GEOLOGICAL SURVEY OF WYOMING
MINERAL REPORT MR92-1

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

by

W. Dan Hausel, Gordon G. Marlatt, Eric L. Nielsen, and Robert W. Gregory

Laramie, Wyoming
1992

CONTENTS

Introduction 1
Acknowledgments 1
Analytical procedures 1
Projects 2
Geology and mineralization of the Cooper Hill mining district 2
Introduction 2
Geography and history 2
Geology 3
Structure and metamorphism 4
Rock units 5
Amphibolite 5
Metalimestone 6
Quartzite and metaconglomerate 6
Mica schist 6
Economic geology 6
Mineralization 6
Mines and occurrences 8
Summary 10
Titaniferous black sandstone deposits 11
Introduction 11
Prospects and occurrences 12
Silicification and alunite alteration of Quaking Asp (Aspen) Mountain 15
Introduction 15
Background 15
Geology 16
Genesis of alunite deposits 16
Diagenetic alunite 17
Hydrothermal alunite 18
Aspen Mountain project 18
Conclusions and recommendations 19
Geology of the Rawlins Red hematite deposit 20
Introduction 20
Arkosic conglomerate 20
Hematitic conglomerate 20
Precious metals in coal deposits 21
Introduction 21
Genetic model 21
Metalliferous carbon and coal 22
Metalliferous Wyoming coals 23
Coal deposits investigated 24
Precious metals in sandstone, shale, limestone, and tar sand 26
Precious metal occurrences in sand and gravel deposits and placers 26
Introduction 26
Sample collecting and processing 27
Sand and gravel deposits and placers 28
Laramie River 28
Little Laramie River 29
Cooper Creek 29
North Fork of Cooper Creek 30
Rock Creek 30
North Platte River 31
Green River 31
Granger 31
Red Creek 31
Investigation of the Leucite Hills lamproites for precious stones 32
Introduction 32
Leucite Hills lamproites 32
Project conclusions 33
References cited 33

Introduction

With the exception of the Medicine Bow Mountains, Sierra Madre, and Laramie Mountains much of southern Wyoming is unexplored for gold and precious stones. Much of this region is underlain by sedimentary basins which do not fit within the classical models for metallic ore deposits, and explains the general lack of exploration in this area. However, the literature and various prospectors describe numerous unverified gold occurrences in a variety of geological environments. These include reports of gold in coal, oil shale, various streams, and sand and gravel deposits. Some of these deposits 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 exhaustively prospected for diamonds in the 1870s because of the 'Great Diamond Hoax' which occurred along the Colorado-Wyoming border south of Rock Springs in the vicinity of Diamond Fields flats near Diamond Peak, Colorado. (3) Nearly 100 years later, in 1975, diamonds were discovered in kimberlite near Tie Siding in the Laramie Mountains of Wyoming, which led to extensive exploration for commercial diamond deposits for more than a decade. The results of this exploration led to the discovery of more than 100 kimberlite pipes and dikes in the Colorado-Wyoming State Line district. (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) More recently, with the discovery of diamonds in lamproites in the Kimberly region of Western Australia, 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. Dozens of samples were collected and reconnaissance maps were prepared of 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 Union Pacific Resources with some matching funds provided from the Geological Survey of Wyoming 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 as a final note, we would like to thank Audrey Cofferman for her 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 analytical lab, or were contracted to Bondar-Clegg or to Gordon Marlatt. Gordon Marlatt utilized a 4-wheel-drive mobile lab which was possible to drive near the outcrop and obtain assay results by the next morning.

Mineralogical determinations were made using binocular and petrographic microscopes. A few enigmatic minerals were analyzed by 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 lab.

Projects

Several project areas were considered for this study, but due to the limited man power 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 available information 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 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 to host anomalous gold.

(5) Gold in coal and scoria. Several gold and silver anomalies had been reported in coal beds elsewhere in the State.

(6) Gold in sand and gravel deposits. These resources are mined all over the state for their gravel resources and have not been considered as potential sources of by-product gold.

(7) Gold associated with sandstones, shales, and limestones.

(8) The Leucite Hills. Lamproites of the Leucite Hills exhibit similarities to diamondiferous lamproites found elsewhere in the world.

Geology and mineralization of the Cooper Hill mining district, Medicine Bow Mountains, Carbon County, Wyoming

Introduction

The Cooper Hill mining district lies along the northeastern edge of the Medicine Bow Mountains in southeastern Wyoming. Cooper Hill, a prominent bald hill from which the district derives its name, is clearly seen from I-80 in the vicinity of Cooper Cove east of Arlington. The mining district was active for a short period in the 1890s and produced minor amounts of gold, copper, silver, and lead ore.

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

Geography and History

Cooper Hill lies along the extreme northeastern edge of the Medicine Bow Mountains and on the western edge of the Laramie Basin in southeastern Wyoming (Figure 1). It forms a distinct

north-south elongated bald hill seen from Interstate 80 at the Cooper Cove Road exit approximately 7 miles east of Arlington. Access to the district is by dirt road across private property from Interstate 80. 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, but whether or not gold was found this early in time can not be accurately accessed. Later, in 1877, the King (40th parallel) Survey reported rumors of gold in Cooper Creek, but no apparent verification was made (Hague and Emmons, 1877). As far as we are aware, the results of this project have provided the first verification of gold in Cooper 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 yielding 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, 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 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) of gold. Beeler also mentioned 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 the early 1950s. In his investigations, 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. Later, King (1963) mapped the northeastern Medicine Bow Mountains paying particular attention to Cooper Hill concluding 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 viewed 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 stratigraphy of the Medicine Bow Mountains and Sierra Madre.

This current investigation began with detailed geologic mapping at a 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 (x-ray diffraction) studies. Schoen (1953) had the advantage of access to some underground workings which were not accessible during this present study.

Geology

Cooper Hill lies along the northeastern edge of the Medicine Bow Mountains in southeastern Wyoming. 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.

Cooper Hill stands out as a steep-sided bald hill flanked on the east side by the North Fork of Cooper Creek and on the west side by Dutton Creek. The hill has been interpreted as a gravity slide originating from the west in the Medicine Bow Mountains proper (King, 1963). Drilling data from nearby oil tests support Cooper Hill to be an allochthonous block. But whether Cooper Hill is a gravity slide or an overthrust salient, is unknown.

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 steep to the southwest.

The regional geologic map of the Medicine Bow Mountains shows the northern portion of Cooper Hill to be underlain by Vagner Formation metasedimentary rocks and the southern portion to be 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; whereas, 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 began to evolve. 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). If this is Cascade Quartzite conglomerate, it is underlain by metalimestone, mica schist, and quartzite typical of the younger Vagner Formation. This perplexing stratigraphy suggests the lithologies to be reversed and overturned. But since no facing indicators could be found to differentiate top from bottom, we elected to eliminate the use of formation names in this report in favor of lithologic descriptions. The possibility that the Cooper Hill succession is overturned is not unique. For instance, a few miles to the west and northwest of Cooper Hill, King (1963) identified relict overturned crossbeds in quartzite.

The results of this mapping study are in general agreement with Schoen (1953) rather than King (1963), and show 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 hill sides are scree covered with few rock exposures. However, there is enough exposure to confidentially 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 to the west (King, 1963).

Sometime between 2.5 Ga and 1.7 Ga, the sediments and mafic volcanics of Cooper Hill were deposited near the margin of the Wyoming craton in a miogeoclinal basin. These were lithified and folded into a series of small scale isoclinal folds with northeast-southwest trending axial plane traces. Refolding produced northwesterly trending open antiforms and synforms.

Some small scale open folds with northeasterly-trending axial plane traces mapped near the Rip Van Winkel mine, may represent another folding event.

A synformal basin cored by quartzite with metaconglomerate, faulted along its southern flank and cut in half by a parallel fault, is the major structure on the northern half of Cooper Hill. The southern half of Cooper Hill appears to mimic this structure. The structure between these two synforms is also a synform occurring in a horst(?) fault block. The traces of antiforms between these three synforms have been cut by Laramide faults.

Laramide deformation resulted in Cooper Hill being thrust eastward followed by the breaking of the hill into a series of fault blocks. Cooper Hill was thrust over younger Phanerozoic sedimentary rocks producing a klippe derived from the eastern Medicine Bow Mountains nappe. The trace of the Arlington thrust appears to lie 1/4 mile west of Cooper Hill (Blackstone, 1973). At Cooper Hill, the thrust (or gravity thrust ?) is buried under a skirt of scree and talus.

Supporting evidence for the allochthonous block comes from oil wells drilled by Union Pacific Resources and Exxon through the toe of the thrust both south and northwest of Cooper Hill. Wells spudded to the northwest and south of Cooper Hill in secs. 10 and 11, T.17 N., R.78W. and sec. 36, T.19 N., R.79W. cut 2,000 to 5,000 feet of Precambrian crystalline rock prior to intersecting overturn Mesaverde sedimentary rock below the thrust sheet (Paul J. Graff, personal communication, 1991) suggesting Cooper Hill to be a rootless klippe lying on Cretaceous Steele Shale, Mesaverde Formation, and Tertiary Hanna Formation (Blackstone,1973, Plate 2). 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 just a salient along the thrust, can not be determined with the existing data.

Folding of Cooper Hill was accompanied by regional amphibolite grade metamorphism, and by one or more episodes of intrusion of gabbroic and basaltic dikes and sills. The supracrustal succession inherited foliation during regional metamorphism 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 producing 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.

Rock Units

Four general rock types were mapped on Cooper Hill. These are amphibolite, quartzite, metalimestone, 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 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. The available data suggest these rocks represent mafic flows and subvolcanic intrusive sills and dikes.

Metalimestone

Relatively thin beds of metalimestone crop out on Cooper Hill. The rock is grey, 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 very reactive to 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 of quartz-rich rocks with about 5% laminated pink feldspar, minor to trace amounts of mica (sericite and/or chlorite), and accessory fuchsite and opaques. Micaceous quartzites are light green to brownish foliated quartzites with 70 to 80% quartz, minor feldspar, abundant chlorite, and lesser sericite.

Quartzites in the northern portion of Cooper Hill contain thin beds of metaconglomerate. These conglomerates 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. 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 and 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 ran to an ancient sea located to the south of the Cheyenne Belt.

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 metagreywacke. The schists and metagreywacke represent metamorphosed siltstones, claystones, and sandstones.

In thin section, King (1963) described mica schist to consist of 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 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 to any great extent. According to Duncan (1990), Cooper Hill had a short-lived prospecting and mining history that lasted from the period of 1893 to 1897. Presumably, some activity also occurred during the Great Depression. In recent years, a few Laramie residents have continued prospecting the district, and essentially all of the accessible mines were recently closed under the State's Federally funded abandoned mine 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 to sulfide mineralization; whereas a second variety, a sugary, yellow-orange limonite after siderite is of no apparent economic value. Lode mineralization includes quartz veins, skarns, and replacement deposits.

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 sec. 27. Skarns are undoubtedly more widespread than mapped simply because large portions of the metalimestone are buried by colluvium and scree on the steep hill sides.

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 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 deposit crosses lithologies. In metalimestone, it takes on the appearance of calc-schist (skarn). In quartzite, it forms a well defined quartz vein. 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 hosted by a thick metabasalt. The vein is a strike-trending (conformable), limonite-stained, several-foot-wide, 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: W/2 sec. 27, T.18N., R.78W. The Albion mine was developed by two adits driven on a quartz vein at the contact between altered hanging wall metalimestone (calc schist) and foot wall 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 (<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 foot wall 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. Further 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. Further 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 foot wall 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 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% 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% 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 in the N/2 SE/4 sec. 34, T.18N., R.78W. 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 southern shaft 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 (parts per million) Au and 1.0 ppm Ag (sample CH21-91, Table 1).

Little Ella Mine: Location unknown. 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 % Cu.

Richmond Mine: Located in the NE/4 sec. 27, T.18N., R.78W., along the crest of Cooper Hill. According to Beeler (1906), the Richmond mine produced the largest amount of free-milling gold of 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 to be 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). Two samples of boxwork quartz contained 0.012 and 0.041 ppm Au, <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% 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: S/2 sec. 27, T.18N., R.78W. Two photographs in Duncan's (1990, p. 192) book indicate this mine near the crest of the hill is the Rip Van Winkle mine. The portal of the adit was cut in amphibolite and the tunnel intersected mica schist and metagreywacke 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 <0.2 ppm Ag. This may be the same mine Schoen (1953, plate 3) calls the Silver King mine.

Silver King prospect: N/2 NE/4 sec. 34, T.18N., R.78W. 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 a 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 no other samples were found. Zinc assays of samples also confirm mineralization from the district is zinc deficient. Thus, the origin of the franklinite sample remains a mystery, but it is apparent that it did not originate from Cooper Hill.

Five additional samples were collected from the dump for study, three of which 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% Cu (sample CH5-91, Table 1).

Silver Queen adit: N/2 N/2 sec. 34, T.18N., R.78W. 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 <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% Cu, and cupriferous quartz (sample CH7-91) yielded >10 ppm Au, <0.2 ppm Ag, and 2.27% Cu. A split of the sample pulp of CH7-91 was also assayed yielding 0.16 opt Au.

Wyoming (?) adit: S/2 S/2 sec. 27, T.18N., R.78W. Located about 400 feet below the Rip Van Winkel 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: W/2 E/2 sec. 27, T.18N., R.78W. Quartz pebble conglomerate crops out in thin beds in quartzite at a couple of different localities at the crest of the hill. At sample location CH12-91, three samples were collected for analysis. 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: SE/4 sec. 34, T.18N., R.78W. A shallow prospect pit on the hill side a short distance north of the Morgan village exposed a quartz vein with common limonite boxworks after pyrite. A sample from the vein assayed >10 ppm Au and 1.4 ppm Ag (sample CH23-91, Table 1). A split of the sample pulp was assayed yielding 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 deposit and placers*). The relative 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 world wide 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 immediately adjacent wall rock. If King's thesis 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. Based on geological observation, none of the quartzites appeared to be significantly mineralized. It is highly recommended 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 is in direct conflict with the geological facts for the following reasons. One, Cooper Hill is a rootless allochthonous 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. Two, the attitude of 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 possibly 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). The most recent period of uplift correlated with a greater gold content in these paleoplacers. These 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. 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 in northwestern Wyoming (Hausel, 1990).

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 year 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 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 of producing 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, and 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 are all located in the McCourt Tongue of the Rock Springs Formation of the Mesaverde Group (Late Cretaceous). According to Roehler (1989), the 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 grey bench forming sandstone unit that is persistent forming a stratigraphic marker bed in the upper part of the Rock Springs Formation. The McCourt Tongue is interpreted to have been deposited during a southeast-ward regression of part of the western shoreline of the interior Cretaceous sea of North America. The heavy mineral deposits 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): secs 30 and 31, T.18N., R.101W. The Black Butte Creek deposit is accessible by driving south from Rock Springs on Highway 430 to the Brady Road turnoff. About 5 miles east of the turnoff, the road splits and runs north and southeast along Black Butte Creek. Approximately, 2 miles north of this split, a jeep trail runs 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.

The titaniferous sandstone is poorly exposed along a brush and talus covered slope. A short adit driven into the slope in sec. 30 exposed the titaniferous sandstone. The sandstone also crops out less than a mile to the south in the center of sec. 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. Prospects pits were also examined in sec. 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 underlying sandstone is a marine sandstone and the overlying units include sandstone and carbonaceous shale interpreted as off-shore marine deposits formed when coal

swamp deposition occurred (Houston and Murphy, 1962). The black sandstone occupies a channel in the marine sandstone.

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% heavy minerals, 41.5% light minerals, and 34.5% acid soluble matrix. The heavy mineral suite included 84% opaque minerals, 11.1% zircon, a trace of monazite, and 1.0% rutile. Chemically, the samples of titaniferous sandstone collected by Houston and Murphy (1962) ranged from 14 to 28% TiO_2 with 15 to 35.8% total iron as Fe_2O_3. Samples taken by the Bureau of Mines averaged 27.3% TiO_2, 2.0% ZrO_2, 22.9% Fe, and 0.06% $eThO_2$ (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 S/2 sec. 11, T.17N., R.102W., about 20 miles southeast of Rock Springs and only about 3 miles southwest of the Black Butte Creek deposit. Access is by Highway 430, 18 miles south of Rock Springs, 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 mineralized sandstone appears to be as much as 20 feet thick locally. 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).

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% TiO_2, 1.4% ZrO_2, 18.4% Fe, and 0.06% $eThO_2$. Ten samples were collected and 8 analyzed for gold. All of the 8 contained abundant heavy minerals but no detectable gold (Table 2). Two samples analyzed for iron average 33.17% 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 E/2 sec. 1, T.17N., R.102W., a few hundred feet east of Black Butte Creek on the Cooper Ridge NE quadrangle. Access is by way of the Brady gas field improved dirt road from Highway 430 from Rock Springs. This deposit is located about 1.25 miles northeast of the Brady Road titaniferous black sandstone, and is exposed over a 3.3 foot thickness and 120 foot length 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 samples of the titaniferous sandstone were tested for gold. Neither sample contained detectable gold. Two samples were also analyzed for iron averaging 29.49% Fe (Table 2).

Camel Rock (Murphy #2): sec. 8, T.16N., R.102W. The Camel Rock titaniferous sandstone lies 22 to 23 miles south of Rock Springs on the east side of Highway 430 (Figure 4). The sandstone crops out along Cooper Ridge in the Rock Springs Formation which is capped here by the Ericson Sandstone (Roehler, 1989). The main body of the titaniferous sandstone crops out over a length of 300 to 450 feet with an average thickness of only about 2.5 feet. Samples collected by the U.S. Bureau of Mines averaged 19.7% TiO_2, 2.0% ZrO_2, 15.4% Fe, and 0.04% $eThO_2$ (Dow and Batty, 1961). One sample collected by the Wyoming Geological Survey contained no detectable gold (Table 2).

Richards Gap (Red Creek): SE/4 sec. 22, T.12 N., R.105W. The Richards gap titaniferous black sandstone (also referred to as the Red Creek deposit) lies 45 miles southwest of Rock Springs and about 1/4 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 way of Highway 373 out of Rock Springs which runs south about 40 miles to the Clay Basin road exit. The Clay Basin road runs a short distance east before intersecting the Red Creek Basin road.

The conspicuous ridge that forms the Richards Mountains at the gap consists of Mesaverde Group rock units. The titaniferous sandstone occurs at the top of a littoral marine sandstone tongue of the Rock Springs Formation (Houston and Murphy, 1962) identified as the McCourt Tongue by Roehler (1989). 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% TiO_2, and 19.0% total iron as Fe_2O_3. Samples collected by Dow and Batty (1961) averaged 25.5% TiO_2, 1.5% ZrO_2, 15.4% Fe, and 0.04% $eThO_2$.

Two of the 4 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. Another sample (RG4-91) yielded 22.71% Fe.

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

Titsworth Gap: SE/4 sec 7, T.14N., R.103W. 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 of Miller Mountain. 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 forms a channel in a marine sandstone at the top of the McCourt Tongue of the Rock Springs Formation (Roehler, 1989). It 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 sediments, thus the downdip extent of the deposit can not 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% TiO_2, 1.9% ZrO_2, 14.5% Fe, and 0.06% $eThO_2$ (Dow and Batty, 1961). Two samples analyzed by Houston and Murphy (1962) yielded 22.5% TiO_2, 25.5% total iron as Fe_2O_3, and 0.003% uranium. One typical sample of sandstone yielded no detectable gold (sample MR1-91, Table 2).

Union Pacific #1: SE/4 sec. 24, NE/4 sec. 25, T.19N., R.102W., and NW/4 sec. 30, SW/4 sec. 19, T.19N., R.101W. This deposit represents the largest of all the titaniferous sandstones examined during this study. In addition to the principal deposit, another previously unreported outcrop of titaniferous sandstone was found north of the main deposit in the NE/4 NE/4 sec. 24, T.19N.,

R.102W. To the south, another dark outcrop was observed in sec. 25 which may represent another small titaniferous sandstone occurrence (Figure 7). This latter outcrop was not visited.

The main titaniferous sandstone deposit caps a butte south of a powerline. This deposit has been heavily prospected as is evidence by several dozer trenches cut in the black sandstone. The deposit of titaniferous sandstone is 2,700 feet long, 2,400 feet wide, with an average thickness of about 3.5 feet. The thickness varies from less than a foot to 7 feet. The northern extension of the deposit has been down-dropped about 120 feet along a east-west trending fault. North of the fault, the titaniferous sandstone crops out over an area of 800 feet by 400 feet with an average thickness of 2 to 2.5 feet. The titaniferous sandstone located about a mile to the north (NE/4 sec. 24) crops out over an area of 500 feet by 200 feet and may average only 1.5 feet thick.

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

Eight samples were collected by the Wyoming Geological Survey in the summer of 1991. Only one of the 8 contained detectable gold, which 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 yielding 29.96% Fe. A ninth sample (UP9-91) was collected as a 2 foot composite from the titaniferous sandstone to the north (Figure 7). This sample contained no detectable gold and 16.56% Fe.

Yenko: sec 13, T.15N., R.103W. The Yenko deposit is accessible by driving 25 miles south of Rock Springs along Highway 430 to the Wells Creek road turnoff. From the turnoff, the titaniferous sandstone lies 3 miles west cropping out along the western flank of a unnamed mesa (Figure 8). The deposit is reported to average 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 section of younger sedimentary rock.

A composite of 4 samples taken from outcrop averaged 22.4% TiO_2, 2.1% ZrO_2, 16.3% Fe, and 0.08% $eThO_2$ (Dow and Batty, 1961). Only one sample was collected for gold analysis. This sample 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, is a northeasterly trending hill that rises 1,700 to 1,800 feet above the surrounding basin. 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 northeasterly-trending fault, kaolinite alteration, and a 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.

Background

An eight 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 claystone was intersected within 30 feet of the surface. A core hole was also drilled about a mile southwest of the trench and penetrated 6 feet of white claystone at 145 feet, suggesting the alunite may be relatively widespread.

About 200 feet southeast of this core hole (in the NE/4 sec.34, T.17N., R.104W.) a gas well drilled apparently before the alunite discovery, cut through 3,704 feet of hard, silicified Cretaceous sandstone and shale (Love and Blackmon, 1962). This silicified zone was also noted during the early investigation by the U.S Geological Survey (Love and Blackmon, 1962).

