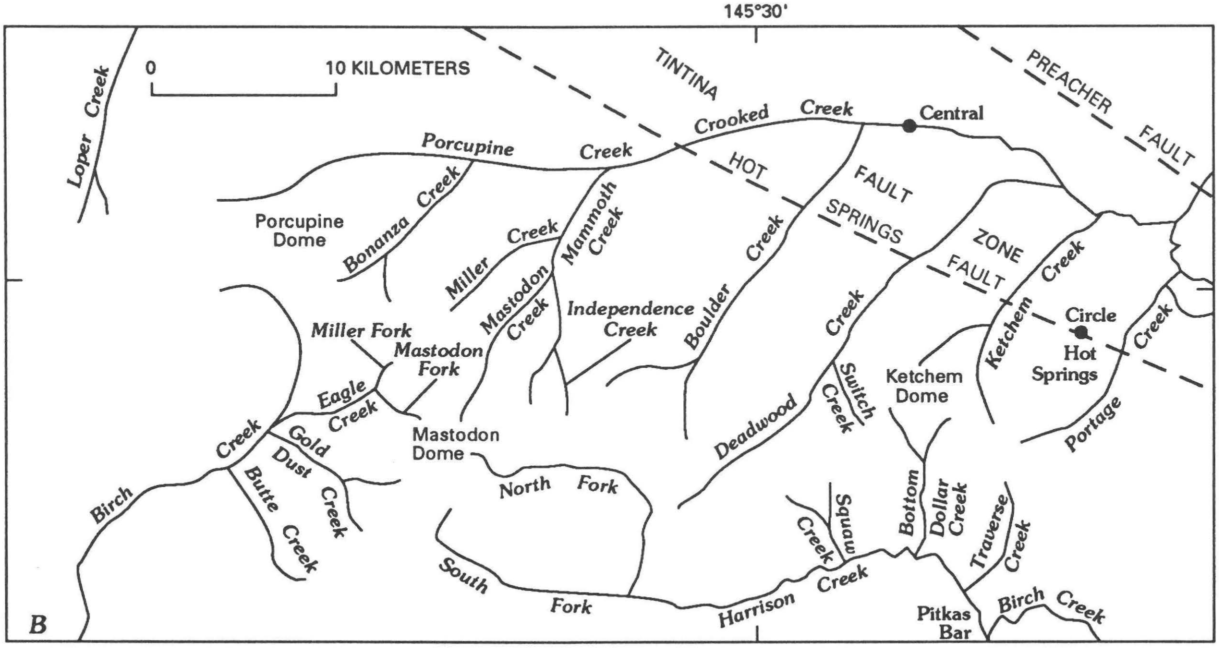


Figure 2. Index maps showing location of study area. *A*, Location of study area. *B*, Area of inset.

of the district and separates greenschist- and amphibolite-facies metamorphic rocks on the south from weakly metamorphosed rocks on the north (Foster and others, 1983). Almost all gold produced in the district has come from south of the Tintina fault zone and some has come from within the fault trench. The rocks south of the fault zone are part of the composite Yukon Crystalline terrane (Churkin and others, 1982). Metamorphic continental rocks occur here with a few mafic and ultramafic rocks. Regional metamorphism is characterized by medium-pressure facies ranging from amphibolite to greenschist. Late Cretaceous and early Tertiary plutons have caused local contact metamorphism of the country rocks. Evidence for at least four deformational events is recognized: penetrative schistosity, two generations of recumbent folding, and a late open folding (Cushing and Foster, 1982).

Three bedrock types—quartzite and quartzitic schists, mafic schist, and granite—are shown on plate 1. The contacts were transferred with only slight modification from the map of Foster and others (1983) to the 1:63,360 scale quadrangle maps used for the compilation of plate 1.

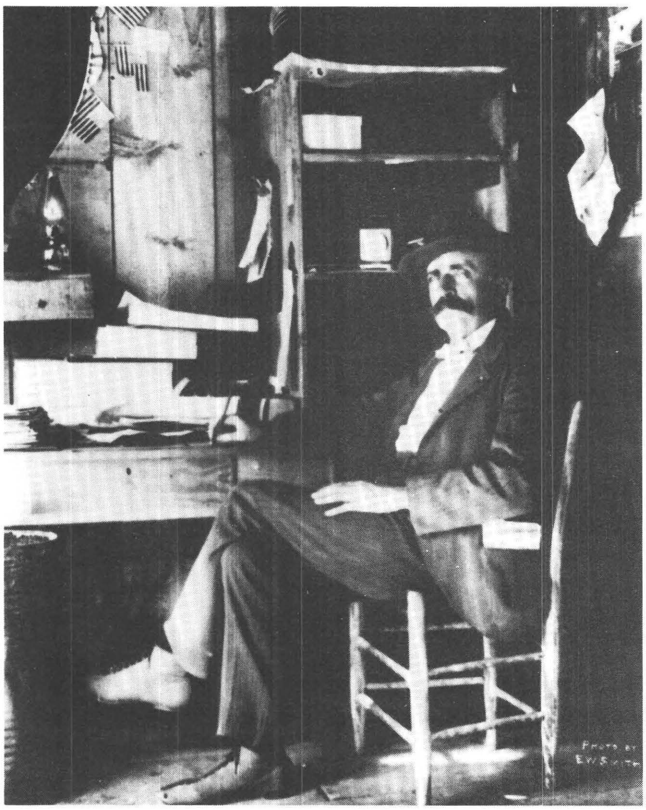


Figure 3. Samuel Dunham, special investigator and statistical expert for the U.S. Department of Labor, visited the Circle district in 1897 and wrote one of the earliest reports about conditions and mining in the area.

Granite

The composite Circle Hot Springs pluton crops out south of the Hot Springs fault from the east boundary of the map area to Independence Creek. It is most widespread in and around Circle Hot Springs. The composite pluton may have formed from two separate intrusive events (Wilkinson, 1987). The northern mass, composed of granodiorite, monzogranite, quartz monzonite, and syenogranite, is dated by potassium-argon (K-Ar) methods at about 57 Ma (million years before present), and the southern body, consisting of granodiorite and monzogranite, is dated at 70 Ma (Wilkinson, 1987). The pluton is cut by porphyritic, aplitic, pegmatitic, and mafic dikes. Quartzites and schists are locally metamorphosed to the hornfels facies near contacts with the pluton, especially in the eastern part of the area. Tin, tungsten, or both are contained in panned concentrates from many creeks in the area of the Circle Hot Springs pluton. Almost half of 18 granite samples analyzed (Menzie and others, 1983) contain detectable tin, and most contain less than 20 ppm. Mineralogy, trace-element data, and normative mineral ratios suggest that the biotite syenogranite is most likely to host tin deposits (Wilkinson, 1987). Additional discussion of the granite as a possible gold source will be covered in the "Gold Source and Resource" section.

Quartzite and Quartzitic Schist

The widespread, primarily quartzite and quartzitic schist bedrock unit is interlayered with pelitic schist, calcschist, mafic schist, and minor amounts of marble. This schist is gray to greenish gray, fine to coarse grained, and equigranular or with megacrysts of quartz and feldspar. Some rocks of this unit may be sheared, recrystallized sandstone. Other protoliths that have been suggested (Foster and others, 1983) are quartzite, arkosic quartzite, and felsic igneous rocks. Shearing and cataclasis prevent identification of original lithologies.

Within this unit is a green or greenish gray, medium-grained, massive to foliated schist that is tentatively placed in the greenschist facies; relict igneous textures were locally preserved. The schist was probably derived from mafic rocks including dikes (Foster and others, 1983).

Regional metamorphism of medium pressure and low temperature resulted in amphibolite to greenschist facies. Contact metamorphism produced local hornfels facies. Age of the protoliths is unknown. Pink zircon from a metamorphosed quartz arenite at Porcupine Dome (B-4 quadrangle) gives a $^{206}Pb/^{238}U$ age of 1,558 Ma, a $^{207}Pb/^{235}U$ age of 1,797 Ma, and a $^{207}Pb/^{206}Pb$ age of 2,086 Ma (Foster and others, 1983). Eight of 77 rock

Figure 4. Historic map of the Circle mining district showing gold discovery location—Pitkas Bar (shown as Pitka's Bar on map), early trails, and named and mined creeks (reduced and modified from original in Dunham, 1898).

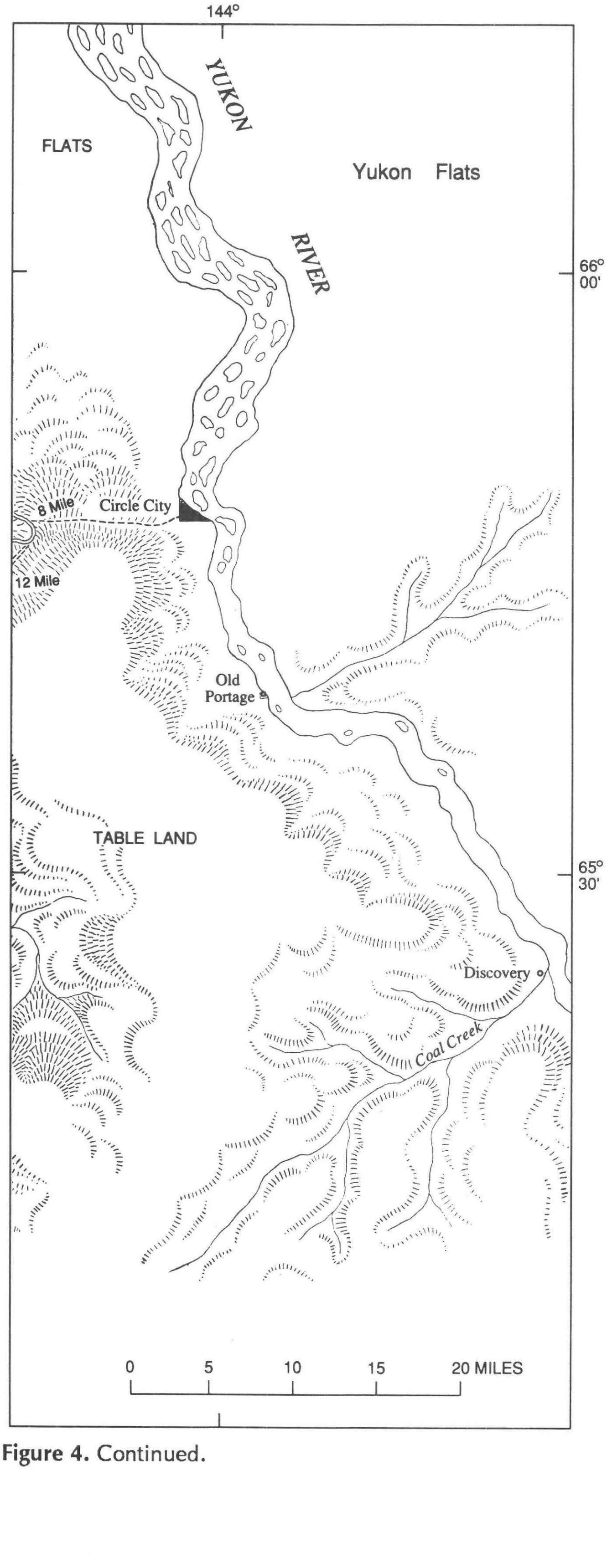


Figure 4. Continued.

samples from this unit contain detectable gold (Menzie and others, 1983).

The blocky outcrops of this unit weather to small, slabby chunks, which are the predominant clast shape in the creek gravel.

Mafic Schist

The mafic schist crops out in a zone about 5 km wide and 38 km long almost directly in the center of the richest placer deposits in the district (pl. 1). The mafic schist is a green chlorite-quartz-carbonate schist with abundant plagioclase porphyroblasts (Foster and others, 1983). It is associated with amphibolite schist, quartzite, pelitic schist, and minor amounts of marble. Locally, it is interlayered with the quartzitic schist unit. The contact of the mafic schist unit with the quartzite and quartzitic schist unit is gradational. Thin layers of mafic schist, interlayered with the quartzite and quartzitic schist unit, are locally present, but they are too small to show at the scale of the map. Because the mafic schist is not a resistant unit, its presence is not always evident in outcrop. More resistant quartzite and quartz-rich schist is predominant in many places within the area mapped as mafic schist. The protolith of the mafic schist may have been mafic pyroclastic rocks depositionally interbedded with protoliths of the quartzite and quartzitic schists (Foster and others, 1983). Geochemistry of 44 samples of mafic schist reveals that only one contains detectable gold (Menzie and others, 1983). Additional discussion of the mafic schist unit as a possible source for gold will be presented in the section "Gold Source and Resource."

Quartz veins cut outcrops of the mafic schist and the quartzite and quartzitic schist at many places. The veins are thin, 1/8 to 1 in. thick, and contain limonite pseudomorphs. Some veins are offset but not folded and others are folded; these differing vein characteristics indicate more than one period of vein formation (Menzie and others, 1983).

Colluvium

Deposits of unsorted to very poorly sorted gravel, sand, silt, and clay are present on the margins of some of the valley alluvial gravels up against the steep bedrock valley walls. This unit includes talus rubble and mixed alluvium and debris flow material as end members. It may possess layers of water-washed detritus, but it is largely composed of boulder- to clay-size material that has accumulated by gravity movements near the foot of steep slopes; boulders are generally angular to subangular in shape. Vegetative organic matter is frequently incorporated in the unit and permafrost is generally present, as well as massive ice lenses and wedges. An organic mat 0.5 to 3 m thick commonly caps the deposit and effectively insulates the permafrost from melting. Where this unit has been disturbed or exposed by excavation, melting and subsequent slumping and flowage are common.

Several of these deposits contain placer gold, and they have been or are being mined. Much of the placer gravel in Portage Creek is colluvium. Portage Creek is very narrow, with steep valley walls, and is an ideal environment for the generation of gravity-induced detrital deposits. The smooth, gentle slopes on the south side of Eagle Creek are also mantled with colluvium. These deposits have been mined where they crop out on the Eagle Creek valley flood plain. Farther back from Eagle Creek, the colluvium is possibly gold bearing. Areas of colluvium bordering the lower stretches of Miller, Mastodon, and Mammoth Creeks have been mined at various times and have produced gold. Values are generally between \$5 and \$20/yd^3. Minable deposits of locally occurring gold-bearing colluvium, too small to map at the 1:63,360 scale, are present along the margins of other steep-sided, narrow placer-rich valleys.

Geologic processes such as mass wasting are generally poor concentrators of heavy minerals, especially gold. Where gold is found in colluvium in minable amounts, gold-rich alluvial deposits were probably somehow incorporated in the mass-wasted deposit during downslope movement. The gold-rich bench gravels along the valley sides are probably at least a partial source of the gold in the colluvium in the Circle district.

Because of the high ice content of these deposits, thawing is necessary prior to mining. Often, thawing is initiated by insolation through stripping of the overlying organic mat one year prior to mining. Occasionally, surface water is redirected to flow over the deposit to aid melting or high-pressure water jets are sprayed on the deposit to melt the low-value overburden as well as the higher value deeper gravel, or both techniques are used. These deposits characteristically contain large amounts of silt and clay-size material, which prevents the thorough washing of the mined gravel and results in "dirty" effluent.

Fan Gravel

This mapped unit refers to those alluvial and colluvial deposits of Quaternary age as distinct from the fan deposits of late Tertiary(?) age discussed in the "Tintina Fault Zone" section. Poorly sorted gravel of both colluvial and alluvial origin is common in the Tintina fault trench and as small scattered exposures in narrow steep-sided valleys. The locally derived gravel is grayish brown and composed of boulders, cobbles, sand, silt, and clay; boulders as much as 1 m in diameter are rare, and the more common size is 10 to 20 cm in diameter. Some of these deposits are gold bearing. The fan gravel filling the Tintina fault trench is of two different ages and possesses a wide range of gold values—Holocene fan gravel, the most gold rich, with values of \$1 to \$10/yd^3 and late Pleistocene fan gravel estimated to have values of only \$0.10 to \$0.50/yd^3.

The extensive deposits of fan gravel filling the Tintina fault trench were derived from the highlands to the south and the Crazy Mountains to the north, and the lithologies of clasts making up the fans reflect the proximity to these different source areas. The probable gold source rocks on the south give rise to the gold-rich fan deposits in and adjacent to Crooked Creek (fig. 5), whereas the cherts, limestones, and sedimentary rocks of the Crazy Mountains that contain relatively little gold supplied the fan deposits on the north. The fan deposits filling the south side of the Tintina fault trench may contain a large albeit low-unit-value resource of placer gold.

Figure 5. Late Pleistocene and Holocene gold-bearing fan gravel exposed along Sawpit Creek road into Crooked Creek; sorting and bedding generally poor to absent.

Silt and Organic Material

Silt and organic material blankets late Pleistocene and late Tertiary(?) fan gravel in the lower, poorly drained part of the Tintina fault trench (pl. 1). The silt is largely eolian, and it has been reworked and transported from its original depositional site to lower slopes and valley bottoms by alluvial and solifluction processes. The silt is highly organic and generally perennially frozen with much ground ice. Peat and organic-rich horizons are commonly interlayered with the silt. Thickness of the unit ranges from 1 to 60 m (Foster and others, 1983).

Late Tertiary(?) Gravel

Until the expanded mining operations in the early 1980's, there were no known exposures of Tertiary rock in the Circle mining district. Placer mining on Crooked, Deadwood, and Portage Creeks has recently exposed orange to orange-brown clay-rich gravel. The gravel is tentatively assigned a late Tertiary age on the basis of its topographic and structural position within the fault trench. This unit is exposed only on the north side of the Hot Springs fault within the Tintina fault trench, and it is in fault contact with blue-gray quartzite and quartzitic schist (fig. 6). The contact is exposed on Crooked Creek about 0.5 km upstream from the confluence of Sawpit Creek (pl. 1).

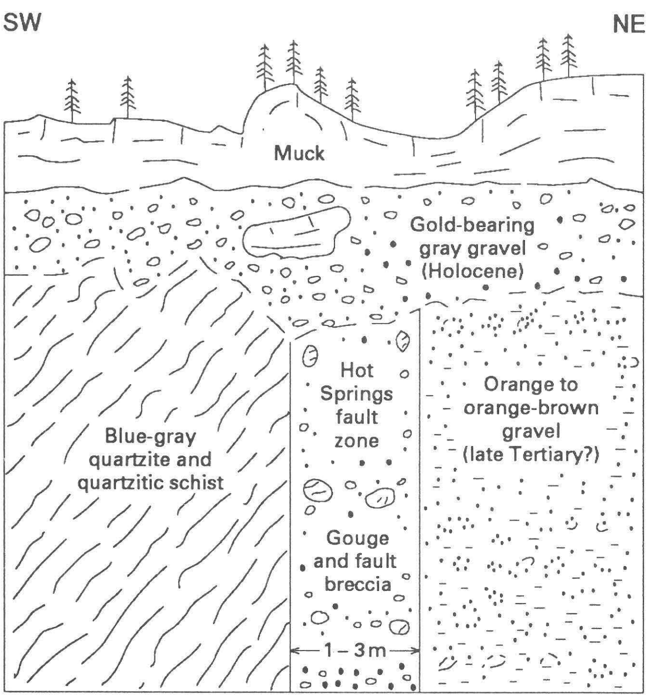


Figure 6. Diagrammatic cross section through Crooked Creek valley showing Hot Springs fault zone and adjacent rock units.

The clasts within the late Tertiary(?) gravel are primarily quartz, quartzite, quartzitic schist, and granite. That all but the quartz clasts are decomposed indicates hydrothermal alteration may have occurred. The schist and granite boulders and cobbles disaggregate readily where removed from the gravel matrix (fig. 7). The unit shows little or no sorting, is high in clay owing to the breakdown of original feldspathic minerals, and is frequently stained yellow to orange-red by the decomposition of ferromagnesian minerals from within the clasts. The alteration does not seem to lessen with depth; however, no more than 3 m of vertical exposure was observed. Miners who have churn drilled in the area report no change in the lithology, color, or texture of the deposit to a depth of 27 m, the deepest of the drill holes. Thickness of the gravel is not known.

Figure 7. Contact of overlying late Pleistocene gray, gold-bearing gravel with altered orange-colored late Tertiary(?) gravel exposed in placer cut in Crooked Creek valley; hat marks contact.

This material is probably fan gravel derived from the highland to the south and deposited in the fault trench. Owing to subsequent faulting, this unit is in sharp contact with the Hot Springs fault.

Although this decomposed gravel unit contains gold, it is a difficult material to wash and process because of its high clay content. Consequently, it is rarely mined. Values vary from \$0.10 to \$5/yd^3.

Possible ice-wedge casts are present in the gravel unit. The upper contact with the overlying gray gravel locally shows a polygonal pattern that indicates possible relict ice-wedges. These pockets in the orange gravel are filled by the younger gray gravel, and because of their higher gold value they are generally excavated and mined (Forbes and others, 1987).

The late Tertiary(?) gravel is less orange and more brown farther downstream along Crooked Creek. This may be a result of the greater distance from the Hot Springs fault, which may have contributed hydrothermal fluids that altered the gravels. The gravels are also deep orange to red-orange in Deadwood and Portage Creeks, which are close to the Hot Springs fault (pl. 1).

