MINERALS AND ROCKS OF WYOMING

A GUIDE FOR COLLECTORS, PROSPECTORS, AND ROCK HOUNDS

BY

W. DAN HAUSEL

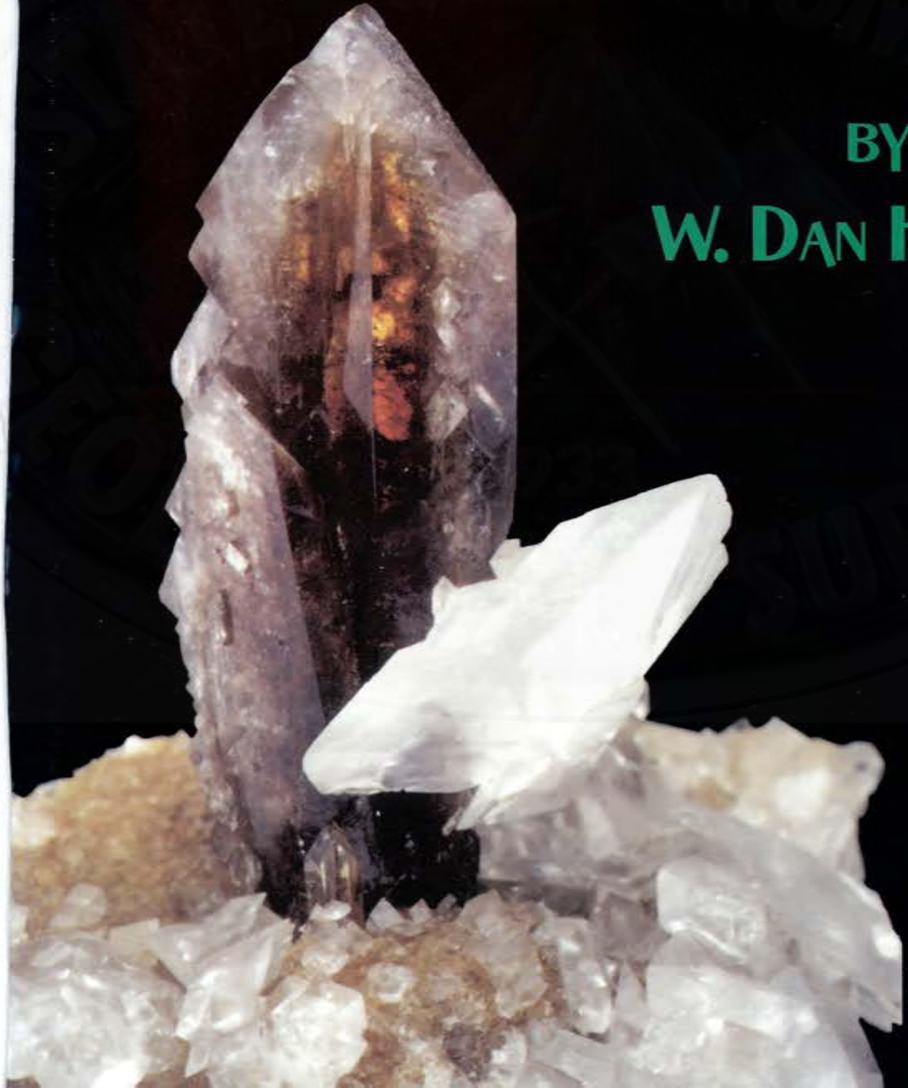


TABLE OF CONTENTS

LIST OF MAPS

INTRODUCTION

This book is a general introduction to Wyoming's minerals and rocks, what they look like, where one can expect to find them, and how to find them. I provide general descriptions of common physical and optical characteristics along with photos of many of these rocks and minerals to aid the layman in finding and identifying various specimens. Throughout the following descriptions, I've attempted to restrict the information to fit the physical characteristics of mineral and rock specimens found in Wyoming. More comprehensive descriptions of the characteristics and physical properties of minerals in general are found in most mineralogy and petrology books—which are highly recommended as an additional tool when using this book. Additional information on many Wyoming minerals is available in a companion book, *Gemstones and Other Unique Minerals and Rocks of Wyoming—A Field Guide for Collectors,* by Hausel and Sutherland (2000).

The reader will find many of the state's important minerals and rocks briefly described herein. These descriptions include information on some of the important physical properties of each mineral, such as heft or specific gravity, crystal habit, mineral and rock associations, color, and where the various minerals or rocks should be found in the state. This book would be best used to help plan weekend collecting trips and build a mineral and rock collection. Soon you will become more competent in mineral and rock identification. After collecting the various specimens, it is worthwhile to label each rock and mineral to include where you found it, the date you found it (corresponding with detailed notes in a field book), and the name of the mineral or rock. This can be done using common 'white out' correction fluid. Paint the fluid on the rock or mineral and write this information on the dried label using a permanent, very fine point marker.

I wrote this book because of the hundreds of requests from various rock hound clubs, mineral associations, gem clubs, treasure hunters, and geological associations who wanted a book on the state's minerals and rocks. During my career at the Wyoming State Geological Survey, I have met several thousand prospectors, gemologists, geologists, rock hounds, mineralogists, and laymen, either in my office, on one of my many field trips, or during one of the more than 400 lectures, short courses, and talks I have given around the region. Being invited to speak by many of the various treasure hunters, mineral, rock, prospector and geological associations and clubs throughout the years has provided me with great insight into the special needs of the average rock and mineral collector.

Wyoming is built of rocks and minerals and some of the best rock exposures in the world are found here. Rocks greater than three billion years old, rocks that are presently being formed, and rocks of nearly every age in between are found in Wyoming. Much of the state is underlain by common rocks and rock-forming minerals that can be found in many regions of the world, but a few are so rare that they are found only at one or two localities in the Cowboy State and at a few scattered localities worldwide.

Some rare rock specimens found in Wyoming include kimberlite and lamproite. Diamond exploration geologists and prospectors, in particular, are attracted to these rock types as they are the only two rock types that so far have produced commercial amounts of diamonds. *Kimberlite*, a potassic alkali peridotite, is a hybrid rock that is typically found in very small pipes or dikes. Kimberlite was first identified in Wyoming in the early 1960s, but it wasn't until 1975 that diamonds were accidentally found in some of these. To date, the two largest kimberlite districts in the United States have been mapped in Wyoming and Colorado (Hausel, 1998; Hausel and others, 1981, 2000, 2003). Following the relatively recent and extraordinary discovery of very rich diamondiferous kimberlite pipes in Canada, that nation became a major source for gem-quality diamonds, surpassing South Africa in diamond production in 2004 (Hausel, in press). Because Wyoming is underlain by rocks similar to the diamond regions of Canada, it is possible that similar rich deposits will be found here some day in the future.

Not only is kimberlite a collector's item, but a variety of peridotite and eclogite cobbles and boulders referred to as nodules by geologists are also found in many kimberlites. These nodules also provide very rare rock specimens that represent fragments of the Earth's mantle that originated 90 to 120 miles below the earth's surface.

Lamproite, an ultrapotassic mafic igneous rock, may also contain diamond. Some rare volcanic flows and plugs found north of Superior and north of Rock Springs are extremely rare rock types that are similar to lamproites found in Australia. In the early 1980s, a world-class diamond deposit was found in the Kimberley Block in Western Australia at what later became known as the Argyle mine (**Figure 1**). For several years, about 30% of the world's annual diamond production was from this

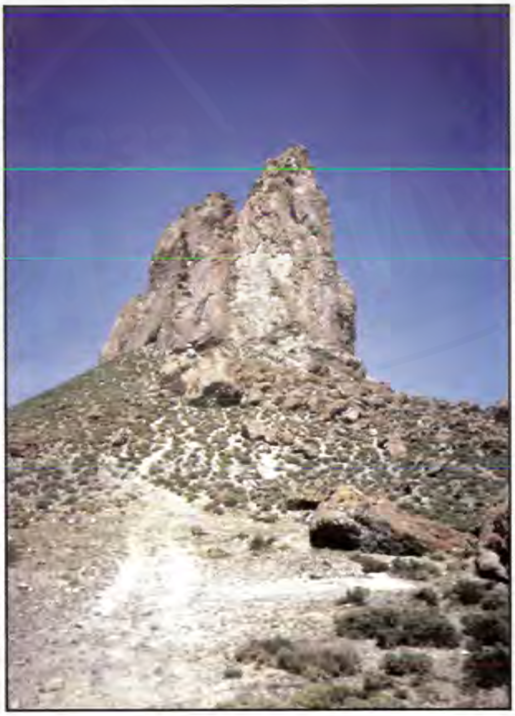
Figure 1. The Argyle diamond mine, Western Australia, as it appeared in 1986. Diamonds at Argyle were found in olivine-lamproite, one of the rarest rock types on Earth. This one mine produced 30% of the world's diamonds annually for several years and even reached a high of 40% of the world's annual production for a few years. Similar rocks are found in Wyoming near Rock Springs.

single lamproite. Since then, a few other lamproites have been found to contain diamonds—notable are some of the Ellendale lamproites in Australia, the Murfeesburo, Arkansas lamproite, and the Majhawan lamproite in India (Erlich and Hausel, 2002). Astounding as it may sound, many of Wyoming's lamproites (as well as several kimberlites) have never been tested for diamond, even though a connection between these rocks and kimberlite has been known for more than 30 years (Carmichael, 1967).

One of the more interesting exposures of lamproite in the world is found at the Boars Tusk, north of Rock Springs. Boars Tusk is a volcanic plug, or basically the remains of the interior plumbing of a 3.1 million-year old volcano (**Figure 2**) that is formed of a lamproite referred to as *wyomingite*. However, modern terminology suggests that the rock be termed phlogopite lamproite rather than wyomingite. Although microscopic, some extremely rare minerals have been identified in lamproites including leucite, potassium richterite, priderite, armalcolite, and others.

Other interesting minerals are found in the same region, including olivine in the Leucite Hills, and red to orange pyrope garnet and green chromium-rich pyroxene found in anthills just north of Cedar Mountain, several miles southwest of the Leucite Hills. A few years ago, 13,000 carats of industrial and gem-quality olivine were collected from just two anthills in the Leucite Hills by the author. Prior to that time, gem-quality olivine (known as peridot) was unknown in the state (see **Olivine**). Other minerals found in this area include pyrope garnet and chromian pyroxene scattered in anthills in the Cedar Mountain and Butcherknife Draw region southwest of Green River (**Figure 3**) (McCandless, 1984; McCandless and others, 1995). The source of most of these minerals has not yet been identified, although some

Figure 2. The Boars Tusk in the Leucite Hills volcanic field north of Rock Springs, Wyoming forms a spectacular lamproitic volcanic neck. This volcano last erupted about 3.1 million years ago—considered fairly recent in geological terms. Other lamproites in the Leucite Hills are younger, with some flows at Zirkel Mesa yielding age dates of only 900,000 years before the present, indicating that the volcanoes get progressively younger to the southeast. Can we possibly expect a future eruption further to the south?



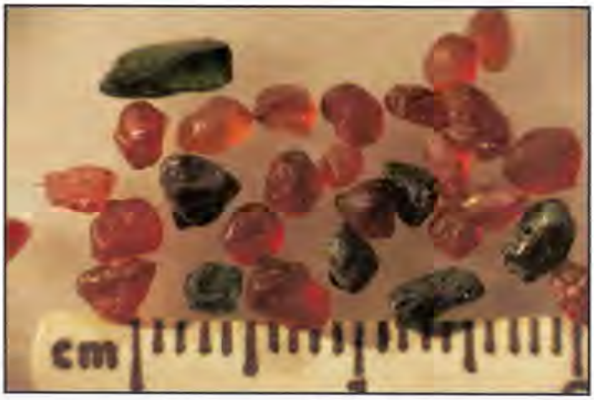


Figure 3. Pyrope (red to pink) and chromian diopside (green) collected from anthills in the Butcherknife Draw region in the Green River Basin south of the town of Green River.

breccia pipes and dikes that contain these minerals, along with eclogite rock fragments and diamonds, were found along the southwestern flank of Cedar Mountain to the southwest of Butcherknife Draw (Hausel and others, 1999). In addition to the pipes and anthills, these *indicator minerals* are also found in the Bishop Conglomerate (Oligocene) in this region.

Wyoming jade is also rare. Some pieces of apple green jade collected in Wyoming are nearly priceless. Jade found in Wyoming is comprised of an amphibole known as nephrite, whereas much of the jade from southeastern Asia is formed from another mineral known as jadeite, a pyroxene. These two forms of jade are essentially indistinguishable to the naked eye and require x-ray diffraction tests to differentiate. Wyoming jade has been reported as far west as the Prospect Mountains at the southern edge of the Wind River Range (although unverified), and as far east as the northeastern slope of the Laramie Range (**Figure 4**). Much of the verified jade has been identified in central Wyoming surrounding Jeffrey City.

