THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

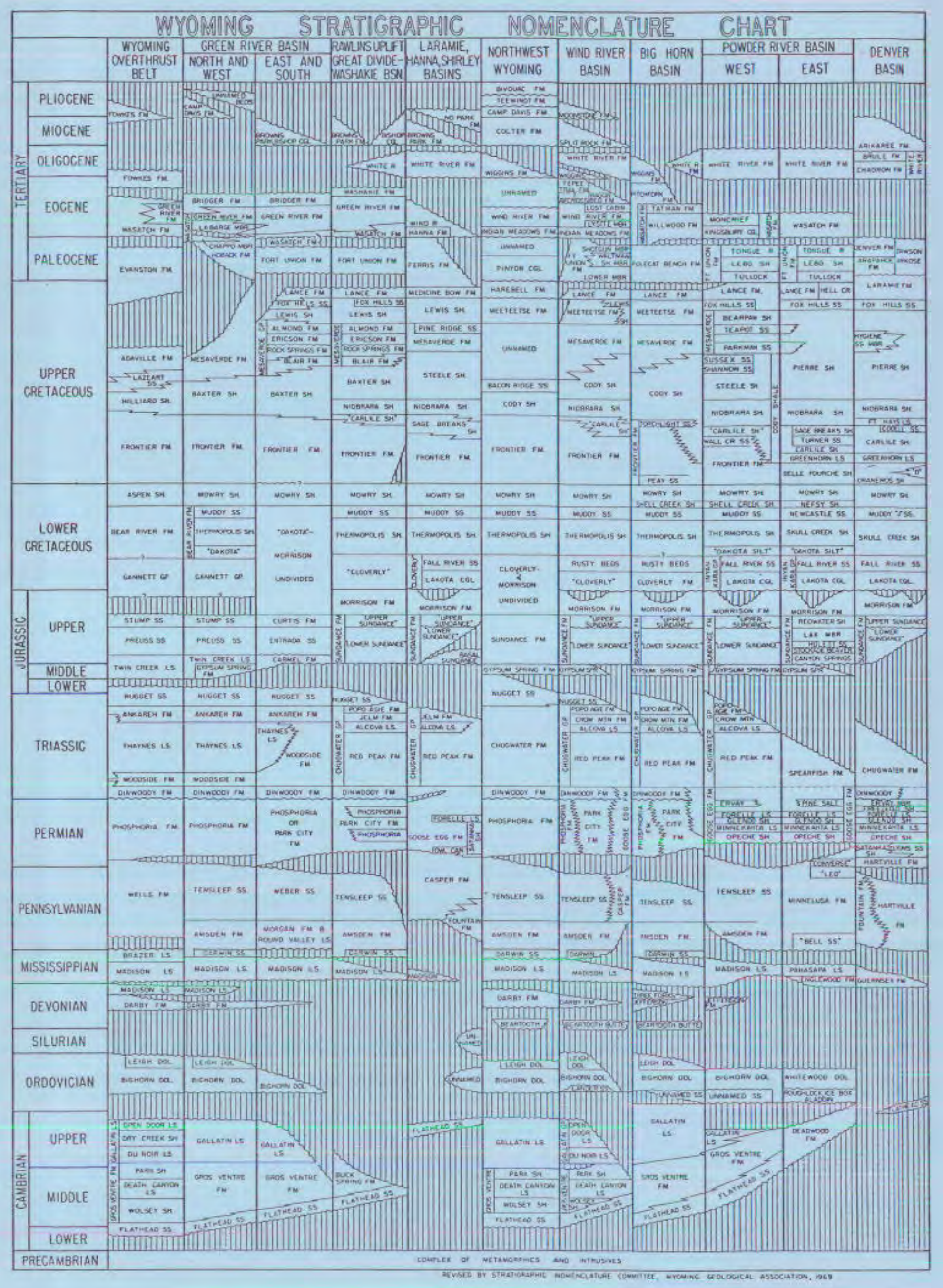
PUBLIC INFORMATION CIRCULAR NO. 19

GENESIS AND EXPLORATION OF METALLIC AND NONMETALLIC MINERAL AND ORE DEPOSITS OF WYOMING AND ADJACENT AREAS

(Extended Abstracts)

Edited by W. Dan Hausel and Ray E. Harris

Abstracts of papers presented at the
Joint Conference of the Geological Survey of Wyoming,
Wyoming Geological Association and the
University of Wyoming Department of Geology and Geophysics
ANNUAL SPRING CONFERENCE - Laramie - April 28-30, 1983


WYOMING STRATIGRAPHIC NOMENCLATURE CHART
WYOMING OVERTHRUST BELT
GREEN RIVER BASIN
NORTH AND WEST
EAST AND SOUTH
RAWLINS UPLIFT GREAT DIVIDE-WASHAKIE BSN
LARAMIE, HANNA, SHIRLEY BASINS
NORTHWEST WYOMING
WIND RIVER BASIN
BIG HORN BASIN
POWDER RIVER BASIN
WEST
EAST
DENVER BASIN
TERTIARY
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
UPPER CRETACEOUS
LOWER CRETACEOUS
JURASSIC
UPPER
MIDDLE
LOWER
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
UPPER
MIDDLE
LOWER
PRECAMBRIAN
COMPLEX OF METAMORPHICS AND INTRUSIVES
REVISED BY STRATIGRAPHIC NOMENCLATURE COMMITTEE, WYOMING GEOLOGICAL ASSOCIATION, 1969

THE GEOLOGICAL SURVEY OF WYOMING

Gary B. Glass, State Geologist

PUBLIC INFORMATION CIRCULAR NO. 19

GENESIS AND EXPLORATION OF METALLIC AND NONMETALLIC MINERAL AND ORE DEPOSITS OF WYOMING AND ADJACENT AREAS

(Extended Abstracts)

Edited by W. Dan Hausel and Ray E. Harris

Abstracts of papers presented at the

JOINT SPRING CONFERENCE, APRIL 28-30, 1983

Joint Conference of the Geological Survey of Wyoming,
Wyoming Geological Association and the
University of Wyoming Department of Geology and Geophysics

Laramie, Wyoming

1983

First Printing, of 1,000 copies, by
Central Duplicating, Cheyenne

Additional copies of this report are available from

The Geological Survey of Wyoming
Box 3008, University Station
Laramie, Wyoming 82071

Front Cover. STRONG MINE (about 1905). Copper mineralization (at the present locality of this mine) was located in 1898, and the shaft and headframe were constructed about 1903. Mining operations were sporadic, and terminated in 1915 with a 360 feet deep shaft, five levels, and at least 1,300 feet (1907) of workings. The host rock occurs as mineralized quartz veins associated with aplitic granite dikes in the Laramie Range anorthosite complex. During the early history of the mine, copper, gold, and silver were produced. Some molybdenum and galena were later discovered on the 350-foot level. In 1943, scheelite was discovered disseminated along some granitic dike contacts with anorthosite on the 350-foot level. Some 100 tons of scheelite-bearing rock, were shipped. Apparently, the tungsten ore was hand-picked from the mine dump waste.

Reported (undoubtedly high-graded) assays ranged from:

	Cu%	Au(oz)	Ag(oz)	WO_3(%)
Maximum	68.50	0.68	13.72	0.53
Minimum	5.08	trace	trace	0.20

Refer to Geological Survey of Wyoming, Bulletin 50, p. 41-43, for more information. Photo courtesy of Dr. Lloyd Evans and the Laramie Plains Museum.

CONTENTS

*Poster session presentations.

WYOMING PROVINCE — EXAMPLE OF THE EVOLUTION OF MINERAL DEPOSITS THROUGH TIME?

Robert S. Houston, Chairman, Department of Geology and Geophysics, University of Wyoming

The suggestion that environments favorable for the formation of mineral deposits have changed through time as the planet evolved has become a popular and reasonable thesis with economic geologists and petrologists in recent years (Watson, 1973; Meyer, 1981; Anhaeusser, 1981). If processes that generate mineral deposits differ through time or if environments of deposition were not the same in the past as they are today, mineral exploration should be guided accordingly. The Wyoming Province which includes the state of Wyoming and adjacent parts of Montana, South Dakota, Idaho and Utah is an excellent area to use as an example of such evolution because of the remarkably complete geologic section preserved; from Archean to Cenozoic. Inasmuch as this conference emphasizes metallic mineral deposits, these deposits, which are chiefly of Precambrian age in this area, will be the main ones treated in this review.

The Precambrian history of the Wyoming Province is complex and perhaps even unique in some ways. There are enough critical anomalies in the Archean history of the Wyoming Province to suggest that the new time-bound evolutionary models do not fit the geology well enough to use them as a guide in exploration. I suspect this has much to do with our incomplete knowledge of the Archean geology and geochronology of the Wyoming Province and perhaps also with the stage of development of Archean time-bound evolutionary models themselves. Certainly the better we understand the geologic history the better our opportunities for using geologic models in mineral exploration, and I believe we are doing much better in the Early Proterozoic. Here we are able to successfully apply plate tectonic models and thus better understand the geology and have greater success in mineral exploration. We certainly need to find something of greater economic interest to prove the Precambrian case to a doubting fraternity, however.

REFERENCES

Anhaeusser, C.R., 1981, The relationship of mineral deposits to early crustal evolution: Economic Geology 75th Anniversary Volume, p. 42-62.

Meyer, Charles, 1981, Ore-forming processes in geologic history: Economic Geology 75th Anniversary Volume, p. 6-41.

Watson, J., 1973, Influence of crustal evolution on ore deposition: Institute of Mining and Metallurgy Transaction, v. 82, section B, p. B107-B113.

GOLD FROM WYOMING GREENSTONE BELTS — PRODUCTION AND PROGNOSTICATIONS

Paul J. Graff, Consultant, Research Associates of Wyoming,
W. Dan Hausel, Deputy Director, Geological Survey of Wyoming

Gold won from greenstone belts accounts for a large portion of the world's mined gold. The Archean belts of South Africa, Western Australia, India, and Canada have produced some 380 million ounces of gold and estimates for total gold production from Archean and younger greenstone belts of the free world exceed 420 million ounces. Production from Wyoming Province belts is small; the total of about one quarter million ounces includes about 226,000 ounces from the South Pass Belt, 500 ounces from the Seminoe Mountains Belt, a few ounces from prospects scattered throughout the other known volcanogenic sequences, and up to 20,000 ounces from granites in the Raft River Range which abut mafic schists that may be part of a previously unrecognized greenstone belt. Despite the slim production of demonstrably Archean belts, about 35 million ounces have been produced from the Homestake Mine which may represent a remobilized Archean deposit or, more probably, a complex Proterozoic belt.

Basic differences in the style of mineralization and the lithologic assemblages of belts formed in different cratonic masses demand that models used for exploration of gold on one craton cannot be strictly applied to another. In a general comparison of the well-known Canadian and South African auriferous belts, volcanics of Canadian belts, which include few ultramafic rocks, have a basaltic:andesitic:felsic rock ratio of 6:3:1. South African belts, while they contain virtually no andesitic component, have lithologic proportions of 7:20:1 for ultramafic:basaltic:felsic rocks. Although volumetric studies have not yet been done on Wyoming belts, they seem to favor the South African sequences as Wyoming greenstones contain flows (?) of komatiitic chemistry and almost no andesitic rocks.