Three diamonds ranging in weight from 0.3 to 1.4 kt have been recovered from the placer-gold operations on Crooked Creek since the beginning of large-scale mining in 1980. Although there is no conclusive proof, the clay-rich late Tertiary(?) gravel may have been the source for these diamonds (Forbes and others, 1987). A bedrock source is not known.

Other areas of Tertiary or possibly Tertiary outcrops are present just outside the map area within the Tintina fault trench and as high-level alluvial deposits adjacent to the Yukon River in the northern corner of the Circle quadrangle (Foster and others, 1983). A poor to moderately consolidated pink conglomerate and sandstone unit, exposed on a tributary of Albert Creek (Weber and Foster, 1982), forms hogbacks paralleling the northeast strike and appears to dip as much as 55° SE. Several small flakes of gold were panned from this unit (Yeend, 1984). Other exposures of possibly Tertiary-age rocks within the Tintina fault zone are near the mouth of Loper Creek, by the headwaters of Rock Creek, and by the headwaters of the North Fork of Preacher Creek (Weber and Foster, 1982). These rocks are conglomerates and sandstones with well-rounded clasts of chert and quartzite within a clay-rich matrix. Lignite fragments as much as 20 cm in diameter are locally present in the conglomerate.

A gravel pit 1.5 mi east of the Birch Creek Bridge on the road to Circle contains rocks that are late Tertiary in age, on the basis of pollen analysis (Yeend and others, 1989). Approximately 30 to 35 m of well-sorted pebble gravel and sand with carbonized wood is present below 7 m of Pleistocene(?) gray cobble gravel. Several gold "colors" were panned from pebble gravel near the base of the section. The lithologies present are Yukon River gravel types, and they were not locally derived. This and other gravel mapped in the Circle quadrangle may be remnants of a high-level Yukon River terrace.

Gold-Bearing Alluvial Gravel

Gold-bearing creek gravel is present throughout the Circle mining district as both contemporary flood-plain and older terrace deposits along the valley margins. Included within this gravel are thin lenses, beds, and horizons of sand, silt, and clay.

In addition to showing the outlines of the gravel deposits in the valley bottoms, areas of mined gravel are indicated on plate 1. In many cases, the same gravel has been repeatedly washed in successive mining operations. Additional information on gravel can be found in the section "Gold-Rich Creeks."

Upper and Lower Contacts

South of the Tintina fault zone, gravel rests on steeply dipping quartzites, quartzitic schists, mafic schists, and granites. A weathered decomposed zone developed on the bedrock, particularly the granite, is locally present. Rock cleavage, jointing, and associated fractures are common within the metamorphic rocks (fig. 8) and have acted as natural traps for the gravel clasts and detrital gold particles. The miners typically tear up 1 to 2 m of underlying bedrock to effect a more complete recovery of the entrapped gold. Within the Tintina fault zone, the gravel rests on older decomposed orange-brown gravel of late Tertiary(?) age, as previously described.

Dark organic silt and peat 1 to 3 m in thickness commonly overlie the gold-bearing gravel, particularly along the creek valley margins. These are in part over-

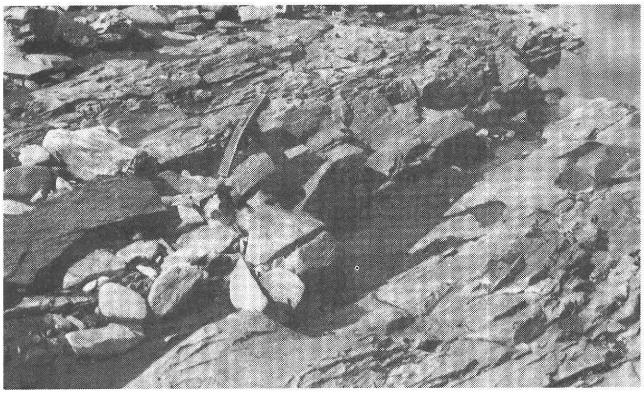


Figure 8. Blocky schist bedrock exposed in Mastodon Creek; irregular surface acts as natural sluice for entrapping gold.

bank deposits and fine-grained colluvium derived from the adjacent steep side slopes. They are almost always ice rich and perennially frozen. After removal of the overlying tundra, this material is allowed to thaw and is then stripped prior to mining the underlying gravel. Only the most active parts of the creek flood plain are free of this fine-grained organic-rich "overburden." Because most creek gravel has been mined at least once, the only remaining ice-rich muck is on the margins of the creeks, in areas that have not been mined.

Lithologies and Textures

Although varying slightly from creek to creek, the lithologies and textures of the gold-bearing gravel are remarkably uniform. The gravel is typically gray to brown, unconsolidated, moderately well sorted and stratified, and is generally dominated by clasts of quartz-mica schist, quartzite, mafic schist, and granite. Because schistose metamorphic rocks predominate, most of the boulders and cobbles are rectangular, slabby, and have rounded edges. Boulders are generally less than 20 cm in diameter, although some are larger. The matrix is typically a coarse gray-brown sand with minor amounts of silt and clay. Organic material in the form of whole to macerated twigs, leaves, and logs is present as isolated pockets in the gravel. Pebble counts and other characteristics of the gravel in individual creeks are discussed in the "Gold-Rich Creek" section. Results of the studies of heavy minerals and detrital gold are discussed in the "Heavy Minerals" section.

Thickness, Age, and Correlation

The gold-bearing alluvial gravel, where restricted to narrow valleys, is usually 2 to 6 m thick. However, where streams debouch from valleys and have built up large fans, as within the Tintina fault zone, the gravel is thicker. At the mined areas in Crooked Creek and at the mined locations farthest downstream in Deadwood, Ketchem, and Portage Creeks, gravel is rarely thicker than 6 m. The overlying organic-rich tundra and muck is commonly 1 to 2 m thick, but it is locally thicker on the valley margins where large amounts of soil and fine colluvium have accumulated from the steep side slopes.

There are three radiocarbon ages from fluvial gravel in the area. A date of more than 32,700 years B.P. (before present) was obtained on wood fragments collected from the uppermost 2 m of sandy pebble gravel overlying 2 m of silty clayey gravel on the north side of the gravel road in the Tintina fault zone approximately 7 km northeast of Central (No. 1, pl. 1). Another date of more than 34,500 years B.P. was determined on carbonized wood from a gravel pit about 13 km farther east along the same road to Circle City, just outside the map area. This wood was collected from a light gray silt that overlies 3 m of sandy, well-rounded pebble gravel approximately 2.5 m below the pit surface. A third date of 1,480±80 years B.P. was obtained on wood collected from the gray gravel in Crooked Creek near the contact of the underlying orange gravel (No. 2, pl. 1). It would seem that most gold-bearing gravel is no older than late Pleistocene (less than 40,000 years); moreover on the the basis of its youthful appearance, topographic position in valley bottoms and on low terraces along modern streams, and the youthful overlying soil development, most gravel is no older than Holocene (less than 10,000 years). Clasts are fresh, with little, if any, noticeable weathering. Isolated vertebrate bones are contained in the frozen muck overlying the gravel. These bones are of animal types similar to those found in late Pleistocene deposits in other areas of Alaska.

The principal placer gold-producing unit in the Klondike area of the Yukon, the White Channel gravels of Morrison and Hein (1987), does not appear to have an equivalent unit in the Circle district. In the Yukon, the White Channel deposit is probably of Pliocene and early Pleistocene age and crops out as terraces on bedrock benches. In the Fairbanks mining district, the principal placer units are the Cripple Gravel, a brown auriferous gravel of late Pliocene and (or) early Pleistocene age, and the Fox Gravel, a tan auriferous gravel of early or middle Pleistocene age (Péwé, 1975). The only unit within the Circle district that might correlate with either of these units is the orange-brown, friable late Tertiary(?) gravel within the Tintina fault zone and it also contains little gold.

Tintina Fault Zone

One of the major geologic structures in Alaska, the Tintina fault zone, trends northwest across the north side of the Circle mining district. It is important to a study of the placers in this region as both a repository of gold-rich sediments throughout the late Cenozoic, and a structure responsible for offset of units related to the gold placers.

The fault zone commonly is referred to as a fault trench because it lies partly in a topographic basin or trench. It is at least 950 km long and is recognized as a major structural and topographic feature in northwestern Canada and eastern Alaska. In the Circle district, the fault zone consists of several strands including the Preacher Creek strand on the northeast and the Hot Springs strand on the southwest (Foster and others, 1983). The fault zone separates metamorphic rocks of the Yukon crystalline terrane on the south from the unmetamorphosed to slightly metamorphosed rocks on the north. The fault zone in the Circle district is a topographic and structural low filled, at least in the uppermost part, with continental clastic rocks ranging in age from Miocene to Holocene.

The fault has an estimated 300 to 420 km of right-lateral displacement (Davies, 1972). Approximately 50 km southeast of the Circle district, the trench transects the Eagle trough. Here faults and other lineaments of the trench extend across a width of 8 to 16 km (Barker, 1986). Dip and strike-slip offset have resulted in the development of basins at various locations along the fault zone. The Eagle trough is filled with Late Cretaceous(?) and early Tertiary coal-bearing sediments (Barker, 1986).

Displacements along faults within the Tintina fault zone probably span much of late Mesozoic and Cenozoic. Most movement probably occurred in Late Cretaceous time (Jones and others, 1981; Tempelman-Kluit, 1977; Tempelman-Kluit and others, 1976). Tertiary displacement is evident in the Eagle trough (Barker, 1986), and in the Yukon Territory, 50 km of middle or late Tertiary movement is implied by the offset of coal-bearing sediments (Hughes and Long, 1980; Barker, 1986). Late Tertiary or early Quaternary right-lateral strike-slip movement is also implied from stream valley patterns in the Eagle trough (Barker, 1986). Evidence of the most recent movement (late Pleistocene) on the Tintina fault system may be in the Circle quadrangle near Medicine Lake; here, the fault trace cuts late Pleistocene alluvium, but this relation is obscured by Holocene alluvium and colluvium (Weber and Foster, 1982). Seismic activity has been detected along the Tintina fault zone (Gedney and others, 1972), and four moderate earthquakes have been recorded in the Crazy Mountain area since 1970 (Weber and Foster, 1982).

Allowing for 80 km of displacement along the Tintina fault zone, Barker (1986) postulated that a spatial connection of the Woodchopper-Coal-Ben Creeks area in the Eagle trough with the Portage-Deadwood-Crooked Creeks area in the Circle district can be made by reconstruction of right-lateral fault movement. This interpretation is supported by the presence of wolframite and cassiterite in drainages in both areas and the occurrence of placer gold predominantly on the south side of the fault trace in the Circle district, and only north of the fault in the Eagle trough area.

Fan gravel fills much of the Tintina fault trench and is of different ages—the oldest as old as late Tertiary(?). Such trench filling with successive generations of fan gravel from the surrounding highlands is thought to have occurred in other areas of Alaska, although in these areas faulting has resulted in fragmented, isolated remnants of the gravel (Yeend, 1989). The Tintina fault trench in the Circle district is filled with at least three ages of superimposed fan gravel—late Tertiary(?), late Pleistocene, and Holocene. The Holocene fan gravel is the most gold rich, with values of \$1 to \$10/yd^3. The older late Pleistocene and late Tertiary(?) fan gravel units are valued at only \$0.10 to \$0.50/yd^3 and consequently have not been extensively mined. Although the grade for most of the trench-filling sediment is low (\$0.10 to \$5/yd^3), the volume is high, and therefore the sediment represents a large resource (Yeend, 1982; Menzie and others, 1983). The price of gold would have to increase significantly, or cheaper mining methods adopted, to allow economic recovery of this resource.

GOLD-RICH CREEKS

Because the local geology and mining conditions vary throughout the district, each creek must be discussed separately. Although most creeks are mined out, some contain enough gold to support small mining operations. The early and modern mining history, bedrock, unconsolidated deposits, valley morphology, gravel textures, lithology and thickness, production, and remaining resources for each creek are discussed in approximate order of gold production, beginning with the richest.

Mastodon Creek

Mastodon Creek has produced more gold than any creek in the Circle district, and in its early history was known as the "best creek in Alaska" (Dunham, 1898). The creek was named in 1894 by prospectors for fossil mastodon bones found in muck overlying the creek gravel (Orth, 1967). Mastodon, a mining camp complete with post office, was established on the creek between 1902 and 1906 (Heiner, 1977). According to some accounts, gold was first discovered in the district on Mastodon Creek (Baker, 1906; Couch, 1953). Dunham (1898), however, lists the discovery as June 15, 1894, by Pat J. Kinnaley and John Gregory, following the earlier (1893) discovery on Birch Creek at Pitka's Bar. These two prospectors panned out about 50 oz a week, and it was not long until the entire length of the creek had been staked. Miners' law prevailing then allowed a discoverer two claims of 500 ft each on the discovery creek. Also, any person could stake his or her claim on each creek, so a small party could tie up much of the ground on several creeks in a region. This happened when a party of miners staked claims simultaneously on Mastodon, Mammoth, Miller and Independence Creeks, all in proximity to each other (unpublished journal of Frederick Currier, Museum of Central, Alaska). The paystreak width was determined by sinking shafts in the creek gravel. This was accomplished by building repeated fires in the shafts and melting the gravel down to bedrock.

The gravel was panned as it melted. There were 59 claims on the creek in the summer of 1897, although only 18 were worked because of the shortage of labor (Dunham, 1898). Once the miners accumulated a "grub stake," they were off to the newly discovered Klondike to prospect. Early exploratory drilling of Mastodon Creek gravel revealed values ranging from $5 to $800 per pan (Dunham, 1898)!

Mining on Mastodon Creek has been nearly continuous since gold was discovered. In the early 1900's, most operations consisted of "shoveling in" gravel to an elevated sluicebox with wood riffles. A steam hoist and a hydraulic plant with a steam scraper were also used (Brooks, 1907).

The first dredge in the district was installed in 1912 on Mastodon Creek. Called the Elmer Dredge after its owner, J.M. Elmer, it was also the first dredge in Yukon Territory having been built on the Stewart River in 1898. It was subsequently floated down the Yukon River to Circle, dismantled, and hauled overland to Mastodon Creek. The dredge contained buckets of $3.5/ft^3$ capacity and had a hull measuring 32 to 70 ft. This dredge operated during the summer of 1912 and 1913 but proved unsatisfactory because it was too small to dig to bedrock (Mertie, 1938). The dredge was abandoned and pieces of it including several buckets can be seen today along the middle part of Mastodon Creek. A dredge assembled on Mammoth Creek in 1915 by the Berry Dredging Company mined the tributary Mastodon Creek for about 2.5 km (Mertie, 1938). Hydraulic mining was the most favored method of mining on Mastodon Creek for most of its history. In 1937, the Mastodon Mining Company began mining in the headwaters of Mastodon Creek using a dragline excavator. More descriptive details of the varied mining methods in operation on the creek in the 1930's are given by Mertie (1938).

Mastodon Creek has its headwaters on the northeast flank of one of the prominent features in the area, Mastodon Dome. It flows in northeasterly direction for approximately 9.5 km before joining Independence Creek. Below this junction the creek is known as Mammoth Creek. The eastern headwater tributary of Mastodon Creek is known as Forty-Two Gulch because it enters the main creek at the 42nd claim above the discovery claim. The discovery claim was approximately 1 km above the mouth of Mastodon Creek. Baker Gulch, about 2.5 km downstream, is the only other tributary of Mastodon Creek. The gradient of the mined part of the creek varies from 3 to 5 percent.

Mafic schist is the predominant bedrock underlying three-fourths of the drainage basin of Mastodon Creek. The lower one-fourth of the creek flows across the quartzitic schist unit, and granite is present just downstream from the mouth of Mastodon Creek. Quartz veins cutting the schist are predominant toward the headwaters of the creek. A pebble count (No. 19, pl. 1) in the lower part of Mastodon Creek reveals a composition of 45 percent quartzite, 25 percent quartz-mica schist, 25 percent mafic schist, and 5 percent quartz.

The gravel in Mastodon Creek is coarse and contains boulders with diameters of 10 to 30 cm, and some boulders are as much as 1 m across. Clasts are commonly subangular to rounded. Silty muck from 1 to 5 m thick overlies the 3 to 5 m of gravel. Most gold was recovered at, or very near, the gravel-bedrock contact; however, higher concentrations were locally found in the 2 to 3 m of gravel above bedrock. Often 0.5 m of bedrock would be broken up and washed for the gold contained in its fractures and joints. The paystreak width ranged from 30 m in the upper valley to 300 m in the lower valley (Mertie, 1938).

The early mining operations recovered $40 to $60 in gold/yd³ of gravel, whereas by the 1930's, $15/yd³ was more typical, and by the 1980's, $4 to $5/yd³ was a common yield. The gold in the upper valley was fairly coarse compared to the fine and flaky gold downstream (Mertie, 1932). Nuggets larger than 1 oz were rarely found, and the coarse gold that was recovered commonly contained attached quartz. Mertie (1938) reported that the gold fineness increased downstream in Mastodon Valley. Such enrichment is commonly assumed to be the result of progressive solution of silver during downstream transport. Mertie (1938) claimed that it could also have been caused by a decreasing "fineness" gradient in the lode source, and so higher fineness gold was eroded first and subsequently carried farther downstream. He concluded that the distribution of fineness in a paystreak is of little value in deducing the character and location of antecedent lodes (Mertie, 1938). Cassiterite is also recovered in panned concentrates from Mastodon Creek (Eberlein and others, 1977).

A low bedrock bench was uncovered during mining in 1936, near the mouth of Mastodon Creek on the northwest side. It is about 3 m in height above the bedrock in the creek floor. Parts of this bench are still visible at the valley edge, mantled with 2 to 3 m of colluvium. A bedrock bench was also reported in the upvalley parts of the creek on claim number 39, above discovery. This bench was mined in the first few years after the gold discovery by sinking a 10-m shaft into the gravel and hoisting the gold-bearing gravel to ground level. This "high bar" as it was called contained high gold values in the 1 m of gravel directly above bedrock and for 0.5 m into bedrock (unpublished journal of Frederick Currier, museum of Central, Alaska). The tributary, Baker Gulch, was heavily prospected with trenching and panning in 1988, but it does not seem to contain enough gold to warrant additional mining. It should be noted that much of the drainage basin of Baker Gulch is outside the mafic schist unit.

Mastodon Creek produced an estimated 150,000 to 200,000 oz of gold. The creek is quite thoroughly mined out (pl. 1), and much of the gravel in the creekbed has been washed several times. Although there have been several operations in the 1980's, it has been difficult to make a "go" of it on the creek. In 1987, an operation in the upvalley part of the creek had to discontinue mining because the values were only \$2/yd^3. Valley-marginal colluvium and the uppermost part of the valley might support small operations for a short time (fig. 9).

Mammoth Creek

Mammoth Creek is the 8-km-long central part of the Mastodon-Mammoth-Crooked Creek system, the most productive creeks in the Circle mining district (pl. 1). Mammoth Creek was named in the early 1890's for tusks and bones contained in the frozen muck overlying the gold-bearing gravel. Gold was discovered on Mammoth Creek in 1894; yields were 0.3 to 0.5 oz of gold per man, per day by the "shoveling-in" method of mining (Dunham, 1898). In 1906, a small steam shovel capable of handling 50 yd^3 of gravel per hour was installed on Mammoth Creek, and a 9.5-km-long ditch was built in 1908 to bring water from Bonanza Creek for hydraulic mining. The largest hydraulic plant in the Circle district was used in mining the entire length of Mammoth Creek from Mastodon to Porcupine Creeks (Ellsworth, 1910; Ellsworth and Parker, 1911).

Figure 9. View north down upper Mastodon Creek. Unmined colluvium and gravel are present on lower valley slopes and in the upper valley.

In 1915 the Berry Dredging Company installed a dredge on the creek. It worked upstream along several parallel paths, was dismantled, carried downvalley, and reassembled several times during the following 35 years. This historic dredge had a wooden hull, 58 buckets of 3.5 ft^3 each, and a rated capacity of 3,000 yd^3/day. In 1937 the dredge was used to dig 1.5 m of gravel and 0.5 m of bedrock below water level and was carrying a 3.2-m face above the waterline. Details of this dredge are presented in Mertie (1938). Subsequent to 1950, when the dredge was operating near the junction of Mammoth and Crooked Creeks trying to work its way down to known "richer ground" on Crooked Creek, it burned. The partly buried remains can be seen today on Crooked Creek, just downstream from the mouth of Bedrock Creek.

Miller House, a historic site on Mammoth Creek at the mouth of Miller Creek, was for many years the local supply center for the mining camps in this area of the Circle mining district. A post office, roadhouse, and general store provided gathering places for the miners. The roadhouse, the oldest in Alaska, was built in 1896 and burned in 1971 (Wold, 1988). The last vestiges of this establishment, several abandoned log and frame buildings, were destroyed during the remining of the creek gravel in the 1980's.

The quartzite and quartzitic schist unit is the predominant bedrock along Mammoth Creek. A small outcrop of granite exposed during the recent period of mining forms an area of decomposed grus on the east side of Mammoth Creek in the Granite Gulch area (pl. 1). Mafic schist, although not present in the immediate area of Mammoth Creek, is present in the gold-rich tributaries of Miller, Mastodon, and Independence Creeks. Quartz veins, some mineralized, are locally present, although they are more prevalent near the headwaters of Mastodon Creek. Mertie (1938) believed these veins were a partial source of the gold in the Mastodon-Mammoth valley. A pebble count (No. 20, pl. 1) in Mammoth Creek shows a composition of 58 percent quartzite, 30 percent quartz-mica schist, 10 percent quartz, and 2 percent granite.

