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PRELIMINARY STUDY OF METALS AND PRECIOUS STONES ALONG THE UNION PACIFIC RIGHT-OF-WAY, SOUTHERN WYOMING

by

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Abstract

This report summarizes the results of an exploration project for metals and precious stones in southern Wyoming. The project examined Cu-Au-Ag-Pb mineralization in Proterozoic metamorphics of the Cooper Hill district; Ti-Fe-Zr-Au-REE (rare earth elements) in titaniferous black sandstones in Cretaceous sedimentary rocks; Au in a large silicified zone at Aspen Mountain; Au-REE in Cambrian conglomerates; Au in coal and related rocks; Au in sandstone, shale, limestone, and tar sands; Au in sand and gravel deposits; and diamonds and peridot in lamproite. The project identified several precious metal anomalies in many of these geologic environments.

Introduction

With the exception of the Medicine Bow Mountains, Sierra Madre, and Laramie Mountains, much of southern Wyoming has not been explored systematically for gold and precious stones. Much of this region is underlain by sedimentary basins that do not fit within the classical models for metallic ore deposits, which may explain the general lack of exploration in this area. However, the literature and various prospectors have described numerous unverified gold occurrences in a variety of geological environments. These include reports of gold in coal, oil shale, Recent stream sediments, and sand and gravel deposits. Some of these geologic environments were examined for gold during this project.

Diamond exploration in southern Wyoming has been more intensive for several reasons: (1) The basement of much of this region is formed of Archean cratonic rocks which have proven to be favorable terranes for diamondiferous kimberlite elsewhere in the world. (2) Southern Wyoming was prospected for diamonds in the 1870s because of the 'Great Diamond Hoax' which occurred near Diamond Peak, Colorado, along the Colorado-Wyoming border south of Rock Springs. (3) More than 100 years later, in 1975, diamonds were discovered in kimberlite near Tie Siding, Wyoming, in the Laramie Mountains. This led to extensive exploration for commercial diamond deposits for more than a decade. The exploration resulted in the discovery of more than 100 kimberlite pipes and dikes in the Colorado-Wyoming State Line district and the recovery of more than 100,000 diamonds. (4) Diamonds were later discovered in 1977 in a gold placer in the Medicine Bow Mountains. (5) The typical 'indicator minerals' of kimberlite (pyrope garnet and chromian diopside) were reported in ant hills in the Cedar Mountain area of the southern Green River Basin in the late 1970s. (6) With the discovery of diamonds in lamproites in the Kimberly region of Western Australia in the 1970s, some interest in the Leucite Hills lamproite field near Rock Springs is expected.

During the 1991 field season, the Geological Survey of Wyoming investigated several areas in southern Wyoming for metal mineralization within the vicinity of the Union Pacific Railroad right-of-way. Dozens of samples were collected and reconnaissance maps were prepared for several deposits. The results of the 1991 field season were encouraging and several gold and other metal anomalies were detected.

Acknowledgments

Financial support was provided by a grant from Union Pacific Resources with additional funds provided from the Geological Survey of Wyoming's general operating budget. We are indebted to Union Pacific Resources and to Dan Dowers (formerly with Union Pacific Resources) for approaching us with this project proposal and financial assistance.

Access to several areas could not have occurred without permission from various land owners, claimants, and lessees. We thank Ron Kuhn, Mike McGill, Steve Palmer, and Chuck Szekula of Laramie, Dale Hiatt with Western Mobile Corp., Jim Jankovski and Kit Westbrook, Dave Ondriezek with Larry's Inc., Ted Wells with the Wyoming Transportation Department, and Union Pacific Resources.

We would also like to thank Ray Ring of Rawlins for his assistance in the Rawlins uplift, and Dean Farris of Laramie for leading us to some interesting gold anomalies. And finally, we would like to thank Chuck and Ester Szekula and Audrey Cofferman for their hospitality at Cooper Hill.

Analytical procedures

Samples collected for this study for assay were analyzed by AA (atomic absorption spectrometer) by Robert W. Gregory at the Geological Survey of Wyoming's analytical laboratory, or were contracted to either Gordon Marlatt or Bondar-Clegg. Gordon Marlatt utilized a 4-wheel-drive mobile laboratory which was driven near the outcrop to obtain very timely assay results by the next morning.

Mineralogical determinations were made using binocular and petrographic microscopes. A few enigmatic minerals were analyzed by x-ray diffractometer (XRD) at the Geological Survey of Wyoming. Samples from the Leucite Hills were beneficiated and processed on a grease table in the Survey's diamond laboratory.

Projects

Several project areas were considered for this study, but due to the limited manpower and time, we selected the following areas as highest priority (**Figure 1**):

(1) The Cooper Hill mining district in the northeastern Medicine Bow Mountains. This area was selected because it was a historic mining district for which there was very little information available on its mineral deposits. Additionally, the available geologic maps contained conflicting information.

(2) Titaniferous black sandstone deposits. These were selected because of their potential widespread occurrence and the presence of associated strategic mineral resources.

(3) The Aspen Mountain silicified zone. This area consists of a widespread silicified zone with alunitic and kaolinitic alteration and was considered as a potential disseminated gold deposit.

(4) Conglomerates in the Rawlins area. Unverified historic reports indicated these rocks hosted anomalous gold.

(5) Gold in coal and related baked and fused rock (scoria or clinker). Several gold and silver anomalies have been reported in coal beds in southern Wyoming and elsewhere in the State.
(6) Gold in sand and gravel deposits. Sand and gravel resources are mined all over the State and have not been considered as potential sources of by-product gold, even though gold has been successfully recovered from sand and gravel deposits in other states.
(7) Gold associated with sandstones, shales, and limestones. Gold anomalies have been reported in some of these rocks.
(8) The Leucite Hills. Lamproites of the Leucite Hills exhibit similarities to diamondiferous lamproites found elsewhere in the world.

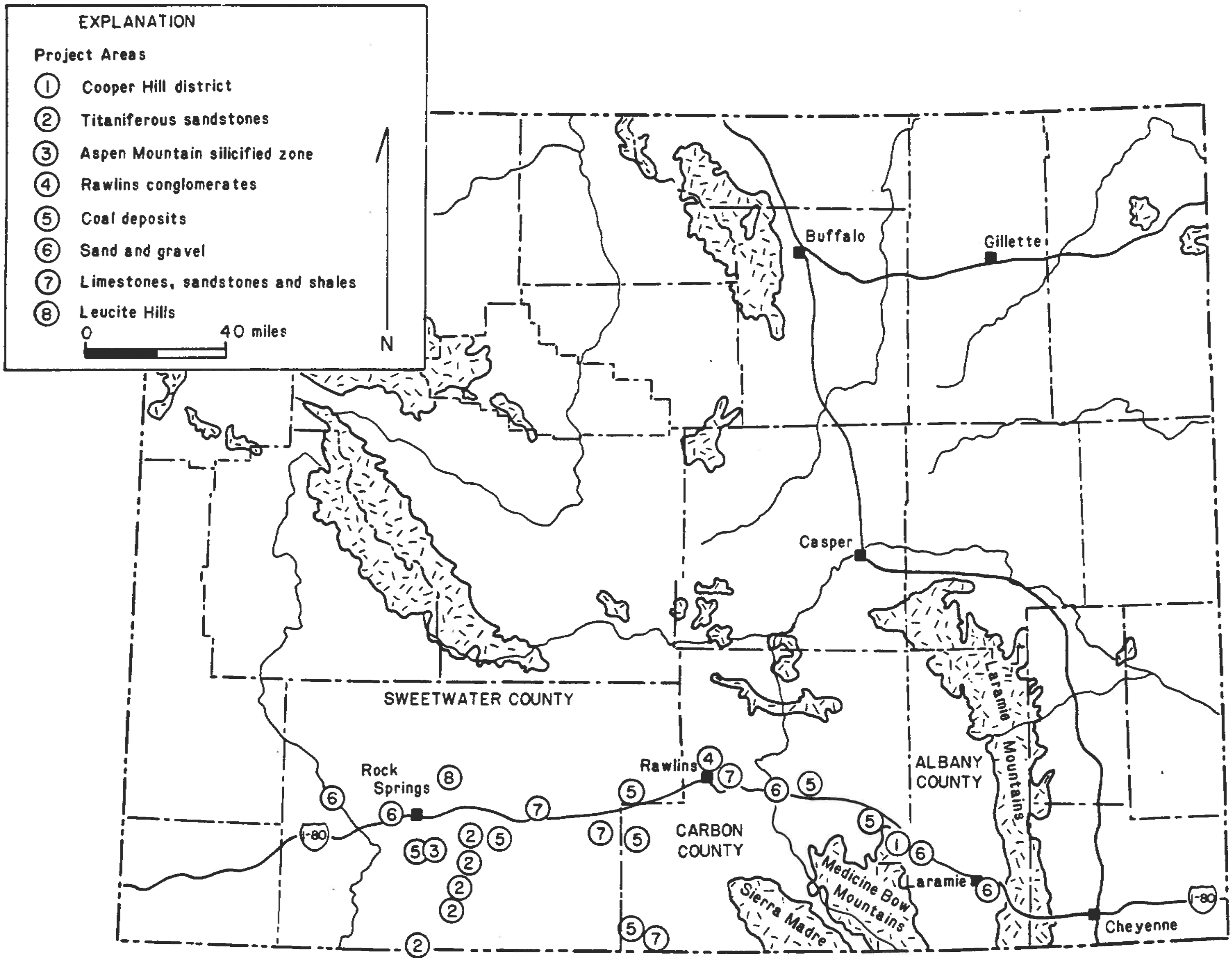

Figure 1. Project areas investigated in southern Wyoming for gold, other metals, and diamonds.

Geology and mineralization of the Cooper Hill mining district, Carbon County

Introduction

The Cooper Hill mining district lies along the northeastern edge of the Medicine Bow Mountains in southeastern Wyoming (**Figure 1**). Cooper Hill, the bald (treeless) feature from which the district derives its name, is clearly seen from Interstate 80 in the vicinity of Cooper Cove. The mining district was active for a short period in the 1890s and produced minor amounts of gold, copper, silver, and lead ore.

Structurally, Cooper Hill has been interpreted as an allochthonous block of Proterozoic crystalline rock. Here, the Arlington thrust has placed ancient Precambrian (Proterozoic) rocks on top of younger Phanerozoic sedimentary rocks (King, 1963; Blackstone, 1973). The Precambrian rocks at Cooper Hill are typical of the miogeosynclinal metasedimentary succession found throughout much of the northern Medicine Bow Mountains and include quartzite, metaconglomerate, metalimestone, mica schist, and amphibolite. Mineralization is associated with quartz veins (Schoen, 1953), replacement deposits, and skarns. Sulfides include chalcopyrite, pyrite, galena, and polybasite (Schoen, 1953).

Geography and history

Cooper Hill forms a distinct, north-south elongated, treeless hill that can be seen to the west from Interstate 80 at the Cooper Cove Road exit, approximately 7 miles east of Arlington. The hill is flanked on the east side by the North Fork of Cooper Creek and on the west side by Dutton Creek. Access to the mining district from Interstate 80 is by two dirt roads across private property. The northern road leads to Woodedge, and the southern road leads to Morgan. Morgan and Woodedge are villages with a small number of summer cabins.

Placer gold may have been found in Cooper Creek as early as 1854. Twenty-three years later, in 1877, the King Survey of the Fortieth Parallel also reported rumors of gold in Cooper Creek, but no apparent verification was made (Hague and Emmons, 1877). By 1896, placer gold had definitely been discovered in the district. According to the Engineering and Mining Journal (1896, v. 62, p. 15), several thousand acres of placer ground were staked along Cooper Creek and on the South [East?] Fork of Dutton Creek.

The first known report of lode mineralization on Cooper Hill was in the early summer of 1893, when claims were staked following the discovery of gossaniferous outcrops. A short time later, small scale mining began (Duncan, 1990). Over the next few years, high-grade ore was mined and stockpiled in anticipation of the construction of a mill and smelter in the district. Then in 1897, a ten-stamp mill was built at the south end of Cooper Hill and 300 tons of the stockpiled ore from the Albion and Emma G. mines were processed, which yielded an average of $17.50 per ton (Duncan, 1990). However, since no smelter was erected in the district, the base metals (lead and copper) and refractory precious metals of the stockpiled ore could not have been recovered unless the ore was shipped. Therefore, the value of the ore reported by Duncan (1990) ostensibly does not reflect these latter metal values. Only sporadic mining occurred after 1897.

In 1906, Henry C. Beeler, the Wyoming State Geologist, visited the Cooper Hill district. His report noted that the Emma G. mine produced the richest float in the district, the Albion mine produced the greatest body of gold and galena, the Richmond mine produced the greatest amount of free-milling gold, and the Cooper Hill mine (location unknown) produced the greatest amount of copper in the district (Beeler, 1906). He also mentioned that an immense vein of sugar quartz along the west side of Cooper Hill carried free-milling gold which consistently averaged 0.1 to 0.2 opt (ounce per ton) gold. Beeler also mentioned that rare specimen grade ore in the district assayed as high as $84,000 per ton.

A detailed study of the geology and mineralization of the Cooper Hill district did not take place until Schoen (1953) characterized Cooper Hill as a folded succession of layered metasedimentary and metaigneous rock that had been subjected to at least two episodes of mineralization. King (1963) mapped the northeastern Medicine Bow Mountains and paid particular attention to Cooper Hill. King (1963) concluded that Schoen's (1953) stratigraphic succession could not be "rigorously demonstrated". In contrast to Schoen's earlier mapping, King's (1963) remapping of Cooper Hill interpreted the district as a large block of quartzite cut by amphibolite with scattered floating marble reefs. A later study by Karlstrom and others (1981) incorporated King's mapping into their regional study of the Precambrian stratigraphy of the Medicine Bow Mountains and Sierra Madre.

The current investigation began with detailed geologic mapping at 1:12,000-scale in the summer of 1991 (**Plate 1**). In conjunction with mapping, samples were collected from most mines and prospects for assay, and additional samples were collected for whole rock, hand specimen, thin section, and XRD studies. Schoen (1953) had the advantage of access to some underground workings which were not accessible during the present study.

Geology

Cooper Hill is an allochthonous block of Precambrian rocks that has been variously interpreted as either a gravity slide originating from the west in the Medicine Bow Mountains proper (King, 1963) or as an eastward klippe on the Arlington thrust. The district is underlain by Proterozoic metasedimentary and metaigneous rock deposited in a miogeoclinal terrane along the margin of the Wyoming craton possibly 1.7 to 2.5 Ga (billion years) ago. The Proterozoic rocks of the northern Medicine Bow Mountains were deposited on an Archean basement (Karlstrom and others, 1981). Archean rocks, however, do not crop out at Cooper Hill.

The attitude of the lithologic units on Cooper Hill are different from the miogeoclinal metasedimentary rocks a short distance to the west in the main block of the Medicine Bow Mountains (R.S. Houston, personal communication, 1991). The lithologic units on Cooper Hill, have relatively flat dips, whereas in the adjacent uplift, they dip comparatively steeply to the southwest.

A regional geologic map of the Medicine Bow Mountains shows the northern portion of Cooper Hill underlain by Vagner Formation metasedimentary rocks and the southern portion underlain by older rocks of the Cascade Quartzite (Karlstrom and others, 1981). Typically, the Vagner Formation consists of diamictite, marble, chlorite-biotite-quartz schist, and quartzite; in contrast, the Cascade Quartzite consists of quartz-arenite with quartz and black chert pebble conglomerate. These formations form part of the Deep Lake Group (Proterozoic).

During mapping of Cooper Hill, some inconsistencies with the earlier studies were noted. Quartz-pebble conglomerate with quartz and black chert pebbles typical of Cascade Quartzite conglomerate (Paul J. Graff, personal communication, 1991) were found and mapped on the northern half of the hill near the 9,198-foot elevation point (**Plate 1**). The conglomerate that could be the Cascade Quartzite is underlain by metalimestone, mica schist, and quartzite typical of the younger Vagner Formation. This perplexing stratigraphy suggests the lithologies are reversed and overturned from the normal sequence to the west. But since no facing indicators could be found to differentiate top from bottom, the use of formation names is eliminated in this report in favor of lithologic descriptions. The possibility that the Cooper Hill succession is overturned is not unique to the area. For instance, a few miles west and northwest of Cooper Hill, King (1963) identified overturned relict crossbeds in quartzite.

The present mapping study generally agrees with Schoen (1953) rather than King (1963), and shows the Cooper Hill district as a folded succession of Proterozoic metasedimentary and metaigneous rocks with a minimum exposed thickness of 800 feet. The stratigraphic succession is dominated by quartzite containing local quartz-pebble conglomerate, underlain by metalimestone, mica schist, amphibolite, and quartzite. The steep hillsides are scree covered with few rock exposures. However, there is enough exposure to confidently confirm much of Schoen's stratigraphic succession.

Both the northern and southern segments of Cooper Hill are synformal structures. Between these two synforms is a topographic saddle in a fault block composed of amphibolite (metabasalt) capped by an erosional remnant of folded metalimestone. The bedding in the limestone is ubiquitously drag folded and has later been refolded, producing an open synform. Possibly three or more episodes of folding affected Cooper Hill during the Proterozoic Eon, followed by brittle deformation during the Laramide orogeny.

Structure and metamorphism

With only a few good exposures over a relatively small area, the structural history of Cooper Hill could not be unravelled with any confidence. Precambrian rocks on Cooper Hill appear to be complexly folded and to have been subjected to several episodes of deformation. Complex folding was also indicated in the metasedimentary succession west of Cooper Hill (King, 1963).

Sometime between 2.5 Ga and 1.7 Ga ago, the sediments and mafic volcanics of Cooper Hill were deposited in a miogeoclinal basin near the margin of the Wyoming craton. These sediments and volcanics were later lithified and folded into a series of small scale isoclinal folds with northeast-southwest trending axial plane traces. Folding of the rocks at Cooper Hill was accompanied by regional amphibolite grade metamorphism, and by one or more episodes of intrusion of gabbroic and basaltic dikes and sills. During regional metamorphism, the supracrustal succession inherited foliation which is displayed in most rocks in the district. Mica in quartzite and metaconglomerate occur in foliation planes, pebbles are stretched in the plane of foliation, mica schists are strongly foliated, and several amphibolites also exhibit distinct foliation. Hydrothermal alteration accompanied the intrusion of some mafic sills, and produced localized skarns in the metalimestone. The folded vein in the Albion mine mapped by Schoen (1953) is evidence that mineralization preceded at least one folding episode. Refolding produced northwestward-trending open antiforms and synforms. Some small scale open folds with northeastward-trending axial plane traces, mapped near the Rip Van Winkle mine, may represent another folding event.

The major structure on the northern half of Cooper Hill is a synformal basin cored by quartzite with metaconglomerate and separated from the southern part of the hill by an east-west trending, fault-bounded horst(?). The southern half of Cooper Hill mirrors the synformal structure to the north. The structure between the two synforms is also a synform that occurs in a horst(?) fault block. The traces of antiformal axes between these three synforms have been cut by Laramide faults (**Plate 1**).

Deformation during the Laramide Orogeny resulted in Cooper Hill being thrust eastward on the Arlington fault, followed by the breaking of the thrust plate into a series of fault blocks. Cooper Hill was thrust (or slid) over younger Phanerozoic sedimentary rocks, producing a klippe derived from the eastern Medicine Bow Mountains. The trace of the Arlington thrust fault appears to lie a quarter of a mile west of Cooper Hill (Blackstone, 1973), but at Cooper Hill, the thrust (or gravity slide?) is buried under a skirt of scree and talus (mapped as Quaternary undivided on **Plate 1**).

Oil wells drilled by Union Pacific Resources and Exxon to the south and northwest of Cooper Hill in sections 10 and 11, T17N, R78W, and section 36, T19N, R79W, respectively, cut 2,000 to 5,000 feet of Precambrian crystalline rock in the toe (hanging wall) of the Arlington thrust prior to intersecting overturned sedimentary rocks of the Mesaverde Formation below the thrust sheet (Paul J. Graff, personal communication, 1991). Because of the large amount of horizontal displacement required on the Arlington thrust fault to achieve these thicknesses of Precambrian rocks reported in the oil wells, Cooper Hill may indeed be a rootless klippe lying on Cretaceous Steele Shale, Mesaverde Formation, and Tertiary Hanna Formation, as shown in Plate 2 of Blackstone (1973). King (1963, 1964) interpreted Cooper Hill as a gravity slide mass in which the allochthonous block "*originated from the west during thrusting along the Arlington Thrust.*" Whether or not Cooper Hill is a gravity slide, or simply a salient along the thrust, cannot be determined (or mapped on **Plate 1**) with the existing data.

Rock units

Four general rock types were mapped on Cooper Hill. These are amphibolite, metalimestone, quartzite, and mica schist.

Amphibolite

Amphibolite, or orthoamphibolite, includes mafic rocks with varied textures. These can be separated into amphibolite, metagabbro, metabasalt, and chlorite schist. The amphibolites are fine- to coarse-grained amphibolites that grade into one another and include foliated, weakly foliated, and nonfoliated varieties on the megascopic scale. For example, a prominent coarse-grained, foliated metagabbro sill occupies a synformal basin developed in quartzite a short distance north of Morgan, on top of the hill surrounding the 9,214-foot elevation benchmark (**Plate 1**). Fine-grained amphibolite (metabasalt and mica schist) dikes are found a short distance north of the benchmark as well as farther north near the 9,198-foot elevation. These rocks contain abundant chlorite, biotite, and hornblende, with plagioclase and minor quartz, in blasto-subophitic and schistose rock fabrics. A whole rock analysis of one metabasalt yielded 12.39 percent MgO (14.9 percent MgO, volatile free) and 1,500 ppm (parts per million) Cr_2O_3. This magnesian basalt is chemically similar to basaltic komatiite. The available data suggest the amphibolites on Cooper Hill represent mafic flows and subvolcanic intrusive sills and dikes.

Metalimestone

Relatively thin beds of metalimestone crop out on Cooper Hill. The rock is gray-white to brown, laminated and contorted metamorphosed carbonate. Typically, the rock is massive to recrystallized and has a fine-grained crystalline texture. The rock is reactive to cold, dilute hydrochloric acid and based on reactivity and its fine-grained to massive texture, the rock is referred to as a metalimestone, although locally it has been upgraded to marble.

In hand specimen, the rock includes abundant calcite, minor quartz, and minor to accessory chlorite and biotite. Schoen (1953) described samples with nearly equivalent amounts of quartz and calcite. Samples collected during this study were dominantly calcite-rich.

Quartzite and metaconglomerate

Quartzites crop out over large areas of Cooper Hill. The quartzites are quartz-arenites and micaceous quartzites. The quartz-arenites are massive white quartzites with about 5 percent laminated pink feldspar, minor to trace amounts of mica (sericite and/or chlorite), and accessory fuchsite and opaque minerals. Micaceous quartzites are light green to brownish, foliated quartzites with 70 to 80 percent quartz, minor feldspar, abundant chlorite, and lesser sericite.

Quartzites in the northern portion of Cooper Hill contain thin beds of metaconglomerate. These metaconglomerates are foliated and consist of abundant stretched, translucent to milky quartz pebbles, ranging up to 5 inches in length, with uncommon black chert pebbles, in a fine-grained matrix of quartz with minor feldspar, mica, and accessory opaque minerals. Fuchsite and sericite occur in minor to accessory amounts. None of the samples collected were radioactive. Of three samples collected for precious metal content, only one (sample CH34-91, **Table 1**) had detectable gold (0.040 ppm Au).

The quartzites and conglomerates are interpreted as fluvial in origin and are assumed to have been deposited in Proterozoic streams draining from a highland to the north. Similar quartzite and conglomerate elsewhere in the Medicine Bow Mountains have been interpreted as part of a widespread braided drainage system that flowed to an ancient sea located to the south of the Cheyenne Belt (Karlstrom and others, 1981).

Mica schist

Mica schists are strongly foliated muscovite-chlorite schists with one or more crenulated cleavages. Porphyroblasts are rare. This unit also includes minor beds of metagraywacke. The schists and metagraywacke represent metamorphosed siltstones, claystones, and sandstones.

In thin section, King (1963) described this mica schist as having a very fine matrix of quartz with sinuous and bifurcating bands of mica and subparallel bands of quartz with rare plagioclase augen. Muscovite and chlorite are the dominant minerals with subordinate amounts of biotite. An ubiquitous opaque mineral occurs as fine dust-like inclusions and as large elongate grains parallel to foliation.

Economic geology

Mineralization

Cooper Hill has not been developed as a mining district to any great extent. According to Duncan (1990), Cooper Hill had a short-lived prospecting and mining history that lasted from 1893 to 1897, although the historical literature indicated that some mining operations were also active in the early 1900s. Presumably, some activity also occurred during the Great Depression. In recent years, a few Laramie residents have continued prospecting the district; however, nearly all of the accessible mines were recently closed under the State of Wyoming's Federally-funded abandoned mine land reclamation program.

Ore minerals reported in veins in the district include pyrite (FeS_2), chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), argentiferous galena [(Pb,Ag)S], polybasite [$(Ag,Cu)_{16}Sb_2S_{11}$], and gold (Au) (Schoen, 1953). Secondary ore minerals derived from the oxidation of the primary sulfides include malachite, cerrusite, and limonite. During this study, two forms of limonite [FeO(OH)] were recognized. One variety, a reddish-brown to tawny limonite, is typically derived from oxidation of sulfides and can be used as an indicator of sulfide mineralization; whereas, a second variety, a sugary, yellow-orange limonite after siderite is of no apparent economic value. Lode mineralization includes skarns, replacement deposits, and quartz veins.

Skarns

Skarns were identified at several sites on Cooper Hill during this study (**Plate 1**). The skarns occur in metalimestone in contact with mafic schist (amphibolite), and range from one foot to more than 100 feet thick. One of the more extensive skarns was mapped north of the Silver King prospect in the southeastern corner of section 27. Skarns are undoubtedly more widespread than mapped simply because large portions of the metalimestone are buried by colluvium and scree on the steep hillsides.

Most skarns on Cooper Hill were prospected in the past, but nowhere were they seriously tested. Other than shallow prospect pits, no tunnels were driven into the skarns. Typically, the skarns are erratic, and contain some pyrite, chalcopyrite, and magnetite. Because of the presence of magnetite, the skarns should be susceptible to magnetic surveys, especially where they continue under colluvium.

Samples of skarn were examined in hand specimen, and petrographic studies are planned in the future. Megascopically, the skarns are varied and include: (1) dark green to black garnet (XRD pattern best fits goldmanite and hydrogrossular), epidote, actinolite, chlorite, idocrase(?), calcite, limonite, ± magnetite hornfels; (2) epidote, pyrite, calcite, quartz hornfels; (3) magnetite hornfels; (4) calcite, epidote, actinolite, pyrite, magnetite marble; (5) actinolite, calcite, quartz, chlorite, ± chalcopyrite hornfels; (6) tremolite, quartz, calcite marble; and (7) calcite, light yellow-green garnet (identified as uvarovite by XRD), magnetite hornfels.

Skarn exposed in a prospect pit (known as the Silver King) in the saddle of the hill east of and above the Silver Queen mine shows clear association to amphibolite (metabasalt). The prospect cut exposes a narrow amphibolite dike intruding metalimestone that is replaced by skarn along both margins of the dike. A short distance from the dike, the skarn grades into metalimestone. All other skarns found in the district also lie adjacent to amphibolite contacts. Skarn samples collected for assay are weakly anomalous in silver, gold, and copper.

Replacement veins

A replacement vein at the Albion mine forms relatively thick pyrite-sericite-limonite-calcite replacement zones in metalimestone (calc-schist) enclosing fractured, pyritiferous milky quartz veins. This deposit could be included under skarn; however, it is considered separately because the vein crosses lithologies. In metalimestone, it takes on the appearance of calc-schist (skarn). In quartzite, it forms a well defined quartz vein (Schoen, 1953). A later stage of silicification is evident where small fractures in some quartz specimens are partially rehealed by minor translucent quartz and jasper. These later zones of silicification are often accompanied by galena. The calc-schist is stained by limonite and contains abundant cubic limonite pseudomorphs after pyrite(?) over the exposed width of the outcrop.

Veins

There are several vein deposits in the district in addition to the replacement vein at the Albion mine. One of particular interest crops out at the Richmond mine (**Plate 1**). This vein is exposed at the north end of the hill and is hosted by metabasalt. The vein is a several-foot-wide, strike-trending (conformable), limonite-stained quartz breccia vein with open vugs filled with radiating actinolite prisms, pyrite, and chlorite.

In addition to the breccia vein at the Richmond mine, other strike veins as well as some crosscutting veins are found in the Cooper Hill district. According to Schoen (1953), the crosscutting veins are typically barren.

Mines and occurrences

Several mines and prospect pits are located on Cooper Hill. None of the mines were developed to any great extent and unfortunately, none of the workings were accessible during this study.

Albion mine

Located in the W2 section 27, T18N, R78W. The Albion mine was developed by two adits driven on a quartz vein at the contact between altered hanging wall metalimestone (calc-schist) and footwall quartzite. Within the mine, the vein apparently crosses lithologies and has disseminated chalcopyrite, chalcocite, and bornite where hosted by calc-schist, and argentiferous galena where hosted by quartzite. The vein frays in the calc-schist, but is well defined in quartzite. Two ore shoots were intersected 70 and 100 feet from the mine portals. The shoots are localized where the vein rolls from a easterly dip to a southerly dip (Schoen, 1953).

The quartz vein is relatively narrow (less than 6 inches wide) at the northern portal, and enclosed by altered, limonite-stained calc-schist containing abundant cubic limonite pseudomorphs after pyrite(?) over the width of the exposed outcrop. At this point, the footwall quartzite is buried. The adit is no longer accessible, but based on Schoen's (1953) study, the adit was driven 80 feet east in calc-schist and cut across the dipping contact of the schist before continuing another 85 feet east in the footwall quartzite. From here, the tunnel turns southeast another 40 feet down an incline where the mine face terminates in quartzite. Near the mine portal, the vein is 2 feet thick. Farther in the tunnel, it pinches to only 2 to 18 inches, but again swells to 2 feet thick near the face of the incline. A winze was sunk at the face, but was full of water at the time of Schoen's investigation.

The southern portal is covered by quartzite scree that apparently buries the calc-schist and vein. According to Schoen (1953), the vein is 2 to 5 feet thick a short distance into the southern portal. Farther into the hillside, the vein cuts across lithologies into the lower quartzite. At about 40 feet into the tunnel, the schist-quartzite contact was intersected and the tunnel continued another 160 feet east into the footwall quartzite before terminating in quartzite. At about 100 feet from the portal, a 50-foot crosscut was driven south. The face of the crosscut is also in quartzite. Schoen (1953) reports the primary vein disappeared below the mine workings near the end of the main tunnel, and that the workings continued to follow another galena-bearing vein to the face.

Samples of the vein and calc-schist were collected from the outcrop at the northern portal during this study; galena-bearing quartz was collected from the mine dump since it is not exposed at the portal. The pyritiferous quartz collected at the portal is weakly anomalous in gold and silver (samples CH40-91 and CH52-91, **Table 1**), as is the calc-schist wallrock (sample CH51-91, **Table 1**). Samples of galena-bearing quartz were relatively well mineralized and assayed 0.62 and 1.12 percent Pb, 1.7 and 7.5 ppm (0.05 and 0.22 opt) Au, and 97.2 and 56.9 ppm (2.83 and 1.66 opt) Ag (samples CH39-91 and CH50-91, **Table 1**).

Schoen (1953) collected a sample of the galena-bearing quartz from the second roll in the mine. The sample yielded 0.83 percent Pb, 0.7 opt Au, and 2.2 opt Ag. Osterwald and others (1966) reported samples from a 5- to 9-foot cerussite-bearing vein in this area assayed 4 to 5.3 opt Au, 50 opt Ag, and some lead. These samples may have been selected samples from the Albion mine, since no other lead-bearing veins have been recognized in the district.

Emma G. Mine

Located at the southern end of Cooper Hill above the village of Morgan, N2 SE section 34, T18N, R78W. The Emma G. mine was developed from three different portals. A shaft with a short adit was driven in metalimestone and amphibolite, and an inclined shaft was sunk on a schist-hosted vein a short distance to the north (**Plate 1**). Mica schist separates these portals.

According to Schoen (1953), the ribs of the incline(?) are in porphyroblastic biotite schist. These porphyroblasts were described as granulated quartz porphyroblasts developed during regional metamorphism (Schoen, 1953, p. 28). A brief field examination of these metacrysts (?) showed them to be quartz-mica augen. Possibly, they are the alteration products of alumino-silicates. Schoen further described the vein as a thick, barren, milky quartz breccia vein conformable to foliation. At 15 feet from the bottom of the shaft, the vein is reportedly 15 feet thick. Fault gouge was intersected at the bottom of the shaft (Schoen, 1953).