The styles of known gold mineralization in or near the Wyoming Province include lode, disseminated, and massive sulfide types. The bulk of gold produced is from lode and disseminated systems (South Pass and Black Hills areas), but minor gold is reported from belts containing Proterozoic massive sulfides (Sierra Madre area).

Future production from Wyoming greenstone belts will require careful studies of the volcanogenic suites. Applications of models used elsewhere in the world (Canada and, particularly, South Africa) will have to be modified in light of future studies which will provide a more complete understanding of Wyoming belts. The emphasis of a modified model must be on low to very low grade deposits and should favor a stratiform, disseminated occurrence.

BASE AND PRECIOUS METAL MINERALIZATION ASSOCIATED WITH THE MULLEN CREEK - NASH FORK SHEAR ZONE AND RELATED FAULT SYSTEMS

M.E. McCallum, Prof. of Geology, Department of Earth Resources, Colorado State University

The Mullen Creek-Nash Fork Shear Zone and associated fault systems in the Medicine Bow Mountains are characterized by locally significant Cu, Cu-Au and Cu-Au-Pt-Pd, and minor Cu-Ag-Pb mineralization. Except for platinoids, similar mineralization is associated with structures of this major tectonic zone in adjacent ranges. Geological relationships of mineralized zones and geochemistry of ore and host rock assemblages suggest that the majority of these deposits were formed by lateral secretion processes. Although the deposits are enclosed in a variety of felsic and mafic intrusive metavolcanic and metasedimentary rocks, all demonstrate a pronounced spatial affinity to mafic assemblages which apparently were the source of both base and precious metals. Mineralization generally is localized at intersections of faults and shear zones, in brecciated zones and fissures in shear zones and faults, and in minor tear faults and fissures associated with major faults.

No age dates are available for the various ore deposits, but field relations suggest that most probably, they are essentially penecontemporaneous. The principal mineralizing event may have been related to a thermal-tectonic disturbance associated with intrusion of the Sherman batholith approximately 1,400 m.y. ago. This and associated intrusions may have served as the heat source needed for the mobilization of metals from comminuted mafic materials present in faults and shear zones. Some ore assemblages show the effects of post-crystallization deformation, and few have been extensively weathered to supergene products.

Chemical and mineralogical studies of ore assemblages and altered wall-rocks indicate that the base and precious metals were transported as chloride complexes. Sericitic alteration of wall rock adjacent to most deposits infers low pH conditions that do not favor transport of metals as sulfide complexes. Gold-rich deposits all contain carbonates, and associated mafic rocks have been variably carbonatized, characteristics that typify many lode gold deposits throughout the world.

METAVOLCANIC ROCKS AND ASSOCIATED VOLCANOGENIC MINERAL DEPOSITS OF THE FLETCHER PARK AND GREEN MOUNTAIN AREAS, SIERRA MADRE, WYOMING

Thomas Schmidt, Department of Geology & Geophysics, University of Wyoming

Stratabound volcanogenic sulfide deposits occur in a number of localities in the Precambrian metavolcano-sedimentary rocks of the Sierra Madre, Wyoming. The deposits are contained within a 12,000 feet (3,750 m) succession of submarine volcanic, volcaniclastic and sedimentary rocks that are Early Proterozoic in age and occupy an approximate time interval from 2,000 to 1,900 m.y.b.p. The volcano-sedimentary strata have been tightly folded and later intruded by granite and granodiorite stocks.

Reconstruction of the depositional environment indicates alternating mafic and felsic volcanism occurred during the Early Proterozoic. Large accumulations of volcanic and clastic sediments were deposited above the mafic and felsic rocks.

The metallic deposits consist primarily of pyrite, chalcopyrite and magnetite and are associated with Ca-rich and brecciated rock. These deposits, which occur at the uppermost portion of the felsic units, are 9 to 15 feet (3-5 m) thick and can be traced for up to 1 mile (2 km).

The metallic deposits are attributed to products of submarine volcanic exhalations.

ON THE REACTIONS LEADING TO THE FORMATION OF MAGNETITE IN FERRUGINOUS ROCKS AND THEIR IMPLICATIONS ON THE CLASSIFICATION OF IRON-FORMATIONS

B. Ronald Frost, Assoc. Professor of Geology, Department of Geology and Geophysics, University of Wyoming

Recent studies of phase relations in metamorphosed iron-formations indicate that the protoliths of most of these rocks probably contained hematite as the major Fe-oxide rather than magnetite. Petrographic studies of weakly metamorphosed iron-formations also show ample evidence for the reaction of greenalite and siderite to magnetite. Due to the extremely low abundance of free oxygen in metamorphic fluids, any conversion of silicates or carbonates to magnetite must have occurred as the result of oxygen-conserved reactions. Two of these reactions may have occurred as internal buffering of the fluid drove the oxygen fugacity down to the hematite-magnetite buffer. As the fluid crossed the buffer these reactions would have ensued:

$$\text{greenalite} + 3\ \text{hematite} = 3\ \text{magnetite} + 2\ \text{quartz} + 2H_2O \quad (1)$$

$$\text{siderite} + \text{hematite} = \text{magnetite} + CH_4 \quad (2)$$

If siderite and greenalite were still present in the rock after reaction (1) and (2) had gone to completion, additional magnetite may have formed by the reaction:

$$\text{greenalite} + 9\ \text{siderite} = 2\ \text{quartz} + 4\ \text{magnetite} + 8CO_2 + CH_4 \quad (3)$$

Reaction (3) will occur only as long as conditions are sufficiently reducing to allow CH_4 to form. As the reaction proceeds, however, the conversion of the Fe component to magnetite will progressively enrich greenalite in Mg. This will cause the buffering surface for the assemblage greenalite-magnetite-quartz to rise to higher oxygen fugacity and eventually this upward shift will cause reaction (3) to cease. Once this happens no further magnetite will form and the remaining reactions occurring with prograde metamorphism of iron-formation will involve only dehydration and decarbonation. The primary effect of these higher-grade reactions is to convert siderite to silicate, a process which for most bulk compositions is complete by lower amphibolite facies.

Recognition that these processes occur in low-grade metamorphism of iron-formation leads to the observation that the traditional classification of iron-formation into oxide, silicate, carbonate, and sulfide facies can lead to gross misinterpretation of the sedimentary environment of some rocks. For most iron-formations the primary sediment either consisted of interlayered hematitic chert and siderite (i.e. the Algoman type iron-formation) or of interlayered hematitic chert-siderite and greenalite (i.e. the Lake Superior type iron-formation). Whether an oxide, silicate, or carbonate iron-formation formed during diagenesis of these rocks would have been as much a function of the original abundance of the primary phases and degree of metamorphism as of the sedimentary environment. For example, an "oxide facies iron-formation" could have formed from a sediment that was originally poor in siderite relative to hematite while a sediment from the same environment that was richer in siderite could have formed a "carbonate facies iron-formation" during diagenesis. Primary magnetite and Fe-sulfides may have occurred in some iron-formations but they are likely to have been restricted to exhalative environments where they could have formed either as a primary deposit on the distal portions of a fumarolic center, or as the result of incomplete suboceanic weathering products of massive sulfides.

THE GEOLOGY OF THE HOMESTAKE MINE, LEAD, SOUTH DAKOTA

Robert D. Woodfill, Manager of Geologic Research, Homestake Mining Company

The Homestake Mine at Lead, South Dakota is a world-class gold mine. Since it began production in 1876, the mine has produced over 35 million troy ounces of gold, worth $16 billion at present prices.

The Precambrian sedimentary formations at Lead total 17,000 feet. The Poorman Formation, the oldest, is an ankerite-bearing phyllite. The Homestake Formation is a quartz-sideroplesite schist altered to cummingtonite schist at higher metamorphic grades. Next, the Elliston Formation comprises quartzites and interbedded quartz-mica phyllites. Younger formations are argillaceous with some quartzites. The Cambrian Deadwood Formation unconformably overlies the Precambrian.

The dominant structure at Lead is an elongated dome about 10 x 12 miles long. The center is cut by an Eocene stock. The Precambrian rocks are isoclinally folded. The folds plunge 10° to 45° SE, with axial plains dipping slightly to the east. At least 11 deformational events have been recognized at the Homestake Mine.

Progressive metamorphism of the Precambrian rocks at Lead increases from the southwest to the northeast from the biotite zone, through the garnet zone, to the staurolite zone. The ore deposits are found in the biotite and garnet zones only.

Two distinct types of mineralization are recognized in the northern Black Hills: Homestake-type ores are restricted to Precambrian host rocks; the Tertiary replacement ores are restricted mostly to Paleozoic host rocks. At the Homestake Mine, major ore bodies, termed ledges, are a group of ore shoots, each pencil-like in shape and parallel to the plunging folds to which they are confined as replacements of the Homestake Formation. These orebodies are in highly chloritized parts of the Homestake Formation and are associated with abundant veins and masses of quartz with pyrrhotite, pyrite, and arsenopyrite. Gold is generally associated with arsenopyrite.

Rye and Rye (1974) showed that stable isotope data are consistent with a sedimentary-exhalative Precambrian origin for the major ore constituents with later migration of syngenetic components during metamorphism. Recent work supports a depositional environment by a thermal spring process during the Precambrian.

REFERENCE

Rye, D.M., and Rye, R.O., 1974, Homestake gold mine, South Dakota I. stable isotope studies: Economic Geology v. 69, #3, p. 293-317.

REVIEW OF KIMBERLITE EXPLORATION AND EVALUATION METHODS

M.E. McCallum, Prof. of Geology, Dept. of Earth Resources, Colorado State University
James B. Lincoln, Geologist, Cominco American Inc.

Kimberlite is the principal primary source of naturally occurring diamonds, and as such it is the target of extensive exploration activity. Exploration for kimberlite is an integrated effort that involves a variety of techniques. Effectiveness of any given method varies as a function of the size, geologic, geographic and climatic nature of the target area, and whether kimberlite is known to be present. Regional studies are designed primarily to establish districts favorable for more detailed evaluation. Airborne surveys are most applicable regionally, and comparison of similarly scaled LANDSAT (infrared reflectance) and radar images, high altitude aerial photographs, aeromagnetic, gravity, geologic, topographic and drainage maps, along with any other available comparable data that may provide information on the surface and subsurface character of an area, may reveal the presence of intersecting or interrupted regional trends. This "textural interference" may reflect deep-seated structures that could have provided the zones of weakness necessary for the emplacement of deeply derived kimberlite melt.

Airborne techniques may be effective locally in determining the location of individual kimberlite occurrences. Surface - near surface structural trends that may be related to pipe and (or) dike emplacement may be readily recognized on a variety of images, and both aeromagnetic and gravity surveys may reveal the location of kimberlite if host rocks are sufficiently different in physical character. Ground geophysical methods appear to be effective only in the delineation of individual kimberlite bodies. Magnetic, gravity, electromagnetic, electrical resistivity, refraction seismic, radioactivity and radiometric surveys have been conducted in a number of kimberlite districts, but generally only the magnetic, electromagnetic and resistivity methods are useful in defining kimberlite-host rock contacts.