Mammoth Creek has a broad valley floor 100 to 500 m across. Boulders are common near the granite outcrop. Elsewhere, cobbles and pebbles of schist predominate. As revealed by the dredging in the 1930's, gravel thickness along Mammoth Creek ranges from 2 to 5 m, and overlying muck thickness is about 2 m.

Most of the gold recovered from Mammoth Creek was flat and flaky. The early miners recovered a few 3- and 4-oz nuggets from gravel that yielded values of \$40 to \$60/yd^3 (Prindle, 1905). The paystreak mined by the dredge was 200 to 300 m wide.

The gravel of Mammoth Creek has been as thoroughly mined for gold as any other creek gravel in the

Circle district. In the 1980's, as many as four separate mining plants were operating along the creek in an attempt to clean the bedrock better than it had been by dredging, as well as to wash pockets of gravel left unmined along the channel margin. In addition, the thin mantle of colluvium on the channel sides yielded some gold following the stripping of the barren overlying ice-rich muck (fig. 10). It is doubtful that there is much gold left in the well-washed gravel of Mammoth Creek.

Deadwood Creek

Deadwood Creek is one of the most productive in the district. Locally in 1894, the creek was rather unflatteringly called "Hog'em" Creek as a result of the greedy nature of the creek discoverer, who attempted to take up an unfairly large part of the richest deposits by filing separate claims for all his many family members as well as fictitious people (Spurr, 1898). Although not officially adopted, "Hog'em" seemed an appropriate name to the early miners on the creek, and it was used almost exclusively during the early days in the district. It was known for awhile as Deadwood Gulch, as it is shown in the 1898 Dunham map, and Deadwood Creek eventually became its accepted name.

There were 47 claims on Deadwood Creek by 1896, and 110 men working 8 of those claims produced approximately 5,000 oz of gold during that year (Dunham, 1898). Yields of 2 to 3 oz "to the shovel" were not uncommon—that is 2 to 3 ounces of gold could be recovered from the gravel shoveled into a sluicebox by one man in a 10-hour day. Ironically, the creek earned a reputation in the early years as a stronghold of conservatism where the miners never attempted to gain more than a living wage from their claims (Brooks, 1907).

Mining on Deadwood Creek has been nearly continuous since the original gold discovery. Initially, the placers were mined by drifting and shallow opencuts. The drift mines were commonly worked during the winter. Hydraulic mining was the primary mining method after 1909. In 1936, there were six individually owned placer mining operations on the creek—two hydraulic plants, two small opencut operations, one small-scale drift mine, and one mechanical excavation operation (Mertie, 1938). A dredge with 4 ft^3 buckets, and capable of digging 5 m below water level, operated during the 1937-38 season (fig. 11). These mines were operating in the central part of the creek both above and below Discovery Gulch; they washed bench and valley-bottom gravel adjacent to older workings. A detailed description

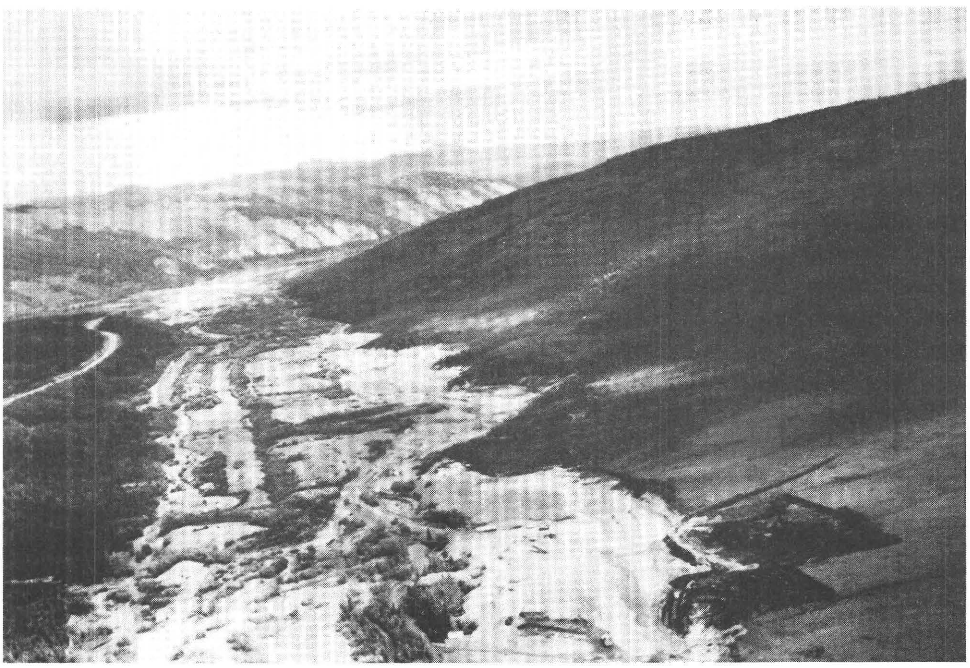


Figure 10. View down Mammoth Creek showing the broad creek valley mined for gold. Recent stripping of muck overlying alluvium and colluvium is evident in foreground to right of channel.

of the hydraulic mining plants operating in 1936-37 was presented by Mertie (1938).

Deadwood Creek is confined to a northeast-trending valley for about 16 km, and it enters the Tintina fault trench at its intersection with the Hot Springs fault (fig. 12). At this junction, the valley flattens into a broad fan across which the creek meanders for 8 km before emptying into Crooked Creek near the center of the fault trench. Placer mining has occurred almost exclusively along the part of the creek that is south of the fault zone. Several levels of bench gravel border the creek, but they are best developed on the west side (fig. 13). Switch Creek, the principal tributary, enters Deadwood Creek approximately 5 km upstream from the Hot Springs fault. Two prominent pinnacles of granite near the mouth of Switch Creek form striking features in the topography. They were called the Deadwood Buttes in the early days (Spurr, 1898).

Figure 11. Dredge of Deadwood Mining Co. on Deadwood Creek. Photograph by J.B. Mertie, 1930's.

The three principal rock types in the Circle mining district—mafic schist, quartzite, and quartzitic schist, and granite—are well represented in the Deadwood Creek valley. Mafic schist is present in the uppermost 5 km, quartzite and quartzitic schist crop out in the middle 4 km, and granite crops out in the lower 6 km of the valley south of its contact with the Hot Springs fault. The position of the fault trace across Deadwood Creek was easily determined when placer mining in the 1980's exposed the orange-brown gravel known to be present near the fault contact. The alluvial fill on the north side of the Hot Springs fault in the "trench" area is in excess of 30 m thick, as indicated by a shaft sunk north of the fault along the creek, which did not penetrate bedrock (Mertie, 1938). Numerous quartz veins ranging from less than a centimeter to almost a meter in width are present in the schists; although some are folded with the enclosing schists, most cut across the foliation and are not folded. The unfolded veins may be genetically related to the granites. Some veins show evidence of sulfide mineralization; however, most do not. Disseminated pyrite and galena are locally present in the schist in the upper part of Deadwood Creek valley.

Gravel in Deadwood Creek ranges from 1 to 5 m in thickness, with muck overburden as much as 3 m in thickness. Boulders are as much as 1 m in diameter, mainly in the granite area, but more commonly are 0.3 m in diameter. Several prominent wide benches mantled with gold-bearing gravel are present along the northwest side of the valley. The bench gravels near the mouth of Twenty-two Pup are reddish-orange due to the oxidation of the iron-rich mafic minerals in the abundant diabase,

Figure 12. View down lower part of Deadwood Creek. Tree-covered benches are present on left side of creek. Hot Springs fault crosses drainage near lowermost part of creek; Tintina fault trench is lowland area in distance.

Figure 13. View up Deadwood Creek road. Unmined bench gravel rests on weathered granite (light-colored outcrop); contact is at car-roof level. Site of pebble count No. 12 (see pl. 1).

mafic schist, and greenstone clasts. A pebble count (No. 12, pl. 1) on a bench in Deadwood Creek indicates a gravel composed of 36 percent quartzite, 30 percent mafic schist, 26 percent granite, 6 percent fine-grained mafic rock, and 2 percent aplite. Mertie (1938) identified three separate bench levels at a location on claim 44 below Discovery, a short distance (1 to 2 km) upstream from the Hot Springs fault. The third, and highest, bench forms the bedrock surface of the spur between Deadwood and Boulder Creeks (Mertie, 1938). Figure 14 is a diagrammatic cross section showing these bench levels with gravel and muck cover as described by Mertie. The gravel deposits on these surfaces have been extensively modified by mining since the 1930's.

Fan gravel is present in and adjacent to Deadwood Creek north of the Hot Springs fault. Panned samples from gravel obtained from pits along the Central Hot Springs road, collected in 1986, yielded one to two colors per pan. Churn drilling was done in here in the early 1900's because the area was being considered for dredging (Ellsworth, 1910, 1912). The late Tertiary(?) gravel exposed by mining near the Hot Springs fault contains less gold than the overlying fan gravel. It also contains weathered clasts and noticeably more clay than the overlying gravel. Because of high clay content and relatively low gold values, this gravel has not been mined. A section of this fan gravel and underlying late Tertiary(?) gravel (fig. 15) was exposed in 1981 in numerous backhoe-dug pits just north of the Hot Springs fault.

Mining in the 1930's revealed that the paystreak in the gravel of Deadwood Creek was as much as 130 m in width and included an additional 80 m on the benches. In areas of quartzite bedrock, gold was found as deep as 1 m in cracks and crevices. On the second highest bench, gold was concentrated in the lower 1 m of gravel and upper 1 m of bedrock. Gold was flaky and fine, averaging 5 to 6 mg, and some nuggets weighed as much as 0.5 oz (Mertie, 1938). Within Deadwood Creek, nuggets as much as 6 oz were recovered and values of gravel ranged from \$3 to \$140/yd^3. The apparent lack of a systematic change in the fineness of gold along Deadwood Creek led Mertie (1938) to conclude that the creek has a complex history of gold accumulation. Mertie inferred that the gold was derived from diverse and widely separated bedrock sources including bench deposits. Discussion of a bedrock gold source will be presented in the section "Gold Source and Resource."

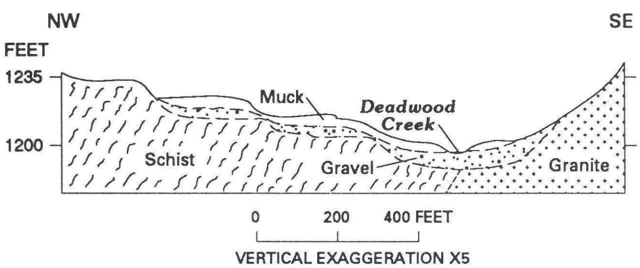


Figure 14. Diagrammatic cross section across Deadwood Creek valley showing three bench levels. Bench width, gravel, and muck thicknesses from Mertie (1938). Location approximately 100 ft upvalley from Hot Springs fault.

Large amounts of wolframite and cassiterite (1 to 2 lb/yd^3) are present in the heavy-mineral fraction of the concentrates recovered in several mining operations on Deadwood Creek (Johnson, 1910). These minerals are particularly abundant in samples collected immediately above the mouth of Switch Creek. Mertie (1938) concluded that tin and tungsten mineralization occurred in the bedrock "south of the southern periphery of the granitic mass that crops out in Deadwood Creek." Other heavy minerals detected in these concentrates include magnetite, ilmenite, arsenopyrite, pyrite, galena, limonite, garnet, scheelite, and cinnabar; small amounts of uranium were detected in several of these minerals (Eberlein and others, 1977). Geochemical studies in this area revealed anomalous amounts of copper, zinc, and lead in sediments (Burand, 1965). Burand (1965) postulated that these anomalies may be related to granitic dikes or the contact zone of massive granite at and above the mouth of Switch Creek.

The entire length of the Deadwood Creek flood plain, as well as significant parts of the marginal benches, have been mined for gold (pl. 1). The creek has the reputation among local miners as being the most "mined-out" creek in the Circle district, although some bench gravel remains unmined, as do the vast deposits of low-value fan gravel north of the Hot Springs fault. As many as six mines have operated in the 1980's along Deadwood Creek, and most activity focused on the widespread gravel near and just upstream from the Hot Springs fault.

Crooked Creek

The placer mining history of Crooked Creek dates only from the most recent gold rush of the 1980's. Although the presence of gold was known before then, many believed that the gold was spread too thin in the wide flood plain of this drainage to be economic.

Crooked Creek is the drainage below the junction of Porcupine and Mammoth Creeks. It flows in fairly tight meanders, hence its name "Crooked Creek," in an easterly direction for approximately 30 km before joining Birch Creek. All but the uppermost part of the creek lies within the Tintina fault zone. Placer mining has been confined to the 8 km of the creek immediately downstream from where the Hot Springs fault crosses Crooked Creek (pl. 1). At this junction the Crooked Creek flood plain dissects late Pleistocene fan gravel that forms

AGE	LITHOLOGY	THICKNESS, IN CENTIMETERS	DESCRIPTION
Late Pleistocene to Holocene		15	Organic mat
		60	Silty, clayey gray gravel containing clasts of quartzite, schist, and quartz
		5 - 7	Organic matter
		15	Sandy gray to black gravel
		40 - 50	Silty, clayey gray gravel containing clasts of quartzite, schist, and quartz
		30 - 60	Sandy, granular gray gravel composed of quartzite, schist, and quartz clasts ranging in size from 1 to 13 cm. Panned sample yielded 12 colors
Late Tertiary(?)		30 - 60	Silty, clayey, orange-brown pebble gravel containing soft, friable clasts, 5 cm or less in diameter, of quartzite, schist, and quartz. Panned sample yielded two colors
			Bottom of pit

Figure 15. Columnar section in backhoe-excavated pit in fan gravel of Deadwood Creek north of Hot Springs fault.

a prominent 20-m-high bench to the north (fig. 16). Several less prominent stair-stepped bench levels of late Pleistocene fan gravel grade down to the Crooked Creek flood plain on the south. The Steese Highway crosses this fan gravel and parallels Crooked Creek on the south between the Hot Springs fault and the town of Central. Gravel pits developed along the road provide good exposures that show the character of the fan gravel. Some gold (one to three colors per pan) can be panned from the fan gravel in these pits.

Quartzitic schist is present upstream from the Hot Springs fault and along the upstream tributaries, and it makes up most of the detritus in the creek gravel. A small granite outcrop is present upstream along Mammoth Creek.

The alluvial gravel in Crooked Creek is composed predominantly of well-rounded to subrounded clasts as much as 15 cm in diameter. A pebble count (No. 16, pl. 1) in Crooked Creek approximately 4 km downstream

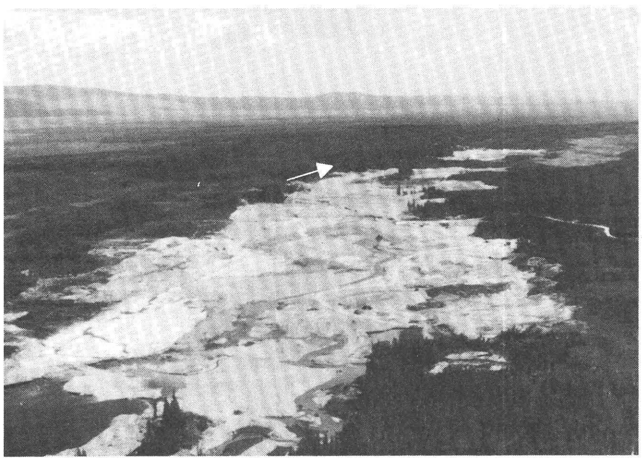


Figure 16. Aerial view down Crooked Creek. The lightest zones within mined areas are late Tertiary(?) clay-rich orange gravel exposed where overlying gold-rich gray gravel has been mined. Arrow points to 20-m-high bench on left side of valley.

from the Hot Springs fault reveals a composition of 43 percent quartz-mica schist, 32 percent quartzite, 21 percent quartz, and 4 percent weathered granite. Gold-bearing gravel that is 2-5 m thick overlies false bedrock, the term used by the local miners to refer to a clay-rich, altered cobble gravel. That few cobbles in this unit resist being cut by a shovel indicates the highly altered nature of the gravel. This unit, which is probably late Tertiary in age, is described in detail in the "Late Tertiary(?) Gravel" section. The orange altered gravel is truncated by the Hot Springs fault (fig. 6). These relations were revealed by mining excavations in the area where the Hot Springs fault crosses the Crooked Creek valley and exposes the fault gouge, altered schist bedrock, and orange gravel. Placer gold occurs primarily in the lower 1-2 m of gray alluvial gravel, which is generally more consolidated than the overlying gravel and sometimes includes blocks of the underlying orange gravel. Locally the overlying muck rests directly on the orange gravel where river scour has eroded the intervening gray gravel. A diagrammatic cross section of the gravel in Crooked Creek is shown in figure 17.

The paystreak in Crooked Creek is as much as 400 m wide and, as mentioned, 1 to 2 m thick; wood fragments are scattered through the gold bearing gravel. The gray gold-bearing gravel unit in contact with the underlying orange gravel yielded an age from wood of 1,480±80 years B.P. This young age implies a continuous reworking of these gravels when, during floods, scour, and subsequent filling with as much as 8 m of sediment occurred in the flood plain.

Gold recovered from the gravel in Crooked Creek is finer grained than that in most of the creeks of the Circle district; this finer grain size results from the lower gradient of Crooked Creek and greater distance traveled by the gold. Gold fragments are generally very flat, and less than 1 mm in diameter, and some fragments are as much as 3 mm in diameter. Values range from \$4 to $\$12/\text{yd}^3$. Upstream from the fault the values are lower, approximately $\$2.50/\text{yd}^3$ as reported by the miners on the basis of exploratory sampling. This value is too close to the break-even point at current gold prices, and consequently, the gravel has not been mined. In this area, 2 to 3 m of gray gravel rests directly on schist bedrock, and no orange gravel is present.

Downstream from the Hot Springs fault are many locations where the gray gravel extends vertically into the orange gravel. In these localities the gold values of the gray gravel warrant excavation. As described in the previous section, "Late Tertiary(?) Gravel," these features are interpreted as sites of former ice wedges. Upon melting of the wedges during a climatic warming, the open cracks and holes in the orange gravel filled with the younger gray gravel as ancestral Crooked Creek reworked its gravel bed and washed over this uneven surface.

The underlying orange clay-rich gravel is not mined except for the upper 1 m, which has acted as a false bedrock or gold trap across which the gold-rich Crooked Creek gravel has been reworked. On the basis of limited samples collected from this unit, gold values are low—pennies per cubic yard. Also, the high clay content of this gravel presents a real mining problem in trying to break up the adhering clay balls to free the contained gold.

A low-value, high-volume gold resource exists in Crooked Creek downstream from the mined area. This gravel will probably be mined someday. The widespread fan gravel filling the Tintina fault trench may be a large, low-grade, high-volume gold resource (Yeend, 1982; Menzie and others, 1983).

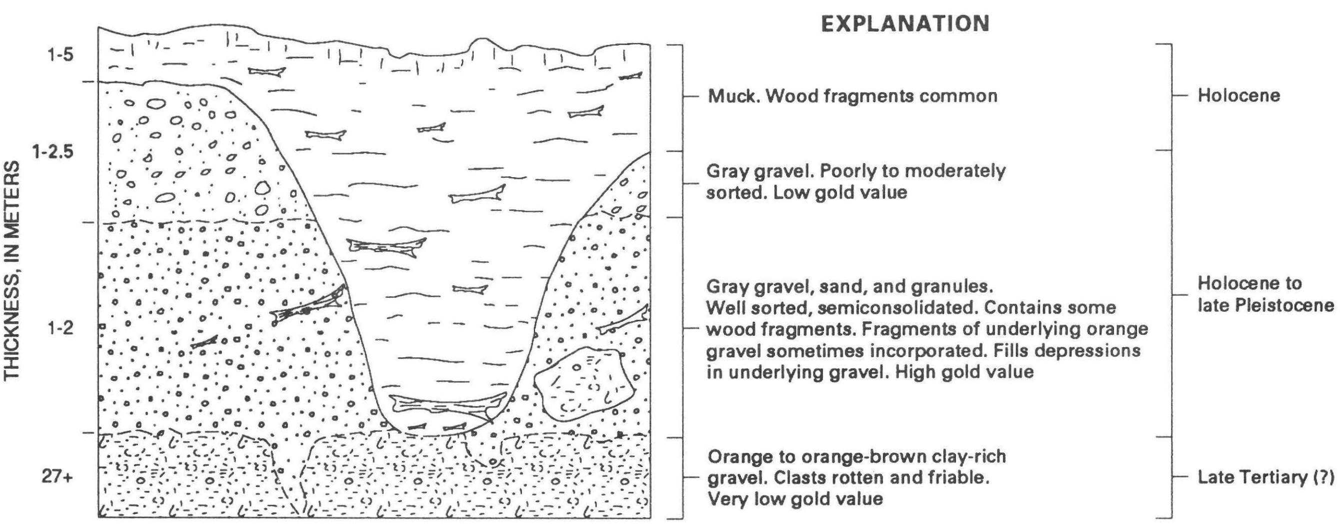


Figure 17. Diagrammatic cross section of gravel exposed in mining cut along Crooked Creek. Contacts dashed where approximately located.