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.

This current study, was undertaken as a initial reconnaissance project recommended by geologists from Union Pacific Resources and the Wyoming Geological Survey, 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. Whether or not this system carries gold was also answered during initial phases of the project. Sixteen samples collected during the investigation were weakly anomalous in gold.

Geology

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

Locally, both of these formations are unconformably overlain by sandstone facies of the Bishop Conglomerate (?) (Oligiocene). The Bishop Conglomerate (?) forms a grey, 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 grey siltstone, sandstone, and quartzite rock fragments. Both Kirschbaum (1986) and Love and Blackmon (1962) place the alunite-bearing claystone within the Bishop Conglomerate. The lower part of this unit includes grey silicified sandstone with some secondary chert. The alunite-bearing claystone appears to be stratified (Love and Blackmon, 1962).

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.

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, sulphate-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 value of alunite distinguishes magmatic-hydrothermal processes from supergene processes, while the comparatively D-enriched ∂ values of alunites formed at surficial temperatures distinguishes between alunites formed by supergene oxidation and 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 this contention (Bird and others, 1989).

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 pre-existing rock (King, 1953). In most deposits, the sulfuric acid assumed to be responsible for the conversion of potash-bearing alumino-silicates 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 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: $KAl_2\{(OH)_2Al_2Si_3O_{16}\} + H_2SO_4 \rightarrow 3\ SiO_2 + KAl_3(SO_4)_2(OH)_6$. 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 being provided by 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, 1954). Alunite is also found to occur 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 local 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 (2200 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).

Alteration associated with gold mineralization at Jerritt Canyon, Nevada, includes silicification and argillization. At Jerritt Canyon, 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 is also 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). Although in a few deposits, 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 sec. 26, T.17N., R.104W., on the south flank of Aspen Mountain to verify the presence

of alunite (samples AM1-91 through AM6-91, and RS20 through RS24, Figure 9). Samples of grey 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 is 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. One sample locality for instance (sample AM10-91, Figure 9) contains a zone of limonite-stained, grey banded chert with crosscutting quartz stringers typical of some jasperoids.

Some other interesting features of the Aspen Mountain area include an apparent magnetic anomaly in the vicinity of sample site RS55 (sec. 4, T.17N., R.104W.). At this site, magnetic deflection of a compass needle was noted. On the south flank of Aspen Mountain along Sulphur Creek (SE/4 sec. 13, T.17N., R.104W.) a spring releasing large quantities of H_2S was encountered. The amount of H_2S emanating from this spring, may be toxic. A sample was collected from the spring during favorable wind conditions (sample RS79, Table 3).

Kirschbaum (1986) mapped a group of small travertine deposits along the western edge of Aspen Mountain in sec 34, T.17N., R.104W., and sec. 4, T.16N., R.104W. 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 RS92-RS96). 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 (healed) by calcite and, to a much lessor 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 (Figure 10). 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. Of the samples collected by the Wyoming Geological Survey, 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.

The available data support Aspen Mountain to be highly 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 (jasperoid?), some free sulfur, and several weak gold anomalies. All of these facts taken together support Aspen Mountain to represent an paleo-epithermal system.

Conclusions and recommendations

Disseminated epithermal gold deposits are known for their difficulty in sampling. Typically, the widespread and very low grade gold contents requires 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 to be tested for gold and other trace metals and petrographic studies, with some sporadic bulk samples for gold analysis.

Geology of the Rawlins Red hematite deposit, Rawlins Uplift, Carbon County

Introduction

Hematitic conglomerate, locally known as 'Rawlins Red', crops out north of Rawlins near the southeastern margin of the Rawlins uplift. An outcrop of arkosic conglomerate occurs nearby on the northern edge of town southwest of the hematite deposit.

The Rawlins uplift is formed of low lying hills (7,000 to 7,800 feet high) that are cored by Precambrian granite and 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 Flathead Formation (Cambrian) conglomerates and sandstones. The upper part of the Flathead Formation near the southeastern margin of the uplift includes a 20 to 30 foot bed of hematitic sandstone and conglomerate. Poorly sorted arkosic conglomerate may be of similar age, although field relations for this latter conglomerate were not established. The hematitic conglomerate is unconformably overlain by Madison Limestone (Mississippian).

Arkosic conglomerate

Outcrops of arkosic conglomerate occur along the northern edge of the town of Rawlins. These conglomerates were eroded from the nearby Rawlins granite. The rock texture of the conglomerates indicate 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 nearby source. The proximal feldspar probably was not transported much more than a few feet to a few hundred feet. 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, Table 4) of arkosic conglomerate were tested for radioactivity, gold, and rare earth element (REE) mineralization. The samples were scanned showing 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 spec of copper carbonate. The amount of copper however, was not worthy of assay.

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. Speculation would suggest that these conglomerates originated by eroding a proximal Archean banded iron formation exposed during uplift in the Cambrian. A banded iron formation source bed would explain the abundance of iron found cementing these conglomerates. This Archean supracrustal unit 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, and 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 of gold 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 historic 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 10). 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 (<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 historic reported gold values possibly suggesting some of the historic values were of 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. Being the deposit is a paleoplacer, zones of higher gold content possibly exist distributed between zones with no gold.

Some samples were also analyzed for total iron content. These samples range from 1.51% Fe to 65.36% Fe (Table 4). A whole rock sample split of RA1-91 was also analyzed for iron yielding 63.36% 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 it possibly could 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 historic and geochemical evidence suggest possibilities for significant mineralization associated with some coals. 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 field of southwestern Wyoming in the past. Recent work by Gordon Marlatt has also established significant silver anomalies in the Kemmerer coal field.

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 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 sulfur are oxidized and partitioned into the flue gasses while metals are retained in the ash. This has positive affects including increasing the metal concentration in the ash relative to the coal by the amount of volume decrease of the coal vs. 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 the literature is filled with volumes of material describing associations of metalliferous deposits with carbonaceous material, whether it be 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 greywackes 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 bituminous shaley clay in the Permian of Texas. Chalcopyrite, chalcocite, and pyrite are associated with Permian anthracite in Nova Scotia at New Annan, and tree trunks altered to galena are reported from the Vesuvius mine in Freihung, Bavaria. Sphalerite and galena also occur in bituminous shales near Joplin, Missouri (Jenny, 1903).

Metalliferous anomalies in coal and 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 strata carrying bituminous coal in Huallanca, Peru. Silver occurs in lignitic sandstone of Triassic age at Silver Reef, Utah. At Silver Reef, native silver was found deposited as thin scales on joints in the coal. The ore occurs only in areas of deformation where the coal has been faulted or brecciated strongly supporting an epigenetic origin for these deposits (Jenny, 1903).

Gold has also been reported in pyrite 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 values were given for these coals since the analyses were nonreproductive suggesting that the gold may be particulate (Boyle, 1979).

In Canada, traces of gold are reported in 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 partings of 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 been identified in coal. Goldschmidt (1954) reported 0.05 ppm Pd, and 0.1 ppm Rh in some coal ashes. Chyi (1982) examined coal in western Kentucky which was depleted in gold averaging only 0.4 ppb Au. However, this same coal showed a factor of 18 enrichment in platinum with respect to average crustal abundance. The values of the coal ranged from none to a maximum of 210 ppb Pt. 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 would have to assume that coal, a reducing organic-rich environment, would have to 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 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 common place 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 as common carriers of uranium in Tertiary age sandstones and uranium and vanadium in the Cretaceous age sandstones in Wyoming. Evidence also suggest 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 coals are some of the most extensive in the world. Hundreds and possibly thousands of coal samples have been analyzed for trace metals, but unfortunately, analyses of the precious metal contents of most coals are not as prolific.

Because of the lack of hydrothermal alteration 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 sedimentary rock including a Cretaceous coal-bearing section.

Oxidizing roll fronts have been quite active during the Tertiary and Cretaceous of Wyoming, and these have been attributed to numerous, low-grade, uranium and uranium-vanadium deposits. Such oxidizing solutions precipitate their metal loads where the solutions are reduced. If these solutions contact coal, significant low-grade metal deposits should develop. One area that immediately comes to mind is the uraniferous coals of the Red Desert.

Wyoming has gigantic, widespread areas of Cretaceous and Tertiary sedimentary rock with scattered gold anomalies (Antweiler and others, 1967; Hausel, 1989a). Thus, a source rock is available, as well as a mechanism for mobilizing and precipitating the precious metal. Recognition of these mineralized coals may be difficult as suggested by Marlatt and Spatz (1991), and chemical analyses may be the only available method. The probability that gold occurs as particulate matter on the gold 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. 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 field (Jenny, 1903). The gold content of coal ash was reported to be 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 could not be found suggesting the metal to be particulate rather than adsorbed on the organic matter (U.S. Geological Survey, 1968).

In 1906, the Mining Reporter described coal samples from a coal mine at Walcott Junction to assay as high as 10 ppm Au (see Hausel, 1989a, p. 61). Possibly, this was a coal ash analysis.

Most notable are the Cambria coal deposits in the Newcastle area of the Black Hills. Samples of coal as well as the hanging wall sandstone were analyzed and found to contain none to 3 ppm Au. Coke samples were also analyzed and yielded 3 ppm Au and 14 ppm Ag, and the ash yielded 16.5 ppm Au (Stone, 1912). Later testing by the U.S. Geological Survey (1968) detected no gold in this area. A single sample of Cambria coal provided to the Wyoming Geological Survey 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). Knell (1985) recently confirmed the presence of gold and silver in the Cambria coal fields. Maximum detected precious metal contents were 4 ppm Au and 19.5 ppm Ag.

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. The main difficulty in this procedure surrounded the locating of the historic coal mine, because the historic report gave no information on 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 historic report.

Other coal deposits examined during this study included the Black Butte mine south of Point of the 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 (S/2 SE/4 SW/4 sec. 14, T.21N., R.84W.) (Figure 11). Whether or not this was the mine described by the Mining Reporter (1906) to carry anomalous gold, is unknown.

The underground mine was developed in a 5 foot thick coal bed in the Medicine Bow Formation (?) of Upper Cretaceous age. The adit has caved and the workings are not accessible. Seventy-two samples were collected from the mine dump, nearby outcrops, soil and gullies to test for gold content. Twelve of the 72 samples (16.6%) 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 there are some localized enriched pockets in the mine that were missed by our sampling procedures, or possibly the gold analyses described by the Mining Reporter were exaggerated.

Black Butte mine: The Black Butte coal mine lies on the eastern flank of the Rock Springs uplift, a north-south trending anticline with dips rarely exceeding 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 coal reserves for the mine are 145.6 million tons (Department of Environmental Quality temporary mine filing permit 1 4/62).

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 is formed of a alternating sequence of light-colored sandstone, light and dark grey 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 (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 low quality parting in the seam assayed 0.100 ppm and 0.080 ppm Au, respectively. Thus 4 of the 5 samples collected in the 'C' seam contained anomalous precious metal values (Figure 12).

The Ft. Union Formation is underlain by the Lance Formation of Upper Cretaceous age. The Lance Formation has a maximum thickness of 900 feet in this area, and is formed of alternating thin sandstones, dark grey shale, carbonaceous shale, and coal. Four to 6 coal beds occur in the lower 200 to 300 feet of the formation 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 the Gibraltar bed which is 5 to 10 feet thick. A total of 11 samples were collected from the Lance Formation in Black Butte Pit 6.

Three of the 9 samples collected from coal and carbonaceous shale in this 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 is underlain by 1,000 to 2,000 feet of dark, marine shale of the Lewis Shale. The Lewis is non coal-bearing and is in turn 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 grey or creme 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 with 10 feet of interburden (Department of Environmental Quality temporary filing permit application 1 4/62). Eight samples were taken in this formation, only 5 of which were in the coal. Three of the 5 coal samples yielded anomalous gold values from 0.060 ppm to 0.100 ppm Au (samples BB6-BB8, Table 5). Two samples of ash were also analyzed. One sample yielded 0.100 ppm Au the other contained no detectable gold (samples BB26 and BB27, Table 5).

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

Cedar Creek coal mine: NE/4 sec 14, T.17N., R.105W. Sixteen samples (RS27 through RS42) were collected from an abandoned coal mine near Aspen Mountain south of Rock Springs (Figure 9). 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 were sampled in the Continental Divide area of the Red Desert for gold (samples CD1-CD31, Figure 13). The scoria

represents baked rock formed from the burning of coal beds. Eight of 31 samples (25.8%) 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 coal or clinker.

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 18). A trace of gold was detected in the coal (sample WI12, Table 6). See section entitled *Precious metals in sandstone, shale, limestone, and tar sand*).

Precious metals in sandstone, shale, limestone, and tar sand, Sweetwater County

Sandstone, shale, limestone, and tar sands were sampled in the Greater Green River Basin (Table 6). Some results were encouraging, particularly samples taken along the Delany Rim in the vicinity of Wamsutter. Gold in this area was initially identified by Dean Farris of Laramie which led to the Survey's investigation of the area. Samples yielded several gold anomalies (samples WM1-91 to WM36-91 and TP2-91 to TP8-91, Table 6) associated with *goniobasis* chert and limestone in a thin unit cropping out along Delany Rim (Figure 14). Of 42 samples, 11 (26%) 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 (Figure 13), yielded only a few localized samples containing detectable gold. Samples of sandstone and peat from the Washakie Basin west of Baggs yielded no detectable gold anomalies (Figure 15, Table 6). Sandstone and quartzite east of Point of the Rocks yielded some weak gold anomalies (Figure 16, Table 6). 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, 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. Samples WI1 through WI5 were collected in a road cut between Rawlins and Sinclair (Figure 10). None of these contained detectable gold. Samples WI6 through WI8 were collected near Walcott Junction (Figure 11a). Gold was not detected in any of these samples either. Samples WI9 through WI12 were collected from outcrops in a hogback along Interstate 80 northeast of the town of Elk Mountain (Figure 18). One sample of low-grade coal contained a trace of gold (sample WI12, Table 6).

In summary of the limestone, chert, sandstone, and chert samples collected for gold analysis listed in Table 6, by far the most intriguing were those associated with fossiliferous limestone and chert on and nearby the Delany Rim. The source of the gold is not known, but the widespread gold anomalies suggests this area may be worthy of detailed investigations.

Precious metal occurrences in sand and gravel deposits and placers

Introduction

As part of the project, Union Pacific Resources staff and the Survey staff agreed 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 is available on S&G (sand and gravel) deposits in the State. This is alarming in that thousands of cubic yards of gravel are mined statewide each year with no attention paid to possible 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) losing valuable revenues.

The results of this study are very encouraging and we established gold anomalies everywhere sampled. Essentially, 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, thus the possibility of finding coarser gold is expected to be good. However, the lack of coarse gold may cause concern for recovery, particularly if gravity separation circuits are to be used to extract gold from some S&G pits. Fine gold is difficult to recover by gravity methods and it may be prudent to research the feasibility of various gravity and chemical leach methods. If gold recovery can be shown to be inexpensive and 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.

One classical example of a loss of a potential by-product resource occurred during the past decade when the Rob Roy Reservoir in the Medicine Bow Mountains was dredged and the dam expanded without consideration for possible recovery of precious metals. The Rob Roy reservoir lies within the Douglas Creek placer district, a historic gold mining district that is credited with a few thousand ounces of gold and some platinum and palladium production. If a heavy mineral recovery circuit would have been used during the dredging of the reservoir, there is no question 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 close-space grids, a procedure that was well beyond the scope of this project.

Sample collecting and processing

Samples of sand and gravel were collected from various locations in S&G pits that were perceived to be favorable sites 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 was also taken (noted as a grab sample) which consisted of unprocessed material that was taken back to the Survey and processed in a Gold Scavenger.

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. Using a shovel and bucket, these lower levels were generally not accessible.

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.

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 the 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 Survey 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 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 resources within the confines of its river bed, as well as in the adjacent flood plains 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: SE/4 NE/4 SW/4 sec. 9, T.16N., R.73W. Approximately 2.5 miles north of the city of Laramie adjacent to Highway 287-30. On the east side of the Highway 287 (Figure 19), 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 on the Chugwater Formation in the Laramie landfill (Bob Jones, personal communication, 1988). This latter 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 surface 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 W/2 sec. 16, E/2 E/2 sec. 8, and W/2 SW/4 sec. 9, T.16N., R.73W., bordering the Laramie River (Figure 19). Approximately 200 acres of gravel resource, 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). Grab sample concentrates yielded 1.2 ppm Au (sample SG3A-91, Table 7).

Sand & gravel pits southwest of Laramie: A large gravel pit leased by Western Mobile Corporation in the SW/4 sec. 24, T.15N., R.74W. was sampled along the Laramie River southwest of Laramie (Figure 19). Approximately 80 to 100 acres of gravel resource in a 9 to 12 foot thick bed occur in the pit area. The deposit thins and pinches 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. Concentrates from a panned sample of the wash pit sand yielded 1.2 ppm Au (samples SG5-91, SG5A-91, and SG4-91, Table 7).

A short distance to the southwest (NE/4 sec. 26, T.15N., R.74W.) another pit was sampled (Figure 19). 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. Concentrates from a grab sample assayed 0.2 ppm Au (samples SG6A-91 and SG6-91, Table 7).

Little Laramie River

The Little Laramie River flows in a northeasterly direction from the east side of the Medicine Bow Mountains through Centennial Valley converging with the Laramie River down stream. The Middle Fork of the Little Laramie River flows through the Centennial Ridge district at the eastern flank of the Medicine Bow Mountains. This district was developed for gold and platinum in the 1870s.

NE/4 sec. 1, T.15N., R.77W.: Samples were collected from the Little Laramie River near the north line of the NE/4 NW/4 NE/4 sec. 1, T.15N., R.77W. north of Table Mountain and Highway 130, several miles east of the Centennial Ridge district (Figure 20). The samples were collected approximately 100 yards south of the Union Pacific Railroad trestle which bridges the river.

The samples were collected from a bar along the west bank of the river. The panned concentrate 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 deserve serious consideration.

Cooper Creek

Cooper Creek and its tributaries flow northeast from the south end of Cooper Hill. Cooper Hill 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 21). 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/4 SE/4 sec. 19, T.18N., R.77W.) lying on a low ridge capped by a oil pumping station. The gravel exposed in the pit is 12 to 15 feet thick. It is estimated 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. Grab sample concentrates assayed 4.4 ppm Au (sample nos. SG7A-91 and SG7-91, Table 7).

SW/4 NW/4 NW/4 sec. 21, T.18N., R.77W.: Approximately 200 yards southwest of the I-80 bridge over Cooper Creek are some small gravel deposits in the creek. 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. Grab sample concentrates yielded 1.8 ppm Au (samples SG13A-91 and SG13-91, Table 7).

E/2 NE/4 sec. 25, T.18N., R.78W.: Limited sand and gravel deposits along a 300 yard stretch of the creek were sampled and panned. The stream channel is floored by mud with side channel and main channel sand and gravel. 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 >9.4 ppm Au (samples SG8A-91 and SG8-91, Table 7).

SW/4 NE/4 SE/4 sec. 35, T.18N., R.78W.: Approximately 1 mile east of Cooper Hill, the 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 for microscopic examination. A grab sample concentrate from this location was assayed and yielded more than 36.5 ppm Au (sample SG11-91, Table 7).

E/2 NE/4 SE/4 sec. 35, T.18N., R.78W.: A cut several feet deep in the hillside north of Cooper Creek contained some gravel. At the base of the cut was a small fan eroded from the cut. This material 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. Grab sample concentrates assayed 0.3 ppm Au (SG12A-91 and SG12-91, Table 7).

North Fork of Cooper Creek

Stream sample concentrates collected on the North Fork of Cooper Creek all contained visible gold as on Cooper Creek (Figure 21).

W/2 SE/4 sec. 25, T.18N., R.78W.: Small sand and gravel accumulations south of a beaver dam were sampled along a 100 foot stretch of the North Fork (Figure 21). 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. The concentrates from a grab sample assayed 2.6 ppm Au (samples SG9A-91 and SG9-91, Table 7).

SE/4 SW/4 SW/4 sec. 25, T.18N., R.78W.: Bar and channel deposits were sampled over an distance of about 200 feet upstream and downstream from a 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 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 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 mountain sides bordering Rock Creek. A few prospects also lie on the bank of Rock Creek a few miles upstream from Arlington. At one of these, sulfides with traces of copper were found. Early reports of gold in the area include a mention of small amounts of placer gold on Rock Creek by Hague and Emmons (1877) and Hyden and others (1967). Duncan (1990) also reports this area was once included in the historic Herman mining district.

Brokaw-Pitcher pit near Arlington: A large gravel pit east of Arlington (N/2 sec. 30, T.19N., R.78W.) is a S&G source for the Wyoming Department of Transportation (Figure 21). The pit contains sand, gravel, and boulders carried downstream (north) by Rock Creek. Approximately 350,000 yds^3 of material remain in the pit above the water table (Ted Wells, personal communication to Eric Nielsen,1991). An additional 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. An assay of grab sample concentrates yielded 4.7 ppm Au (samples SG2A-91 and SG2-91, Table 7).

Rock Creek placer: A sample was collected from a sand bar in Rock Creek (SW/4 sec. 25, T19N, R79W) (Figure 21). 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 were collected. These assayed greater than 100 ppm Au (sample SG14A-91, Table 7).

North Platte River

On either side of I-80 along the North Platte River at Fort Steele are several sand and gravel pits (Figure 22). Samples were collected from both sides of the Interstate for gold analysis.

SE/4 SE/4 SW/4 sec. 26, T.21N., R.85W.: North of the Interstate near the public rest area of historic 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. Grab sample concentrates assayed 0.3 ppm Au (samples SG15A-91 and SG15-91, Table 7).

W/2 W/2 sec. 36, T.21N., R.85W.: A second deposit on the south side of the Interstate forms a terrace on the east bank of the Platte River. A sample was collected from the bottom of a 20 foot long, 10 to 12 foot deep trench in an active S&G pit. This deposit consists of poorly sorted sand, pebbles, and cobbles. The panned concentrates from this gravel bed assayed 2.7 ppm Au. However, grab sample concentrates yielded no detectable gold. Panned concentrates from the sand from a wash pit yielded 8.0 ppm Au. A grab sample concentrate from the gravel layer and from the wash pit yielded no detectable gold (samples SG16A-91, SG16-91, SG16B-91, SG16W-91, Table 7).