Some other unusual minerals in Wyoming include corundum (sapphire and ruby), aquamarine beryl, helidor beryl, cordierite (iolite), blue-transparent barite, opal, gold nuggets, sperrylite, varisite, and others. Agate and jasper are also widespread and found at many places throughout the state. The uniqueness of some varieties of Wyoming chalcedony is manifested in the arrangement of color bands and patterns (**Figure 5**). Beautiful specimens found in eastern Wyoming, such as a pink chalcedony breccia known as youngite, are prized by rock hounds and collectors all over North America.

GEOLOGIC HISTORY OF WYOMING

A description of Earth's history is nearly inescapable in any discussion of rocks and minerals. Therefore, a very brief summary of geologic history is provided below. More detailed information is available in *Traveler's Guide to the Geology of Wyoming* by Blackstone (1988). A more detailed treatise on Wyoming's geology is found in *Geology of Wyoming* edited by Snoke and others (1993).

Geologic time is generally divided into the Precambrian (greater than 543 million years old) and Phanerozoic (less than 543 million years old). Even though the Pha-

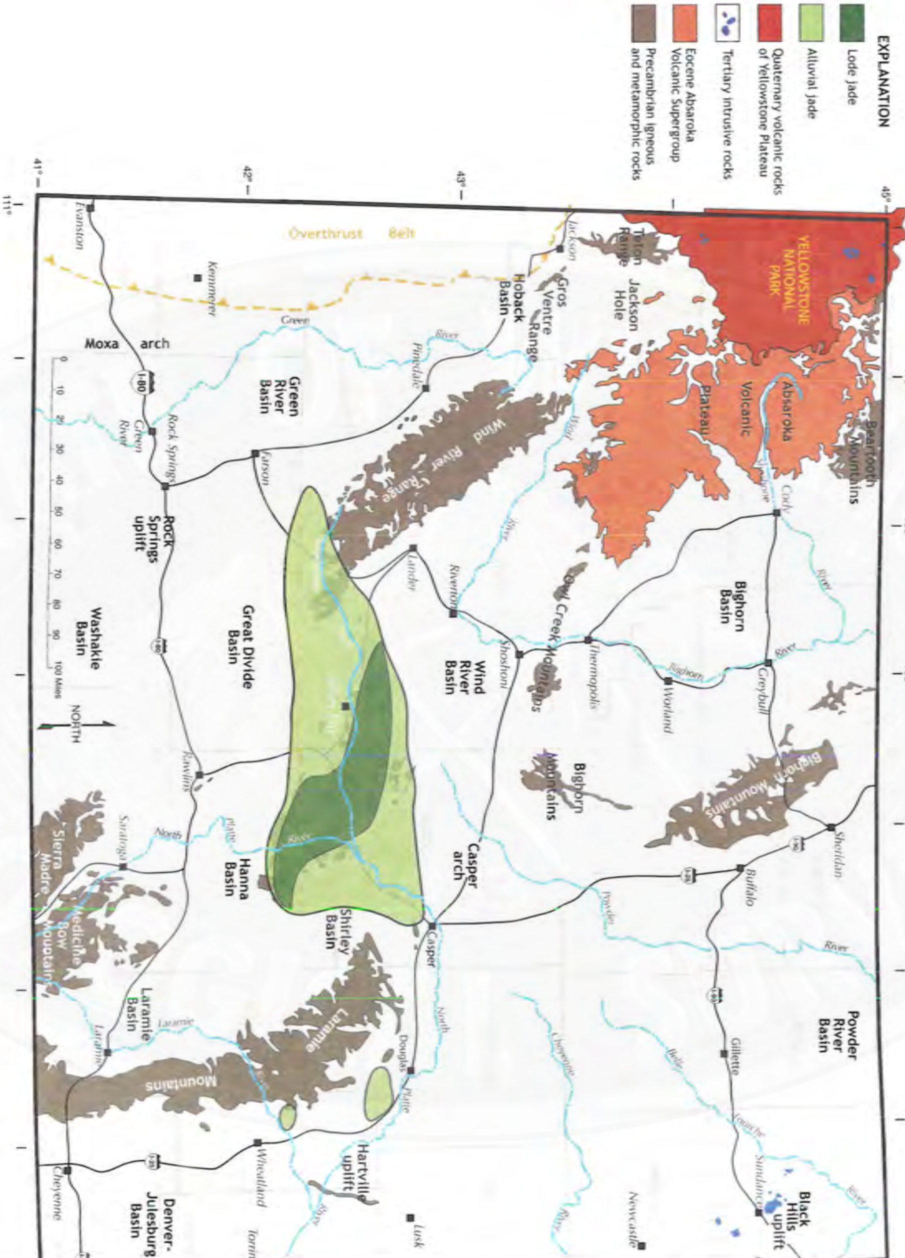


Figure 4. Principal jade occurrences in Wyoming.

Figure 5. Cabochons cut from Wyoming rocks. Clockwise starting at left center: tawny to reddish yellow jasperized iron formation from Seminoe Mountains; silver metallic specular hematite with copper from Charter Oak mine, Encampment district; specular hematite from the Hartville uplift; distinctly banded jasperoid from Quaking Asp Mountain near Rock Springs; banded iron formation from the Lewiston district, South Pass; bluish-green fuchsitic quartzite from Snowy Range, Medicine Bow Mountains. These surround large cab of Sweetwater agate from the Granite Mountains.

nerozoic rock record includes substantially less time, it is much more complete and is subdivided into the Paleozoic, Mesozoic, and Cenozoic eras. These are further subdivided on the basis of important geologic events (see **Table 1**).

The Precambrian includes the greatest amount of geologic time, but less is known about the events in the Precambrian because metamorphism, deformation and erosion have destroyed much of the record. However, Precambrian rocks are important in Wyoming because they are found in the cores of most of the state's mountain ranges and lie deeply buried under all of the sedimentary basins.

The Precambrian

Precambrian time includes the very beginning of the geological record of the Earth (about 4 billion years ago) to approximately 543 million years ago. Geoscientists divide the Precambrian into the Archean (greater than 2.5 billion years ago) and Proterozoic (less than 2.5 billion years ago). About 2.5 to 2.0 billion years ago, the Earth's atmosphere became sufficiently enriched in oxygen to dramatically change the surface of the Earth forever. Before oxygen was a common component, many minerals remained unoxidized. Vast accumulations of magnetite iron formation were common and stream placers contained pyrite, uranium, and copper nuggets much the same as modern placers contain gold nuggets. But when oxygen became enriched in the atmosphere, it combined with (or oxidized) many minerals. Magnetite was commonly replaced by rust (hematite). Pyrite was oxidized to hematite, limonite, and sulfuric acid. Uranium and copper were oxidized and often carried away in solution. Pyrite, copper, and uranium nuggets were no longer deposited in stream placers.

Through time, the Precambrian rocks in Wyoming were weathered to a featureless plain and buried under hundreds of feet of layered sedimentary rock. How-

Table 1. Geologic time chart of Wyoming.

TIME[1]	ERA[2]	PERIOD[2]		EPOCH[2]	EVENTS IN WYOMING	MINERAL RESOURCES IN WYOMING
0	CENOZOIC	QUATERNARY		Holocene	Present climate	Sand and gravel, placer gold, travertine, sulfur, diatomite, clinker, sodium sulfate, epsomite, silica sand, leonardite
.01				Pleistocene	Ice Age. Yellowstone calderas	
1.8		TERTIARY	NEOGENE	Pliocene	Volcanic activity continued in Yellowstone area, Teton Mountains formed, terrestrial deposition	Diatomite, pumicite, agate
5.3				Miocene	Volcanic activity began near Yellowstone, extensional faulting of mountain ranges, temperate climate	Uranium, agate
23.8			PALEOGENE	Oligocene	Terrestrial deposition of great amounts of volcanic ash, warm temperate climate, diatreme emplacement	Copper-molybdenum porphyries, paleoplacer gold, diamonds
33.7				Eocene	Absaroka volcanism, Green River lake and terrestrial deposition, subtropical climate	Uranium, coal, trona, oil shale, zeolites, gold paleoplacers, rare earths, fluorite, thorium, copper-molybdenum porphyries
54.8				Paleocene	Major Laramide orogenic activity, terrestrial deposits, tropical climate	Uranium, coal, natural gas
65	MESOZOIC	Cretaceous			Transgression and regression of Interior Seaway, Rocky Mountains begin to rise, abundant cephalopods and other marine life, deltaic deposits	Bentonite, coal, oil and natural gas, uranium, silica sand, titaniferous black sand paleoplacers
144		Jurassic			Eolian deposits to shallow seas with marine life to broad flood plains with many dinosaurs	Copper-silver-zinc, oil and natural gas, gypsum
206		Triassic			Fluctuation of shoreline, wide tidal flats, mild but arid climate	Gypsum, oil and natural gas
248	PALEOZOIC	Permian			Complex rock types and environments-open ocean to west, shallow or emergent shelf to east; invertebrates common	Phosphate rock and associated vanadium; gypsum; oil and natural gas
290		Pennsylvanian			Local uplift in south-central and southern Wyoming; eolian and marine deposits elsewhere	Limestone, oil and natural gas, copper, silica sand
323		Mississippian			Entire state submerged in warm tropical seas; emergent near end of period	Limestone, oil and natural gas (including carbon dioxide and helium)
354		Devonian			Seas in northwestern and western Wyoming; diatreme emplacement	Diamond-bearing kimberlites, oil and natural gas
417		Silurian			Carbonate deposition in clear-water seas (incomplete record due to subsequent erosion)	Only preserved rocks are in southern Wyoming kimberlite diatremes are on western border
443		Ordovician			State inundated by shallow warm waters	Oil and natural gas
490		Cambrian			Diatreme emplacement Seas transgressed from west across entire state	Oil, some hematite, decorative stone, diamonds
543	Major unconformity				Long interval of erosion at close of era	
1000	PRECAMBRIAN	PROTEROZOIC[3]			Land reduced to broad plains of low relief Mountain building Widespread ancient seas Continents in existence Atmosphere becoming more oxygen-rich	Anorthosite in the Laramie Mountains Gold, copper, platinum (?) veins and shears in the Medicine Bow Mountains Beryl, lepidolite, feldspar, copper sulfide pegmatites at Copper Mountain Gold-bearing quartz veins Numerous beryl and feldspar pegmatites Tantalum-and niobium Copper and gold in the Silver Crown district, Laramie Mountains Volcanogenic copper-zinc-silver sulfide deposits in the Sierra Madre Railroad ballast from quartzofeldspathic rocks and metadolomites Copper-bearing quartzites in the Sierra Madre Uranium and diamond paleoplacers in the Medicine Bow Mtns Sierra Madre, hematite iron ore in Hartville area
2500 4500		ARCHEAN[3]			Reducing atmosphere (low oxygen) Formation of primitive continents	Banded magnetite iron formation at South Pass, Copper Mountain, and Seminoe Mountains Pegmatites with beryl, lepidolite, feldspar, and copper sulfides Uranium, diamond and gold paleoplacers in the Medicine Bow Mountains and Sierra Madre Jade, sapphires, rubies, iolite, kyanite gems Gold-bearing veins and shears at South Pass Talc and asbestos Tungsten deposits at Copper Mountain

[1] In millions of years before the present. (From Geological Society of America 1999 Geologic time scale). Note: Not all the time intervals shown for the periods are represented by rocks in Wyoming due to erosion and for non-deposition.

[2] The height of each box representing time units is **not** proportional to either the time interval or the thickness of rocks for that age.

[3] Resources in Precambrian rocks are not necessarily in chronological order.

ever, hundreds of millions of years after the Precambrian, Wyoming and the rest of western North America experienced major tectonic events. At many localities, long thin slices of the Earth were forced upwards hundreds to thousands of feet as the western edge of the North American continent (craton) was compressed in what became known as the Laramide Orogeny, producing the Rocky Mountains. Within the now eroded cores of these slices, or what are better known as mountain ranges, are the only exposures of Precambrian rocks found at the surface in Wyoming. As one can imagine, we have only a fragmented Precambrian terrain to piece together; it is like having a large jigsaw puzzle with most of the pieces missing. This is one of the primary reasons why so little is known about the geologic history of the Precambrian. However, research by the Wyoming State Geological Survey, the University of Wyoming, and the U.S. Geological Survey during the past three decades has given us a much better understanding of these ancient rocks.

The cores of these mountain ranges contain very old metamorphic rocks that represent former sedimentary, volcanic, and plutonic rocks that have been altered by heat and pressure. Many of these rocks were initially deposited on an ancient continent, others along the margin of the continent, and still others in ancient oceans and seas. In many areas, these rocks are now highly deformed and fractured and contain numerous quartz veins (**Figure 6**). Many of the historic gold and copper mining districts in the state, such as South Pass and Encampment, are found in these terrains.

Large regions of Precambrian terrain were intruded by granite during a cratonization or stabilization event of the continent. Some of these granites cover several hundred square miles of surface area, and are found in the ancient mountains.

Figure 6. Faulted quartz vein exposed in the Mary Ellen gold mine at South Pass.