Harrison Creek

Harrison Creek, one of the longest in the district, drains a large area in the southern part of the district. The headwaters of the North Fork are on the southeast slope of Mastodon Dome. North Fork flows east and south for a total of approximately 14.5 km before it joins the South Fork. The main branch of Harrison Creek flows eastward from the junction of North and South Forks for 21 km. The gold-rich tributaries Squaw and Bottom Dollar Creeks flow southward into Harrison Creek near the southern border of the map.

Harrison Creek was prospected early in the history of the district. Mertie (1938) described the first gold discovery in the district as taking place in 1893 at the mouth of the North Fork of Harrison Creek at a location he called Pitka Bar. Pitka's Bar, however, is shown on contemporary maps as being on Birch Creek (pl. 1). Spurr (1898) reported the first gold discovery on Harrison Creek was in 1895(?) near the head of the North Fork a mile below Mastodon Dome. The name Harrison Creek appears on the Dunham (1898) map, and according to Orth (1967) it was named by the early prospectors, probably after one of their own. Dunham (1898) described 100 claims on the creek in 1897 that had been relocated following the rush to the Klondike. One hundred adjacent claims, each 402 m in length along the creek, totaled 15 km, or almost the entire length of the creek. Dunham (1898) predicted the creek would be rich and "produce many millions [dollars] under hydraulic processes." He was right because it has been intensively mined for almost its entire length—many stretches several times—and has proven very gold rich.

It was not until after hydraulic mining was developed that the potential for the creek was realized. The creek was nearly abandoned until about 1905, when the first hydraulic plant in the Circle district was installed (Ellsworth, 1910). However, because of poor design and inadequate water supply, the plant was not a viable operation. Little mining occurred until the 1930's, when hydraulic mining became the primary mining method throughout the district. Mining was concentrated primarily on the North Fork until the 1970's and 1980's, when the gold price increase allowed the lower valued South Fork and main branch of Harrison Creek to be mined at a profit.

The North Fork of Harrison Creek flows entirely within mafic schist. The South Fork and main branch of Harrison Creek flow approximately at the mafic schist-quartzite and quartzitic schist contact. The coincidence of this contact with the stream valley is close enough to infer a lithologic control (pl. 1).

The gold-bearing gravel in the valley of the North Fork ranges from 1 to 4 m in thickness, and it averages about 2 m in thickness. Muck capping the gravel is rarely encountered during mining. The absence of an insulating muck layer has allowed most gravel to remain unfrozen and thereby facilitates mining. Boulders are present mainly near the headwaters. Schist is the predominant clast type in the gravel, but granitic clasts were reported by Mertie (1938) and imply the presence of small unmapped granite bodies. A pebble count (No. 15, pl. 1) in the North Fork valley reveals a gravel composed of 56 percent quartz-mica schist, 29 percent quartzite, and 15 percent quartz.

Much of the east-trending valley of the North Fork is 70 to 100 m wide. In the several kilometers of the lower part of the North Fork upstream from where it joins the South Fork, the valley is constricted, less than 50 m in width, and the creek has a steep gradient with small rapids. Here winter buildup of aufeis (ice) frequently delays the startup of summer mining; this happened most recently during the 1985-86 winter. The South Fork valley is wider in cross section, as is the main branch of Harrison Creek. The paystreak along the North Fork generally ranges from 30 to 80 m in width. Gold is frequently concentrated in the lowermost meter of gravel and uppermost meter of bedrock. The fractured bedrock has allowed the bouldery gravel and the gold to work down into the bedrock fractures (fig. 18). Recovered gold was generally fine, flaky, and bright. Nuggets weighing as much as 3 oz were recovered, but they were rare. Gold recovered from the upstream part of the North Fork was often ragged and frequently occurred with attached quartz. Spurr (1898) reported a block of quartz-schist containing a quartz vein "... richly spotted with flakes and specks of gold ..." in the upper valley of the North Fork. Mertie (1938), after studying fineness values of gold from the North Fork, concluded that there was much irregularity in the distribution of gold of varying grades and inferred that gold was derived from diverse local sources. Cassiterite, garnet, and pyrite occur in the heavy-mineral concentrates.

Placer mining along Harrison Creek, including the North and South Forks, reached an almost fever pitch in the early 1980's. The State of Alaska improved the narrow dirt road into the creek, which leaves the Steese Highway near Mammoth Creek and extends up Independence Creek over the summit and down into the valley of the North Fork. This facilitated the transportation of massive loads of heavy equipment such as D9 "cats" and large washing plants. A flight over the creek in the summer of 1980 revealed many mining operations from the mouth of Bottom Dollar Creek to the upper part of the North Fork. These operations resulted in the almost complete mining and in many cases remining of the creek gravel. By the summer of 1987, there were only some short stretches along the South Fork and one near the upper reaches of the North Fork that had not been mined (pl. 1). Unmined fan and colluvial gravel marginal to the main stream gravel are locally present and do support small-scale mining for short intervals. Also, irregularities in the bedrock were not always completely cleaned by the large earth-moving equipment, and these areas provide weekend recreational mining opportunities upon permission from the claim owners.

Probably the last hydraulic mining operation in the district operated along the North Fork of Harrison Creek during the summer of 1980. Three giants were used, one to break up gravel and bedrock, one to move gravel and broken-up bedrock through the sluicebox, and one as a tailings stacker. The gravel deposits being mined were 3 m thick and 30 to 45 m wide. One meter of bedrock was being ripped and washed along with the gravel. Values ranged from \$1 to \$5/yd^3. The cost of mining by this hydraulic method is \$0.02/yd^3! Is it any wonder that this method has been responsible for most placer mining in this district up until the past decade?

Figure 18. Gravel-bedrock contact (shown by dashed line) exposed by hydraulic mining along North Fork of Harrison Creek. Note how boulders have worked down into bedrock fractures.

Eagle Creek

Eagle Creek, of which there are at least 30 in Alaska (Orth, 1967), was named by the early prospectors, probably for the presence of eagle nests. The discovery of gold on Eagle Creek in 1895 generally coincided with the discovery of gold on the other creeks in the Mastodon Dome area. The entire creek was staked by August 1896 (Spurr, 1898), and it is named "Eagle" on the early map of Dunham (1898). In 1897 only 4 of the 46 claims on the creek were worked because of a labor shortage. During that year, 75 miners produced approximately 3,750 oz of gold (Dunham, 1898). Since about 1901, mining has been almost continuous on the creek. Open-cut and drift mining methods were soon replaced by hydraulic plants when the Berry Holding Company took over much of the workable ground in 1906. They mined intermittently until 1942. Hydraulic mining allowed the working of lower grade placers that previously used mining methods did not. Production through 1906 was about 29,000 oz of gold (Eberlein and others, 1977). Eagle Creek was the first area in Alaska where the "elevating" of gravel was used in placer mining. A gin pole and steam scraper were used to elevate and dump tailings alongside the cut, and these partly vegetated rock piles are still present in Mastodon Fork (fig. 19).

Eagle Creek drains the northwest slope of Mastodon Dome and eventually joins Ptarmigan Creek to form the headwaters of Birch Creek. The two forks that form the headwaters of Eagle Creek are called Miller and Mastodon Forks. Cripple Creek is a small tributary emptying into Eagle Creek from the south. A splendid vista of Eagle Creek and its tributaries can be seen from the Steese Highway as one ascends toward Eagle Summit.

Figure 19. View up Mastodon Fork of Eagle Creek; tailings produced from "elevating" during 1930's are on left side of creek. Creek on right; road on left.

The principal bedrock in the drainage is quartzite and quartzitic schist, but some mafic schist is present near the headwaters of the Mastodon Fork (pl. 1). In contrast, no mafic schist is present in the drainage basin of Miller Fork, which has not produced gold; a correlation of no mafic schist, no gold is suggested. Quartz veins as much as 45 cm thick were exposed by early mining on Mastodon Fork (Mertie, 1938).

The gravel in Eagle Creek and Mastodon Fork varies in texture from small cobbles to subangular 1-m slabs. A pebble count (No. 2, pl. 1) in Mastodon Fork indicates a composition of 61 percent quartz mica schist, 28 percent quartzite, and 11 percent quartz. Gravel thickness varies from 2 m on Mastodon Fork to 5 m in Eagle Creek below the forks. Overlying muck, which was usually ground sluiced prior to hydraulic mining, is 1 to 5 m thick. The "pay zone" varies from 10 to 60 m in width. Bedrock benches with a thin colluvial and alluvial cover occur locally on the south side of the creek, and they have been prospected and mined at selected locations.

Gold was commonly concentrated in the upper 1 m of bedrock (in crevices) and lowest 2 m of gravel. The gold recovered was both coarse and fine; fragments as much as 1 cm across were fairly common, frequently intergrown with quartz. Nuggets weighing as much as 3 oz were rare (Mertie, 1938).

Prior to 1980 much of the rich gravel in Eagle and almost all of Mastodon Fork was mined. Since 1980 a large operation (fig. 20) remined some of the hydraulic tailings in Eagle Creek and areas of gravel along the creek margins that were left unmined by the earlier miners. The width of the "cut" across the creek valley is as much as 100 m, and yields are \$5 to \$15/yd^3. A detailed description of this recent mining operation was presented by Colp (1984). Stripping of barren overburden along the south margin of lower Eagle Creek preceded mining of the underlying alluvium and colluvium at this locality.

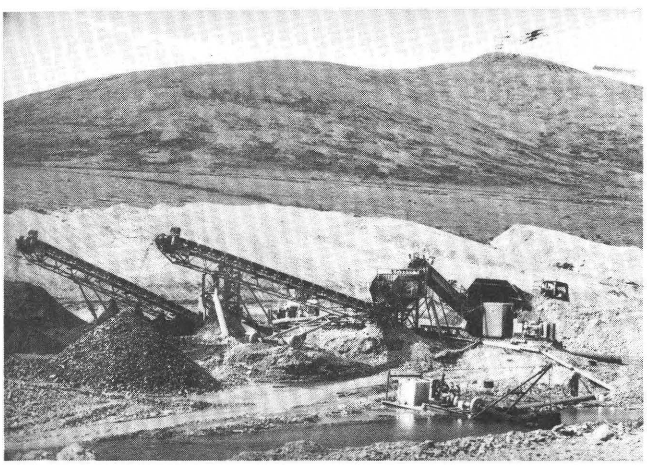


Figure 20. Placer mining on Eagle Creek in July 1986.

A mantle of colluvium borders Eagle Creek on the south near the Cripple Creek tributary (pl. 1), and it may contain some gold. Prospecting is on going in this area. Small amounts of unmined gravel are still present in the uppermost parts of Mastodon Fork, but they are currently uneconomic.

Independence Creek

Gold was discovered on Independence Creek in 1893, soon after the original gold discovery in the district, and the creek has been mined almost continuously since then. There were 29 claims on the creek by 1897, and the yield, using the simple hand-mining methods then in practice, was about 1 oz of gold per man per day (Dunham, 1898). In the early years many of the new claims sat idle because of a labor shortage. In the 1920's the Berry Dredging Company used its dredge to recover gold on the lower part of Independence Creek, and in the 1930's hydraulic mining was common on the lower 3-km stretch of the creek.

Independence Creek is about 6.5 km long. Below the junction of Independence and Mastodon Creeks the drainage is known as Mammoth Creek. Five kilometers above its mouth, Independence Creek forks; the east fork, the only one with a name, is called Harrison Fork. Very little mining has been done on this creek because it is narrow and its gravel is thin. The discovery claim for Independence Creek is about 0.5 km above the mouth of the creek.

The lower half of Independence Creek flows through quartzitic and quartzite schist bedrock, common to much of the district. These rocks strike northwest and dip about 20° SW. Quartz veins as much as 0.5 m thick cut these rocks in places. The upper parts of both forks of Independence Creek are underlain by the mafic schist unit. A pebble count in Independence Creek (No. 4, pl. 1) indicates a composition of 51 percent quartzite, 22 percent quartz-mica schist, 17 percent mafic schist, and 10 percent quartz.

Gravel in the creek is coarse and blocky, and it contains poorly rounded clasts as much as 1 m in diameter. Mining in the 1930's demonstrated that the paystreak reaches a maximum width of 120 m (Mertie, 1938). Gravel thickness varies from 1 to 3 m, and overlying muck thickness varies from 1 to 2 m. Most gold was recovered from the lowermost 1 m of gravel and the uppermost 1 m of bedrock. Gold recovered was flat and scaly and contained some nuggets to 5 pennyweight. Early mining yielded values of \$20 to \$160/yd^3 (Mertie, 1938). Heavy minerals in the concentrate samples include wolframite, xenotime, zircon, garnet, and hematite, some of which are slightly uraniferous (Eberlein and others, 1977).

Much of the gravel in Independence Creek has been washed at least three times during multiple mining operations spanning 90 years. There are still probably a few small "pockets" of unmined alluvium and colluvium on the creek margins, and these have been the sites of the more recent (post-1980) mining (fig. 21). The upstream forks of Independence Creek would seem to hold a small resource of gold; however, gravel volume is low, water for mining is scarce, barren overlying muck is thick, and gold grade is variable owing to steep and changing stream gradients.

Miller Creek

Following his discovery of gold on one of the richest creeks in the Fortymile district, O.C. Miller came to the Circle area in 1894 and discovered gold in the creek that now bears his name. Miller did not remain long in the new district; after spending a brief time there in the spring of 1894 (Spurr, 1898), he moved on. The discovery was made in the middle part of the creek, and the claim initially (1896) yielded $6 to the pan. There were 64 claims along the creek by the summer of 1897; 40 men produced about 1,500 oz of gold from 9 claims that were being worked that year (Dunham, 1898). Claims have been worked intermittently since the initial gold discovery; however, Miller Creek has produced substantially less gold than its neighboring creek to the south, Mastodon Creek. Initially, claims were worked by simple "shoveling in" and drifting. Most of the creek was mined by hydraulic methods during the early 20th century.

Miller Creek is about 8 km in length and empties into Mammoth Creek about 2 km below the mouth of Mastodon Creek. The Steese Highway parallels the lower 4 km of Miller Creek on the north side and provides good views down the broad, open drainage.

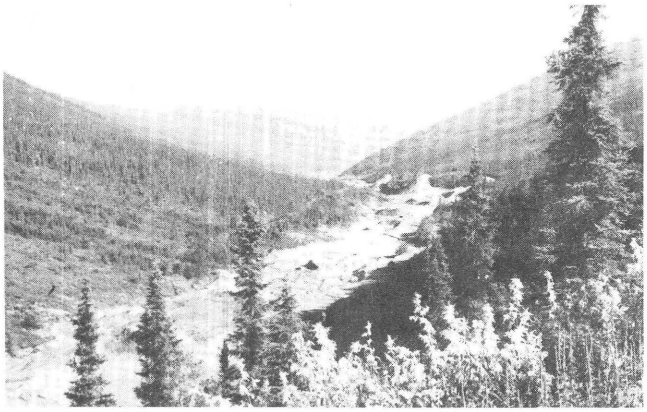


Figure 21. View down Independence Creek. Colluvium coming off slope to left (west) and interfingering with creek gravel has been occasionally mined in the 1980's.

Bedrock in the drainage basin is primarily quartzite and quartzite schist with quartz veins. Felsic dikes occur in the upper headwaters along the ridge between Miller and Eagle Creeks. Only the upper 2 km of Miller Creek flows across mafic schist, whereas nearby Mastodon Creek drains terrain that is mostly underlain by mafic schist. Approximately 7 km of Mastodon Creek flows within the mafic schist unit, and this drainage basin composition may account for the differences in gold production of the two creeks.

Clasts in Miller Creek gravel are subangular to well rounded and are as much as 1 m in diameter. In the lower valley, gravel thickness is 2 to 3 m and overlying muck is 1 to 2 m thick. Locally, a 1-m-thick bed of clay is present at the base of the gravel (Mertie, 1938). A pebble count (No. 3, pl. 1) in the lower stretch of the creek reveals a composition of 35 percent quartzite, 32 percent schist, 23 percent quartzitic schist, 9 percent quartz, and 1 percent granite.

Most gold was recovered from the lower meter of gravel and at the gravel-bedrock contact in a width across the valley ranging from of 15 to 20 m. The gold formed fine flat scales and only a few nuggets weighing as much as 1 oz were recovered (Mertie, 1938). Cassiterite and scheelite were also recovered along with gold.

Little unmined gravel remains in Miller Creek. Hydraulic mining was common throughout the district in the middle 20th century and only the thin, muck-covered, low-grade gravel was left unmined. In the early 1980's only one mining operation was active on Miller Creek, near the mouth of the creek. That operation involved thawing and moving a 10-m-thick section of gravel (Wilkinson, 1984). By 1986 the operation had moved elsewhere in the district. The steeply sloping colluvial bench bordering the creek on the south side of the valley (pl. 1) may contain some unmined gold, but it is buried beneath a thick section of ice-rich muck and would be expensive to mine.

Gold Dust Creek

Although gold was discovered on Gold Dust Creek as early as 1896, it was not mined until much later (1970's-1980's). There were 60 claims on the creek by 1896; however, they were all abandoned during the rush to the Klondike (Dunham, 1898). The FE Company prospected the creek and drilled gravel during the summer of 1936. Parts of the lower half of the creek were mined before 1980, but most of the upper part of the creek has been mined since 1980. About 8 km of the 11-km-long creek has been mined, but the upper 3 km has a steep gradient and contains little gravel, and so it remains unmined.

Gold Dust Creek drains the southwest slope of Mastodon Dome and empties into Birch Creek just below the mouth of Eagle Creek. Most of Gold Dust Creek flows within the quartzite and quartzitic schist unit. However, the north-flowing tributaries of the upper 5 km of the creek drain areas underlain by the mafic schist unit (pl. 1). A pebble count (No. 5, pl. 1) midway along the length of the creek reveals a composition of 60 percent quartzite, 15 percent quartz, 13 percent quartzite schist, and 12 percent mafic schist.

Gravel clasts in Gold Dust Creek are subangular to subrounded; commonly they are as much as 30 cm in diameter and rarely are 1 m in diameter. The width of mined gravel is 70 m or more for most of the creek length.

The simple sluicebox operation used in the early 1980's was moderate to highly efficient in recovering coarse gold, but low in recovering fine gold (fig. 22). As a result, considerable study and research by the local miners led to the introduction of a sophisticated washing plant that used jigs. Gold in the 120- to 400-mesh range was routinely recovered in this operation, and some characteristics of this fine gold were revealed that had not been previously recognized. Besides the typical bright yellow gold, some was a brown-gray with a porous surface. Shape ranged from crystalline wire gold to granular beads. An excellent discussion of the principle behind using jigs in a more efficient washing plant for use on Gold Dust Creek was presented by Ackels (1985).

Figure 22. Simple sluicebox used to mine gravel on Gold Dust Creek in early 1980's. This method is effective in capturing coarse gold, but it allows much fine gold to escape.

Ketchem Creek

Ketchem Creek flows northeast, drains the north slope of Ketchem Dome, and leaves the highlands to cross the Hot Springs fault; it then merges into the lake-dotted flats northeast of Medicine Lake below which it empties into Crooked Creek. The western fork is called Holdem Creek. When mining began on Ketchem Creek is not known; however, the creek was probably named by some of the early prospectors, and the name appears on a map of the district published in 1898 (Dunham). Mining was in progress in the 1930's (Mertie, 1938) and has probably occurred on and off since then. Mertie described the miners' use in 1936 and 1937 of small dragline excavators and elevated washing plants (fig. 23). Only short stretches of the creek had been mined prior to 1980, and most of that was near the junction of Holdem Creek with Ketchem Creek (fig. 24). Gold was discovered on Holdem Creek in 1932 (Eberlein and others, 1977), but little mining appears to have taken place there.

The middle part of Ketchem Creek is floored by a coarse-grained porphyritic granite, and granite tors are common on the low hills to the northwest. Ketchem Creek and Portage Creek to the east are unique among the gold-rich creeks in the Circle district in that most of their drainage basins, south of the Tintina fault zone, are within granite. Cassiterite grains disseminated in a greisen matrix were identified within the granite body in the drainage basin of Ketchem Creek. The largest and most developed greisen vein is approximately 1 m wide, strikes northwest, and can tentatively be traced from Boulder Creek to Portage Creek (Dahlin and others, 1987). An east-trending mafic dike intrudes the granite on the east side of Ketchem Creek about a quarter of a mile above the junction with Holdem Creek; it varies from 2 to 8 m in width. Quartzite and quartzitic schist crops out near the headwaters of both Ketchem and

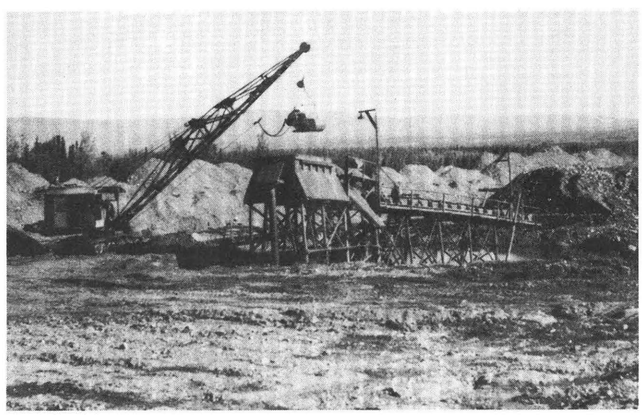


Figure 23. Dragline excavator and elevated washing plant of Enstrom Brothers on Ketchem Creek, Sept. 5, 1937. Photograph by J.B. Mertie.