Green River

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

Sec. 25 and 36, T.19N., R.108W.: A grab sample consisting of six 5 gallon buckets was dug from the eastern river bank on the section line of about 4 to 5 miles northwest of the town of Green River (Figure 23). This sample consisted of sand with minor pebbles 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 State Survey for processing where 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).

Granger

A sample was taken from an active pit (NE/4 sec. 29, T.19N., R.111W.) operated by Union Pacific along the Blacks Fork near the confluence of the Blacks Fork with the Hams Fork about a half mile northeast of the town of Granger (Figure 24). 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).

Red Creek

Sand and gravel was sampled from a several foot thick cut bank on the west bank of Red Creek at Richards Gap (Figure 6). 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 RG1-91) was collected 0.75 mile upstream (north) from the Richards Gap titaniferous black sandstone deposit. Here, sand with cobbles and pebbles were dug from the cut bank and placed in three 5 gallon buckets and transported to the Survey for processing. Part of the sample was panned and the remainder was processed in the Gold Scavenger. Sample concentrates were assayed yielding a gold value of 11.4 ppm (sample RG1-91, Table 7).

Investigation of the Leucite Hills lamproites for precious stones

Introduction

The Leucite Hills north of Rock Springs consists of a unique group of rocks found only at a few other localities in the world. These rocks are lamproites and are known to occur in only 25 provinces or fields in the world (Mitchell and Bergman, 1991) making them some of the rarest rocks in the world. 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 Proterozoic to Archean 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 texturally variable of all lamproite facies. Diamondiferous lamproite vents belong to the crater facies. In such vents, pyroclastic or fragmental rocks have typically 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 in the world. 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, and 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 consist 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. Micophencrystal 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 25). The olivine phenocrysts are translucent to transparent olive-green subhedral grains up to 1/2 inch across, some of which are relatively high quality, although highly fractured. Fifty to 100 pound samples were collected at various locations from the two flows and processed for diamonds in the Survey's diamond extraction lab.

None of the samples yielded diamond. However, the size of the samples and the restricted number of samples are not considered as a diagnostic test. Future testing should include a much larger volume of material restricting the samples to 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 clear, translucent, octahedral spinel was recovered.

Project conclusions

The final results of this reconnaissance project were very encouraging especially when it is considered that much of the terrane that was examined has historically been considered to be some of the lowest potential ground in Wyoming for metal deposits. Future efforts should continue along the lines of this initial project with follow-up studies to include detailed sampling and alteration studies of Aspen Mountain, sampling studies of other coal deposits (particularly in the Kemmerer coal field), 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 as high priority.

Some lower priority projects to be considered 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 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.

References cited

Albert, K.G., 1986, Reported gold concentrations in sediment samples from U.S. Department of Energy's National Uranium Resource Evaluation (NURE) reports: Geological Survey of Wyoming Open File Report 86-4, scale 1:1,000,000.

Antweiler, J.C., and Love, J.D., 1967, Gold-bearing sedimentary rocks in northwest Wyoming: a preliminary report: U.S. Geological Survey Circular 541, 12 p.

Anonymous, 1873, Summaries of early newspaper accounts on the Rawlins hematite and Seminoe gold district: Geological Survey of Wyoming files, 15 p.

Beeler, H.C., 1906, Mineral and allied resources of Albany County, Wyoming: Office of the State Geologist miscellaneous printed report, Cheyenne, Wyoming, 79 p.

Berger, B. R., and Henley, R. W., 1989, Advances in the understanding of epithermal gold-silver deposits, with special reference to the western United States:

Birak, D.J., and Hawkins, R.B., 1986, The geology of the Enfield Nell Mine and the Jerritt Canyon district, Elko County, Nevada in Tingley, J.V., and Bonham, H,.F., Jr, editors, Sediment-hosted precious-metal deposits of northern Nevada: Nevada Bureau of mines and Geology Report 40, p. 56-64.

Bird, M. I., Andrew, A. S., Chivas, A. R., and Lock, D. E., 1989, An isotopic study of surficial alunite in Australia: 1. hydrogen and sulphur isotopes: Geochimica et Cosmochimica Acta, v. 53, p. 3223-3237.

Blackstone, D. L., Jr., 1973, Structural geology of the eastern half of the Morgan Quadrangle, the Strouss Hill Quadrangle, and the James Lake Quadrangle, Albany and Carbon Counties, Wyoming: Geological Survey of Wyoming Preliminary Report 13, 45 p.

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

Carmichael, I.S.E., 1967, The mineralogy and petrology of the volcanic rocks from the Leucite Hills, Wyoming: Contributions to Mineralogy and Petrology v. 15, p. 24-66.

Chyi, L.L., 1982, The distribution of gold and platinum in bituminous coal: Econ Geology v. 77, no. 6, p. 1592-1597.

Dow, V.T., and Batty, J.V., 1961, Reconnaissance of titaniferous sandstone deposits of Utah, Wyoming, New Mexico, and Colorado: U.S. Bureau of Mines Report of Investigations 5860, 52 p.

Duncan, M., 1990, The Medicine Bow mining camps: Jelm Mountain Publications, Laramie, Wyoming, 244 p.

Field, C.W., 1966, Sulfur isotope method for discriminating between sulfates of hypogene and supergene origin: Economic Geology v. 61, p. 1428-1435.

Finkelman, R.B., and Brown, R.D., Jr., 1989, Mineral resource and geochemical exploration potential of coal that has anomalous metal concentrations, in K.S. Schindler, editor, 5th annual McKelvey forum on mineral and energy resources (programs and abstracts): U.S. Geological Survey Circular 1035, p. 18-19.

Fyfe, W.S. and Kerrich, R., 1984, Gold: natural concentration processes, in Foster, R.S., editor, Gold '82: the geology, geochemistry and genesis of gold deposits: Geological Society of Zimbabwe Special Publication 1, p. 99-127.

Goldbery, R., 1980, Early diagenetic, Na-alunites in Miocene algal mat intertidal facies, Ras Sudar, Sinai: Sedimentology, v. 27, p. 189-198.

Goldschmidt, V.M., 1954, Geochemistry: Clarendon Press, Oxford, 730 p.

Gunter, W.L., Hammitt, J.W., Babcock, R.C., Gibson, T.R., and Presnell, R.D., 1990, Geology of the Barleys Canyon and Melco gold deposits, Salt Lake County, Utah; in Hausen, D. M. and others, editors, Gold 90: Society of Mining, Metallurgy, and Exploration, Inc., Littleton, CO., p. 41-50.

Hague, A. and Emmons, S.F., 1877, Descriptive geology, in Clarence King's report of the geological exploration of the Fortieth Parallel, v. 2, 890 p.

Hall, R.B., and Bauer, C. W., 1983, Alunite in Lefond, S.L., editor, Industrial minerals and rocks: American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, N.Y., 722 p.

Hausel, W.D., 1989a, The geology of Wyoming's precious metal lode and placer deposits: Geological Survey of Wyoming Bulletin 68, 248 p.

Hausel, W.D.,1989b, Geology and alteration map of the Snow Grid, Donlin Creek, Alaska: Western Gold Exploration and Mining, scale 1:500.

Hausel, W.D., 1990, Strategic mineral resources of Wyoming-titanium: Geological Survey of Wyoming Open File Report 90-7, 18 p.

Hausel, W.D.,1991 Economic geology of the South Pass granite-greenstone belt, southern Wind River Mountains, Wyoming: Geological Survey of Wyoming Report of Investigations 44, 129 p.

Hausel, W.D., and Jones, S., 1982, Geological reconnaissance report of metallic deposits for in situ and heap leaching extraction research possibilities: Geological Survey of Wyoming Open File Report 82-4, 51 p.

Houston, R.S., and Murphy, J.F., 1962, Titaniferous black sandstone deposits of Wyoming: Geological Survey of Wyoming Bulletin 49, 120 p.

Houston, R.S., and Murphy, J.F., 1970, Fossil beach placer in sandstones of Late Cretaceous age in Wyoming and other Rocky Mountain states: Wyoming Geological Association 22nd annual field conference guidebook, p. 241-249.

Hyden, H.J., King, J.S., and Houston, R.S., 1967, Geologic map of the Arlington quadrangle, Carbon County, Wyoming: U.S. Geological Survey Geological Quadrangle Map GQ-643, scale 1:24,000.

Jenny, W.P., 1903, The chemistry of ore deposition: Transactions of the American Institute of Mining Engineers, v. 33, 1120 p.

Karlstrom, K.E., Houston, R.S., Flurkey, A.J., Coolidge, C.M., Kratochvil, A.L., and Sever, C.K., 1981, Volume 1, A summary of the geology and uranium potential of Precambrian conglomerates in southeastern Wyoming: U.S. Department of Energy NURE Open File Report GJBX-139(81), 541 p.

Khalaf, F. I., 1990, Diagenetic alunite in clastic sequences, Kuwait, Arabian Gulf: Sedimentology, v. 37, p. 155-164.

King, D., 1953, Origin of alunite deposits at Pidinga, South Australia: Economic Geology

King, J.K., 1991, Rare earth elements and yttrium in Wyoming: Geological Survey of Wyoming unpublished Mineral Report 91-3, 125 p.

King, J.K., and Hausel, W.D., 1991, Rare earth elements and yttrium in Wyoming-from oddities to resources in Frost, B.R., and Roberts, S., editors, Mineral resources of Wyoming: Wyoming Geological Association 42nd Annual Field Conference Guidebook, p. 49-70.

King, J. S., 1963, Petrology and structure of the Precambrian and post-Mississippian rocks of northeastern Medicine Bow Mountains, Carbon County, Wyoming: PhD dissertation, University of Wyoming, Laramie, 125 p.

King, J. S., 1964, Cooper Hill- A gravity slide in the northeastern Medicine Bow Mountains, Wyoming: University of Wyoming, Contributions to Geology, v. 3, no. 1, p. 33-37.

Kirschbaum, M. A., 1986, Geologic map of the Kappes Canyon Quadrangle, Sweetwater County, Wyoming: U.S. Geological Survey GQ-1607, scale 1:24,000.

Knell, G.W., 1985, The sedimentology and petrology of the Cambria coal, Newcastle, Weston County, Wyoming: M.S. thesis, South Dakota School of Mines and Technology, Rapid City, 115 p.

Knight, W.C., 1893, Notes on the mineral resources of the State: University of Wyoming Experiment Station Bulletin 14, p. 103-212.

Love, J. D., and Antweiler, J.C., 1973, Copper, silver, and zinc in the Nugget Sandstone, western Wyoming: Wyoming Geological Association 25th annual field conference guidebook, p. 139-147.

Love, J. D., and Blackmon, P. D., 1962, Alunite on Aspen Mountain, southwestern Wyoming: U.S. Geological Survey Professional Paper 450 D, p. 11-15.

Madsen, M., 1978, A statistical analysis of heavy mineral variations in upper Cretaceous black sandstone deposits of the Rocky Mountain states: M.S. thesis, University of Wyoming, Laramie, 138 p.

Marlatt, G., and Spatz, D., 1991, Gold concentrations hosted in coal - an exploration model in Frost, B.R., and Roberts, S., editors, Mineral resources of Wyoming: Wyoming Geological Association 42nd Annual Field Conference Guidebook, p. 33-36.

McDowell, F. W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West no. 2, p. 1-16.

Meyer, R., and Pena Dos Reis, R. B., 1985, Paleosols and alunite silcretes in continental Cenozoic of Western Portugal: Journal of Sedimentary Petrology, V. 55, no. 1, p. 76-85.

Mitchell, .R.G., and Bergman, S.C., 1991, Petrology of lamproites: Plenum Press, New York, 447 p.

Murphy, J.F., and Houston, R.S., 1955, Titanium-bearing black sand deposits of Wyoming: Wyoming Geological Association 10th annual field conference guidebook, p. 190-196.

Ogden, P.R., 1979, The geology, major element geochemistry, and petrogenesis of the Leucite Hills volcanic rocks, Wyoming: PhD dissertation, University of Wyoming, Laramie, 137 p.

Osterwald, F.W., Osterwald, D.B., Long, J.S., Jr., and Wilson, W.H., 1966, Mineral resources of Wyoming: Geological Survey of Wyoming Bulletin 50, 287 p.

Ott, L. E., Groody, D., Follis, E.L., and Seims, P.L., 1986, Stratigraphy, structural geology, ore mineralogy and hydrothermal alteration at the Cannon mine, Chelan County, Washington, U.S.A. in Gold 86

Pickthorn, W.J. and O'Neil, J.R., 1985, $\partial^{18}O$ relations in alunite minerals: a potential single-mineral geothermometer: Geological Society of America Abstracts with Programs 17, p. 689.

Roehler, H.W., 1989, Origin and distribution of six heavy-mineral placer deposits in coastal-marine sandstones in the Upper Cretaceous McCourt Sandstone Tongue of the Rock Springs Formation, southwest Wyoming: U.S. Geological Survey Bulletin 1867, 34 p.

Schoen, R., 1953, Geology of the Cooper Hill district, Carbon County, Wyoming: M.A. thesis, University of Wyoming, Laramie, 41 p.

Stone, R.W., 1912, Coal near the Black Hills Wyoming-South Dakota: U.S. Geological Survey Bulletin 499, 66 p.

U.S. Geological Survey, 1968, Gold content of coal, peat, and associated rocks, in U.S. Geological Survey heavy metals program progress report 1966 and 1967: U.S. Geological Survey Circular 560, 24 p.

Wyant, D.G., Sharp, W.N., and Sheridan, D.M., 1956, Reconnaissance study of uranium deposits in the Red Desert Sweetwater County, Wyoming: U.S. Geological Survey Bulletin 1030-I, p. 237-308.

Table 1. Geochemical analyses of rock samples from the Cooper Hill district. Refer to Plate 1 for sample locations. Analyses by Bondar-Clegg. (Dashes imply not analyzed).

Sample #	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 (N/2 NE/4 sec. 34)	< 0.005	1.6	--	22	5	--	--	--	--	--	--
CH5-91	Cupriferous quartz in metalimestone from prospect pit (NW/4 NE/4 sec. 34)	0.187	0.8	0.065	10	--	--	0.04	--	--	--	--
CH45-91	Weak skarn from prospect pit (NW/4 NE/4 sec. 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 (N/2 N/2 NE/4 sec. 34)	< 0.005	< 0.2	0.014	7	1	--	--	--	--	--	--
CH11-91	Milky quartz with limonite boxworks after siderite from Rip Van Winkel 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/4 SE/4 sec. 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 (E/2 sec. 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/4 NW/4 sec. 27)	0.013	< 0.2	--	--	--	--	--	--	--	--	--
CH16-91	Limonite boxworks after siderite in quartz from mine dump	0.037	0.8	--	56	45	0.07	--	--	--	--	--

Sample #	Description	Au (ppm)	Ag (ppm)	Cu (%)	Pb (ppm)	Zn (ppm)	Ga (ppm)	Cr_2O_3 (%)	Ni (ppm)	W (ppm)	Sn (ppm)	Ti (ppm)
CH19-91	Milky quartz breccia vein containing massive limonite after siderite from prospect pit (E/2 NE/4 sec. 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/4 sec. 34)	>10.0	1.4	--	--	--	--	--	--	--	--	--
CH26-91	Milky quartz breccia vein from mine dump (W/2 NW/4 sec. 35)	< 0.005	0.5	--	--	--	--	--	--	---	--	--
CH28-91	Limonite-stained skarn (S/2 SE/4 sec. 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/4 SE/4 sec. 27)	< 0.05	--	--	--	--	--	--	--	--	--	--
CH32-91	Limonite-stained, grey-black quartz (SE/4 sec. 27)	0.190	< 1.0	--	--	--	--	--	--	--	--	--
CH38-91	Limonite boxworks in quartz from mine dump (E/2 sec. 27)	0.160	1.8	--	72	48	--	--	--	--	--	--
CH39-91	Grab sample of galena-bearing quartz, Albion mine (W/2 sec. 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 form 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	--	--	--	--	--	--

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

Sample Number	Description	Au (ppm)	Fe (%)
Richards Gap			
RG1-91	Chocolate-brown to tawny sandstone collected at southeastern-most exposure. At this point, the Ti-sandstone is only about 1 foot thick and poorly mineralized.	0.100	-
RG2-91	A two-foot composite chip of poorly mineralized rock.	0.060	-
RG3-91	3 to 3 1/2 ft composite chip from lower end (western edge) of deposit.	nd	-
RG4-91	Six-foot composite chip. Relatively well mineralized.	nd	22.71
Black Butte Creek			
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	-
Cooper Ridge			
CR1-91	Chip sample of Ti-sandstone from 3 ft thick layer.	nd	27.36
CR2-91	Chip of Ti-sandstone.	nd	-
CR3-91	Chip of Ti-sandstone.	-	31.62
Brady Road			
BR1-91	Massive Ti-sandstone from lower outcrop.	nd	-
BR2-91	Massive Ti-sandstone collected from buckeled outcrop.	nd	-
BR3-91	Composite across 2 ft of Ti-sandstone exposed in dozer cut.	nd	-
BR4-91	Float sample.	-	33.58
BR5-91	Sample of steeply dipping Ti-sandstone.	nd	-
BR6-91	Ti-sandstone exposed in dozer cut east of BR5 at ridge top.	nd	-
BR8-91	1 1/2 ft 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	-
Camel Rock			
CM1-91	Composite of 2 1/2 ft Ti-sandstone outcrop from southern-most exposure.	nd	-
Union Pacific #1			
UP1-91	Composite of 4 ft of Ti-sandstone from western edge of butte.	nd	-
UP2-91	7 ft composite of Ti-sandstone in northern dozer trench, west rib.	nd	-
UP3-91	4 ft composite of Ti-sandstone outcrop from south edge of butte.	nd	-
UP4-91	4 ft composite collected from rib of dozer trench.	nd	29.96
UP5-91	6 ft composite from dozer trench in northern, down-dropped block.	nd	-
UP6-91	5 ft thick outcrop west of prospect pit.	nd	-
UP7-91	7 ft composite, west edge of northern block.	0.060	-
UP8-91	Selected sample of massive Ti-sandstone.	nd	-
UP9-91	2 ft composite of Ti-sandstone.	nd	16.56
Yenko			
YN1-91	Grab sample of Ti-sandstone float at base of cliff.	nd	-
Titsworth Gap			
MR1-91	Grab of Ti-sandstone from 200 ft long outcrop.	nd	-

Table 3. **Geochemical analyses of samples from the Aspen Mountain area, southwestern Wyoming (n.d. = not detected; tr = trace; dash = not tested). With the exception of the NURE (National Uranium Resource Evaluation) samples, all samples analyzed by Gordon Mariatt.**

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	Grey silty sandstone	nd	--	--	--	--	--
RS-24	Grey 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" seam)	nd	--	--	--	--	--
RS-37	Tar sand above coal	nd	--	--	--	--	--
RS-38	Coal (top of seam) with about 5% pyrite	nd	--	--	--	--	--
RS-39	Coal (middle of seam) with about 2% pyrite	0.08	--	--	--	--	--

Sample Number	Description	Au (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ba (ppm)	W (ppm)
RS-40	Coal (bottom of seam) with about 8% 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	--	--	--	--	--
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	--	--	--	--	--

Sample Number	Description	Au (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ba (ppm)	W (ppm)
RS-82	Stream sediment sample	nd	--	--	--	--	--
RS-83	Stream sediment sample	nd	--	--	--	--	--
RS-84	Stream sediment sample	nd	--	--	--	--	--
RS85	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	Nonsilicified sandstone	nd	--	--	--	--	--
RS-92	Calcite-cemented sandstone breccia	nd	--	--	--	--	--
RS-93	Calcite-cemented sandstone breccia	nd	--	--	--	--	--
RS-94	Subsilicified sandstone	tr	--	--	--	--	--
RS-95	Nonsilicified sandstone	nd	--	--	--	--	--
RS-96	Nonsilicified sandstone	nd	--	--	--	--	--
NURE 8519	Stream sediment	nd	13	--	24	606	--
NURE 8520	Stream sediment	nd	13	90	8	--	--
NURE 8526	Stream sediment	--	14	136	12	--	--
NURE 8527	Stream sediment	--	--	--	13	--	--
NURE 8532	Stream sediment	nd	--	--	--	--	--
NURE 8533	Stream sediment	nd	--	--	--	--	--
NURE 8534	Stream sediment	nd	--	--	--	--	--
NURE 8535	Stream sediment	nd	17	100	10	--	18
NURE 8536	Stream sediment	nd	--	--	--	--	--
NURE 8537	Stream sediment	nd	11	--	14	--	23
NURE 8538	Stream sediment	nd	16	44	--	--	--
NURE 8539	Stream sediment	nd	20	115	46	--	--
NURE 8556	Stream sediment	nd	26	131	8	--	--
NURE 8555	Stream sediment	nd	--	--	--	--	--
NURE 8554	Stream sediment	nd	--	90	13	--	25
NURE 8553	Stream sediment	nd	--	--	--	--	--

Table 4. Geochemical analyses of conglomerates from the Rawlins uplift (analyses by Bondar-Clegg and Robert 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	Basal 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	Basal 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	Basal 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	Conglomerate (hematitic)	< 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	Immature, poorly sorted 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	Immature, poorly sorted 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

Table 5. Precious metal analyses of coal, scoria, ash and related rock (nd = not detected; tr = trace). Analyses by Gordon Marlatt.