The Phanerozoic

The Phanerozoic rock record includes rocks ranging in age from 543 million years old to those formed in relatively recent time; these rocks are found primarily in the basins and basin margins between the mountain ranges. These record a diversified geologic history and events of oceans, seas, lakes, rivers, numerous global warming and freezing episodes, mountain building, erosion, etc. that have affected Wyoming many times in the past. The Phanerozoic is conveniently separated into the Paleozoic, Mesozoic, and Cenozoic eras.

Paleozoic Era (543 million to 248 million years ago)

The Paleozoic is broken down into periods. The earliest period, which marks the beginning of the Paleozoic Era, is known as the Cambrian. Life took a dramatic turn 543 million years ago at the beginning of the Cambrian Period. Stokes (1966, p. 183) wrote, "It is generally agreed that the Cambrian began with the appearance of certain primitive arthropods, the trilobites...." Shells and other preserved hard parts of various complex creatures are found in many rocks from the Paleozoic periods that followed. Prior to the Cambrian Period, all forms of life were relatively simple—primarily single-celled organisms and simple bacteria. Through time, a definite progression of complexity is recognized in fossils as life evolved.

During much of the Paleozoic, Wyoming was submerged under seas that deepened to the west. Similar to our oceans today, these ancient seas were saturated in calcium carbonate, which allowed carbonate-producing organisms to deposit thick layers of limestone. East of Laramie, a deep canyon cut into Pennsylvanian and Permian Casper Formation limestone exposed some of this rock. This canyon lies west of the Lincoln Monument along I-80 and is just one of several similar canyons cut in limestone. Another spectacular canyon, Wind River Canyon between Thermopolis and Shoshoni along U.S. Highway 20, exposes a variety of rock units including a thick section of Mississippian Madison Limestone that was also deposited in a marine environment. Because the formations are labeled with highway signs, this canyon provides a great opportunity to identify examples of limestone and dolomite. The Madison and Ordovician Bighorn formations are two of the more prominent limestone and dolomite units exposed in the canyon.

At times, deposition of marine sediments during the Paleozoic was interrupted by minor upwarping of the shelf, causing the seas to retreat and erosion to occur. During such events, Paleozoic conglomerates, sandstones, shales, evaporites, and chert were deposited. Some time during the early Paleozoic (Cambrian to Devonian), several diamond-bearing kimberlites erupted at the surface in southeastern Wyoming, and evidence supports that this was a relatively widespread event in Wyoming, Colorado, and Montana (Hausel, 1998).

Late in the Mississippian Period, the seas were pushed back by a rising mountain range (orogeny) known as the Ancestral Rockies. These were the ancient forerunners of the Rocky Mountains. Uplift and erosion continued into the Pennsylvanian Period. By Permian time, tectonic stability returned to the region. The Ancestral Rockies were eroded away; the only evidence of this former mountain range is found in rock units preserved in other areas, including thick conglomerates deposited as these ancient mountains eroded. The ancient seas again covered much of the state. In western Wyoming, unusual conditions resulted in the deposition of thick phosphorites in a deep marine trough.

Mesozoic Era (248 million years to 65 million years ago)

Wyoming remained relatively stable during the early part of the Mesozoic Era (**Table 1**). Shallow seas covered much of Wyoming and deepened to the west in Idaho. The deep trough along the western edge of Wyoming continued to receive sediment. The Late Jurassic rocks in Wyoming record a gradual retreat of the seas, and these rocks contain numerous land-dwelling fossils. At Como Bluff, Wyoming, Morrison Formation sedimentary rocks contain abundant dinosaur bones, many of which were quarried from the late 1800s until 1903. Many excellent dinosaur skeletons were recovered from this quarry (Hausel and Jones, 1984; Blackstone, 1988).

Beginning in the Cretaceous Period, tectonic forces greatly altered the Wyoming landscape. Rocks in a deep sediment-filled trough along the western edge of Wyoming began to rise, forming a range of mountains. Along the eastern flank of this uplift, thick layers of sandstones, shales, and coals were laid down in a vast interior seaway that extended from the Gulf of Mexico to northern Canada. Near the end of the Cretaceous, the whole area was uplifted, the seas withdrew, and another episode of mountain building began, known as the Laramide Orogeny.

During this orogeny, the Rocky Mountains towered over the adjacent basins and plains. The intense deformation and contemporaneous erosion associated with the Laramide Orogeny spanned at least 40 million years from the Late Cretaceous (of the Mesozoic Era) into the early Cenozoic.

Cenozoic Era (65 million years ago to present)

When the Cenozoic Era began, the Wyoming mountain ranges and adjacent basins were well defined. In the early part of the Cenozoic, tropical climates and distinct (flat-bottom) basins were the right combination for swamps and vast lakes (**Table 1**). Organic debris (peat) accumulated in giant rain forests and swamps, eventually to be buried and transformed into thick coals of almost unimaginable proportions. Glass (1984) and Ayers (1986) estimated that there probably is more than 1.1 trillion tons of coal in Paleocene and Eocene rocks in the Powder River Basin of northeastern Wyoming. A number of coal beds are more than 100 feet thick, and several exceed 200 feet in thickness. These are not only a source of coal, but also a source of coalbed natural gas.

In southwestern Wyoming during the early Eocene, an intermontane lake so large it could have swallowed the Great Salt Lake covered much of southwestern Wyo-

Figure 7. Fresh water herring fossil fish found in lake bed sedimentary rocks of the Tertiary Green River Formation.

ming. This body of water, known as Lake Gosiute, contained untold species of fish. At times it shrank to a relatively small saline lake that precipitated unique assemblages of evaporite alkaline minerals including trona. The remains of this lake were captured in the Green River Formation fossil fish beds (Grande, 1984) (**Figure 7**), oil shales, and trona beds. The Wyoming trona beds are the largest in the world, with an estimated resource of 134 billion tons. Trona is a valuable industrial mineral used in manufacturing glass, soaps, and specialty chemicals.

In the Yellowstone National Park region, volcanic activity began in the middle Eocene (about 45 million years ago) with enormous outpouring of lavas and unbelievable destruction. This resulted in the deposition of an enormous thickness of volcanic rock in northwestern Wyoming, as well as many thick volcanic ashes all over Wyoming and the Midwest. Some of the thick lava flows and associated sediments now form one of the more impressive groups of mountains in Wyoming and Montana, known as the Absaroka Range.

Much later in the Cenozoic Era, starting about 14 million years ago, the Yellowstone area was subjected to recurrent episodes of explosive volcanism and lava flows, culminating in the massive eruptions of the Yellowstone supervolcano 1.8, 1.2, and 0.6 million years ago that created the present landscape and geologic features. Yellowstone remains very active even today, as evidenced by the largest geyser and thermal areas known anywhere on Earth.

Also, in late Cenozoic time (Pleistocene Epoch), worldwide climates cooled considerably and many mountain glaciers formed in the Wyoming ranges. This was just one of many natural global freezing events recognized throughout geologica time. Only one to three million years ago, a group of very rare potassium-rich lavas, known as lamproite, erupted near the present site of Rock Springs.

MINERAL & ROCK IDENTIFICATION

The enthusiast needs to get used to using a variety of tests and become familiar with the various physical and optical characteristics of minerals and rocks. Minerals and rocks are nothing more than solid chemicals and their appearance and characteristics obey the laws of nature. To help in field identification, it is recommended you obtain a small but sensitive magnet, a small dull knife, and two hand lenses. I find that a 10x and a 14x hand lens work fine. These tools can be found in various geological supply catalogs, such as *Miners*.

Mineral and rock identification is aided by a number of physical and chemical tests. Many of these tests are relatively easy to perform; however, it is important that the collector become familiar with many of the characteristics of minerals and rocks in order to be confident in their identification. To identify a given rock with confidence, the minerals that form the rock must first be identified.

Minerals are essentially solid chemicals that have distinctive chemical and physical properties. To identify minerals, these properties have to be determined. Experience is helpful in deciding which test to begin with, but generally testing is done in a specific order.

To start, examine the geometry and habit of the mineral. Is it a cube? Does it form bladed crystals? Is it just a mass of material? Write this information down in a notebook. Next, note the color. Note the luster: does it appear to be metallic, earthy, or glassy? Test its relative hardness by scratching it with a knife. Does it scratch? If it does, what is the color of the scratch or streak? How hard is the mineral? What does the fracture look like? Does it cleave along a plane surface? Is it very heavy, is it light, or about average weight?

These are many of the questions about a mineral's physical properties that will assist you in the identification of the mineral. Additional simple chemical tests may also assist in identification. In a few cases, sophisticated tests such as (XRD) x-ray diffraction or microscopic examination by a trained mineralogist may be necessary.

If you are trying to identify a rock, you will need to identify the major mineral components. After the minerals are identified, their relative percentages are noted and the texture of the rock is described. This information is applied to simple charts to determine the rock name. In the following pages, some physical and chemical tests are described and simplified rock identification charts are provided.

In general, a *mineral* is a natural homogenous solid substance with distinct physical and chemical properties. Minerals possess well-defined internal atomic structures. Because synthetic minerals are becoming more common in our daily lives, the adjective *synthetic* is used to distinguish them from natural minerals. If we envision a mineral as a single homogeneous component, then we can imagine rocks to be made up of several of these components, or minerals. Rocks form from numerous crystals of the same mineral species, such as Wyoming jade (which is an aggregate of many nephrite crystals) or they more often form from combinations of a variety of minerals. For example, the primary minerals that form granite include quartz, orthoclase, plagioclase, and biotite.

While collecting in the field, typically you will be limited to the use of a few simple tools. In most cases these are sufficient (**Table 2**). These tools are easy to carry and can provide information about the hardness of a mineral, the crystal form or habit, magnetism, and chemistry. Some minerals may be more reluctant to give up their identity than others. In these cases, more specialized tests (i.e., XRD) may be required for positive identification (**Figure 8**). Equipment for a more elaborate, but low-cost laboratory for rock and mineral identification is listed in **Table 3**. Items shown as optional are more expensive, but can be added to your home laboratory through time.

Table 2. Tools for Field Identification of Minerals
Fingernail (hardness = 2 ½)
Pocketknife (hardness = 5)
Hand magnifying lens
Magnet
Plastic bottle of dilute (10%) Hydrochloric acid (HCl)*

*Vinegar will work in place of dilute HCl, although chemical reactions will be mild. Muratic acid (dilute HCl) can be purchased at many drugstores.

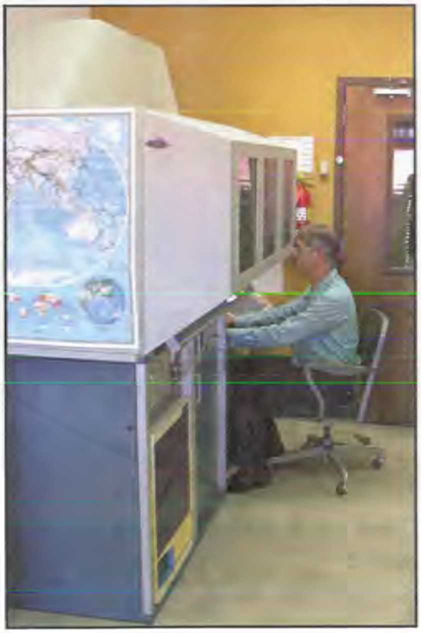


Figure 8. Mineral identification by specialized tests such as XRD is common at many geological surveys and universities.

Table 3. The Home Mineral and Rock Testing Laboratory
Equipment
Pocketknife
Hand lens or magnifying glass
Plastic bottle of dilute (10%) hydrochloric acid
Hardness kit
Streak plate (white porcelain tile)
Charcoal block
Magnet
Flame and bead test kit
Butane torch or alcohol candle
Gold pan
Porcelain crucible
Optional Equipment
Stereo microscope
Geiger counter or scintillometer
Polarscope
Mineral light
Specific gravity balance[1]

[1] An inexpensive specific gravity beam balance or jolly balance can be constructed at very low cost (see Sinkankas, 1963, p. 182-190).

PHYSICAL TESTS FOR MINERALS

Minerals have distinct physical properties that can be used to identify them. Identification of crystal habit, mineral and rock associations, color, cleavage, parting, heft, hardness, streak, luster, and tenacity may be used in the field or in the lab as initial tests for identifying an unknown mineral (e.g., Berry and Mason 1959; Sinkankas, 1972; Walton, 2004). In the laboratory, additional tests may be applied to help identify the unknown mineral. These tests may include specific gravity, index of refraction and dispersion measurements. Other various optical and chemical tests may also be used if necessary, but most should only be used as a last resort. These include a binocular microscope, petrographic microscope, x-ray diffractometer and/or electron microprobe. Unfortunately, many of these instruments are located at universities and are seldom available to the layman.

Gemologists are better trained to identify fashioned stones, whereas geologists are better trained to identify rough material. Even so, gemologists use many of the same physical and optical properties to verify the gemstone's identification, with the only difference being the equipment employed. LeGrand (2003) briefly described tools used in the gemstone trade, some of which are affordable. These include a refractometer, dichroscope, polariscope, heavy liquids, and spectroscope. Discussions on the use of these instruments are beyond the scope of this book and I recommend that you obtain a copy of LeGrand's article (2003) for further information on how to use these instruments.