Holdem Creeks. The Hot Springs strand of the Tintina fault zone cuts across Ketchem Creek and marks the boundary between the hills and the flats. Most mining has been done south of the fault. The fault zone exposed by mining is marked by deep-orange clay-rich gravel. The gravel of Ketchem Creek north of the fault, which is not confined by valley sides, has spread laterally, and it is shown on the geologic map as fan gravel. Gold of two to three colors per pan can be collected from the gravel pits developed in this fan gravel.

Placer gravel in Ketchem Creek varies from 2 to 5 m in thickness and commonly is overlain by 1 to 2 m of muck. Gravel near the Hot Springs fault, much of which has been recently mined, is as much as 200 m in width. Ketchem Creek contains boulders of granite as much as 1 m in diameter, and the granite bedrock beneath the gravel is generally rough and weathered but is locally smooth (fig. 25). A pebble count from a gravel pit in the Ketchem Creek fan gravel (No. 1, pl. 1) indicates a composition of 41 percent quartzite, 25 percent quartz, 22 percent granite, 11 percent quartz-mica schist, and 1 percent undifferentiated schist. Gold is concentrated in the lower 1 m of gravel and is generally coarse and flattened. Nuggets of 1 to 3 ounces have been rarely recovered. Heavy minerals in this gravel include scheelite, cassiterite, allanite, garnet, sphene, and zircon; the gravel also contains a small amount of uranium (Eberlein and others, 1977).

Post-1980 mining efforts have focused on the area between the Hot Springs fault and Holdem Creek. Low water in Ketchem Creek often limits the volume of gravel that can be mined during a season. In 1986 the Department of Environmental Conservation of the State of Alaska awarded a placer-demonstration grant to a miner on Ketchem Creek; a discussion of mining Ketchem Creek gravel was presented by Wilkinson (1987). A moderate gold-placer resource remains on Ketchem Creek above its junction with Holdem Creek. Small amounts of gravel lie within Holdem Creek and appear to contain a small gold resource. The broad fan north of the Hot Springs fault contains a large volume of gravel; gold grades are low and the gravel is not economic to mine at current gold prices. However, current mining does extend a short distance north of the fault into this gravel (pl. 1).

Birch Creek

Birch Creek was the namesake for the Birch Creek mining district, the forerunner of the Circle mining district. The creek originally was called Too-whun-na by the local Indians, which translates to water-lake-river. It was subsequently given the name Birch Creek by traders of the Hudson's Bay Company at Fort Yukon in the mid-1800's (Orth, 1967). Although the initial gold discovery in the district was on Birch Creek, the rich deposits in the Mastodon and Deadwood Creek areas quickly drew the early miners away from the lower grade deposits on Birch Creek. Early descriptions of the district place the original discovery on Pitka's Bar, a river bar on the north side of Birch Creek just downstream from the mouth of Harrison Creek. Whether the original discovery was here or at some other location along this

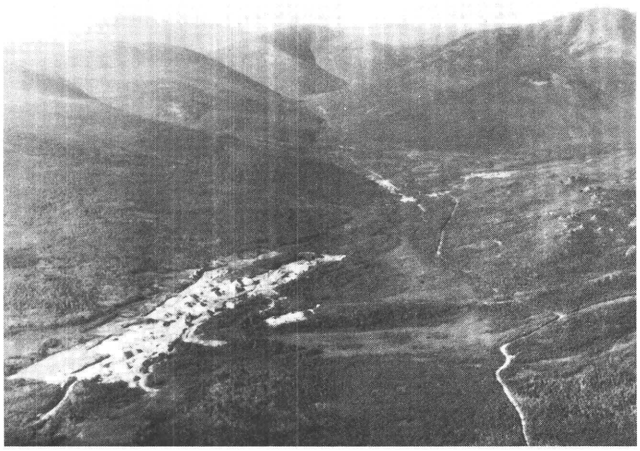


Figure 24. Aerial view up Ketchem Creek. Holdem Creek branches off to right in mid-distance. Hot Springs fault crosses drainage near farthest downvalley placer mining operation shown in lower left. Much of Ketchem Creek was unmined when photograph was taken in July 1986.

Figure 25. Granite exposed on floor of Ketchem Creek. Because of its coarse-grained porphyritic texture, it frequently forms a rough, irregular surface and is a moderately good trap for gold.

part of Birch Creek is not really clear, but it is likely that Birch Creek would have been one of the first drainages prospected. Gold in small quantities can still be panned from just about anywhere along the upper 160 km of the creek.

Birch Creek is approximately 560 km long and empties into the Yukon River some 50 km below Fort Yukon. The headwaters were, most likely, captured from a west-flowing drainage, perhaps the headwaters of the ancestral Chatanika River. Upper Birch Creek resembles a gigantic fish hook, flowing west, south, east, and north as it parallels the lower Yukon River for 240 km.

Although some of the headwater tributaries of Birch Creek drain areas underlain by mafic schist, Birch Creek does not flow across mafic schist. Rather, it flows within quartzite and quartzite schist before crossing into the Tintina fault trench (east of area shown on pl. 1); then it flows within broad lowlands floored with Pleistocene and Holocene surficial deposits.

The broad flood plain of the upper and middle stretches of Birch Creek is composed predominantly of pebble to cobble gravel that contains a few boulders of primarily quartz and quartzite. A pebble count in Birch Creek (No. 7, pl. 1) between the mouth of Gold Dust and Butte Creeks reveals a composition of 72 percent quartzitic schist, 20 percent quartz, and 8 percent schist. Panned concentrates are low in magnetite and ilmenite, but they are rich in garnet.

Aside from the discovery period, little mining was done on Birch Creek until the 1980's. During the spring of 1894 about a half ounce of gold per man per day was being taken from the discovery site on Pitka's Bar (Dunham, 1898). Mining operations using heavy equipment with modern high-volume sluiceboxes have been active along the upper part of Birch Creek in the 1980's. The Steese Highway parallels the upper creek (pl. 1) on the northern most edge of the 400- to 800-m-wide colluvium-mantled flood plain. Mining operations here in the early 1980's washed as much as 2,000 yd^3 of gravel per day, and yields were \$2 to \$3/yd^3. Nuggets recovered were generally less than 1 oz. Gold can be panned all along Birch Creek to the point where it leaves the highlands and crosses the Tintina fault trench beyond the map area. Several flakes per pan, however, is probably not economic at present prices, although the volume of gravel is large.

Portage Creek

There are two different Portage Creeks in the Circle mining district, both of which flow away from the same divide. They were probably named for the portage at their headwaters. Both creeks were named by 1896 and appeared on Dunham's map (1898). Miners from the Forty-Mile district to the south used the portage to cross from Birch Creek to Crooked Creek drainage on their way to Circle and nearby placer mines. One Portage Creek flows north-northeast 15 km to Crooked Creek and is described herein; the other flows south-southwest and has not yielded gold.

Gold was not discovered on the creek until the early 1900's (Eberlein and others, 1977). Ten ounces of gold were reportedly recovered from one claim on the creek in 1906. Full-scale mining, however, did not begin on the creek until 1933. Two miners worked in the uppermost valley of the creek in 1936; one was drift mining, and one was prospecting in a shaft, both using wood fires for thawing the frozen ground (Mertie, 1938). Gravel valued at \$10 to \$25/yd^3 was being mined in 1937 by several miners shoveling in an opencut. There were two operations on the creek in 1975 and anywhere from two to five operations per year during the 1980's.

Portage Creek is almost entirely underlain by granite. The quartzite and quartzitic schist unit crops out as isolated inliers in the granite and supplies some detritus to the creek. The mafic schist unit crops out at the headwaters divide, but it would seem to provide little, if any, detritus to the creek. A pebble count (No. 11, pl. 1) in the upper part of Portage Creek reveals a composition of 45 percent porphyritic granite, 34 percent quartz-mica schist, 12 percent quartzite, 5 percent diabase, and 4 percent quartz.

Portage Creek crosses the Hot Springs fault at the topographic break between hills and flats (pl. 1). North of the fault, placer mining has exposed decomposed brownish to orange schist-rich gravel similar to that exposed by mining along the fault in creeks to the west. Only the upper 0.5 m of this late Tertiary(?) gravel is mined because the gold is restricted to this upper zone. Almost all the mining in the creek has been south (upstream) of the fault trace (pl. 1), although some older mining (1930's) is indicated by the presence of tailing piles just north of the fault. Gold recovered near the fault was fine and ragged.

A high percentage of the detritus in Portage Creek is colluvium; the creek is narrow with steep side slopes that readily supply colluvial detritus (fig. 26). Consequently, the mined gravel is poorly sorted; it contains angular to subangular boulders as much as 1m in diameter. One meter of muck typically overlies 2 m of colluvial-alluvial gravel. A so-called "paystreak" is not often present, owning to colluvial mixing and lack of alluvial water washing and sorting. Because of the thick colluvial cover on the side slopes, the mined gravel channel is quite narrow, only 20 to 30 m. Values from gravel mined along the middle to upper creek during the early 1980's ranged from \$10 to \$15/yd^3.

Small amounts of unmined gravel remain upstream from the fault in Portage Creek. North of the Hot

Springs fault the gravel deposited by Portage Creek forms a fan. Although gold is present in this fan gravel, values are low—approximately \$0.50 to \$3/yd^3, as determined from scattered panning near the Circle Hot Springs Airfield.

Bottom Dollar and Half Dollar Creeks

Bottom Dollar and Half Dollar Creeks were named by local prospectors early in the history of the district. Bottom Dollar Creek appears on the Dunham map (1898) and was also known as Squaw Creek and Bottom Gulch (Orth, 1967). Gold was discovered on the creeks in the winter of 1909-1910 (Eberlein and others, 1977), and there was small-scale mining in 1912, 1936, 1938-39, 1975, and during the 1980's.

Bottom Dollar Creek is about 7 to 8 km long and flows southward in a narrow valley, which empties into Harrison Creek. Half Dollar Creek is a 3-km southwest-flowing tributary of Bottom Dollar Creek.

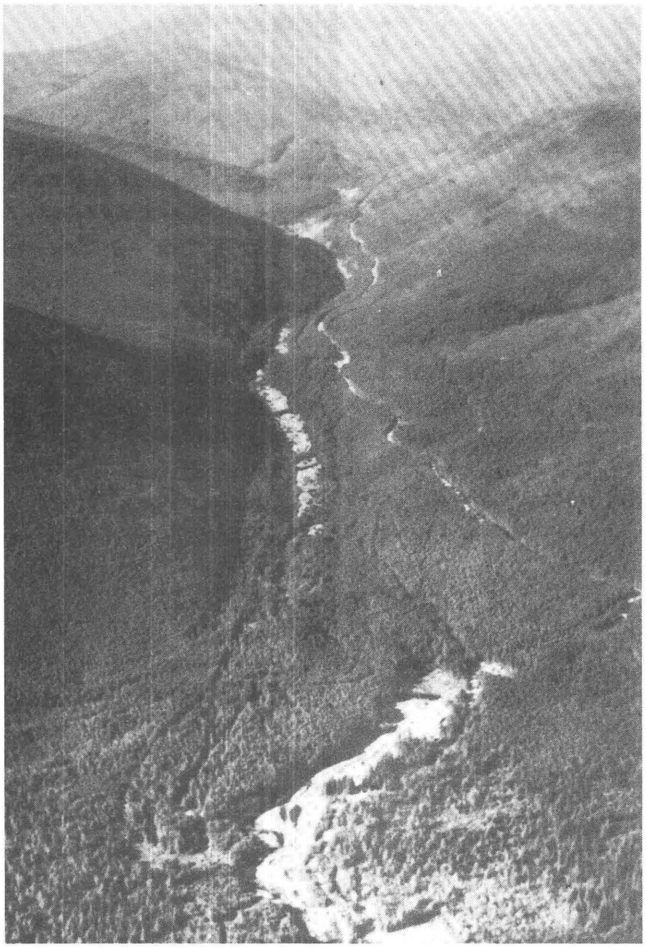


Figure 26. Aerial view up Portage Creek. Note narrow drainage and steep side slopes. Much of the gold-rich detritus mined is colluvium coming off slopes.

The upper 3 km of Bottom Dollar Creek and all of Half Dollar Creek drain areas underlain by granite, whereas the lower 4 km of Bottom Dollar Creek lies within mafic schist. The granite contains the heavy minerals allanite, garnet, hematite, limonite, pyrrhotite, sphene, and zircon; uranium has also been detected by fluorimetric tests (Eberlein and others, 1977).

The lower 4 km of Bottom Dollar Creek is narrow, about 30 m in width, and has steep side slopes. The coarse gravel along this part of the creek has been thoroughly mined. A pebble count (No. 14, pl. 1) near the mouth of the creek reveals 77 percent quartzite, 13 percent quartz, and 10 percent mica schist. Half Dollar Creek produced more gold than Bottom Dollar Creek, according to local miners; however, production records for the creeks are not available. The unmined gravel on Half Dollar Creek and upper Bottom Dollar Creek is mostly colluvium derived from side slopes, and, although it is not high in volume, it is often high in value. Several small placer mines were operated along these drainages in the early 1980's.

Porcupine Creek

Porcupine Creek was first prospected in the early 1890's and by 1896 several claims were located principally for hydraulic mining (Dunham, 1898). Panning yields, however, were disappointingly low for the times, on the order of \$1 per pan (Spurr, 1898). The claims were abandoned and later relocated. The creek was the site of hydraulic mining in the 1930's, when three giants with 4-in. nozzles were used. Mining since then has been intermittent—in the late 1950's, in the early 1960's, in 1975, and during the 1980's.

Porcupine Creek (fig. 27) flows in an easterly direction for 20 km, and then it joins Mammoth Creek to form Crooked Creek. Bonanza Creek, the principal tributary, enters Porcupine Creek from the south about 8 km

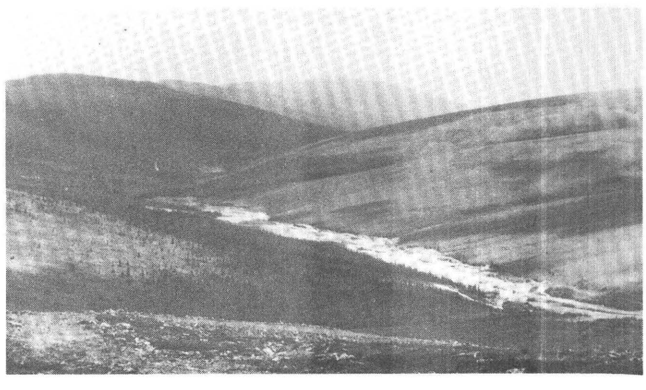


Figure 27. View down upper Porcupine Creek. The lighter area in drainage bottom is mine tailings.

above its mouth. Yankee Creek, also a north-flowing tributary, enters Porcupine Creek about 10 km above the mouth of Bonanza Creek. Placer gold was mined in the upper third of Porcupine Creek; along its tributaries, Yankee and Bonanza Creeks; and at small downstream locations. Much of the lower two-thirds of Porcupine Creek is unmined (pl. 1).

Mica schist and quartzite are the predominant rock types in the drainage basin of Porcupine Creek. Only the upper headwaters of the Bonanza Creek tributary extend into the mafic schist unit. A lode gold prospect was reported along the ridge west of Porcupine Dome at the head of Dome Creek (Mertie, 1938), however, this prospect was not located during fieldwork. A pebble count (No. 9, pl. 1) several hundred meters below the mouth of Yankee Creek indicates a composition of 65 percent mica schist, 24 percent quartzite, and 11 percent quartz.

Gravel in the mined sites of Porcupine Creek is composed of subangular and slabby boulders and cobbles of schist and quartz; most boulders are 30 cm in diameter or less but some are as much as 1 m in diameter. Gravel is 3 to 8 m thick and is overlain by as much as 1 m of muck. The paystreak is 30 to 70 m wide. Less than 2 m of the lower gravel was put through the sluiceboxes during hydraulic mining in the 1930's, because the high values occurred primarily on, and in, the underlying bedrock. The high-powered jets of water from the 4-in. giants were effective in cleaning and ripping up the fractured bedrock. Gold recovered was coarse and ragged and contained several nuggets weighing as much as 3 oz that were considerably intergrown with quartz (Mertie, 1938).

In recent mining two varieties of gold having different textures and lusters were recovered; one variety was much more ragged and duller than the other. The largest nugget recovered was 8.5 oz. Yields were from \$4 to \$5/yd^3. Cassiterite and scheelite occur in the concentrates. A short discussion of the recent mining and environmental concerns on Porcupine Creek is presented in Warner (1984).

Although abundant unmined gravel remains in the middle and lower stretches of Porcupine Creek, the grades are too low to be profitably mined at current economic conditions. Small-scale opencut mining has been attempted at least three times during the 1970's and 1980's on the lower part of Porcupine Creek, and each attempt was unsuccessful. An attempt was made in 1987 to ascertain if it would be economically feasible for a miner to recover flood gold from gravel in the lower stretch of Porcupine Creek. Using a 2.5-in. suction dredge with a gold screw, a return of \$3.50 per hour was the best that could be attained (Madonna, 1988). Should the price of gold substantially increase, the gravel would most certainly be mined.

Bonanza Creek

Gold was known to be present on Bonanza Creek early on, and the creek name appears on the Dunham map (1898). There was probably little mining prior to 1927 (Mertie, 1938), and, as on Porcupine Creek, hydraulic mining methods were those first used.

Bonanza Creek, the main tributary of Porcupine Creek, is about 11 km long and has a somewhat steeper gradient than Porcupine Creek proper. A narrow, recently mined tributary, referred to as Rebel Creek by the local miners, flows into Bonanza Creek about 5 km above its mouth.

The upper headwaters of Bonanza Creek drain an area underlain by mafic schist; otherwise, the entire drainage basin lies within the quartzite and quartzitic schist unit. A pebble count (No. 10, pl. 1) taken 3 km above the mouth of Bonanza Creek shows a composition of 55 percent quartz-mica schist, 36 percent quartzite, and 9 percent quartz. Zircon, garnet, ilmenite, pyrolusite, pyrrhotite, pyrite, and galena are present in the heavy-mineral concentrates (Mertie, 1932).

Materials mined in Bonanza Creek include 1 to 2 m of bedrock and 1 m of overlying gravel. The paystreak is as much as 60 m wide. Miners in the 1930's washed the gravel along the lower 3 km of the creek using two giants with 2-in. nozzles. Gravel values in the early mining were \$15 to \$20/yd^3. The gold recovered was coarse and contained nuggets weighing as much as 10 oz. Quartz was typically intergrown with the coarse gold fragments (Mertie, 1938).

Mining during the 1980's has been confined to the middle and upper parts of Bonanza Creek; however, one miner was planning to explore the feasibility of rewashing the tailings in the lower creek. Problems associated with ownership of claims have hindered development in some parts of the creek. Exploratory drilling (early 1980's) in the gravel in the upstream part of the creek revealed subeconomic values.

Switch Creek

Switch Creek is a 3 km northwest-flowing tributary of Deadwood Creek. The name, Switch Creek, was in use by 1903 and appears on the 1904 reconnaissance map of Fairbanks and Birch Creek district (Prindle, 1905). Gold has been mined sporadically on Switch Creek since 1906. Initially, opencut and drifting were the only mining methods used, and after hydraulic mining was introduced in 1922 it was the predominant mining method used on the creek through the 1930's (Mertie, 1938).

The headwaters of Switch Creek are in an area underlain by granite; the creek flows through a small area underlain by quartzite and quartzitic schist, and the lower part flows through qranite and empties into Deadwood Creek. The schist is garnetiferous at granite contacts. Although the mafic schist unit crops out nearby, it does not extend into the drainage basin of Switch Creek. A pebble count (No. 17, pl. 1) near the mouth of Switch Creek reveals a composition of 60 percent quartzite, 16 percent quartz-mica schist, 11 percent quartzite, 7 percent granite, 4 percent mafic schist, and 2 percent fine-grained mafic minerals.

Flood-plain and bench gravel have been mined for gold on Switch Creek. A bench on the west side of the creek in the lower valley is 12 to 15 m above the creek floor. Remnants of other benches upvalley are sites of former mining operations (Mertie, 1938). The bench gravel is too small to show on plate 1. The gravel on the benches is composed of cobbles and a few boulders, whereas boulders are fairly common in the present valley; this difference indicates differing creek gradients.

Gold has been concentrated within the lower 1 m of gravel and upper 1 m of bedrock. The largest nugget found was 4 oz (Mertie, 1938). Heavy-mineral concentrates contain arsenopyrite, pyrite, galena, magnetite, ilmenite, garnet, tourmaline, and limonite in addition to gold (Eberlein and others, 1977).

Switch Creek is almost completely mined out, except for a few pockets of bench gravel. At least two mining operations were present on the creek in the 1980's (pl. 1).

Squaw Creek

Squaw Creek, originally named Squaw Gulch on early maps (Spurr, 1898; Dunham, 1898), is a 4- to 5-km southeast-flowing tributary of Harrison Creek. Gold was discovered here in 1894 (Brooks and others, 1907), although other information about early mining on the creek has not been found. Considerable mining occurred on the creek in the late 1970's and early 1980's, and so little unmined gravel remains.