Sample Number	Description	Au (ppm)
	Black Buttes coal mine (Almond coal)	
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	high-sulfur 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 Buttes Pit #6 (Lance coal)	
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 Buttes Pit #3 (Ft. Union coal)	
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	low-grade parting in C coal seam	0.080
BB25	sample from C seam	0.100
	Walcott Junction (St. Marys Hill) coal mine	
W1	grid sample from mine dump (see figure 11b)	nd
W2	grid sample from mine dump	nd
W3	grid sample from mine dump	tr
W4	grid sample from mine dump	nd
W5	grid sample from mine dump	nd
W6	grid sample from mine dump	nd
W7	grid sample from mine dump	nd
W8	grid sample from mine dump	nd
W9	grid sample from mine dump	nd
W10	grid sample from mine dump	nd
W11	grid sample from mine dump	nd
W12	grid sample from mine dump	nd
W13	grid sample from mine dump	0.060

Sample Number	Description	Au (ppm)
W14	grid sample from mine dump	nd
W15	grid sample from mine dump	nd
W16	grid sample from mine dump	nd
W17	grid sample from mine dump	nd
W18	grid sample from mine dump	nd
W19	grid sample from mine dump	nd
W20	grid sample from mine dump	tr
W21	grid sample from mine dump	nd
W22	grid sample from mine dump	nd
W23	grid sample from mine dump	nd
W24	grid sample from mine dump	nd
W25	grid sample from mine dump	nd
W26	grid sample from mine dump	nd
W27	grid sample from mine dump	0.095
W28	grid sample from mine dump	nd
W29	grid sample from mine dump	nd
W30	grid sample from mine dump	nd
W31	grid sample from mine dump	nd
W32	grid sample from mine dump	nd
W33	grid sample from mine dump	nd
W34	grid sample from mine dump	nd
W35	grid sample from mine dump	nd
W36	grid sample from mine dump	nd
W37	grid sample from mine dump	nd
W38	grid sample from mine dump	0.060
W39	grid sample from mine dump	nd
W40	grid sample from mine dump	nd
W41	grid sample from mine dump	nd
W42	grid sample from mine dump	nd
W43	grid sample from mine dump	nd
W44	grid sample from mine dump	nd
W45	grid sample from mine dump	nd
W46	grid sample from mine dump	nd
W47	grid sample from mine dump	nd
W48	grid sample from mine dump	nd
W49	grid sample from mine dump	nd
W50	grid sample from mine dump	nd
W51	grid sample from mine dump	nd
W52	grid sample from mine dump	nd
W53	grid sample from mine dump	nd
W54	grid sample from mine dump	nd
W55	grid sample from mine dump	nd
W56	grid sample from mine dump	nd
W57	grid sample from mine dump	nd
W58	grid sample from mine dump	0.060
W59	grid sample from mine dump	tr
W60	grid sample from mine dump	nd
W61	grid sample from mine dump	nd
W62	grid sample from mine dump	nd
W63	grid sample from mine dump	nd
W64	grid sample from mine dump	tr
W65	grid sample from mine dump	nd
W66	grid sample from mine dump	0.060
W67	grid sample from mine dump	nd

Sample Number	Description	Au (ppm)
W68	grid sample from mine dump	nd
W69	grid sample from mine dump	tr
W70	grid sample from mine dump	nd
W71	grid sample from mine dump	0.050
W72	grid sample from mine dump	0.110
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	glassey botryoidal scoria	nd
CD9	coal, below burn	nd
CD10	coal	tr
CD11	hard, red, silty sandstone	tr
CD12	grey glassey 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

Table 6. **Sandstone, shale, limestone, and tar sandstone gold analyses from various areas in the Greater Green River Basin (nd = not detected; tr = trace). Analyses by Gordon Marlatt.**

Sample Number	Description	Au (ppm)
BA1	Manganese-oxide (?) cemented sandstone	nd
BA2	Pyrolusite (?) cemented sandstone	nd
BA3	orange, friable sandstone	nd
BA4	buff to grey, iron-stained sandstone	nd
BA5	grey 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	peat	nd
BA14	white to brown sandstone below peat	nd
RSJ1	brown, iron-stained sandstone	tr
RSJ2	grey-green hard shale (?)	nd
RSJ3	quartzite with some iron-rich boxworks after pyrite	nd
RSJ4	grey to green quartzite	nd
RSJ5	grey quartzite with manganese dendrites	nd
RSJ6	friable sandstone, iron-stained	nd
RSJ7	black to grey shale with quartz vein	0.060
RSJ8	brown to orange friable sandstone	nd
RSJ9	friable sandstone	nd
RSJ10	friable sandstone	nd
RSJ11	friable sandstone	nd
RSJ12	friable sandstone	tr
WI1	carbonaceous shale	nd
WI2	carbonaceous shale	nd
WI3	buff sandstone	nd
WI4	grey, calcitic sandstone	nd
WI5	grey calcitic sandstone	nd
WI6	grey-grey, well-sorted sandstone	nd
WI7	brown sandstone with minor conglomerate	nd
WI8	green to orange, well-sorted sandstone	nd
WI9	sub-silicified sandstone	nd
WI10	white, kaolinitic sandstone	nd
WI11	grey fissle shale	nd
WI12	coal with abundant iron sulfate partings	tr
TS1	iron-stained sandstone	0.060
TS2	litic, 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
WM1	stromalolitic limestone	nd
WM2	limestone	0.070

Sample Number	Description	Au (ppm)
WM3	goniobasis chert	0.100
WM4	conglomeratic sandstone	0.100
WM5	olive-green sandstone	0.070
WM6	grey-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
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, glassey 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

Table 7. Results of sand and gravel deposits tested for gold (nd = not detected).

Sample Number	Description	Au (ppm)
SG1-91	Grab sample concentrates, Dirt Bike pit	1.7
SG3-91	Panned concentrate, Western Mobil Pit, Laramie River	0.87
SG3A-91	Grab sample concentrate, Western Mobil, Laramie River	1.2
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
SG17-91	Grab sample concentrates, Little Laramie River	12.7
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 concentrate, Cooper Creek placer	1.8
SG13A-91	Panned concentrate, Cooper Creek placer	35.9
SG9-91	Grab sample concentrate, North Fork Cooper Creek	2.6
SG9A-91	Panned concentrate, North Fork Cooper Creek	>10.0
SG10-91	Grab sample concentrates, North Fork	8.0
SG14A-91	Panned concentrate, Rock Creek placer	>100.0
SG2-91	Grab sample concentrate, Arlington pit	4.7
SG2A-91	Panned concentrate, Arlington pit	>100.0
SG15-91	Grab sample concentrate, Ft. Steele pit	0.3
SG15A-91	Panned concentrate, Ft. Steele pit	2.2
SG16-91	Grab sample concentrate, North Platte River	nd
SG16A-91	Panned concentrate, North Platte River	2.7
SG16B-91	Panned concentrate, wash pit, North Platte River	8.0
SG16W-91	Grab sample concentrates, wash pit, North Platte	nd
ST1-91	Grab sample concentrate, Green River	2.8
GG1-91	Grab sample concentrate, Blacks Fork River	2.2
RG1-91	Grab sample concentrate, Red Creek	11.4

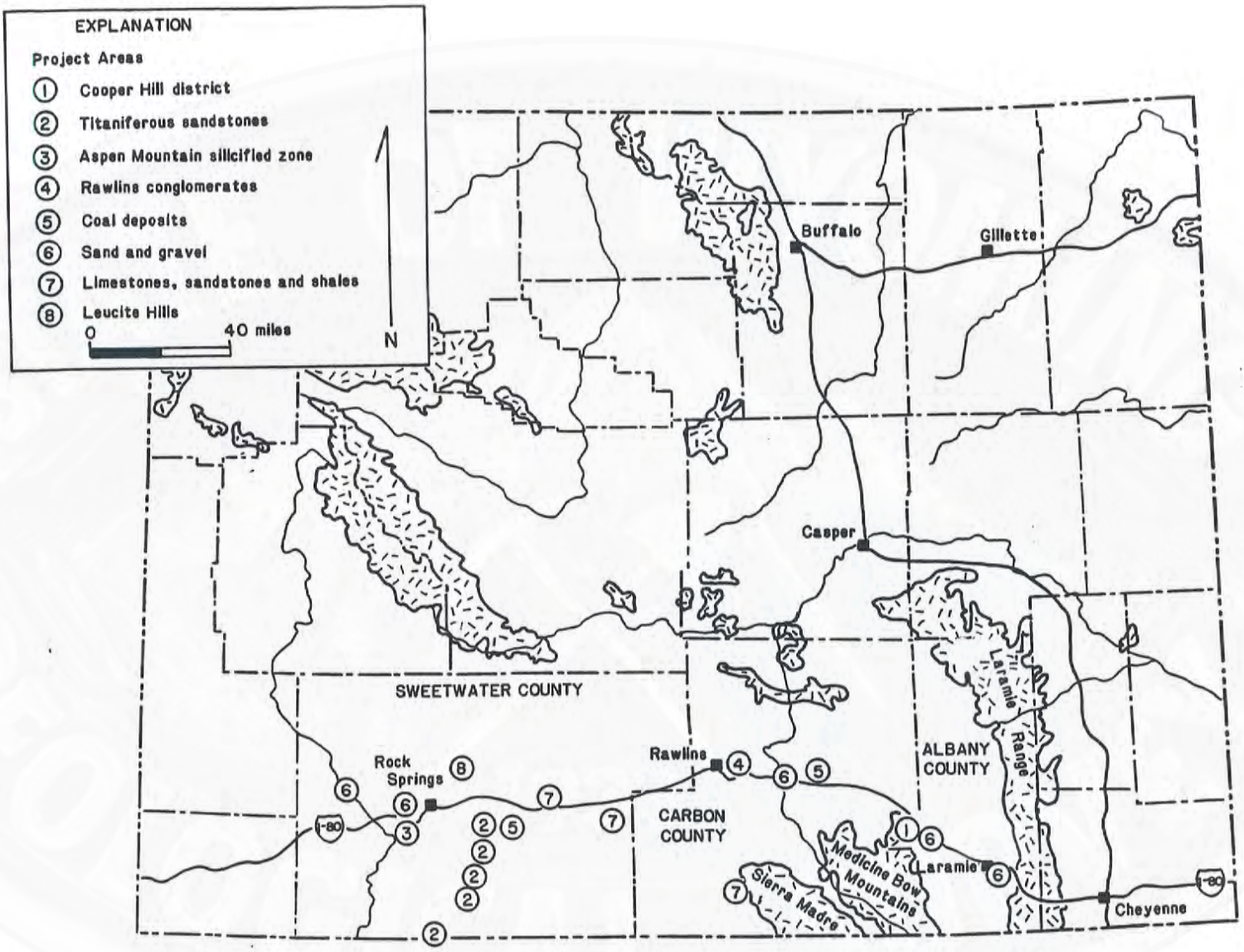

Figure 1. Project areas investigated in southern Wyoming for gold, other metals, and diamonds.

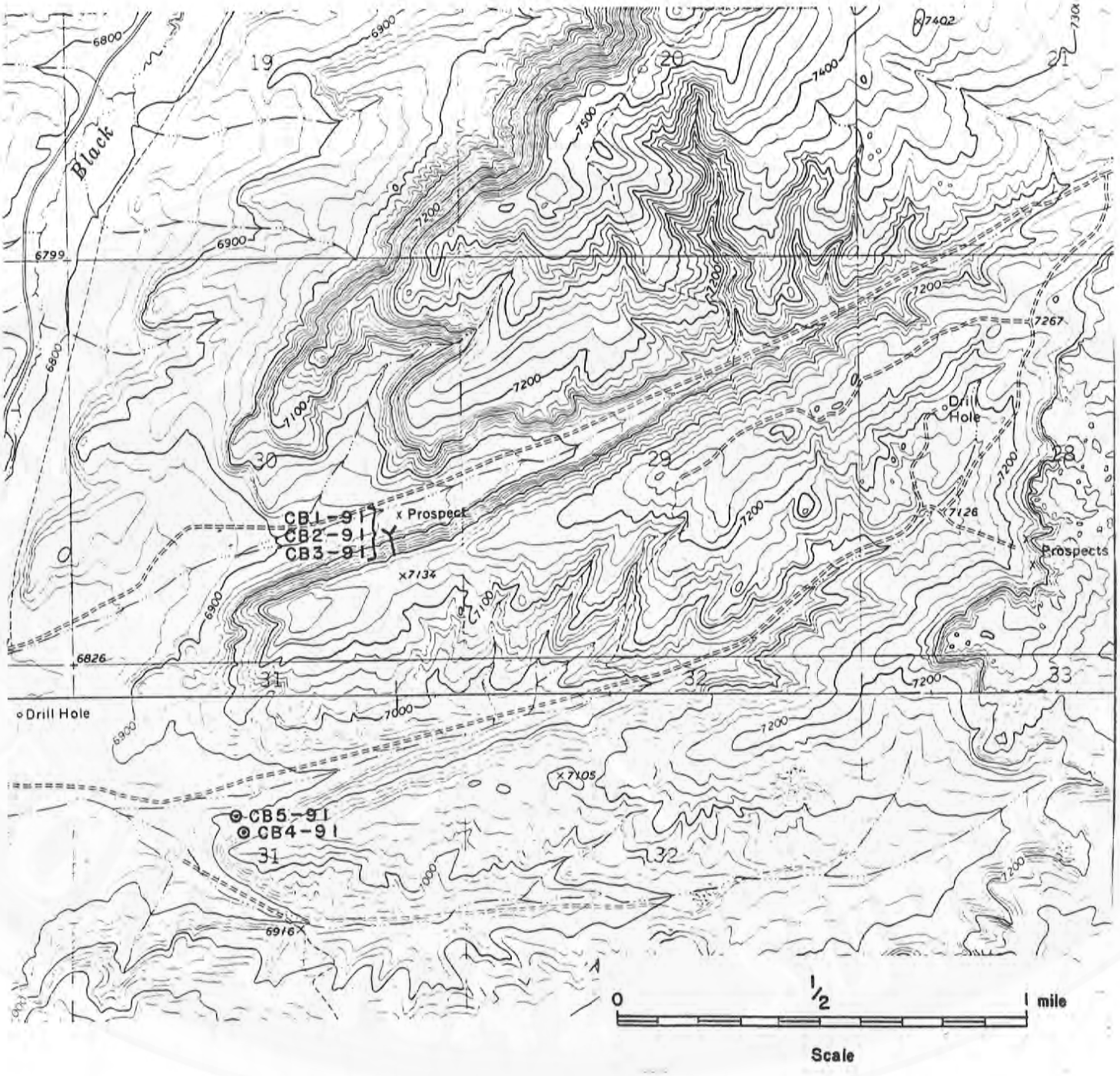

Figure 2. Sample location map for the Black Butte Creek titaniferous sandstone (secs. 30 and 31, T.18N., R.101W.) on the Cooper Ridge NE and Point of Rocks SE (1:24,000) quadrangles. The small 'Y' near the sample numbers marks the location of an adit driven into the titaniferous sandstone. Assay results of samples are found in Table 2.

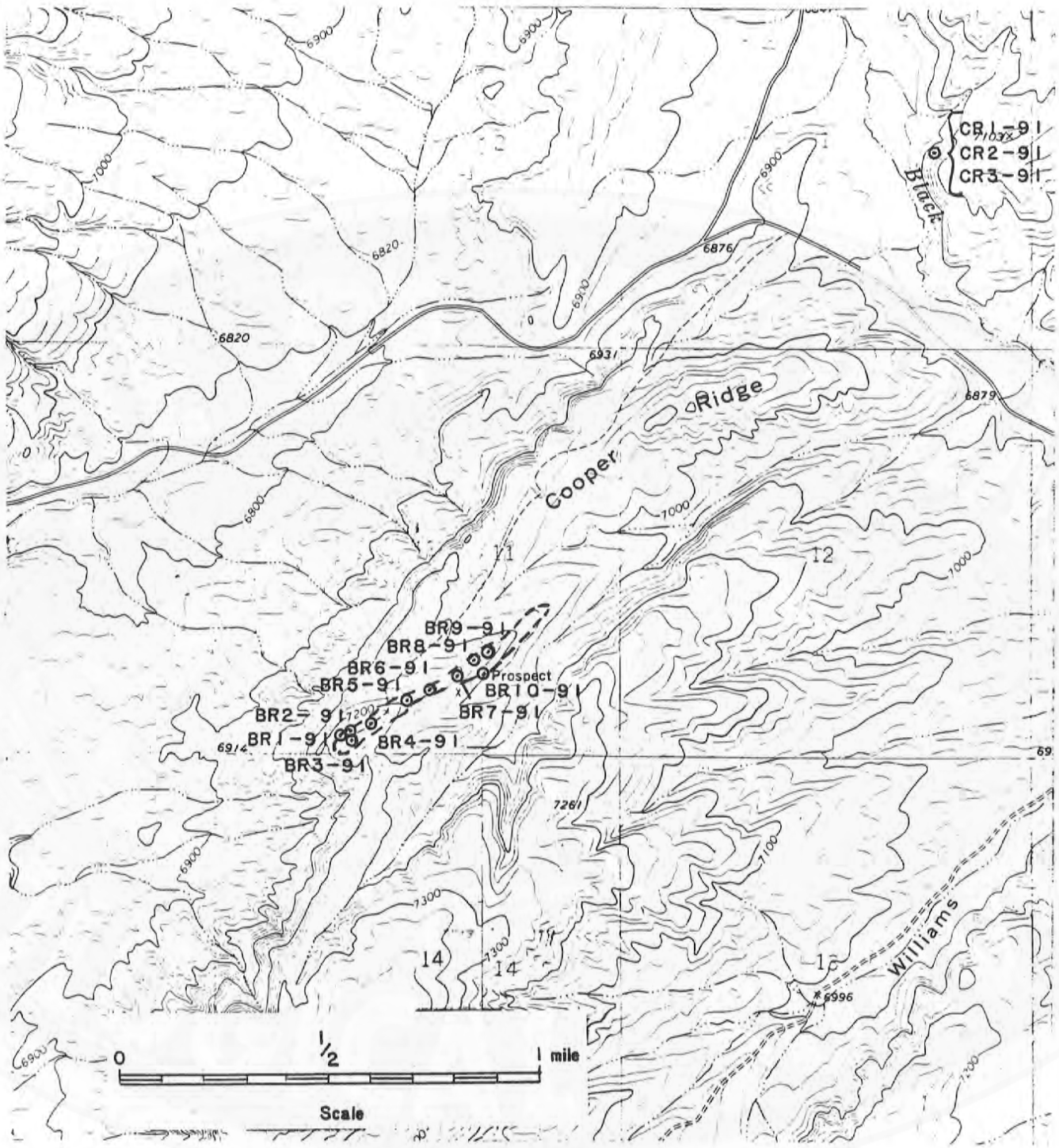

Figure 3. Location map of the Brady Road titaniferous sandstone (sec. 11, T.17N., R.102W.) and the Cooper Ridge titaniferous sandstone (sec. 1, T.17N., R.102W.) on the Camel Rock and Cooper Ridge NE (1:24,000) quadrangles. The extent of the Brady Road deposit is shown by a dashed line. The Cooper Ridge deposit is too small to show the outcrop on this scale.

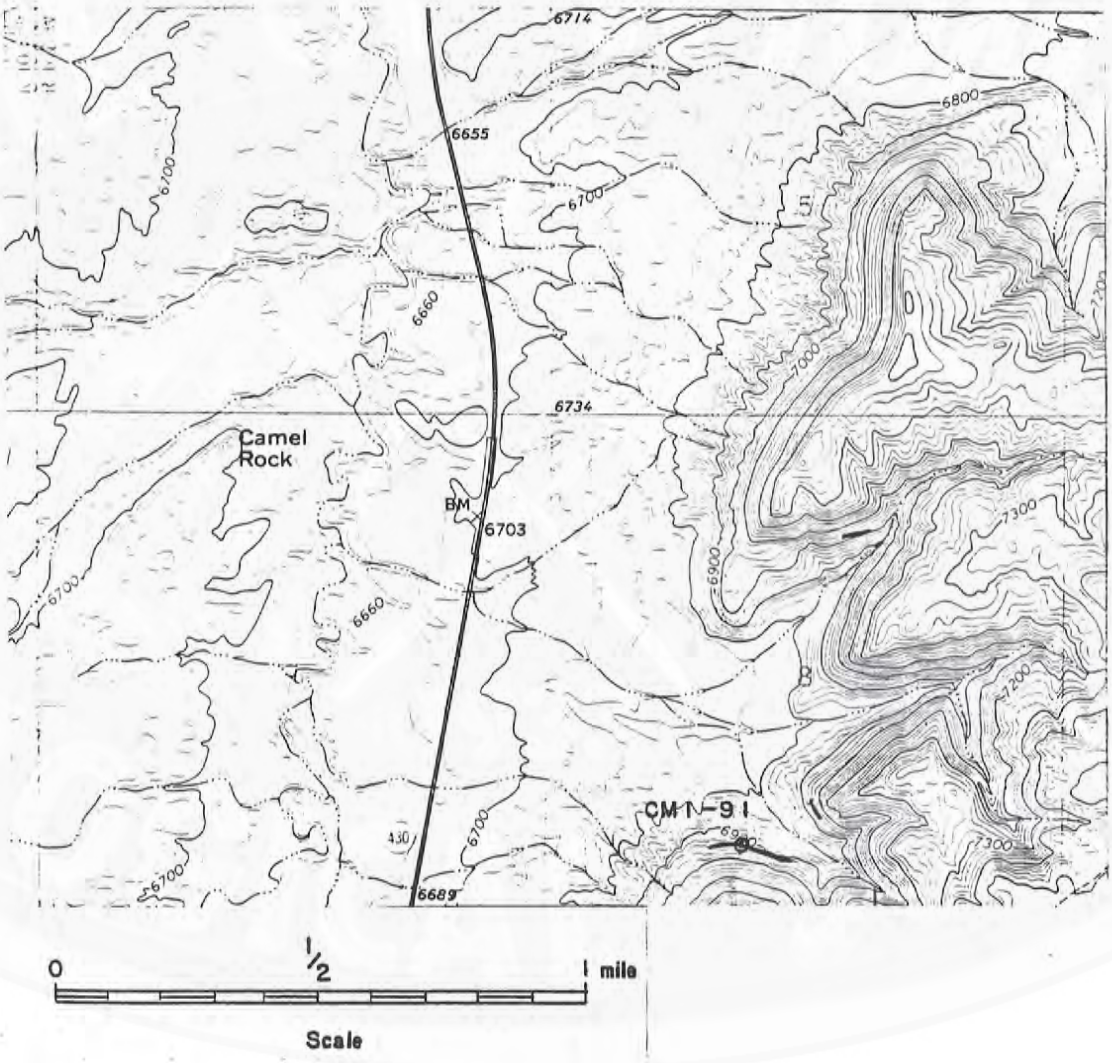

Figure 4. Sample location map of the Camel Rock titaniferous sandstone (sec. 8, T.16N., R.102W.) of the Camel Rock (1:24,000 scale) quadrangle. Solid black lines in sec. 8 mark the approximate extent of the deposit.