Most effective in the search for kimberlite are the heavy mineral surveys which rely on the recognition of one or more of the kimberlite indicator minerals (pyrope garnet, magnesian ilmenite, chromian diopside or chromian spinel) in the heavy mineral fraction of alluvial, colluvial or eluvial material. These minerals are common only in ultramafic rocks and all but diopside are relatively resistant to abrasion and weathering, thus they persist for considerable lengths of time and over considerable transport distances (miles to tens of miles) except in regions with tropical climates. Definitive identification of the indicator minerals is dependent upon chemical, optical and (or) X-ray determinations; however, they generally can be recognized based on color and magnetic properties. The opaque oxides Mg-ilmenite (picroilmenite) and chromian spinel commonly can be distinguished from their more abundant counterparts ferro-ilmenite and magnetite based on their lower magnetic potentials, although more Fe-rich varieties of both indicators may be appreciably magnetic. Chromian diopside is readily recognized by its emerald green color, and its presence indicates relatively close proximity to source. However, this indicator mineral also is characteristic of a variety of locally abundant non-kimberlitic rocks (e.g., alpine peridotites). Pyrope garnets generally can be recognized by their red-purple, burgundy to deep greenish-purple colors although some may be characterized by lighter shades of red and purple. Other garnets derived from deep-seated xenoliths transported to the surface in kimberlite magma also may be useful locally in exploration if no other deep source intrusive rocks are present. For example, many pink, reddish-orange to reddish brown and brown garnets are characteristic of websterites, pyroxenites, eclogites and granulites that may represent xenolithic assemblages. A rapid, detailed color classification of garnet grains using a Rock Color Chart is useful in defining garnet populations that although not "kimberlitic" might be related to associated xenolith suites.

Geochemical surveys are useful in some districts, but generally only as part of detailed evaluations of target areas established by other means. Kimberlites generally are enriched in such elements as Mg, Ca, Ni, Co, Cr, Ti, Nb and rare earths, but use of these elements as pathfinders is dependent upon their dispersion into overlying and adjacent materials and insignificance or absence in host rocks.

Final ground surveys in target areas utilize a variety of surface characteristics to establish the presence of kimberlite. Of particular value are linear structural controls and the intersections of cross-structures, presence of contrasting soils (e.g., green to gray montmorillonite-rich vs. brown to orange kaolinite-rich), sharp vegetative changes, nodules of exotic rocks (e.g., in the Colorado-Wyoming kimberlite district, rounded xenoliths of garnet peridotite, eclogite, websterite, granulite, and lower Paleozoic sedimentary units occur in weathered granitic material), nodules and xenocrysts of kimberlite minerals (e.g., pyrope, Mg-ilmenite and diopside), and localized caliche deposits in non-carbonate terrains.

Many models have been proposed to relate various parameters of a given kimberlite to its diamond content. Most of these models suggest a correlation between the Cr, Ni, Ti and Fe content of the kimberlite and the presence or absence of diamond. Although the indicated trends may apply locally, it does not appear that such models have regional applicability. More recent studies on the chemistry of pyrope, Mg-ilmenite and spinel demonstrate considerable promise. The Cr_2O_3-CaO content of pyrope and the Cr_2O_3-MgO contents of Mg-ilmenite and spinel in kimberlite appear to correlate reasonably well with the diamond content of individual kimberlite occurrences.

Consideration of the morphological features of diamonds present in a kimberlite may also be of value in predicting the economic potential of a given pipe. Resorption of diamond crystals in kimberlite is an extremely important process, and is responsible for converting primary octahedron and cube forms to the tetrahexahedroid form (rounded dodecahedron). Robinson (1980) has demonstrated that this conversion process involves a mass loss of at least 45 percent and there is a correlation between the proportion of diamonds with octahedral and (or) cubic surfaces and the diamond content of the host kimberlite.

REFERENCE

Robinson, D.N., 1980, Surface textures and other features of diamonds: unpublished PhD dissertation, University of Cape Town, Cape Town, South Africa, v. 1, 221 p., v. 2, 161 p.

REMOTE SENSING EXPLORATION FOR POORLY EXPOSED KIMBERLITE IN THE COLORADO-WYOMING REGION

Janet E. Marks, Dept. of Geology and Geophysics, University of Wyoming
Ronald W. Marrs, Professor of Geology, Dept. of Geology and Geophysics, University of Wyoming

In February of 1982, the University of Wyoming, Department of Geology began an exploration project for diamondiferous kimberlite diatremes in the Laramie Range of southeast Wyoming and the Front Range of north-central Colorado using remote sensing techniques. Since 1964, several kimberlite pipes have been discovered in the study area. Anomalous heavy mineral indicators found in stream channels indicate that numerous undiscovered kimberlite diatremes may be present in the study area.

The object of this study is to evaluate the utility of the Thematic Mapper Simulator data for detection of kimberlite diatremes. This involves an integrated approach of remote sensing techniques, geologic mapping, and geophysical and geochemical surveys. A test area is first defined that includes a known kimberlite diatreme. Its unique surface expression and spectral characteristics are then determined. Image processing and enhancement techniques are used to intensify these specific characteristics. After extracting the maximum possible information from the multispectral data over the test area, data for the rest of the study area is digitally processed using techniques which were successful in the initial tests to delineate potentially favorable target areas. Using this procedure we hope to reveal previously undiscovered diatremes.

This presentation is mostly concerned with the concepts of multispectral remote sensing and the techniques used specifically for exploration for kimberlite diatremes. As economic mineral resources become more scarce in the next few decades and demand for these minerals increases, remote sensing may become very important as a tool for locating these new, potentially economic sources.

The study area consists of mountainous terrain of the Laramie Range and Front Range of Wyoming and Colorado. The mean elevation of the ground is approximately 2,286 meters (approx. 7,500 ft.). The vegetation consists of a montane forest and the climate is temperate. Because of this mountainous terrain and the limited field season, this environment lends itself to the use of aircraft obtained imagery data.

Aerial coverage was obtained in late June and early July of 1982 by a NASA C130B aircraft flying at an average altitude (above mean terrain) of 1,524 meters (approx. 5,000 ft.). A Zeiss Camera obtained color infrared images between 510-900 nanometers. The NS-001 multispectral Thematic Mapper Simulator imaged the surface in eight spectral bands. The bands included are 0.45-0.52, 0.52-0.60, 0.63-0.69, 0.76-0.90, 1.00-1.30, 1.55-1.75, 2.08-2.35 and 10.4-12.5 micrometers.

Soils derived from these ultramafic rocks generally contain large amounts of blue-green clays which, when well exposed, show up as a pale blue tint on false-color infrared film. These clays may prove directly detectable using the multispectral thematic mapper data even if they are present in visually undetectable concentrations at the surface. The water absorbing properties of these clays, especially montmorillonite, cause the soil to retain moisture longer even in the semi-arid environment of the study area. This moisture often supports lush grassy vegetation in areas of the kimberlite. As a result the exposed kimberlites can sometimes be detected as bright red on false-color infrared images (this is because the chlorophyll in the healthy vegetation is highly reflective of the near infrared spectrum).

The ultramafic character of the kimberlite causes it to weather more quickly than the quartz-rich soils that develop over the surrounding Sherman Granite. The surface weathers low over most of the kimberlite pipes due to the removal of the soluble material and they are often covered or poorly exposed.

Granitic areas develop soils that are quartz-rich and light-brown toned. Because of the low clay content, grus often produces xeric plant environments. The granitic soils generally support sparse tree growth in this mountainous terrain while the kimberlite soils develop grassy cover only. This may be due to toxicity of heavy metals in serpentine-rich soils. The heavy metal cations compete with iron for the location in the chlorophyll molecule. When concentrations of these cations reaches a given threshold, the plant is no longer able to properly absorb sunlight and becomes stressed. In severe situations the plant no longer is able to grow and dies.

All of these surface effects are readily detectable in areas of good outcrop; but many of the kimberlite bodies are poorly exposed or covered by a layer of soils. In such cases the surface expression is extremely weak and is not detectable using ordinary visual and photographic reconnaissance. However, the multispectral data has potential to provide discrimination of very subtle soil and vegetation contrasts. The multispectral data can be processed in many ways to assist the evaluation.

Some of the processing procedures to be tested include contrast stretching of the various single bands, color compositing, band ratioing, ratio color composites, classification, structural analysis with edge enhancement, density slicing, and principal components analysis.

Computer processed digital image data has an excellent potential as a very efficient tool for regional reconnaissance for kimberlite intrusives. The techniques discussed in this paper should give exploration geologists some insight into the state-of-the-art remote sensing techniques available for this and similar applications.

ACKNOWLEDGMENTS

This project is funded by NASA headquarters Earth Resources Division. Contract monitor is Dr. Michael Abrams, NASA-JPL. Flight data information was obtained through the NASA-Ames medium-altitude aircraft program. This research is the joint endeavor of the University of Wyoming and the Wyoming Geological Survey. Special thanks to Dan Hausel and Stan Miller for numerous intellectual discussions on the subject and help with getting the computer interface set up.

LAKE ALICE COPPER DISTRICT, LINCOLN COUNTY, WYOMING

W.W. Boberg, Consultant, Casper, Wyoming

The Lake Alice District is within the Overthrust Belt of Western Wyoming about 20 miles north of Cokeville, Wyoming. The principal prospect of the district is the Griggs Mine Prospect which was discovered in 1895. The Griggs Mine consists of several adits into sediments of the Triassic/Jurassic Nugget Sandstone and the Gypsum Spring Member of the Jurassic Twin Creek Limestone. It had minor production between 1914 and 1920. Bleached-white sandstones of the normally reddish colored Nugget Sandstone, dirty grey silty sandstones and petroliferous cherty dolomites of the Gypsum Spring Member contain extremely variable concentrations of copper, lead and zinc sulfides with some associated silver.

The Griggs Mine Prospect contains the greatest observed thicknesses and grades of sulfide in the district and appears to be the result of concentration in a structurally prepared zone on the flank of an anticline. This is the only area where sulfides can be observed in the bleached-white Nugget Sandstone. Outcrop samples of bleached-white Nugget occasionally contain numerous cavities which have been interpreted as having been formed from the complete leaching of sulfide minerals at the surface. Sulfides are nearly ubiquitous in low but observable concentrations within specific units of the Gypsum Spring Member. A locally continuous, two to three feet thick grey to yellow-grey silty sandstone within the Gypsum Spring contains low-grade copper (0.2% Cu) and silver (0.1 oz/ton Ag) wherever found in an area of more than two square miles. A thin (two to five feet thick) discontinuous cherty petroliferous dolomite and limestone contains variable amounts of lead and zinc as well as some silver.