Crystal geometry

Crystals are well-formed minerals that have symmetry and are separated into six crystal systems based on symmetry. Unless you have a well-developed crystal, it may be difficult to determine which system the crystal fits into, but if you can determine the crystal system, you have an important piece of information to aid in identification of an unknown mineral. For an experiment, get a household salt shaker and a magnifying lens. Salt or sodium chloride (NaCl) is a simple mineral that has both chemical and physical properties (one of them being taste). Shake a few grains out on the table and examine the crystal shape, or geometry, of the salt with a magnifying lens. It's a cube. Pyrite, gold, galena, diamond and many other crystals also form cubes, or modifications of cubes, and are included in the isometric (cubic) crystal system (**Figure 9**).

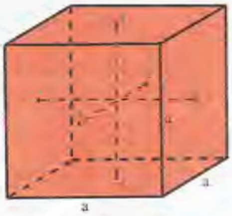
Such crystals are bounded by natural planes referred to as faces. These faces may or may not be evident in a given mineral. If the mineral is euhedral (well-crystallized like salt) the crystal faces will be apparent. If they are subhedral, the mineral is only partially crystallized and it may take some examination to determine the form of the crystal. Most often, minerals are anhedral (poorly crystallized) showing no distinct crystal faces which makes mineral identification difficult.

There are six crystal systems in which all minerals can be categorized (**Figure 9**): (a) isometric, (b) tetragonal, (c) orthorhombic, (d) hexagonal (trigonal), (e) monoclinic, and (f) triclinic. The external form of a crystal is an expression of the internal arrangement of its atoms. As described by Sinkankas (1964) the crystal systems exhibit distinct symmetry. In their basic forms, each system can be described as being made from a basic cubic cell (known as a unit cell) that is distorted in every system except for the isometric system.

When mineralogists discuss mineral symmetry, they use units known as Miller Indices. These consist of a set of three or four symbols (letters or numbers) that are used to describe the position and orientation of a crystal face or crystal plane. They are simply numbers used to describe how crystal faces interact with one another and are determined by projecting imaginary axes through a crystal. Where each crystal face cuts the imaginary axes, it is given a unit number. This number corresponds to the relative distance that a crystal face lies from the intersection of the axes. For example, the symmetry of a cube suggests that three axes can be projected into the cube to intersect at its center. These axes are termed the a, b, and c axis (a,b,c) of the crystal. Since the cube has high symmetry, each face would lie at the same distance from the center of the cube. If we describe the position of a particular crystal face on the cube along the 'a' axis using Miller Indices, we would simply write (100). This means that this particular face intersects the 'a' axis at one unit from its

Figure 9. The crystal systems.

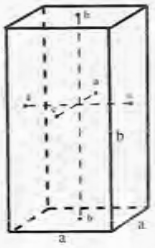
(a) Isometric system



Common Crystal Habits
Cubes
Octahedrons
Dodecahedrons
Trapezohedrons
Pyritohedrons
Tetrahedrons

All axes are of equal length a=a=a and all angles between axes are right angles (90°).

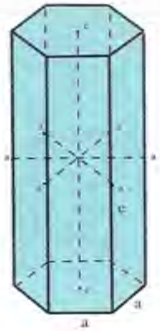
(b) Tetragonal system



Common Crystal Habits
Square Prisms
Square Prisms with Pyramids
Dipyramids without prisms
Flattened square prisms
Pseudotetrahedral

Two axes are of equal length a=a=b, and all angles between the axes are right angles (90°).

(c) Hexagonal system



Common Hexagonal Crystal Habits
Long hexagonal prisms
Short hexagonal prisms
Tabular hexagonal prisms
Hexagonal prisms with pyramids and
rhombohedrons
Rhombohedrons
Scalenohedrons

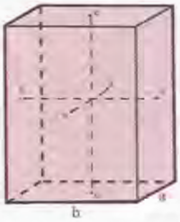
Only the horizontal axes are equal in length a=a=a=c. The horixontal axes are separated by 120° and all of the horixontal axes (a) form right angles with the vertical axis (c).

center. This same face does not intersect the 'b' or 'c' axis, and is assigned 0 for each of these. To describe the position of a crystal face of a cube on the 'c' axis, it would be assigned the Miller Indices (001). If we have a crystal face that intersects all three axes at the same distance from the center, this would be designated as (111).

The isometric system (*iso* meaning same and *metric* meaning measure) has the highest symmetry (**Figure 9a**). Examples of minerals with isometric symmetry include diamond, spinel, peridot, gold, garnet, and many others including salt. The examination of the crystal surfaces of a cube shows that each of the three sets of parallel planes (faces) provide mirror images of one another. Optically, isometric minerals are all isotropic (singly refracting), whereas all of the remaining crystal systems are anisotropic and birefringent (*bi* meaning two, and *refringent* meaning refracting). Birefringence is a characteristic of some minerals that allows the mineral to split white light into two different beams with different velocities.

Figure 9. The crystal systems (continued).

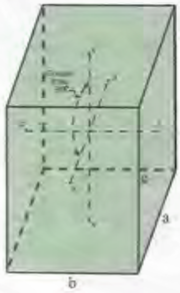
(d) Orthorhombic system



Common Crystal Habits
- Long prisms
- Short prisms
- Tabular prisms
- Stubby grains
- Pseudohexagonal prisms

All axes have different lengths $a \neq b \neq c$, and each axis is located at right angles from the other two.

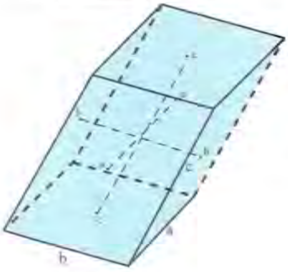
(e) Monoclinic system



Common Crystal Habits
- Long prisms
- Short prisms
- Blocky
- Platy

All axes have different lengths $a \neq b \neq c$, and each axis is inclined to the c axis. Monoclinic means one-inclined.

(f) Triclinic system



Common Crystal Habits
- Platy
- Tabular
- Blocky

All axes have different lengths $a \neq b \neq c$, and there are no right angles.

The tetragonal system (*tetra* meaning four and *gonal* meaning square) has a tetragon prism as its simplest form (**Figure 9b**). Two of the imaginary axes for this crystal system lie at the same distance from the crystal center and thus have the same length. The third axis will either be longer or shorter than the other two. Thus four of the crystal faces will be separated from the center of the crystal by an equal distance: the remaining two (along the c-axis) will have either a greater or smaller distance from the center and may look like a rectangle. For example, the faces represented by the Miller indices may be (002) as compared to (100) and (010) for the faces along the a- and b-axes. Examples of minerals with tetragonal symmetry include zircon and rutile.

The hexagonal system (*hexa* meaning six) has two divisions (**Figure 9c**). In one division, a six-sided prism is formed with individual sides of the prism intersecting at 120° angles. This prism is usually capped by pinacoids (flat surface planes) or pyramids. The other division, referred to as the rhombohedral division, forms distinct six-sided rhombohedra, such that all of the faces intersect one another at 120°. Examples of minerals with hexagonal habit include apatite $[Ca_5(PO_4)_3(OH)_3]$, phenakite ($BeSiO_4$), quartz, tourmaline, benitoite, ruby, sapphire, emerald, and aquamarine. The trigonal division is represented by minerals such as calcite ($CaCO_3$).

In the orthorhombic system (*ortho* meaning all right angles) (**Figure 9d**), all of the faces of the basic crystal cell intersect at right angles. However, each set of the mirror-image faces lie at different distances from the center. Examples include orthopyroxene, andalusite (Al_2SiO_5), chrysoberyl, and zoisite.

The monoclinic system (*mono* meaning one and *clinic* meaning inclined) has two imaginary axes projecting through the mineral at right angles, while the third is inclined to the other two (**Figure 9e**). Examples include orthoclase, epidote $[Ca_2Al_2FeSi_3O_{12}(OH)]$ and diopside.

In the triclinic system (*tri* meaning three), all three axes are inclined to one another such that all faces appear as parallelograms (**Figure 9f**). The imaginary axes are projected perpendicular through these crystal faces intersecting the center of the mineral at angles other than 90°. Kyanite, plagioclase, and microcline provide good examples of the triclinic system.

Crystal habit

Under favorable geologic conditions many minerals develop crystals with well-formed geometric shapes. Often mineral species form characteristic *habits* or forms that are very common and used for mineral identification. For example, quartz often grows in very characteristic columnar hexagonal prisms capped by a hexagonal pyramid. The characteristic prism, transparency, and glassy luster are a dead give away for quartz (**Figure 10**). Bronze-colored cubes with me-

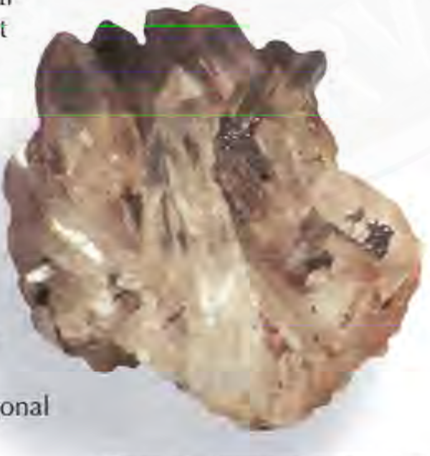


Figure 10. Hexagonal quartz crystals from the Big Creek mine, Medicine Bow Mountains. The largest crystals are about 2 inches in length (photograph by Mel Dyck).

tallic luster are so typical of pyrite that often no other tests are needed for identification. One characteristic habit of diamond is in the form of octahedral crystals (two 4-sided pyramids attached at their bases) (**Figure 11**). The habit combined with a brilliant (adamantine) luster are often enough to identify diamond. For verification, you can test hardness (it will scratch ruby) or use a simple GEM tester marketed by the Gemological Institute of America. These easy-to-use instruments test the unique surface conductivity of diamond. Some common crystal habits are described in **Figure 12**.

Figure 11. Very high quality transparent 14.2 carat octahedral gem-quality diamond from the Kelsey Lake diamond mine, Colorado-Wyoming State Line district (photograph courtesy of Howard Coopersmith).

Each crystal system includes a basic crystal form, but each also includes a variety of crystal habits or modifications of the basic form as a result of temperature and pressure conditions encountered by the mineral during crystal growth. For example, an isometric crystal (sometimes referred to as the cubic crystal system) includes the cube as the basic form. But these cubic crystals also have several other habits exhibiting isometric symmetry. These include the octahedron (*octa* meaning eight), dodecahedron (*do-deca* meaning two plus 10 or 12 faces), tetrahexahedron (*tetra-hexa* meaning four times six, or 24 faces), trisoctehedron (*tris-octa* meaning three times eight or 24 faces), trapezohedron (this is an odd-shaped crystal with three odd shaped faces on each octahedral face), and hexoctahedron (*hex-octa* meaning six times eight or 48 faces). In addition to these, there are combinations of each basic habit that produce additional habits (Sinkankas 1964). These habits reflect an internal atomic geometry and therefore, the crystal system of the mineral.

In addition to the internal atomic structure, the minerals' habits are also influenced by their environment. For instance, during crystallization of a liquid magma, some minerals will initially crystallize as the temperature of the magma is dissipated to produce minerals with good crystal faces that slowly grow in the cooling magma. These first-formed minerals are typically euhedral. The lack of pressure during crystal growth allows them to grow uninhibited to produce well-formed crystal faces. Others will crystallize later and the outline of these minerals will be influenced by limited space in the partially crystallized magma. Limited space results in minerals with only a few crystal faces known as *subhedral* habit. Those that crystallize last usually lack sufficient space to form crystal faces and are referred to as *anhedral*. Where crystals are allowed to grow slowly in liquid and/or in a gas-rich pocket, they will often be larger than a similar crystal that grows fast. Sometimes this process is so efficient, especially in a rock known as pegmatite, that some giant log-sized minerals up to 2.5 tons in weight will form.

Various impurities also affect the crystal's appearance. The adsorption of trace impurities may retard the rate of growth of a crystal face, resulting in an uncommon crystal habit. Some impurities are enough to affect the color of a crystal. In cases where crystal inclusions are incorporated in the primary crystal, these will preferentially grow along various crystal planes such that they may all reflect light simulta-

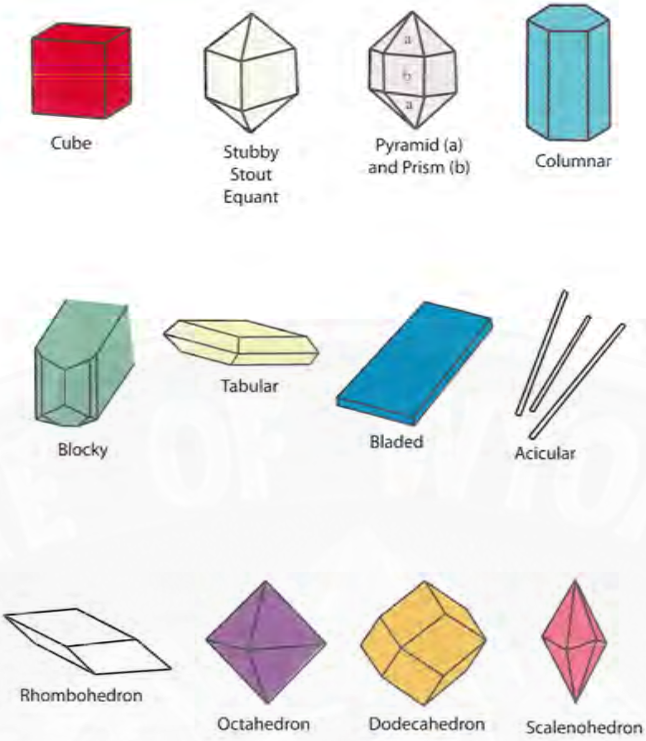


Figure 12. Diagrams of some common crystal habits (modified from Sinkankas, 1964).

neously to produce distinct asterism or cat's eye effects. Large, well-formed crystals are relatively uncommon and most are poorly formed such that mineral habits are more often expressed as finely crystalline, earthy, granular, formless masses or aggregates. This information is useful when supplemented with other tests and observations. Vanders and Kerr (1967) provided an excellent review of crystal habits and the affects of impurities, temperature and pressure.