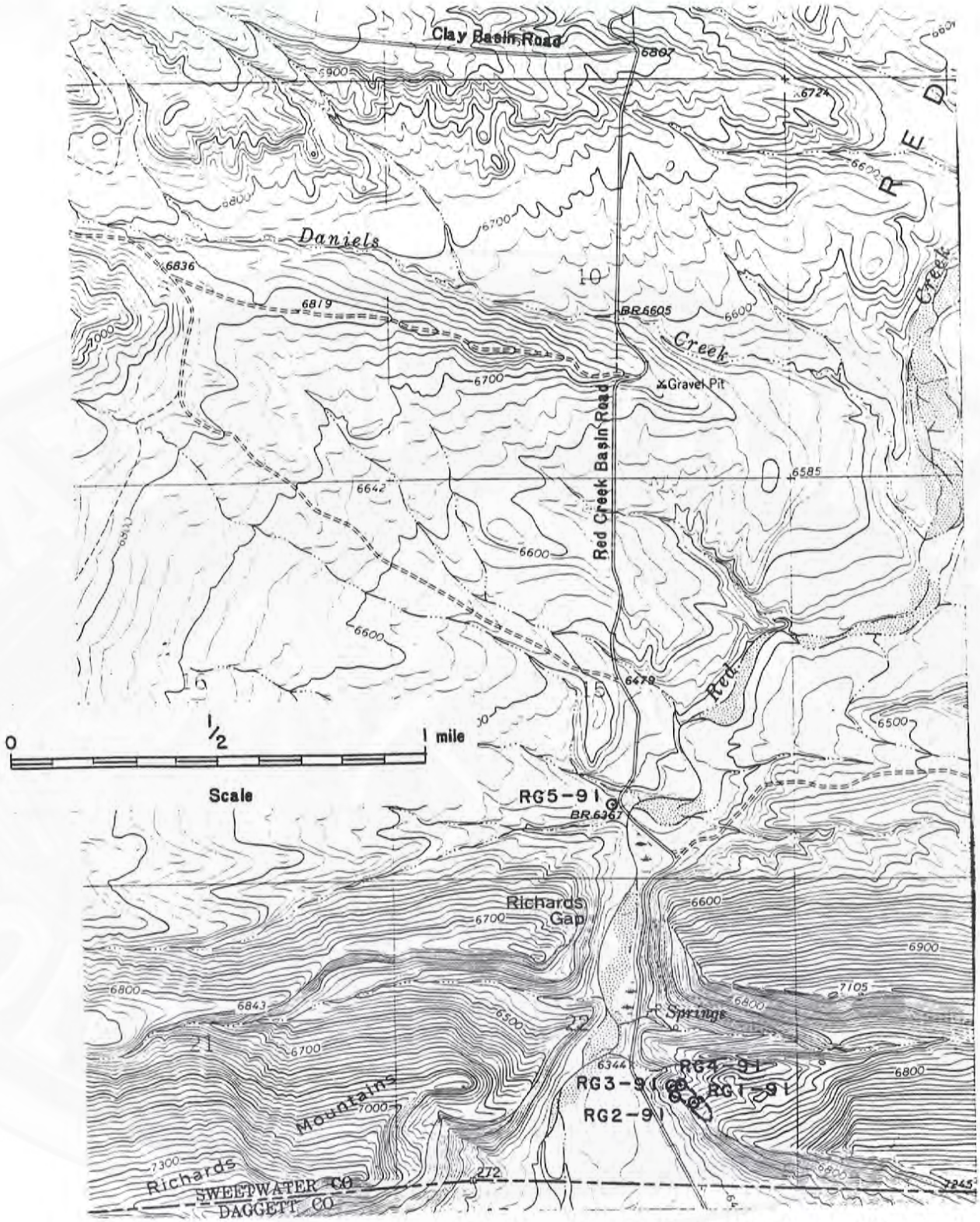

Figure 5. Location map of the Richards Gap titaniferous sandstone deposit (sec. 22, T.12 N., R.105W.) of the Richards Gap, Wyoming-Utah (1:24,000 scale) quadrangle. The heavy dashed line marks the approximate outcrop of the sandstone. Sample location sites include a sand and gravel sample (RG5-91, see Precious metals in sand and gravel deposits and placers).

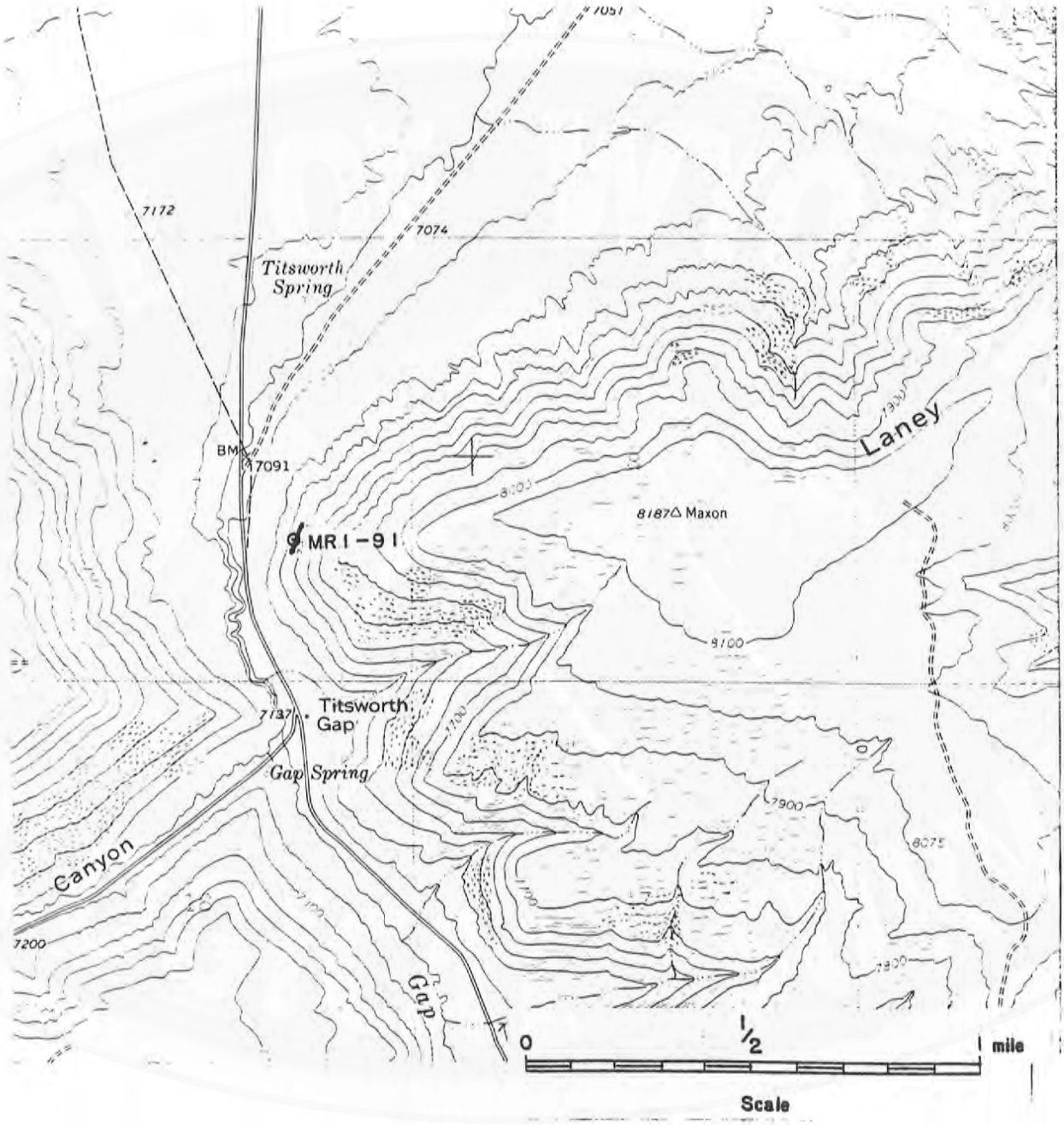

Figure 6. Sample location map for the Titsworth Gap titaniferous sandstone (SE/4 sec 7, T.14N., R.103W.) of the Titsworth Gap (1:24,000 scale) quadrangle. Solid line marks the approximate extent of outcrop. The small circle is the sample locality.

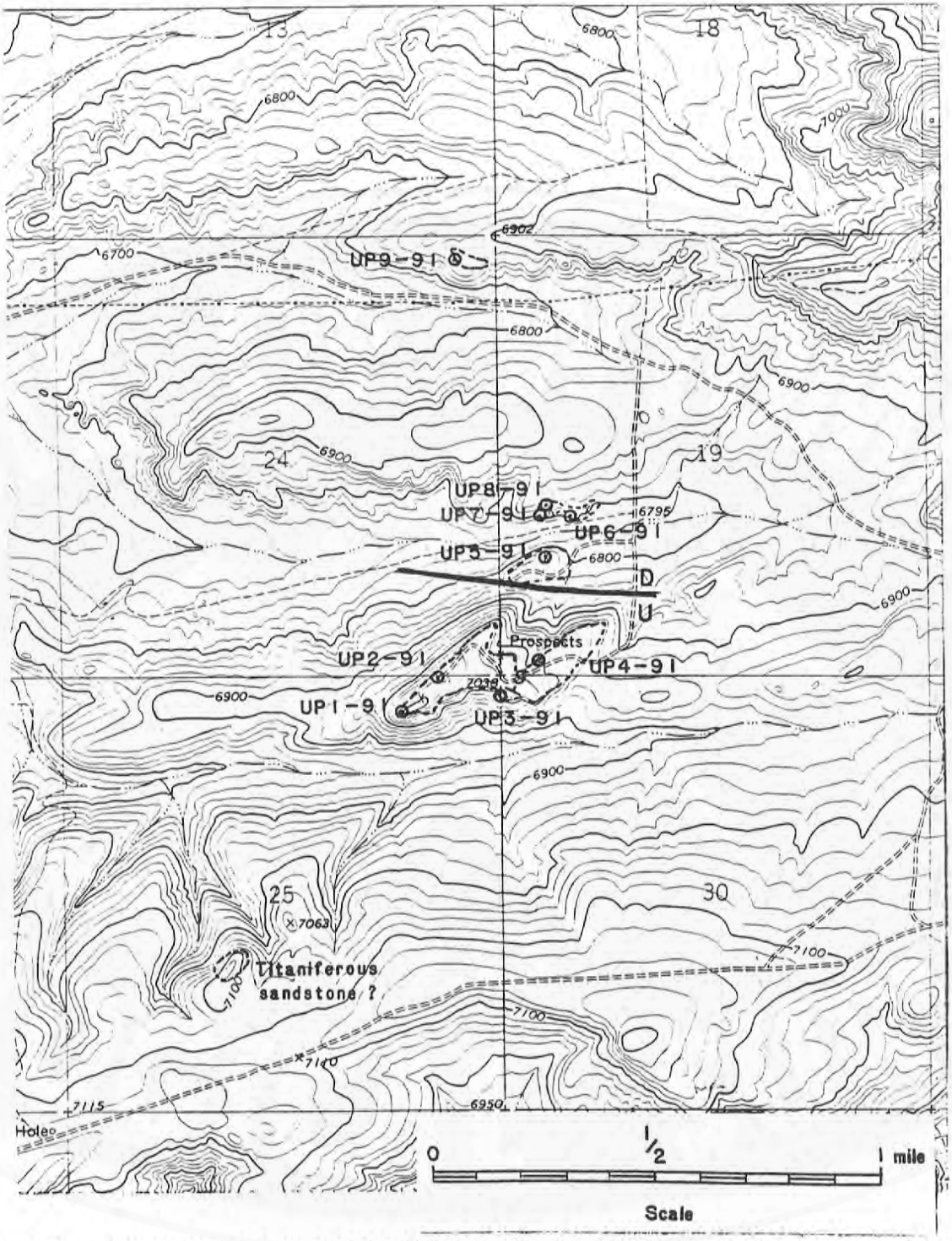

Figure 7. Sample location map of the Union Pacific #1 titaniferous sandstone (secs. 24 and sec. 25, T.19N., R.102W., and secs. 30 and sec. 19, T.19N., R.101W.) of the Point of the Rocks SE (1:24,000 scale) quadrangle. The extent of the black sandstone is outlined by dashed lines and is split into two blocks by a normal fault (D=downthrown side, U=upthrown side).

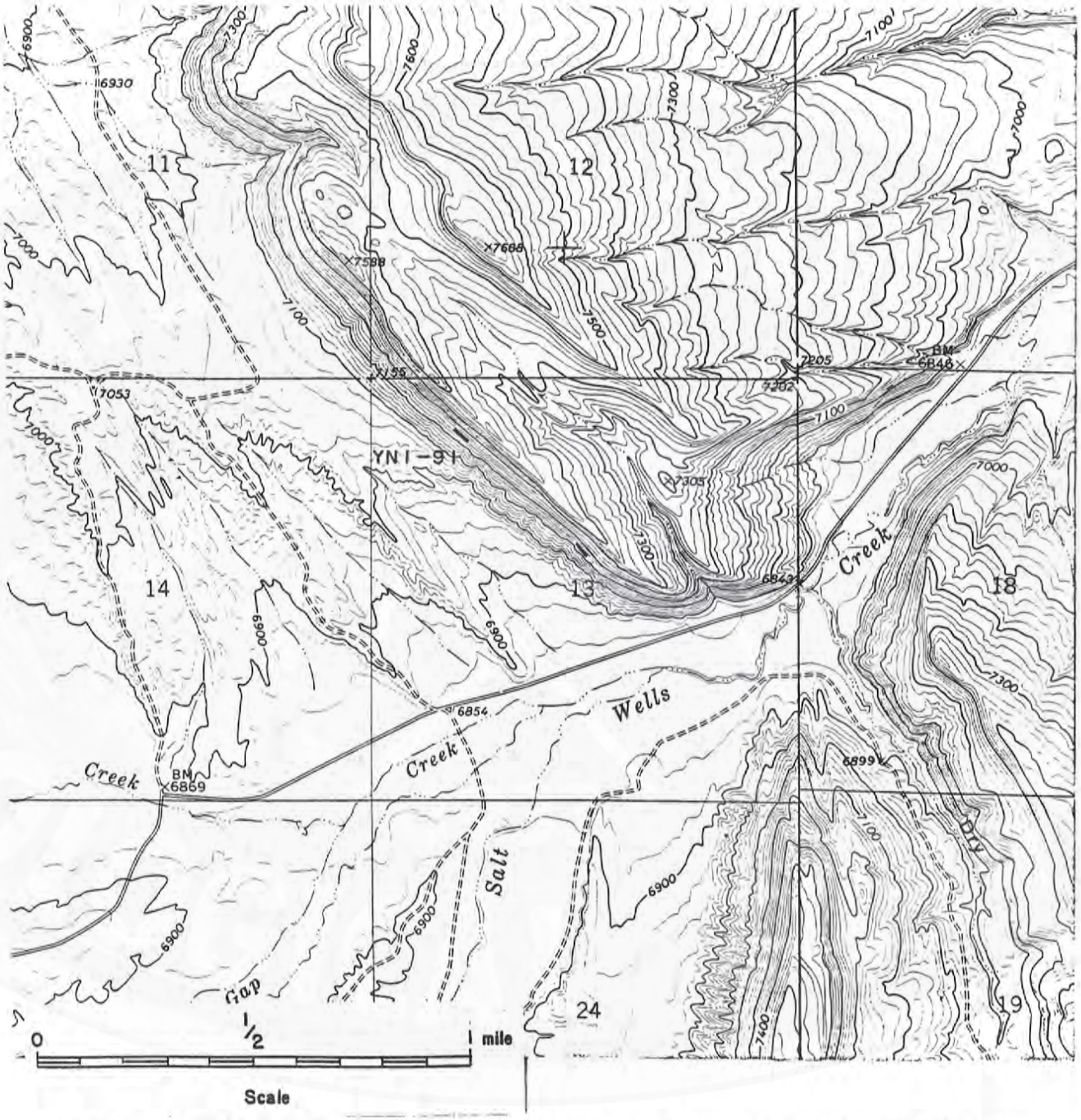

Figure 8. The Yenko titaniferous sandstone in marked by two solid lines in the cliff of an unnamed butte in sec. 13, T.15N., R.103W. of the Mud Springs Ranch (1:24,000 scale) quadrangle. Refer to Table 2 for analysis of sample YN1-91.

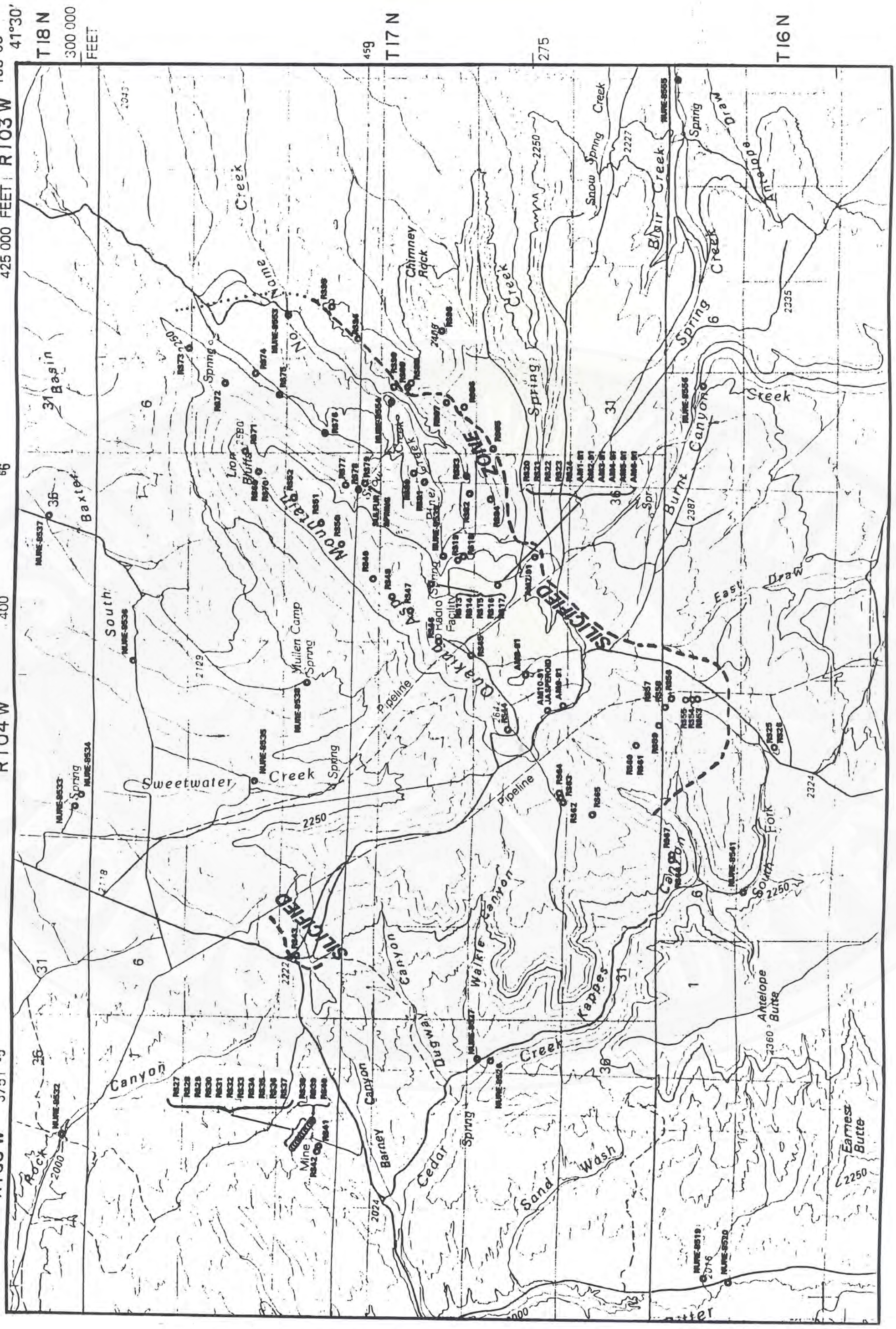

Figure 9. Location map of the Aspen Mountain silicified zone showing locations of sample sites (refer to Table 3 for analyses).

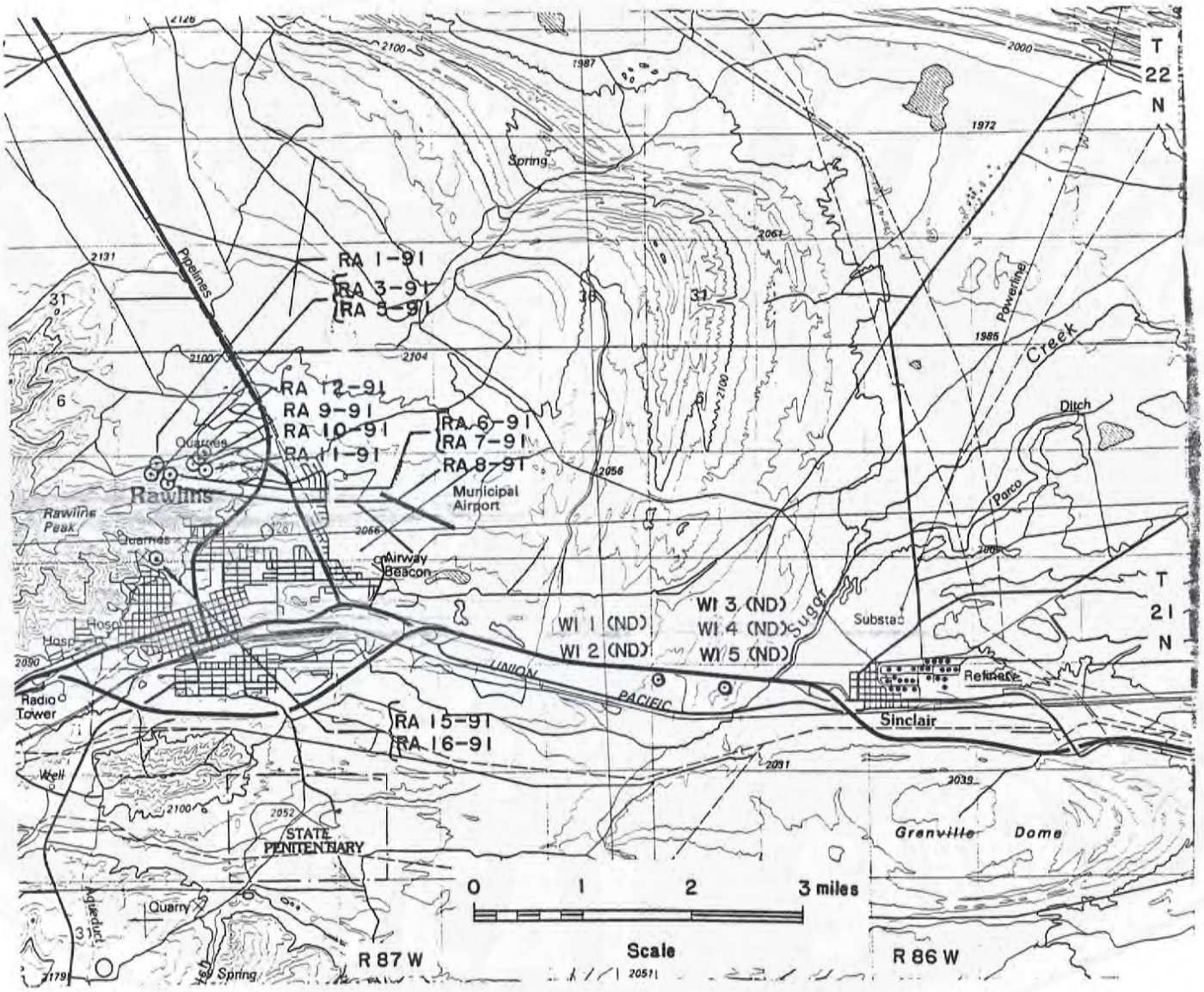

Figure 10. Sample location map of arkosic conglomerates, hematitic conglomerates, sandstone, and carbonaceous shale in the Rawlins-Sinclair area, Rawlins (1;100,000 scale) metric map. Refer to Table 4 for analytical results of samples RA1-91 to RA16-91, and Table 6 for WI1 to WI6.