The sulfide occurrences at Lake Alice are felt to have been formed solely by sedimentary and hydrodynamic processes in much the same manner as the major stratiform sulfide deposits of Central Europe. The metals are felt to have precipitated from a briny formation fluid developed within the red-bed sequence of the Nugget and underlying Ankareh Formation. The presence of a petroliferous shale, limestone, or dolomite above the red-bed sandstones is important to limit fluid flow as well as providing varying chemical environments to affect the briny formation fluid. The type and amount of metals available in the red-bed sequence determine the availability of metals in the briny formation fluid. Deep-basin hydrodynamic flow during diagenesis and burial, causing fluid flow of the variously metal-enriched briny formation fluid upward into and through the less permeable, reducing, reactive petroliferous and limy sediments will result in precipitation of metals carried by the formation fluid at or near the formation contact. Specific facies of the overlying sediments (Gypsum Spring Member) will tend to localize greater amounts of metals or be more consistent in localizing metals. The intense variations in hydrodynamic flow in the Nugget Sandstone generated by overthrusting during Laramide time and the formation of folds and the opening of faults near the crest of anticlines introduces another, structurally controlled, phase of mineralization. It appears that the metal content of the initial "ore-forming" briny formation fluid was not sufficient to develop large, blanket-like sulfide deposits and it took the second stage of structurally controlled fluid flow to develop small deposits of higher grade, such as the Griggs Mine Prospect. Hydrocarbons within the Nugget Sandstone were subject to the same pressures and hydrodynamic flow during overthrusting and may have been involved in the movement of metals and formation of the later structurally controlled deposits.

FURTHER THOUGHTS ON THE GENESIS OF PLATINUM REEFS OF THE STILLWATER/ BUSHVELD TYPE

Craig S. Bow, Geologist, Anaconda Minerals Company

Platinum Group Metal (PGM) mineralization within the Stillwater Complex occurs in a distinctive portion of Banded Zone stratigraphy, coincident with the reappearance of olivine in the crystallization of the complex. The immediate host rocks to the mineralization are distinguished by variable proportions of olivine, orthopyroxene, plagioclase, and augite. Hornblende, phlogopite, apatite, sulfides, and chrome-spinel are accessory.

Significant concentrations of PGM within the reef are restricted to sulfide minerals. The sulfides show clear evidence for an origin as accumulated, immiscible sulfide liquid droplets. The extreme concentrations of PGM in a subordinate weight fraction of sulfide melt, confined to an extremely narrow stratigraphic interval, constitutes the most fundamental constraint on models of genesis.

The presence of olivine- and sulfide-bearing rocks within reef stratigraphy is attributed to the influx of a pulse of primitive magma during a unique interval in the evolution of the chamber. The prolonged interval of plagioclase crystallization resulted in a significant decrease in the residual melt density, to the point where the new pulse of mafic/ultramafic magma was actually buoyant. As a consequence of this density inversion, a diapiric upwelling of hot, but less dense, magma ascended towards the roof of the chamber, rather than flowing across the floor. The critical PGM collector was provided by subsequent saturation and formation of an immiscible sulfide melt. The ascent, ponding and subsequent decay of the plume, with attendant magma mixing and crystallization, accounts for the high volume of silicate magma to sulfide melt required to explain the extreme PGM concentrations in the reef. This mechanism also explains, at least in an intuitive way, the complex mineral assemblage and sulfide-silicate textures of the reef.

The fundamental lithologic makeup and distribution of economic mineralization within the Stillwater and Bushveld igneous complexes are strikingly similar. Certainly the most singular and enigmatic similarity between the two intrusions — from an economic geologist's point of view — is the positioning of the PGM reefs with respect to the major cumulus phases. We consider this compelling evidence that very similar mechanisms controlled the evolution of these deposits, and a strong argument against *ad hoc* models that seek to explain mineralization in one or the other intrusion.

One of the many shared characteristics between the Bushveld and Stillwater intrusions is the presence of thick cycles of ultramafic cumulates in the lower portions of the stratigraphy. Recent research has provided new insight into the origins of cyclic layering in layered intrusions that may affect ultimately the tenor of PGM mineralization. The fluid dynamic behavior of successive pulses of mafic magma, introduced into a partly crystallized chamber, has been modeled theoretically, and with low-temperature solution analogs (Huppert and Sparks, 1980). These studies, interpreted in the light of fractional crystallization processes in open-system, magma chambers, provide a plausible mechanism for enriching residual melts in PGM prior to the critical pluming event.

REFERENCE

Huppert, H.E., and Sparks, R.S., 1980, Fluid dynamics of a basaltic magma chamber replenished by influx of hot, dense ultrabasic magma: Contributions to Mineralogy and Petrology, v. 75, p. 279-289.

BIOGEOCHEMICAL PROSPECTING IN THE STILLWATER (Pt) COMPLEX, MONTANA: A CASE STUDY

Walter C. Riese, Project Geochemist, Anaconda Minerals Company
Gerald K. Arp, Exploration and Production Research Center, ARCO Oil and Gas Company

The Stillwater Mining District is located in south-central Montana, immediately north and east of Yellowstone National Park. Its general geologic setting and the character of the platinum/palladium-bearing horizon were most recently discussed by Bow et al. (1982); the following generalized description is taken from that work:

The Stillwater Complex is a large, stratiform, tholeiitic intrusion which was intruded into a stable Archean craton approximately 2,700 m.y. ago. Platinum-group elements are concentrated in the lower part of the banded zone of the complex in a unit referred to as the Howland reef. Significant concentrations of platinum-group elements within the reef are restricted to sulfide minerals; the dominant minerals belong to the braggite-vysotskite/(Pt, Pd, Ni)S/solid solution series.

The Howland reef is continuous over the exposed length of the Stillwater Complex. It strikes approximately N70°W and dips steeply to the north between 60° to 70° in the area covered by this study.

The geochemical orientation study performed on the Stillwater Complex was designed to test the viability of using either pedogeochemical (B-horizon soils) or biogeochemical (Douglas Fir) samples to map the subcrop of the Howland reef.

The survey was conducted in early August. In all, sixty-five (65) samples of each medium were collected at twenty-five (25) meter intervals along lines which were approximately three hundred (300) meters apart.

Of the elements analyzed in the soils, only platinum and palladium showed any significant variance relative to the subcropping location of the platinum-palladium zone. These were also the only elements which mapped the platinum-palladium zone in the biogeochemical samples.

The reason for the lack of pedogeochemical response is due in large measure to the fact that most of the soils in this area are developing on tills (kame terraces) or colluvial materials. Both are transported materials which bear little or no relation to the underlying rock. Any anomaly present in these materials is therefore interpreted as reflecting hydromorphic dispersion of elements: leaching of the subcropping platinum-palladium zone by percolating snow melt and humic acids with subsequent downslope groundwater migration to precipitation points at break-in-slope anomalies.

In summary, this orientation survey was designed to test the utility of pedogeochemical and biogeochemical samples to map the Howland reef platinum-palladium zone of the Stillwater Complex: platinum and palladium appear to be useful for this purpose in both media, although the palladium in biogeochemical samples is admittedly questionable.

In selection of a sampling medium and elemental suite for exploration, particular care must be taken to assure that the resulting data will provide an interpretable background-to-anomaly contrast. If possible, these thresholds should be at absolute levels sufficiently high to eliminate any questions that they may be analytical relics. The platinum in Douglas Fir fulfills these requirements most admirably and will be the preferred sampling medium for subsequent work in this area.

REFERENCE

Bow, C., and others, 1982, Investigations of the Howland reef of the Stillwater Complex, Minneapolis Adit area – stratigraphy, structure, and mineralization: Economic Geology v. 77, no. 6, p. 1481-1492.

THE GENESIS OF CANADIAN AND NORTHERN AUSTRALIA UNCONFORMITY URANIUM DEPOSITS — WYOMING EXPLORATION SIGNIFICANCE.

Ray E. Harris, Uranium and Industrial Minerals Geologist, Geological Survey of Wyoming

Worldwide, the largest uranium resources are found in the Athabasca Basin of Canada and the Pine Creek Geosyncline of northern Australia. These uranium deposits occur in graphitic and pyritic metasediments immediately beneath an unconformity above which the overlying units are less highly metamorphosed red sandstones.

Although there is some discussion regarding the importance of the 1,700 Ma date of the Canadian and Australian unconformities, these deposits appear to have formed by the reduction of uranium introduced to the area by low-temperature water solutions. The graphite (and probably pyrite) of the underlying metasediments is a likely reductant. The permeable nature of the overlying red sandstones provides a pathway for the introduction of uranium-bearing, oxidizing groundwater containing uranium as phosphate or carbonate complexes. Thorium is notably absent and, inasmuch as it does not form soluble complexes in groundwater, this absence supports a groundwater transportation theory. This sounds suspiciously like the roll front concept, except for the location of the reductant and the Eh and pH gradients across the deposit.

In our region, an unconformity-related uranium occurrence exists beneath the Cambrian Flathead Sandstone in pyritic Precambrian quartzo-feldspathic gneiss 10 miles north of the Wyoming-Montana boundary in the Beartooth Mountains. Elsewhere along the Beartooth Mountain front, uranium occurrences are present in a similar geologic setting. Four other occurrences related to unconformities are reported within twenty miles of Wyoming, in South Dakota and Utah.

If the conditions necessary for the formation of this kind of deposit are a reductant-bearing fractured unit beneath permeable red sediments, several areas of Wyoming become exploration targets, and, sure enough, there are uranium or radioactivity anomalies associated with these areas. These areas are: the Hartville Uplift, Bighorn Mountains, Black Hills, Beartooth Mountains, Owl Creek-Bridger Mountains, Gros Ventre Mountains, Rawlins Uplift, and the northern flanks of the Granite Mountains and Wind River Range.

ORIGIN AND CHARACTERISTICS OF WYOMING BENTONITE DEPOSITS

David L. Rath, Geologist, International Minerals and Chemical Corporation

Wyoming bentonites were formed as a result of the *in situ* devitrification and chemical alteration of volcanic ash usually in a shallow marine environment. The source of the ash is believed to have been from the west, originating in the area that is now the Rocky Mountain Region. The original composition of the ash was probably latitic to andesitic. Most of the alteration occurred contemporaneously with deposition and was nearly complete shortly thereafter. The alteration products are primarily clay minerals of the smectite group, predominantly montmorillonite and sometimes beidellite. Montmorillonite usually accounts for 65 to 90 percent of the minerals present in bentonite. Other clay minerals found in bentonite are usually kaolinite and illite. Accessory minerals were introduced at the time of deposition, and some minerals present are the result of secondary mineralization due to weathering in the zones where bentonite exists under light overburden.

Bentonite deposits of economic importance occur in Cretaceous sediments and are exposed on the north and west flanks of the Black Hills and around the margins of most of the major basins in Wyoming. Thicknesses vary from less than one foot to ten feet or more. Beds presently being mined usually average three feet or less in thickness. Beds mined in the Northern and Western Black Hills districts are thinner than those mined in the Bighorn Basin or at Kaycee. The beds are generally lens-shaped and quite often thicken and thin considerably within local areas. The most persistent bed of bentonite is the Clay Spur bed (locally referred to as the commerical bed or bed "C") which occurs at the top of the Mowry Formation. Historically, most of the high-yield bentonite mined has come from the Clay Spur bed. Other formations hosting bentonite of commerical interest are: the Newcastle Formation (Black Hills District), Frontier Formation (Belle Fourche Shale, Black Hills District), and the Thermopolis Shale. Other Cretaceous and Tertiary formations host bentonite beds which may be of interest in the future, but none are extensively mined at this time.