The shaft south of the incline was sunk on the contact between metalimestone and amphibolite. No mineralization was recognized on the dump. Possibly, this was an exploration shaft in search of skarn, or was dug to explore gossaniferous metalimestone. The limonite here is after carbonate (siderite) rather than sulfides. One sample of limonite-stained quartz from the mine dump assayed only 0.089 ppm Au and 1.0 ppm Ag (sample CH21-91, **Table 1**).

Little Ella Mine (Senator Stewart shaft)

Located in the SE SW section 16 and NE NW section 21, T18N, R78W. Some select ore from the mine was reported by Knight (1893) to have assayed 32.17 opt Au, 4 to 10.0 opt Ag, and 10 to 12 percent Cu.

Table 1. Geochemical analyses of rock samples from the Cooper Hill district (ppm = parts per million, % = weight percent, < = less than, > = greater than, dashes indicate not analyzed). Refer to Plate 1 for sample locations. Analyses by Bondar-Clegg.

Sample Number	Description	Au (ppm)	Ag (ppm)	Cu (%)	Pb (ppm)	Zn (ppm)	Ga (ppm)	Cr_2O_3 (%)	Ni (ppm)	W (ppm)	Sn (ppm)	Ti (ppm)
CH1-91	Limonite after siderite from Silver Queen mine dump	<0.005	0.6	—	—	—	23	—	—	—	—	—
CH2-91	Limonite after sulfides in chloritized mafic rock, Silver Queen dump	0.034	0.3	—	—	—	30	0.05	264	—	—	—
CH7-91	Cupriferous quartz from Silver Queen mine dump	>10.0	<0.2	2.27	<2	12	—	—	—	—	—	—
CH25-91	Limonite-stained chalcopyrite-bearing schist from Silver Queen dump	0.046	0.7	0.35	<2	20	—	—	—	—	—	—
CH4-91	Marble from prospect pit (N2 NE section 34)	<0.005	1.6	—	22	5	—	—	—	—	—	—
CH5-91	Cupriferous quartz in metalimestone from prospect pit (NW NE section 34)	0.187	0.8	0.065	10	—	—	0.04	—	—	—	—
CH45-91	Weak skarn from prospect pit (NW NE section 34)	<0.05	1.4	0.03	134	45.5	—	—	—	—	—	—
CH46-91	Skarn from pit	<0.05	3.5	0.004	31	7.3	—	—	—	—	—	—
CH8-91	Pyrite-actinolite-epidote-garnet hornfels (N2 N2 NE section 34)	<0.005	<0.2	0.014	7	1	—	—	—	—	—	—
CH11-91	Milky quartz with limonite boxworks after siderite from from Rip Van Winkle mine	0.006	<0.2	—	—	—	—	—	—	—	—	—
CH12-91	Quartz pebble conglomerate with disseminated pyrite and minor fuchsite	<0.005	<0.1	0.003	—	—	—	—	—	<2.0	8	—
CH18-91	Limonite- and hematite-stained quartz pebble conglomerate (NW SE section 27)	<0.005	<0.2	—	—	—	—	—	—	—	—	—
CH34-91	Quartz pebble conglomerate with hematite pseudomorphs after magnetite (?) or pyrite (?)	0.040	<0.2	—	—	—	—	—	—	<2.0	<5	<50
CH13-91	Massive limonite and hematite in quartz vein (E2 section 27)	0.240	<0.2	—	—	—	—	—	—	—	—	—
CH14-91	Boxwork-filled quartz from Richmond mine dump	0.041	0.2	—	—	—	—	—	—	—	—	—
CH35-91	Select sample of quartz from ore sack at Richmond mine	0.012	<0.1	0.10	25	63	—	—	—	—	—	—
CH36-91	Twenty-foot composite chip sample across Richmond breccia vein	0.080	1.2	0.07	11	50	—	—	—	—	—	—
CH15-91	Limonite boxworks from mine dump along East Fork Dutton Creek (NE NW section 27)	0.013	<0.2	—	—	—	—	—	—	—	—	—
CH16-91	Limonite boxworks after siderite in quartz from mine dump	0.037	0.8	—	56	45	0.07	—	—	—	—	—
CH19-91	Milky quartz breccia vein containing massive limonite after siderite from prospect pit (E2 NE section 34)	<0.005	0.5	—	—	—	—	—	—	—	—	—
CH20-91	Milky quartz in mafic schist selvage in quartzite. Minor limonite after sulfide	0.022	<0.2	—	—	—	—	—	—	—	—	—
CH21-91	Limonite-stained quartz from Emma G. mine dump	0.089	1.0	—	—	—	—	—	—	—	—	—
CH23-91	Limonite boxworks after sulfides in quartz from prospect (SE section 34)	>10.0	1.4	—	—	—	—	—	—	—	—	—
CH26-91	Milky quartz breccia vein from mine dump (W2 NW section 35)	<0.005	0.5	—	—	—	—	—	—	—	—	—
CH28-91	Limonite-stained skarn (S2 SE section 27)	0.012	<0.2	0.04	34	21	44	—	—	<2.0	31	—
CH30-91	Limonite boxworks from skarn	0.170	<0.2	0.09	<2	10	—	—	—	—	—	—
CH31-91	Limonite boxworks from skarn (SE SE section 27)	<0.05	—	—	—	—	—	—	—	—	—	—
CH32-91	Limonite-stained, gray-black quartz (SE section 27)	0.190	<1.0	—	—	—	—	—	—	—	—	—
CH38-91	Limonite boxworks in quartz from mine dump (E2 section 27)	0.160	1.8	—	72	48	—	—	—	—	—	—
CH39-91	Grab sample of galena-bearing quartz, Albion mine (W2 section 27)	7.5	56.9	0.04	11,242	2.6	—	—	—	—	—	—
CH40-91	Boxwork quartz from Albion mine	<0.05	3.5	0.003	60	15.8	—	—	—	—	—	—
CH50-91	Galena-bearing quartz from Albion mine dump	1.7	97.2	—	6,193	<0.005	—	—	—	—	—	—
CH51-91	Decalcified pyritiferous metalimestone from Albion mine	0.6	1.0	0.003	93	36.7	—	—	—	—	—	—
CH52-91	Boxwork quartz with pyrite from Albion mine	0.2	<0.1	0.003	122	12.7	—	—	—	—	—	—

Richmond Mine

Located in the NE section 27, T18N, R78W, along the crest of Cooper Hill. According to Beeler (1906), the Richmond mine produced the largest amount of free-milling gold of all the Cooper Hill mines. The Richmond shaft was sunk in a quartz breccia vein in a fine-grained hornblendic amphibolite (metabasalt). The vein lies at the bottom of the amphibolite outcrop near the contact with underlying quartzite. The vein disappears a short distance east and west under colluvium and does not reappear, indicating the vein is very limited in strike length.

The vein is more than 20 feet thick at the Richmond shaft and consists of fractured, iron-stained quartz with angular clasts of amphibolite country rock. The quartz is pitted with open vugs filled with well-developed radiating actinolite prisms on a fine-grained mass of chlorite, actinolite, and calcite. Uncommon sulfides occur as chalcopyrite and chalcocite blebs with small (1mm) pyritohedrons and octahedral pyrite grains. Minor stains of malachite occur on some fracture surfaces in the quartz.

Three samples were collected from the Richmond mine for assay (samples CH14-91, CH35-91, and CH36-91, **Table 1**). An additional sample (CH37-91) was collected from this mine for later petrographic studies and was not assayed. Two samples of boxwork quartz contained 0.012 and 0.041 ppm Au, less than 0.1 to 0.2 ppm Ag, and traces of lead, zinc, and copper. One 20-foot composite chip sample chipped across the vein width assayed only 0.08 ppm Au (0.002 opt), 1.2 ppm Ag (0.035 opt), 0.07 percent Cu, 11 ppm Pb, and 50 ppm Zn. These analyses are not consistent with Beeler's (1906) report indicating free-milling gold in the vein.

Rip Van Winkle adit

Located in the S2 section 27, T18N, R78W. Two photographs in Duncan (1990, p. 192) identify this mine near the crest of the hill as the Rip Van Winkle mine. The portal of the adit was cut in amphibolite and the tunnel intersected mica schist and metagraywacke a short distance into the hill side. Only a few fragments of quartz were found on the mine dump and these contained uncommon limonite boxworks after siderite. One sample of the limonite-stained quartz (sample CH11-91, **Table 1**) yielded only 0.006 ppm Au, and less than 0.2 ppm Ag. This may be the same mine Schoen (1953, plate 3) called the Silver King mine.

Silver King prospect

Located in the N2 NE section 34, T18N, R78W. This is a small prospect dug in skarn in the saddle of Cooper Hill. The open cut exposes a narrow mafic sill in metalimestone. The metalimestone adjacent to the sill is altered to skarn, producing an epidote-calcite-actinolite skarn with some chalcopyrite. A narrow quartz vein exposed in this pit carries some chalcopyrite, chalcocite, and minor malachite.

One small sample of calcite found on the dump in 1991 had minor amounts of franklinite and willemite. The calcite fluoresces a bright red-orange under short wavelength ultraviolet light, and dull red under long wavelength. The willemite fluoresces bright green under short wave. Follow-up investigations were conducted to search for similar material on the dump and in place, but none was found. Zinc assays of samples also confirm that mineralization from the district is zinc deficient. Thus, the origin of the franklinite sample remains a mystery, but it apparently did not originate from Cooper Hill.

Five additional samples were collected from the dump for future petrographic/mineralogical studies; three of the samples were assayed, but none were well mineralized. The maximum assay was of a sample of cupriferous quartz which yielded only 0.187 ppm Au, 0.8 ppm Ag, and 0.065 percent Cu (sample CH5-91, **Table 1**).

Silver Queen adit

Located in the N2 N2 section 34, T18N, R78W. This mine is located on the Silver Queen claim (Schoen, 1953, plate 2). The mine portal has been sealed by a locked wooden door. The adit was driven into amphibolite. Mine dump material consists of chloritized mafic schist and amphibolite. A few samples of quartz and silicified amphibolite were collected from the dump and contained secondary chlorite, sericite, and biotite with minor sulfides. Ore minerals included chalcopyrite, cuprite, malachite, chrysocolla, and limonite after sulfides. Samples collected from the mine dump included a sample of limonite after siderite which assayed less than 0.005 ppm Au, 0.6 ppm Ag, and 23 ppm Ga (sample CH1-91, **Table 1**). A sample of limonite-stained mafic rock (sample CH2-91) assayed 0.034 ppm Au, 0.3 ppm Ag, and 30 ppm Ga. Chalcopyrite-bearing schist (sample CH25-91) assayed 0.046 ppm Au, 0.7 ppm Ag, and 0.35 percent Cu, and cupriferous quartz (sample CH7-91) yielded greater than 10 ppm Au, less than 0.2 ppm Ag, and 2.27 percent Cu. A split of the sample pulp of CH7-91 that was fire-assayed yielded 0.16 opt Au. Sample CH3-91 was collected for future petrographic studies.

Wyoming (?) adit

Located in the S2 S2 section 27, T18N, R78W. This adit is west of and about 400 feet below the Rip Van Winkle adit on the Wyoming claim (see Schoen, 1953, plate 2). Duncan (1990, p. 193) indicates this to be the Rip Van Winkle tunnel, however, Schoen (1953, p. 7, figure 2) published a photograph apparently of the same mine and labeled it as the old Copper King mine renamed the Silver Queen mine. The workings were inaccessible, and the adit was driven in quartzite scree. Based on the rock types found on the mine dump, the tunnel intersected amphibolite somewhere near the mine face. Very little evidence of mineralization could be found on the dump other than a few specimens of quartz with minor limonite after siderite.

Quartz pebble conglomerate

Located in the W2 E2 section 27, T18N, R78W. Quartz pebble conglomerate crops out as thin beds in quartzite at several different localities at the crest of Cooper Hill. At sample site CH12-91, three samples were collected for analysis (samples CH12-91, CH18-91, and CH34-91, **Table 1**). This quartz pebble conglomerate contained milky quartz and uncommon black chert pebbles in a quartz matrix with some fuchsitic mica and hematite pseudomorphs after magnetite(?) or pyrite(?). None of the samples were radioactive. One of the three samples contained detectable gold of 0.04 ppm Au (sample CH34-91, **Table 1**).

Morgan prospect

Located in the SE section 34, T18N, R78W. A shallow prospect pit on the hillside a short distance north of the Morgan village exposed a quartz vein with common limonite boxworks after pyrite. A sample from the vein assayed greater than 10 ppm Au and 1.4 ppm Ag (sample CH23-91, **Table 1**). A split of the sample pulp that was fire-assayed yielded 0.53 opt Au. Unfortunately, there does not appear to be much tonnage associated with the vein.

Cooper Creek placers

Sand bars, bank deposits, and sand and gravel deposits in the vicinity of Cooper Hill were sampled for gold. Essentially all of the panned concentrates yielded some visible gold (see section on ***Precious metals in sand and gravel deposits and placers***). The relatively common occurrence of gold in the streams is worthy of further investigation.

Summary

Copper (Cu), gold (Au), silver (Ag), and lead (Pb), were found in anomalous amounts on Cooper Hill. A number of other metals (zinc, gallium, chromium, nickel, tungsten, tin, and titanium) were also analyzed in some samples from Cooper Hill (see **Table 1**). These other metals were found only in background to trace amounts.

Skarns are known worldwide for their magnificent mineral assemblages and endowment of ore minerals. The skarns on Cooper Hill are in metalimestone in contact with mafic metaigneous rock. Skarns developed in these types of rocks generally are copper-lead-zinc bearing skarns, and typically are relatively small compared to their counterparts associated with more felsic intrusives. Skarns are typically discontinuous and erratic, making exploration difficult. In all probability, hidden skarn deposits occur in the district and could be easily located by magnetic surveys. The replacement vein at the Albion mine also offers some potential for precious and base metal mineralization. However, the potential tonnage associated with this deposit is also confined to the metalimestones and to the footwall quartzite. If King (1963, 1964) is correct that Cooper Hill is a gravity slide, exploration for the source terrane could lead to the discovery of additional skarn and replacement deposits to the west of the district.

Metaconglomerate found on Cooper Hill is similar to the auriferous conglomerates mined in South Africa. One of three samples collected and analyzed for gold yielded weak, but anomalous mineralization. The extent of these beds is not great, thus it would not be prudent to search for ore mineralization in the conglomerates on Cooper Hill. Similar metaconglomerates to the west in the main block of the Medicine Bow Mountains, however, would make excellent exploration targets because of their much greater extent.

Possibly the greatest potential for an ore deposit in the district may be associated with a deposit described by Beeler (1906). Beeler reported an immense dike of sugar quartz containing low-grade gold values (0.1 to 0.2 opt) on the west side of Cooper Hill. Nowhere did we find evidence of such a deposit. Possibly Beeler was referring to one of the massive quartzite beds, or to a deposit immediately west of Cooper Hill. However, based on geological observation, none of the quartzites appeared to be significantly mineralized. It is recommended that future studies search for evidence of this dike.

It has been erroneously suggested by some historians that the Cooper Hill district may require deep exploration to find extensions of ore deposits. This proposal conflicts with the following geological facts. First, Cooper Hill is a rootless block of Precambrian rock overlying relatively undeformed Cretaceous sedimentary rocks located at relatively shallow depths. 'Deep' vertical mining would ultimately enter the underlying Cretaceous and Tertiary sedimentary rock units (possibly only 600 to 800 feet below the highest point of Cooper Hill) which are geologically too young to host extensions of Precambrian mineralization. Second, the rocks on Cooper Hill are relatively flat lying and most mineral deposits examined appear to be stratabound or stratiform. Thus exploration seeking the continuation of mineralization would logically have to follow the attitude of the rock units.

In summary, the geology does not provide evidence of any major ore deposits at Cooper Hill. Instead, the geology provides evidence for some relatively limited mineral and possibly ore deposits. Based on Beeler's (1906) historic report, it is entirely possible that some of these mineral deposits include enriched shoots with some specimen grade mineralization.

Titaniferous black sandstone deposits, Sweetwater County

Introduction

Titaniferous black sandstones represent lithified concentrations of heavy minerals that were deposited in paleobeach environments. The heavy minerals (black sands) in these sandstones include a variety of strategic metals and sometimes gold.

The gold content of titaniferous black sandstone paleoplacers in Wyoming was briefly examined by Madsen (1978), who recognized paleoplacer development during three periods of uplift at 82, 75, and 70 Ma (million years) ago. Madsen (1978) concluded that the most recent period of uplift correlated with a greater gold content in these paleoplacers and that the younger titaniferous sandstones are located in the eastern part of Wyoming. For example, Houston and Murphy (1970) reported 1.3 ppm Au in the Sheep Mountain titaniferous sandstone on the northeastern flank of Sheep Mountain in the Medicine Bow Mountains (southeastern Wyoming). In western Wyoming, however, little or no gold has been detected from titaniferous black sandstones. Contrary to Madsen's study, William H. Graves (personal communication to Hausel, 1990) reported a 1.7 ppm Au value from the Dugout Creek titaniferous sandstone deposit in the southern Bighorn Basin of northwestern Wyoming.

Exploration for these types of deposits is accomplished by searching marine sandstones for dark-colored sandstones. Since nearly every titaniferous sandstone in Wyoming is located in the Mesaverde Formation or Mesaverde Group, efforts in past years have concentrated on various tongues, formations or members of this unit. The black sandstones are also weakly radioactive, which led to much of their interest during the uranium boom years of the 1950s. They also contain abundant magnetite and are susceptible to magnetic prospecting. This method can be quite effective as demonstrated at the Sheep Mountain black sandstone deposit on the edge of the Medicine Bow Mountains. This deposit was mapped on the surface by Houston and Murphy (1962) over a length of 1,900 feet; magnetometer surveys by Hausel and Jones (1982) extended the length of the deposit to a total of 4,300 feet.

In past years, titaniferous black sandstones have been noted for their potential to produce heavy minerals containing strategic metals and possibly gold. The heavy mineral suite includes garnet, tourmaline, spinel, apatite, staurolite, kyanite, epidote, pyroxene, amphibole, chlorite, biotite, glaucophane, and the potentially economic minerals of brookite, allanite, altered ilmenite (leucoxene), chromite, titaniferous magnetite, anatase, monazite, magnetite, ilmenite, rutile, sphene, zircon, native gold, and niobium-bearing opaque minerals (Houston and Murphy, 1970).

The deposits investigated in this study (**Figure 1**) are all located in the McCourt Tongue of the Rock Springs Formation of the Mesaverde Group (Late Cretaceous). According to Roehler (1989), the Rock Springs Formation is as much as 1,600 feet thick and consists of interbedded shale, carbonaceous shale, coal, siltstone, and sandstone, mostly of delta plain origin. The formation thins to the southeast (at Richards Gap it is less than 300 feet thick) and intertongues with the Blair Formation. The McCourt Tongue crops out as a tan and gray bench-forming sandstone unit that is a persistent stratigraphic marker bed in the upper part of the Rock Springs Formation. The McCourt Tongue is interpreted to have been deposited during a southeastward regression of part of the western shoreline of the interior Cretaceous sea of North America. The heavy minerals appear to have been deposited along a single wave-dominated shoreline representing one stage of this regression (Roehler, 1989).

Prospects and occurrences

Black Butte Creek (Zalenka)

Located in sections 30 and 31, T18N, R101W. The Black Butte Creek deposit is accessible via Wyoming Highway 430 south from Rock Springs to the Brady Road turnoff. About 5 miles east of the turnoff, the road forks and continues both north and southeast along Black Butte Creek. Approximately 2 miles north of this fork, a jeep trail can be followed east to the deposit. The deposit lies on the south side of a unnamed draw, and is located 1 to 2 miles northeast of the Cooper Ridge deposit (described below).

The titaniferous sandstone is poorly exposed along a brush and talus covered slope. A short adit driven into the slope in section 30 exposed the titaniferous sandstone. The sandstone also crops out less than a mile to the south in the center of section 31. Dow and Batty (1961) reported the adit to have been driven 30 feet into the titaniferous sandstone; however, a cursory examination of the adit showed it to be only about 10 feet in length. Prospect pits were also examined in section 28, but no evidence of titaniferous sandstone was found in this latter location (**Figure 2**).

The sandstone is only about 4 feet thick (Dow and Batty, 1961) in the adit, and the length of the deposit, as reported by Houston and Murphy (1962), is about 1,500 feet. However, the relatively widespread occurrence of titaniferous sandstones in this area may indicate that this and other deposits in this region may be more extensive. The sandstone occurs within a littoral sequence (McCourt Tongue) of the Rock Springs Formation (Houston and Murphy, 1962; Roehler, 1989). The black sandstone occupies part of a beach berm deposit preserved at the top of the McCourt Tongue (Roehler, 1989).

The rock is composed of quartz, feldspar, titanium minerals, zircon, magnetite, and monazite cemented by hematite and carbonate (Dow and Batty, 1961). Samples collected by Houston and Murphy (1962), contained 24 percent heavy minerals, 41.5 percent light minerals, and 34.5 percent acid soluble matrix. The heavy mineral suite included 84 percent opaque minerals, 11.1 percent zircon, a trace of monazite, and 1.0 percent rutile. Chemically, the samples of titaniferous sandstone collected by Houston and Murphy (1962) ranged from 14 to 28 percent TiO_2 with 15 to 35.8 percent total iron as Fe_2O_3. Samples taken by the U.S. Bureau of Mines averaged 27.3 percent TiO_2, 2.0 percent ZrO_2, 22.9 percent Fe, and 0.06 percent $eThO_2$ (equivalent thorium) (Dow and Batty, 1961).

Five samples were collected for this study. One of the five samples was weakly anomalous in gold (CB5-91, **Table 2**) and assayed 0.1 ppm Au. The sample contained comparatively abundant light minerals relative to the heavy mineral suite.

Brady Road Deposit (Union Pacific #2)

The Brady Road deposit, also known as the Union Pacific #2, is located in the S2 section 11, T17N, R102W, about 20 miles southeast of Rock Springs and only about 3 miles southwest of the Black Butte Creek deposit. Access is gained by proceeding 18 miles south of Rock Springs on Wyoming Highway 430, and then east for 4 miles on Brady Road along Cutthroat Draw. The deposit lies south of the road on Cooper Ridge and is continuous in a southwest direction for 2,500 feet (**Figure 3**). The width of the outcrop of titaniferous black sandstone is only 100 to 200 feet. The sandstone appears to be as much as 20 feet thick locally but Dow and Batty (1961) report it to average only 4 feet thick. The sandstone is part of the McCourt Tongue of the Rock Springs Formation (Roehler, 1989).

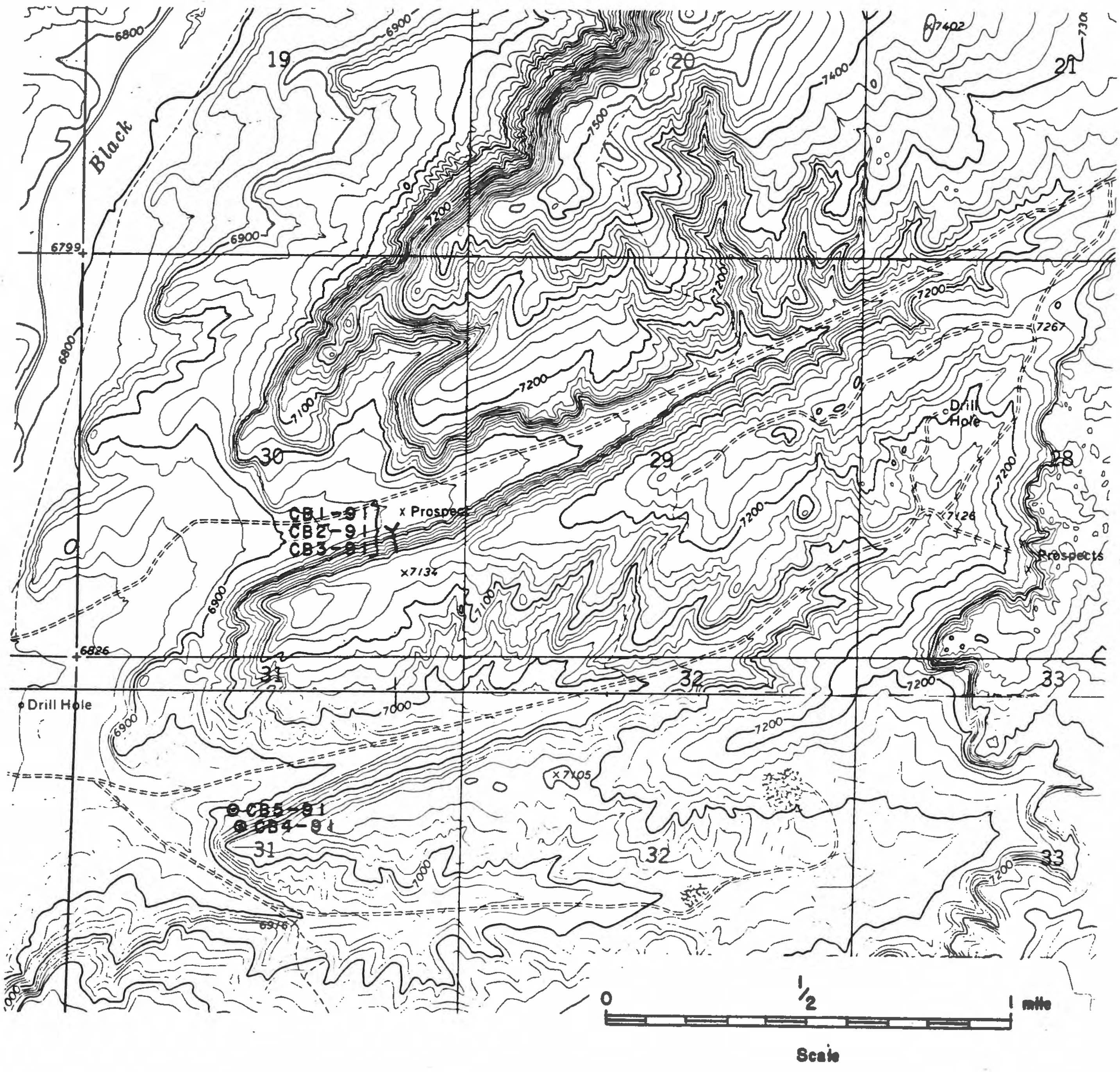

Figure 2. Sample location map for the Black Butte Creek titaniferous sandstone (sections 30 and 31, T18N, R101W) (Cooper Ridge NE and Point of Rocks SE 1:24,000-scale topographic quadrangle maps). The small 'Y' near the sample numbers marks the location of an adit driven into the titaniferous sandstone. Assay results for samples are found in **Table 2**.

Table 2. Geochemical analyses of titaniferous black sandstones, Rock Springs uplift. Analyses by Bondar-Clegg and Gordon Marlatt. (nd = not detected; dash indicates not analyzed).

Sample Number	Description	Au (ppm)	Fe (%)	TiO_2 (%)	ZrO_2 (%)	La (ppp)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)	Hf (ppm)
	Black Butte Creek (Figure 2)																			
CB1-91	Massive black sandstone from short adit.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB2-91	Banded black to yellow sandstone from adit.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB3-91	Massive black Ti-sandstone from adit.	nd	22.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB4-91	Poorly mineralized Ti-sandstone.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB5-91	Relatively light and weakly magnetic Ti-sandstone.	0.100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Brady Road (Figure 3)																			
BR1-91	Massive Ti-sandstone from lower outcrop.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR2-91	Massive Ti-sandstone collected from buckled outcrop.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR3-91	Composite across 2 feet of Ti-sandstone exposed in dozer cut.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR4-91	Float sample.	-	33.58	40.74	0.78	497.0	1,080	80	260	55.4	6.2	38	5.2	28	6.8	20	3.1	31.1	4.35	664
BR5-91	Sample of steeply dipping Ti-sandstone.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR6-91	Ti-sandstone exposed in dozer cut east of BR5 at ridge top.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR7-91	Ti-sandstone.	nd	-	39.16	0.54	576.0	1,040	100	330	49.6	5.4	36	6.2	26	6.2	18	4	31.1	4.2	585
BR8-91	1.5-foot composite chip at the top of ridge east of BR7.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR9-91	Thin outcrop of Ti-sandstone from ridge top east of BR8.	nd	32.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BR10-91	Ti-sandstone from prospect pit.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cooper Ridge (Figure 3)																			
CR1-91	Chip sample of Ti-sandstone from 3-foot thick layer.	nd	27.36	39.00	0.87	1,540.0	2,670	190	685	105	9.4	62	11.2	47	12	29	7.6	35.8	4.6	707
CR2-91	Chip of Ti-sandstone.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CR3-91	Chip of Ti-sandstone.	-	31.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Camel Rock (Figure 4)																			
CM1-91	Composite of 2.5-foot thick Ti-sandstone outcrop from southernmost exposure.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2 continued.

Sample Number	Description	Au (ppm)	Fe (%)	TiO_2 (%)	ZrO_2 (%)	La (ppp)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)	Hf (ppm)
	Richards Gap (Figure 5)																			
RG1-91	Chocolate-brown to tawny sandstone collected at southeasternmost exposure. At this point, theTi-sandstone is only about 1-foot thick and poorly mineralized.	0.100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RG2-91	A 2-foot composite chip of poorly mineralized rock.	0.060	-	-	-	-	-	-	-	-	-	-	-	-	-	-	—	—	-	-
RG3-91	3- to 3.5-foot composite chip from lower end (western edge) of deposit.		nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RG4-91	6-foot composite chip. Relatively well mineralized.	nd	22.71	26.5	1.41	590.0	1,090	86	340	51.2	5.8	30	5.3	27	6.6	20	4.9	30.3	5.1	492
	Titsworth Gap (Figure 6)																			
MR1-91	Grab sample of Ti-sandstone from 200-foot long outcrop.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Union Pacific #1 (Figure 7)																			
UP1-91	Composite of 4 feet of Ti-sandstone from western edge of butte.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP2-91	7-foot composite of Ti-sandstone in northern dozer trench, west rib.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP3-91	4-foot composite of Ti-sandstone outcrop from south edge of butte.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP4-91	4-foot composite collected from rib of dozer trench.	nd	29.96	31.25	<0.2	801.0	1,430	110	420	58.8	6.2	36	6.6	38	9.2	29	4.9	47.8	7.92	1,200
UP5-91	6-foot composite from dozer trench in northern, down-dropped block.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP6-91	5-foot thick outcrop west of prospect pit.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP7-91	7-foot composite, west edge of northern block.	0.060	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP8-91	Selected sample of massive Ti-sandstone.	nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP9-91	2-foot composite of Ti-sandstone.	nd	16.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UP9-91A	2-foot composite of Ti-sandstone.	0.018	-	7.95	1.06	791.0	1,350	92	370	58.5	6.0	39	5.9	30	7.6	21	46	21.8	3.5	368
	Yenko (Figure 8)																			
YN1-91	Grab sample of Ti-sandstone float at base of cliff.		nd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

According to Dow and Batty (1961), Union Pacific Resources trenched and drilled the property at several locations. Samples collected by the U.S. Bureau of Mines averaged 22.2 percent TiO_2, 1.4 percent ZrO_2, 18.4 percent Fe, and 0.06 percent $eThO_2$. Ten samples were collected by the Geological Survey of Wyoming and analyzed for gold. All of these latter samples contained abundant heavy minerals but no detectable gold (**Table 2**). Two samples analyzed for iron averaged 33.17 percent Fe, considerably higher than reported by the U.S. Bureau of Mines.

Cooper Ridge

The Cooper Ridge titaniferous sandstone is located 20 miles southeast of Rock Springs in the center of the E2 section 1, T17N, R102W, a few hundred feet east of Black Butte Creek on the Cooper Ridge NE Quadrangle. Access is by way of the Brady gas field's improved dirt road off Wyoming Highway 430 from Rock Springs. This deposit is located about 1.25 miles northeast of the Brady Road titaniferous black sandstone, and is 3.3 feet thick and 120 feet long where it crops out near the base of Cooper Ridge (**Figure 3**) (Roehler, 1989). The deposit is in the upper part of the McCourt Tongue of the Rock Springs Formation. According to Roehler (1989), the sedimentary structures seen in the adjacent sandstones indicate this unit is part of the surf lithofacies. The sandstone below the heavy mineral deposit exhibits planar crossbeds and the titaniferous sandstone is thin bedded with small-scale, low-angle, trough crossbedding.

Two of the three samples of the titaniferous sandstone were tested for gold. Neither sample contained detectable gold. Two samples that were also analyzed for iron averaged 29.49 percent Fe (**Table 2**). Sample CR1-92 was also analyzed for rare earth elements (REE) and yielded some of the highest REE values of all the titaniferous sandstones analyzed. Total REE content for this sample amounted to 6,115.6 ppm (**Table 2**).

Camel Rock (Murphy #2)

Located in section 8, T16N, R102W. The Camel Rock titaniferous sandstone lies 22 to 23 miles south of Rock Springs on the east side of Wyoming Highway 430 (**Figure 4**). The sandstone crops out along Cooper Ridge in the McCourt Tongue of the Rock Springs Formation (Roehler, 1989). The main body of the titaniferous sandstone crops out over a length of 300 to 450 feet and has an average thickness of only about 2.5 feet. Samples collected by the U.S. Bureau of Mines averaged 19.7 percent TiO_2, 2.0 percent ZrO_2, 15.4 percent Fe, and 0.04 percent $eThO_2$ (Dow and Batty, 1961). The one sample collected by the Geological Survey of Wyoming contained no detectable gold (**Table 2**).