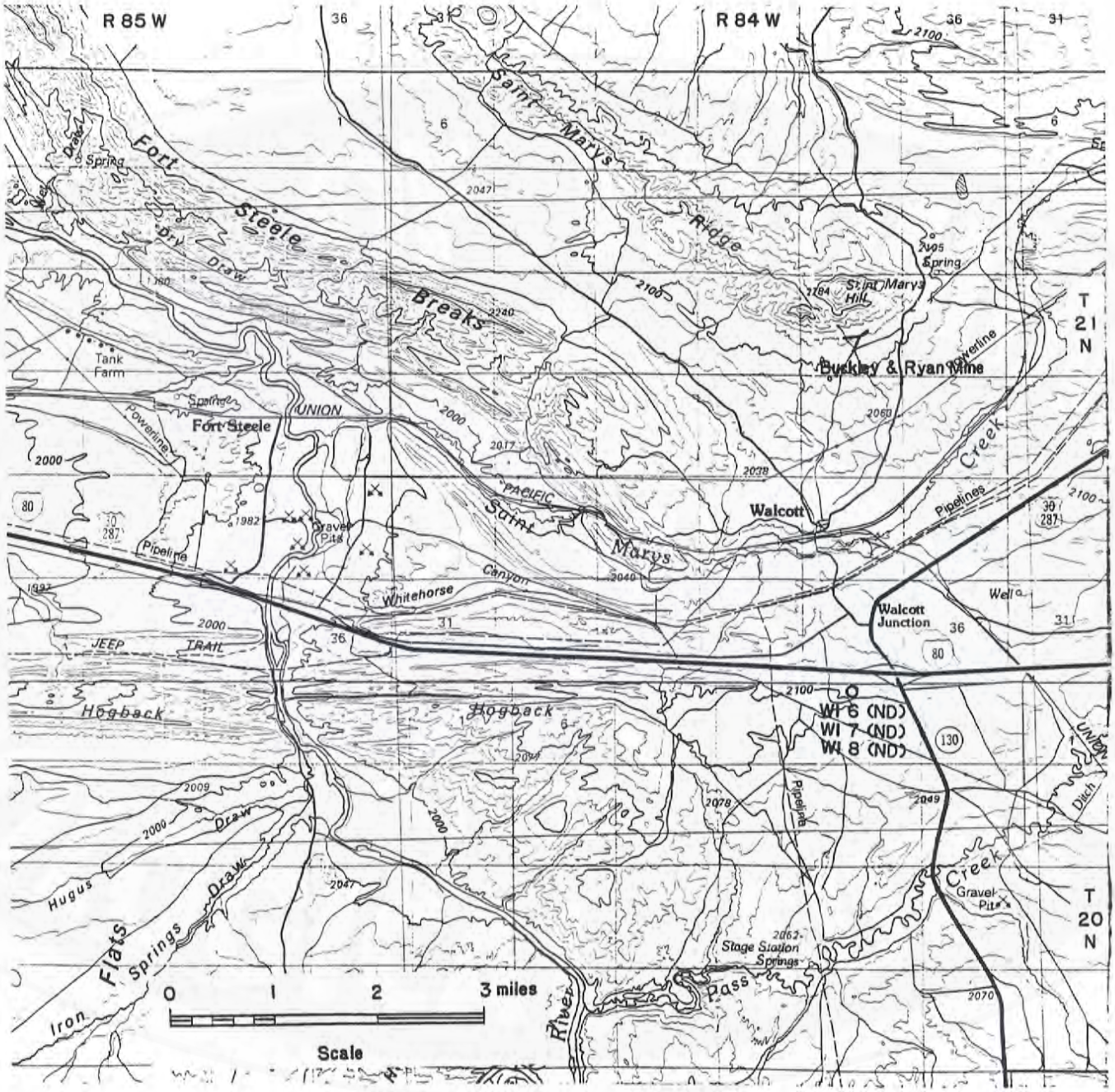

Figure 11a. Location map of the Buckley and Ryan coal mine at St. Marys Hill and sandstones collected at Walcott Junction (WI6 through WI8, Table 6).

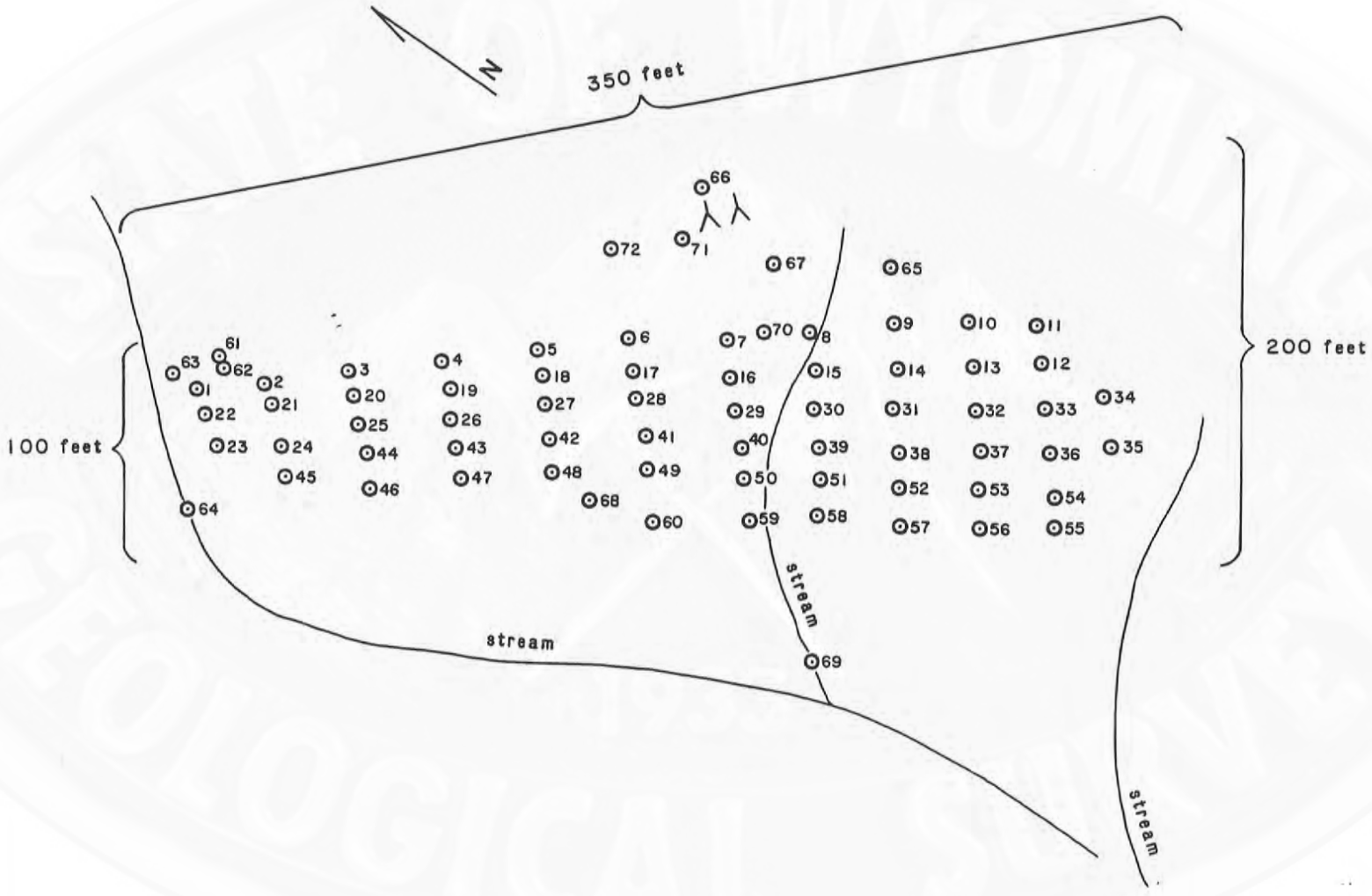

Figure 11b. Sketch sample location map of the Buckley and Ryan coal mine, Walcott Junction. Sample numbers refer to Table 5 (W1 through W72). The two 'Y's near sample site W66 mark the location of the mine adit.

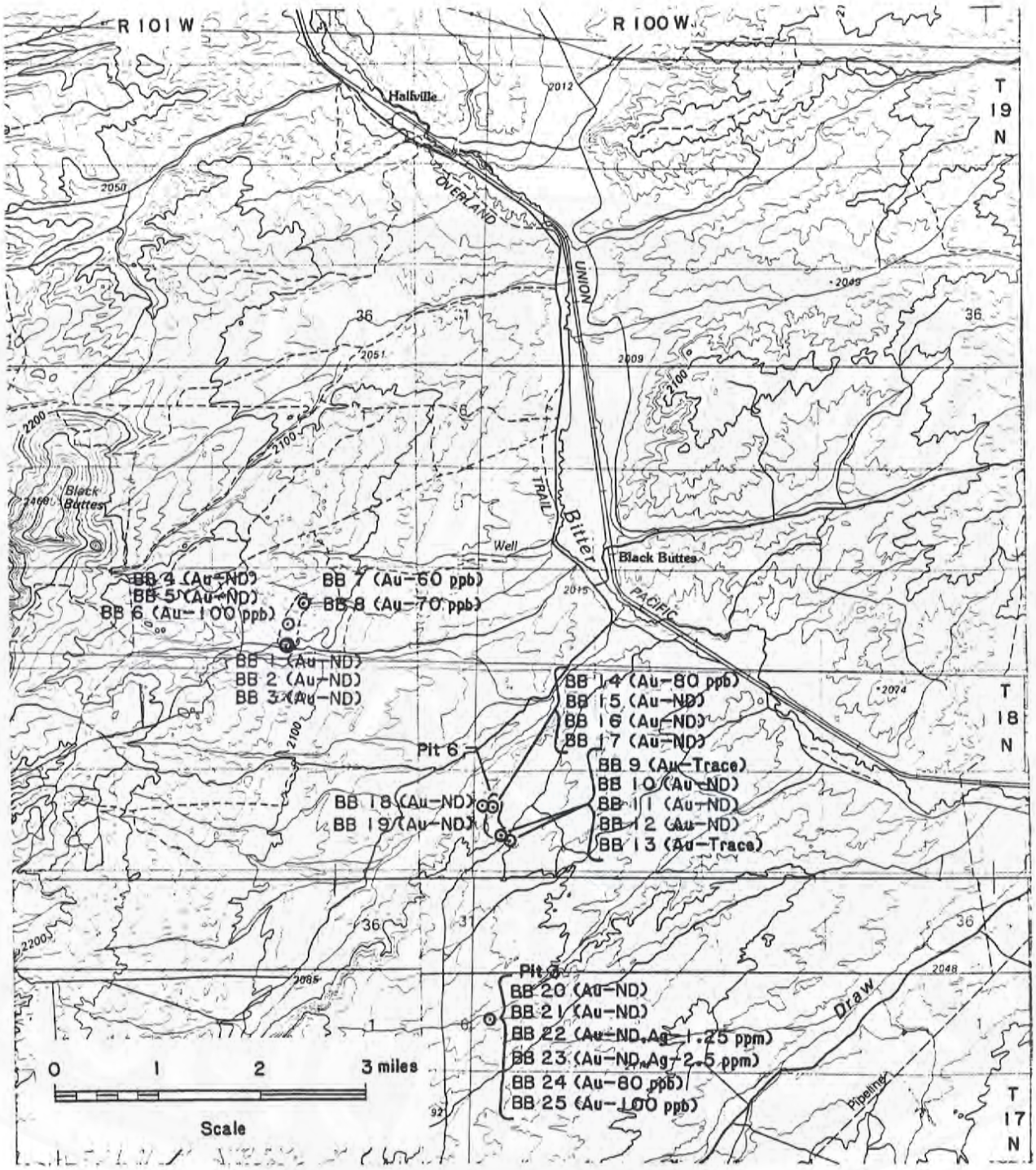

Figure 12. Sample location map of the Black Butte coal mine, Red Desert Basin and Kinney Rim (1:100,000 scale) metric maps. Sample numbers include gold analyses also listed in Table 5 (ND=not detected, ppb=parts per billion).

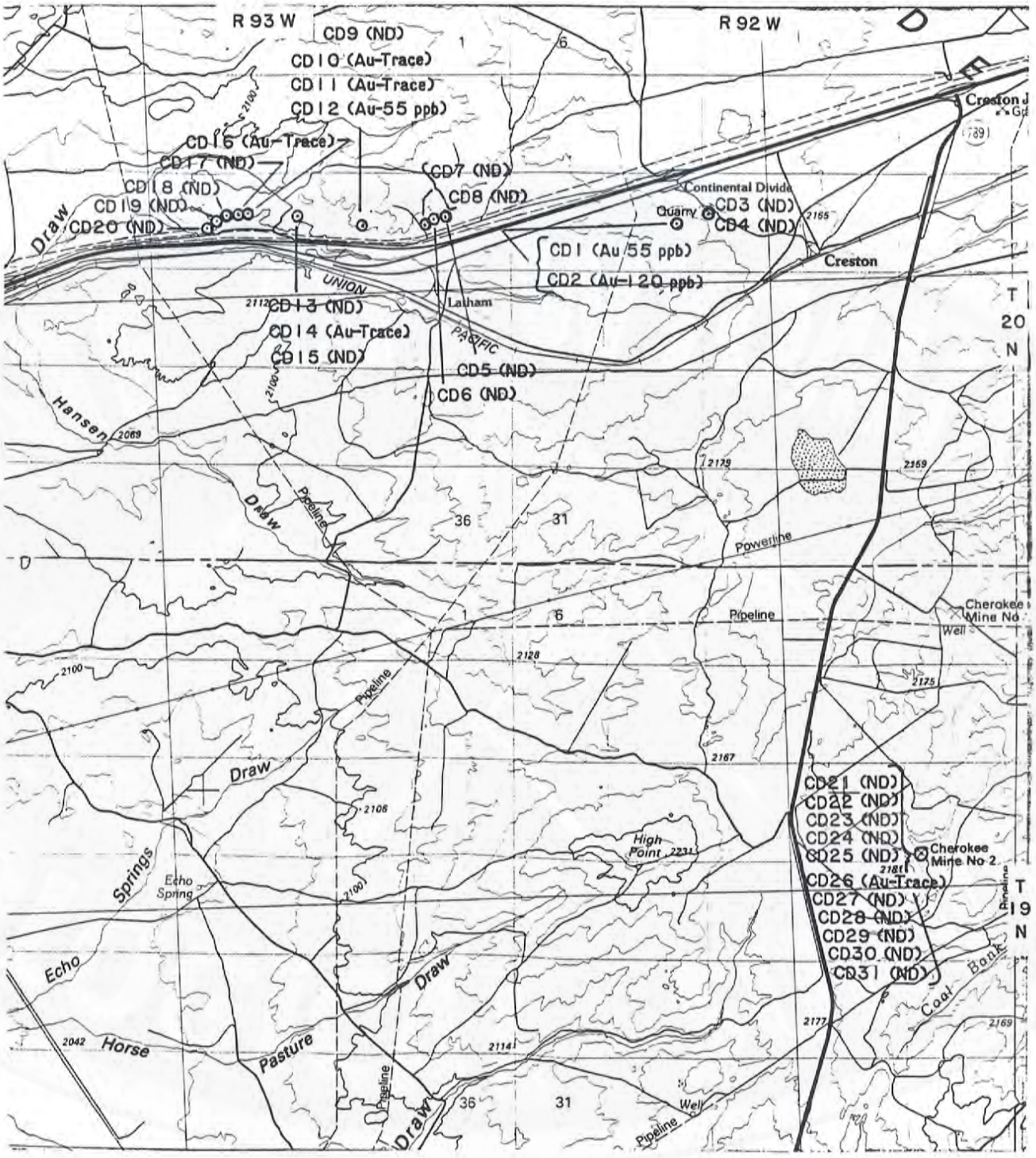

Figure 13. Sample location map of scoria, coal, shale, and sandstone near Wamsutter (Rawlins 1:100,000 scale metric map). Sample numbers refer to Table 5 (ND=not detected, ppb=parts per billion).

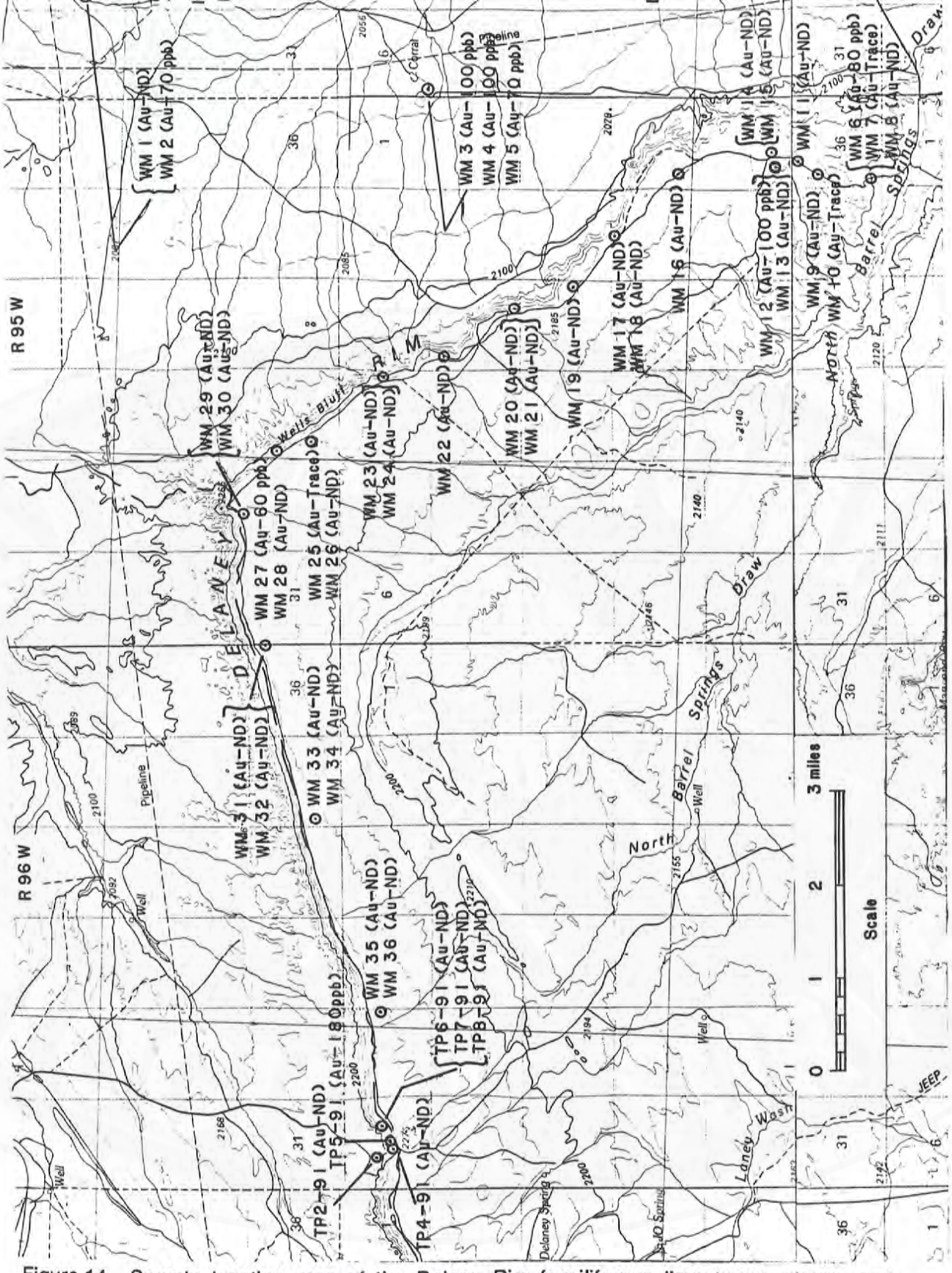

Figure 14. Sample location map of the Delany Rim fossiliferous limestones, cherts, and sandstones near Wamsutter, Kinney Rim and Red Desert Basin (1:100,000 scale) metric maps. Sample numbers correspond to Table 6 (ND=not detected, ppb=parts per billion).