A complex relationship which is poorly understood exists between the mineralogical and chemical composition of bentonite and its rheologic properties. Wyoming bentonites considered to have desirable rheologic qualities, such as high viscosity and swelling capacity and low water loss, have sodium as the dominant exchangeable cation (60 - 75+ meq/100 g) with a calcium plus magnesium content of between 25 and 40 meq/100g. The clay should have an overall cation exchange capacity of between 100 and 150 meq/100g to be considered high grade. However, lower-grade bentonite may meet quality specifications for many users. In conjunction with the Na/Ca + Mg ratio, characteristics influencing the quality of bentonite are:

1) the oxidation state of the iron present, the ratio of FeO to Fe_2O_3;

2) net charge imbalance;

3) percent non-smectite clay minerals present;

4) percent of non-clay minerals present. Analysis of X-ray diffraction data on bentonites from different areas around the Black Hills has shown that some samples contain from 5 to 40 percent non-clay minerals in the minus 200-mesh fraction. Some of these minerals may be colloidal in size. Generally, non-clay minerals act as a dilutant;

5) the degree of crystallinity;

6) and possibly, smectite particle size and shape.

The wide variations observed in the quality of bentonite within a given bed are probably due to the depositional environment rather than the composition of the parent ash. Attempts to correlate physical and chemical characteristics of bentonite to rheologic properties have been mostly unsuccessful. The problem is simply one of too many variables. As high-grade bentonite reserves dwindle, producers are forced to mine deeper and lower-grade bentonites which presents a challenge to research the possibilities of economically altering the physical and/or chemical characteristics of bentonites to enhance the rheologic properties.

MINERAL DEPOSITS ASSOCIATED WITH ALKALINE INTRUSIVE COMPLEXES: EXAMPLES FROM WYOMING, COLORADO, MONTANA, AND CALIFORNIA

Theodore J. Armbrustmacher, Geologist, U.S. Geological Survey

Ore-forming processes have been operative in and around certain alkaline intrusive complexes, resulting in economic and (or) near-economic deposits of rare-earth elements, niobium, titanium, copper, iron, thorium, vermiculite, phosphate, and other commodities. Mineral deposits have been found in nearly every part of a typical alkaline intrusive complex: the early stage mafic-ultramafic rocks are known to contain iron and titanium minerals concentrated in magmatic segregations (Powderhorn, Colorado), and vermiculite formed by hydrothermal alteration and weathering (Rainy Creek, Montana); the more leucocratic rocks, such as nepheline syenite, ijolite, and others, can contain disseminated pyrochlore (Miask, U.S.S.R.) or eudialyte (Ilimaussaq, Greenland), and residual concentrations of bauxite (Arkansas); the central-core carbonatite can contain disseminated rare-earth minerals (Mountain Pass, California) or niobium (Oka, Quebec), and residual concentrations of phosphate (Cargill, Ontario); fenite zones surrounding the complex can be enriched in uranium and thorium (Ilimaussaq, Greenland); later stage carbonatite dikes can contain anomalous amounts of rare-earth elements and thorium (Powderhorn, Colorado); and latest stage hydrothermal veins can contain abundant thorium and barite (Wet Mountains, Colorado) or copper (Bear Lodge Mountains, Wyoming).

Most of these kinds of mineral deposits tend to be found in *carbonatitic* alkaline complexes; such as the Iron Hill complex at Powderhorn, Colorado, which possesses many of the characteristics of this type of complex. Although a number of examples of the *gabbroic* alkaline complex are found in the Western United States, such as at Iron Mountain in the Wet Mountains area, Colorado, and at Rainy Creek, Montana, few mineral deposits, other than vermiculite, appear to be genetically related to these kinds of complexes.

VOLCANIC GEOLOGY AND MINERALIZATION IN THE UPPER WOOD RIVER-KIRWIN AREA, ABSAROKA MOUNTAINS, PARK COUNTY, WYOMING

William H. Wilson, Independent Geologist, Centennial, Wyoming

Rocks exposed in the Wood River map area (located 20-30 miles southwest of Meeteetse and 45 miles south of Cody, Wyoming), consist of the lower Eocene Willwood Formation, the middle Eocene Pitchfork Formation, and the upper Eocene Wiggins Formation. The contact between the base of the Pitchfork Formation and the top of the Willwood Formation has been mapped as the toe of the detachment fault. Breakaway faults and other vertical faults and shear zones cut and offset both the Pitchfork and Wiggins Formations.

Most of the map area is underlain by the Wiggins Formation. These andesite flows and flow breccias, which probably represent a shield volcano or large complex vent, intertongue with and grade into a volcaniclastic facies in all directions away from the central Kirwin vent area. Although the vent and alluvial facies are essentially andesitic in composition; the former is more felsic. Total thickness of the volcanic rocks is 6,500 feet. Intrusive rocks consist of granodiorite, andesite, and dacite plugs, as well as many andesite and dacite dikes of north-northwest to sub-radial trend around the granodiorites.

Mineralization at Kirwin consists of narrow, steeply-dipping, lead-silver, and minor gold and copper veins, essentially clustered radially around the central disseminated copper-molybdenum zone in the Bald Mountain area. Drill hole data indicate that the rocks on Bald Mountain are composed of an outer doughnut-shaped mineralized stockworks, a central volcanic vent zone of intrusive breccia of older rocks and mineralized rock fragments-partially intruded into the stockworks, and fine-grained quartz porphyry (or highly altered and silicified andesite ?) which occupies a major area of the central vent zone. A zone of welded(?) tuff, which occurs to the north-northwest, is of obscure relationship, but may be intrusive to the others above.

The stockworks shows a crude hypogene zoning in which low pyrite and chalcopyrite and molybdenite occur in the center, and high pyrite and chalcopyrite and low molybdenite occur in the inner zone with high molybdenum around the vent rocks contact described above. A secondary enriched zone, containing chalcocite, digenite, and covellite overlies part of the stockworks, which, in turn, is overlain by a barren leached cap.

Copper mineralization in Meadow Creek (approximately four miles north of Kirwin) occurs in a multiple pluton composed of a westernmost, earlier, dark gray, fine-grained granodiorite in contact with an easternmost, younger, light to medium gray, coarse-grained to porphyritic granodiorite. An ill-defined zone trending north-northwest across the western half of the stock is more granitic in composition and is believed to represent the chilled contact facies of the younger granodiorite. The location of the intrusion, as a whole, is believed to have been partially controlled by the intersection of the main east-west Wood River fault and a north-trending fault which offsets the volcanics to the north of the plug.

An intense area of quartz-sericite-pyrite alteration and disseminated copper mineralization occurs in an irregular north-striking zone within the younger granodiorite along the north fork of Meadow Creek. The zone, which is about 3,000 feet long and of an average width of 300 feet, contains disseminated chalcopyrite and azurite- and malachite-coated fracture surfaces. Traces of molybdenite (?) associated with quartz veining also occur here. Copper concentrations in this zone range from 200 to 700 ppm.

Rhyolite and granodiorite plugs, crosscut by andesite dikes, crop out in the Yellow Ridge area at the head of the Greybull River. A northeasterly-trending mineralized zone, 200-300 feet wide by 2,500 feet long, associated with an andesite (dike ?), is exposed in the southeasterly part of the composite granodiorite-(andesite ?) plug. Data are sparse, but malachite, pyrite, chalcopyrite, bornite (?), and molybdenite (?), in the order of decreasing abundance, occur as fracture coatings and disseminations in the main mineralized zone and sporadically elsewhere in the intrusive mass.

In summary, mineralization is confined to areas of Wiggins vent facies rocks intruded by granodiorite plugs, which, in turn, are cut by andesite dikes that are often weakly mineralized as well. All mineralized areas show varying degrees of bleaching, silicification, and argillic and potassic alteration. Propylitization of andesite flows and breccias is common and generally increases in intensity (along with secondary silicification) towards the centers of mineralization.

MODERN WETLANDS: GUIDES TO UNDERSTANDING COAL BED DEPOSITION AND MORPHOLOGY

Fredick J. Rich, Assistant Professor, Department of Geology and Geological Engineering, South Dakota School of Mines and Technology

Wetland areas are very common features of the Earth's surface. Their modern extent is well-known, and their chemical and physical characteristics are understood with considerable detail. Most wetlands, whether they be tree-filled swamps, or marshes dominated by herbaceous vegetation, produce organic sediments. It is the common occurrence of "fossil" swamp/marsh sediments (i.e., carbonaceous shales and coal) that tells us wetlands have been common through much of Earth history. This paper is a brief discussion of the types of wetlands which are believed to have appeared in Wyoming during the Cretaceous and early Tertiary.

Two initial parameters may be used to differentiate wetlands; size and species composition of the flora. Swamps and marshes vary in size from small herb-filled depressions, such as kettle holes filled with cattails, to the vast expanse of arctic muskeg. Muskeg is considered to cover nearly 1,300,000 km^2 in Canada alone (Radforth, 1969).

Certainly, such a wetland community exercizes great control over surface processes such as water and nutrient cycling, as well as sediment production and distribution. The size of a given swamp or marsh will be a function of many things, ranging from local topography and stream patterns to global phenomena such as climatic shifts and changes in sea level. The extent and thickness of ancient wetland deposits has, accordingly, changed greatly over time.

The composition of wetland floras is and has been as variable as ranges in size. Bottom land hardwood forest covered some 202,000 km^2 of the southeastern quarter of the United States before 1803 (Blair, 1981). The species composition of that flora is tremendously diverse even in the few modern remnants of that community. Hundreds of species, ranging from mosses to grasses, shrubs, and trees live in the lowland hardwood swamps of this country. The marshes of the Upper Nile stand in remarkable contrast. The Bahr el Jebel, Bahr el Zeraf, and Bahr el Ghazal together cover nearly 30,000 km^2 of the Sudan. The size of the wetlands notwithstanding, the species composition is remarkably lacking in diversity. Papyrus and a few species of giant grasses make up most of the marsh flora (Rzoska, 1974).

Whether large or small, diverse or monotonous, swamps and marshes can have an effect on their environment that goes far beyond the actual limits of the wetland. The most extensive wetlands, such as muskeg, undoubtedly affect global climate to an extent. The floodplain forests and myriad of ponds and marshes that fill the valley of the Mississippi

River and its tributaries affect the hydrology of the entire river system, and contribute substantially to the composition of the deltaic sediments and, ultimately, the sediments of the Gulf of Mexico. Even comparatively smaller wetlands, such as the Okefenokee Swamp of Georgia (1,650 km^2) can have significant impact on environments outside their boundaries. Reuter and Beck (1974) found, for example, that the Okefenokee loses "upward of 100,000 metric tons of humic matter per year by the flushing action of the [Suwanee River]"

Wetlands have been important factors in controlling surface processes on Earth since Late Devonian time, when the earliest extensive deltaic forests grew in the northern hemisphere. The geological influence of wetlands in what we now call Wyoming has occurred over less time, with significant coal deposits extending back only to Upper Cretaceous strata. The combination of suitable geological factors, benign climate, and adequate species diversity through Late Cretaceous and early Tertiary time lead, however, to the accumulations of tremendous amounts of coal in Wyoming over that time span.

Rich (1983) discusses 11 types of wetlands which have left more or less of a geologic record around the globe. Not all of them have existed in Wyoming, so some types are not discussed here. Other wetland environments have been extraordinarily important, though. Among these are the following: deltaic swamps; non-deltaic shoreline swamps; and inland river swamps.