Richards Gap (Red Creek)

Located in the SE section 22, T12 N, R105W. The Richards Gap titaniferous black sandstone (also referred to as the Red Creek deposit) lies 45 miles southwest of Rock Springs and about a quarter of a mile north of the Utah-Wyoming border within the Richards Mountains. The deposit is exposed on the east side of the Red Creek Gap on a low lying ridge that is clearly visible from the Red Creek Basin road (**Figure 5**). Access is by Wyoming Highway 373 south out of Rock Springs. The road continues south about 40 miles to the Clay Basin road turnoff. The Clay Basin road continues a short distance east of the highway before intersecting the Red Creek Basin road that continues south.

The conspicuous ridge that forms the Richards Mountains at the gap consists of rock units in the Mesaverde Group. The titaniferous sandstone occurs in a fluvial channel (Roehler, 1989) cut into the top

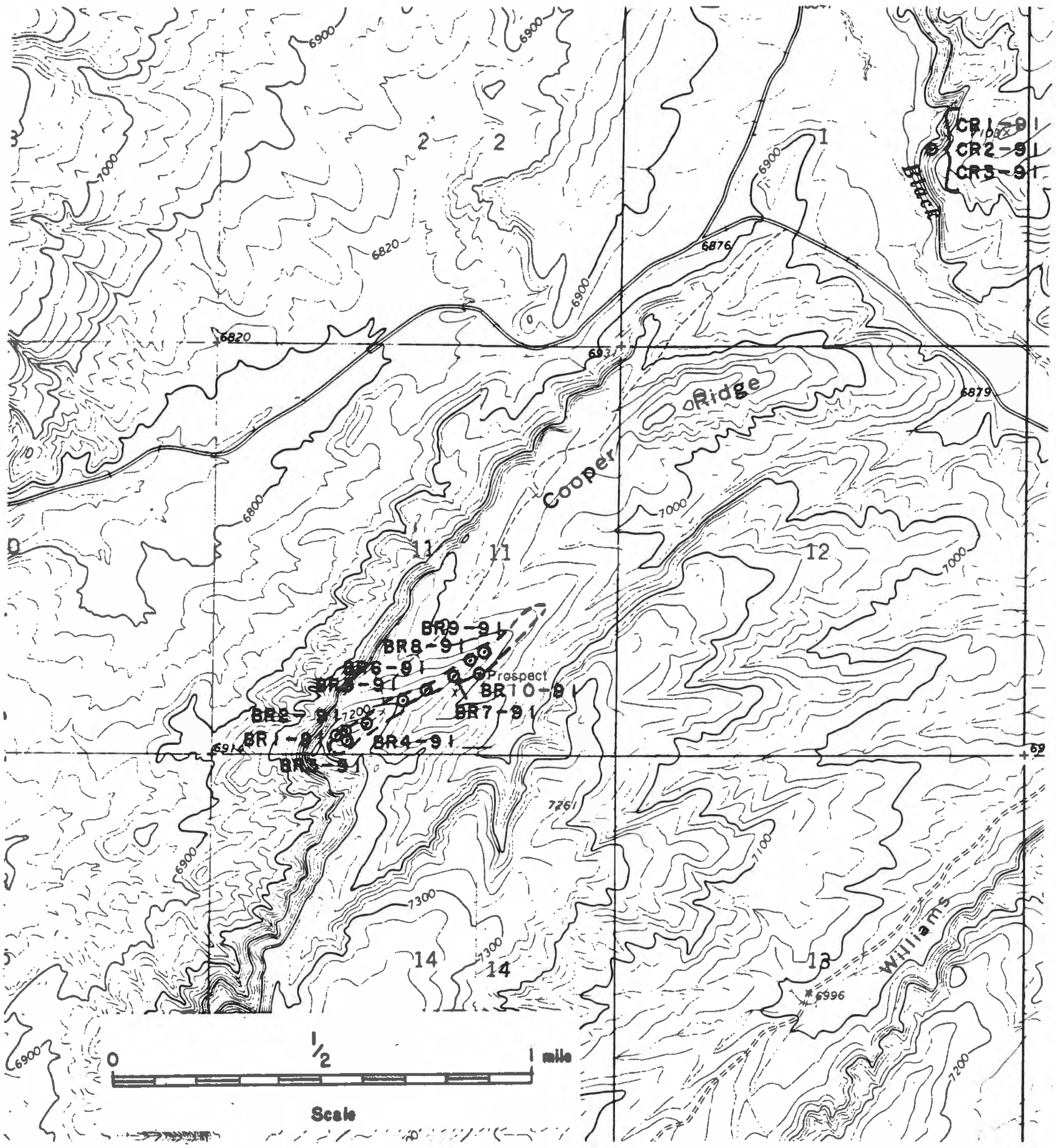

Figure 3. Location map of the Brady Road titaniferous sandstone (section 11, T17N, R102W) and the Cooper Ridge titaniferous sandstone (section 1, T17N, R102W) (Camel Rock and Cooper Ridge NE 1:24,000-scale topographic quadrangle maps). The extent of the Brady Road deposit is shown by a dashed line. The Cooper Ridge deposit is too small to show the outcrop on this scale. Assay results for samples are found in **Table 2**.

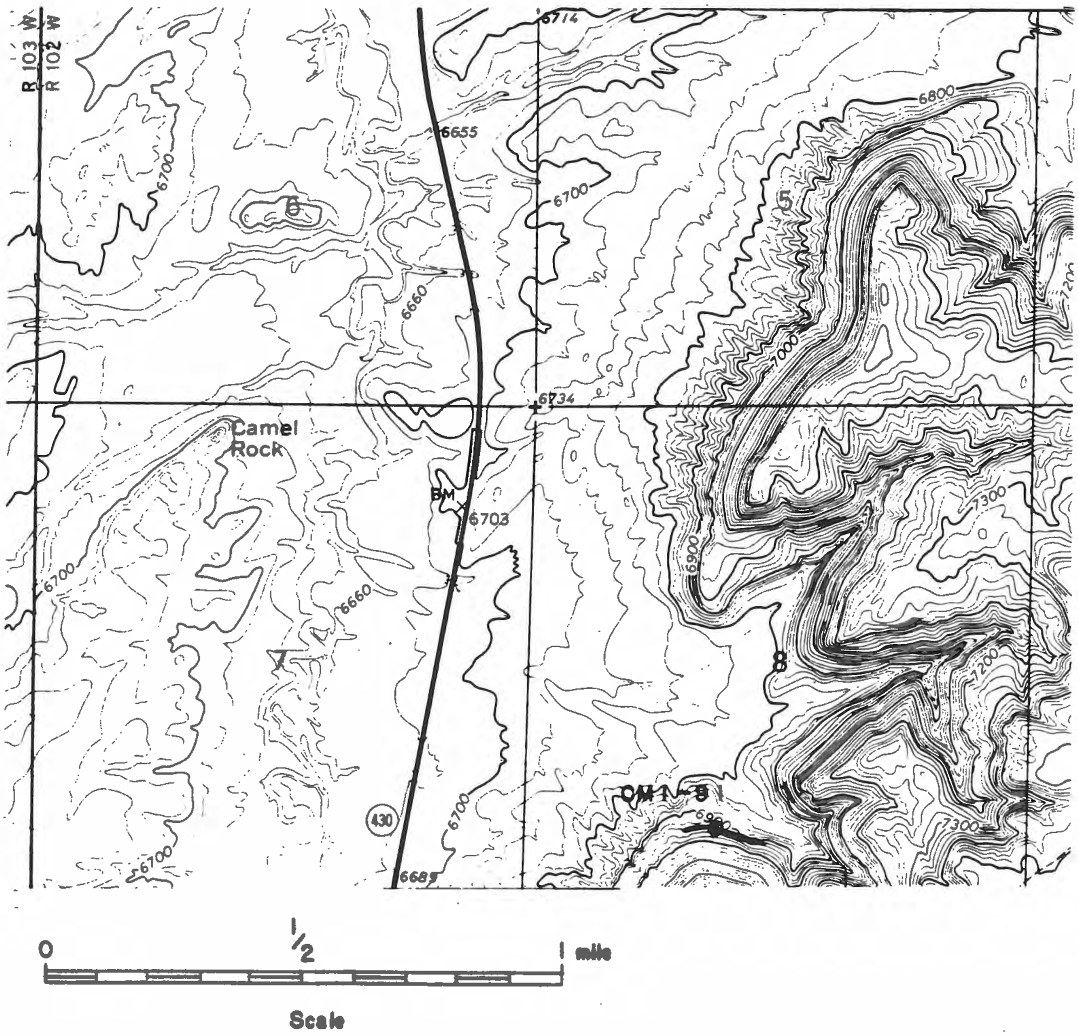

Figure 4. Sample location map of the Camel Rock titaniferous sandstone (section 8, T16N, R102W) (Camel Rock 1:24,000-scale topographic quadrangle map). Solid black lines in section 8 mark the approximate extent of the deposit. Assay results for Sample CM1-91 is found in **Table 2**.

of a littoral marine sandstone tongue of the Rock Springs Formation (Houston and Murphy, 1962). Roehler (1989) identified the sandstone as the McCourt Tongue. The deposit was mapped over an east-west trend of about 700 feet and caps a ridge at the south end of the gap, forming an irregularly-shaped wedge which is 6 feet thick on its northwestern edge and pinches out upslope (to the east).

Petrographic studies of titaniferous sandstone concentrates revealed the presence of several heavy minerals including ilmenite, magnetite, garnet, zircon, rutile, monazite, and spinel. Some globules of pyrite were also noted in polished section (Murphy and Houston, 1955). These heavy minerals are mixed with quartz, feldspar, and biotite, and the sandstone is cemented by carbonates and hematite (Dow and Batty, 1961).

Eight samples collected by Houston and Murphy (1962) averaged 14.3 percent TiO_2 and 19.0 percent total iron as Fe_2O_3. Samples collected by Dow and Batty (1961) averaged 25.5 percent TiO_2, 1.5 percent ZrO_2, 15.4 percent Fe, and 0.04 percent $eThO_2$.

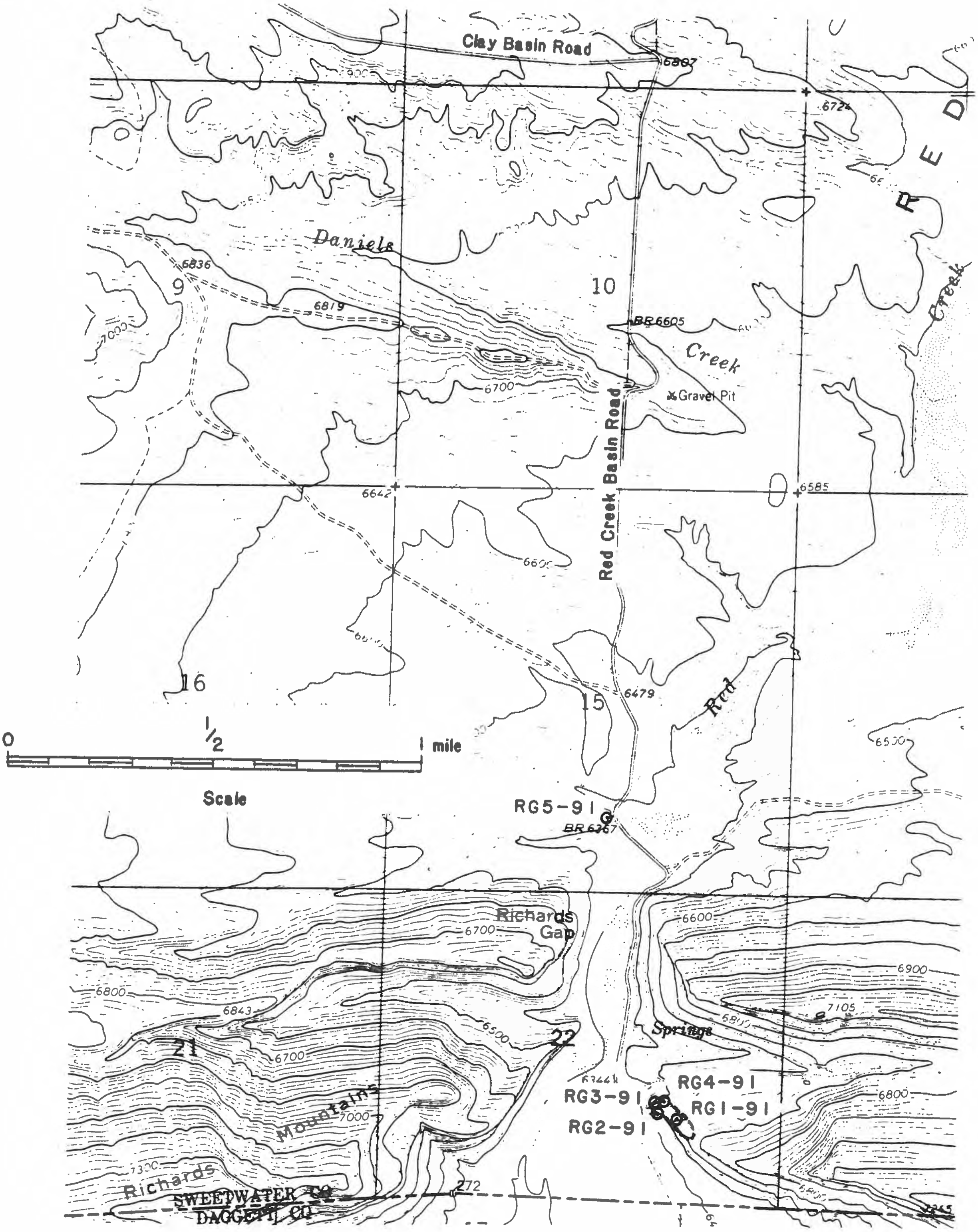

Figure 5. Location map of the Richards Gap titaniferous sandstone deposit (section 22, T12N, R105W) (Richards Gap, Wyoming-Utah 1:24,000-scale topographic quadrangle map). The heavy dashed line marks the approximate outcrop of the sandstone. Assay results for samples are found in **Table 2**. Sample location sites include a sand and gravel sample (RG5-91, see **Precious metals in sand and gravel deposits and placers**).

Two of the four black sandstone samples collected for gold analysis for this study contained anomalous gold. Sample RG1-91 contained 0.1 ppm Au, and sample RG2-91 contained 0.06 ppm Au (**Table 2**). These two samples were collected from the eastern portion of the deposit, which has relatively smaller amounts of heavy minerals compared to the western portion. Sample RG4-91 was also analyzed for iron (22.71 percent), titanium (26.5 percent), zirconium (1.41 percent), and total REE (2,784 ppm).

A large resource of sand and gravel was noted upstream from the gap and a sample of this material collected for assay yielded anomalous gold (see section on **Precious metals in sand and gravel deposits and placers**).

Titsworth Gap (Murphy 1)

Located in the SE section 7, T14N, R103W. The Titsworth Gap (also known as the Murphy 1 and the Salt Wells) titaniferous sandstone, lies about 35 miles south of Rock Springs on the north edge of Laney Rim. The sandstone crops out 200 feet above the road on the east side of the gap cut by Gap Creek (**Figure 6**).

The Titsworth Gap titaniferous sandstone was reported to occupy a channel in the basal member of the overlying Ericson Sandstone by Dow and Batty (1961); however, Roehler (1989) reported the titaniferous sandstone was within a light gray forebeach sandstone lithofacies near the top of the McCourt Tongue of the Rock Springs Formation. The deposit is lenticular and crops out for only about 200 feet along strike with a maximum thickness of 3 feet. The outcrop trends N60°E and dips 6°SE under younger rocks; thus, the downdip extent of the deposit cannot be determined without magnetic surveys or drilling.

Samples of the sandstone consist of quartz, feldspar, titanium minerals, zircon, and magnetite cemented by hematite and carbonate. A composite of three samples assayed 17.4 percent TiO_2, 1.9 percent ZrO_2, 14.5 percent Fe, and 0.06 percent $eThO_2$ (Dow and Batty, 1961). Two samples analyzed by Houston and Murphy (1962) yielded 22.5 percent TiO_2, 25.5 percent total iron as Fe_2O_3, and 0.003 percent uranium. One typical sample of sandstone yielded no detectable gold (sample MR1-91, **Table 2**).

Union Pacific #1

Located in the SE section 24 and NE section 25, T19N, R102W, and NW section 30 and SW section 19, T19N, R101W. This deposit represents the largest of all the titaniferous sandstones examined during this study. In addition to the principal deposit, Roehler (1983) described another outcrop of titaniferous sandstone north of the main deposit in the NE NE section 24, T19N, R102W, that we subsequently examined. To the south, another dark outcrop was observed (but not visited) in section 25, which may represent another small titaniferous sandstone occurrence (**Figure 7**).

The main titaniferous sandstone deposit caps a butte south of a powerline. This deposit has been heavily prospected as is evidenced by several dozer trenches cut in the black sandstone. The deposit of titaniferous sandstone is 2,700 feet long, 2,400 feet wide, and averages about 3.5 feet in thickness. The thickness varies from less than a foot to 7 feet. The northern extension of the deposit has been dropped down about 120 feet along an east-west trending fault. North of the fault, the titaniferous sandstone crops out over an area of 800 feet by 400 feet and averages 2 to 2.5 feet in thickness. The titaniferous sandstone located about a mile to the north (NE section 24) crops out over an area of 500 feet by 200 feet and may average only 1.5 feet thick.

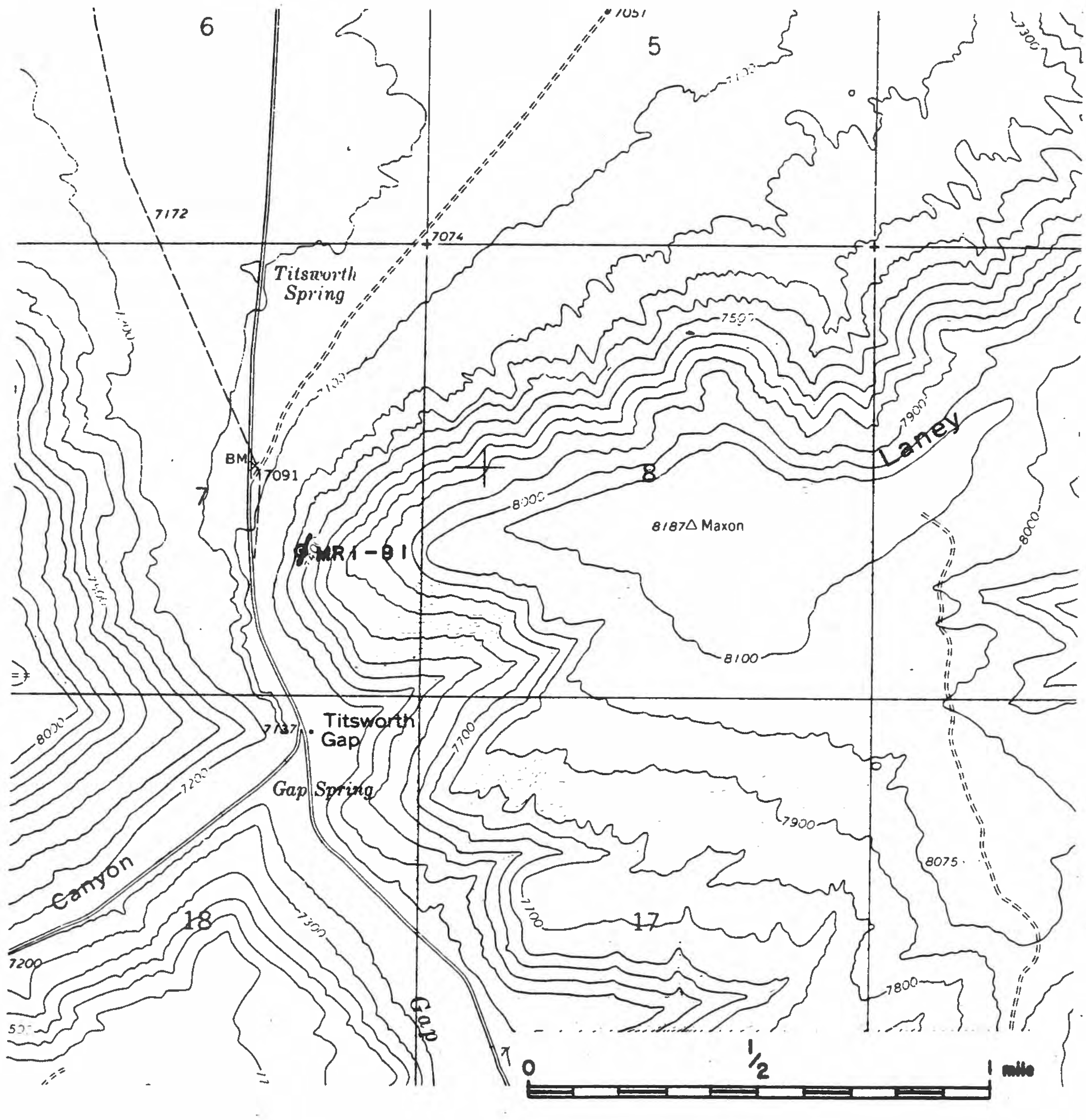

Figure 6. Sample location map for the Titsworth Gap titaniferous sandstone (SE section 7, T14N, R103W) (Titsworth Gap 1:24,000-scale topographic quadrangle map). Solid line marks the approximate extent of outcrop. The small circle is the sample locality. Assay results for samples are found in **Table 2**.

Roehler (1979, 1983) recognized and mapped these deposits as part of a fluvial sandstone immediately above delta-front sandstones in the lower part of the Rock Springs Formation, about 85 feet below the base of the Chimney Rock Tongue.

Dow and Batty (1961) reported that samples collected from a shaft sunk through the main deposit by Union Pacific and from other points along the outcrop averaged 21.1 percent TiO_2, 3.4 percent ZrO_2, 20.2 percent Fe, and 0.1 percent $eThO_2$. Samples taken from various dozer cuts on the property averaged 22.2 percent TiO_2, 1.4 percent ZrO_2, and 18.4 percent total Fe.

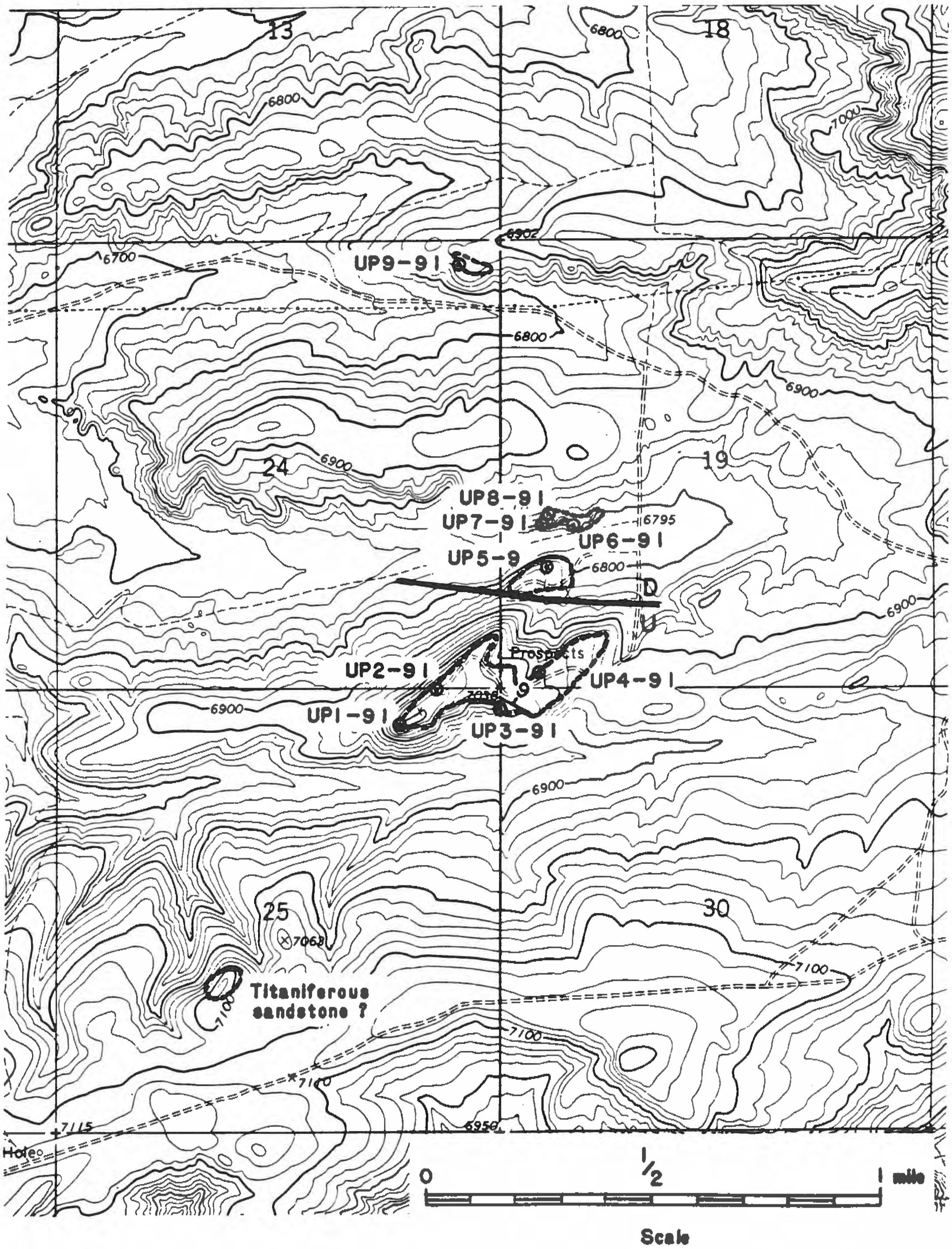

Figure 7. Sample location map of the Union Pacific #1 titaniferous sandstone (sections 24 and 25, T19N, R102W, and sections 30 and 19, T19N, R101W) (Point of Rocks SE 1:24,000-scale topographic quadrangle map). The extent of the black sandstone is outlined by dashed lines and is split into two blocks by a normal fault (D=downthrown side, U=upthrown side). Assay results for samples are found in **Table 2**.

Eight samples were collected by the Geological Survey of Wyoming in the summer of 1991. Only one of the eight contained detectable gold; that sample was a 7-foot composite of massive titaniferous sandstone. The sample assayed only 0.06 ppm Au (sample UP7-91, **Table 2**). Sample UP4-91 was also analyzed for iron, titanium, zirconium, and total REE (**Table 2**). A ninth sample (UP9-91) was collected as a 2-foot thick composite from the titaniferous sandstone to the north (**Figure 7**). This sample contained no detectable gold and 16.56 percent Fe. A sample split (UP9-91A) yielded 0.018 ppm Au, and was also analyzed for titanium (7.95 percent), zirconium (1.06 percent), and total REE (3,210 ppm) (**Table 2**).

Yenko

Located in section 13, T15N, R103W. The Yenko deposit is accessible by driving 25 miles south of Rock Springs on Wyoming Highway 430 to the Wells Creek road turnoff. From the turnoff, the titaniferous sandstone lies 3 miles west and crops out along the western flank of a unnamed mesa (**Figure 8**). The deposit reportedly averages 5.5 feet thick over a length of 250 feet. The width of the deposit is unknown in that the sandstone disappears under a 200-foot thick section of younger sedimentary rock. The sandstone appears to be in the McCourt Tongue of the Rock Springs Formation (Roehler, 1983).

A composite of four samples taken from outcrop averaged 22.4 percent TiO_2, 2.1 percent ZrO_2, 16.3 percent Fe, and 0.08 percent $eThO_2$ (Dow and Batty, 1961). Only one sample was collected for gold analysis. This sample (YN1-91) contained no detectable gold (**Table 2**).

Silicification and alunite alteration of Quaking Asp (Aspen) Mountain, Sweetwater County

Introduction

Quaking Asp Mountain (also known as Aspen Mountain), located south of Rock Springs (**Figure 1**), is a northeast trending hill that rises 1,700 to 1,800 feet above the surrounding basin (**Plate 2**). The hill stands as positive relief due to intense and widespread silicification which has made it relatively resistant to erosion. In addition to widespread silicification over a 20- to 30-square-mile region, several other anomalies have been recognized. These include a zone of alunite discovered by drilling along the southeastern margin of the hill (Love and Blackmon, 1962), travertine on the western edge of the hill (Kirschbaum, 1986), chert (jasperoid ?) in crosscutting(?) bands closely associated with a projected northeast-trending fault, kaolinite alteration, and a hydrogen sulfide (H_2S) spring on the southern flank of the hill. The only other alunite deposits reported in Wyoming are found in association with solfatara and hot springs deposits in Yellowstone National Park.

The source of the alunite at Aspen Mountain is unknown. But because of the potential for extending the known occurrence of alunite mineralization and the possibility of finding associated gold mineralization, the economic geology of this deposit is considered high priority.

Background

An 8-foot thick bed or zone of alunite alteration was discovered on the south flank of Aspen Mountain in 1957 by geologist E.R. Keller with Mountain Fuel Supply Company from drill cuttings of an oil and gas exploration hole. This zone was later trenched and investigated by the U.S. Geological Survey in 1958 and 1960 (Love and Blackmon, 1962). At the time of the trenching, the alunite-bearing claystone was intersected within 30 feet of the surface. A core hole was also drilled about a mile southwest of the trench. It penetrated 6 feet of white claystone at 145 feet, suggesting the alunite may be relatively widespread. About 200 feet southeast of this core hole, a gas well in the NE section 34, T17N, R104W, apparently drilled before the alunite discovery, cut through 3,704 feet of hard, silicified Cretaceous sandstone and shale (Love and Blackmon, 1962).

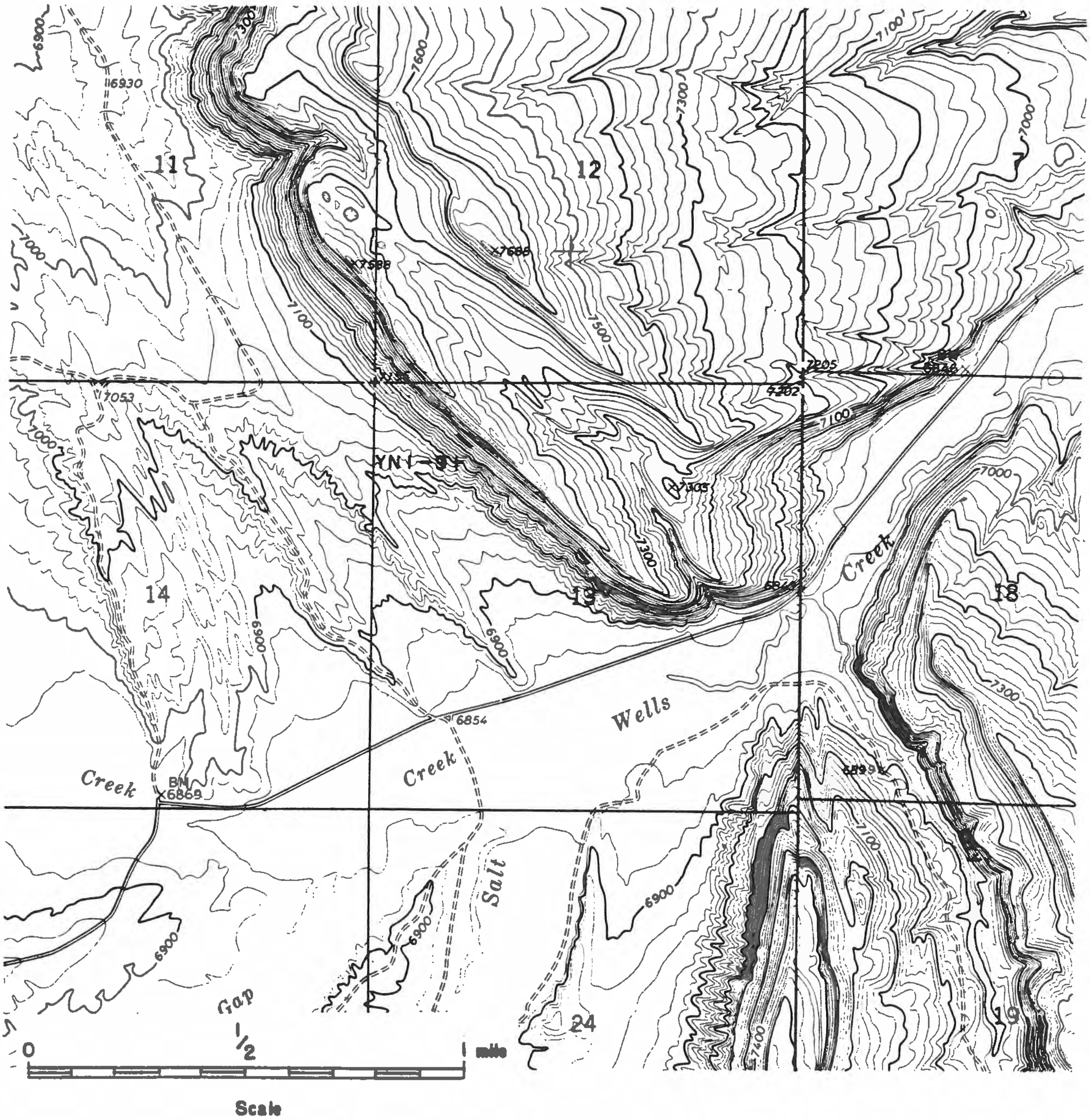

Figure 8. The Yenko titaniferous sandstone is marked by two solid lines in the cliff of an unnamed butte in section 13, T15N, R103W (Mud Springs Ranch 1:24,000-scale topographic quadrangle map). Refer to **Table 2** for analysis of sample YN1-91.