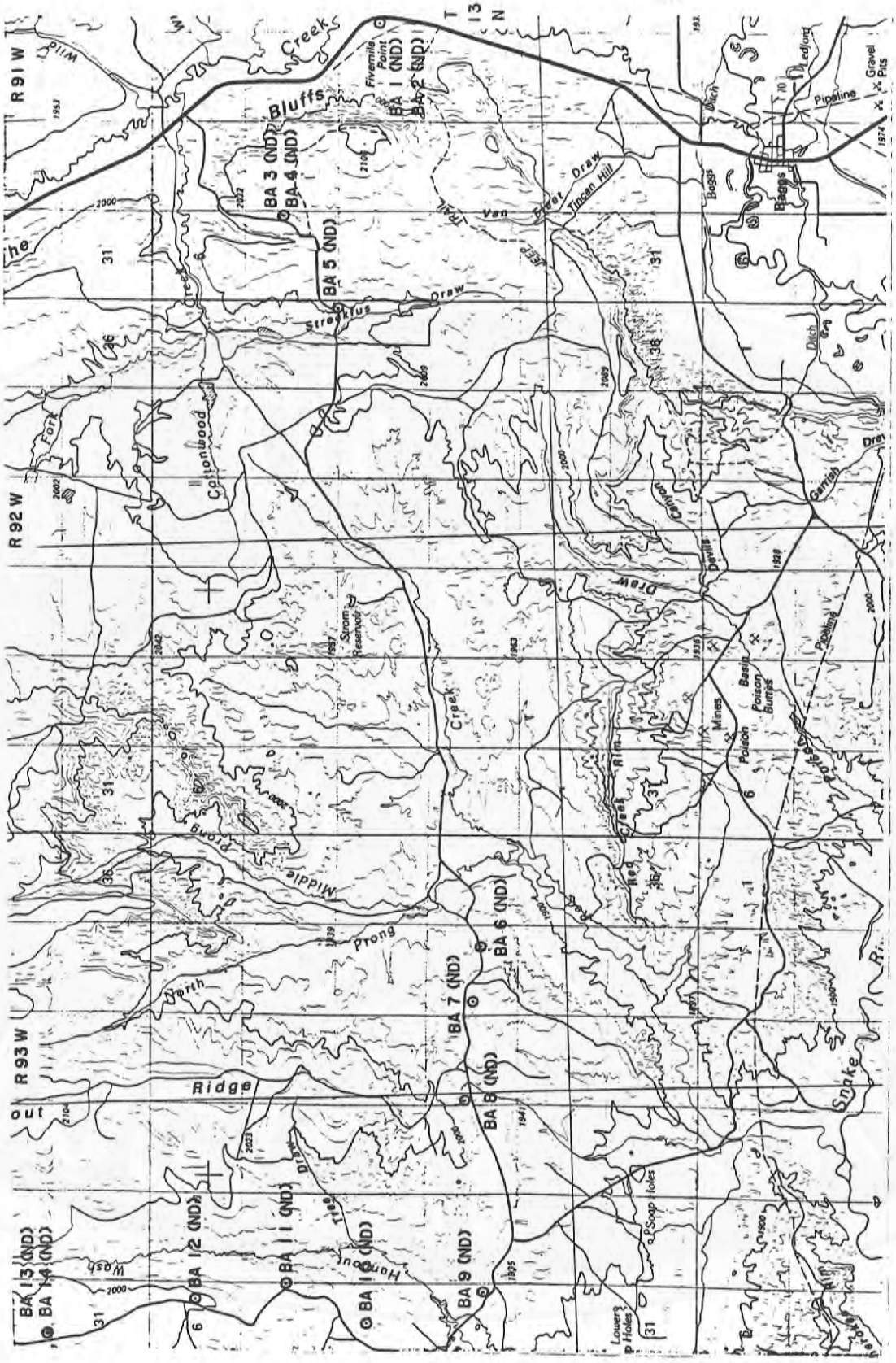

Figure 15. Sample location map of sandstone and peat in the Washakie Basin near Baggs, Baggs (1:100,000 scale) metric map.

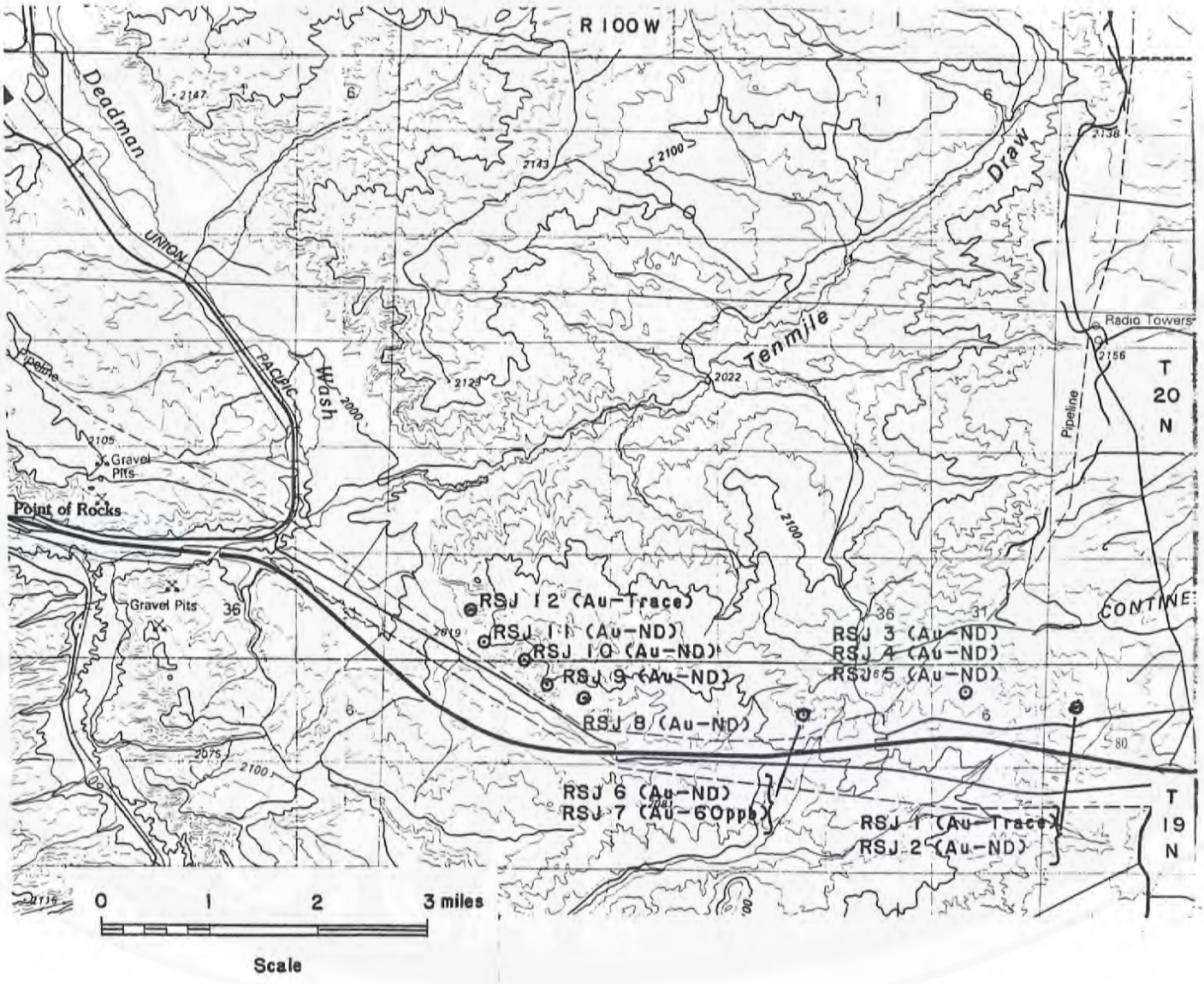

Figure 16. Sample location map of sandstone, quartzite, and shale along Interstate 80 east of Point of Rocks (Red Desert Basin 1:100,000 scale metric map). Sample numbers refer to Table 6 (ND=not detected, ppb=parts per billion).

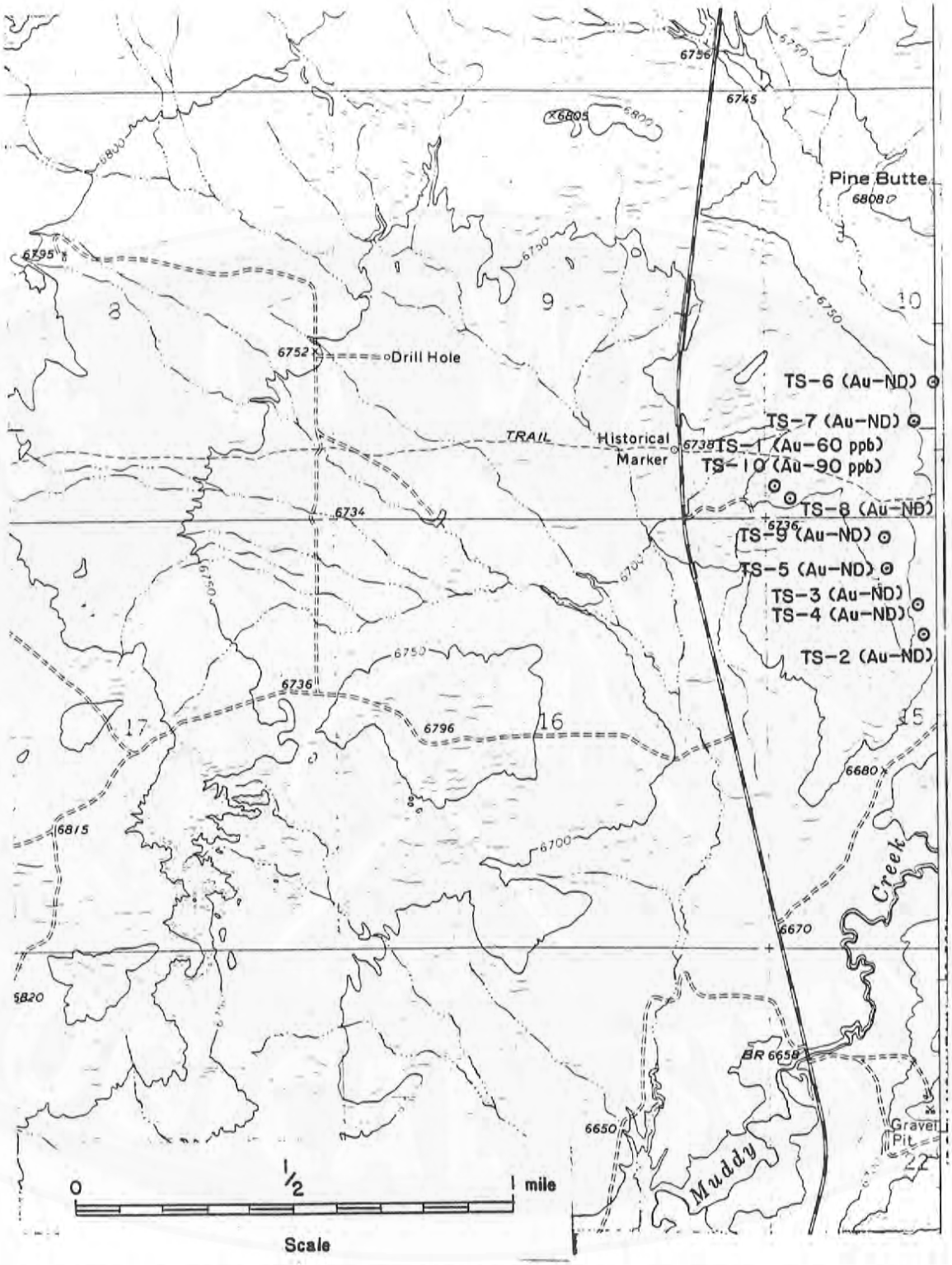

Figure 17. Tar sand, sandstone, and claystone sample location map north of Baggs along Highway 789 (secs. 10 and 15, T.17 N., R.92 W. of the Duck Lake 1:24,000 scale map). Sample numbers refer to Table 6 (ND=not detected, ppb=parts per billion).

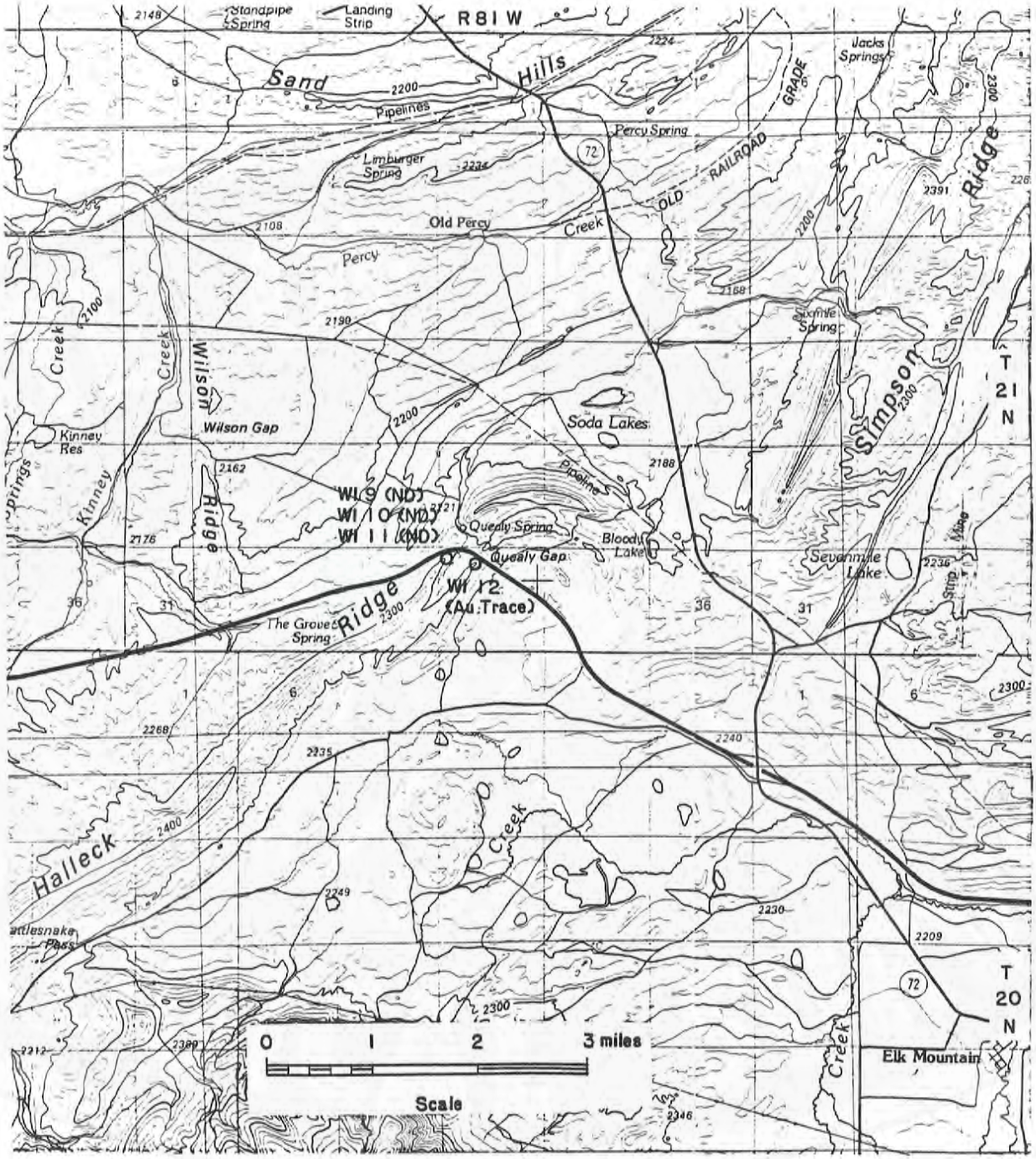

Figure 18. Sample location map of sandstone, shale, and coal collected northwest of the town of Elk Mountain (Rawlins 1:100,000 scale metric map). Samples WI9 through WI 12 refer to Table 6.

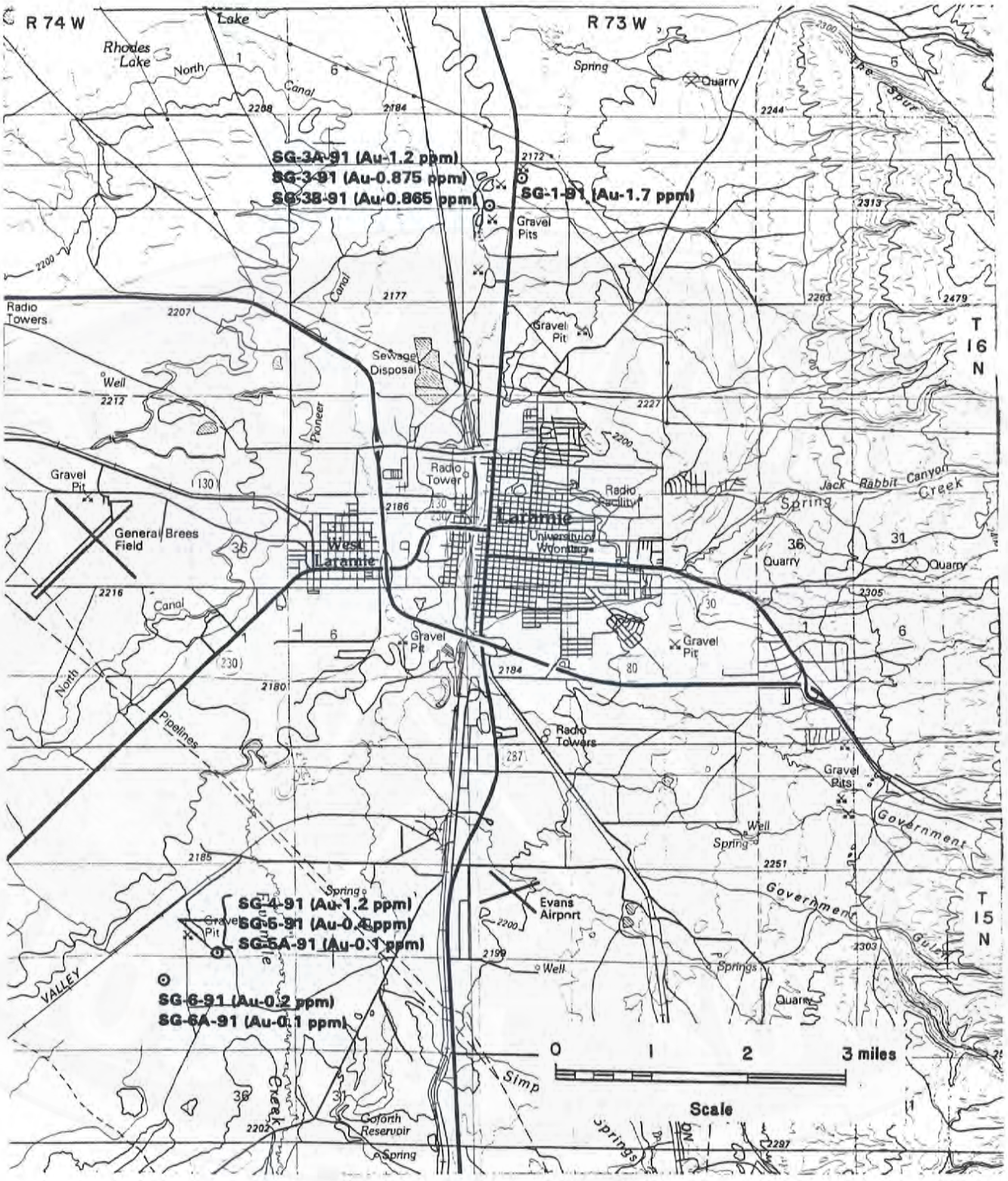

Figure 19. Sample locations of sand and gravel deposits tested for gold along the Laramie River flood plain (Laramie 1:100,000 scale metric map) Sample numbers refer to Table 7 (ppm=parts per million).

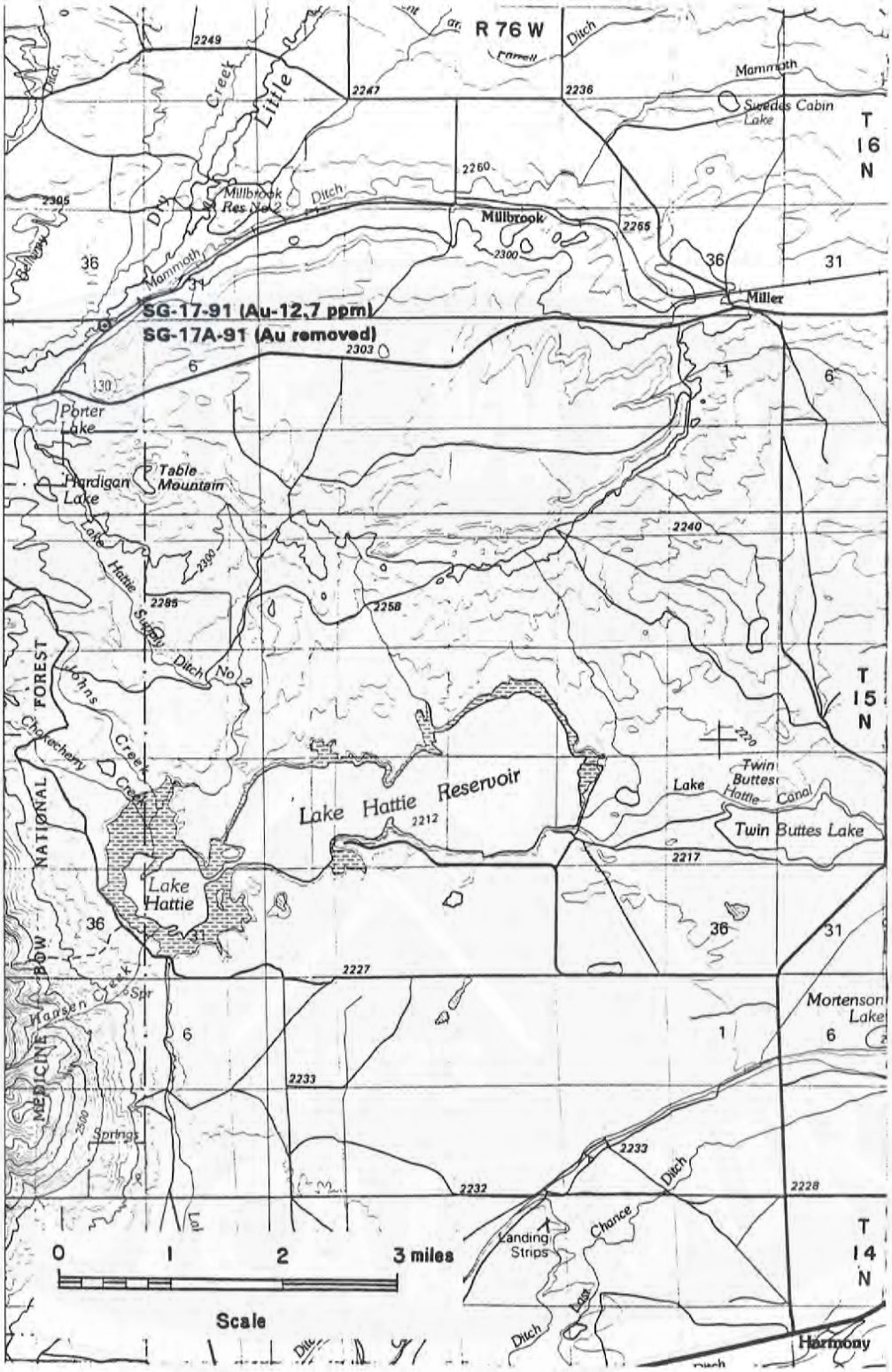

Figure 20. Sample location map for the Little Laramie River placer deposit north of Highway 130 near Table Mountain (Laramie 1:100,000 scale metric map) Sample numbers refer to Table 7 (ppm=parts per million).