The entire creek is underlain by mafic schist, and the mouth of the creek is at the southern mafic schist-quartzite and quartzitic schist contact.

The steep gradient of Squaw Creek results in a narrow flood plain, less than 30 m wide, with coarse gravel and boulders as much as 1 m in diameter. The coarse gold recovered included some 1-oz nuggets. Fine gold was rare, having been flushed into Harrison Creek where the gradient is lower. Values of \$5 to \$15/yd^3 were being recovered in 1981, just below the upper forks of Squaw Creek. A small bench is present at the mouth of Squaw Creek on the east side of the creek. Unmined gravel remains only in the uppermost Squaw Creek drainage, where the gravel is very coarse and of low volume.

Butte Creek

Little is known about the early mining history of Butte Creek. The creek name first appeared on a 1904 topographic map (Prindle, 1905). A hydraulic mining plant was installed on Butte Creek in 1916 (Brooks, 1918), and a dragline excavating plant was operated on the creek in 1937.

Butte Creek is a 7- to 8-km northwest-flowing tributary of Birch Creek. It joins Birch Creek about 3 km below the mouth of Gold Dust Creek. Prior to the 1980's, only short stretches of the lower 3 km of the creek had been mined.

Almost the entire drainage basin of Butte Creek flows within the quartzite and quartzitic schist unit. Only the uppermost steep slopes of one of the headwater tributaries are underlain by mafic schist (pl. 1). This might account for Butte Creek's lower gold values relative to creeks to the northeast. A pebble count (No. 6, pl. 1) in the lower part of Butte Creek reveals a composition of 43 percent quartzite, 26 percent quartz, 18 percent garnet schist, and 13 percent mica schist.

The gravel in Butte Creek is coarse and typically contains boulders of quartz and quartzite as much as 0.5 m in diameter. A 3-m section of varved clay indicating some local ponding was observed overlying the gravel at one cut in the lower 1.6 km of the creek. The streambed in the lower stretches is about 80 m wide.

Extensive mining was done in the lower 3.2 km of Butte Creek in the 1980's. The upper parts of the creek are unmined, possess steep gradients, and small volumes of gravel. These areas are not economical to mine at current gold prices.

Greenhorn Gulch

Greenhorn Gulch, a short north-flowing tributary of Boulder Creek, has been mined for placer gold on a small scale. Mining occurred on the gulch as early as 1896 (Spurr, 1898) and as recently as the 1980's. It was named by the early prospectors (Orth, 1967) and appears on the Spurr map (1898).

The creek within Greenhorn Gulch flows almost due north for 5 km to join Boulder Creek. Fully one-half of the creek flows within the mafic schist unit, and the lower part cuts through quartzite and quartzitic schist. An alluvium-covered bench on the west side of the gulch is 8 to 12 m above the valley bottom (fig. 28) and grades to the bench in Boulder Creek. The creek gravel is composed of boulders as much as 70 cm in diameter, but more commonly the boulders are 10 to 30 cm across. A pebble count (No. 18, pl. 1) of the creek gravel in Greenhorn Gulch reveals a composition of 30 percent quartzite, 22 percent mica schist, 16 percent mafic schist, 18 percent quartz, and 14 percent quartzite schist. The gravel in the creek is 1 to 2 m thick on schist bedrock, and the flood plain is as much as 30 m wide. Mining on Greenhorn Gulch has been hampered by lack of water. A 2.5-oz gold nugget was recovered in the early days of mining, and vein quartz in the gravel reportedly contained finely disseminated free gold (Spurr, 1898). Recent mining has occurred on the creek at its junction with Tinhorn Gulch (pl. 1).

Boulder Creek

This popular name for creeks in Alaska (at least 43 Orth, 1967) was applied early (1896) in the history of the Circle district, and it appears on the maps of Dunham (1898) and Spurr (1898). Boulder Creek was probably named for the large boulders of granite that choke the creek bottom where it crosses a west-trending granite outcrop (fig. 29). The presence of so many large boulders (2 to 3 m in diameter) has discouraged miners from attempting to wash gravel in this part of the creek.

When mining began on Boulder Creek is uncertain, and published references to mining on the creek are few. Mertie (1938) referred to the creek as being the site of small-scale mining for many years, although he did not visit the area. Hydraulic mining on bench gravel occurred in the 1930's (Mertie, 1932). A north-flowing tributary, Greenhorn Gulch, has probably been mined as much as or more extensively than Boulder Creek.

Boulder Creek is about 21 km in length. On the basis of surface disturbance and examination of 1980 aerial photographs, there does not appear to have been any mining on the creek downstream from the granite outcrop. Hence the only mining on the creek was restricted to the 2-km stretch downstream from Greenhorn Gulch.

Boulder Creek and its north-flowing tributaries Slate Creek, Greenhorn Gulch, and Boulder Pup have headwaters in the mafic schist bedrock. Downstream, the creek cuts through both quartzite schist and granite before crossing the Hot Springs fault and entering the Tintina fault trench. A pebble count (No. 13, pl. 1) on Boulder Creek north of the Hot Springs fault indicates a composition of 50 percent quartzite, 27 percent quartz-mica schist, 17 percent quartz, and 6 percent granite. Heavy-mineral concentrates obtained from the granite contain allanite and chalcopyrite. Several other minerals from the granite give positive fluorimetric tests for the presence of uranium (Eberlein and others, 1977).

Alluvium covering a bench on the northwest side of Boulder Creek just upstream from the granite-schist contact contains clasts that are the same as those in the streambed. Gold-bearing creek gravel is 2 to 3 m thick at this contact, and most gold occurs in the lowermost 1 m of gravel (Eberlein and others, 1977). Quartz and schist boulders as much as 1 m in diameter are rare, and boulders of about 0.5 m in diameter are more common. The valley near past mining operations is 70 to 100 m wide, and fan gravel is common at the mouths of small side gulches. North of the Hot Springs fault the flood plain of Boulder Creek merges with the fan gravel of the Tintina fault trench. Miners report two types of gold in the gravel—fine, flaky gold and coarse, rough gold with adhering quartz.

That Boulder Creek would have a history of such meager gold production compared to the adjacent rich Deadwood Creek is puzzling because both creeks have drainage basins within similar bedrock. Deadwood Creek does extend farther into the mafic schist unit, and therefore has a slightly larger drainage basin within this unit. The part of Boulder Creek below the granite outcrop extending to the Hot Springs fault, about 6 km, would seem to be a good prospecting area; however, access is

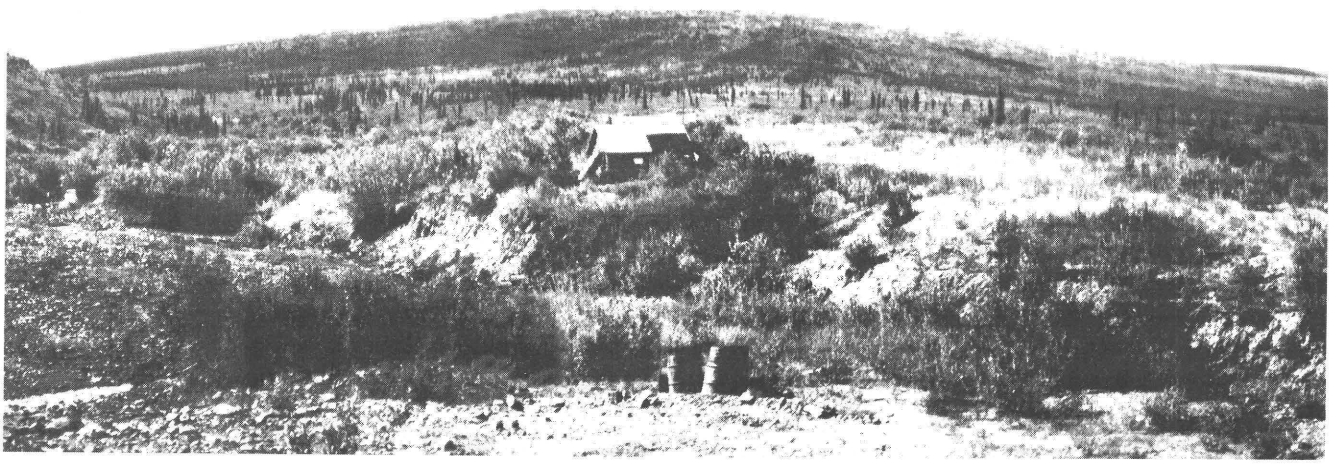


Figure 28. Composite photograph of Greenhorn Gulch showing gravel-covered bench on right (west) side of creek.

poor in that area, with no summer roads and only a winter tractor trail.

Other Creeks

There are several creeks in the district that have produced little, if any, gold, but should be briefly mentioned. These are Bedrock, Loper, Preacher, Ptarmigan, Traverse, and Willow Creeks.

Bedrock Creek is noted for the absence of mining along its course. Surrounded by the gold-producing Independence, Mammoth, Crooked, and Boulder Creeks, Bedrock Creek at first glance would be expected to be gold rich. The critical element lacking in the geology of Bedrock Creek compared to the other creeks is the absence of mafic schist in the drainage basin. All the other creeks mentioned above have headwaters in the mafic schist unit, which may be the source of gold.

Loper Creek was known to carry gold and was prospected for several years in the early history of the district (Ellsworth, 1910). However, values were too low to sustain any systematic mining effort. In the mid-1980's a rough road was bulldozed from the upper part of Porcupine Creek across the drainage divide and down into the upper part of Loper Creek. Some stripping of muck was done along the margins of Loper Creek, although it is not known if any mining was subsequently done. Loper Creek's headwaters are in similar rock and in the same general area as those of Porcupine Creek, and Porcupine Creek was a producer of gold for a number of years. Although no mafic schist has been mapped in this area of Loper Creek's headwaters, mafic schist may possibly be interbedded with the quartzite and quartzitic schist, but too small to show at the scale (1:250,000) of Foster and others' (1983) map.

Figure 29. View down Boulder Creek. Large granite boulders occupy floor of creek where it crosses west-trending belt of granite. Gold-bearing gravel is probably present here, but large boulders discourage miners.

Preacher Creek, just off the map area to the northwest, flows northeast, cuts through the Crazy Mountains and joins Birch Creek in the Yukon Flats. This creek was most certainly named for the illustrious Reverend Robert McDonald, who was sent to Fort Yukon by the Church of England in 1862 (Wharton, 1972). McDonald traveled throughout the region, and among his many stories was one that told in glowing words of a local gold-rich creek. The drainage now termed Preacher Creek was the creek frequently alluded to as being gold rich. No gold-rich location is known today along this creek, although an early report (Ellsworth and Parker, 1911) describes large bodies of low-gold-value gravel existing in the Preacher Creek valley below the mouth of Bachelor Creek. As with so many early gold bonanza stories, the legends live on despite the absence of hard data to support them.

Ptarmigan Creek is a tributary in the headwaters of Birch Creek and flows south from Porcupine Dome. Gold can be readily panned from the thin veneer of gravels on bedrock in Ptarmigan Creek just upstream from its junction with Eagle Creek. Some small-scale mining has been intermittent during the 1980's along the lower part of the creek, but the paucity of gravel in the drainage will preclude this creek from ever being a major gold producer.

Traverse Creek empties into Harrison Creek just above its junction with Birch Creek. Gold can be panned from the gravel in Traverse Creek, but the drainage has a steep gradient, is narrow with steep sides, and contains little gravel. Although gold is present, there is probably not enough to warrant setting up a placer mining operation.

The very small drainage, Willow Creek, which empties into Birch Creek several kilometers above the mouth of the North Fork, has been mined at one location on a very small scale. The creek valley is narrow, steep-sided, and contains small quantities of gravel and consequently will produce little gold.

HEAVY MINERALS

Panned concentrates were obtained from most gold-producing creeks in the Circle mining district, gravel pits in fan deposits along roads, and from soils developed on bedrock. A binocular microscope was used to obtain percentages of the heavy minerals in the concentrates from 130 samples. Heavy minerals, in addition to gold, are contained in these panned concentrates. Several observations were made on the basis of this study.

1. Gravel from streams whose drainage basins lie principally within metamorphic rocks, quartzites, and schists is rich in garnet, as is ancestral Yukon River gravel.

2. Streams having part of their drainage basin in granitic rocks are rich in ilmenite, magnetite, and some are rich in amphibole. The late Pleistocene fan deposits bordering the Tintina fault trench on the south, which are also derived partially from granitic rocks, contain these same minerals.

3. Yukon River gravel is rich in garnet, magnetite, and ilmenite.

4. Soils developed on bedrock in the Eagle, Portage, and Independence Creek summit areas are high in rock fragments and contain from 5 to 15 percent tourmaline and few other heavy minerals.

5. That the orange-brown, friable late Tertiary(?) gravel within the Tintina fault trench is rich in ilmenite, magnetite, and amphibole implies either a short transportation of the detritus or, more likely, the presence of more granitic source rocks in the drainage basin of the past than are present now.

6. Panned-concentrate samples from the Hot Springs fault zone contain from 15 to 30 percent pyrite.

7. Zircon is present in panned-concentrate samples from almost every stream; however, some zircon is much more rounded than other zircon and implies a multicycle erosional history.

8. Cassiterite is present in some of the streams whose drainage basins are in granite, such as Deadwood and Ketchem Creeks.

9. There does not seem to be any systematic difference in the heavy-mineral contents of the streams whose drainage basins lie in large areas of mafic schist compared to those whose drainage basins lie primarily in the quartzite and quartzitic schist, except for gold contents. This difference will be discussed in the "Gold Source and Resource" section.

A study of the heavy minerals in streams in this area is primarily useful in differentiating gross differences in source rocks. Also, gold values could be useful in differentiating schist bedrock.

GOLD OCCURRENCE

Examining the occurrence of gold relative to bedrock in the vertical section, relative to channel borders in the horizontal section, and relative to downstream distance from the source in the longitudinal section is useful for comparing patterns of distribution between drainages and for determining source areas and origins. Such studies also help determine size, shape, and trace-element content of the gold.

Most placer gold in the Circle district, as in most placer districts, is recovered at or near the gravel-bedrock contact. The lowermost 1 m of gravel and the uppermost 0.5 m of bedrock may contain as much as 80 to 90 percent of the gold ultimately recovered. An explanation for the concentration of gold in the lower part of river gravel presented for the ancestral Yuba River in California (Yeend, 1974) seems plausible for creeks in the Circle district. Gold, because it is much heavier than the associated sedimentary silicate particles, works its way down to the lowest horizon of unconsolidated detritus during water transport. The gold remains stationary and is covered by gravel during much of the time it is in this alluvial environment. Only during turbulent water flow, as associated with floods, will the full thickness of the creek gravel be put into suspension and moved along the creekbed. Whereas most constituents of gravel are undergoing transport downstream during floods and high runoff, gold lags behind, much as it does in a sluicebox. As more and more gold-rich detritus is brought into the drainage, all but the gold is broken down to smaller and smaller particles and flushed downstream, and it eventually ends up in a marine or lacustrine environment. The gold, however, stays in the alluvial environment and increases in concentration through time as more and more is carried into the creek. Some of the very finest flour gold may be transported out of the river system, but most gold stays in the creekbed. During each succeeding flood, the gold continues its downward migration through the sediment; consequently, most placer gold is found on or near bedrock in the streambed.

Within an alluvial environment transporting gold, areas of slight decreases in stream gradient, and consequently lower water velocity, are the sites of gold deposition. The insides of meanders, plunge pools at the downstream ends of rapids and riffles, and the downvalley sides of large boulders are good places to search for gold because these areas are sites of slowing water velocity, a process which results in the deposition of contained sediment. Trying to find such sites in the stratigraphic section that records a stream's history is a challenge to the miner. A resistant bedrock unit crossing a stream as a tough dike, a major contact of hard against soft bedrock, or a fault cutting across a drainage often produces a change in stream gradient, and may become a site of gold deposition.

Metz (1987) found in the Fairbanks district that the upper limit at which a placer deposit would form was a gradient of 83 m/km (440 ft/mi); consequently, parts of creeks with gradients steeper than this would not contain rich gold placer deposits, although they might contain some gold. In the Circle district there are no known creeks where mining has occurred at locations of gradients greater than 83 m/km (440 ft/mi) Equally important is that gold of economic concentration will not always be found all the way up a valley to regions where creek gradients are this steep. Numerous mining operations in the Circle district have not been extended above 57 m/km (300 ft/mi) gradients, and several have been stopped near 38 m/km (200 ft/mi) gradients.

Gold is also concentrated laterally and longitudinally along a stream valley in irregular patterns governed primarily by gradient. There may be several paystreaks vertically in the gravel section and also laterally across and longitudinally up and down valley in a creek. Paystreaks within creeks of the Circle district are generally several tens of meters wide in a valley of a minimum width of 100 m. A paystreak is often several hundreds of meters in length. Water velocity in the stream valley, besides being governed by streambed gradient, is also dependent on discharge. During floods, velocities increase and most erosion, transport, and reworking of detritus occurs. Climate is a factor affecting the amount of water in a drainage, and as climates change differing amounts of rock and gold will be eroded, transported, and finally concentrated. With so many factors affecting the final location and richness of a paystreak, the difficulty of accurately predicting their locations within placer gravel becomes apparent.

Gold nuggets in the Circle district are rare. Most gold recovered is in the form of flattened fragments less than 5 mm in greatest dimension. The gold particles have round, often curled edges, and a few have abrasion scratches on the lustrous surfaces. Some grains are not flattened and are often compared to wheat grains and matchheads in shape. A few ragged, uneroded gold flakes have also been recovered. Such flakes do not necessarily imply a nearby bedrock source; rather, they most likely spent most of their erosional history as part of a cobble or boulder of quartz or schist and retained their raggedness after subsequent separation from the clast because of little transport. A variety of nugget shapes have been recovered, although they generally have rounded edges (fig. 30). Nuggets larger than 5 oz are extremely rare in this district.

Figure 30. Three-ounce gold nugget from North Fork of Harrison Creek. Such large nuggets are rarely found in the Circle district.

Gold flakes are almost always shiny and are easy to identify in a gold pan with other heavy minerals present. A few gold grains have been recovered that have a dull luster because of thin coatings of iron and manganese oxide and quartz. More grains have been found with adhering minerals such as quartz, magnetite, and ilmenite. Most quartz adhering to gold grains is partially crystalline.

Trace elements were determined for several gold samples in the Circle district (Yeend, 1985). Table 1 gives the trace-element contents of gold from the Circle district and, for comparison, trace-element contents of placer gold from other areas of Alaska and from California. Gold samples from the Circle district are characterized by moderately high silver contents (average 16.1 percent) and antimony. The presence of antimony in all the samples from the Circle district contrasts markedly with samples from other areas and appears to be a distinguishing feature of the gold. The significance of antimony as a trace element in gold will be discussed in the "Gold Source and Resource" section.

GOLD FINENESS

The purity of gold from different areas, even in the same district, is variable. A measure of this purity is gold fineness. Even though the significance of fineness values in interpreting the genesis or history of a deposit is not always evident, fineness values can give some idea of the similarity or dissimilarity of the gold from different areas. As used herein, fineness, often called true fineness, is defined as the ratio of gold to gold plus silver, times 1,000 ($Au/(Au+Ag) \times 1{,}000$) (Boyle, 1979, p. 197). True fineness values of placer gold from 22 creeks in the Circle district are shown below. Most of this data is taken from a report by Metz and Hawkins (1981). They concluded that individual mining districts within Alaska cannot be distinguished by fineness alone. Additionally, they determined that the samples from the Circle district have large coefficients of variation and bimodal distributions; these characteristics suggest different sources for the placer gold (Metz and Hawkins, 1981). Sources may be from different host rock types, such as quartz veins associated with intrusives, or massive sulfide deposits associated with metamorphic rocks. Varying temperature of formation in the same geologic environment could also produce different fineness values. Also, weathering and diagenetic changes occurring during the erosion, transportation, and deposition of gold particles could cause changes in the gold-silver ratios (Forbes, 1980). Consequently, it is difficult to associate a valid meaning to the fineness data.