In 1970, geologists from Union Pacific Resources investigated the Aspen Mountain alunite deposit looking for possible extensions of the claystone. A fault was projected along the trend of the hill associated with the Aspen Mountain silicified zone.

The current study was undertaken as an initial reconnaissance project recommended by geologists from Union Pacific Resources and the Geological Survey of Wyoming to determine a source for the silicification and clay alteration on Aspen Mountain. Our preliminary study indicates that Aspen Mountain may represent a paleo-epithermal system. The possible presence of gold in this system was also investigated during initial phases of the project. Sixteen samples collected during the investigation were weakly anomalous in gold.

Geology

Aspen Mountain is formed of westward dipping, highly silicified Upper Cretaceous shales and sandstones. The mountain is capped by highly silicified, fine- to medium-grained sandstone and quartzite of the Rock Springs Formation, which is underlain by highly silicified gray silty and sandy shale interbedded with gray siltstone and fine-grained sandstone of the Blair Formation (Kirschbaum, 1986).

Locally, both of these formations are unconformably overlain by flat-lying sandstone facies of the Bishop Conglomerate (?) (Oligocene). The Bishop Conglomerate (?) consists of a gray, yellow-green, and white, subrounded to well-rounded, fine to coarse-grained tuffaceous to limy sandstone; yellowish-green mudstone; white, silty to sandy tuff; and tuffaceous conglomerate containing some angular gray siltstone, sandstone, and quartzite rock fragments. Both Kirschbaum (1986) and Love and Blackmon (1962) place the alunite-bearing claystone within the Bishop Conglomerate. According to the geologic map of Wyoming, this area is underlain by pale-green to tan tuffaceous sandstone and claystone of Miocene(?) age with a conglomerate of uncertain age locally at the base of the unit (Love and Christiansen, 1985).

Genesis of alunite deposits

Alunite, $(K,Na)Al_3(SO_4)_2(OH)_6$, is a basic sulfate of potassium and aluminum, and has been used in the production of alum, a filler in fertilizer. Sodium-rich alunites are termed natroalunite and are defined to have Na:K ratios equal to, or exceeding, unity. Even more sodium-rich alunites, with Na:K ratios exceeding 3:1, are termed sodian alunites.

Although alunite and alunite-group minerals are commonly reported as by-products of hydrothermal alteration of igneous rocks, they are also products of weathering in acid, oxidizing, sulfate-rich environments (Bird and others, 1989). Thus, two genetic types of alunite have been established, namely hydrothermal and diagenetic.

Field (1966) demonstrated that hypogene alunite could be distinguished from supergene alunite by comparing their sulfur isotope values. This distinction is even clearer when hydrogen- and sulfur-isotope compositions of alunites are used together to distinguish alunite formed in magmatic-hydrothermal environments and alunite formed in supergene environments. The sulfur-isotope values of alunites distinguish magmatic-hydrothermal processes from supergene processes, while the comparatively deuterium (D)-enriched δD values of alunites formed at surficial temperatures distinguish between alunites formed by supergene oxidation and those formed in steam-heated environments (Bird and others, 1989). The isotopically light hydrogen-isotope values reported for hypogene alunites from Goldfield, Nevada (Pickthorn and O'Neil, 1985), provide some support for Bird and others' (1989) conclusion.

Alunite is almost universally of secondary origin, and most theories ascribe the mineral to metasomatic replacement of potash feldspar or of the kaolin components of preexisting rock (King, 1953). In most deposits, the sulfuric acid assumed to be responsible for the conversion of potash-bearing aluminosilicates to the sulfate is attributed to volcanic agencies. In other examples, the acid is explained as an oxidation product of pyrite or other sulfides (King, 1953). A kaolinite-alunite association is common to many deposits and some investigators have found evidence to suggest that kaolinite is an intermediate stage in the derivation of alunite from feldspar (King, 1953). The process of alunitization is also associated with kaolinization and silicification (Meyer and Pena Dos Reis, 1985).

Diagenetic alunite

Alunite-group minerals in the supergene zone of many ore deposits have been widely reported, as have their occurrence in weathering profiles unrelated to mineralization, particularly in micaceous, sulfide-bearing sediments. Non-hydrothermal alunite deposits have been described from several localities in the world including the United States, Hungry, Australia, Greece, Kuwait, Portugal, and Sinai (Goldbery, 1980; Meyer and Pena Dos Reis, 1985; Khalaf, 1990). Genesis of these types of alunite deposits is generally attributed to weathering processes whereby sulfuric acid is generated by the oxidation of pyritic sediments (or H_2S), producing alunite from clay minerals (Goldbery, 1980).

The critical stages for the genesis of diagenetic non-hydrothermal alunites include: (1) the generation of H_2S and/or pyrite under anaerobic conditions by the metabolism of sulfate-reducing bacteria; (2) a change from reducing to oxidizing conditions related either to subaerial exposure or contact with aerobic waters, to produce sulfuric acid; and (3) generation of the aluminium-sulfate produced by sulfuric acid attacking clay minerals. The oxidation of H_2S can also yield sulfur as an intermediary phase (Goldbery, 1980).

At Warah Hill, Kuwait, alunite is associated with an iron-rich mudstone layer located at the contact between a calcrete profile and silicified sandstone (silcrete) (Khalaf, 1990). In this region, Khalaf (1990) suggested that sulfuric acid was produced during periods of abundant hydrogen sulfide seepage and was oxidized and reacted with illitic clay and K-feldspar to produce alunite. The reaction produced both silica and aluminum-sulfate: $KAl_2\{(OH)_2Al_2Si_3O_{16}\} + H_2SO_4 » 3\ SiO_2 + KAl_3(SO_4)_2(OH)_6$. Some authigenic kaolinite with the alunite precipitated from Al- and Si-rich solutions (Khalaf, 1990).

In southern Australia, alunite-group minerals have been reported as an authigenic component of Quaternary salt-lake sediments (Bird and others, 1989). Some of these salt lakes are characterized by low pH (2 to 4) and by the authigenic precipitation of alunite and jarosite. The formation of alunite and jarosite in these lakes is thought to be in response to the influx of acid waters from the surrounding basement rocks. The potassium was derived from the weathering of extensively sericitized granites (Bird and others, 1989).

Alunite is also present in the clays of saline lagoons at the eastern margin of the Nullarbor plain of South Australia. Here the alunite-bearing clays occur in localized areas characterized at the surface by the presence of siliceous and ferruginous lateritic cappings. The alunite occurs in close association with kaolinite which was formed as an intermediate stage of the breakdown of feldspar to alunite during lateritization (King, 1953). Alunite also occurs as an alteration product of deeply weathered granitic rocks; however, the largest deposits are developed as locally alunitized zones in Lower Miocene lacustrine sediments (King, 1954).

In Western Portugal, authigenetic alunite is closely associated with silica (Meyer and Pena Dos Reis, 1985). Some of the alunite deposits contain continuous layers of silcrete, and others have only locally silicified layers. The thickness of the silicified layers does not exceed 6 feet (Meyer and Pena Dos Reis, 1985).

Hydrothermal alunite

Typically, hydrothermal alteration in epithermal gold deposits is accompanied by sulfides and enrichment in several metals. In the sedimentary-hosted, Carlin-type gold deposits of Nevada, for example, the ore zones exhibit metal enrichments of Ba (2,200 ppm), As (480 ppm), Zn (185 ppm), Sb (130 ppm), B (70 ppm), Cu (35 ppm), Pb (30 ppm), La (30 ppm), Hg (25 ppm), W (18 ppm), Au (11 ppm), Mo (7 ppm), Se (2 ppm?), and Ag (0.4 ppm) compared to the host rock (Boyle, 1979). The mineralization is also closely associated with near vertical normal faulting and carbonaceous carbonates. A general ore-stage alteration zonation pattern recognized at Carlin has dickite and kaolinite near the now-silicified areas. In some deposits, the occurrence in the host sedimentary rocks of fault-controlled, intensely silicified, tabular zones referred to as jasperoids has been recognized as an important exploration characteristic of Carlin-type deposits. A later episode of silicification resulted in crosscutting quartz veins and additional silicification of the jasperoids (Berger and Henley, 1989).

At Jerritt Canyon, Nevada, disseminated gold mineralization is associated with silicification, argillization, and sericitization. The alteration assemblages include quartz, kaolinite, smectite, iron oxides, sericite, calcite, dolomite, alunite, and jarosite (Birak, 1986). At the Cannon mine in Washington, the ore body consists of widely spaced veins of quartz, chalcedony, adularia, calcite, sulfides, and gold in a pervasively silicified and mineralized section of Eocene feldspathic sandstone and sandy siltstone. Gold also occurs in local silicified stockworks and breccias (Ott and others, 1986). The Melco gold deposit in the Oquirrah Mountains, Utah, occurs in folded and altered sandstone, orthoquartzite, conglomerate, bedded breccia, and siltstone. The altered units are weakly argillized to silicified. Some of the mineralized breccia zones are described as containing massive kaolinite with minor alunite (Gunter and others, 1990).

In many volcanic-hosted epithermal gold deposits, the vent of the epithermal system seems to have been a large fracture or fault, so that the alteration pattern is elongated with strongly silicified rock along a main axis flanked successively by alunitic, argillic, and finally propylitic zones on each side of the siliceous axial zone. The alunitization process is generally a near-surface phenomenon, but essentially is hypogene rather than supergene (Hall and Bauer, 1983). In a few deposits, however, alunitic rock has been found at considerable depth, particularly in pervasively altered districts. For example, a drillhole in a deposit in Beaver County, Utah, penetrated nearly 1,000 feet of alunite-bearing rock (Hall and Bauer, 1983). Hypogene alunite has also been found at depths of several hundred feet in the El Salvador porphyry copper deposit of northern Chile (Hall and Bauer, 1983).

The cap of many of these hydrothermal deposits is highly siliceous and may resemble chert or opalite, and if formed at or near the surface, it may be porous like siliceous sinter. Native sulfur commonly is present in pores and cavities. The siliceous zone grades outward to a zone of highly altered rock composed mainly of microcrystalline quartz and alunite. Kaolinite (or its polymorph, dickite) as well as opaline cristobalite, are common in the argillic zone. Pyrite may be found in quartz-alunite rock, particularly at depth. Characteristic minerals of the propylitic zone include epidote, chlorite, zeolites, pyrite, and calcite (Hall and Bauer, 1983).

Aspen Mountain project

At the beginning of this project, samples were collected from the original alunite discovery trench in section 26, T17N, R104W, on the south flank of Aspen Mountain, to verify the presence of alunite (samples AM1-91 through AM6-91 and RS20 through RS24, **Plate 2**). Samples of gray to yellow claystone with reddish crusts from the bottom of the trench yielded XRD patterns compatible with alunite.

During field studies, it was noted that the vegetative cover on the Aspen Mountain silicified zone was different from the surrounding non-silicified areas. The silicified zone covers an area of 20 to 30 square miles and transcends the contacts of the Rock Springs Formation, the Blair Formation and the Bishop Conglomerate. The silicified zone is covered with grass, but lacks brush compared to the nonsilicified rocks. This vegetative difference should be favorable for mapping the extent of alteration on aerial photography.

Where the silicification is intense, the sandstones have been converted to hard quartzites containing some secondary kaolinite. In many places, the sandstones are so intensely silicified that they ring when struck by a hammer. Locally, zones of banded chert occur within the silicified zone. For instance, one sample locality (sample AM10-91, **Plate 2**) contains a zone of limonite-stained, gray banded chert with crosscutting quartz stringers, typical of some jasperoids. At sample site RS48, some brightly colored red and yellow-banded cherts are mixed with similar gray cherts.

Some other interesting features of the Aspen Mountain area include an apparent magnetic anomaly in the vicinity of sample site RS-55 (section 4, T16N, R104W). At this site, magnetic deflection of a compass needle was noted. On the south flank of Aspen Mountain along Sulphur Creek [erroneously labeled Snow Creek on the 1:100,000-scale metric topographic map] (SE section 13, T17N, R104W), a spring releasing large quantities of H_2S was encountered. The amount of H_2S emanating from this spring may be toxic. A stream sediment sample was collected from the spring during favorable wind conditions (sample RS-79, **Table 3**).

Kirschbaum (1986) mapped a group of small travertine deposits along the western edge of Aspen Mountain in section 34, T17N, R104W, and section 4, T16N, R104W. Some previous reconnaissance studies in the area have also noted local occurrences of free sulfur in the silicified zone.

Near the southern edge of the silicified sandstone is a zone of brecciation, with an areal extent of about 100 by 200 feet (samples RS-92 and RS-93). The breccia clasts range up to 1 to 2 inches in diameter, and are all re-oriented as if the fragments were lifted in a fluidized state by passage of a gas phase. The breccia has been re-cemented (rehealed) by calcite and, to a much lesser extent, by quartz.

There is also some limonite, probably after pyrite. Brecciation occurred after silicification since the sandstone fragments are silicified. This breccia may represent a steam vent rather than a hot spring.

During this initial reconnaissance study, 94 rock chip, soil, and stream sediment samples were taken in and around the silicified zone on Aspen Mountain (**Plate 2**). In addition, we reviewed the National Uranium Resource Evaluation (NURE) stream sediment sample data for this region. None of the NURE samples contained detectable gold (Albert, 1986). Of the samples collected by the Geological Survey of Wyoming, 16 contained detectable gold ranging from a trace to a maximum of 0.115 ppm Au (**Table 3**). All of these lie within the Aspen Mountain silicified zone.

Table 3. Geochemical analyses of selected elements from samples collected in the Aspen Mountain area, southwestern Wyoming (ppm = parts per million, nd = not detected, tr = trace, dash indicates not analyzed). With the exception of the NURE (National Uranium Resource Evaluation) samples, all samples were analyzed by Gordon Marlatt.

Sample Number	Description	Au (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ba (ppm)	W (ppm)
AM1-91	Clay-cemented sandstone from west wall of trench	nd	—	—	—	—	—
AM2-91	Alunite-cemented sandstone breccia from floor of trench	nd	—	—	—	—	—
AM3-91	Limonite-stained, silicified sandstone from trench floor	nd	—	—	—	—	—
AM4-91	Alunite(?)-kaolinite-cemented sandstone	nd	—	—	—	—	—
AM5-91	Silicified sandstone	nd	—	—	—	—	—
AM6-91	Kaolinite-cemented sandstone	nd	—	—	—	—	—
AM7-91	Highly silicified sandstone	nd	—	—	—	—	—
AM8-91	Weakly silicified and iron-stained sandstone	nd	—	—	—	—	—
AM9-91	Highly silicified sandstone	nd	—	—	—	—	—
AM10-91	Limonite-hematite-stained banded jasperoid (?) with secondary, cross-cutting quartz veinlets	nd	—	—	—	—	—
RS-13	Kaolinized sandstone	tr	—	—	—	—	—
RS-14	Hard, silicic sandstone with disseminated limonite after pyrite	0.10	—	—	—	—	—
RS-15	Silicified sandstone	nd	—	—	—	—	—
RS-16	Silicified sandstone with some limonite after pyrite	nd	—	—	—	—	—
RS-17	Silicified, kaolinized sandstone	nd	—	—	—	—	—
RS-18	Silicified sandstone	0.08	—	—	—	—	—
RS-19	Soil sample	nd	—	—	—	—	—
RS-20	Yellow clay from trench	nd	—	—	—	—	—
RS-21	White clay	nd	—	—	—	—	—
RS-22	Alunitic (?) shale	tr	—	—	—	—	—
RS-23	Gray silty sandstone	nd	—	—	—	—	—
RS-24	Gray silty sandstone	tr	—	—	—	—	—
RS-25	Permeable sandstone with limonite in streaks	nd	—	—	—	—	—
RS-26	Permeable sandstone with some kaolinite and limonite	nd	—	—	—	—	—
RS-27	Iron-stained sandstone	nd	—	—	—	—	—
RS-28	Carbonaceous shale	nd	—	—	—	—	—
RS-29	Carbonaceous shale (hydrocarbon-rich)	nd	—	—	—	—	—
RS-30	Well-sorted sandstone	nd	—	—	—	—	—
RS-31	Well-sorted sandstone	tr	—	—	—	—	—
RS-32	Shale at base of sandstone	nd	—	—	—	—	—
RS-33	Sandstone	nd	—	—	—	—	—
RS-34	Sandstone	nd	—	—	—	—	—
RS-35	Gysum-rich sandstone	nd	—	—	—	—	—
RS-36	Coal (6 -inch seam)	nd	—	—	—	—	—
RS-37	Tar sand above coal	nd	—	—	—	—	—
RS-38	Coal (top of seam) with about 5 percent pyrite	nd	—	—	—	—	—
RS-39	Coal (middle of seam) with about 2 percent pyrite	0.08	—	—	—	—	—
RS-40	Coal (bottom of seam) with about 8 percent pyrite	nd	—	—	—	—	—
RS-41	Clinker	nd	—	—	—	—	—
RS-42	Clinker	nd	—	—	—	—	—
RS-43	Thin-bedded sandstone (limonite after pyrite)	nd	—	—	—	—	—
RS-44	Extremely hard, silicified sandstone	nd	—	—	—	—	—
RS-45	Quartzite	nd	—	—	—	—	—
RS-46	Quartzite	nd	—	—	—	—	—
RS-47	Partially silicified sandstone with abundant kaolinite and chert	tr	—	—	—	—	—

Table 3 continued.

Sample Number	Description	Au (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ba (ppm)	W (ppm)
RS-48	Claystone with bedded chert	nd	—	—	—	—	—
RS-49	Sub-silicified sandstone	0.115	—	—	—	—	—
RS-50	Sandstone with manganese (?) veins	nd	—	—	—	—	—
RS-51	Kaolinitic sandstone	nd	—	—	—	—	—
RS-52	Silicified sandstone	nd	—	—	—	—	—
RS-53	Clay	nd	—	—	—	—	—
RS-54	Soil sample on top of travertine	nd	—	—	—	—	—
RS-55	Soil sample on top of travertine (magnetic deflection of compass needle)	nd	—	—	—	—	—
RS-56	Soil sample from base of travertine	nd	—	—	—	—	—
RS-57	Calcite-cemented breccia	0.06	—	—	—	—	—
RS-58	Tuffa (evaporite calcite)	tr	—	—	—	—	—
RS-59	Soil sample on limestone (?) (travertine?)	nd	—	—	—	—	—
RS-60	Kaolinite-cemented sandstone	tr	—	—	—	—	—
RS-61	Soil sample	nd	—	—	—	—	—
RS-62	Hard, silicified sandstone	nd	—	—	—	—	—
RS-63	Soil sample	nd	—	—	—	—	—
RS-64	Soil sample	nd	—	—	—	—	—
RS-65	Soil sample	nd	—	—	—	—	—
RS-66	Limonite-stained, silicified sandstone	nd	—	—	—	—	—
RS-67	Soil sample	nd	—	—	—	—	—
RS-68	Soil sample	nd	—	—	—	—	—
RS-69	Silicified sandstone with minor kaolinite	nd	—	—	—	—	—
RS-70	Extremely hard silicified sandstone with kaolinite	nd	—	—	—	—	—
RS-71	Silicified sandstone	nd	—	—	—	—	—
RS-72	Silicified sandstone	nd	—	—	—	—	—
RS-73	Soil sample	nd	—	—	—	—	—
RS-74	Stream sediment sample	nd	—	—	—	—	—
RS-75	Stream sediment sample	nd	—	—	—	—	—
RS-76	Stream sediment sample	nd	—	—	—	—	—
RS-77	Stream sediment sample	nd	—	—	—	—	—
RS-78	Stream sediment sample	nd	—	—	—	—	—
RS-79	Stream sediment sample from mouth of H_2S-spring	nd	—	—	—	—	—
RS-80	Stream sediment sample	nd	—	—	—	—	—
RS-81	Stream sediment sample	nd	—	—	—	—	—
RS-82	Stream sediment sample	nd	—	—	—	—	—
RS-83	Stream sediment sample	nd	—	—	—	—	—
RS-84	Stream sediment sample	nd	—	—	—	—	—
RS-85	Soil sample	nd	—	—	—	—	—
RS-86	Soil sample	nd	—	—	—	—	—
RS-87	Silicified sandstone, some kaolinite	0.08	—	—	—	—	—
RS-88	Nonsilicified shale	nd	—	—	—	—	—
RS-89	Stream sediment sample	tr	—	—	—	—	—
RS-90	Silicified sandstone	0.08	—	—	—	—	—
RS-91	Non-silicified sandstone	nd	—	—	—	—	—
RS-92	Calcite-cemented sandstone breccia	nd	—	—	—	—	—
RS-93	Calcite-cemented sandstone breccia	nd	—	—	—	—	—
RS-94	Sub-silicified sandstone	tr	—	—	—	—	—
RS-95	Non-silicified sandstone	nd	—	—	—	—	—
RS-96	Non-silicified sandstone	nd	—	—	—	—	—
NURE 8519	Stream sediment sample	nd	13	—	24	606	—
NURE 8520	Stream sediment sample	nd	13	90	8	—	—
NURE 8526	Stream sediment sample	—	14	136	12	—	—
NURE 8527	Stream sediment sample	—	—	—	13	—	—
NURE 8532	Stream sediment sample	nd	—	—	—	—	—
NURE 8533	Stream sediment sample	nd	—	—	—	—	—
NURE 8534	Stream sediment sample	nd	—	—	—	—	—
NURE 8535	Stream sediment sample	nd	17	100	10	—	18
NURE 8536	Stream sediment sample	nd	—	—	—	—	—
NURE 8537	Stream sediment sample	nd	11	—	14	—	23
NURE 8538	Stream sediment sample	nd	16	44	—	—	—
NURE 8539	Stream sediment sample	nd	20	115	46	—	—
NURE 8541	Stream sediment sample	nd	10	79	8	442	—
NURE 8556	Stream sediment sample	nd	26	131	8	—	—
NURE 8555	Stream sediment sample	nd	—	—	—	—	—
NURE 8554	Stream sediment sample	nd	—	90	13	—	25
NURE 8553	Stream sediment sample	nd	—	—	—	—	—

Conclusions and recommendations

The available data confirm that Aspen Mountain is anomalous. This area lies within a vast sedimentary basin and contains an extensive fault-controlled zone of silicification covering a surface area of 20 to 30 square miles with a minimum depth of 3,700 feet. The zone has associated alunite and kaolinite alteration of unknown extent, minor travertine, banded chert, some free sulfur, and several weak gold anomalies. All of these facts taken together support the conclusion that Aspen Mountain may represent a paleo-epithermal system.

Disseminated epithermal gold deposits are known for their difficulty in sampling. Typically, the widespread and very low grade gold contents require bulk sampling to isolate significant gold anomalies. Samples collected to date on Aspen Mountain have all been rock chip, soil, and stream sediment samples. Our recommendation is to establish a sampling grid for additional rock chip and soil samples. The samples should then be tested for gold and other trace metals as well as studied petrographically. Some bulk samples for gold analyses should also be taken.

Geology of the Rawlins hematite deposit, Carbon County

Introduction

Hematitic conglomerate, locally known as 'Rawlins Red', crops out north of Rawlins on the southeastern flank of the Rawlins uplift (**Figure 1**). An outcrop of arkosic conglomerate occurs nearby on the northern edge of town southwest of the hematite deposit. Both of these conglomerates were investigated during this project.

The Rawlins uplift is formed of low lying hills (elevations from 7,000 to 7,800 feet above mean sea level) around the town of Rawlins (elevation 6,755 feet). The uplift is cored by Precambrian granite, flanked by Paleozoic sedimentary rocks on the east, and onlapped by Tertiary sedimentary rocks on the west. The base of the Paleozoic section consists of conglomerates and sandstones in the Flathead Sandstone (Cambrian). The upper part of the outcrop of the Flathead Sandstone includes a 20- to 30-foot thick bed of hematitic sandstone and conglomerate. A poorly sorted arkosic conglomerate to the southwest of the hematitic conglomerate may be at about the same stratigraphic level, although field relations for this arkosic conglomerate were not established.

Arkosic conglomerate

Outcrops of arkosic conglomerate occur along the northern edge of the town of Rawlins. Many clasts in these conglomerates were eroded from the nearby Rawlins granite. The rock texture of the conglomerates indicates the pebbles originated from two separate source terranes. A distal source is required to explain the presence of well-rounded quartz pebbles, some of which are as large as an inch across, but a proximal source (the Rawlins granite) supplied feldspar and some additional quartz to the rock. Orthoclase feldspar in these rocks is fresh and forms subhedral grains typical of what would be expected from a source nearby. Our interpretation is that the proximal material in these conglomerates worked its way into an active stream as slope wash.

Two grab samples (RA15-91 and RA16-91, **Figure 9** and **Table 4**) of arkosic conglomerate were tested for radioactivity, gold, and rare earth element (REE) mineralization. The samples were scanned with a geiger counter but showed only background radioactivity levels. Chemical analyses showed no detectable gold, but both yielded elevated REE contents (520 to 690 ppm total REE). The lanthanum (La) and cerium (Ce) contents, in particular, were anomalous at about 4 to 5 times that of average upper continental crustal abundance. The anomalies are comparable to low grade REE anomalies reported for Proterozoic quartzite and quartz pebble conglomerate in the Medicine Bow Mountains (see King, 1991; King and Hausel, 1991). One hand sample also contained a speck of copper carbonate. The amount of copper however, was not worthy of assay.

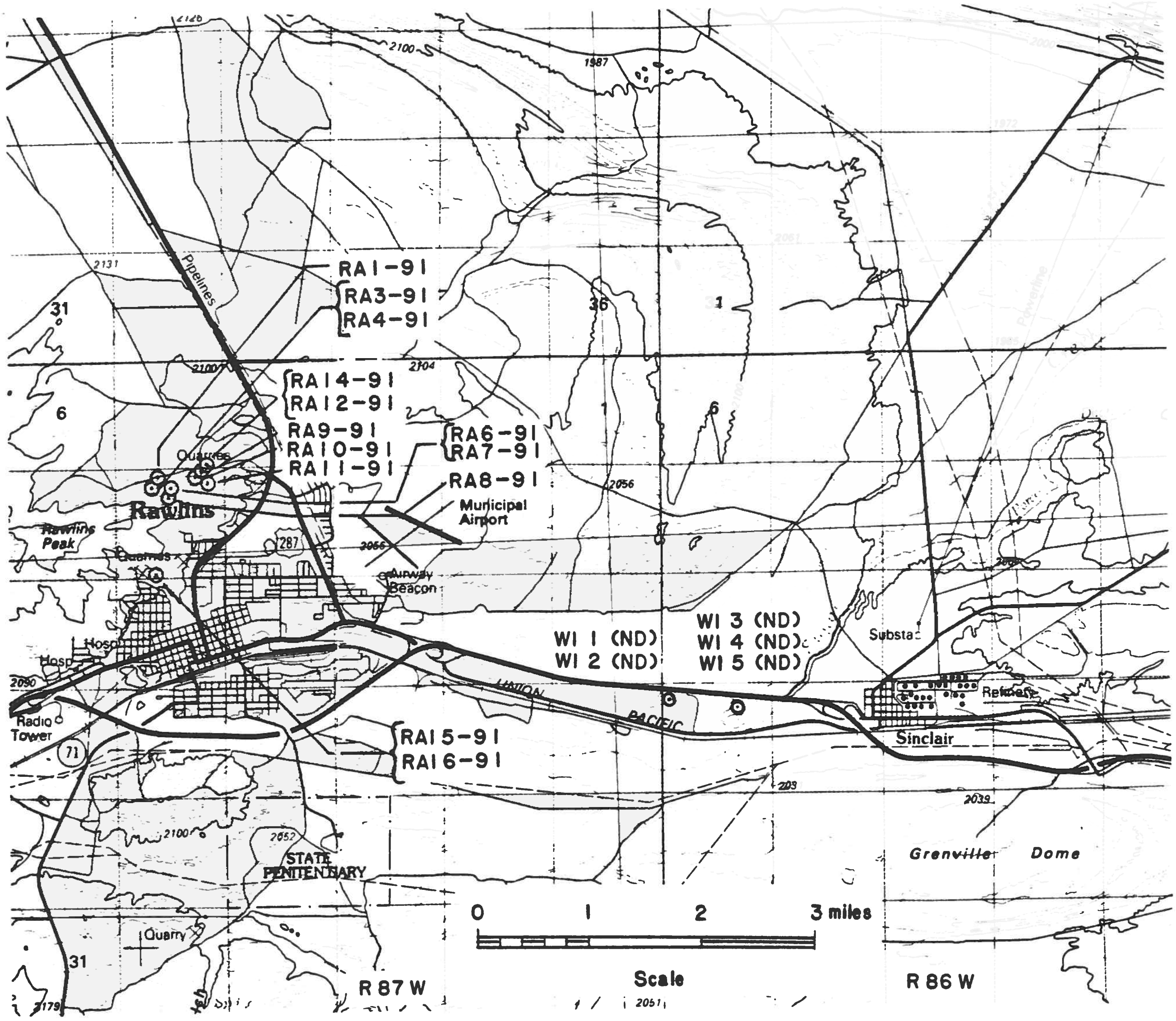

Figure 9. Sample location map of arkosic conglomerates and hematitic conglomerates and sample location map for gold analyses in sandstone, and in carbonaceous shale in the Rawlins-Sinclair area (Rawlins 1:100,000-scale metric topographic map). Refer to **Table 4** for analytical results of samples RA1-91 to RA16-91, and **Table 6** for WI1 to WI5 (ND=not detected).

Table 4. Geochemical analyses of gold, iron, and rare earth elements in conglomerates from the Rawlins uplift (ppm = parts per million, % = weight percent, < = less than, > = greater than, dashes indicate not analyzed). Analyses by Bondar-Clegg and/or Robert W. Gregory.

Sample Number	Description	Au (ppm)	Fe (%)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
RA1-91	Panned concentrate of massive hematite	2.4	65.36	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RA3-91	Conglomerate, crossbedded, cemented by hematite	< 0.005	8.17	4.1	7	< 4	4	0.75	0.2	< 3	0.2	0.8	0.1	< 3	< 0.5	0.4	0.06
RA4-91	Conglomerate	< 0.005	13.48	4.2	8	< 4	5	1.0	0.3	< 3	0.2	1.0	0.2	< 3	< 0.5	0.5	0.08
RA6-91	Hematitic conglomerate	< 0.005	1.51	5.6	10	< 4	6	1.07	0.2	< 3	0.2	0.8	0.2	< 2	< 0.5	0.4	0.07
RA7-91	Hematitic conglomerate	< 0.005	2.08	4.3	8	< 4	5	0.83	0.2	< 3	0.1	0.8	0.2	< 2	< 0.5	0.4	0.07
RA8-91	Hematitic conglomerate	< 0.005	1.54	7.9	18	< 4	11	3.00	0.9	< 5	0.6	1.9	0.3	< 2	< 0.3	0.6	0.07
RA9-91	Hematitic conglomerate from mine dump	< 0.005	16.14	17.5	44	< 4	16	3.00	0.6	2	0.4	2.1	0.6	1	< 0.5	1.5	0.21
RA10-91	Hematite-cemented conglomerate	< 0.005	5.91	5.4	16	< 4	8	1.80	0.3	< 5	0.2	1.0	0.2	< 5	< 0.5	0.5	0.09
RA11-91	Hematitic conglomerate	0.006	2.22	5.7	14	< 4	7	1.06	0.2	< 5	< 0.1	0.5	< 0.1	< 3	< 0.5	0.4	0.06
RA12-91	Massive hematite from pit	< 0.005	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RA14-91	Massive hematite	< 0.005	47.90	9.5	60	< 5	82	4.76	1.0	3	0.5	2.6	0.3	< 5	< 0.5	0.8	0.13
RA15-91	Arkosic conglomerate	< 0.005	—	120.0	230.0	18	85	17.3	1.2	18	1.8	11.0	2.2	6	0.9	5.6	0.83
RA16-91	Arkosic conglomerate	< 0.005	—	156.0	305.0	24	122	23.0	1.6	18	2.5	14.0	3.0	7	1.4	7.6	1.10

Hematitic conglomerate

The hematitic conglomerates consist of quartz pebbles cemented by earthy and specular hematite. The amount of hematite is sufficient to stain the entire conglomerate rusty red. We speculate that these conglomerates originated by erosion of an Archean iron formation (or some similar iron-rich material) exposed during uplift in the Cambrian. This Archean source has either been completely removed by erosion or is now buried under the conglomerates or nearby Phanerozoic sedimentary rocks.