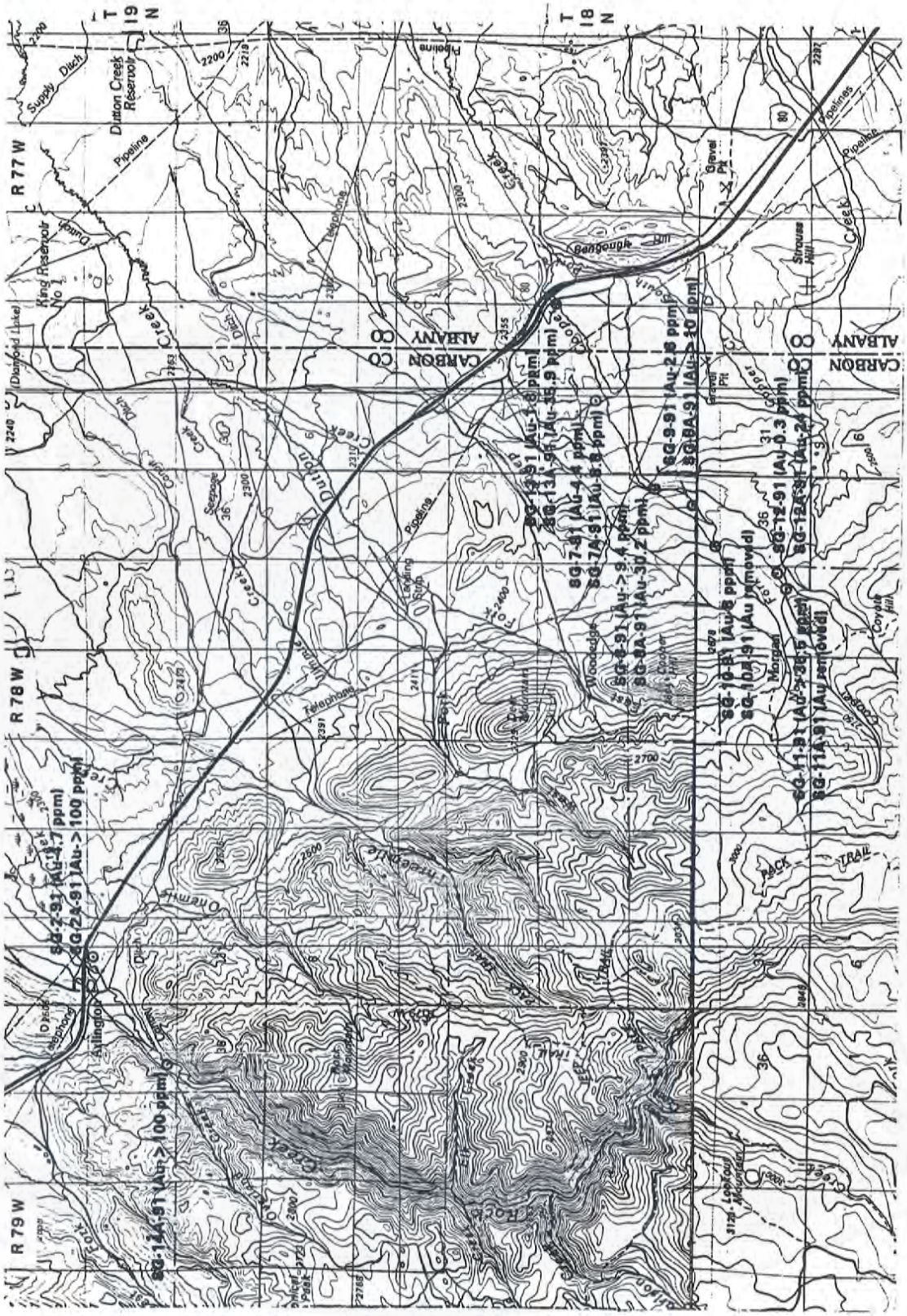

Figure 21. Sample location map for sand and gravel and placer sites tested for gold in the Cooper Hill district and Arlington area (Medicine Bow and Saratoga 1:100,000 scale metric map) Sample numbers refer to Table 7 (ppm=parts per million).

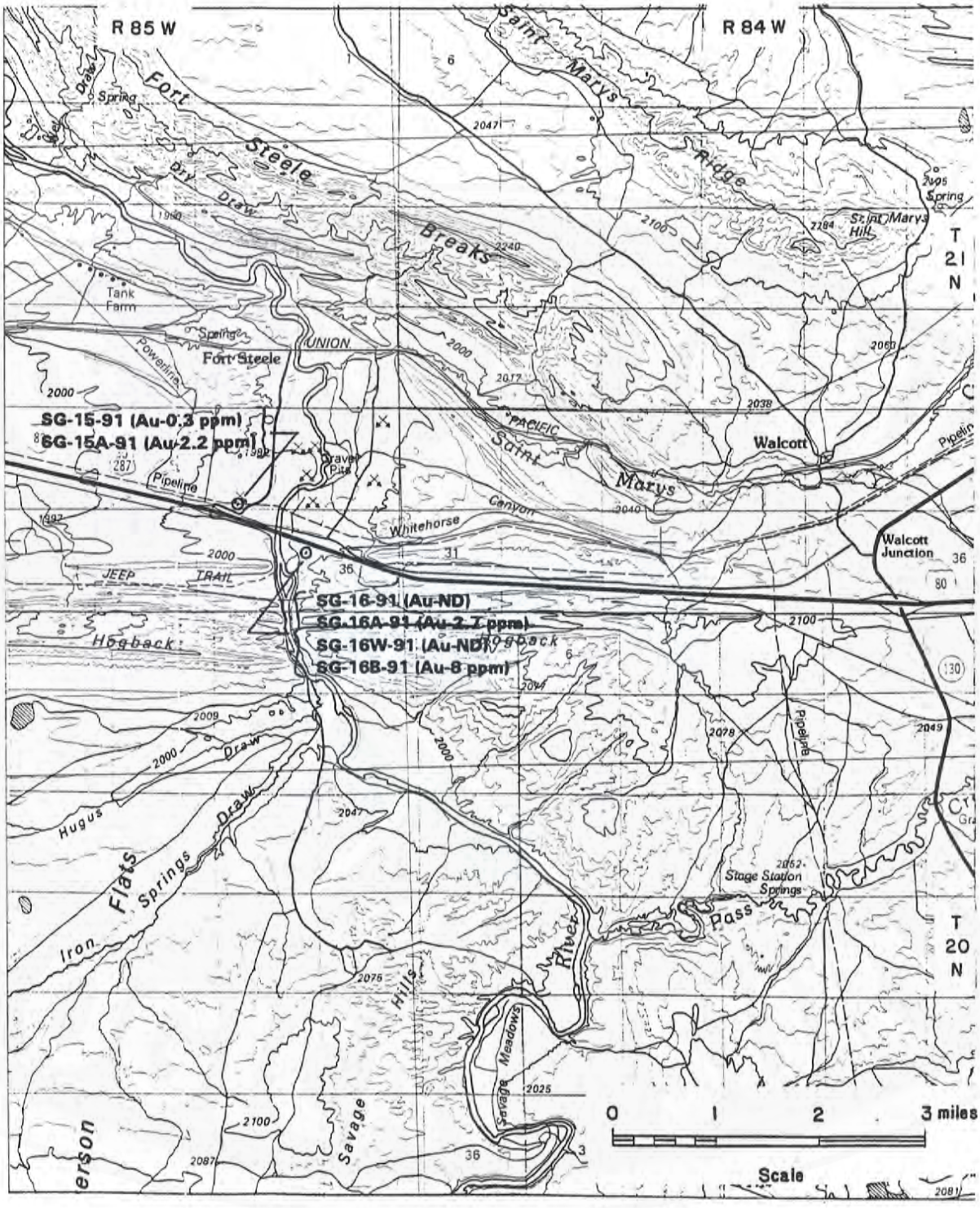

Figure 22. Sample location map for sand and gravel deposits tested for gold on the North Platte River near Fort Steele (Medicine Bow 1:100,000 scale metric map). Sample numbers refer to Table 7 (ppm=parts per million).

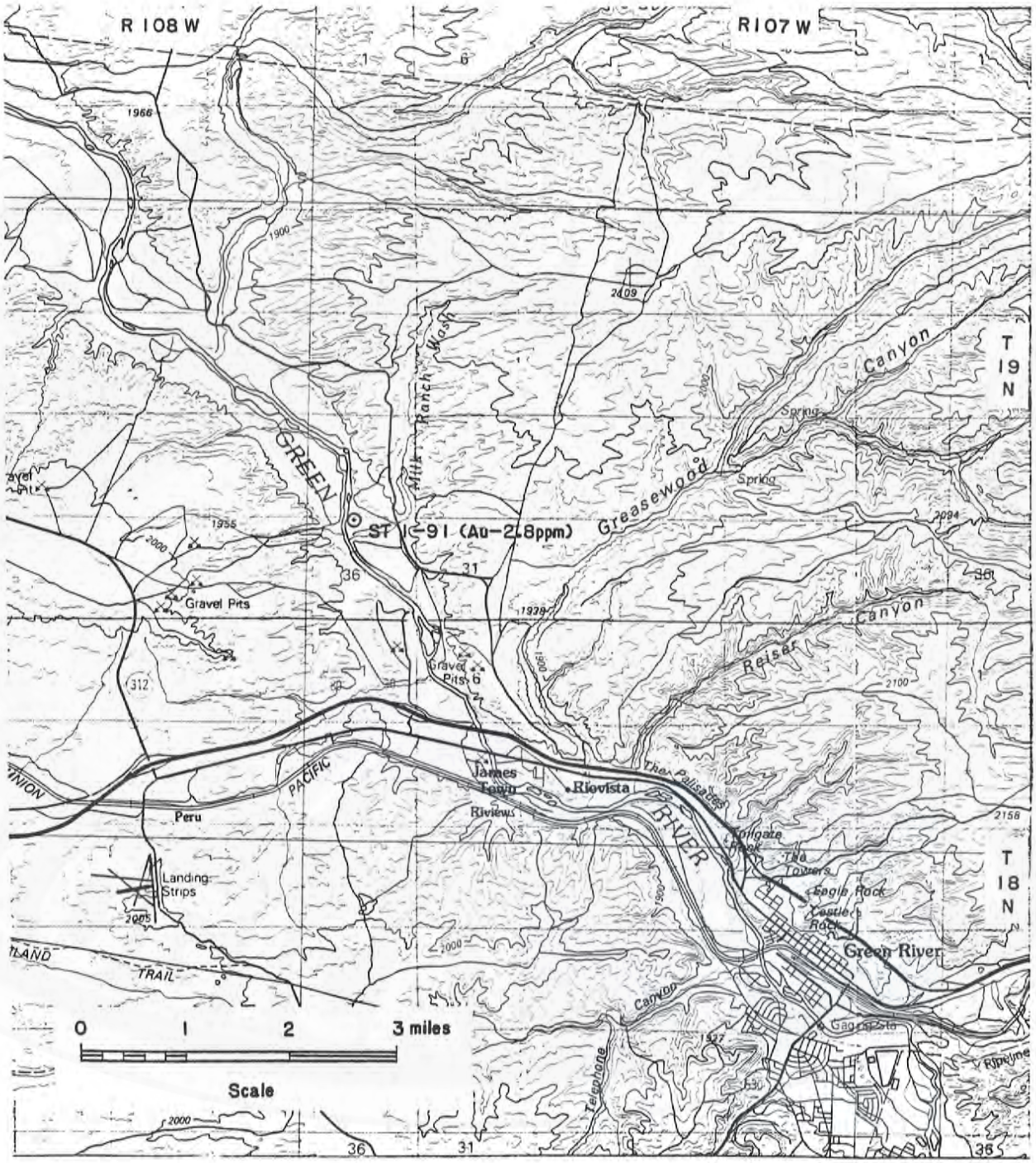

Figure 23. Sample location map of sand and gravel sampled along the Green River (Rock Springs 1:100,000 scale metric map). Sample numbers refer to Table 7 (ppm=parts per million).

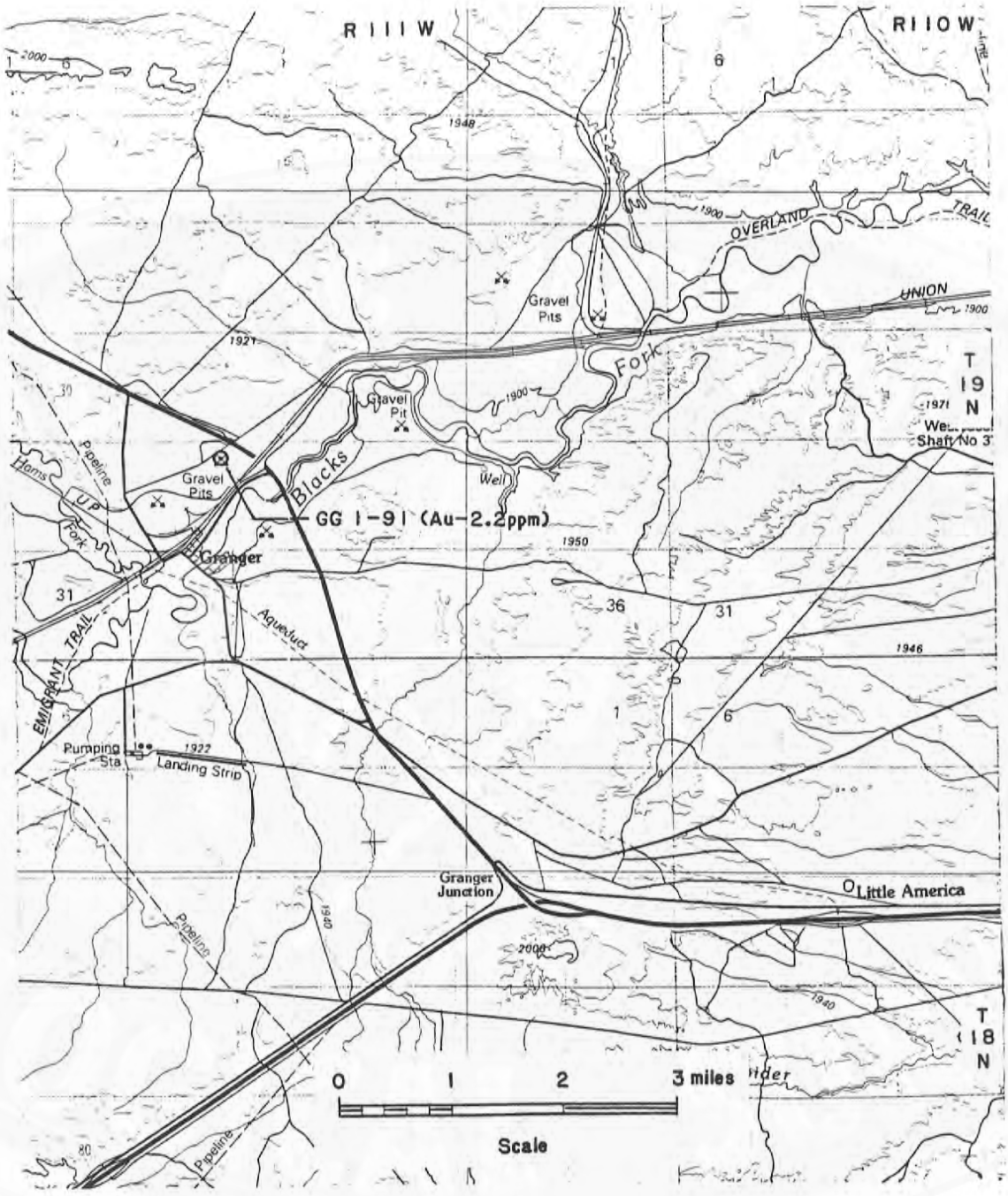

Figure 24. Sample location map for sand and gravel on the Blacks Fork at Granger, southwestern Wyoming (Rock Springs 1:100,000 scale metric map). Sample numbers refer to Table 7 (ppm=parts per million).

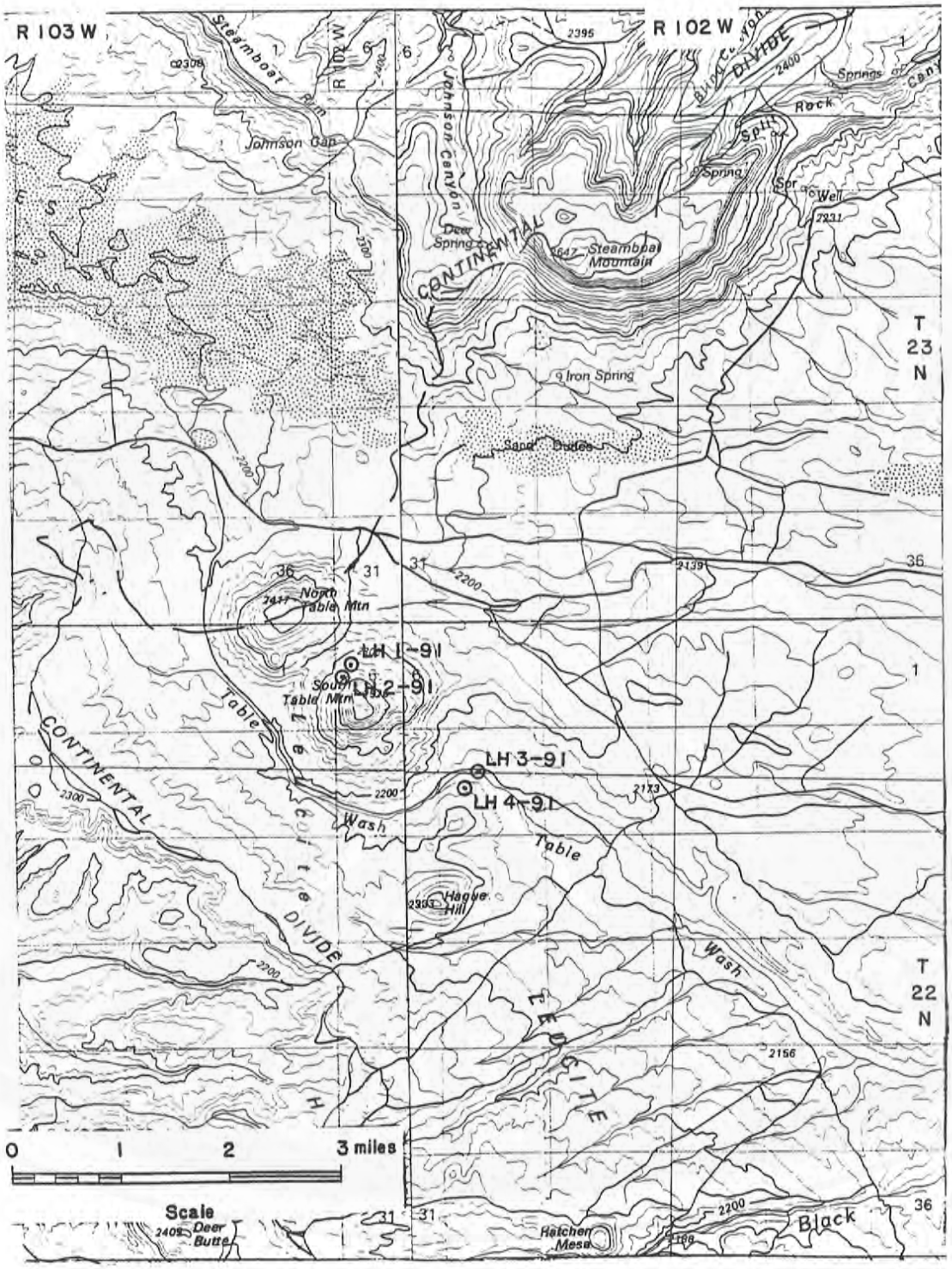

Figure 25. Sample location map of olivine-bearing lamproite in the Leucite Hills, southwestern Wyoming (Rock Springs 1:100,000 scale metric map).

PLATE 1

GEOLOGIC MAP OF THE COOPER HILL MINING DISTRICT, WYOMING

by

W. Dan Hausel
1992

EXPLANATION

PROTEROZOIC

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

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

Pq — **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.

Ps — **Mica schist.** Chlorite and biotite schists and phyllites.

Pml — **Metalimestone.** White metalimestone and fine-grained marble.

MAP SYMBOLS

MINES & PROSPECTS

- shaft
- adit
- prospect pit

VEINS & ALTERATION

- 20 — dipping quartz vein
- unexplored gossan
- skarn

BEDDING & FOLIATION

- 35 — dipping beds
- 30 — dipping foliation

FAULTS & JOINTS

- U / D — fault showing relative movement. U = up, D = down-thrown side
- 25 — dipping joints

LARGE SCALE FOLDS

- plunging antiform
- synform

MINOR FOLDS

- plunging isoclinal fold
- plunging open fold
- 30 — plunging open fold with dipping fold plane

MISCELLANEOUS

- metaconglomerate bed
- spring

CH 2 91 — sample site

0 — 1/4 — 1/2 Mile

scale

N — MN — 12 1/2

T.18N.

T.17N.

R.78W.