Color

Color is sometimes an important clue in mineral identification. Many of us can easily visualize the colors of jade, gold and turquoise. In the metallic minerals, color is usually fairly constant for a particular mineral. The bright brass color of untarnished chalcopyrite is unmistakable, as is the warm yellow color of gold.

Many of the nonmetallic minerals appear in a wide range of colors. Quartz, a silicate, can be colorless, white, gray, purple, blue, green, yellow, brown, red, pink, or even black. Garnets come in nearly every color except blue. In such cases, the color of the mineral is not by itself sufficient evidence for identification. Variations in color in a single mineral species are due principally to different amounts of impurities in the crystal structure. For example corundum, an aluminum oxide, generally occurs as an unattractive cloudy mineral with as much as 10 percent impurities. The impurities not only render corundum cloudy, but will also produce a wide variety of colors including gray, grayish blue, blue, brown, violet, green, and red (**Table 4**).

Table 4. The Corundum Gemstones

Color	Variety
Red	Ruby
Blue	Sapphire
Colorless	Leuco-sapphire
Light bluish green	Oriental aquamarine
Green	Oriental emerald
Yellow green	Oriental chrysolite
Yellow	Oriental topaz
Aurora red	Oriental hyacinth
Violet	Oriental amethyst

Source: Bauer, 1968.

When specific wavelengths of light are absorbed by a mineral, the resulting color is from the remaining, non-absorbed, transmitted wavelengths. For example, if the blue wave is absorbed, the mineral will appear red (the complementary color) and so forth. Light transmission and absorption may be affected by the presence of tiny mineral inclusions, structural defects, and/or chromophores (color centers), which are trace ions in a mineral. The transition metal ions (titanium, vanadium, chromium, manganese, iron, cobalt, nickel, and copper) are excellent chromophores and responsible for much color in minerals. The oxidation state of chromophores are important because different ions will absorb different wavelengths of light. For example, traces of the ferrous iron (Fe^{2+}) often produce a green color in olivine (peridot), whereas traces of the ferric iron (Fe^{3+}) may result in a yellow color in chrysoberyl.

Many minerals are colorless or occur in a variety of hues. When certain minerals exhibit a variety of hues, it implies there is no inherent color and that the mineral is *allochromatic* (*allo* meaning not usual and *chromatic* meaning color). When a mineral exhibits a distinct hue, it is termed *idiochromatic* (*idio* meaning inherent). In such minerals, color is an innate property used in their identification. For example, rhodochrosite ($MnCO_3$) is always pink to red, malachite and dioptase are always green, azurite is always blue, and cuprite is always red. Most minerals with metallic luster are idiochromatic.

Allochromatic minerals are colorless when pure; impurities provide color in these minerals. Hurlbut and Switzer (1979) reported that nephrite jade is allochromatic; even so, colorless transparent jade is very rare (**Figure 13**). Nephrite jade is a magnesium-iron silicate that is typically magnesium-rich. But with increasing iron substitution for magnesium in the crystal structure, the mineral will be darker and darker green until it reaches a point where light is completely absorbed by increasing amounts of iron ions. At this point, nephrite is black. Thus, nephrite jade shows a wide range of colors from light apple green to black due to this chromophore.

Figure 13. Transparent to translucent nephrite jade pendant from the Green Mountain area of Wyoming (specimen from the Jay Sundberg collection, photograph by Sharon Hall).

Corundum is a colorless, allochromatic mineral. However, when trace amounts of chromium are present, blue light is absorbed and the specimen will have the deep red color of ruby. When the corundum contains trace amounts of titanium and iron, red light is absorbed and the mineral appears the distinct blue of oriental sapphire. Due to differences in chemistry and crystal structure, the trace chromium responsible for coloring corundum red will color beryl deep-green. Chromophores are often not evenly distributed, resulting in irregular patches or splotches in some minerals.

Some rare varieties of corundum may have oriented needle-like microscopic inclusions of rutile. These typically align along crystallographic planes and produce a star effect when polished (star sapphire). The presence of manganese dendrites in moss agate leads to an attractive and popular lapidary mineral known as the Sweetwater agate. Sweetwater agate is found in gravels and soils surrounding the granitic rocks of the Granite Mountains north of Jeffrey City in central Wyoming. Some transparent quartz may also be distinctly rutilated (with numerous needles of rutile), a phenomenon that is referred to as *"Venus hairstone"* (Kraus and Slawson,1947). This kind of quartz will have distinct, long, slender inclusions of rutile that give an impression of hair or long wires in clear quartz. Another mineral, sunstone feldspar, finds its beauty due to the presence of numerous golden inclusions of limonite.

Special optical effects

Several interesting optical effects are sometimes seen in minerals. These include aventurine, adularescence, labradorescence, color play, opalescence, iridescence, chatoyancy, and asterism.

Aventurescence results from swarms of tiny slivers of aligned mineral inclusions lying parallel to crystal structures. These inclusions tend to sparkle in light as the mineral is rotated since the tiny mineral inclusions have crystal faces that reflect light like tiny mirrors. Commonly, these inclusions include hematite, goethite, sericite and/or fuchsite. When rotated in a light source, such aventurine gemstones present a spangling of light. Without mineral inclusions, most aventurine minerals would not be attractive. Both hematite and goethite inclusions are common in feldspar and are especially brilliant in sunstone gems (Sinkankas,1959).

Another optical effect is *adularescence*, which is seen in several varieties of feldspar. It occurs as a bluish to silvery gleam in moonstone. Moonstones contain microscopic grid-like structures as a result of two different feldspars being intricately intergrown. This process is referred to as exsolution lamellar intergrowths. Favorably spaced grid lines will split white light into various colors of the rainbow. A variety of adularescence is known as *labradorescence*. Labradorite, a feldspar found in Sybille Canyon in the central Laramie Mountains, periodically has characteristic adularescence that results in the dark gray mineral coming to life with flashes of brilliant blue color play, or *schiller* when properly oriented in light (**Figure 14**).

Schiller seen in labradorite is the result of exsolution lamellar intergrowths of two feldspars of slightly different compositions. When the thickness and periodicity of the lamellae are favorable, white light projected on the crystal surface produces iridescent flashes of colored light. In some cases, light is scattered internally within a transparent to translucent mineral by tiny particles or structural defects. The scattered light provides the stone with a pearly or milky sheen known as *opalescence* best seen in raw common opal and in moonstone cabochons.

On an atomic scale, opal is composed of tiny uniform spheres of amorphous silica that are about 1,500 to 3,000 Angstroms in diameter. These spheres can only be observed at magnifications of 8,000x to 9,000x with a scanning electron microscope.

At this magnification, the structure of the opal is visible and may show distinct hexagonal packing of silica spheres arranged in an orderly, closely-packed array with voids between the spheres. The voids are filled with air and water.

When white light passes through colorless opal and strikes these voids, certain color wavelengths are diffracted producing a nearly pure spectral color. As the angle of incidence of light changes, light will be diffracted as flashes of brilliant colors. However, common opal does not show this attractive play of colors. The lack of color play is the result of the spheres of uniform size and packing being so small that they merely scatter light, producing an opalescence effect without play of color.

Iridescence is visible in some minerals such as opal, covellite (CuS), bornite (Cu_5FeS_4), chalcedony, and some quartz. In some translucent chalcedonies, layers of microscopic goethite ($HFeO_2$) inclusions produce attractive reflections of red, brown, and green light. Some gray chalcedony with closely banded growth layers may mimic diffraction grating, causing white light to separate into colors of the rainbow. This effect is best seen on banded chalcedony when sliced as thin as possible and polished (Sinkankas,1959). The light is diffracted along the banded grating and is seen impressively only when light is viewed through the specimen.

Mineral inclusions may produce other interesting effects such as chatoyancy. A *chatoyant* mineral will exhibit a silky sheen due to closely packed parallel mineral fibers, needle-like inclusions, or cavities. When a chatoyant mineral is cut into a cabochon, the surface displays a band of light along the length of the inclusions. As the cabochon is rotated in sunlight, the narrow, silky sheen will move from side to side giving an impression of a cat's eye. Where two or more sets of chatoyant mineral inclusions are present in a host mineral, it may result in star gemstones. A distinctive star is seen when the mineral is cut into a cabochon to take advantage of the orientations of the inclusions. This is referred to as *asterism*. Asterism is sometimes found in ruby, sapphire, quartz, and garnet and can be either four- or six-rayed.

Figure 14. Prominent schiller as seen in labradorite. Specimen from Wyoming (from the Norma Beers collection).

Luster

Luster describes the appearance of a mineral's surface in reflected light. It is a function of transparency, light reflection and refraction, and mineral structure. This is not a useful quality in identifying most minerals, but there are some that exhibit distinctive luster (**Figures 15a, 15b, 15c,** and **15d**). Pyrite, galena, and chalcopyrite have the appearance of metals, and are thus said to display metallic luster. Vitreous luster describes a mineral, such as quartz, which has the appearance of glass. Adamantine luster occurs in minerals like diamond that strongly refract light. The luster of raw diamond is also greasy, as a rough diamond appears as if it has a thin film of grease coating. Other minerals with adamantine luster include zircon, sapphire, ruby, and demantoid. The luster for these is particularly notable after they have been faceted into gems. Other terms used to describe luster of nonmetallic minerals include *resinous* (i.e., sphalerite) and *silky* (i.e., asbestos). Minerals like chromite that have a luster between metallic and vitreous are said to have *submetallic* luster. Minerals that lack a bright or shiny surface have *dull* luster, such as fluorite.

Light transmission

Another important property in some minerals, particularly those used as gemstones, is light transmission. Light transmission takes into account how much light is transmitted, reflected, and absorbed. Categories of light transmission include: (1) transparent; (2) translucent; and (3) opaque. Light easily passes through *transparent* minerals. When placed over an object, the object underneath should be entirely visible through a transparent mineral. Light is only weakly transmitted through a *translucent* mineral and objects placed beneath some minerals are indistinguishable when looking through the mineral. If no light is transmitted through the mineral, it is *opaque*.

In some raw materials, surface coating or pitting may disguise the underlying characteristics of the mineral. This happens when opal is coated with a surface rind that disguises the quality of gem material beneath. Some coated diamonds may require a window to be polished in the surface to ascertain the quality of light transmission. Many diamonds tend to be coated with calcium carbonate as seen in several found south of Laramie in the State Line district. Other minerals, such the olivine from the Leucite Hills north of Rocks Springs in the Green River Basin, have a pitted rim that can result in misleading clues of its transparency. Yet these have very good light transmission that is noticeable when faceted into gem peridot.

Dispersion

The separation of white light into its spectral colors is known as *dispersion* and is best seen by passing light through a prism. White light splits into the spectrum of colors when passing from air into a dense transparent gemstone. At one end of the spectrum, red light (the longest wavelength) has the greatest velocity and will be refracted the least, and at the other end, violet light (the shortest) has the least velocity and will be refracted the most.

Pleochroism

Pleochroism (meaning 'many colors') is important in some anisotropic minerals such as tanzanite and iolite. When found in the anisotropic minerals, it is the result of different wavelengths of light being absorbed in different vibration directions in the mineral. This absorption results in color variations in some minerals when viewed at different angles. Isotropic minerals do not show pleochroism, uniaxial minerals may show two different pleochroic colors, and biaxial minerals may show three pleochroic colors. Faceted iolite is an excellent example of a pleochroic mineral. It may look sapphire blue from one direction, but it will look violet-blue and then a gray blue as it is rotated further. Raw iolite also shows pleochroism. It is not as obvious in massive specimens, but quite distinct in thin, transparent fragments.

Streak

The *streak* of a mineral is its color in a fine, powdered form. For example, pyrite (fool's gold) forms brittle brassy metallic crystals, but has a greenish black streak.