The hematitic conglomerate was mined prior to 1890 and used as a smelter flux and paint pigment (Osterwald and others, 1966). Total production amounted to about 100,000 tons prior to 1890; no records are available for post-1890 production. According to several local residents, the pigment was used to paint the Brooklin Bridge and many of the early Union Pacific Railroad cabooses and boxcars.

The hematite mined for flux was used to smelt silver ore from Utah and Colorado in the 1870s. During this period, it was reported that there were notable increases in the gold content of the assayed silver ore when using the hematite as a flux, which led to speculation that gold may be present in the hematite. Some of this same flux was crushed and panned and reported to have fine visible gold in the concentrates (Anonymous, 1873). Another historical report from 1895 indicated the gold content of the conglomerates ranged from 0.04 opt to 0.19 opt Au (see Hausel, 1989, p.148). Some controversy existed over possible fraud related to the gold content of the conglomerates (Anonymous, 1873).

Several samples of the hematitic conglomerate were collected from various points along the outcrop and from various mine dumps (**Figure 9**). These samples were tested for gold and REE mineralization. Gold and REE have been reported in similar conglomerates at South Pass, the Black Hills, and Bald Mountain in the Bighorn Mountains.

The analyses of the rock chip samples for the hematitic conglomerate showed no detectable gold (less than 0.005 ppm Au) for most of the samples, with background REE levels. Sample RA11-91 contained background gold (0.006 ppm) and REE (**Table 4**).

Another sample (RA1-91) was crushed and panned, and the panned concentrates yielded anomalous gold (2.4 ppm Au). This value is equivalent to 0.07 opt Au and lies within the limits of the historical reported gold values, which suggests some of the historical values may have been panned concentrates. The analysis confirms the presence of traces of gold in the conglomerates, although it is not known if the noble metal occurs in the hematite matrix or in the quartz pebbles. Because the deposit is a paleoplacer, zones of higher gold content could possibly exist distributed between zones with no gold.

Some samples were also analyzed for total iron content. These samples range from 1.51 percent Fe to 65.36 percent Fe (**Table 4**). A whole rock sample split of RA1-91 yielded 65.36 percent Fe (**Table 4**). The analyses show significant iron content in some samples; however, the exposed deposit is too small for serious economic considerations for metallic iron, although the iron could possibly be used as a pigment.

Precious metals in coal deposits

Introduction

Little effort has been made to search for heavy metal anomalies (particularly precious metals) in coal, even though historical and geochemical evidence suggest possibilities for significant mineralization associated with some coals. In the past, significant amounts of gold and silver were reported in coal in the Black Hills of Wyoming, and significant amounts of gold were reported in a mine near Walcott Junction in southern Wyoming and in the Kemmerer coal mining district of southwestern Wyoming. Recent work by Gordon Marlatt (unpublished) has also established significant silver anomalies in the Kemmerer coal mining district.

Some coal beds in Wyoming have also shown an affinity for other metals, particularly uranium (Wyant and others, 1956). Even heavy mineral anomalies have recently been reported in coal. For example, diamonds and garnets were reported in a coal bed in the Powder River Basin by Exxon Research (personal communication to Hausel, 1988) and the U.S. Geological Survey (Finkelman and Brown, 1989).

Genetic model

Most metals are soluble as organic complexes in naturally occurring saline, organic-acid solutions. If such metalliferous solutions impinge on a coal or some other high-carbon zone in permeable sediments, the metals in solution can be extracted by the carbon and deposited. When metals are adsorbed from a solution by carbon, they are extracted molecule by molecule. Because of the nature of the process, the nucleation of the metasol occurs simultaneously at a great number of points. This leads to a large number of very small particles of native metal which will not be visible or mechanically separable from the coal and will only be detectable by chemical analysis. As an example of this process, carbon in commercial gold mill circuits is routinely loaded to as much as 200 to 400 opt (6,800 to 13,700 ppm) gold without any metal passover or the gold being visible or separable from the carbon by mechanical means (Marlatt and Spatz, 1991).

Recovering gold and other metals from coal may be relatively simple. When coal is burned in a power plant, carbon and most of the sulfur are oxidized and partitioned into the flue gases while metals are retained in the ash. This increases the metal concentration in the ash relative to the coal by the amount of volume decrease from coal to ash, which is about one order of magnitude. Thus, coal with 1 ppm gold could produce ash with 10 ppm gold (Marlatt and Spatz, 1991).

Metalliferous carbon and coal

Carbon is an important precipitate of metals, and there is voluminous literature that describes associations of metalliferous deposits with carbonaceous material, whether it is coal, petroleum, graphite, or carbon trash. Biomolecules can leach and transport gold, followed by gold precipitation in the reducing environment generated by carbonaceous debris (Fyfe and Kerrich, 1984).

Examples of gold-carbon and base metal-carbon associations are many and include the Carlin-type epithermal gold deposits of Nevada. The Mercur gold deposit in Utah (another Carlin-type deposit) also has significant carbon associated with ore. In the Lake Alice district of Wyoming's Overthrust Belt, copper-silver-zinc mineralization is suggested to have precipitated from metalliferous petroleum (Love and Antweiler, 1973). An epithermal gold deposit at Snow Gulch, Alaska, north of Aniak near Crooked Creek, contains abundant graphite clots in the auriferous graywackes and silicic volcanics (Hausel, 1989b). Possibly, the graphite at Snow Gulch represents baked petroleum (P.J. Graff, personal communication, 1988). In the South Pass district, Wyoming, gold deposits at the Garfield, 1914, Caribou, and the Exchange mines all occur in graphitic schist (Hausel, 1991). Copper is found replacing wood of trunks and branches in Triassic fluvial conglomerates at Cuba, New Mexico, and in Permian sandstones of Russia. Copper occurs as replacements of wood and branches in carbonaceous shaley clay in the Permian of Texas. Chalcopyrite, chalcocite, and pyrite are associated with Permian anthracite at New Annan, Nova Scotia, and tree trunks altered to galena are reported from the Vesuvius mine in Freihung, Bavaria. Sphalerite and galena also occur in carbonaceous shales near Joplin, Missouri (Jenny, 1903).

Metalliferous anomalies either in coal or associated with other organic carbon are described from several localities around the world (Boyle, 1979). Vanadium is reported in lignite in the Mendoza Province of Argentina and in anthracite near Yauli, Peru. Tetrahedrite is described in association with bituminous coals in Huallanca, Peru. Silver occurs in lignite-bearing sandstone of Triassic age at Silver Reef, Utah. At Silver Reef, native silver was found deposited as thin scales on joints in the lignite. The ore occurs only in areas of deformation where the lignite has been faulted or brecciated, which strongly supports an epigenetic origin for these deposits (Jenny, 1903).

Gold in pyrite has also been reported in coal, in coaly matter, and in sandstones and conglomerates of coal measures in Borneo; Gippsland, Victoria; Tallawand, New South Wales; New Zealand; Tasmania; and Deadwood, South Dakota. A rich gold deposit was discovered in lignite in Japan; and gold was mined from coal in the Batrina mine, Transylvania (Boyle, 1979). Small amounts of gold were reported at Wales, Utah, but no quantitative values were given for these coals (since the analyses were nonreproducible). Boyle (1979) suggested that the gold may be particulate.

In Canada, traces of gold are reported in the Cretaceous Edmonton series. The higher gold contents are generally recorded from coal seams low in ash and rich in other trace metals such as Cu, Pb, and Zn. Higher gold contents accompany non-coaly partings in the seams or their overlying or underlying host rocks that are enriched in sulfides. Higher gold and silver contents tend to occur in coal near the top and the bottom of individual seams (Boyle, 1979).

In addition to gold and silver, anomalous amounts of platinoids have also been identified in coal. Goldschmidt (1954) reported 0.05 ppm Pd and 0.1 ppm Rh in some coal ashes. In western Kentucky, Chyi (1982) examined coal which was depleted in gold (averaging only 0.4 ppb Au). However, this same coal showed an 18-fold enrichment in platinum with respect to average crustal abundance. The platinum concentration of the coal ranged from none to a maximum of 210 ppb. Platinum contents in the low-temperature ash were reported to be as high as 2 ppm! It was suggested that gold and platinum mix with organic acids and form colloidal precipitates (Chyi, 1982).

Coal deposits around the world have, in general, been neglected for their trace metal content. Yet the literature contains numerous references to reports on metalliferous coal. Based on its physical properties, one could assume that coal in a reducing, organic-rich environment would be an important sink for epigenetic mineralization. Metalliferous solutions contacting coal should precipitate metals at the point of contact (Marlatt and Spatz, 1991). The possibility of syngenetic mineralization must also be considered, although it may not be as important.

Any hydrothermal solutions passing though coal should produce significant metal deposits. Recognizing hydrothermally altered coal may, however, be difficult (Marlatt and Spatz, 1991). Such deposits undoubtedly occur in places such as Japan and New Zealand where volcanic activity and geothermal springs are commonplace and significant gold mineralization has been identified in coal.

Low temperature, oxidizing roll fronts, which have been relatively active in the Wyoming basins, could effectively produce metalliferous deposits where the solution front contacts coal. Such fronts are known for uranium mineralization in Tertiary age sandstones and as common carriers of uranium and vanadium in the Cretaceous age sandstones in Wyoming. These oxidizing fronts may have mobilized other heavy metals such as gold (Gordon Marlatt, personal communication, 1986, *in* Hausel, 1989a, p. 42).

Metalliferous Wyoming coals

Wyoming coal deposits contain some of the thickest, most extensive coal beds in the world. Unfortunately, trace element analyses for the precious metal contents of most coals are not prolific.

Because hydrothermal alteration is absent in the coal-bearing Wyoming basins, the probability of high-grade mineralization associated with coal is unlikely. A possible exception may be the Black Hills uplift, where several alkalic intrusive complexes intrude Paleozoic and Mesozoic sedimentary rocks, including a Cretaceous coal-bearing section.

Oxidizing roll fronts have been quite active in Wyoming during the Tertiary and Cretaceous, and these have produced numerous low-grade uranium and uranium-vanadium deposits. Oxidizing solutions flowing through bedrock precipitate their metal loads where the solutions are reduced. If these solutions contact coal, significant low-grade metal deposits should develop. One area in Wyoming where this may have happened is the Red Desert and its uraniferous coal deposits.

Wyoming has widespread areas of Cretaceous and Tertiary sedimentary rocks that are potential source rocks for precious metals. Scattered gold anomalies have been reported from these rocks (Antweiler and Love, 1967; Hausel, 1989a) and a mechanism for mobilizing and precipitating the precious metal may exist (as described above). Recognition of these mineralized coals may be difficult, as suggested by Marlatt and Spatz (1991), and chemical analyses may be the only available method for their recognition. The probability that gold occurs as particulate matter on the coal further complicates exploration and may require bulk sampling of suspected areas. But the benefits of finding gold and recovering the metal in a commercial coal deposit are obvious.

Prior to this study, precious metals had been reported in three separate coal fields in Wyoming. In 1906, the Mining Reporter described coal samples from a coal mine at Walcott Junction (in the western part of the Hanna Coal Field) that assayed as high as 10 ppm Au (see Hausel, 1989a, p. 61). Possibly, this was an analysis of coal ash.

The most notable reports of precious metals in Wyoming coals come from the Early Cretaceous Cambria coal deposits in the Newcastle area of the Black Hills Coal Field. Samples of coal as well as the roof sandstone were analyzed and found to contain none to 3 ppm Au. Samples of coke produced from the coal were also analyzed and yielded 3 ppm Au and 14 ppm Ag; the ash from the coke yielded 16.5

ppm Au (Stone, 1912). Later testing by the U.S. Geological Survey (1968), however, detected no gold in this area. Knell (1985) reconfirmed the presence of gold and silver in the Cambria coal deposit: maximum detected precious metal contents were 4 ppm Au and 19.5 ppm Ag. A single grab sample of part of the Cambria coal bed provided to the Geological Survey of Wyoming was weakly anomalous and contained 0.019 ppm Au and 1.1 ppm Ag. The ash from this sample assayed 0.054 ppm Au and 3.1 ppm Ag (Hausel, 1989, p. 49).

Recently, Marlatt and Spatz (1991) reported a silver analysis of carbonaceous shale in contact with coal in the Green River Basin to be as high as 25 ppm Ag. In this same general area in 1903, gold was reported in coal ash in the Kemmerer coal mining district (Jenny, 1903). The gold content of coal ash was reportedly as high as 1.0 to 1.4 ppm. Follow-up studies by the U.S. Geological Survey confirmed the presence of gold, but found the analyses could not be reproduced. The anomalous samples were examined microscopically, but gold was not found. This suggests the metal is particulate rather than adsorbed on the organic matter (U.S. Geological Survey, 1968).

This current research program was designed to test a few coal beds for gold and silver. The highest priority was to relocate the Walcott Junction coal mine and attempt to reproduce the reported results. This was difficult because the historical report gave no information on the mine's location. The available production reports on mines in this area indicate that there was at least one active coal mine in 1906 at the base of St. Mary's Hill near Walcott Junction (R.W. Jones, personal communication, 1991), but it is not known if this is the same mine described in the early historical report.

Other coal deposits examined during this study included those at the active Black Butte mine south of Point of Rocks, and an old abandoned mine near Aspen Mountain south of Rock Springs. Samples of scoria and associated coal in the Red Desert area were also collected for gold analyses.

Coal deposits investigated

Walcott Junction

Coal samples were collected from a mine dump and from adjacent soil at the abandoned Buckley and Ryan coal mine at the base of St. Marys Hill a short distance north of Walcott Junction (S2 SE SW section 14, T21N, R84W) (**Figure 10a** and **b**). Whether or not this was the mine that carried anomalous gold, as described by the Mining Reporter in 1906, is unknown.

The underground mine was developed in a 5-foot thick coal bed in the Medicine Bow Formation (?) of Late Cretaceous age. The adit has caved and the workings are not accessible. Seventy-two samples were collected from the mine dump, nearby outcrops, the soil, and gullies to test for gold content. Twelve of the 72 samples (16.6 percent) contained detectable gold ranging from a trace to 0.110 ppm Au (**Table 5**).

The analyses confirm the presence of trace to anomalous gold. Some of the analyses are high enough that upgrading in coal ash could be significant. However, our results are not consistent with the early 1906 report which reported gold values as high as 10 ppm, two orders of magnitude higher than the highest value obtained by our study. Possibly, this is not the same mine described in the Mining Reporter, or some localized Au-enriched pockets exist in the mine, or the gold analyses described by the Mining Reporter were exaggerated. In addition, our samples were of waste material from the mine dump and are probably not representative of the coal that was extracted and sold.

Black Butte mine

The Black Butte coal mine lies on the eastern flank of the Rock Springs uplift, a north-south trending anticline where eastern dips rarely exceed 5 degrees. The uplift is a Laramide structure affected by deformation 90 to 40 Ma (million years) ago. The area north of the Black Butte mine site is cut by a group of east-west trending faults, although no significant faults have been recognized in the mine area. Estimated remaining coal reserves for the mine are 88.5 million tons (Jones and Glass, 1992).

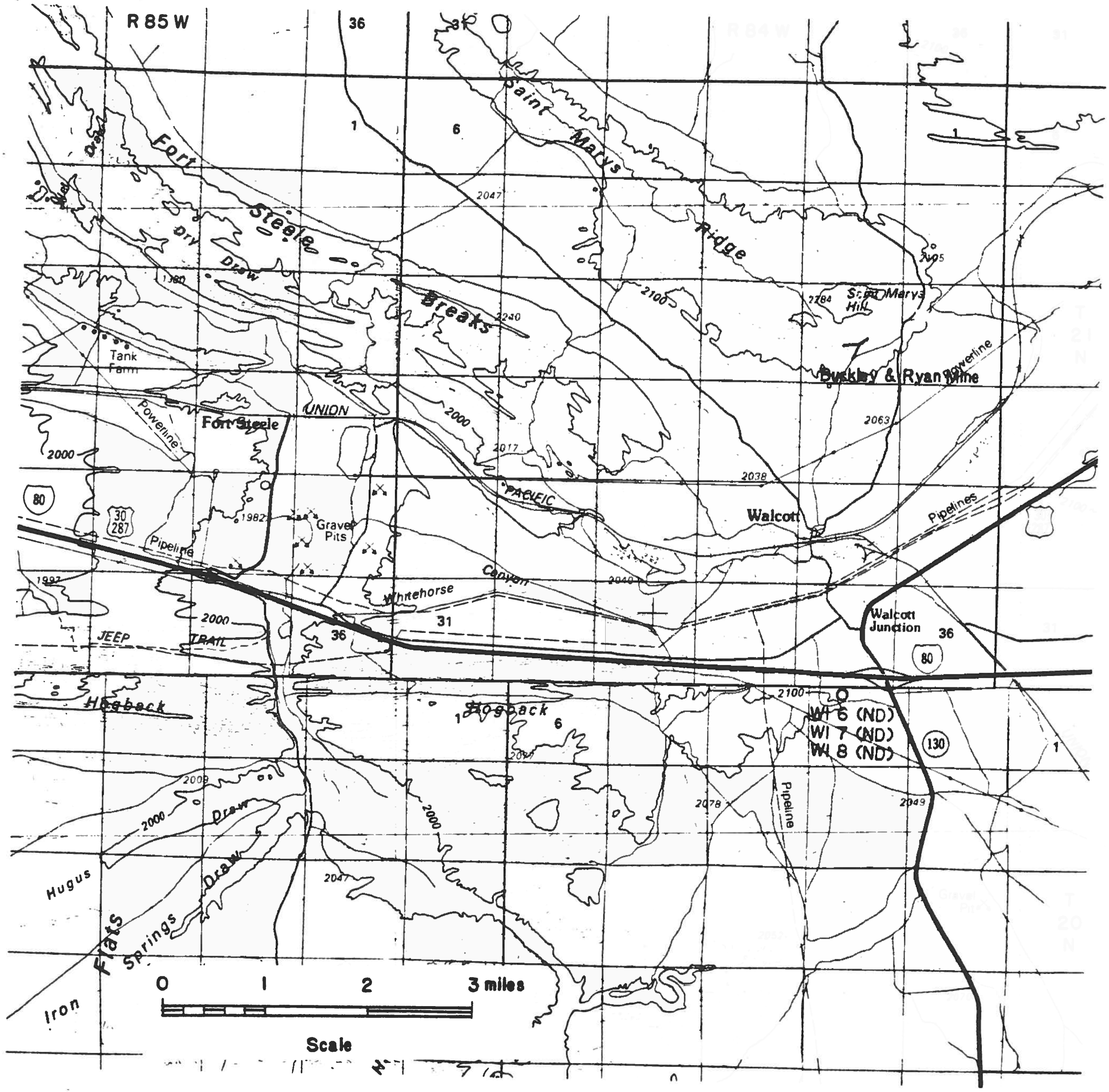

Figure 10a. Location map for the Buckley and Ryan coal mine at St. Marys Hill and location map for gold analyses in sandstones collected at Walcott Junction (Medicine Bow 1:100,000-scale metric topographic map). Sample numbers W16 through W18 include gold analyses also listed in **Table 6** (ND=not detected).

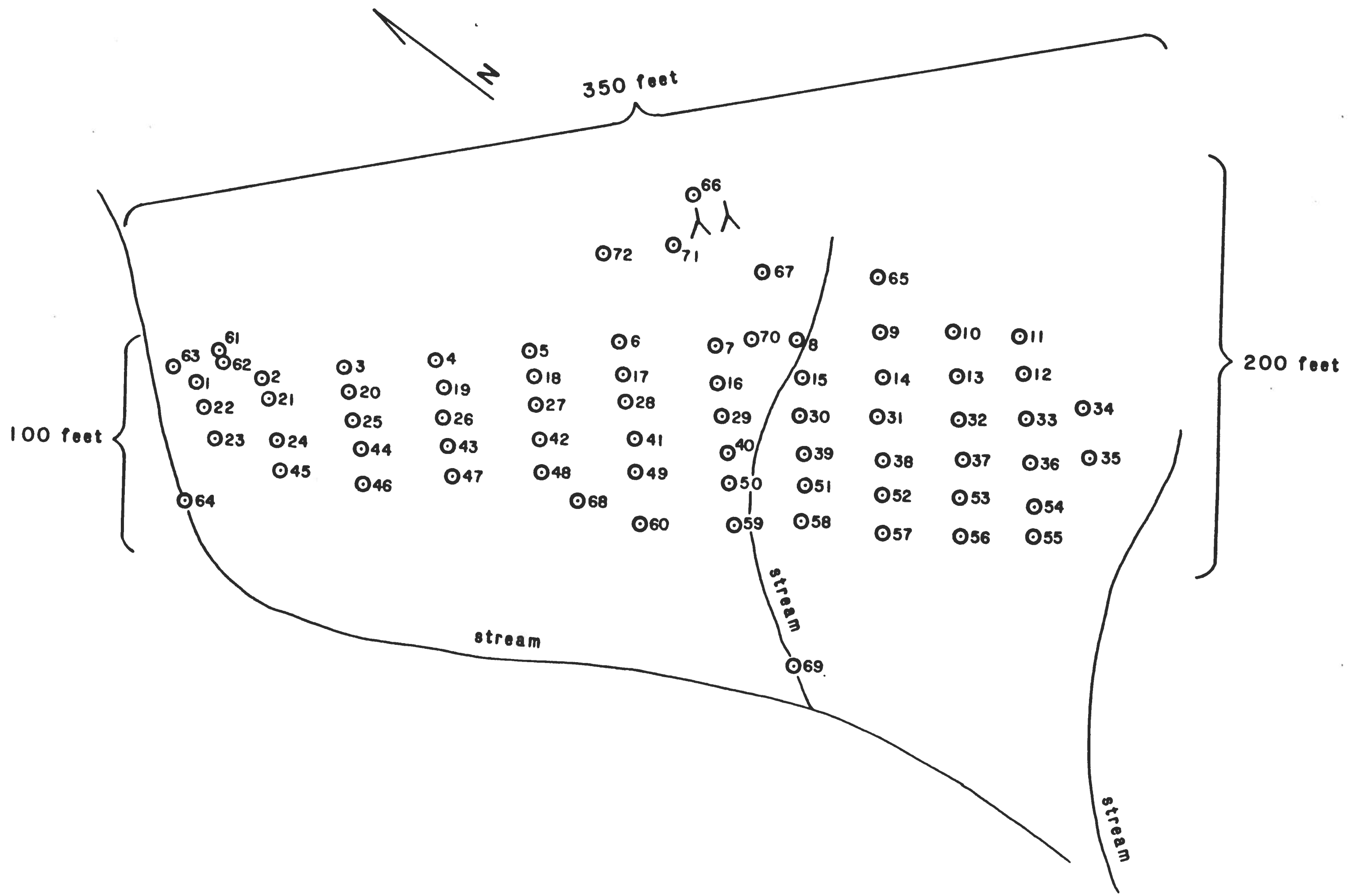

Figure 10b. Sketched sample location map for the Buckley and Ryan coal mine, Walcott Junction. Sample numbers refer to **Table 5** (W1 through W72). The two 'Y's near sample site W66 mark the location of the mine adits.

Table 5. Gold analyses of coal, scoria, ash, and related rocks (ppm = parts per million, nd = not detected, tr = trace). Analyses by Gordon Marlatt.

Sample Number	Description	Au (ppm)
	Black Butte coal mine (Almond Formation)	
BB1	subcalcic sandstone	nd
BB2	carbonaceous shale at base of upper seam	nd
BB3	volcanic ash	nd
BB4	coal, middle of upper seam	nd
BB5	pyritiferous coal, middle of second seam	nd
BB6	coal, upper part of seam	0.100
BB7	coal, middle of seam	0.060
BB8	coal, bottom of seam	0.070
BB26	boiler ash, Almond coal	0.100
BB27	reacted fly ash, Almond coal	nd
	Black Butte Pit #6 (Lance Formation and Fox Hills Sandstone)	
BB9	coal, base of A-B seam	tr
BB10	coal, middle of A-B seam	nd
BB11	coal, top of A-B seam	nd
BB12	coal, middle of C seam	nd
BB13	coal, top of C seam	tr
BB14	coal, top of C seam	0.080
BB15	coal, middle of C seam	nd
BB16	shaley coal, bottom of C seam	nd
BB17	carbonaceous shale, below C seam	nd
BB18	white, well-sorted, Fox Hills Sandstone	nd
BB19	white, sub-calcic, well-sorted Fox Hills Sandstone	nd
	Black Butte Pit #3 (Ft. Union Formation)	
BB20	white sandstone with carbonaceous partings	nd
BB21	coal, top of C seam	nd
BB22	pyritiferous, carbonaceous zone at base of coal (1.25 ppm Ag)	nd
BB23	pyritiferous, carbonaceous zone, middle of coal (2.5 ppm Ag)	nd
BB24	poorly carbonaceous parting in C coal seam	0.080
BB25	sample from C seam	0.100
	Coal mine dump at Walcott Junction (St. Marys Hill)	
W1	grid sample (see **Figure 10b**)	nd
W2	grid sample	nd
W3	grid sample	tr
W4	grid sample	nd
W5	grid sample	nd
W6	grid sample	nd
W7	grid sample	nd
W8	grid sample	nd
W9	grid sample	nd
W10	grid sample	nd

Table 5 continued.

Sample Number	Description	Au (ppm)
W11	grid sample	nd
W12	grid sample	nd
W13	grid sample	0.060
W14	grid sample	nd
W15	grid sample	nd
W16	grid sample	nd
W17	grid sample	nd
W18	grid sample	nd
W19	grid sample	nd
W20	grid sample	tr
W21	grid sample	nd
W22	grid sample	nd
W23	grid sample	nd
W24	grid sample	nd
W25	grid sample	nd
W26	grid sample	nd
W27	grid sample	0.095
W28	grid sample	nd
W29	grid sample	nd
W30	grid sample	nd
W31	grid sample	nd
W32	grid sample	nd
W33	grid sample	nd
W34	grid sample	nd
W35	grid sample	nd
W36	grid sample	nd
W37	grid sample	nd
W38	grid sample	0.060
W39	grid sample	nd
W40	grid sample	nd
W41	grid sample	nd
W42	grid sample	nd
W43	grid sample	nd
W44	grid sample	nd
W45	grid sample	nd
W46	grid sample	nd
W47	grid sample	nd
W48	grid sample	nd
W49	grid sample	nd
W50	grid sample	nd
W51	grid sample	nd
W52	grid sample	nd
W53	grid sample	nd
W54	grid sample	nd
W55	grid sample	nd
W56	grid sample	nd
W57	grid sample	nd
W58	grid sample	0.060
W59	grid sample	tr

Table 5 continued.

Sample Number	Description	Au (ppm)
W60	grid sample	nd
W61	grid sample	nd
W62	grid sample	nd
W63	grid sample	nd
W64	grid sample	tr
W65	grid sample	nd
W66	grid sample	0.060
W67	grid sample	nd
W68	grid sample	nd
W69	grid sample	tr
W70	grid sample	nd
W71	grid sample	0.050
W72	grid sample	0.110
	Continental Divide (Red Desert) area	
CD1	reddish-brown sandstone	0.055
CD2	silty sandstone	0.120
CD3	white friable, well-sorted sandstone	nd
CD4	white friable, well-sorted sandstone	nd
CD5	scoria	nd
CD6	scoria	nd
CD7	scoria	nd
CD8	glassy botryoidal scoria	nd
CD9	coal, below burn	nd
CD10	coal	tr
CD11	hard, red, silty sandstone	tr
CD12	gray glassy scoria	0.055
CD13	red, vesicular scoria	nd
CD14	scoria	tr
CD15	yellow, friable sandstone	nd
CD16	red, vesicular scoria	tr
CD17	red shale	nd
CD18	red sandstone below coal	nd
CD19	massive red scoria	nd
CD20	vesicular scoria	nd
CD21	yellow, baked shale	nd
CD22	red, friable shale	nd
CD23	specular hematite vein in shale	nd
CD24	hard, silicified, baked shale	nd
CD25	red, silicified baked shale	nd
CD26	shale	tr
CD27	white clay	nd
CD28	red scoria	nd
CD29	specular hematite vein in shale	nd
CD30	specular hematite vein	nd
CD31	carbonaceous shale	nd

Six formations have been recognized in the Black Butte mine area, but only three have minable coal. The youngest of these is the Fort Union Formation of Tertiary age. In the mine area, the Fort Union has a maximum thickness of 800 feet, and consists of an alternating sequence of light-colored sandstone, light and dark gray shale, and coal. One minable coal bed ('C' seam) varies from 10 to 26 feet thick.

Samples collected from the Fort Union Formation in Black Butte Pit 3 included sandstone and coal (**Figure 11** and **Table 5**). A sample of sandstone above the 'C' seam contained no detectable gold or silver. Two samples taken from a high-pyrite zone in the coal contained no detectable gold but 1.25 ppm and 2.5 ppm Ag (samples BB22 and BB23, **Table 5**). Two other samples taken from the 'C' seam and from a poorly carbonaceous parting in the seam assayed 0.100 ppm and 0.080 ppm Au, respectively (**Table 5**). Thus, four of the five samples collected in the 'C' seam contained anomalous precious metal values.

The Fort Union Formation is underlain by the Lance Formation of Late Cretaceous age. The Lance Formation has a maximum thickness of 900 feet in this area, and consists of alternating thin sandstones, dark gray shale, carbonaceous shale, and coal. The Fox Hills Sandstone occurs immediately below the Lance Formation. Four to six coal beds occur in the lower 200 to 300 feet of the Lance and range from 2 to 8 feet thick. These beds are laterally inconsistent, and thin and grade into carbonaceous shale. The principal coal seam is 5 to 10 feet thick.

A total of 11 samples were collected from the Lance Formation and the Fox Hills Sandstone in Black Butte Pit 6 (**Figure 11**). Three of the nine samples collected from Lance Formation coal and carbonaceous shale in Pit 6 contain a trace to 0.080 ppm Au. The two samples collected in the Fox Hills Sandstone contained no detectable gold (**Table 5**).

The Lance and Fox Hills are underlain by 1,000 to 2,000 feet of the dark, marine Lewis Shale. The Lewis is noncoal-bearing and is underlain by the Almond Formation (Upper Cretaceous), the youngest formation of the Mesaverde Group. The Almond Formation consists of 300 to 500 feet of brown and light gray or cream colored sandstone, sandy shale, and claystone. The principal Almond coal seam is 12 feet thick and splits to the north into two beds of 7 and 5 feet thick separated by 10 feet of interburden (Department of Environmental Quality temporary filing permit application 1 4/62).

Eight samples were taken from the Almond Formation (**Figure 11**), only five of which were in coal. Three of the five coal samples yielded anomalous gold values from 0.060 ppm to 0.100 ppm Au (samples BB6 to BB8, **Table 5**). One sample of boiler ash and one sample of reacted fly ash from these coals were also analyzed (samples BB26 and BB27, **Table 5**). These samples were furnished by the company operating the mine and were not identified as to power plant source. One sample yielded 0.100 ppm Au; the other contained no detectable gold.

These results, based on a limited number of samples, show that all three formations yield weak gold anomalies associated with coal. Further work is recommended on the gold content of the fly ash of these coals.

Cedar Creek coal mine

Located in the NE section 14, T17N, R105W. Sixteen samples (RS27 through RS42) were collected from an abandoned coal mine near Aspen Mountain south of Rock Springs (**Plate 2**). Two of the samples contained a trace and 0.080 ppm Au, respectively (samples RS31 and RS39, **Table 3**). The remaining samples did not contain detectable gold.