Deltaic swamp deposits are quite well-known in western Wyoming, where strata of the Mesaverde Group, the Almond and Adaville Formations occur. Lawrence (1982) presents a discussion of coal-forming environments associated with the Adaville Formation. The paper nicely summarizes sedimentological controls over swamp/marsh distribution on the various Adaville deltaic surfaces. Presumably, such controls as slow deltaic progradation or strand line stabilizations (i.e., still-stand) have always encouraged extensive swamp/marsh development. Subsequent accumulation of very thick peat deposits and, hence, coals has occurred. The Adaville No. 1 coal ranges from 22 to 26 m in thickness (Glass, 1978) and is a good example.

The composition of particular Cretaceous deltaic floras is not well-known. While authors such as Nichols and Jacobsen (1982) have observed fossil pollen and spores from various Cretaceous formations, the authors' intent has not been to reconstruct the paleoecology of the swamps or marshes. The diversity of plant microfossils does suggest, however, that a wide variety of ferns, conifers, and more advanced seed plants (angiosperms), may have occupied the deltaic surfaces in distinct communities. In all likelihood, detailed paleobotanical, palynological and petrographic studies of the deltaic coals will show similar distributions of plant communities to what Montz and Cherubini (1973) have described for the Mississippi delta. There, lowland hardwoods, conifer forests (especially cypress) and marshes are found in distinct communities whose distribution is affected by slight differences in water level and salinity. Variations in plant community composition and distribution within modern wetlands has been shown to have a great impact on peat characteristics (Spackman et al., 1976; Rich, 1979). Variations are carried through the coalification process and result in variable chemical characteristics within the coals. Understanding Cretaceous plant community distributions within the Adaville and Almond Formations, then, could serve as an exploration tool for coals of particular compositions.

Non-deltaic shoreline coal-bearing deposits have only recently been reported from Wyoming. Livingston and Wilson (1982) discuss such a deposit as it occurs in Carbon County, Wyoming. The lower Almond Formation at their Atlantic Rim locality bears numerous coals averaging 1.5 m thick which accumulated on a lower coastal plain (Livingston and Wilson, 1982). Those authors note that upper Almond marginal marine paralic deposits overlie the lower Almond.

Similar deposits have been described by Rich and Goodrum (1982) and Goodrum (1983) from Harding County, South Dakota. The Fort Union Formation in the Cave Hills consists of a non-marine, coal-bearing alluvial flood plain deposit overlain by a nearshore marine sandstone, which is in turn covered by another sequence of lower alluvial coastal plain sediments.

Both the Atlantic Rim and Cave Hills deposits could be likened to what is accumulating now at various places along the Atlantic coastal plain of the U.S. Extensive lower coastal plain, freshwater swamps extend from southern New Jersey to Florida. They generally overlie shallow-marine sands of Pleistocene age, and lie at such a low topographic level and in such close proximity to the ocean that any rise in sea-level of more than a few meters would cover most of them. Rich and Goodrum (1982) compared the Cave Hills deposits to the Pine Barrens swamps of southern New Jersey, and it is suggested here that the Atlantic Rim deposits are equally similar.

The principal differences between deltaic coals and non-deltaic coastal plain coals is in their thickness and lateral extent. Deltas are dynamic features where subsidence varies and streams constantly rework the delta surface. The swamps may remain in one place for many years, or might be displaced by invading marine water or migrating streams. The result is that while deltaic coals may be quite thick at one location, they are thin or absent at other locations. Non-deltaic coastal plain coals, on the other hand, develop in a fairly stable environment which isn't anywhere near as dynamic as a delta. Slow subsidence rates on the coastal plain may preclude the development of very thick coals, but the absence of numerous meandering streams ensures much greater lateral extent of swamps and, thus, coal beds.

Ancient freshwater swamps which developed adjacent to major river systems have been well-described (e.g., Flores, 1981, and Winczewski and Groenewold, 1982). The most well-known deposits in Wyoming are those that occur within the Powder River Basin (PRB). There, the Tertiary Fort Union and Wasatch Formations host numerous thick coals which, based upon stratigraphic and paleontologic considerations, appear to be exclusively of freshwater origin. Flores (1980) presents a good discussion regarding those coal-forming environments in the northern PRB.

Any number of modern river systems may be suitable analogues for the Tertiary environments of the PRB. Rich (1983) suggests that the White-Arkansas River swamps of the south-central U.S., or Lorian Swamp in Kenya might be similar to the Tertiary swamps. Floristically, the lowland hardwood swamps of the southeastern U.S. are certainly very good modern analogues. There appears to be something peculiar about the tectonic behavior of the PRB during the Tertiary, however, which made it especially suitable for the accumulation of very thick coal deposits.

Most modern river systems of any size flow across fairly stable continental interiors, as, for example, the Mississippi, Congo, and Amazon Rivers. The tectonic stability of the river valleys tends to prevent the subsidence which is necessary for the accumulation of extremely thick peat deposits. Though the floodplain swamps of the Mississippi River are quite extensive, very thick peats are found only in comparatively isolated places, as on the delta, or in abandoned oxbows or bayous.

The tectonic behavior of the Powder River Basin must have been much different, however, as shown by coal seams which are commonly 15 m thick. The well-known Wyodak bed near Gillette is 30 m thick in places, and the recently discovered coal bed known informally as "Big George" is as much as 55 m thick (Pierce et al., 1982). The great thickness of these beds implies continuous, perhaps rapid subsidence of the basin, adequate to allow for the continuous accumulation of great quantities of peat over several millions of years.

The unusual thicknesses of PRB coals appears to have a geometric relationship with the axis of the basin. Pierce et al., (1982) note that "Throughout the basin, resources are commonly concentrated in difinable subareas where several named coal beds merge locally to form thick deposits of combined coal". Kent (personal communication) has shown that the "definable subareas" are usually elongated north-south, and thus parallel the axis of the basin. One implication is that intermittent periods of comparatively rapid down-dropping occurred during which very thick accumulations of peat developed parallel to the major streams. As down-dropping periodically slowed, the thick accumulations of peat were buried beneath clastic debris derived from the major streams Peat beds which formed subsequently were frequently interrupted by layers of sand and silt as streams migrated across the basin surface.

Regardless of how one interprets the tectonic behavior of the PRB during the early Tertiary, it is clear that the swamps and peat beds that existed there were under the influence of very different tectonic forces than any comparable river-swamp systems that can be found today.

Coal deposits in Wyoming have accumulated under a variety of environmental conditions. Delta swamps, coastal plain swamps, and inland river swamps have all contributed to the formation of the Wyoming coal beds. Modern swamps and marshes may be used as analogues to help us understand how and why the ancient deposits accumulated as they did. One must realize, however, that ancient environments, though similar to modern ones in many respects, were influenced by floristic or tectonic parameters which cannot be observed in modern situations.

REFERENCES

Blair, W.D., Jr., 1981, The Conservancy's R.K. Mellon grant: great expectations: The Nature Conservancy News, v. 31, no. 2, p. 4-5.

Flores, R., 1980, Fluvial coal settings of the Tongue River Member of the Fort Union Formation in the Powder River-Clear Creek Area, Wyoming, *in* G. Glass, editor, Guidebook to the Coal Geology of the Powder River Coal Basin, Wyoming: Geological Survey of Wyoming Public Information Circular no. 14, p. 71-96.

Flores, R., 1981, Facies modeling of surface and subsurface Tertiary coal-bearing deposits, Powder River and Williston Basins, Wyoming, Montana, and North Dakota: AAPG Coal Bearing Sequences short course notes, Steamboat Springs, Colorado.

Glass, G.B., 1978, Wyoming coal fields: Geological Survey of Wyoming Public Information Circular no. 9, 91 p.

Goodrum, C., 1983, A paleoenvironmental stratigraphic study of the Paleocene Fort Union Formation in the Cave Hills Area of Harding County, South Dakota: unpublished M.S. thesis, South Dakota School of Mines and Technology, 134 p.

Lawrence, D.T., 1982, Influence of transgressive-regressive pulses on coal-bearing strata of the Upper Cretaceous Adaville Formation, southwestern Wyoming, *in* K. Gurgel, editor, Fifth Symposium on the Geology of Rocky Mountain Coal, Proceedings: Utah Geological and Mineralogical Survey Bulletin 118, p. 32-49.

Livingston, A.L. and Wilson, W.L., 1982, Stratigraphy and coal development potential of Upper Mesaverde Group, Carbon County, Wyoming, *in* K. Gurgel, editor, Fifth Symposium on the Geology of Rocky Mountain Coal, Proceedings: Utah Geological and Mineralogical Survey Bulletin 118, p. 50-61.

Montz, G.N., and Cherubini, A., 1973, An ecological study of Bald Cypress Swamp in St. Charles Parish, Louisiana: Castanea, v. 38, no. 4, p. 378-386.

Nichols, D.J., and Jacobsen, S.R., 1982, Palynostratigraphic framework for the Cretaceous (Albian-Maestrichtian) of the Overthrust Belt of Utah and Wyoming: Palynology, v. 6, p. 119-148.

Pierce, F.W., Kent B.H., and Grundy, W.D., 1982, Geostatistical analysis of a 113-billion-ton coal deposit, central part of the Powder River Basin, northeastern Wyoming, *in* K. Gurgel, editor, Fifth Symposium on the Geology of Rocky Mountain Coal, Proceedings: Utah Geological and Mineralogical Survey Bulletin 118, p. 262-272.

Radforth, N.W., 1969, Environmental and structural differentials in peatland development, *in* E.C. Dapples and M.E. Hopkins, editors, Environments of Coal Deposition: Geological Society of America, Special Paper 114, p. 87-104.

Reuter, J.H. and Beck K.C., 1974, Hydrology and geochemistry of the Suwannee River, *in* W. Spackman, et al., editors, The Comparative Study of the Okefenokee Swamp and the Everglades - Mangrove Swamp - Marsh Complex of southern Florida: Geological Society of America field trip guidebook, trip no. 6, p. 21-24.

Rich, F., 1979, The origin and development of tree islands in the Okefenokee Swamp, as determined by peat petrography and pollen stratigraphy: unpublished Ph.D. dissertation, Pennsylvania State University, 301 p.

Rich, F., 1983, A brief survey of modern wetlands and their potential as coal-forming environments: AAPG coal bearing sequences short course notes, Park City Utah (in press).

Rich, F., and Goodrum, C., 1982, Paleoecology and sedimentology of the Fort Union Formation, Harding County, South Dakota: *in* K. Gurgel, editor, Fifth Symposium on the Geology of Rocky Mountain Coal, Proceedings: Utah Geological and Mineralogical Survey Bulletin 118, p. 158-162.

Rzoska, J., 1974, The upper Nile swamps, a tropical wetland study: Freshwater Biology, v. 4, no. 1, p. 1-30.

Spackman, W., Cohen, A.D., Given, P., and Casagrande, D.J., 1976, A field guidebook to aid in the comparative study of the Okefenokee Swamp and the Everglades-Mangrove Swamp-Marsh complex of southern Florida: Pennsylvania State University, 403 p.

Winczewski, L., and Groenewold, G., 1982, A tectonic-fluvial model for Paleocene coal-bearing sediment, Williston Basin, southwestern North Dakota, *in* K. Gurgel, editor, Fifth Symposium on the Geology of Rocky Mountain Coal, Proceedings: Utah Geological and Mineralogical Survey Bulletin 118, p. 76-88.