Table 1. Trace-element content of placer gold in the Circle District of Alaska compared to other districts in Alaska and California

[All elements are reported in parts per million, except Ag, which is reported in percent. Analyses of the samples by Elwin Mosier (U.S. Geological Survey) using the method described in Mosier (1975). —, element below detection limits. (Alaska gold district information from Cobb, 1973)]

Sample No.	Locality	Fe	Mg	Ti	Mn	Ag	As	B	Ba	Be	Bi	Cd	Co	Cr	Cu	La	Mo	Ni	Pb	Sb	Sr	V	Zn	Zr	Pd	Si	Hg
ALASKA																											
Circle quadrangle (Circle district)																											
YD-13-80	Birch Creek	2,375	98	102	30	12	20	--	5	--	--	1	--	3	212	--	--	10	11	93	--	4	--	3	--	2,300	463
YD-15-80	Deadwood Creek	3,000	150	1,500	100	20	30	15	10	--	--	--	--	--	100	--	--	10	1	30	--	--	--	50	--	2,000	70
YD-19-80	Gold Dust Creek	1,700	38	55	7	10	--	--	--	--	--	--	--	--	195	--	--	5	5	20	--	5	--	--	--	815	1,200
YD-28-80	Independence Creek	1,300	175	235	18	19	485	7	14	--	--	--	--	--	145	--	--	10	25	35	--	--	--	7	--	13,000	140
YD-33-80	N. Fork Harrison Cr.	2,167	36	60	10	23	--	--	--	--	--	--	--	--	33	--	--	8	2	17	--	3	--	--	--	953	80
YD-39-80	Crooked Creek	541	33	49	3	10	--	--	8	--	--	--	--	--	167	--	--	--	1	5	--	--	--	--	--	1,567	61
YD-41-80	Ptarmigan Creek	930	93	19	9	28	--	--	--	--	--	--	--	--	190	--	--	--	4	930	--	--	--	--	--	1,900	190
YD-45-80	Cripple Creek	600	25	75	28	5	--	--	--	--	--	--	--	--	400	--	--	--	5	85	--	--	--	40	--	850	2,000
YD-46-80	Eagle Creek	1,775	170	61	16	21	41	6	12	--	18	--	--	--	107	--	--	7	53	128	--	--	--	--	--	2,300	258
Charley River quadrangle (Circle district)																											
YD-59-80	Coal Creek	3,200	55	58	20	12	--	3	11	--	4	--	--	--	283	--	--	10	14	72	--	--	--	--	--	--	--
Mount Hayes quadrangle (Chistochina district)																											
YD-29-79	Quartz Creek	5,400	900	270	90	6	--	35	54	--	--	--	--	--	125,000	--	--	--	54	--	--	--	180	--	--	5,400	3,600
YD-67-79	Broxson Gulch	1,400	140	47	28	9	94	14	9	--	1	--	19	5	2,800	--	19	14		--	--	--	--	--	--	4,700	6,600
YD-43-79	Tertiary(?) conglomerate	18,500	305	430	121	7	--	19	25	--	--	--	--	22	3,100	--	--	16	8	--	--	105	--	131	--	16,400	11,000
YD-62-79	Tertiary(?) conglomerate	2,500	170	125	17	17	--	--	--	--	--	--	--	--	830	--	--	--	17	--	--	--	--	--	--	2,500	420
Healy Quadrangle (Valdez Creek district)																											
YD-59-80	Valdez Creek	1,600	220	330	22	8	--	--	16	--	--	--	--	--	220	--	--	--	5	--	--	--	--	--	33	1,600	7,600
Ophir Quadrangle (Innoko district)																											
YD-67-80	Spruce Creek	3,125	42	55	8	8	25	--	8	--	--	--	--	8	168	--	--	6	29	--	--	--	25	--	--	2,875	1,875
YD-68-80	Spruce Creek	4,750	50	41	18	13	23	5	30	.5	--	--	--	8	150	--	--	23	23	--	--	--	150	--	--	1,875	2,125
YD-69-80	Anvil Creek	828	78	66	6	10		3	24	--	--	--	--	--	153	--	--	--	17	--	--	--	--	--	--	3,360	1,675
YD-76-80	Colorado Creek	987	88	59	14	14	167	3	110	--	27	--	--	3	240	17	--	7	695	433	150	--	--	3	--	3,233	20,507
CALIFORNIA																											
Tertiary gravels, Sierra Nevada																											
YD-A162-70		6,700	190	67	67	10	--	--	10	--	5	--	29	480	290	--	48	19	48	--	--	--	67	--	--	1,900	1,900
YD-B-168-70		1,500	94	39	11	7	5	--	--	--	--	--	4	33	250	--	--	12	14	9	--	--	25	--	--	1,875	1,625
YD-C109-70		2,667	133	1,100	71	6	--	7	--	--	--	--	--	7	366	--	--	--	6	17	--	7	--		--	2,000	2,667

Creek	Fineness (Au/Au+Ag) = 1,000
Birch	874
Bonanza	984
Bottom Dollar	714
Butte	915
Crooked	828
Deadwood	824
Eagle	879
*Gold Dust	796
*Greenhorn	911
Half Dollar	721
Harrison	825
Independence	809
Ketchem	769
Loper	900
Mammoth	831
Mastodon	854
Miller	860
North Fork Harrison	861
Portage	806
Porcupine	803
Squaw	891
Switch	836

* Data from local miners

GOLD SOURCE AND RESOURCE

The lode source for the placer gold in the Circle district has eluded the search by prospectors and geologists. The placers are recovered from creeks whose drainage basins are within sparsely mineralized quartzite, quartzitic and mafic schist, and granite. Early reports attempted to relate the placers to the schist bedrock. Spurr (1898) reported the occurrence of a gold-rich quartz vein in a block of quartz schist, and he concluded on the basis of similar rocks in the Circle, Fortymile, and Klondike districts that the quartz veins and quartz schists were the source of the gold. Prindle (1905) thought that the gold found on the creeks of the Birch Creek region had been derived from large areas of bedrock almost uniformly mineralized and that there were probably no zones or pockets especially rich in the metal. Mertie (1938) reported numerous occurrences of placer gold fragments with attached quartz and stated that quartz veins and mineralized zones in bedrock are the source of gold at least in Mastodon and Mammoth Creeks. He did not think that commercial gold lodes would necessarily be found in these areas. He explained the apparent lack of a rich lode source by claiming that "given a sufficiently long span of time and erosion, gold lodes of exceedingly low value may produce very rich placers * * *." More recently, Menzie and others (1983) concluded that the distribution of gold by rock type and by its location suggests that gold occurs in small fracture zones, in veins, and in association with felsic dikes that developed and were emplaced above the granite in the Circle mining district. Thinly laminated muscovite schist containing traces of gold and sulfides and inferred to be a volcanogenic rock with potential for massive sulfide mineralization has also been suggested as the source for much of the gold in the placers (Burton, 1985). A more recently published report, a product of this project, discusses the probability of the mafic schist being a source, and much of this section is taken from that report (Yeend, 1987).

It is useful to construct the outlines of a hypothetical source for the placer gold on the basis of knowledge of creeks that contain placer gold, relative amounts of gold recovered, and existing topography. This construction can be done for both a hypothetical bedrock source and a fossil placer source (both shown in fig. 31 *A*, *B*). The outline of the hypothetical lode source was drawn assuming that streams rich in gold would have had at least part of their drainage basin within the lode source rock and that the very richest creeks would have had a substantial part of their drainage basin within the boundaries of the lode source. Thus, an outline of the hypothetical lode source was drawn on the basis of existing topography and the location of creeks containing gold. This construction is remarkable for its close similarity to the distribution of the mafic schist (fig. 32). A hypothetical fossil placer source was also drawn using the existing topography and assuming the topographic highs with accordant summits (fig. 33) might be an old erosion surface, the location of a fossil placer river system. However, there are problems with a hypothetical fossil placer source. These are: no remnants of high-level gravel are present in the summit areas, a highland bedrock source for the fossil placer is missing, and surrounding areas lack contemporary gold placers through which an old river system would have flowed.

It is reasonable, therefore, to look for a local bedrock gold source. Only since the mapping by Foster and others (1983) has the bedrock in the district been mapped in enough detail to distinguish separate schist units. This mapping allowed the delineation of a mafic schist unit within the quartzitic schist (pl. 1). That the mafic schist crops out near headwaters of many of the most productive creeks suggests a possible genetic relationship. Furthermore, gold production from each creek is correlated with the amount of its drainage within the outcrop limits of the mafic schist. Mastodon Creek, one of the most productive creeks in the district, has at least three-fourths of its drainage basin within the mafic schist (pl. 1). Similarly, the very productive North Fork of Harrison Creek has almost all of its drainage basin within the mafic schist. Other very productive creeks, Dead-

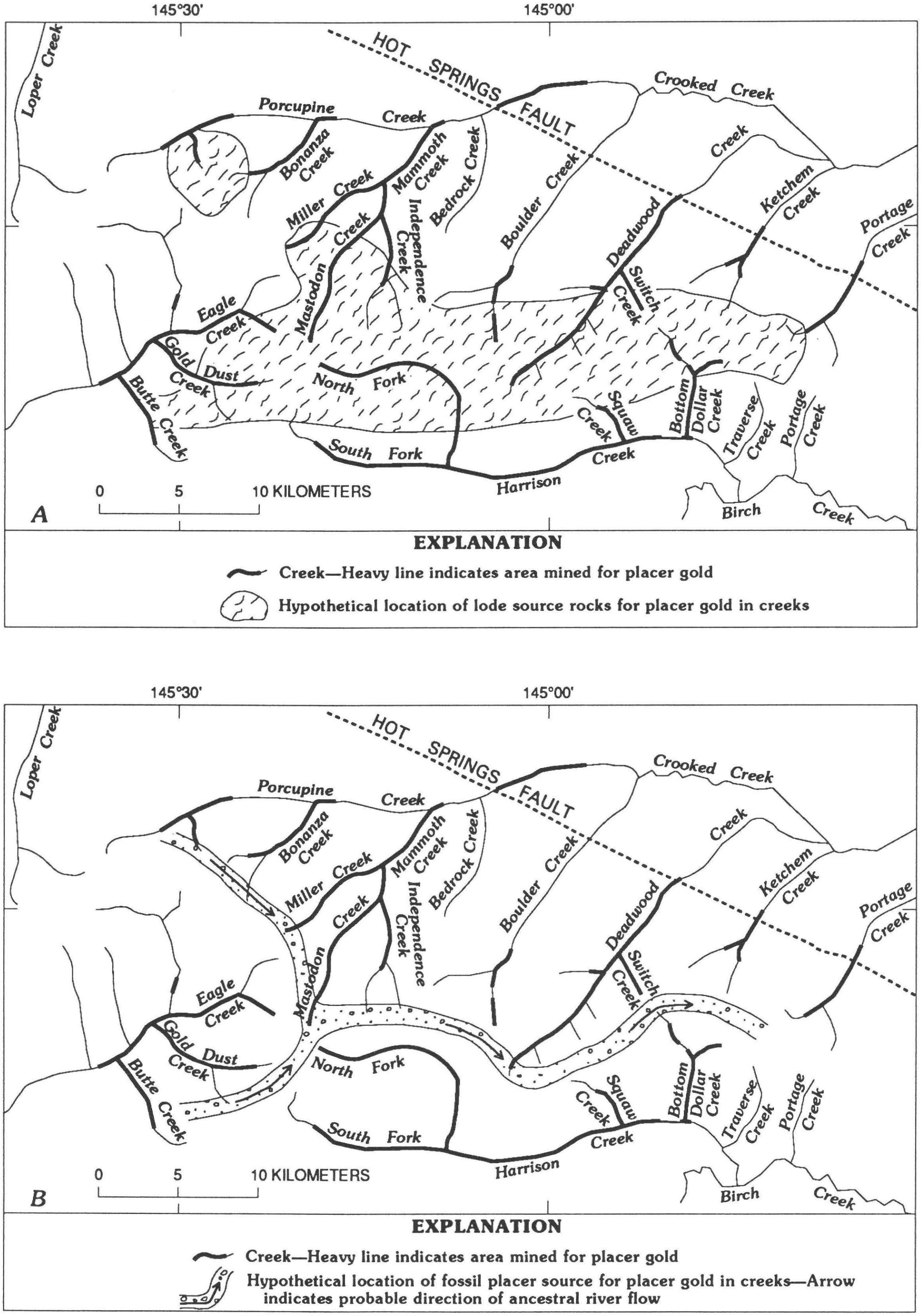


Figure 31. Hypothetical location of lode and fossil placer for placer gold in creeks of Circle district. *A*, Load source. *B*, Fossil placer source.

wood, Harrison, Independence, and Gold Dust, also drain substantial areas underlain by mafic schist. Bedrock, Boulder, Butte, and Portage Creeks, which drain areas containing little or no mafic schist, have been less productive. The two headwater tributaries of Eagle Creek illustrate this difference in drainage basin terrane. The Miller Fork does not drain any area of mafic schist and has not produced gold, whereas the Mastodon Fork drains a small area underlain by mafic schist and has produced a great deal of gold.

The granite that crops out predominantly in the eastern part of the study area, mainly in the drainages of Deadwood, Ketchem, and Portage Creeks, does not appear to be spatially related to the presence of placer gold. However, the granite is high in tin (Menzie and others, 1983).

The contact of the mafic schist with the quartzite and quartzitic schist is generally gradational. Thin units of mafic schist, too small to show at the map scale 1:63,600 (pl. 1), are locally interlayered in the quartzite and quartzitic schist unit. Assuming that the mafic schist is, in fact, a gold source or host rock for gold, these unmapped scattered occurrences could account for the presence of gold in creeks where no mafic schist has been mapped in the drainage basin such as Portage and Ketchem Creeks. The uppermost parts of Loper and Porcupine Creeks seem to be such areas.

The uppermost parts of some gold-producing creeks and those creeks with little or no gold production that drain areas underlain by mafic schist generally have such steep gradients that, although they have transported gold-rich gravel, there has been little deposition and accumulation of gold. Although incapable of supporting a large placer gold mining operation, they might contain sufficient gold to support a small mining operation. South-flowing Traverse and Portage Creeks, which empty into Birch Creek, and several south-flowing tributaries of Harrison Creek are such creeks.

The contact of the mafic schist unit with surrounding rock units is not sufficiently well understood to iden-

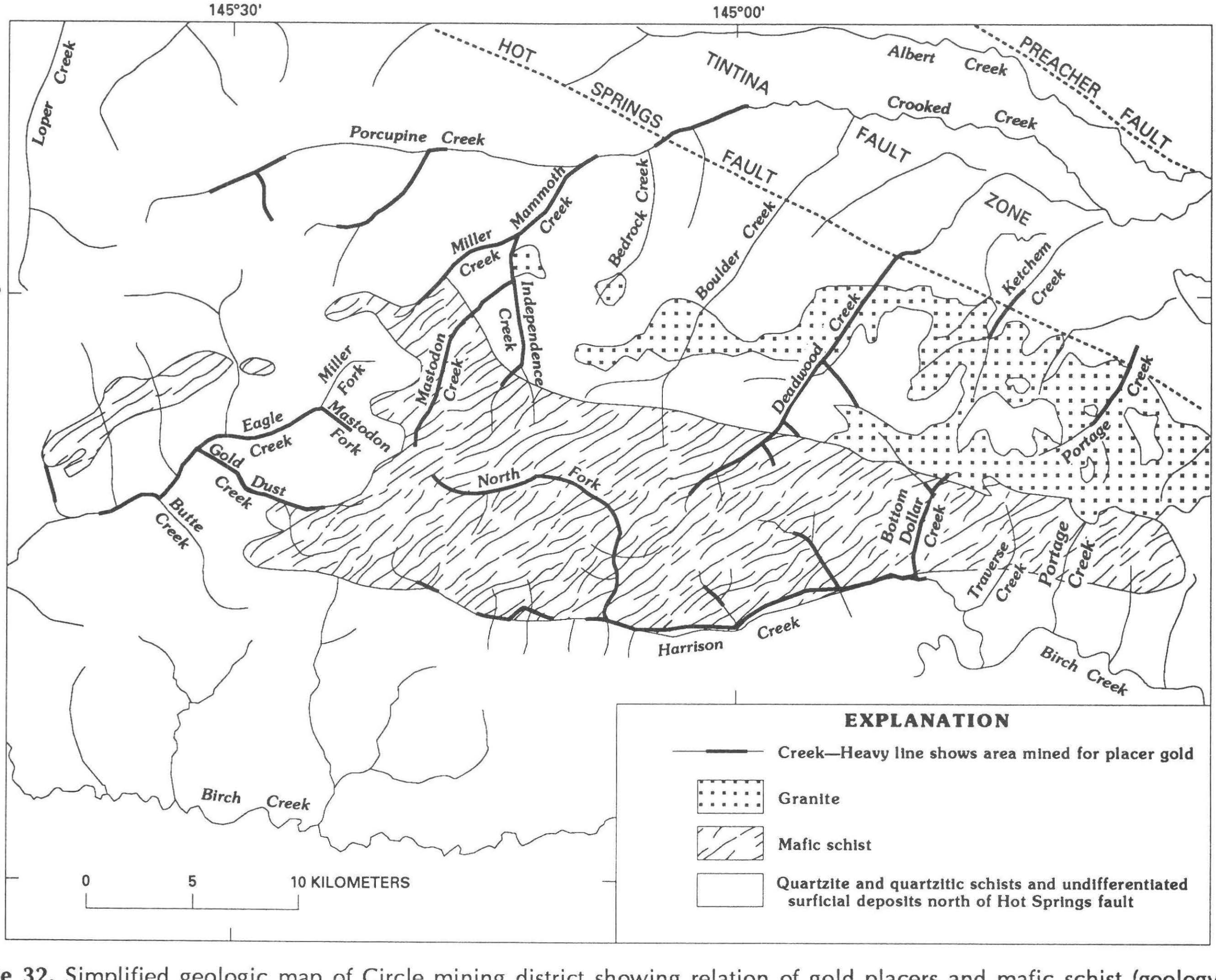


Figure 32. Simplified geologic map of Circle mining district showing relation of gold placers and mafic schist (geology from Foster and others, 1983).

tify the structural setting of these units, and so it is unclear how large an area of mafic schist was available for erosion in earlier geologic time. More detailed mapping might reveal the nature of these contacts and allow a better understanding of the size of the original gold source area.

Although the Circle district has no reported production of lode gold, the adjacent Fairbanks mining district has produced 245,000 oz (7,600 kg) of gold from lode sources. The lode gold, present within quartz-sulfide veins with associated lead-antimony sulfosalts, is hosted by the Cleary sequence, a mafic and felsic schist of probable volcanic origin (Burton, 1985). The very productive placers of the Fairbanks district, from which 7,555,000 oz (235,000 kg) of gold has been taken since 1902, are in close spatial association with the rocks of the Cleary sequence and most probably were derived from them (Burton, 1985). Placer gold within the Circle quadrangle, as mentioned in the "Gold Occurrence" section, is anomalously high in antimony compared to placer gold from other areas in Alaska; this characteristic might suggest a lode association similar to than in the Fairbanks mining district—high antimony in veins within the mafic schist.

The quartz veins cutting the metasedimentary and metavolcanic rocks have been suggested as a source for the placer gold in the Circle district (Spurr, 1898; Mertie, 1938). Although some quartz veins carry small amounts of gold, no substantial lode has ever been found that could have supplied the rich placers here. It is conceivable, however, that such a lode source has either been eroded or, less likely, concealed by soil and weathering products.

If the mafic schist is the primary lode gold source in the Circle district, the occurrence of gold within the schist remains to be determined. That only 1 of 44 rock samples collected within the mafic schist unit contains detectable gold (Menzie and others, 1983) suggests that the gold, if present in significant amounts, is not uniformly distributed through the schist.

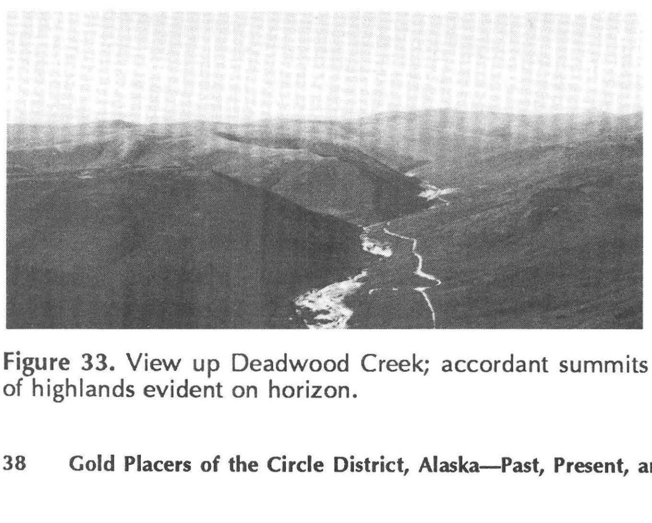


Figure 33. View up Deadwood Creek; accordant summits of highlands evident on horizon.

Although the placers in the Circle district have been mined for almost 100 years, there still remains unmined gold in the gravel. The rise in the gold price in the early 1980's stimulated a tremendous increase in mining activity, and another burst of activity would occur should the price rise sharply again. Gravel that is uneconomic at one gold price becomes economic at a higher price. Consequently, tailings are remined, gravel along the margins of creeks is mined, colluvial gravel marginal to the alluvial gravel is mined, headwater reaches where gradients are steep are mined, new creeks are mined that had not been previously economic, and the downstream portions of creeks where volumes of gravel are high, but values low, are mined. Unmined gravel exists in Ketchem, Porcupine, Bonanza, Butte, Boulder, and the South Fork of Harrison Creek (pl. 1). The largest gold resource remaining in the Circle district is probably in the lower reaches of Crooked Creek and the alluvial fill within the Tintina fault zone (Menzie and others, 1983; Yeend, 1982). Until exploratory drilling is done within this area, the distribution and richness of the gravel here will remain unknown.

PLACER MINING

Mining of placer gold deposits has been nearly continuous for almost a century in the Circle district, although mining methods have changed for several reasons. Environmental degradation has become an issue that the mining community has had to address. In recent years, demonstration grant projects financed by the State of Alaska have become available for miners as an incentive to improve the "health" of the placer mining industry.

The first decade of mining following the discovery of gold was characterized by simple methods, and maximum human labor. Miners used shovels, picks, gold pans, wheelbarrows, and sluiceboxes to extract gold from gravel, as they had for the past 2,000 years (Agricola, 1912). Only the richest parts of the gravel were mined, often by drifting. This type of mining allowed work to progress through the winter months because gold-bearing gravel was hauled out of the drifts to the surface and stock-piled to be sluiced during the spring and summer. A shortage of labor in the early years of mining limited the rate at which the high-grade gravel was mined. A detailed discussion of these early small-scale mining methods is found in Purington (1905).