Continental Divide (Red Desert) coal

Scoria, coal, and associated rocks in the Wasatch Formation were sampled for gold in the Continental Divide area of the Red Desert (samples CD1 through CD31, **Figure 12**). The scoria (clinker) represents

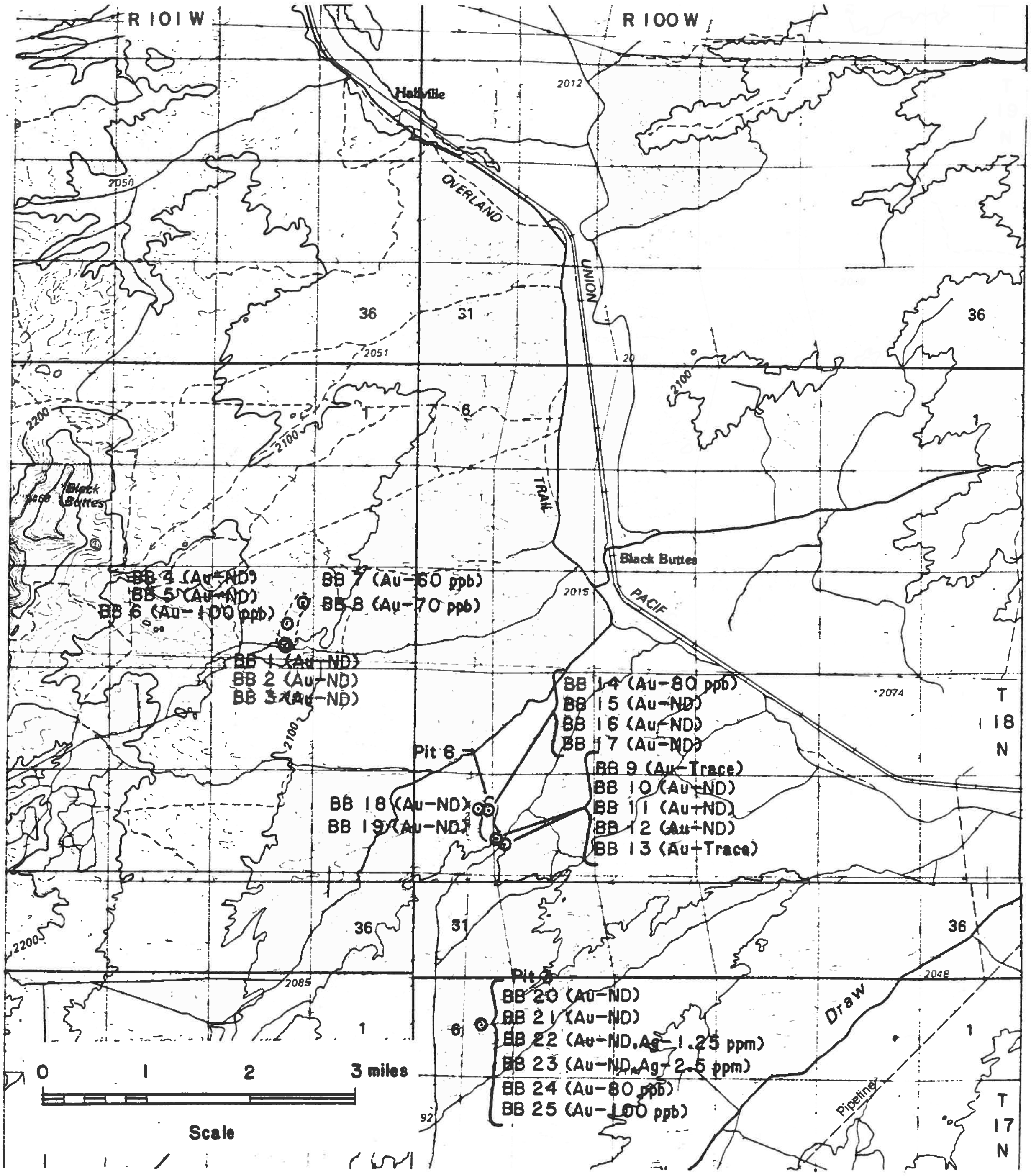

Figure 11. Sample location map of the Black Butte coal mine (Red Desert Basin and Kinney Rim 1:100,000-scale metric topographic maps). Sample numbers include gold analyses also listed in **Table 5** (ND=not detected, ppb=parts per billion).

baked rock formed from the burning of coal beds. Eight of 31 samples (25.8 percent) taken in this area yielded detectable gold ranging from a trace to 0.120 ppm Au (**Table 5**). The high gold values were from sandstones rather than from coal or clinker.

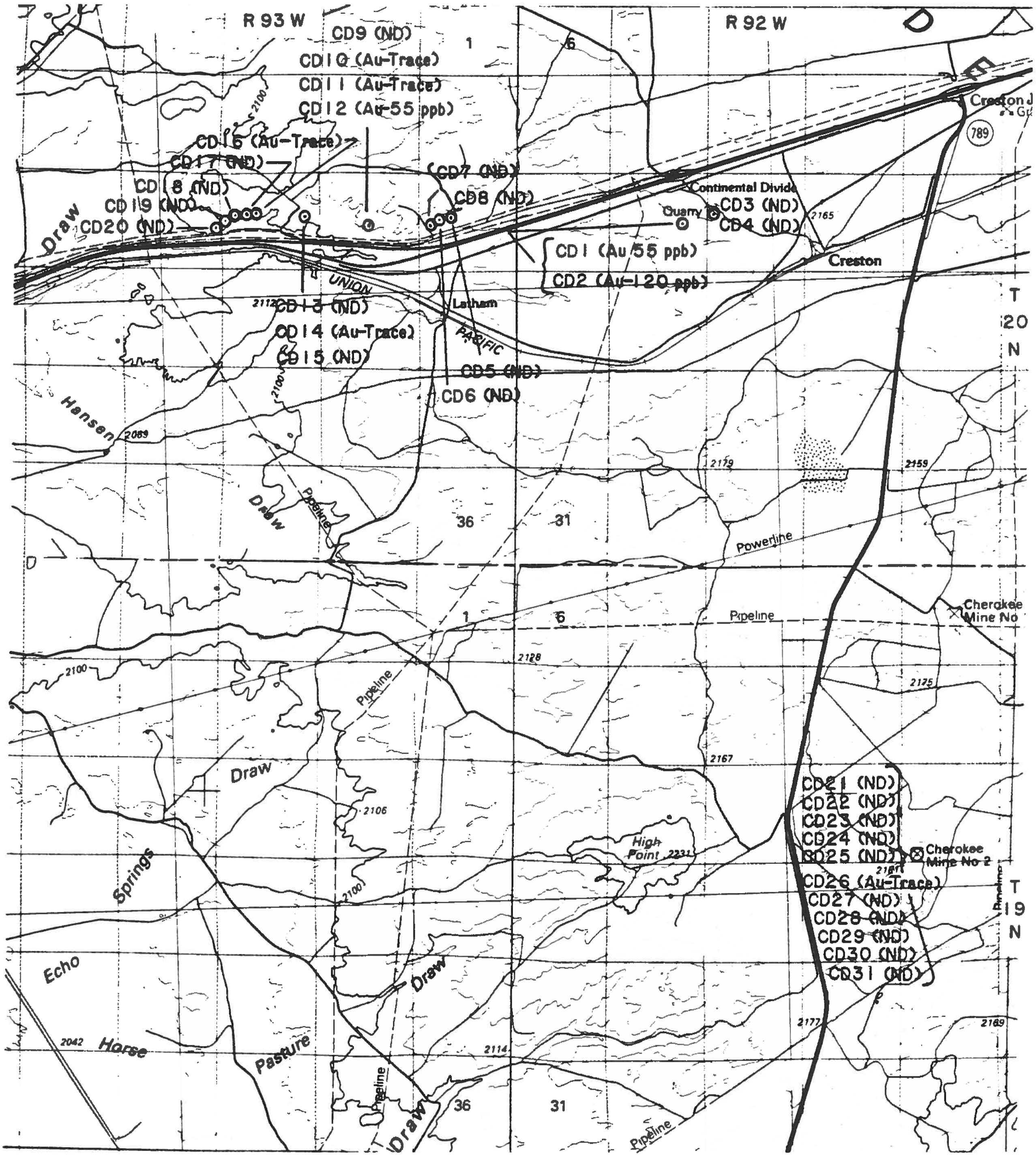

Figure 12. Sample location map of scoria, coal, shale, and sandstone near Wamsutter (Rawlins 1:100,000-scale metric topographic map). Sample numbers include gold analyses also listed in **Table 5** (ND=not detected, ppb=parts per billion).

Elk Mountain coal

A sample of coal was collected with carbonaceous shale and sandstone northwest of the town of Elk Mountain along Interstate 80 (**Figure 13**). A trace of gold was detected in the coal (sample WI12, **Table 6**). See **Precious metals in sandstone, shale, limestone, and tar sand,** below.

Table 6. Gold analyses of sandstone, shale, limestone, and tar sandstone from various areas in the Greater Green River Basin (ppm = parts per million, nd = not detected, tr = trace). Refer to figure number in bold for sample locations. Analyses by Gordon Marlatt.

Sample Number	Description	Au (ppm)
	Sandstone and carbonaceous shale east of Rawlins (Figure 9)	
WI1	carbonaceous shale	nd
WI2	carbonaceous shale	nd
WI3	buff sandstone	nd
WI4	gray, calcitic sandstone	nd
WI5	gray calcitic sandstone	nd
	Sandstone near Walcott Junction (Figure 10a)	
WI6	gray, well-sorted sandstone	nd
WI7	brown sandstone with minor conglomerate	nd
WI8	green to orange, well-sorted sandstone	nd
	Sandstone, shale, and coal northwest of Elk Mountain (Figure 13)	
WI9	sub-silicified sandstone	nd
WI10	white, kaolinitic sandstone	nd
WI11	gray fissile shale	nd
WI12	coal with abundant iron sulfate partings	tr
	Fossiliferous limestone, chert, and sandstone along Delaney Rim (Figure 14)	
WM1	stromatolitic limestone	nd
WM2	limestone	0.070
WM3	*Goniobasis* chert	0.100
WM4	conglomeratic sandstone	0.100
WM5	olive-green sandstone	0.070
WM6	gray-green sandstone	0.080
WM7	*Goniobasis* chert float	tr
WM8	fossiliferous claystone	nd
WM9	brown, silicified sandstone	nd
WM10	*Goniobasis* chert float	tr
WM11	*Goniobasis* chert	nd
WM12	black, *Goniobasis* chert float	0.100
WM13	soil sample	nd
WM14	tuffaceous claystone	nd
WM15	black *Goniobasic* chert	nd
WM16	olive-green siltstone	nd
WM17	*Goniobasis* chert	nd
WM18	soil sample	nd
WM19	*Goniobasis* and stromatolitic chert	nd
WM20	hard, silicified, oolitic chert	nd
WM21	soil sample	nd
WM22	fossiliferous chert	nd
WM23	fossiliferous chert	nd
WM24	soil sample	nd
WM25	brown chert	tr
WM26	soil sample at WM25	nd

Table 6 continued.

Sample Number	Description	Au (ppm)
WM27	oolitic limestone	0.060
WM28	oolitic limestone	nd
WM29	black chert replacing oolitic limestone	nd
WM30	soil sample at WM29	nd
WM31	fossiliferous chert	nd
WM32	soil sample at WM31	nd
WM33	black, fossiliferous chert	nd
WM34	soil sample at WM33	nd
WM35	brown, glassy fossiliferous chert	nd
WM36	soil sample at WM35	nd
TP2-91	*Goniobasis* limestone	nd
TP4-91	*Goniobasis* limestone	nd
TP5-91	*Goniobasis* limestone	0.180
TP6-91	*Goniobasis* limestone	nd
TP7-91	*Goniobasis* limestone	nd
TP8-91	*Goniobasis* limestone	nd
	Sandstone and coal in the Washakie Basin (Figure 15)	
BA1	manganese oxide (?)-cemented sandstone	nd
BA2	pyrolusite (?)-cemented sandstone	nd
BA3	orange, friable sandstone	nd
BA4	buff to gray, iron-stained sandstone	nd
BA5	gray to orange sandstone	nd
BA6	brown, oolitic, silicified sandstone	nd
BA7	calcite-cemented, lithic sandstone	nd
BA8	calcite-cemented, lithic sandstone	nd
BA9	lithic sandstone	nd
BA10	sandstone	nd
BA11	brown to black, silicified limestone	nd
BA12	brown to black chert float	nd
BA13	coal	nd
BA14	white to brown sandstone below coal	nd
	Sandstone, quartzite, and shale in the Red Desert along I-80 (Figure 16)	
RSJ1	brown, iron-stained sandstone	tr
RSJ2	gray-green hard shale (?)	nd
RSJ3	quartzite with some iron-rich boxworks after pyrite	nd
RSJ4	gray to green quartzite	nd
RSJ5	gray quartzite with manganese dendrites	nd
RSJ6	friable sandstone, iron-stained	nd
RSJ7	black to gray shale with quartz vein	0.060
RSJ8	brown to orange friable sandstone	nd
RSJ9	friable sandstone	nd
RSJ11	friable sandstone	nd
RSJ12	friable sandstone	tr
	Tar sandstone, sandstone, and claystone north of Baggs (Figure 17)	
TS1	iron-stained sandstone	0.060
TS2	lithic, tar-saturated sandstone	nd
TS3	white, kaolinitic sandstone	nd
TS4	brown to white sandstone	nd
TS5	brown calcitic, iron-stained sandstone	nd
TS6	claystone	nd
TS7	sandstone with iron oxide matrix	nd
TS8	tar-filled sandstone	nd
TS9	brown to white, calcite-cemented, lithic sandstone	nd
TS10	buff, calcite-cemented sandstone	0.090

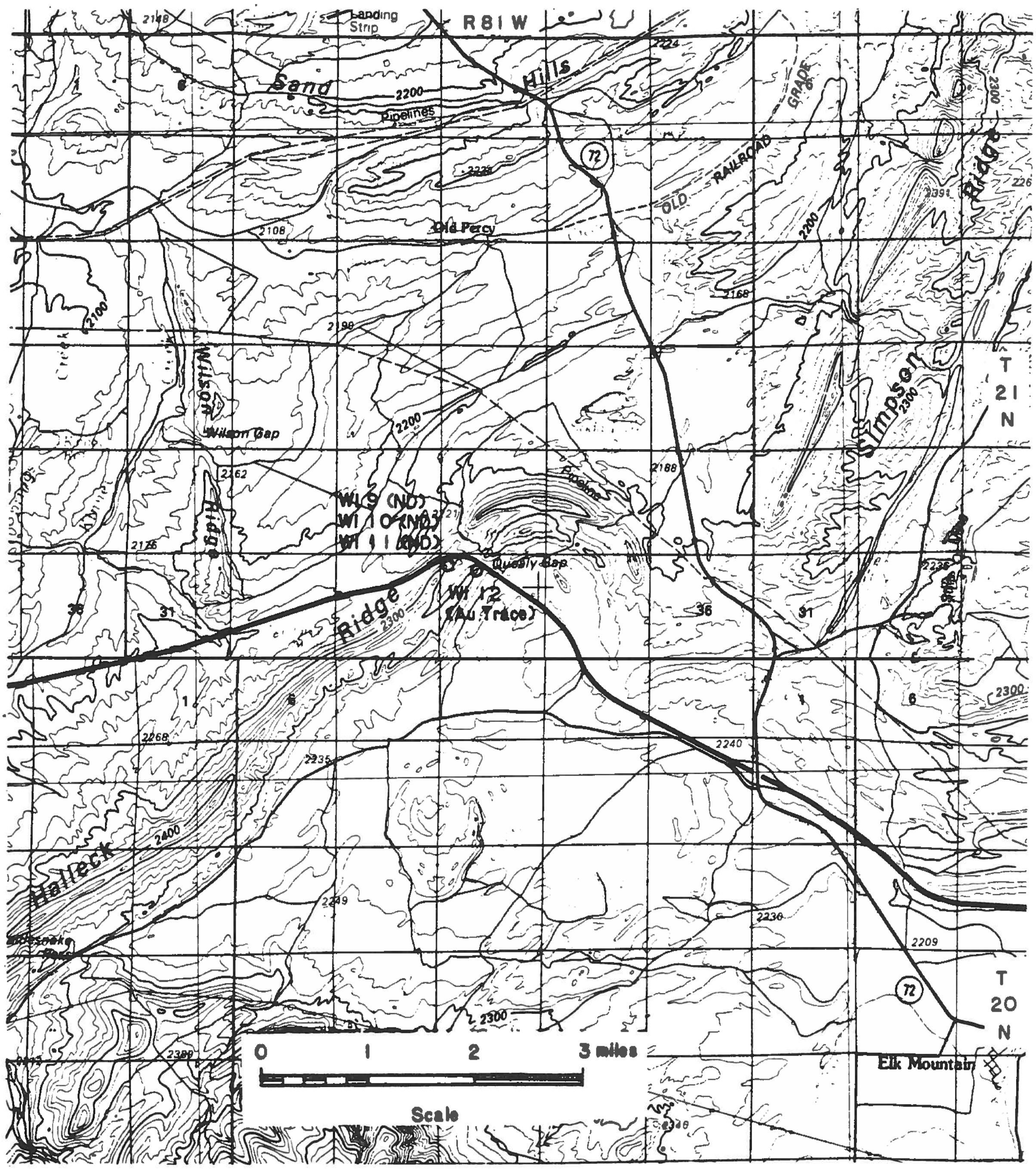

Figure 13. Sample location map of sandstone, shale, and coal collected northwest of the town of Elk Mountain (Medicine Bow 1:100,000-scale metric topographic map). Sample numbers include gold analyses also listed in **Table 6** (ND=not detected).

Precious metals in sandstone, shale, limestone, and tar sand, Green River and Hanna Basins

Sandstone, shale, limestone, and tar sands were sampled in the Green River and Hanna Basins (**Table 6**). Some results were encouraging, particularly samples taken along Delany Rim in the vicinity of Wamsutter. Gold in this area was initially identified by Dean Farris of Laramie, which led to the Geological Survey of Wyoming's investigation of the area. Samples yielded several gold anomalies (samples WM1 to WM36, TP2-91, and TP4-91 to TP8-91, **Table 6**) associated with *Goniobasis* chert and limestone in a thin unit of the Green River Formation (Tertiary) that crops out along Delany Rim (**Figure 14**). Of 42 samples, 11 (or 26 percent) contained detectable gold ranging from a trace to 0.180 ppm. The presence of gold in these rocks is not understood, although there are a notable number of rocks that have been agatized.

Other rocks sampled in this region, with the exception of scoria (**Table 5** and **Figure 12**), yielded only a few localized samples containing detectable gold. Samples of sandstone and weathered coal from the Washakie Basin west of Baggs yielded no detectable gold anomalies (**Figure 15** and **Table 6**). Sandstone and quartzite east of Point of Rocks yielded some weak gold anomalies (**Figure 16** and **Table 6**). Although tar sands sampled north of Baggs near Pine Butte yielded no detectable gold, two samples of sandstone in this same area yielded weak gold anomalies (**Figure 17** and **Table 6**).

Twelve samples of carbonaceous shale, coal, and sandstone collected adjacent to Interstate 80 east and west of Rawlins were also sampled and analyzed (**Table 6**). Samples WI1 through WI5 were collected in a road cut of the Frontier Formation between Rawlins and Sinclair (**Figure 9**). None of these contained detectable gold. Samples WI6 through WI8 were collected near Walcott Junction (**Figure 10a**). Gold was also not detected in any of these samples. Samples WI9 through WI12 were collected from outcrops in a hogback of the Pine Ridge Sandstone of the Mesaverde Group along Interstate 80 northeast of the town of Elk Mountain (**Figure 13**). One sample of coal contained a trace of gold (sample WI12, **Table 6**).

In summary, the most intriguing analyses listed in **Table 6** were those associated with fossiliferous limestone and chert on and near Delany Rim. The source of the gold is not known, but the widespread gold anomalies suggests this area may be worthy of further investigations.

Precious metal occurrences in sand and gravel deposits and placers

Introduction

As part of this project, staff from both Union Pacific Resources and the Geological Survey of Wyoming agreed that a study on sand and gravel resources and placers was paramount. With the exception of the established gold mining districts and a few areas outside of the districts, not much data are available on sand and gravel (S&G) deposits in the State. This is alarming in that thousands of cubic yards of gravel are mined Statewide each year, and no attention is paid to possibly valuable heavy minerals that might be recovered as a by-product. In other words, private industry, local, county, and state agencies could be (and probably are) unaware of or ignoring the potential for recovering these valuable by-products.

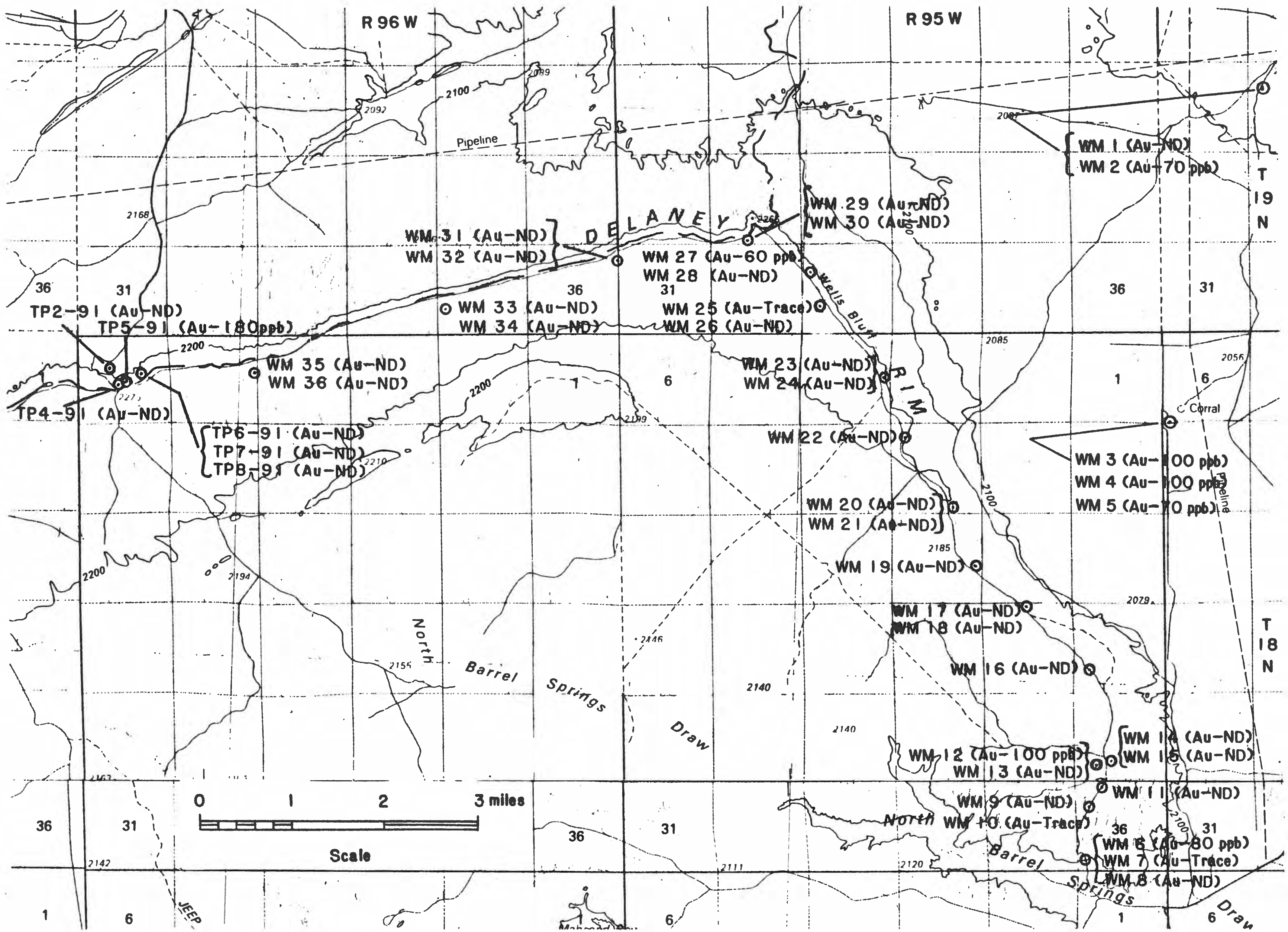

Figure 14. Sample location map of the Delany Rim fossiliferous limestones, cherts, and sandstones near Wamsutter (Kinney Rim and Red Desert Basin 1:100,000-scale metric topographic maps). Sample numbers include gold analyses also listed in **Table 6** (ND=not detected, ppb=parts per billion).

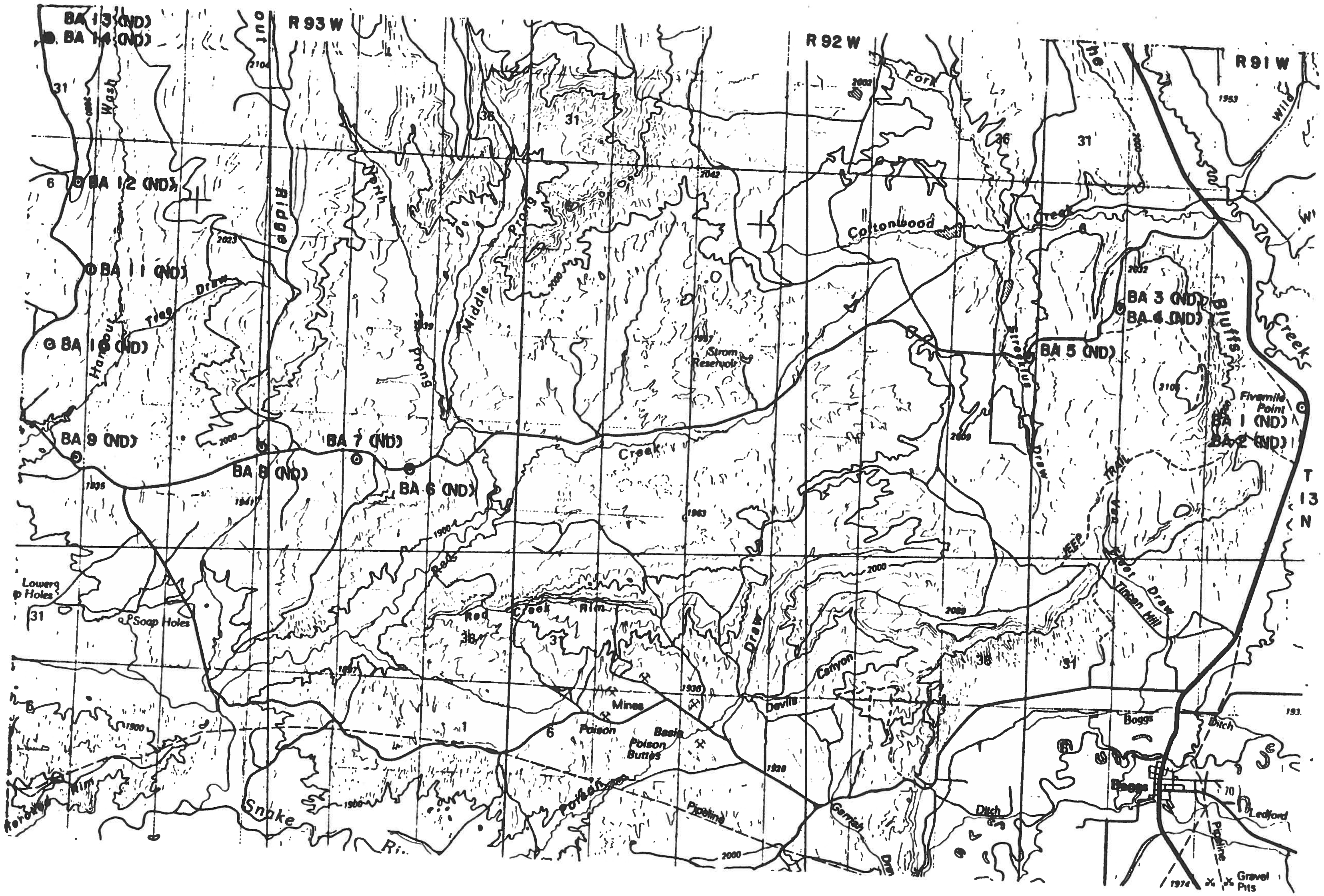

Figure 15. Sample location map of sandstone and coal in the Washakie Basin near Baggs (Baggs 1:100,000-scale metric topographic map). Sample numbers include gold analyses also listed in **Table 6** (ND=not detected).

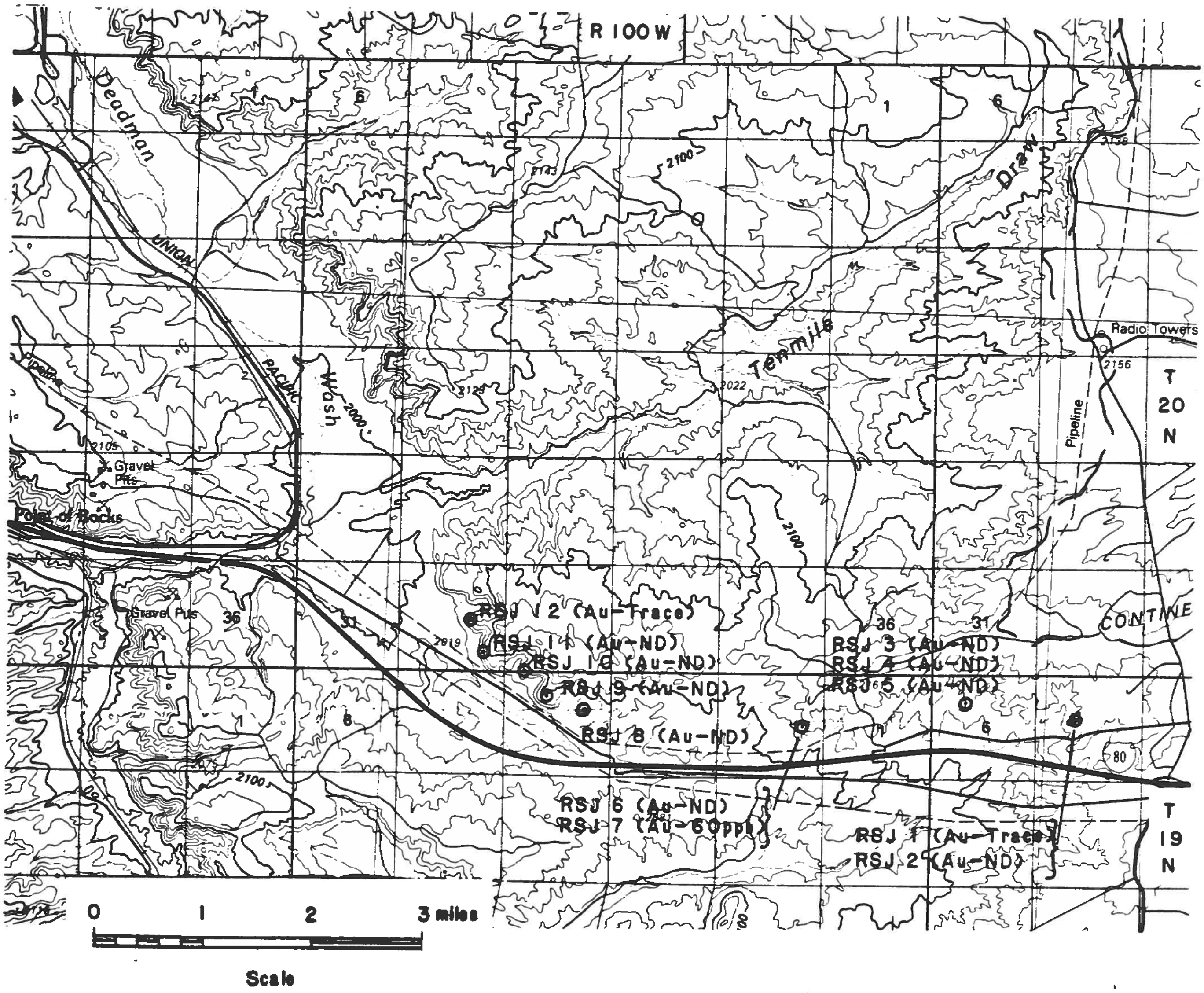

Figure 16. Sample location map of sandstone, quartzite, and shale along Interstate 80 east of Point of Rocks (Red Desert Basin 1:100,000-scale metric topographic map). Sample numbers include gold analyses also listed in **Table 6** (ND=not detected, ppb=parts per billion).

The results of this study are encouraging: we established gold anomalies everywhere we sampled. All of the anomalous samples collected contained smaller than pinhead colors or no observable gold. The volume of material collected at each sample site was small, therefore the possibility of finding coarser gold should be good. However, the lack of coarse gold may cause concern for recovery, particularly if gravity separation circuits would be used to extract gold from some S&G pits. Fine gold is difficult to recover by gravity methods; it may be prudent to research the feasibility of various gravity and chemical leach methods. If gold recovery can be done inexpensively and with equipment that is simple to operate, by-product gold (and other valuable heavy minerals) could possibly be recovered from some S&G operations in the State. Other heavy minerals that might be recovered and have already been reported in placers in the State include native platinum, palladium, and silver; diamond, garnet, scheelite ($CaWO_3$), cassiterite (SnO_2), chromite (Cr_2O_3), ruby, sapphire, aquamarine, topaz, and monazite.