WASHAKIE BASIN, WYOMING, ZEOLITES

H.D. Curry, Geologist, Salt Lake City, Utah
K. Santini, Geologist, Anaconda Minerals Company

The Washakie Basin is a large, sub-rectangular, equidimensional structural basin southeast of the Rock Springs Uplift and immediately north of the Colorado-Wyoming border. An area of some 2,500 square miles is covered by sediments of Wasatch, Green River, and Bridger (Washakie) age, comprising nearly the entire Eocene epoch. The upper Eocene particularly, has long been known to contain considerable volcanic ash. Bradley (1964) and later workers have reported disseminated zeolites and essentially monomineralic units of analcite, mordenite, and clinoptilolite, but only the latter is here considered to have potential commercial importance.

Roehler (1973) noted that the variegated tuff occurring just above the thick, widespread, brown cliff-forming sandstone marking the base of the Adobe Town Member of the Washakie Formation was clinoptilolite-bearing, and he traced this unit (his marker bed 579) intermittently almost completely around the basin. The Adobe Town Member is best developed on the north. It is locally missing or obscured by structural complications or by a large influx of sands, such as occurs in the southeast. The Miocene Browns Park Formation overlies it unconformably on the southwest. Although it is not one continuous bed, and it pinches out laterally and varies in color and sedimentary features, the Adobe Town Member is remarkably persistent. In a few places clinoptilolite lenses are also found just below the basal brown sandstone, but they are small in size and of minor importance. Similarly, thin zeolitized tuffs occur in places several hundred feet stratigraphically higher in the section.

The main clinoptilolite-rich tuff unit is variegated in color, with pastel shades ranging from off-white through lemon-yellow, buff, orange, light olive-green, and a distinctive and striking robin's-egg blue. It is dense, fine-grained, hard, brittle, splintery, and moderately attrition-resistant. The main unit varies from a few inches to as much as twelve feet in thickness and intertongues laterally and vertically with tuffaceous mudstones and siltstones. The clinoptilolite content may exceed 90%, with an ammonia adsorption capacity as high as 2.0 milliequivalents per gram. It is nearly completely altered with common relict glass shards and scattered biotite flakes.

The volcanic ash apparently had a distant source, probably the Absaroka area of northwestern Wyoming which was active during the late-Eocene. It is a largely reworked ash-fall tuff deposited in a relatively high-energy, fluvial-lacustrine environment during one or more short episodes, rather than in a true deep-water lake such as is believed to characterize the underlying Laney Shale Member of the Green River Formation. A few thin, irregularly bedded, rust-colored layers of rather coarsely crystalline analcite occur in several horizons in the upper part of the varved and laminated Laney Shale Member, indicative of a low-energy environment.

Rocky Mountain Energy Corporation staked claims on the clinoptilolite deposits several years ago. This claim block, plus contingu-ous acreage held in fee, is estimated to contain several million tons of relatively high-grade material. Other areas of zeolite are characterized by thin beds, low grade, thick overburden, and inaccessibility which makes mining less attractive.

Eventually, these deposits should prove of real commercial value. There are many clinoptilolite occurrences in the west, but few with such desirable properties, mining configuration, and commercial promise.

REFERENCES

Bradley, W.N., 1964, Geology of the Green River Formation and associated Eocene Rocks in southwestern Wyoming and adjacent part of Colorado and Utah: U.S. Geological Survey Professional Paper 496-A, 86 p.

Roehler, H.W., 1973, Stratigraphic divisions and geologic history of the Laney Member of the Green River Formation in the Washakie Basin in southwestern Wyoming: U.S. Geological Survey Bulletin 1372E, p. 1-28

GENESIS AND DISTRIBUTION OF TRONA DEPOSITS IN SOUTHWEST WYOMING

William C. Culbertson, Geologist, U.S. Geological Survey

Trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 10H_2O$), a primary source of the industrial chemical soda ash, occurs in as many as 42 beds that underlie an area of about 1,300 mi^2 in the Green River Basin west of Rock Springs, Wyoming. The 25 major beds range in thickness from 3 to 37 feet, in areal extent from 100 to 850 mi^2, in depth from 800 to 3,500 feet, and contain an estimated 81.7 billion tons of trona and 52.7 billion tons of mixed trona and halite.

The trona beds were formed about 50 million years ago by the repeated evaporation of a large, chemically unique, inland lake. They occur within a sequence of thin persistent beds of oil shale, marlstone, and tuff, as well as blanket-like beds of sandstone and mudstone, which constitute the Wilkins Peak Member of the Eocene Green River Formation.

Three episodes of trona deposition are recognized. Most trona beds deposited during the first episode (beds 1-18) occupy large areas in the southern and central parts of the trona area, and locally contain large amounts of intermixed and interlayered halite. Trona beds of the second episode (beds 19-23) mostly occupy small areas in the northwest, and are halite-free. Trona beds of the last episode (beds 24 and 25) occupy small areas in the northeast, and also are halite free.

THE FUTURE OF EXPLORATION IN WYOMING

W. Dan Hausel, Deputy Director, Geological Survey of Wyoming

About 10 percent of the State's surface area lies within Laramide uplifts that are cored by Precambrian crystalline rock, and less than 3 percent (if we exclude Yellowstone) is covered by Tertiary volcanics. Much of the remaining surface area occurs within broad Tertiary basins (with Cretaceous sediments on their flanks) that are favorable environments for energy and industrial minerals, but generally unfavorable for base, ferrous, ferroalloy and precious metals (other than placers), and apparently diamond-bearing kimberlite.

This remaining 13 percent of surface area that is exposed in mountainous terrains contains large regions of relatively unmineralized Archean granite-gneiss basement. Approximately 90 percent of the Wyoming province consists of gneisses, migmatites, and granitic plutons and batholiths. This considerably narrows down the potential areas of exploration for metals, however the possibility of Devonian age diamond-bearing kimberlite extending throughout the exposed Precambrian must be considered.

When compared to many other western states, Wyoming contains less surface area that was affected by Tertiary volcanism and hydrothermal activity, and less area of exposed Precambrian rock. Large regions within the Precambrian and Tertiary volcanic terrain have also been restricted from exploration by man-made laws and regulations. When considering all of these factors it is obvious why energy and industrial minerals are important to Wyoming's economy, and metals relatively unimportant.

To be more optimistic, Wyoming has several regions in which the geology is favorable for metal and possibly diamond deposits. Some of these regions extend beyond the Precambrian and Tertiary volcanics as placers. For example, large areas containing Cretaceous to Recent auriferous placers have been reported in northwestern Wyoming, Tertiary to Recent gold placers occur in southwestern Wyoming, and the possibility of diamond placers in late Paleozoic red-beds (i.e. Fountain Formation) as well as Recent alluvium, has not been considered.

Although Wyoming possibly has less area that is favorable for hosting metallic deposits, the state is relatively unexplored compared to its neighbors. Even with the relatively lesser amount of exploration, just within the last decade a number of important discoveries, rediscoveries, and interesting finds have been enticing to the exploration geologist. For example, the following (undoubtedly incomplete) list of these discoveries, etc., should remind us that our mountains are relatively untouched,

(1) In 1981 significant amounts of gold were detected in analyses from selected samples collected in the Bradley Peak area. These specimens were collected from a historic mining camp (Penn Camp) which lies within metagabbros and ultramafic rocks that form part of the Seminoe Mountains "greenstone belt" (Hausel, 1982a, Hausel and Harris, 1983). The metals are believed to have been mobilized from the adjacent country rock and transferred to dilational zones (Klein, 1981). There appear to be similarities between the Bradley Peak gold deposits and the Yellowknife region (e.g. Boyle, 1959).

(2) Between 1975 and 1978, Precambrian quartz pebble conglomerates in the Sierra Madre and Medicine Bow Mountains were discovered to be radioactive (Houston and others, 1977; Houston and Karlstrom, 1979). To date, large regions of these metaconglomerates have not been tested for uranium, let alone for gold, although it was suggested as early as 1968, that these could be a gold placer source (Houston and others, 1968).

(3) During 1979 and 1980, Conoco Minerals discovered a stratiform massive volcanogenic zinc-copper-silver sulfide deposit in the southern Sierra Madre. This deposit occurs in a eugeoclinal setting with thick successions of Proterozoic calc-alkaline metavolcanic and metavolcaniclastic rock (Divis, 1976; 1977). Many nearby copper mines and prospects have not been evaluated for their potential volcanogenic genesis, although two nearby mines, the Itmay and the Hinton (Verde), were suggested as possible volcanogenic massive sulfide bodies (Hausel, 1982a, Hausel and Harris, 1983). These two historic mines have recently been considered in the thesis projects of Schmidt (1983), and Swift (1982), respectively.

(4) The accidental discovery of diamond in 1975, in a mantle nodule collected from a Wyoming kimberlite pipe (McCallum and Mabarak, 1976) led to the discovery of numerous kimberlite intrusives as well as additional diamondiferous pipes (McCallum and others, 1977, 1979; Hausel and others, 1979, 1981). Large regions remain unexplored, and some areas that have received reconnaissance stream sampling, contain anomalies suggesting the presence of several undiscovered kimberlites. To date, no potential placer deposits have been tested, even though the known kimberlites are considered to be deeply eroded (e.g. McCallum and Mabarak, 1976, figure 6).

Of additional interest was the recent discovery of placer diamonds in the northern Medicine Bow Mountains (Hausel and others, 1979), the reported occurrence of pyrope garnets and chrome diopside in ant hills over a six to eight square mile area in the Green River Basin (Hausel and others, 1979), and unverified reports of diamonds found in the Wind River Range and in the Gros Ventre Range (J.D. Love, pers. comm., 1981).

(5) The rediscovery of copper-silver-zinc mineralization in Nugget red-beds of the Lake Alice District (Love and Antweiler, 1973; Boberg, 1983) has led to the rediscovery and discovery of several more occurrences in red-beds of the Overthrust Belt (Love and Antweiler, 1973; Hausel and Harris, 1983).

(6) Love and others (1978) reported significant amounts of gold disseminated throughout Wasatch Formation (Tertiary) boulder conglomerates in the Dickie Spring region several miles south of South Pass. It has been estimated that more than 28,500,000 ounces of gold may occur within these conglomerates.

(7) Antweiler and others (1977) reported significant amounts of gold in Cretaceous and Tertiary conglomerates, as well as alluvial gravels in the Snake River region.

(8) Several porphyry copper-molybdenum deposits have been discovered in the wilderness areas of the Absaroka Plateau in recent years (Wilson, 1971, 1975; Fisher and Antweiler, 1980; Fisher and others, 1977; Fisher, 1981; Hausel, 1982b).

REFERENCES

Antweiler, J.C., Love, J.D., and Campbell, W.L., 1977, Gold content of the Pass Peak Formation and other rocks in the Rocky Mountain Overthrust Belt, northwestern Wyoming: Wyoming Geological Association, 29th Annual Field Conference Guidebook, p. 731-749.

Boberg, W.W., 1983, Lake Alice copper district, Lincoln County, Wyoming, *in* W.D. Hausel and R.E. Harris, editors, Genesis and Exploration of Metallic and Nonmetallic Mineral and Ore Deposits of Wyoming and Adjacent Areas abstracts: Geological Survey of Wyoming Public Information Circular 19, p. 14.