Figure 15. *Examples of some different lusters. (a) Amethyst in ring showing its vitreous luster (photograph courtesy of Sharon Hall). (b) Satin spar with silky luster from Green River Basin. (c) A 7.5 ounce gold nugget with metallic luster from South Pass (photo by Dave Freeman). (d) Uncut Wyoming diamonds exhibiting adamantine luster from the State Line district south of Laramie.*

Figure 16. Scratch test on a steak plate tile with hematite which produces a distinctive red streak.

The streak is best observed by scratching the specimen across hard, white, unglazed porcelain tile (streak plate) (**Figure 16**), or by scratching the surface of the mineral with a knife blade. Minerals that are harder than tile or a knife blade do not streak. The white streak they produce on the streak plate is actually powdered tile.

Hardness

The *hardness* (H) of a mineral can be very important to aid in the identification of mineral species. The conventional hardness scale used by many mineralogists is known as Mohs scale (**Table 5**). Mohs scale is a relative scale defined by 10 relatively common minerals that have been assigned an arbitrary hardness. The hardness of these is compared to unknown minerals. For example, a given stone is obviously harder than those it can scratch, but softer than those that can scratch it. The following minerals comprise Mohs hardness scale and are arranged in ascending order of hardness: (1) talc; (2) gypsum; (3) calcite; (4) fluorite; (5) apatite; (6) feldspar; (7) quartz; (8) topaz; (9) corundum; and (10) diamond.

In order to test for hardness, the sample to be tested should be relatively unweathered and not stained or altered on the surface. Otherwise an erroneous hardness may be determined. Splintery and granular minerals can also give an erroneous hardness. When testing, a fair amount of pressure must be applied in order to scratch the unknown mineral.

Diamond is considered the hardest naturally occurring substance and has a relative hardness of ten. This is for cubic diamond. An extremely rare polymorph of diamond, known as lonsdaleite, found in some astroblemes, forms hexagonal crystals that are harder than cubic diamond (Erlich and Hausel, 2002). This mineral is so rare it is not included on Mohs hardness scale.

Note that window glass has a hardness of only six (**Table 5a**). Many minerals including diamond are harder than window glass. Unfortunately, the old adage that *"whatever will scratch glass is diamond"* is obviously not true (Hausel, 2000a). So don't make the mistake of thinking that only diamond will scratch glass. Several minerals including diamond will scratch window glass. Even so, I often hear

Table 5a. Mohs Hardness Scale

Hardness	Mineral	Common tools for measuring hardness
1	Talc	
2	Gypsum	Fingernail (H = 2.5)
3	Calcite	Old copper penny (H = 2.5)
4	Fluorite	
5	Apatite	Knife blade (H = 5)
6	Feldspar	Window glass (H = 6)
7	Quartz	Steel file (H = 7)
8	Topaz	
9	Corundum	Carborundum (H = 9.5)
10	Diamond	

of prospectors testing for diamond by scratching their vehicles' windshields. It's a wonder they can even see to drive. Also, a very light blow with a hammer will break diamond quite easily, so they are not as indestructible as many people are led to believe.

A true hardness scale, known as Knoop's scale, is based on the pressure required to make an indentation in the surface of a mineral by using a rhombohedral-shaped diamond indenter (**Table 5b**). The values for Knoop, unlike the Mohs scale, are absolute and depend on the depth of indents engraved on the mineral's surface when applying pressure. On the Knoop scale, hardness is nearly linear for all of the Mohs minerals in the range of 1 to 8. This is followed by a rise in Mohs hardness from 8 to 9 and a dramatic increase from 9 to 10. Thus, a Knoop hardness is only 1 kg/mm^2 for talc (H=1) and linearly rises to about 1,340 kg/mm^2 for topaz (H=8). Corundum (H=9) is about 1,800 kg/mm^2 and diamond (H=10) is 7,000 kg/mm^2 or greater on Knoop's scale.

Table 5b. Comparison of Mohs relative hardness scale and the Knoop Hardness Scale.

Mineral	Mohs	Knoop (kg/mm^2)
Talc or graphite	1	1
Gypsum or sulfur	2	32
Calcite	3	135
Fluorite	4	163
Apatite	5	430
Orthoclase or feldspar	6	560
Quartz	7	820
Topaz	8	1,340
Corundum	9	1,800
Diamond	10	7,000

Hardness will also vary along different crystallographic directions. With diamond, certain directions are slightly softer than others. In other directions (parallel to the octahedral plane), it is nearly impossible to polish because of its extreme hardness. Some crystals exhibit a very distinct difference in hardness depending on which crystallographic direction is tested. Kyanite, which is found in numerous places in Wyoming's mountains such as the West Cooney Hills west of Wheatland, is one such crystal. Kyanite has a hardness of 7 parallel to its *c*-axis and a hardness of only 5 parallel to its *a*-axis. Few other minerals show such extreme hardness variations.

Fracture and cleavage

If a mineral breaks along definite parallel planes, these planes are known as *cleavage* or *parting*. Cleavage planes are parallel planes of weakness in the mineral's

Figure 17. (a) Mica has such perfect cleavage that one can literally strip thin sheets along cleavage to the point that the mica (in this case muscovite) is transparent. (b) Parting planes can be seen in this specimen of faceted ruby from Palmer Canyon, Wyoming. Note the distinct parallel lines in the specimen—these are parting planes (specimen from the Vic Norris collection, photograph by Robert W. Gregory).

Figure 18. The Cullinan I diamond (530.2 carats) was the largest piece faceted from the Cullinan rough diamond (3,106 carats). It is also known as the Star of Africa (photograph courtesy of famousdiamonds.tripod.com).

internal atomic structure. For example, mica has perfect cleavage in one direction and layers can be peeled like pages in a book along the cleavage (**Figure 17a**). Other minerals, such as feldspar and ruby (**Figure 17b**), have two distinct cleavage directions, and some are bound by as many as three directions of cleavage. Calcite, for example, has three directions of perfect cleavage that are clearly seen in many specimens.

Cleavage is unlike ordinary fractures, which are unpredictable. Cleavage may be quite distinct in some crystals, indistinct in others, and absent in others. Cleavage planes often repeat themselves many times in a single crystal. Predicting the location of cleavage can sometimes be challenging. For instance, long and extensive studies preceded the cleaving of the largest diamond in history, known as the Cullinan. This fist-size diamond (3,106 carats) was irregularly-shaped and rounded. It was presented to King Edward VII of England on his birthday (Bruton,1978). Since the diamond was so large and had some impurities, it was decided to cleave the stone to produce workable pieces. Joseph Asscher, the best-known diamond cutter in Europe at the time, was hired to cleave the diamond. Asscher studied the priceless mineral for 6 months before he found the best place to cleave. After a deep kerf was scratched in the stone, the first attempt to cleave ended up with the chisel breaking. On the second attempt, the diamond was successfully cleaved, at which time Asscher fainted from the stress of potentially shattering the most valuable gemstone found in history (Harlow, 1998). One of the cleaved diamonds is shown in **Figure 18**.

The quality of cleavage is expressed as indistinct, poor, good, or perfect by mineralogists. There are types of cleavage described by such descriptive terms as cubic, basal (micaceous), prismatic, etc. (**Figure 19**). In addition to describing perfection, cleavage is also described by a number of cleavages and directions. The directions can be described as cubic, octahedral, rhombohedral, etc. and reference may be made to Miller Indices. For example, basal cleavage in a hexagonal mineral can be described as (0001). In a monoclinc crystal, basal cleavage can be described as (001) and octahedral cleavage can be described as being parallel to the octahedral (111) face of a mineral. Parting is very similar in appearance to cleavage. Partings form parallel to planes of weakness between mineral twins. Some crystals will have twin crystals (**Figure 20**) attached along the parting plane.

Figure 20. Corundum twin.

A mineral that does not break along planar surfaces will fracture. Quartz for example, exhibits a distinct fracture known as *conchoidal,* which simply means that the surface of the break is smooth and rounded like the interior surface of a

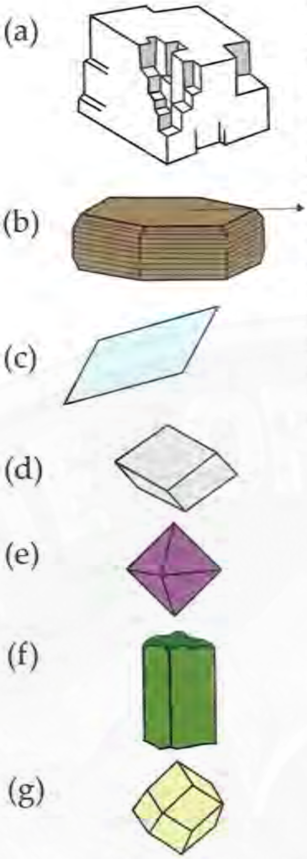


Figure 19. Types of cleavage include: (a) cubic - three cleavage directions that intersect are right angles (e.g., salt, galena); (b) basal - one plane parallel to the crystal base (e.g., mica, topaz); (c) pinachoidal - one plane parallel to front, side, or base of crystal (e.g. stibnite); (d) rhombohedral - three planes parallel to the sides of a rhombohedron (e.g., calcite); (e) octahedral - four planes parallel to each pair of faces (e.g. diamond, fluorite); (f) prismatic - two parallel planes or three parallel planes along the sides of a mineral (e.g., amphibole, pyroxene); and (g) dodecahedral - six planes parallel to each pair of faces on a dodecadron (e.g. sphalerlite). Modified from Vanders and Kerr (1967).

seashell. Some other common and distinctive types of fractures include fibrous, splintery, and hackly (jagged with sharp edges). The names of these fractures are descriptive and need little explanation.

Tenacity

The *tenacity* of a mineral is its relative resistance to breaking, crushing, bending, or cutting. Most minerals are brittle and can be crushed to a fine powder. Some native metals, such as gold and platinum are malleable, and can be shaped by applying pressure with a knife or by hammering. Soft minerals, which have a hardness of less than three, are termed *sectile* and can be cut into shavings with a knife. Flexible minerals bend easily prior to breaking and elastic minerals spring back to their original shape after they are released.

Specific gravity and heft

Specific gravity is a ratio of the weight of a given volume of a substance to the weight of an equal volume of water. If a mineral has a specific gravity of 3.0 (water has been assigned a specific gravity of one), a given volume of that mineral weighs 3.0 times as much as the same volume of water.

Specific gravity (SG) is measured as follows:

$$SG = \frac{\text{(weight of mineral in air)}}{\text{(weight of mineral in air) - (weight of mineral in water)}}$$

For example, for an unknown mineral with the following measurements:

weight of mineral in air=1,250 grams
weight of mineral in water=800 grams,

$$\text{Its specific gravity} = \frac{\text{(1,250 grams)}}{\text{(1,250 grams) - (800 grams)}} = 2.78$$

An accurate measurement of specific gravity is not practical in the field. Therefore, the mineral collector should develop a good feel for the relative weight, or *heft* of a rock or mineral specimen. Heft is a subjective expression of the relative density, or weight of a specimen. For example, the heft of a hand specimen of galena (SG = 7.4 to 7.6) would be high when compared to quartz (SG = 2.65). Halite (SG = 2.16), better known as common salt, is light and has a low heft. Nephrite (Wyoming jade) (specific gravity of 3 to 3.5) has a moderate heft. Of course, similar size specimens should be compared for heft.

Magnetism

Magnetism is determined by moving a magnet over a mineral and noting whether or not there is an attractive force. Because some magnets are very weak, it is best to obtain a strong magnet so that there can be no question about the magnetic properties of a sample. A very useful magnet is a geologist's magnet. This looks like a pen or mechanical pencil, has a clip to attach to one's pocket, and has a small wire axis that allows the magnet to easily pivot. Minerals that are strongly magnetic are termed *ferromagnetic*. These include magnetite and pyrrhotite. Weakly magnetic minerals are termed *paramagnetic*, which can include some iron silicates.

CHEMICAL TESTS FOR MINERALS

Reaction to HCl

Carbonates, which are relatively common at the Earth's surface, react with a dilute (10%) hydrochloric acid solution by releasing carbon dioxide (CO_2) bubbles, the same gas found in many soft drinks. The reaction produces effervescence or bubbling action from hundreds of tiny CO_2 bubbles being released from the surface of the carbonate. Some carbonates, like calcite, react readily; others, like dolomite, have only weak reactions; and some, like rhodochrosite, have to be stimulated by heating to produce a reaction.

Dilute hydrochloric acid can also be used to identify certain metallic copper oxides such as tenorite or cuprite. Tenorite forms a relatively indistinct black, sooty, copper-oxide stain on the surface of some mineralized samples. Cuprite forms masses of earthy red material or is found as surface coatings. If a sample of tenorite or cuprite is doused with dilute hydrochloric acid and vigorously rubbed with a well-used rock pick or pocket knife, native copper will replace the rust on the pick or knife, forming a distinct, thin, shiny, copper-penny-colored metal coat. The hydrochloric acid used is dilute (10% acid and 90% water). Concentrated acid should never be used. A very dilute hydrochloric acid known as muriatic acid can be purchased in some drug stores.