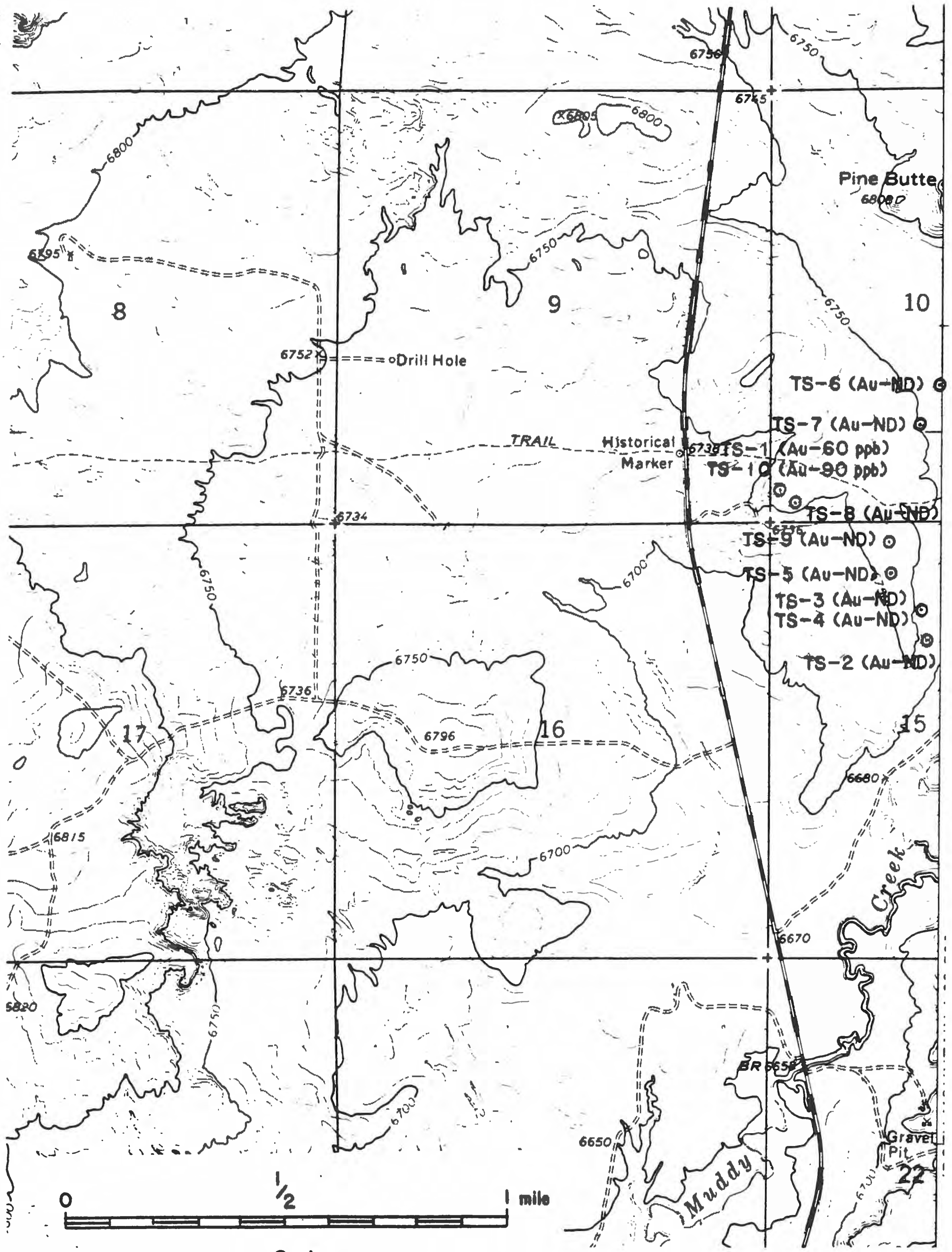

Figure 17. Sample location map of tar sand, sandstone, and claystone north of Baggs along Wyoming Highway 789 (sections 10 and 15, T17N, R92W) (Duck Lake 1:24,000-scale topographic quadrangle map). Sample numbers include gold analyses also listed in **Table 6** (ND=not detected, ppb=parts per billion).

One example of the loss of a potential resource of by-products from a sand and gravel operation occurred during the past decade when the Rob Roy Reservoir in the Medicine Bow Mountains was dredged and the dam expanded. The reservoir lies within the Douglas Creek placer district, a historic gold mining district that produced a few thousand ounces of gold and some platinum and palladium. If a heavy mineral recovery circuit had been used during the dredging of the reservoir, enough gold could have been recovered to defray some of the costs of expanding the reservoir. It has been said by more than one prospector that the Rob Roy Dam is probably worth its weight in gold!

Our objective for this study was only to establish the presence or absence of gold, and no attempt was made to determine the grades of the gold-bearing gravels. To establish reliable placer grades would require the taking of large bulk samples on closely-spaced grids, a procedure that was well beyond the scope of this project.

Sample collecting and processing

Samples of sand and gravel (S&G) were collected from various locations in S&G pits that appeared favorable for gold deposition. These included layers of S&G with large pebble- and cobble-size material and/or layers of black sand. The samples were panned and all of the panned concentrates in a single gravel pit were combined for analysis. A second sample, which consisted of unprocessed material, was also taken (noted as a grab sample) and processed in a Gold Scavenger at the Geological Survey of Wyoming.

Some streams (placers) were also sampled where sand and gravel had accumulated in bar or in channel deposits. Natural traps at the ends of the bars, at the lower end of swift water runs, behind boulders and other obstructions, and anywhere else gold may have been deposited were chosen as sample sites. Typically, greater accumulations of coarse gold occur in the lower levels of thick placer deposits at or near bedrock or false bedrock. These lower levels were not accessible using a shovel and bucket.

The small volume of material collected from the placers and S&G pits represented only a very small portion of the placer, thus large areas of gold accumulation could easily have been overlooked and in all probability, were overlooked.

Panning was accomplished using a green plastic 14-inch Garrett gold pan. Material was panned down to heavy black sand concentrates. Sufficient time was spent panning material from each location in order to collect adequate concentrates for analysis. Where black sand was scarce, more time was necessary to collect enough concentrates for a good sample. Several samples contained visible gold particles, and some of these particles were removed for microscopic examination to study the morphology for evidence of crystal growth. In a few cases, all of the visible gold was removed for examination. In this latter case, the sample was not assayed since the visible gold was removed and it was already obvious that the sample was anomalous. None of the recovered particles showed evidence of crystal growth.

The grab samples were transported to the Geological Survey of Wyoming for processing. These were dried, crushed to 30 mesh, and processed in a Gold Scavenger. This device is designed to stratify the sample under water pressure in order to concentrate gold in layers. All of the sample concentrates, either panned in the field or stratified in the Scavenger, were then analyzed by standard AA at the Geological Survey of Wyoming's laboratory.

Sand and gravel deposits and placers

Laramie River

The Laramie River along the outskirts of the city of Laramie contains sizable sand and gravel (S&G) resources within the confines of its river bed, as well as in the adjacent floodplains and terraces. The sand and gravel resources are immense and are continually being mined for construction projects in and around Laramie. In the recent past, some Laramie residents have reported finding gold in the Laramie River. These reports have now been verified by this study. Several samples of S&G were collected in terrace deposits of the Laramie River, both north and south of town.

Dirt Bike track gravel pit

Located in the SE NE SW section 9, T16N, R73W. Approximately 2.5 miles north of the city of Laramie adjacent to U.S. Highway 287/30. On the east side of the Highway 287 (**Figure 18**), Laramie River terrace gravel is used as a recreational dirt bike track. Sand and gravel is also recovered from the south end of the deposit. The gravel beds are only a few feet thick at the excavation site.

The gravel was reported to contain anomalous gold (Dean Farris, personal communication, 1991). Anomalous gold has also been reported nearby in some fluvial sands of the Chugwater Formation in the Laramie landfill (Bob Jones, personal communication, 1988), but this location was not investigated.

A small grab sample was collected from the exposed gravel in the bank on the west edge of the bike pit, approximately 3 feet below the level of the highway. The sample was processed in the Gold Scavenger. The sample concentrate yielded 1.7 ppm Au (sample SG1-91, **Table 7**).

Western Mobile gravel pit

Western Mobile Corporation operates a S&G operation in the W2 section 16, E2 E2 section 8, and W2 SW section 9, T16N, R73W, bordering the Laramie River (**Figure 18**). Approximately 200 acres of gravel resources, 7 to 9 feet thick, occur on both sides of the river in this area (Dale Hiatt, Western Mobile Corp., personal communication to Eric Nielsen, 1991).

Sand and gravel had been bulldozed on the south side of the excavation. Material from the dozer piles was chosen due to the presence of visible black sand and the probability that this material was from the deepest point of excavation. Relatively large amounts of black sand concentrates with some tiny particles of gold about the size of a pin point were recovered from the panned samples. Panned concentrate assays yielded an average of 0.87 ppm Au (samples SG3-91 and SG3B-91, **Table 7**). Grab sample concentrates yielded 1.2 ppm Au (sample SG3A-91, **Table 7**).

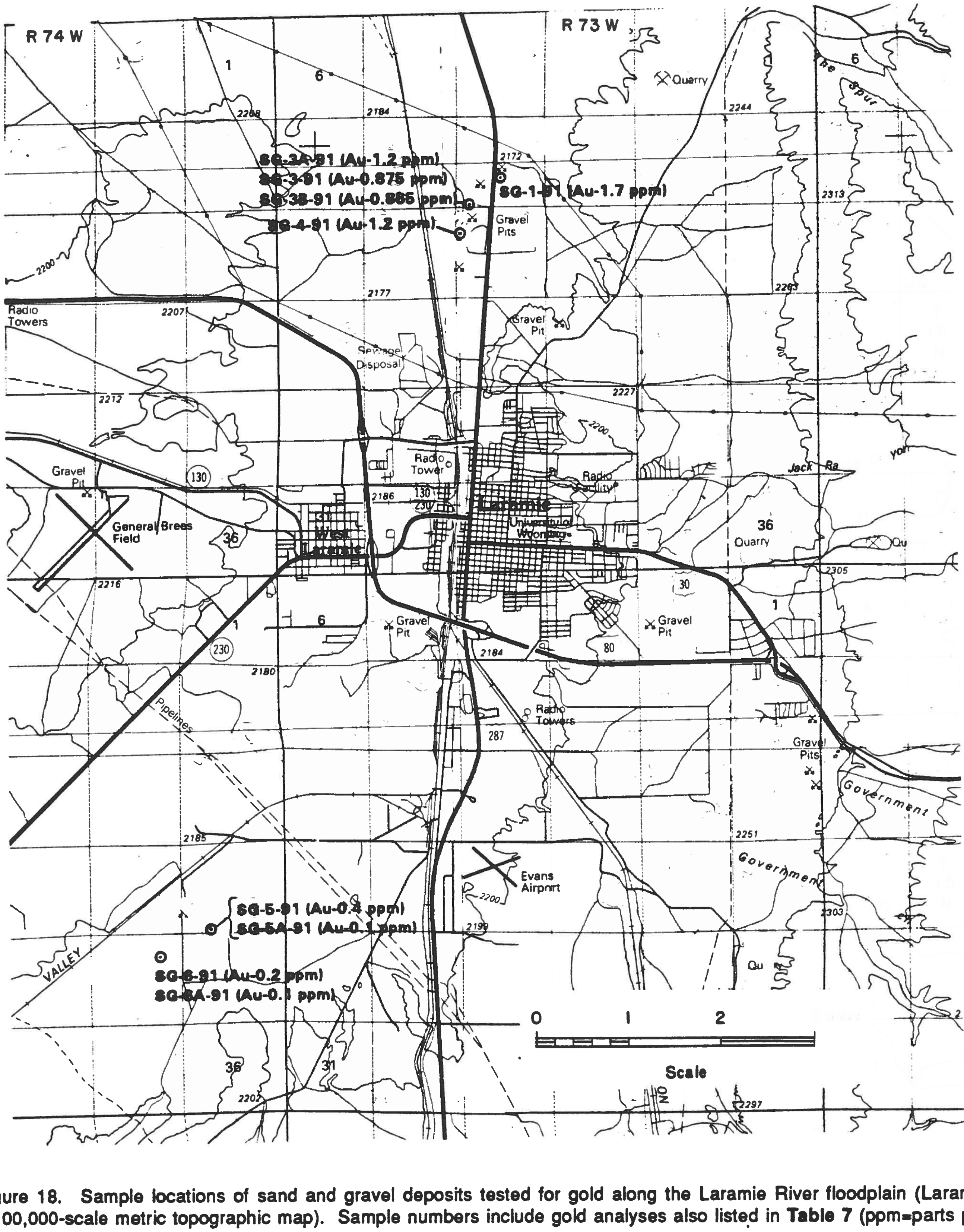

Figure 18. Sample locations of sand and gravel deposits tested for gold along the Laramie River floodplain (Laramie 1:100,000-scale metric topographic map). Sample numbers include gold analyses also listed in **Table 7** (ppm=parts per million).

Table 7. Results of sand and gravel deposits tested for gold (ppm = parts per million, nd = not detected). Refer to figure number for sample locations. Analyses by Robert W. Gregory.

Sample Number	Description	Au (ppm)
	Laramie River floodplain (Figure 18)	
SG1-91	Grab sample concentrates, dirt bike pit	1.7
SG3-91	Panned concentrates, Western Mobile pit, Laramie River	0.88
SG3A-91	Grab sample concentrates, Western Mobile pit, Laramie River	1.2
SG3B-91	Panned concentrates, Western Mobile pit, Laramie River	0.87
SG4-91	Wash pit concentrates, Laramie River	1.2
SG5-91	Grab sample concentrates, Laramie River	0.4
SG5A-91	Panned concentrates, Laramie River	0.1
SG6-91	Grab sample concentrates, Laramie River	0.2
SG6A-91	Panned concentrates, Laramie River	0.1
	Little Laramie River (Figure 19)	
SG17-91	Grab sample concentrates, Little Laramie River	12.7
	Cooper Hill district and Arlington area (Figure 20)	
SG7-91	Grab sample concentrates, Cooper Cove pit	4.4
SG7A-91	Panned concentrates, Cooper Cove pit	8.8
SG8-91	Grab sample concentrates, Cooper Creek	>9.4
SG8A-91	Panned concentrates, Cooper Creek	30.2
SG11-91	Grab sample concentrates, Cooper Creek placer	>36.5
SG12-91	Grab sample concentrates, Cooper Creek placer	0.3
SG12A-91	Panned concentrates, Cooper Creek placer	24.0
SG13-91	Grab sample concentrates, Cooper Creek placer	1.8
SG13A-91	Panned concentrates, Cooper Creek placer	35.9
SG9-91	Grab sample concentrates, North Fork Cooper Creek	2.6
SG9A-91	Panned concentrates, North Fork Cooper Creek	>10.0
SG10-91	Grab sample concentrates, North Fork Cooper Creek	8.0
SG14A-91	Panned concentrates, Rock Creek placer	>100.0
SG2-91	Grab sample concentrates, Arlington pit	4.7
SG2A-91	Panned concentrates, Arlington pit	>100.0
	North Platte River near Ft. Steele (Figure 21)	
SG15-91	Grab sample concentrates, Ft. Steele pit	0.3
SG15A-91	Panned concentrates, Ft. Steele pit	2.2
SG16-91	Grab sample concentrates, North Platte River	nd
SG16A-91	Panned concentrates, North Platte River	2.7
SG16B-91	Panned concentrates, wash pit, North Platte River	8.0
SG16W-91	Grab sample concentrates, wash pit, North Platte River	nd
	Green River northwest of Green River townsite (Figure 22)	
ST1-91	Grab sample concentrates, Green River	2.8
	Blacks Fork at Granger (Figure 23)	
GG1-91	Grab sample concentrates, Blacks Fork	2.2
	Red Creek or Richards Gap (Figure 5)	
RG5-91	Grab sample concentrates, Red Creek	11.4

Western Mobile gravel processing site

Located in the W2 section 16,T16N, R73W. A sample was collected from the wash pit where material from Western Mobile's gravel pits in the Laramie area was processed. The probable source of the material sampled, according to Western Mobile, was from their S&G pits located in SW section 24, T15N, R74W (**Figure 18**). Concentrates from this panned sample yielded 1.2 ppm Au (sample SG4-91, **Table 7**).

Sand and gravel pits southwest of Laramie

A large gravel pit leased by Western Mobile Corporation in the SW section 24, T15N, R74W, was sampled along the Laramie River southwest of Laramie (**Figure 18**). Approximately 80 to 100 acres of gravel resources in a 9- to 12-foot thick bed occur in the pit area. The deposit thins and pinches out in the surrounding ridges to the east and southeast.

Panned concentrates contained abundant black sands and a few tiny particles of gold smaller than a pin head. Panned concentrates assayed 0.1 ppm Au, and grab sample concentrates assayed 0.4 ppm Au (samples SG5-91 and SG5A-91, respectively, **Table 7**).

A short distance to the southwest (NE section 26, T15N, R74W), another pit was sampled (**Figure 18**). The entire surrounding area has gravel pits of varying sizes. Much of the terrane to the north, west, and south also appears to have significant gravel resources. Panned concentrates from this location assayed 0.1 ppm Au and concentrates from a grab sample assayed 0.2 ppm Au (samples SG6A-91 and SG6-91, respectively, **Table 7**).

Little Laramie River

The Little Laramie River flows northeast from the east side of the Medicine Bow Mountains through Centennial Valley and converges with the Laramie River downstream. The Middle Fork of the Little Laramie River flows through the Centennial Ridge district on the eastern flank of the Medicine Bow Mountains. This district was developed for gold and platinum in the 1870s.

NE section 1, T15N, R77W

Samples were collected from the Little Laramie River north of Table Mountain and Wyoming Highway 130 (**Figure 19**), 6 miles east of the Centennial Ridge district. The samples were collected approximately 100 yards south of the Union Pacific Railroad trestle which bridges the river.

The samples were collected from a sand bar along the west bank of the river. The panned concentrate (sample SG17A-91) contained a relatively large amount of black sand with abundant almandine garnet. Small particles of visible gold were observed in nearly every pan, and all of the visible gold from the panned concentrate was removed for microscopic examination. This sample was not assayed. Sample concentrates from a grab sample from this location assayed 12.7 ppm Au (sample SG17-91, **Table 7**). Considering the distance this sample was collected from the Centennial Ridge district (about 6 miles), gravels upstream from the samples deserve serious consideration for prospecting.

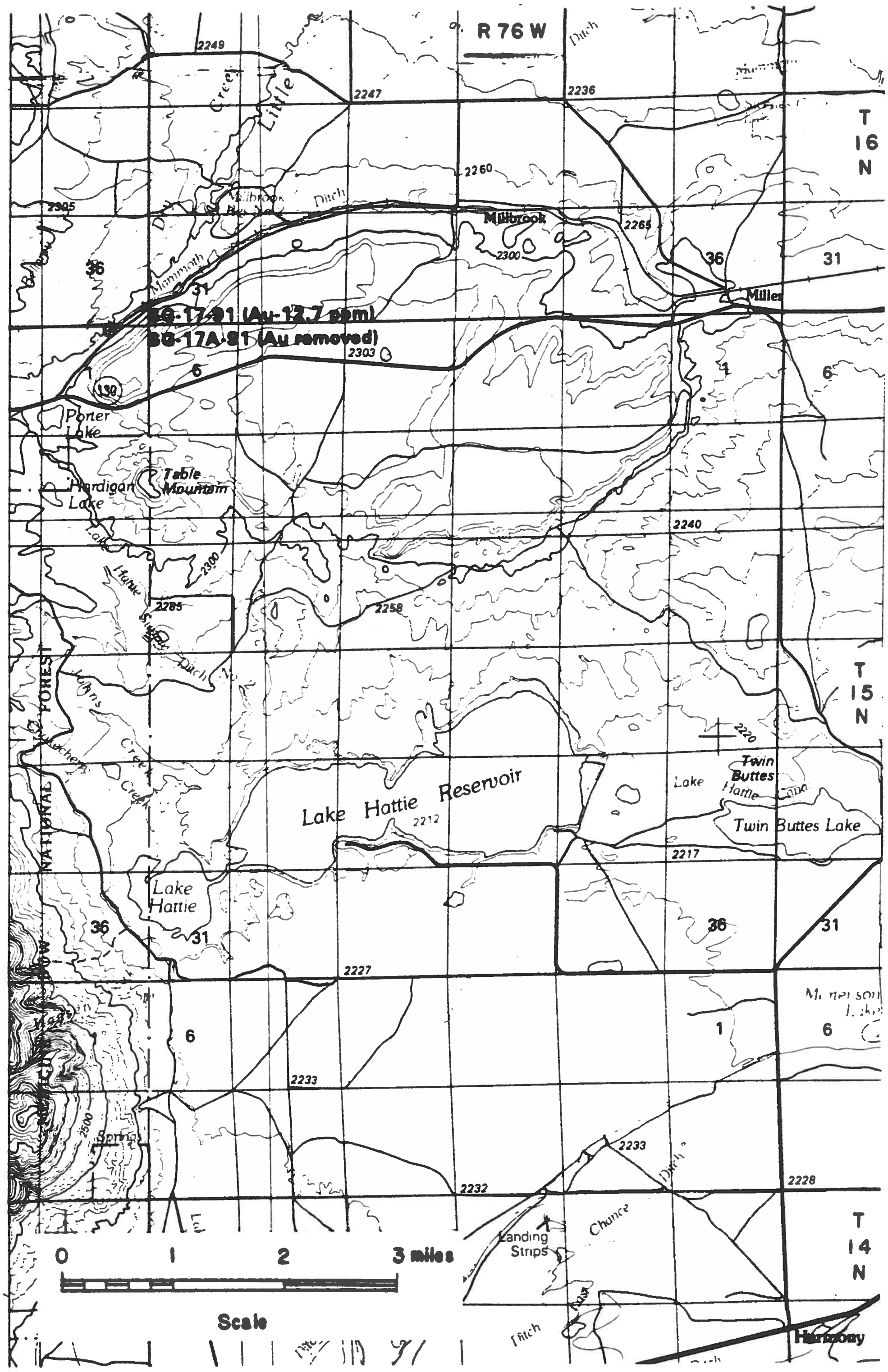

Figure 19. Sample location map for the Little Laramie River placer deposit north of Wyoming Highway 130 near Table Mountain (Laramie 1:100,000-scale metric topographic map). Sample numbers include gold analyses also listed in Table 7 (ppm=parts per million).

Cooper Creek

Cooper Creek and its tributaries flow northeast from the south end of Cooper Hill. Cooper Creek lies within the Cooper Hill mining district, which consists of Proterozoic metasedimentary and metaigneous rocks. Several samples taken along Cooper Creek and the North Fork of Cooper Creek contained visible gold (**Figure 20**). The ubiquity of gold in the sample concentrates suggest this area should be examined in detail.

Cooper Cove gravel pit

Samples were collected in a gravel pit (NE SE section 19, T18N, R77W) that lies on a low ridge capped by an oil pumping station (**Figure 20**). The gravel exposed in the pit is 12 to 15 feet thick. About 10 acres of surface area are underlain by gravel. The deposit consisted of pebbles and cobbles mixed with sand. Panned concentrates from the bottom of the pit yielded 8.8 ppm Au and grab sample concentrates assayed 4.4 ppm Au (samples SG7A-91 and SG7-91, respectively, **Table 7**).

SW NW NW section 21, T18N, R77W

Approximately 200 yards southwest of the Interstate 80 bridge over Cooper Creek are some small gravel deposits in the creek (**Figure 20**). The material consists of tightly packed pebbles and cobbles. Material was panned over a distance of about 100 yards and tiny particles of gold were observed in the concentrates. One flake was removed for microscopic study. The remaining panned concentrates assayed 35.9 ppm Au and grab sample concentrates yielded 1.8 ppm Au (samples SG13A-91 and SG13-91, respectively, **Table 7**).

E2 NE section 25, T18N, R78W

Limited sand and gravel deposits along a 300-yard-long stretch of Cooper Creek were sampled and panned (**Figure 20**). The stream channel is floored by mud with sand and gravel in the side channels and main channel. Even though black sands are relatively sparse, some visible gold was observed in the concentrates. Panned concentrates yielded 30.2 ppm Au and grab sample concentrates assayed greater than 9.4 ppm Au (samples SG8A-91 and SG8-91, respectively, **Table 7**).

SW NE SE section 35, T18N, R78W

Approximately 1 mile east of Cooper Hill, Cooper Creek contains abundant sand and gravel bars and channel deposits. A gravel bar provided an adequate amount of black sand concentrates as well as several small flakes of gold. The gold flakes were recovered from the panned concentrates (sample SG11A-91, **Figure 20**) for microscopic examination. A grab sample concentrate from this location was assayed and yielded greater than 36.5 ppm Au (sample SG11-91, **Table 7**).

E2 NE SE section 35, T18N, R78W

A cut several feet deep into the hillside north of Cooper Creek contained some gravel. At the base of the cut was a small alluvial fan eroded from the cut. The material in the cut was sampled and yielded relatively minor amounts of black sand. Tiny particles of visible gold were present and the panned concentrates assayed 24 ppm Au (sample SG12A-91, **Table 7**). Grab sample concentrates assayed 0.3 ppm Au (sample SG12-91, **Table 7**).

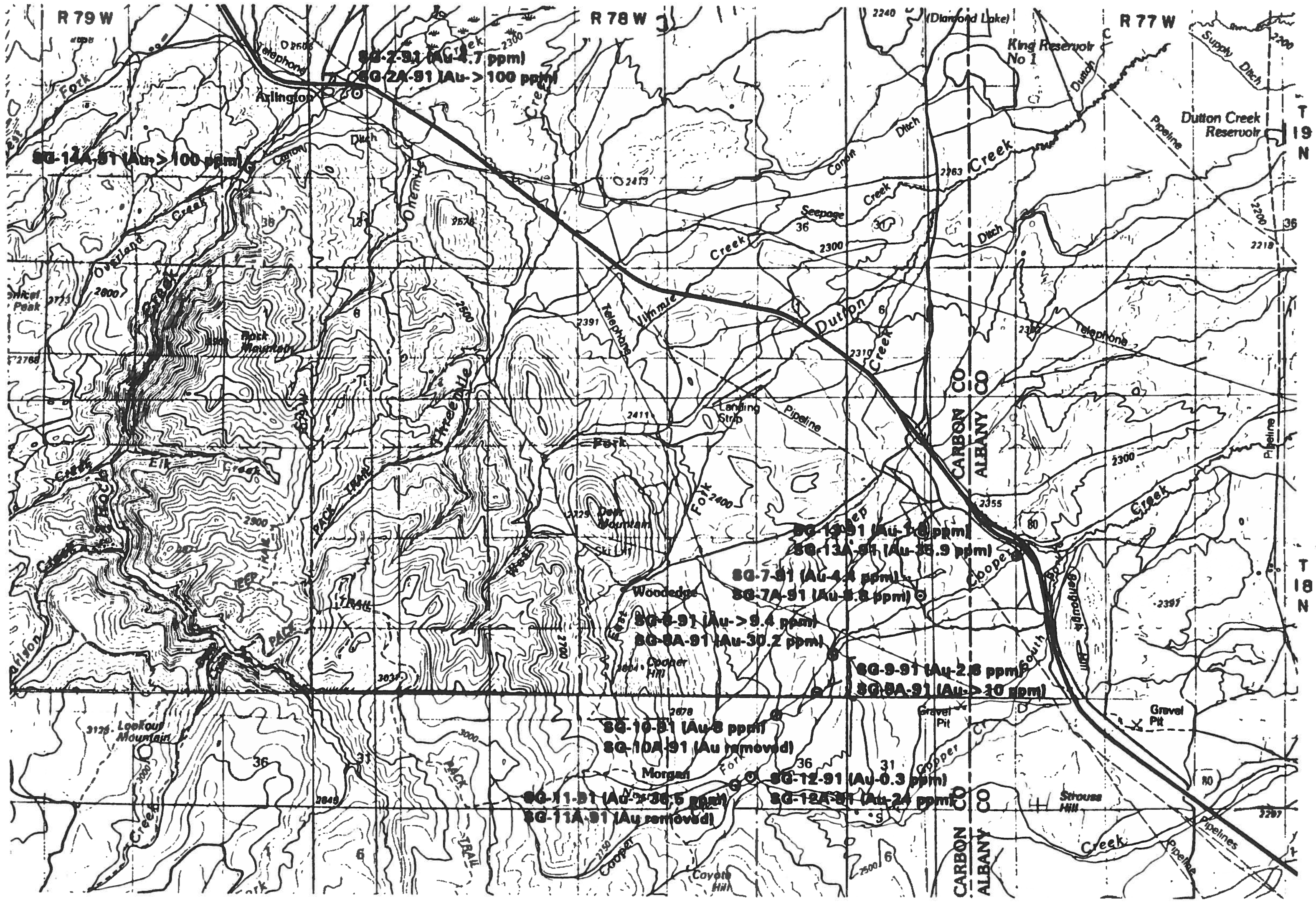

Figure 20. Sample location map for sand and gravel and placer sites tested for gold in the Cooper Hill district and Arlington area (Medicine Bow and Saratoga 1:100,000-scale metric topographic maps). Sample numbers include gold analyses also listed in **Table 7** (ppm=parts per million).

North Fork of Cooper Creek

Stream sample concentrates collected on the North Fork of Cooper Creek all contained visible gold as did the samples on Cooper Creek (**Figure 20**).

W2 SE section 25, T18N, R78W

Small sand and gravel accumulations south of a beaver dam were sampled along a 100-foot-long stretch of the North Fork (**Figure 20**). Several tiny colors and one gold flake were panned and the flake was removed from the concentrates for microscopic examination. These panned concentrates assayed greater than 10 ppm Au and the concentrates from a grab sample assayed 2.6 ppm Au (samples SG9A-91 and SG9-91, respectively, **Table 7**).

SE SW SW section 25, T18N, R78W

Bar and channel deposits were sampled over a distance of about 200 feet upstream and downstream from the ford of a trail that crosses the North Fork of Cooper Creek. The sand and gravel was abundant in areal extent but in very thin beds. The stream bed under these deposits consists of a cohesive, moderately compacted clay. Panned concentrates (sample SG10A-91, **Figure 20**) contained several easily visible gold colors. The visible gold was removed for microscopic examination. Concentrates from a grab sample from this same location yielded 8.0 ppm Au (sample SG10-91, **Table 7**).

Rock Creek

Rock Creek drains part of the the northern Medicine Bow Mountains, an area consisting of Proterozoic miogeoclinal metamorphics that overlie Archean basement rocks. This area is underlain by metasedimentary and metaigneous rocks, including several beds of metaconglomerate. Similarities have been suggested between some of these metaconglomerates and the auriferous metaconglomerates of the Witwatersrand of South Africa. In the recent past, radioactive minerals and a few gold anomalies have been detected in some metaconglomerates in the Medicine Bow Mountains.

Rock Creek also cuts rock that hosts some weakly mineralized shear zones and quartz veins. Several prospects occur upstream from Arlington on the high mountainsides bordering Rock Creek. A few prospects also occur on the bank of Rock Creek a few miles upstream from Arlington. At one of these prospects, sulfides with traces of copper were found. An early report by Hague and Emmons (1877) and a subsequent report by Hyden and others (1967) both mentioned placer gold on Rock Creek. Duncan (1990) also reports that this area was once included in the historic Herman mining district.

Brokaw-Pitcher pit near Arlington

A large gravel pit east of Arlington (N2 section 30, T19N, R78W) is a S&G source for the Wyoming Department of Transportation (**Figure 20**). The pit contains sand, gravel, and boulders carried downstream (north) by Rock Creek. Approximately 350,000 cubic yards of material remain in the pit above the water table (Ted Wells, personal communication to Eric Nielsen, 1991). An additional S&G resource lies below the water table.

Samples were collected in the north half of the pit from various sites and the resulting concentrates were combined for assay. These panned concentrates contained several particles of visible gold and assayed greater than 100 ppm Au (sample SG2A-91,**Table 7**). An assay of grab sample concentrates yielded 4.7 ppm Au (sample SG2-91, **Table 7**).

Rock Creek placer

A sample was collected from a sand bar in Rock Creek (SW section 25, T19N, R79W) (**Figure 20**). The bar is dominated by sand size particles with little to no gravel, and by relatively minor amounts of black sand. Only a small quantity of panned concentrates was collected but these assayed greater than 100 ppm Au (sample SG14A-91, **Table 7**).

North Platte River

On either side of Interstate 80 along the North Platte River at Fort Steele are several sand and gravel pits (**Figure 21**). Samples were collected from both sides of the Interstate for gold analysis.

SE SE SW section 26, T21N, R85W

North of the Interstate near the public rest area at historical Fort Steele, is a 1- to 7-foot-thick sand and gravel deposit with an areal extent of 5 to 10 acres. Panned sample concentrates from here assayed 2.2 ppm Au and grab sample concentrates assayed 0.3 ppm Au (samples SG15A-91 and SG15-91, respectively, **Table 7**).

W2 W2 section 36, T21N, R85W

A second deposit on the south side of the Interstate forms a terrace on the east bank of the Platte River. This deposit consists of poorly sorted sand, pebbles, and cobbles. A sample was collected from the bottom of a 20-foot-long, 10- to 12-foot-deep trench in an active S&G pit. The panned concentrates from this gravel bed assayed 2.7 ppm Au, but grab sample concentrates yielded no detectable gold (samples SG16A-91 and SG16-91, respectively, **Table 7**). Panned concentrates from the sand in a wash pit yielded 8.0 ppm Au and a grab sample concentrate from the wash pit yielded no detectable gold (samples SG16B-91 and SG16W-91, respectively, **Table 7**).

Green River

Sand and gravel along the Green River is widespread and constitutes an enormous resource. The deposits extend from the river banks into the adjacent terraces for distances up to 3 miles from the river bed. The Green River has long been known for its fine particles of gold.