Boyle, R.W., 1959, The geology, geochemistry, and origin of the gold deposits of the Yellowknife District: Geological Survey of Canada Memoir 310, 193 p.

Divis, A.F., 1976, The geology and geochemistry of the Sierra Madre Mountains, Wyoming: Colorado School of Mines, Quarterly, v. 71, no. 3, p. 1-95.

Divis, A.F., 1977, Isotopic studies on a Precambrian geochronological boundary, Sierra Madre Mountains, Wyoming: Geological Society of America Bulletin, v. 88, p. 96-100.

Fisher, F.S., 1981, Controls and characteristics of metallic mineral deposits in the southern Absaroka Mountains, Wyoming: Montana Geological Society Field Conference Guidebook, p. 343-348.

Fisher, F.S., and Antweiler, J.C., 1980, Preliminary geological and geochemical results from the Robinson Creek, Birthday, and Clouds Home Peak mineralized areas in the Washakie Wilderness, Wyoming: U.S. Geological Survey Open File Report 80-781, 12 p.

Fisher, F.S., Antweiler, J.C., and Welsch, E.P., 1977, Preliminary geological and geochemical results from the Silver Creek and Yellow Ridge mineralized areas in the Washakie Wilderness, Wyoming: U.S. Geological Survey Open File Report 77-225, 11 p.

Hausel, W.D., 1982a, Ore deposits of Wyoming: Geological Survey of Wyoming Preliminary Report 19, 39 p.

Hausel, W.D., 1982b, General geologic setting and mineralization of the porphyry copper deposits, Absaroka volcanic plateau, Wyoming: Wyoming Geological Association, 33rd Annual Field Conference Guidebook, p. 297-313.

Hausel, W.D., Glahn, P.R., and Woodzick, T.L., 1981, Geological and geophysical investigations of kimberlites in the Laramie Range of southeastern Wyoming: Geological Survey of Wyoming Preliminary Report 18, 13 p.

Hausel, W.D., and Harris, R.E., 1983, Metallogeny of some Wyoming deposits: Colorado Mining Association Yearbook, in press.

Hausel, W.D., McCallum, M.E., and Woodzick, T.L., 1979, Exploration for diamond-bearing kimberlite in Colorado and Wyoming: an evaluation of exploration techniques: Geological Survey of Wyoming Report of Investigations 19, 29 p.

Houston, R.S., Graff, P.J., Karlstrom, K.E., and Root, F.K., 1977, Preliminary report on radioactive conglomerate of Middle Precambrian age in the Sierra Madre and Medicine Bow Mountains of southeastern Wyoming: U.S. Geological Survey Open File Report 77-584, 31 p.

Houston, R.S., and Karlstrom, K.E., 1979, Uranium-bearing quartz-pebble conglomerates: exploration model and United States resource potential: U.S. Department of Energy Report GJBX-1 (80), 510 p.

Houston, R.S., and others, 1968, A regional study of rocks of Precambrian age in that part of the Medicine Bow Mountains lying in southeastern Wyoming: Geological Survey of Wyoming Memoir 1, 167 p.

Klein, T.L., 1981, The geology and geochemistry of the sulfide deposits of the Seminoe District, Carbon County, Wyoming: unpublished Ph.D. dissertation, Colorado School of Mines, 232 p.

Love, J.D., Antweiler, J.C., and Mosier, E.L., 1978, A new look at the origin and volume of the Dickie Spring-Oregon Gulch placer gold at the south end of the Wind River Mountains: Wyoming Geological Association, 29th Annual Field Conference Guidebook, p. 379-391.

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.

McCallum, M.E., and Mabarak, C.D., 1976, Diamond in State Line kimberlite diatremes, Albany County, Wyoming-Larimer County, Colorado: Geological Survey of Wyoming Report of Investigations 12, 36 p.

McCallum, M.E., Mabarak, C.D., and Coopersmith, H.D., 1979, Diamonds from kimberlites in the Colorado-Wyoming State Line District: American Geophysical Union, 2nd International Kimberlite Conference, Proceedings, v. 1, p. 42-53.

Schmidt, T., 1983, Metavolcanic rocks and associated volcanogenic mineral deposits of the Fletcher Park and Green Mountain areas, Sierra Madre, Wyoming, *in* W.D. Hausel and R.E. Harris, editors, Genesis and Exploration of Metallic and Nonmetallic Mineral and Ore Deposits of Wyoming and Adjacent Areas abstracts: Geological Survey of Wyoming Public Information Circular 19, p. 4

Swift, P.N., 1982, Precambrian metavolcanic rocks and associated volcanogenic mineral deposits of the southeastern Sierra Madres, Wyoming: unpublished MS thesis, University of Wyoming, 61 p.

Wilson, W.H., 1971, Volcanic geology and mineralization, Absaroka Mountains, northwest Wyoming: Wyoming Geological Association, 23rd Annual Field Conference Guidebook, p. 151-155.

Wilson, W.H., 1975, The copper-bearing Meadow Creek granodiorite, upper Wood River area, Park County, Wyoming: Wyoming Geological Association, 27th Annual Field Conference Guidebook, p. 235-241.

STREAM SEDIMENT EXPLORATION SAMPLING FOR KIMBERLITE IN COLORADO-WYOMING, AND TECHNIQUES OF DIAMOND EXTRACTION

Carl Brink, Geological Survey of Wyoming
Karl Albert, Geological Survey of Wyoming
W. Dan Hausel, Deputy Director, Geological Survey of Wyoming

Exploration for kimberlites in Wyoming and Colorado is based on methods that have been effectively used for many years in Africa, Australia, and the U.S.S.R. The most efficient of these is reconnaissance stream sediment sampling for the diagnostic kimberlitic "indicator" minerals pyrope garnet, chrome diopside, and magnesian ilmenite that have been released into the surrounding soil and drainages by decomposition of kimberlite.

Once a promising area has been selected, sample sites are plotted on the U.S.G.S. 7½- or 15-minute topographic map. These sites are spaced 0.5-1.0 miles apart on all major drainages. This spacing has been chosen because studies done in Colorado (Leighton and McCallum, 1979) have shown that abrasion of grains during transport effectively destroys indicator minerals at relatively short distances from their parent rock. Magnesian ilmenite grains survive up to 2.5 miles, garnet 1.5 miles and chrome diopside only 0.25 miles.

Sample locations in the field are chosen to take advantage of the best possible heavy mineral collection site in the drainage. Samples are collected from one to three feet below the surface. The sample is shoveled into a grizzly pan, and material greater than ¼ inch is visually examined before being rejected. Material smaller than ¼ inch (coarse fraction) passes through the grizzly onto a 1.2 mm nylon mesh. Finer material passes through the mesh and is collected in a gold pan. This fine fraction is repeatedly panned in gently running water until all lighter minerals have been washed away, leaving only a black heavy mineral concentrate. This pan concentrate is briefly examined for distinctive purple to lavender pyrope garnet and emerald green chrome diopside before being placed in a separate bag. Between three and five pounds of concentrate are collected at each site.

At the laboratory, the samples are dried and run through a magnetic separator to remove any magnetic minerals. The coarse non-magnetic fraction is then further concentrated in a jig, while the fines go to a Wilfley Table where material of less than 3.2 s.g. is removed. The final concentrates are then dried and are ready for optical examination for indicator minerals. The most important indicator minerals are pyrope garnet, chrome diopside, and magnesian ilmenite. Pyrope garnet is well-rounded and recognizable by its deep red-purple color and refractive index; chrome diopside is emerald green and has excellent cleavage and parting;

and magnesian ilmenite is glossy black and non-magnetic.

Kimberlite rock is crushed and sieved into two size fractions. After passing through a magnetic separator, the coarse fraction (+16 mesh; >1.19 mm) is passed over a grease table, the grease consisting of a mixture of Vaseline and paraffin up to ¼ inch thick. Diamonds, being non-wettable by water, adhere to the grease while other minerals are washed off. Tests have shown that the grease table is 100% efficient on this size sample. The fine fraction (-16 mesh; <1.19 mm) is processed in a skin flotation unit (as well as on the grease table). In the skin flotation unit, the sample falls from a vibrating container onto a smooth tensional water surface created by a constant volume rising water flow. Being non-wettable, diamonds float on this surface and are recovered as they pass over the edge of the water container. Other minerals break through the surface tension layer and so are effectively separated from any diamonds. This unit is 80% effective (Hausel and others, in preparation).

The concentrates from the grease table and skin flotation unit are placed in a hydrofluoric acid bath to digest any silicate minerals. The final sample is then examined for diamonds which can be recognized by their characteristic crystal shapes (i.e. octahedrons and dodecahedrons) and surface features (trigons) (Hausel and others, in preparation).

ACKNOWLEDGMENTS

This project has been funded by various grants from the U.S. Office of Surface Mining, and the University of Wyoming Mining and Mineral Resource and Research Institute (W. Dan Hausel, principal investigator), and by NASA (W. Dan Hausel and Ronald W. Marrs, co-investigators).

REFERENCE

Hausel, W.D., and others, in preparation, Stream sediment sampling and heavy mineral extraction in the search for diamondiferous kimberlite — and a summary of sample site localities at Boulder Ridge on the Best Ranch and Johnson Ranch 7½-minute quadrangles, Albany County, Wyoming.

A MODEL FOR LOW TEMPERATURE COPPER TRANSPORT AND DEPOSITION

Robert J. Starkey, Department of Geology and Geophysics, University of Wyoming
B. Ronald Frost, Associate Prof. of Geology, Department of Geology and Geophysics, University of Wyoming

The zonal sequence pyrite-chalcopyrite-bornite-chalcocite ± native copper has been described in sediment-hosted, syngenetic and diagenetic copper deposits (i.e. the copper deposits of Zambia and White Pine, Michigan) as well as in higher temperature hydrothermal deposits (i.e. the Sustut deposit, British Columbia and Messina, South Africa). The remarkable consistency and continuity of these mineral zones within a deposit and the variety of geologic settings and rock types in which these deposits occur suggest a similar, geologically simple mode of formation. Copper mineralization typically is associated with a permeable hematitic oxidized layer and an impermeable reduced layer leading many workers to deduce that the zonation is a result of progressive reduction of an oxidized, copper-bearing fluid possibly in the presence of hydrogen sulfide. Simple calculations of copper mineral stabilites from 25°C to 300°C in the presence of aqueous sulfur species in log f_{O_2} vs. pH space show that over geologically reasonable pH ranges at constant aqueous sulfur concentrations, the progression of mineral stabilities with increasing oxygen fugacity is pyrite-chalcopyrite-bornite-chalcocite-native copper. In addition, these calculations reveal that bornite, chalcocite, and native copper are stable with respect to hematite and aqueous sulfate which suggests that copper and sulfur can be transported in the same fluid, and upon reduction of this fluid, copper sulfides will be precipitated. Calculations also show that native silver is stable with chalcocite and native copper and that lead and zinc are very soluble under the oxidizing conditions associated with native copper. This explains the common occurrence of native silver in low-temperature copper deposits and the absence of galena and sphalerite within the zonal sequence in these deposits.