Table 6. Characteristic Flame Test

Flame Color	Element
Vivid red	Strontium
Streaks of red	Lithium
Red orange	Calcium
Vivid and persistent yellow	Sodium
Yellow green	Barium
Yellow green flashes	Boron
Faint yellow green	Molybdenum
Pale green	Antimony
Pale greenish white	Bismuth
Strong vivid green	Copper
Pale blue green	Phosphorus
Streaky blue green	Zinc
Vivid blue	Arsenic
Pale blue	Lead
Persistent violet	Potassium

Flame test

Heating powdered minerals in a torch flame may produce vivid-colored flames diagnostic of certain chemical elements (**Table 6**). The results of a flame test can provide the collector with some additional information to help identify unknown mineral species. One drawback of this test is that a portion of the mineral must be pulverized and destroyed.

Tools necessary for this test include a torch (for example, butane), a iron wire loop, a cobalt-blue glass filter (optional), and dilute hydrochloric (muriatic) acid. The iron wire loop can be made from soft iron wire by forming a 1/8-inch diameter loop on one end and a five- to six-inch handle on the opposite end. Sodium, which is common in all but distilled water, will contaminate the iron wire each time the wire is cleaned in water. To remove the effects of the contaminant, a cobalt-blue filter that absorbs the bright yellow sodium light band can be used in the line of sight of the flame, or the wire will need to be thoroughly cleaned in hydrochloric acid. To clean the loop, dip it in hydrochloric acid and place it in the torch flame to burn off sodium contaminants. To do the flame test, wet the iron wire loop in hydrochloric acid and dip it into the powdered mineral. Hold the loop in the flame and note the color of the flame.

Charcoal block test

The charcoal block test aids in the identification of some metals. By heating a metalliferous oxide, carbonate, sulfide, or silicate powder in contact with charcoal, specks of the native metal can be reduced onto the charcoal (**Figure 21**). To do this test, place the unknown mineral powder into a small pit scooped out of the charcoal block. The powder should be wetted to keep it from blowing away. In some cases, sodium carbonate is mixed with the mineral powder to aid in reduction. The unknown mineral powder is then melted and specks of native metal may be reduced onto the charcoal block. This test can be used to help identify certain metals such as copper, lead, gold, and platinum.

Bead test

A bead test will produce a small globule of stained glass colored by trace-metal oxides. The procedure requires the manufacture of a glass globule from borax or

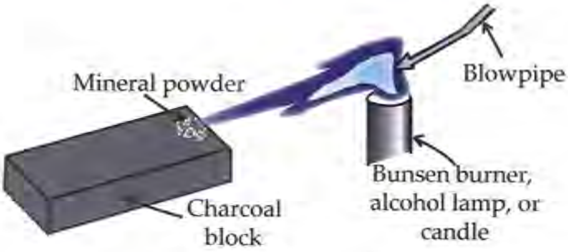


Figure 21. Charcoal block test.

phosphate flux, which is then contaminated with mineral powder. Borax powder can be found in almost any grocery store and sodium phosphate (or sodium ammonium phosphate) can be obtained from a drug store. A 28-gauge wire platinum wire is also required for the procedure and is sold by mineralogical supply houses. One end of the wire is imbedded into a glass or wooden rod to use as a handle and the other end is curled around a pencil point to form a small loop.

First, heat the platinum loop to remove any contaminates, then dip it into the flux. Melt the flux on the loop and repeat the process until a well-formed clear glass globule surrounds the loop. After the bead forms, pick up one or two specks of mineral matter on the bead and reheat until the mineral powder is absorbed. Heat the bead with the aid of a blowpipe in a reducing flame (**Figure 22a**). Repeat the test with a fresh bead and heat in an oxidizing flame (**Figure 22b**). Do this for the borax bead followed by the phosphate bead and compare the results to **Table 7**. Just a few small specks of mineral powder are necessary to color the bead. Too much mineral powder will make the bead opaque.

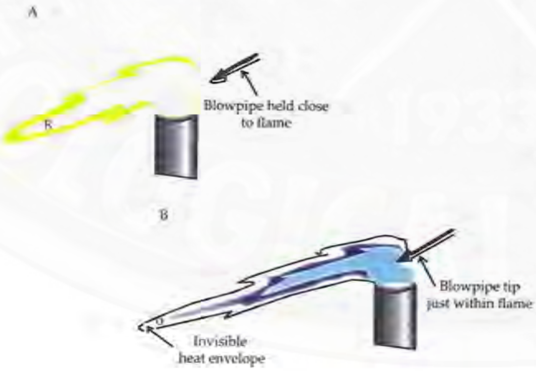


Figure 22. Oxidizing (O) and reducing (R) flames produced with the aid of a blowpipe. (A) The reducing flame is produced by holding a blowpipe near the flame and constantly blowing air through the pipe directed into the flame. The reducing (oxygen-removing) flame is the blue portion of the flame. (B) The oxidizing flame results from blowing oxygen into the flame with the blowpipe in the flame. The oxidizing (oxygen-adding) portion of the flame is the invisible heat envelope surrounding the flame (after Vanders and Kerr, 1967).

SPECIALIZED TESTS

X-ray diffraction (XRD)

X-ray diffractometers are expensive and sophisticated instruments used to identify unknown minerals. They work on the premise that each mineral species has its own unique atomic structure and that the structure can be identified by the reflection of x-rays along specific crystallographic planes in the mineral. But because there are

Table 7. Bead Tests

		Borax Bead		Phosphate Bead	
Element	Bead Color	Oxidizing Flame	Reducing Flame	Oxidizing Flame	Reducing Flame
Copper	Opaque red	--	X	--	X
	Blue green	X	--	--	--
	Blue	--	--	X	--
Chromium	Green	X	X	X	X
Cobalt	Blue	X	X	X	X
Iron	Yellow	X	--	--	--
	Pale yellow	--	--	X	--
	Green	--	X	--	--
	Colorless	--	--	--	X
Manganese	Violet	X	--	X	--
	Colorless	--	X	--	X
Molybdenum	Green	--	--	--	X
	Brown	--	X	--	--
	Colorless	X	--	X	--
Nickel	Yellow	--	--	X	X
	Brown	X	--	--	--
	Opaque gray	--	X	--	--
Titanium	Violet	--	X	--	X
	Colorless	X	--	X	--
Tungsten	Yellow	--	X	--	--
	Blue	--	--	--	X
	Colorless	X	--	X	--
Uranium	Yellow	X	--	--	--
	Green	--	--	--	X
	Pale green	--	X	X	--
Vanadium	Yellow	--	--	X	--
	Green	--	X	--	X
	Colorless	X	--	--	--

Source: Modified from Sinkankas, 1964, p. 269.

more than 2,000 known mineral species, the effectiveness of XRD depends partially upon having a complete list of diffraction patterns to compare with the unknown pattern. Computerization has made this task easier, but impure mineral species, interference from mineral inclusions, and interference from mineral aggregates often makes identification time consuming. Ideally, XRD works well with single, pure minerals.

X-rays are electromagnetic vibrations that have a much shorter wavelength (about 10,000 times shorter) than visible light. Because of the extremely small wavelength, x-rays will pass through almost any substance to a greater or lesser degree and they are not visible to the human eye. Photographic plates or films are much more sensitive to electromagnetic radiation than our eyes, so we can photograph x-rays.

In a similar way that light is reflected by a mirror, x-rays are reflected by the atomic planes in minerals. By reflecting x-rays off of these "atomic mirrors" or planes, scientists can obtain a "picture" of the crystal structure. Each mineral has its own individual arrangement of atomic planes and thus can be identified by its individual x-ray pattern. The x-ray pattern obtained from an unknown mineral is compared to a file of known x-ray patterns to find a match.

Single well-formed crystals can be x-rayed directly, depending on their size. If a mineral is not well formed, it can be crushed to a powder and x-rayed. During crushing, the unknown mineral is broken into millions of tiny specimens and many of these, by statistical chance, will have the proper orientation to reflect x-rays from their atomic planes.

Polarizing microscope

Polarizing microscopes are used to examine the optical characteristics of slices of rock or minerals known as thin sections. Thin sections are cut, mounted on microscope slides, and ground to about 0.001 inch thick so that light can be transmitted through the specimen. When these thin sections of rocks are examined under a microscope, many crystallographic features of individual minerals appear to be more distinctive than they would be in an "in hand" specimen.

The microscope is also used for individual mineral specimens. An unknown mineral can be crushed and placed on a glass slide and examined with the microscope to determine several optical properties.

Fluorescence

Certain minerals fluoresce under ultraviolet light and in some cases fluorescence aids in mineral identification. However, fluorescence is diagnostic only in a few cases because it often results from minor impurities. For example, calcite from Franklin, New Jersey contains traces of manganese that cause the mineral to fluoresce bright pink. At other localities, different trace elements cause calcite to fluoresce orange, yellow, or green. Also, some calcite will not fluoresce.

The term fluorescence is derived from the mineral fluorite, which is well known for its brightly fluorescent mineral specimens. Some of the best fluorite in Wyoming occurs in the Bear Lodge Mountains north of Sundance. This fluorite is purple to lavender in color, but is only weakly fluorescent.

Scheelite, a calcium-tungstate found on Copper Mountain north of Shoshoni, Wyoming, and at the old Strong mine in the Laramie Mountains northeast of Laramie, is white and blends in with quartz and feldspar of the country rock gneiss and granite. The scheelite is essentially indistinguishable in visible light, but under short-wavelength ultraviolet light it strongly fluoresces light blue. Under long-wavelength ultraviolet light it does not fluoresce. In the case of scheelite, fluorescence is diagnostic.

Only a few other minerals from Wyoming fluoresce. Many specimens of calcite fluoresce white in short- and long-wave ultraviolet light. Some Wyoming diamonds fluoresce blue and many varieties of chalcedony fluoresce blue. Youngite fluoresces light yellowish-green and many of the brightly colored secondary uranium minerals fluoresce a brilliant yellowish-green, yellow, or green.

Radioactivity

Some minerals spontaneously emit subatomic particles from their atomic structure. This spontaneous emission is known as radioactive decay. One product of radioactive decay is the release of gamma rays.

Geiger and scintillation counters are designed to detect and measure gamma radiation in the field or laboratory. Uranium, thorium, and some potassium minerals are radioactive. Radiation detectors can be used to help identify some minerals that contain these radioactive elements and their daughter elements (new elements produced by radioactive decay). For more information on radioactivity, refer to Phillips and Greeley (1978).

WYOMING MINERALS

The following mineral descriptions address the characteristics and habits of minerals and rocks found in Wyoming. I have attempted to refrain from describing characteristics of specimens outside of Wyoming, unless a comparison is needed for a specific reason. For the characteristics of mineral species found in general, I recommend that you obtain a good text on mineralogy, such as *Mineralogy* by Sinkankas (1964).

One should also be aware that some minerals that are currently unknown in the state may be found here in the future, based on the favorable geology. Almost every year, a new mineral that was previously unknown in Wyoming is found by some collector, geologist, rock hound, or prospector. Some examples include diamond, chromian diopside, pyrope garnet, peridot, iolite, variscite, and others.

One excellent example of a mineral discovery in the state was the discovery of diamonds. Diamonds were accidentally discovered in Wyoming in 1975, and since then, more than 130,000 diamonds have been found along the Colorado-Wyoming border south of Laramie. Along with diamonds, these deposits include other minerals (chromian diopside, chromian enstatite, and pyrope garnet) that are considered semi-precious gems and collectibles, as well as some unique rock types (i.e., peridotite, eclogite, and kimberlite). It should have been possible to predict the discovery of diamonds simply based on Wyoming's favorable geology to host these kinds of minerals, but the diamonds were overlooked. The geology of Wyoming is favorable for many more diamond discoveries and one might anticipate that more will be found.

Another example of a relatively recent (1994) mineral discovery was peridot (gem-quality olivine), which was first described in the Leucite Hills by the author. This was an interesting discovery because olivine had been known in this region for many years, but apparently no one paid attention to the clarity of the mineral grains. Many of the 13,000 carats of mineral grains collected in the Leucite Hills by the author were translucent and transparent olivine, which is known as peridot to the gemologist.

A mineral discovery made in 1996 was gem-quality cordierite, known as iolite. This was found by the author in the Palmer Canyon area west of Wheatland. Similar high-quality gem iolite was identified recently (2004) by the author and Wayne Sutherland. Both of these deposits also contain some gem-quality sapphire and ruby along with significant kyanite occurrences. The mode of occurrence of these minerals allows geologists to predict that similar occurrences should be found at a number of other nearby localities based on similar geology.

Another interesting find was made by private collectors. The phosphate-bearing minerals variscite and minyulite were found in the Phosphoria Formation near Cody as well as further south near Kemmerer. I expect similar minerals will be discovered elsewhere in the Phosphoria Formation in the Overthrust Belt of western Wyoming. Thus, the lesson to be learned is that not everything has been discovered. Wyoming is still a mineralogists' and petrologists' frontier and many new discoveries will be made in the future.

In the following mineral descriptions, I've tried to use characteristics that are descriptive of the material found in Wyoming, as well as photographs of characteristic Wyoming specimens. Unfortunately, most mineralogy books on the market tend to use photographs of world class mineral specimens that have excellent crystal habit and form and are found in museums. Therefore, rather than using museum photographs, I've tried to use photographs of what one might expect to find in the field in Wyoming.