Sections 25 and 36, T19N, R108W

A grab sample consisting of six 5-gallon buckets was dug from the eastern river bank on the section line about 4 to 5 miles northwest of the town of Green River (**Figure 22**). This sample of sand with minor pebbles was dug from the grass roots down to a depth of about 3 feet. The material was dominated by light minerals with a very small proportion of heavy black sands. The sample was transported to the Geological Survey of Wyoming for processing; part of it was panned and the remaining material was processed in the Gold Scavenger. The concentrates were combined and assayed 2.8 ppm Au (sample ST1-91, **Table 7**).

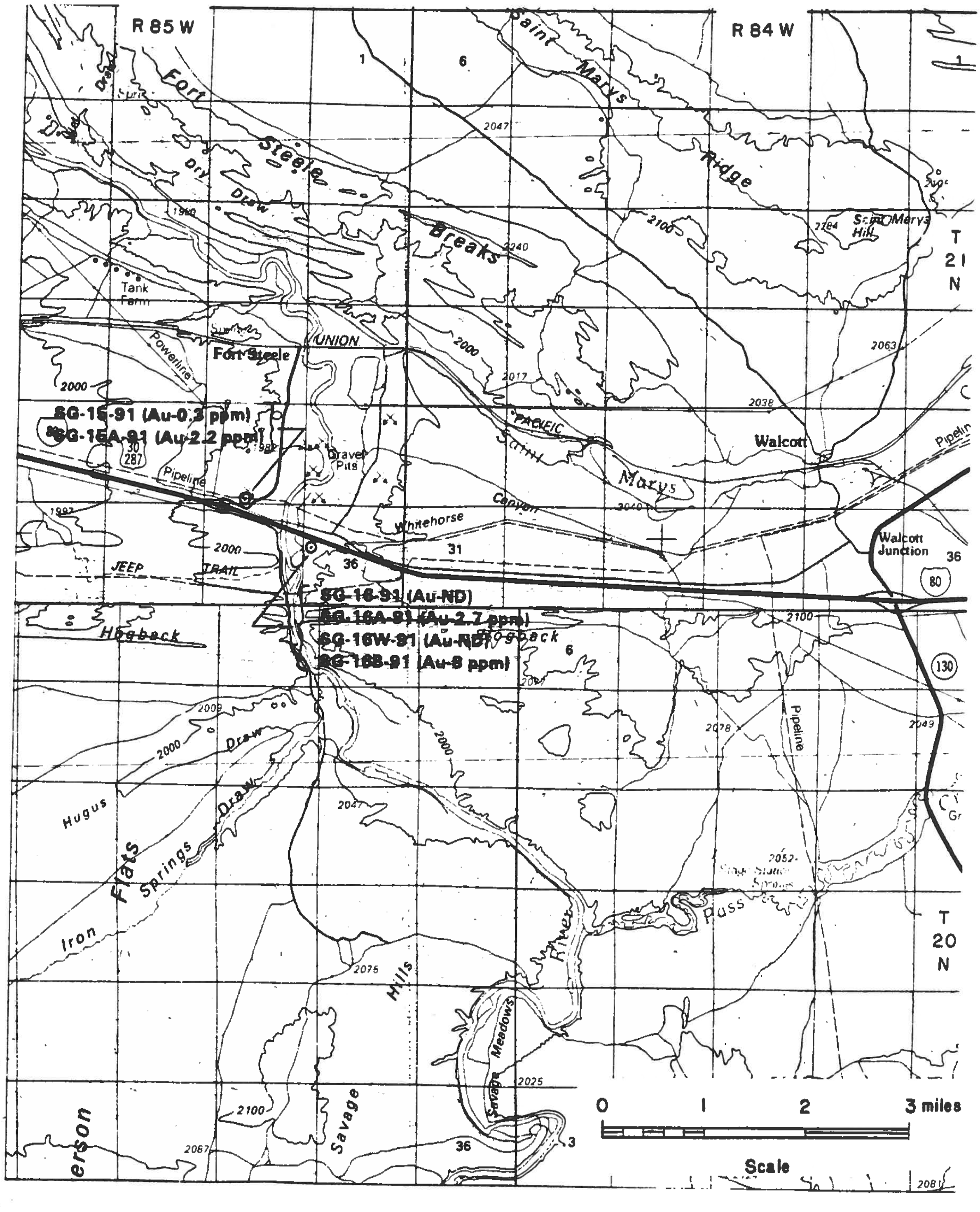

Figure 21. Sample location map for sand and gravel deposits tested for gold on the North Platte River near Fort Steele (Medicine Bow 1:100,000-scale metric topographic map). Sample numbers include gold analyses also listed in **Table 7** (ND=not detected, ppm=parts per million).

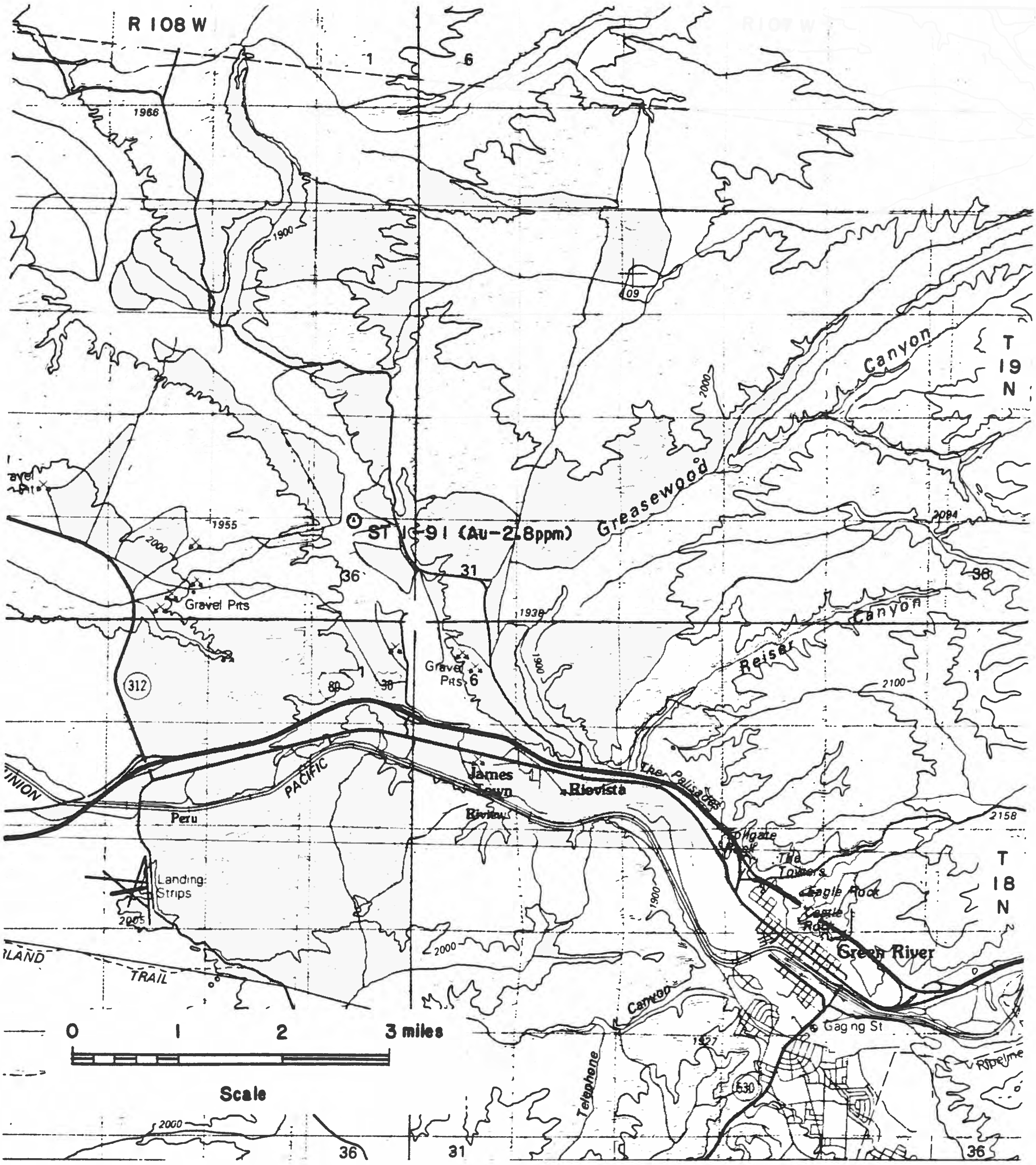

Figure 22. Sample location map for sand and gravel along the Green River (Rock Springs 1:100,000-scale metric topographic map). Sample number includes a gold analysis also listed in **Table 7** (ppm=parts per million).

Granger

A sample was taken from an active S&G pit (NE section 29, T19N, R111W) operated by Union Pacific along the Blacks Fork near its confluence with the Hams Fork, about half a mile northeast of the town of Granger (**Figure 23**). The sample, consisting of seven 5-gallon buckets, was collected from washed and sorted material. The sand and gravel resource in this area appears to be large. The sample was panned and concentrated in the Gold Scavenger and the combined concentrates were assayed. The sample yielded 2.2 ppm Au (sample GG1-91, **Table 7**).

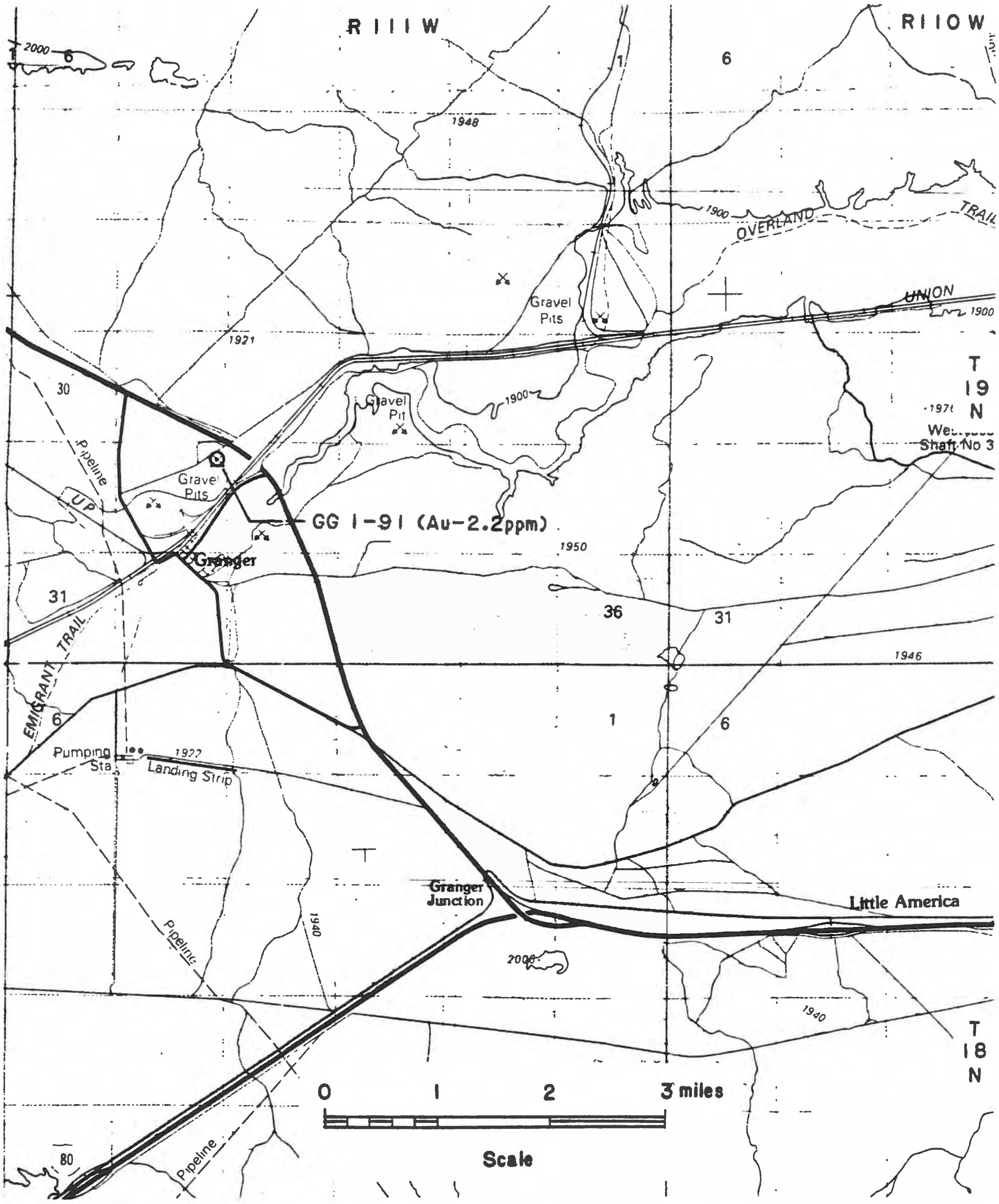

Figure 23. Sample location map for sand and gravel on the Blacks Fork at Granger, southwestern Wyoming (Rock Springs 1:100,000-scale metric topographic map). Sample number include a gold analysis also listed in **Table 7** (ppm=parts per million).

Red Creek

Sand and gravel was sampled from a several-foot-thick cut bank on the west bank of Red Creek at Richards Gap (S2 S2 section 15, T12N, R105W) (**Figure 5**). The sand and gravel resources are restricted to the stream bed and adjacent banks, and do not appear to extend very far beyond the banks. The sample (sample RG5-91) was collected 0.75 mile upstream (north) from the Richards Gap titaniferous black sandstone deposit. Sand with cobbles and pebbles were dug from the cut bank and placed in three 5-gallon buckets and transported to the Geological Survey of Wyoming for processing. Part of the sample was panned and the remainder was processed in the Gold Scavenger. Sample concentrates were assayed and yielded a gold value of 11.4 ppm (sample RG5-91, **Table 7**).

Investigation of the Leucite Hills lamproites for precious stones

Introduction

The Leucite Hills north of Rock Springs consist of a unique group of rocks. These rocks, which are lamproites, are known to occur in only 25 provinces or fields in the world (Mitchell and Bergman, 1991). This makes them some of the rarest rocks found. Lamproites are a unique group of ultrapotassic volcanic rocks characterized by the presence of some highly unusual mineral assemblages including titanium phlogopite, titanium-potassium richterite, titanium-tetraferriphlogopite, sodium-and aluminum-deficient leucite, iron-rich sanidine, aluminum-poor diopside, potassium-barian titanites (priderite, jeppeite), and potassium zirconian or titanium silicates (wadeite, davenite, shcherbakovite) (Mitchell and Bergman, 1991). Lamproite is enriched in K, Mg, and Cr, and has K_2O/Na_2O ratios greater than 2. The lavas are generally peralkaline ($K_2O + Na_2O > Al_2O_3$) and enriched in the incompatible elements (Rb, Sr, Zr, P, and Ba) (Mitchell and Bergman, 1991).

Significant interest in lamproites was generated after the discovery of diamonds in some lamproites in Western Australia in the 1970s. It is now known that there are seven known diamondiferous lamproite provinces, fields, or occurrences on five different continents. These diamondiferous lamproites range in age from Proterozoic (1.2 Ga) to Miocene (20-22 Ma) (Mitchell and Bergman, 1991), and include the most diamond-rich deposit in the world at Argyle, Western Australia.

Many of the diamondiferous lamproites are crater facies lamproites, and possess some geochemical and mineralogical similarities with kimberlites. Principal among these are the presence of high modal olivine, Cr-rich spinels, and similar enrichments in Cr, Ni, and incompatible elements (Mitchell and Bergman, 1991). Whereas economic diamondiferous kimberlites are found in the central regions of stable Archean cratons, diamondiferous lamproites occur on their margins in crustal domains which experienced Archean to Proterozoic accretionary and/or other orogenic events. Kimberlites occurring in these mobile belts are typically subeconomic or barren of diamonds (Mitchell and Bergman, 1991).

Crater and pyroclastic facies lamproites are the most important and most texturally variable of all lamproite facies. Diamondiferous lamproite vents belong to the crater facies. In such vents, pyroclastic or fragmental rocks typically have the highest diamond grade relative to associated magmatic rocks (Mitchell and Bergman, 1991).

Leucite Hills lamproites

The Leucite Hills lamproites represent a group of some of the most unique volcanic rocks in the world. Based on the known occurrences in the world, lamproites are volumetrically minor, and the Leucite Hills represent the youngest and best preserved lamproites found anywhere to date. The age of volcanism is only 1.1 ± 0.4 Ma (McDowell, 1971). The Leucite Hills lie within the Green River Basin and within the confines of the Wyoming Archean craton. The Wyoming craton hosts the largest volume of lamproites in the world.

Three rock types were originally described in the Leucite Hills and were named wyomingite, orendite, and madupite. According to Ogden (1979), the principal mineralogy of wyomingite consists of phlogopite phenocrysts in a groundmass of diopside, leucite, apatite, and glass. Orendite has phlogopite phenocrysts in a groundmass of diopside, sanidine, leucite, and apatite. Madupite consists of poikilitic phenocrysts of phlogopite enclosing diopside in a groundmass of diopside, leucite, apatite, and glass. The essential difference between wyomingite and orendite is that leucite occurs to the exclusion of sanidine in the groundmass of wyomingite.

Carmichael (1967) proposed a fourth rock type, olivine-orendite, on the basis of olivine phenocrysts in orendite at South Table Mountain and at North Table Mountain. Ogden (1979) noted that olivine is not confined to orendite but also occurs in wyomingite at South Table Mountain. Olivine-bearing lamproites are also reported from the Wortman dike, Endlich Hill, and Black Rock (Ogden, 1979).

The olivine in the olivine-orendites consists of discrete anhedral olivine phenocrysts mantled by phlogopite lathes. The mantled olivines are demonstrably not in equilibrium with their host magma and may represent upper mantle derived xenocrysts. Microphenocrystal olivines are clearly primary phases that crystallized after phlogopite (Mitchell and Bergman, 1991).

Because of the greater affinity of diamond for olivine lamproite, sampling of the Leucite Hills was confined to the olivine-bearing lamproites at South Table Mountain and Endlich Hill (**Figure 24**). The olivine phenocrysts are translucent to transparent olive-green subhedral grains up to half an inch across, some of which are relatively high quality, although highly fractured. Samples weighing from 50 to 100 pounds were collected at various locations from the two flows and processed for diamonds in the Geological Survey of Wyoming's diamond extraction laboratory.

None of the collected samples yielded diamond. However, because of the small size of the samples and the restricted number of samples, these results are not considered as diagnostic or representative of the area. Future testing should include a much larger volume of material and should sample principally olivine lamproites and crater facies lamproites.

Earlier tests of volcanic breccia from the Boars Tusk lamproite also yielded no diamonds. However, one specimen of a microscopic, translucent, octahedral spinel was recovered.

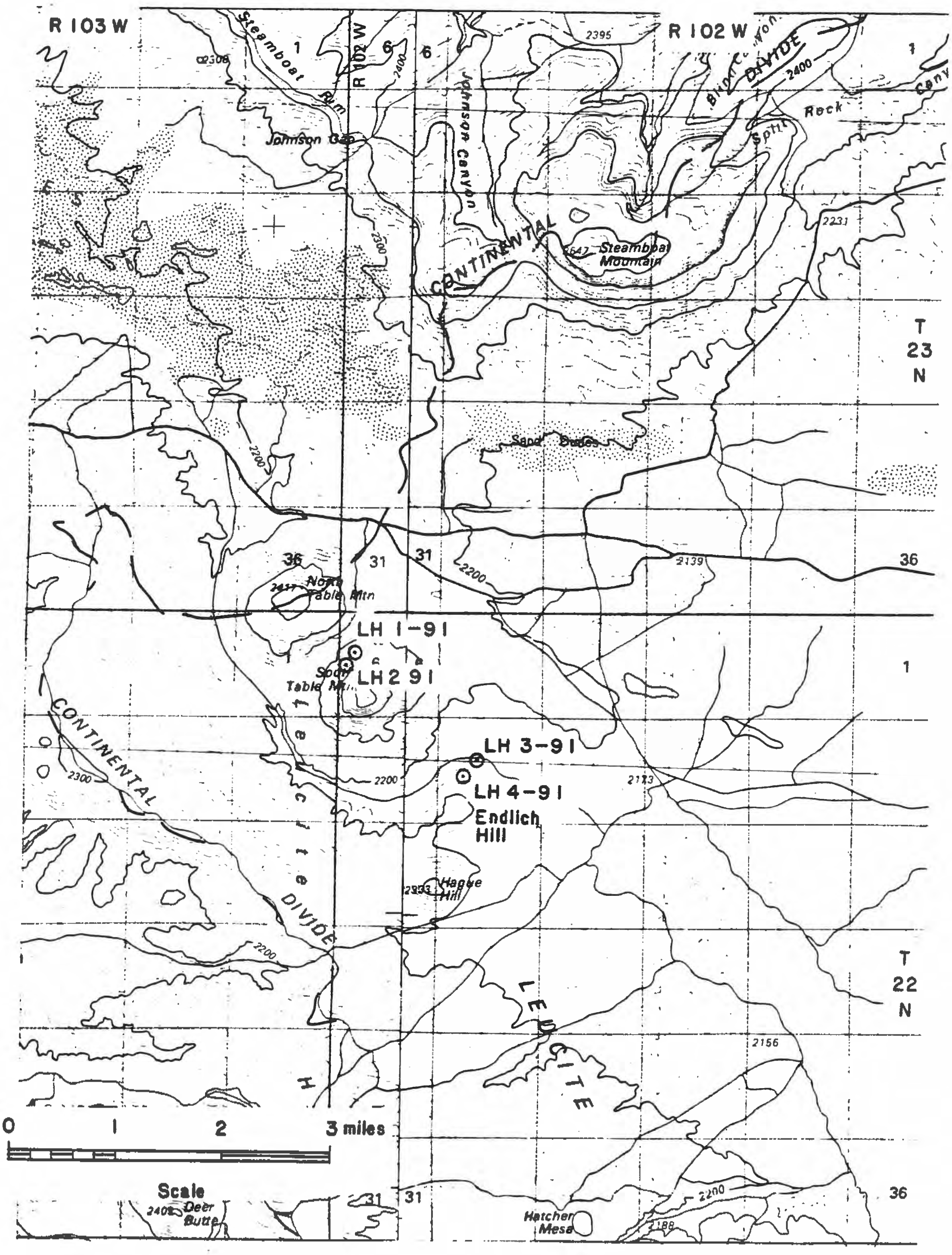

Figure 24. Sample location map of olivine-bearing lamproite in the Leucite Hills, southwestern Wyoming (Rock Springs 1:100,000-scale metric topographic map).

Project conclusions

The final results of this reconnaissance project were very encouraging, especially when much of the terrane that was examined has historically been considered to have some of the lowest potential for metal deposits in Wyoming. Future efforts should continue along the lines of this initial project with high priority follow-up studies to include detailed sampling and alteration studies of Aspen Mountain, sampling studies of other coal deposits (particularly in the Kemmerer coal mining district), sampling of titaniferous sandstones in the Kemmerer region, further sampling in the Delany Rim area near Wamsutter, continued sampling of sand and gravel deposits and placers, and detailed sampling of the olivine-bearing lamproites in the Leucite Hills.

Some lower priority projects for consideration in future studies should include follow-up sampling in the Cooper Hill district, particularly to search for the reported 'gold-bearing immense sugar dike'; sampling and alteration studies of the Copper King and Strong mines in the Laramie Mountains; sampling of the cupriferous red bed deposit north of Kemmerer; sampling of oil shale in the Green River Basin for gold; and follow-up studies of some unusual gold anomalies reported by the Department of Energy's NURE project (Albert, 1986).

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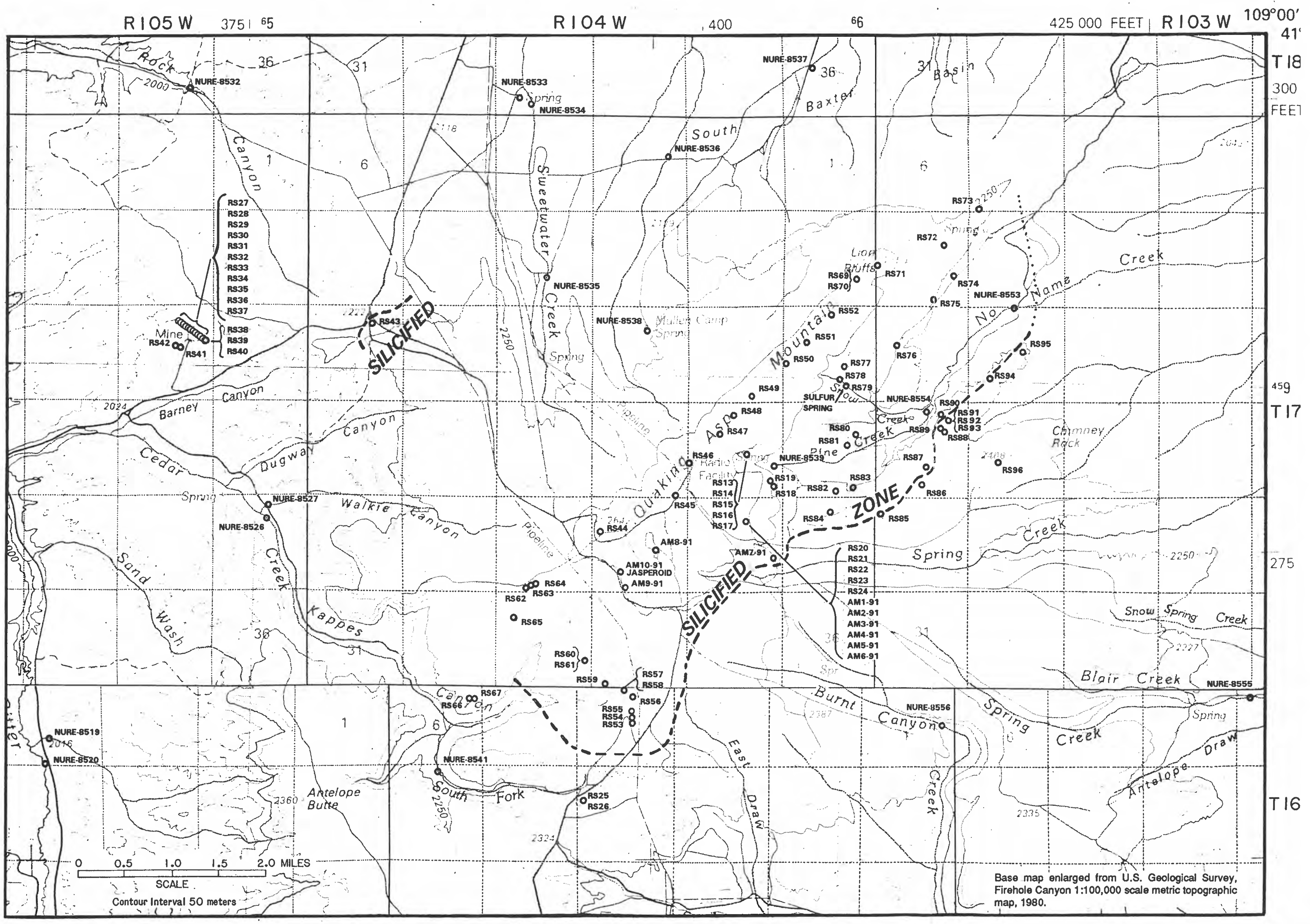
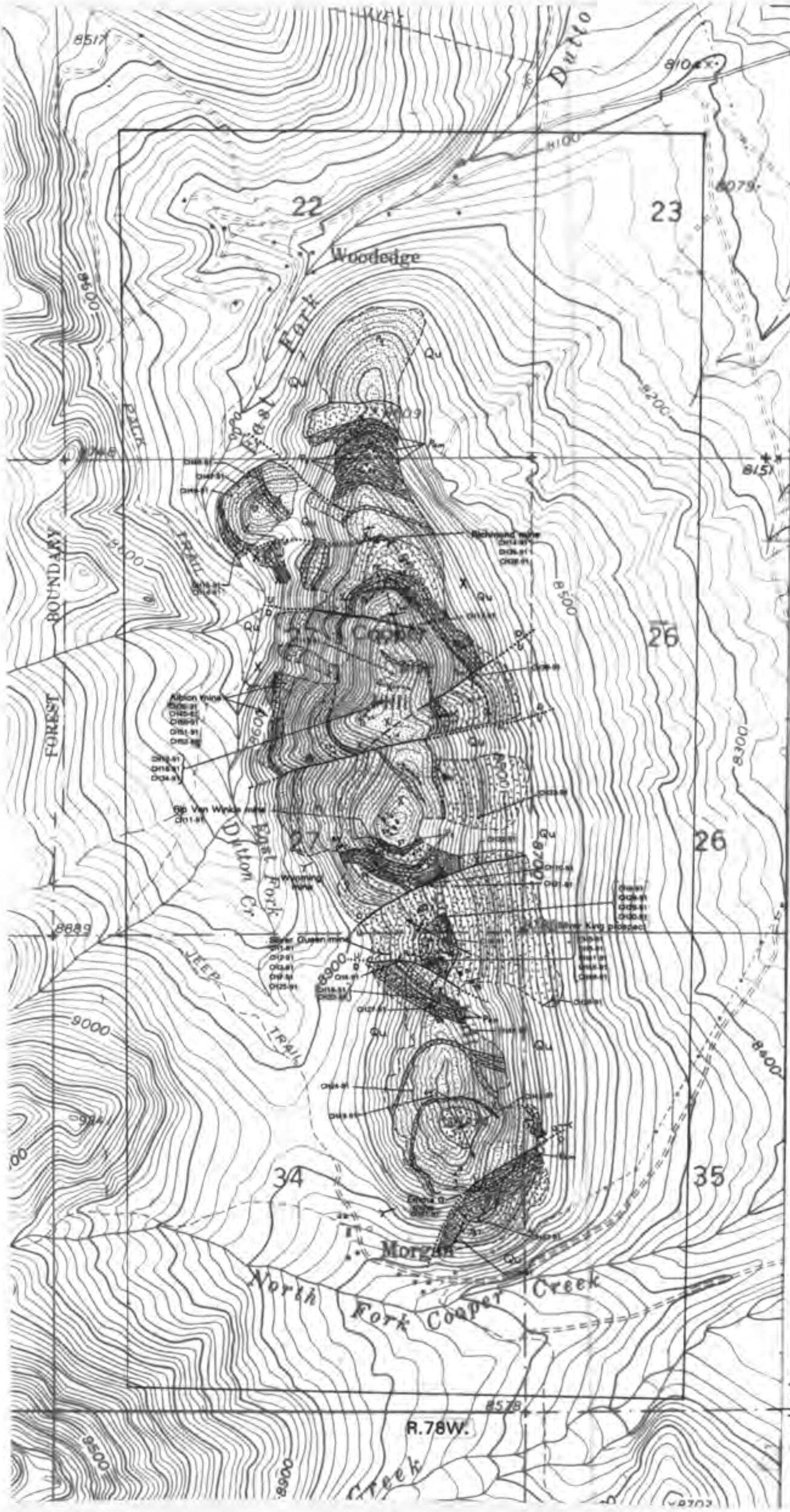


LOCATION MAP OF THE ASPEN MOUNTAIN SILICIFIED ZONE SHOWING SAMPLE SITES
(REFER TO TABLE 3 FOR ANALYSES)



OPEN FILE REPORT 92-5
PLATE 1

GEOLOGIC MAP OF THE PROTEROZOIC ROCKS OF THE COOPER HILL MINING DISTRICT, WYOMING

by

W. Dan Hausel
1992

EXPLANATION

Qu — **Quaternary undivided**. Includes scree and talus covered slopes and stream aluvium.

PROTEROZOIC

Amphibolite, metagabbro, and metabasalt. Fine-, medium-, and coarse-grained mafic, metaigneous rocks with schistose, blasto-ophitic, and blasto-subophitic textures.

Quartzite. Pink, cream, to greenish, fine- to medium-grained quartzite and schistose micaceous quartzite with minor muscovite, chlorite, and orthoclase and trace fuchsite. Locally, beds of stretched-pebble metaconglomerate occur with milky quartz pebbles and minor black chert pebbles.

Mica schist. Chlorite and biotite schists and phyllites.

Metalimestone: White metalimestone and fine-grained marble.

MAP SYMBOLS

MINES & PROSPECTS
- shaft
- adit
- prospect pit

VEINS & ALTERATION
- dipping quartz vein
- unexplored gossan
- skarn

BEDDING & FOLIATION
- dipping beds
- dipping foliation

FAULTS & JOINTS
- fault showing relative movement, dashed where approximately located, dotted where concealed. U = up, D = downthrown side
- dipping joints

LARGE SCALE FOLDS
- plunging antiform
- synform

MINOR FOLDS
- plunging isoclinal fold
- plunging open fold
- plunging open fold with dipping fold plane

MISCELLANEOUS
- metaconglomerate bed
- spring
- sample site

scale

Base map enlarged from U.S. Geological Survey, Morgan and Strouss Hill 1:24,000-scale topographic quadrangle maps.