By the 1930's, more sophisticated mining methods were used, and these methods included such mechanical equipment as steam-powered shovels, scrapers, draglines, cableway excavators, and bucketline dredges. Hydraulic mining was widespread in the district by the first decade of the 20th century and was used for many years where ample water was available. Ditches were dug to bring water to many of the hydraulic operations. Bucketline dredges were used for 2 years on Deadwood (fig. 11) and Mastodon Creeks, and 35 years on Mammoth Creek. Methods and costs of mining up to 1930 are presented in detail by Wimmler (1927).

The development of the diesel engine used in bulldozers, draglines, and pumps, as well as the more durable steel sluiceboxes, enabled mining of lower value gravel (Thomas and others, 1959). Backhoes, front-end loaders, elevated trommels, high-pressure hydraulic giants, conveyors, and huge bulldozers, including more sophisticated washing plants combining such features as vibratory classifying stages with efficient sluiceboxes and jigs, have appeared in the past two decades (Cook, 1983; Wilkinson, 1987; Colp, 1984; Ackels, 1985).

Mining costs have increased, but so has the price of gold. The cost of hydraulicking in the district in 1926 was \$0.25 to \$0.50 /yd^3 with gold at \$35/oz (Wimmler, 1927). By 1940 the costs were up to \$1/yd^3 (Mathews, 1940). In the 1980's, with gold averaging around \$400/oz, mining costs varied from \$0.50 to \$5/yd^3 and were dependent on mining method used and site conditions.

Following the precipitous gold price rise in the early 1980's, the number of placer mines in the State greatly increased, which led to concern for the integrity of Alaska's water resources. Stream sedimentation and associated turbidity became a problem, as most miners found it difficult to meet the criteria established by the Federal Environmental Protection Agency and Alaska Department of Environmental Conservation. Turbidity is measured in nephelometric turbidity units (NTU). NTU's are a measure of the amount of light scattered by a sample of water. The law states that turbidity should not exceed 25 NTU's above the background level, which is the level that has been determined to not harm stream life. The water in mined streams without settling ponds is much higher—200 to 300 NTU's. Settling ponds are now mandatory for placer mines. Many mines now recycle the wastewater through their washing plants, although recycling is expensive and hinders the recovery of fine gold. The U.S. Bureau of Mines has spent several years experimenting with a flocculant, a water-soluble resin called polyethylene oxide (PEO). The method involves mixing PEO with the dirty water, a process which forms a floc with the clay-size particles. The floc is then separated from the water, and the clean water is either recirculated to the washing plant or discharged into the stream. This system, although requiring extra equipment and some technical expertise, is useable in some placer mining situations (Pain, 1987).

The Alaska Legislature, in an attempt to help the mining industry evaluate the most cost-effective methods of gold recovery while complying with new Federal and State environmental regulations, established the Placer Mining Demonstration Grants Program in 1985. This program encouraged and helped finance experienced placer miners study and test new methods of (1) fine gold recovery, (2) water-use reduction and water-pollution control, and (3) waste disposal. Several grants were made to miners in the Circle district operating on Gold Dust, Eagle, Deadwood, Portage, and Ketchem Creeks. Conclusions taken from Peterson and others (1987) are summarized.

1. There is a small amount (16 percent) of fine gold (less than minus-60 mesh) in the placers, and so using complex, high-technology recovery equipment designed to capture this gold is rarely warranted. Classification through washing as well as feed to the sluice proved to be more cost effective in most cases compared to gold recovery devices added to the end of a sluicebox such as jigs, Reichert spirals, Gyro-Separator, Knudsen bowl, and Knelson concentrator.

2. Simple techniques to reduce water use include classification, recycle, bypass, improved settling ponds, and tailings filtration. Flocculant use requires technical expertise to design an effective system and select the correct flocculant, and although flocculants do work, those available have not consistently produced water quality required by the State and Federal regulations. Vegetative filters such as tundra, although not able to remove all sediment from high concentrations of effluent, are nevertheless useful in cleaning up "dirty" water prior to recirculating or discharge back to the stream system.

3. Using coarse tailings to bury the fine tailings and slimes is a viable method for stabilizing these unwanted mine products. Also, using a slurry pump or hydraulic lift to spray fine tailings on top of coarse tailings is a good method preparatory to revegetation.

Although most mining in the Circle district today is done with expensive, sophisticated equipment, there is still a place for small, low-budget mines. There are unmined creeks with small drainage basins that contain gold. These creeks cannot support a large mining operation because of low grade and (or) volume, but they can provide a working wage for a miner and the thrill of finding an occasional nugget or rich pocket to the recreational miner.

CONCLUSIONS

1. The Tintina fault trench is at least partially filled with orange-brown, altered gravel exposed by placer mining in the 1980's, which is late Tertiary(?) or early Quaternary in age. The gravel is most intensely altered, near the Hot Springs fault where it is deep orange brown color and suggests that hot water associated with the fault has caused the alteration.

2. Colluvium marginal to creek deposits in steep-sided valleys often contains enough gold to warrant mining, as in Portage, Eagle, Miller, Mastodon, and Mammoth Creeks.

3. The Tintina fault trench contains at least three superimposed fan gravel units of late Tertiary(?), late Pleistocene, and Holocene age. The Holocene fan gravel is the most gold rich, with values of $1 to $10/yd^3. The late Tertiary(?) and late Pleistocene gravel possess gold values of only $.10 to $.50/yd^3; however, the volume of these gravel units is very high.

4. The Tintina fault trench was filled with successive generations of continuous, extensive fan gravel from the surrounding highlands; such filling is thought to have occurred in other areas of Alaska, but in these areas faulting has resulted in fragmented, isolated remnants of the gravel.

5. Gold fineness from the district varies from 714 to 984, but it is difficult to attach any significant geologic meaning to the fineness data.

6. Gold from the Circle district is moderately high in silver (average 16.1 percent), and all samples contain antimony, whose presence distinguishes the gold here from the gold in many other areas in Alaska which does not contain antimony.

7. Deadwood Creek is one of the most mined-out creeks in the district, although some gold-bearing bench gravel remains unmined, as do the vast deposits of low-value fan gravel north of the Hot Springs fault.

8. The gravel in Mastodon Creek, the richest in the district, has produced between 150,000 to 200,000 oz of gold and has been thoroughly mined.

9. The gravel in Crooked Creek seems to be richest north of the Hot Springs fault; little, if any, mining has been done south of the fault in the creek gravel where the quartzite and quartzitic schist bedrock is present beneath several meters of creek gravel.

10. The North Fork of Harrison Creek produced a great deal of gold from mining in the early 1980's.

11. Unmined gravel is present on Ketchem, Porcupine, Bonanza, Butte, Boulder, and South Fork Creeks.

12. The mafic schist should be seriously considered as a source for the placer gold on the basis of its mapped outcrop position relative to the occurrence of placer gold in the creeks.

13. Streams draining principally the metamorphic rock, quartzite, and schist are rich in garnet, whereas streams draining granitic rocks are rich in ilmenite, magnetite, and some are rich in amphibole.

14. There are no apparent systematic differences in the heavy-mineral contents in streams draining large areas of mafic schist compared to those draining primarily quartzite and quartzitic schist, except for gold. Gold is more prevalent in the creeks draining mafic schist.

15. Most placer gold in the Circle district has been recovered at, or near, the gravel-bedrock contact. The lowermost 1 m of gravel and the uppermost 0.5 m of bedrock may contain as much as 80 to 90 percent of the gold that is ultimately recovered.

16. Gold nuggets are rare, as most of the gold recovered is in the form of flattened fragments less than 5 mm in greatest dimension.

17. A fossil placer source for the gold in the Circle district, although a possibility, is not probable.

18. The largest gold resource remaining in the Circle district is probably in the lower reaches of Crooked Creek and the alluvial fill within the Tintina fault trench.

19. Environmental constraints imposed by Federal and State agencies have slowed, but not stopped, placer mining in the Circle district, and a significant gold price rise would result in more mining.

REFERENCES CITED

Ackels, Del, 1985, Some aspects of gold recovery with IHC jigs, *in* Madonna, J.A., ed., Proceedings of the seventh annual conference on Alaskan placer mining: Fairbanks, Alaska Prospectors Publishing, p. 86-99.

Agricola, Georgius, 1912, de re metallica [on the study of metals] (translated from the first Latin edition of 1556, by H.C. Hoover and L.A. Hoover): The Mining Magazine, 640 p.

Baker, Marcus, 1906, Geographic dictionary of Alaska, 2nd ed.: U.S. Geological Survey Bulletin 299, 690 p.

Barker, J.C., 1986, Placer gold deposits of the Eagle Trough, upper Yukon River region, Alaska: U.S. Bureau of Mines Information Circular 9123, 23 p.

Berton, Pierre, 1958, The Klondike fever: The life and death of the last great gold rush: New York, Alfred A. Knopf, 457 p.

Boyle, R.W., 1979, The geochemistry of gold and its deposits: Geological Survey of Canada Bulletin 280, 584 p.

Brooks, A.H. and others 1918, Mineral resources of Alaska. Report on progress of investigation in 1916: U.S. Geological Survey Bulletin 662, 459 p.

Brooks, A.H. and others, 1907, Report on progress of investigations of mineral resources of Alaska in 1906: U.S. Geological Survey Bulletin 314, 235 p.

Burand, W.M., 1965, A geochemical investigation between Chatanika and Circle Hot Springs, Alaska: Alaska Division of Mines and Minerals Geochemical Report 5, 11 p.

Burton, Jeff, 1985, Mining and Minerals in the golden heart of Alaska: Fairbanks, North Star Borough, 80 p.

Churkin, Michael, Jr., Foster, H.L., Chapman, R.M., and Weber, F.R., 1982, Terranes and suture zones in east-central Alaska: Journal of Geophysical Research, v. 87, no. 135, p. 3718-3730.

Cobb, E.H., 1973, Placer deposits of Alaska: U.S. Geological Survey Bulletin 1374, 213 p.

Colp, D.B., 1984, Mining and recovery techniques on Eagle Creek, *in* Sixth Annual Conference on Alaskan Placer Mining: Fairbanks, University of Alaska Mineral Industry

Research Laboratory Report 69, p. 23-26.
Cook, D.J., 1983, Placer mining in Alaska: Fairbanks, University of Alaska Mineral Industry Research Laboratory Report 65, 157 p.
Couch, J.S., 1953, Philately below zero, a postal history of Alaska: State College of Pennsylvania, The American Philatelic Society, 81 p.
Cushing, R.W., and Foster, H.L., 1982, Recumbent folding in the northeastern Yukon-Tanana Upland, Alaska [abs.]: Geological Society of America, 78th Annual Meeting, Abstracts with Programs, p. 158.
Dahlin, D.C., Brown, L.L., and Warner, J.D., 1987, Characterization of Ketchem Dome tin prospect, east-central Alaska: U.S. Bureau of Mines Report of Investigations 9145, 11 p.
Davies, W.E., 1972, The Tintina trench and its reflection on the structure of the Circle area, Yukon-Tanana Upland, Alaska: International Geological Congress, 24th, Proceedings, p. 211-216.
Dunham, S.C., 1898, The Alaskan gold fields and the opportunities they offer for capital and labor: Department of Labor Bulletin No. 14, p. 297-495.
Eberlein, G.D., Chapman, R.M., Foster, H.L., and Gassaway, J.S., 1977, Map and table describing known metalliferous and selected nonmetalliferous mineral deposits in central Alaska: U.S. Geological Survey Open-File Report 77-0168-D, 132 p., 1 sheet, scale 1:1,000,000.
Ellsworth, C.E., 1910, Placer mining in the Yukon-Tanana region: U.S. Geological Survey Bulletin 442, p. 230-245.
———1912, Placer mining in the Fairbanks and Circle districts: U.S. Geological Survey Bulletin 520, p. 240-245.
Ellsworth, C.E., and Davenport, R.W., 1913, Placer mining in the Yukon-Tanana region: U.S. Geological Survey Bulletin 542, p. 203-222.
Ellsworth, C.E., and Parker, G.L., 1911, Placer mining in the Yukon-Tanana region: U.S. Geological Survey Bulletin 480, p. 153-172.
Forbes, R.B., 1980, Chemical zonation in gold nuggets, *in* Second Annual Conference on Alaskan Placer Mining—Focus on gold: Fairbanks, University of Alaska Mineral Industry Research Laboratory Report No. 46, p. 72-77.
Forbes, R.B., Kline, J.T., and Clough, A.H., 1987, A preliminary evaluation of alluvial diamond discoveries in placer gravels of Crooked Creek, Circle district, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 87-1, 26 p.
Foster, H.L., Laird, Jo, Keith, T.E.C., Cushing, G.W., and Menzie, W.D., 1983, Preliminary geologic map of the Circle quadrangle, Alaska: U.S. Geological Survey Open-File Report 83-0170-A, 32 p., 1 sheet, scale 1:250,000.
Gedney, L., Shapiro, Leonard, Van Wormer, D., and Weber, F.R., 1972, Correlation of epicenters with mapped faults, east-central Alaska, 1968-1971: U.S. Geological Survey open-file report 72-0128, 1 sheet, scale 1:1,000,000.
Heiner, V.D., 1977, Alaska mining history, a source document: Anchorage, Alaska, Office of History and Archaeology, Alaska Division of Parks, History, and Archaeology Series No. 17, 463 p.
Hughes, J.D., and Long, D.F.G., 1980, Geology and coal resource potential of early Tertiary strata along Tintina Trench, Yukon Territory: Geological Survey of Canada Paper 79-32, 21 p.
Johnson, B.L., 1910, Occurrence of wolframite and cassiterite in the gold placers of Deadwood Creek, Birch Creek district: U.S. Geological Survey Bulletin 442-F, 4 p. *in* Brooks, A.H. and others, 1910, Mineral Resources of Alaska Report on Progress of Investigation in 1909, 417 pages, U.S. Geological Survey Bulletin 442.
Jones, D.L., Silberling, N.J., Berg, H.C., and Plafker, George, 1981, Map showing tectonostratigraphic terranes of Alaska, columnar sections and summary descriptions of terranes: U.S. Geological Survey Open-File Report 81-792, 2 sheets, scale 1:250,000.
Madonna, J.A., 1988, The profitable small-scale mining of flood gold, *in* Madonna, J.A., ed., Proceedings of the Tenth Annual Conference on Alaska Placer Mining, Fairbanks, Alaska, March 24, 1988, p. 12.
Mathews, R.T., 1940, Placer mining methods and costs in the Circle district, Alaska: College, Alaska, University of Alaska, Bachelor of Science in Mining Engineering thesis, 80 p.
Menzie, W.D., Foster, H.L., Tripp, R.B., and Yeend, W.E., 1983, Mineral resource assessment of the Circle quadrangle, Alaska: U.S. Geological Survey Open-File Report 83-0170-B, 61 p., 1 sheet, scale 1:250,000.
Mertie, Evelyn, 1982, Thirty summers and a winter: Fairbanks, University of Alaska Mineral Industry Research Laboratory, 187 p.
Mertie, J.B., Jr., 1932, Mining in the Circle district: U.S. Geological Survey Bulletin 824-D, p. 155-172.
———1937, The Yukon-Tanana region, Alaska: U.S. Geological Survey Bulletin 872, 276 p.
———1938, Gold placers of the Fortymile, Eagle, and Circle districts, Alaska: U.S. Geological Survey Bulletin 897-C, p. 133-261.
Metz, P.A., 1987, Geological factors governing the formation of the gold placer deposits of the Fairbanks Mining District, Alaska, *in* Albanese, Mary, and Campbell, Bruce, compilers: Proceedings of the Ninth Annual Alaska Conference on Placer Mining, Fairbanks, Alaska, p. 195-223.
Metz, P.A., and Hawkins, D.B., 1981, A summary of gold fineness values from Alaska placer deposits: Fairbanks, University of Alaska Mineral Industry Research Laboratory Report No. 45, 63 p.
Morrison, S.R., and Hein, F.J., 1987, Sedimentology of the White Channel gravels, Klondike area, Yukon Territory: Fluvial deposits of a confined valley, *in* Ethridge, F.T. and others, eds., Recent developments in fluvial sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 205-216.
Mosier, E.L., 1975, Use of emission spectroscopy for the semiquantitative analysis of trace elements and silver in native gold, *in* Ward, F.N., ed., New and refined methods of trace analysis useful in geochemical exploration: U.S. Geological Survey Bulletin 1408, p. 97-105.
Orth, D.J., 1967, Dictionary of Alaska place names: U.S. Geological Survey Professional Paper 567, 1084 p.
Pain, Stephanie, 1987, After the gold rush: New Scientist, v. 115, no. 1574, p. 36-40.
Peterson, L.A., Hanneman, R.C., and Tsigonis, R.C., 1987, Placer mining demonstration grant project, final report:

Prepared for: State of Alaska Department of Environmental Conservation, [available from L.A. Peterson & Associates, Inc., Fairbanks, Alaska] 113 p.
Péwé, T.L., 1975, Quaternary stratigraphic nomenclature in unglaciated central Alaska: U.S. Geological Survey Professional Paper 862, 32 p.
Prindle, L.M., 1905, The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska: U.S. Geological Survey Bulletin 251, 89 p.
Purington, C.W., 1905, Methods and costs of gravel and placer mining in Alaska: U.S. Geological Survey Bulletin 263, 263 p.
Spurr, J.E., 1898, Geology of the Yukon gold district, Alaska: U.S. Geological Survey 18th Annual Report, pt. 3, p. 87-392.
Tempelman-Kluit, D.J., 1977, Stratigraphic and structural relations between the Selwyn Basin, Pelly-Cassiar Platform, and Yukon Crystalline Terrane in the Pelly Mountains, Yukon: Geological Survey of Canada Paper 77-1A, p. 223-237.
Tempelman-Kluit, D.J., Gordey, S.P., and Read, B.C., 1976, Stratigraphic and structural studies in the Pelly Mountains, Yukon Territory: Geological Survey of Canada Paper 76-1A, p. 97-106.
Thomas, B.I., Cook, D.J., Wolff, Ernest, and Kerns, W.H., 1959, Placer mining in Alaska; methods and costs at operations using hydraulic and mechanical excavation equipment with nonfloating Washington plants: U.S. Bureau of Mines Information Circular 7926, 34 p.
Warner, Helen, 1984, Mining on Porcupine Creek, Circle district, *in* Sixth Annual Conference on Alaskan Placer Mining: Fairbanks, University of Alaska Mineral Industry Research Laboratory Report 69, p. 26-27.
Weber, F.R., and Foster, H.L., 1982, Tertiary(?) conglomerate and Quaternary faulting in the Circle quadrangle, Alaska, *in* Coonrad, W.L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 58-60.
Wharton, C.B., 1972, The Alaska gold rush: Bloomington, Indiana University Press, 302 p.
Wilkinson, Fred, 1984, Excavating frozen muck, *in* Sixth Annual Conference on Alaskan Placer Mining: Fairbanks, University of Alaska Mineral Industry Research Laboratory Report 69, p. 20-22.
———1987, Countercurrent sluicing on Ketchem Creek, *in* Albanese, Mary, and Campbell, Bruce, compilers, Proceedings of the Ninth Annual Alaska Conference on Placer Mining, p. 229-233.
Wilkinson, Katy, 1987, Geology of a subarctic, tin-bearing batholith, Circle Hot Springs, Alaska: Fairbanks, University of Alaska Mineral Industry Research Laboratory Report 74, 70 p.
Wimmler, N.L., 1927, Placer mining methods and costs in Alaska: U.S. Bureau of Mines Bulletin 257, 236 p.
Wold, Jo Ann, 1988, The way it was of people, places, and things in pioneer interior Alaska: Anchorage, Alaska Northwest Publishing Company, 97 p.
Yeend, W.E., 1974, Gold-bearing gravel of the ancestral Yuba River, Sierra Nevada, California: U.S. Geological Survey Professional Paper 772, 44 p.
———1982, Placers and placer mining, Circle district, Alaska, *in* Coonrad, W.L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 64.
———1984, Gold in Tertiary(?) rocks, Circle quadrangle, Alaska, *in* Coonrad, W.L., and Elliott, R.L., eds., The United States Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 65-66.
———1985, Trace elements of placer gold, *in* Bartsch-Winkler, S., and Reed, K., eds., The United States Geological Survey in Alaska: Accomplishments during 1983: U.S. Geological Survey Circular 945, p. 4-7.
———1987, Placer gold related to mafic schist(?) in the Circle district, Alaska, *in* Hamilton, T.D., and Galloway, J.P., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1986: U.S. Geological Survey Circular 998, p. 74-76.
———1989, Late Cenozoic sedimentary history along major fault zones, Alaska, *in* Carter, L.D,, Hamilton, T.D., and Galloway, J.P., eds., Late Cenozoic history of the interior basins of Alaska and the Yukon, U.S. Geological Survey Circular 1026, p. 55-59.
Yeend, Warren, Ager, Thomas, and Kline, J.T., 1989, Stratigraphy and palynology of an upper Tertiary terrace deposit of the ancestral Yukon River near Circle, Alaska, *in* Dover, James, H. and Galloway, John P., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1988: U.S. Geological Survey Bulletin 1903, p. 62-67.