Wyoming has a large variety of minerals and rocks. Those found within the cores of the old mountain ranges are similar to those that would be found in similar geological terrains around the world, such as in much of Canada, Montana, South Africa, northern Australia, Zimbabwe, India, and several other places in the world. However, much of Wyoming's geology is radically different from that of places like Idaho, Utah, Arizona, Nevada, California, as well as the Midwest and eastern U.S., so many of the minerals and rocks found in Wyoming are not found in these places and vise versa. The following mineral descriptions are listed in alphabetical order.

ACTINOLITE–TREMOLITE

$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

(also see **Nephrite Jade** and **Amphibole group**)
H = 5.5 to 6.5
SG = 2.8-3.5
Crystal System – Monoclinic
Color – Green to black
Luster – Vitreous to waxy

Physical characteristics and crystal habit

Tremolite is the name given to the white variety of amphibole that is rich in magnesium and poor in iron, and actinolite is the blackish or greenish iron-rich member (**Figure 23**). Actinolite and tremolite form a solid solution series, such that the pure end members are uncommon in nature. Most often the mineral is a mixture of the two end members exhibiting coloration that ranges between the two end members. Typically actinolite-tremolite ranges in color from light-green to green to dark-green to black, and often one specimen may contain a range of colors.

The common habit of actinolite-tremolite is prismatic, asbestos-form masses, or coarse crystalline grains with excellent amphibole cleavage. The tough, compact masses of this mineral are termed nephrite (jade). Actinolite-tremolite is typically found in association with a distinctly green mineral assemblage of talc, serpentine, chlorite, and epidote in some of Wyoming's mountain ranges. Coarse crystalline grains are relatively brittle because of their excellent amphibole cleavage, but most often the mineral is found as a fibrous mineral mass.

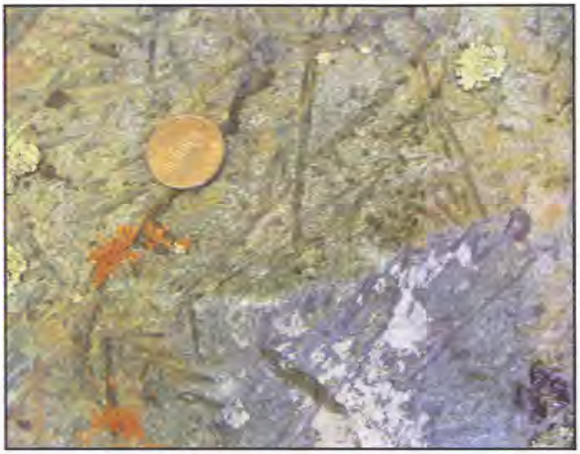


Figure 23. Blades of black and bluish, prismatic tremolite in tremolite-actinolite matrix (sample of metakomatiite from the Seminoe Mountains).

Localities

Fibrous actinolite-tremolite has been found at a number of localities in the state. One of the best localities is the South Pass greenstone belt in the southern Wind River Range south of Lander. In particular, actinolite-tremolite forms a massive metamorphic rock found near some historical gold mines in the South Pass area. At the Carissa gold mine near South Pass City (NW section 21, T29N, R100W) an intensely deformed and folded outcrop of actinolite-tremolite lies adjacent to the historical mine shaft and head frame (Hausel and Love, 1991; Hausel, 1991). The descriptions in these publications should provide enough information on how to get to the outcrops of actinolite-tremolite for sampling.

Actinolite-tremolite was also mapped in the Seminoe Formation, the Bradley Peak Formation, and the Sunday Morning metavolcanics in the Seminoe Mountains greenstone belt north of Sinclair (Hausel, 1994). Some of the actinolite-tremolite is associated with serpentine, and some occurs in a rock known as ultramafic metakomatiite, which has unusual rock textures known as spinifex and cumulate (see **Komatiite**) (Blackstone and Hausel, 1991).

Significance

The presence of actinolite-tremolite, a magnesium-rich rock, can provide a guide to nearby jade deposits or in greenstone terrains such as South Pass, may suggest nearby gold. These rocks are also spatially associated with nickel, chromium, and platinum-group metals in other areas of the world. In the Wawa region of Canada, similar actinolite schists (see **Glossary**) recently were found to contain diamond. At the time this book was written, none of the Wyoming actinolite schists had been tested for diamond.

AGATE (see CHALCEDONY)

ALLANITE
$(Ca,Ce,La,Na)_2(Al,Fe,Mn,Be,Mg)_3Si_3O_{12}OH$

H = 5.5 to 6
SG = 3.9 to 4 (relatively high heft)
Crystal System – Monoclinic
Color – Brown to black
Luster – Submetallic

Physical characteristics and crystal habit

Allanite forms complex, brown to black, translucent to opaque, resinous and pitchy to submetallic monoclinic crystals. These have no cleavage and will produce a white streak when attempting to scratch a streak plate. Allanite has a relatively high heft and commonly forms compact masses. Less commonly, allanite has been found as tabular, prismatic to acicular, monoclinic crystals. Allanite often contains trace thorium, making the mineral radioactive. In Wyoming the mineral is most often found as compact masses in pegmatites, or as disseminated grains in some granites.

Localities

Allanite has been identified in several pegmatites in Wyoming. Four-inch long allanite crystals have been found in some granitic pegmatites in the state. Most notable is a pegmatite in Albany County in the Laramie Mountains within section 2, T18N, R72W. Crystals as large as 3 inches have been reported in pegmatites in sections 12 and 13, T39N, R88W, and in sections 7 and 18, T39N, R87W in the southern Bighorn Mountains (Osterwald and others, 1966, p. 220-222).

Significance

Allanite is a rare-earth-bearing mineral typically found in some pegmatites.

AMBER

H = 2 to 2.5
SG = 1.05 to 1.1 (very low heft)
Crystal System – Amber is an organic material and not crystalline
Color – Brownish yellow
Luster – Resinous

Physical characteristics

By definition, a mineral is a naturally occurring inorganic crystalline solid having definite chemical composition. Amber is a fossil plant resin and thus is not a true mineral. It is non-crystalline and organic.

Amber forms a soft, plastic-appearing material of low specific gravity that is easily cut, carved, and polished. It has a conchoidal fracture with oily luster and ranges from nearly colorless to yellow, brownish-yellow and orange-yellow. Amber melts at a relatively low temperature (250° to 325°C) and is composed of about 79% carbon, 10.5% hydrogen, and 10.5% oxygen with a trace of sulfur. Its main constituent is succinic acid, $COOH(CH_2)_2COOH$ (Sinkankas, 1964).

When burned, amber gives off an aroma similar to pine. Because it is so soft, amber has limited use as a gem, although some amber has been used for beads and other decorations. Inclusions of insects in some amber enhance its value to collectors.

Localities

Good-quality, Early Eocene amber with a deep reddish-brown color was found by J. David Love in 1934 in the early Tertiary Hanna Formation in the Hanna Basin in southeastern Wyoming. A few sizable lumps of amber were also identified in Late Cretaceous (Mesaverde Formation equivalent) coaly shales in the Jackson Hole area. Small pieces of amber were also recovered from the Healy coal bed at the east edge of Buffalo from core drilled by the U.S. Geological Survey in 1975 (Hausel and Sutherland, 2000).

Small nodules and veins of amber have been reported in Upper Cretaceous coals of the Adaville Formation and in Paleocene and Eocene coals in the Powder River Basin (Glass, 1975). Veins of amber, up to 3 inches wide and several feet long, are periodically reported in the thick Wyodak coal seam near Gillette (Hausel and Sutherland, 2000). Thin veins of amber-like material were reported by Sinkankas (1959) and Glass (1975) from the Fort Union Formation coal beds in Converse County. It is quite likely that amber, in small amounts, may be found associated with coal in all of the Tertiary basins of Wyoming.

AMPHIBOLE GROUP
complex silicates

H = 5-6
SG = 2.98-3.35 (moderate heft)
Crystal System – Monoclinic
Color – Green to black
Luster – Vitreous to silky

Physical characteristics and crystal habit

Amphiboles form distinct monoclinic prisms with perfect prismatic cleavage planes that intersect at approximately 56° (**Figure 24**). The cleavage results in diamond-shaped cross-sections when viewed down the c-axis (longest length) of the crystal. When viewed along the a- or b-axis, the crystal will appear as an elongated prism. Many samples collected in Wyoming show prismatic habit, or have a radiating fibrous habit. When found as nephrite (jade), the habit is massive. Because of its hardness, it has a white streak.

The following varieties of amphibole are known in Wyoming:

Hornblende $(Ca,Na)_{2-3}(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$
Hornblende typically forms jet-black prisms as well as fibrous crystals.

Actinolite-Tremolite $Ca_2(Mg\text{-}Fe)_5(Si_8O_{22})(OH)_2$
Actinolite-Tremolite typically occurs as straight fibers, compact forms, and as a tough, massive variety of jade known as *nephrite* (see **Jade**).

Richterite $(Na,K)_2(Mg,Mn,Ca)_6Si_8O_{22}(OH)_2$
Richterite is a very rare amphibole that is found only as microscopic grains in some

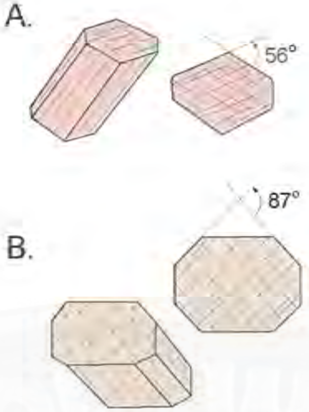


Figure 24. Schematic diagram showing (A) typical amphibole cleavage, and (B) typical pyroxene cleavage.

rare rocks known as lamproite. It is found in the Leucite Hills near Superior and Rock Springs.

Associated minerals and rocks

Some associated minerals found with hornblende may include pyroxene, biotite, and plagioclase. Talc and chlorite are typically found in some of the same rocks with tremolite-actinolite. Many hornblende-bearing rocks include dark, mafic (magnesium-rich) rocks known as amphibolites or metagabbros. Although some of the andesites in the Absaroka Range east of Yellowstone contain some hornblende, these rocks are more silicic (high silica and low magnesium) and may be gray in color. Tremolite-actinolite form some mafic and ultramafic rocks known as xenoliths that have been altered by granitic rocks in the Granite Mountains of central Wyoming. In these xenoliths, hydrothermal fluids derived from the crystallization of granites are thought to have altered the mafic rocks. This produces a distinct alteration assemblage consisting of nephrite jade, zoisite, epidote, chlorite, and sericite. This unique mineral assemblage has been used by the author to locate previously undiscovered occurrences of jade.

Some ultramafic rocks that are by definition enriched in magnesium may also contain tremolite-actinolite. These include, or may be associated with metakomatiites, talc-chlorite schists, tremolite-actinolite schists, and/or serpentinites. Some of these rocks result from hydrothermal alteration and may be associated with faults or shear zones, but most appear to be the result of metamorphic recrystallization of ultramafic igneous rocks.

Localities

Most Precambrian rocks in Wyoming have been metamorphosed at the relatively high pressure and temperature of what is termed *amphibolite-grade metamorphism*. As a result, hornblende is a stable mineral in this environment and is typically found in many metamorphic rocks in several mountain ranges in Wyoming. Hornblende is also a common rock-forming mineral of some volcanic rocks. It has been identified in several basalts and andesites in the Absaroka volcanic plateau in northwestern Wyoming.

Tremolite-actinolite has been identified in ultramafic rocks in the state's Archean greenstone belts (e.g., South Pass, Seminoe Mountains, Rattlesnake Hills, Elmers Rock) as well as with many hydrothermally altered mafic rock xenoliths in the Granite Mountains near Jeffrey City.

Richterite is an extremely rare amphibole that is reported in the Leucite Hills lamproites north of Rock Springs and Superior. The largest grains of richterite found in the Leucite Hills are microscopic and have only been reported in grains 0.5 mm in length or less.

ANDALUSITE
Al_2SiO_5

Also see **Kyanite**, **Sillimanite**, **Cordierite**
H = 6.5-7.5
SG = 3.1-3.2
Crystal System – Orthorhombic
Color – Gray, brown, brownish pink, brownish red, white, rose, green, yellow, violet
Luster – Vitreous to dull

Physical characteristics and crystal habit

Andalusite typically forms elongated prisms known as porphyroblasts that are found in some mica schists. These porphyroblasts are often yellowish-brown to black to gray forming rectangular to square cross-sections. However, many are rounded to elliptical and most are altered. In good specimens, andalusite may exhibit perfect prismatic cleavage. Most specimens found in Wyoming exhibit poor cleavage and show partial to complete replacement by sericite (fine-grained white muscovite mica) and quartz. A variety of andalusite known as chiastolite has not yet been recognized in Wyoming. Chiastolite exhibits cruciform cross-sections as a result of tiny mineral inclusions and carbonaceous material concentrated along crystallographic directions.

Associated minerals and rocks

Aluminum-rich metamorphic sedimentary rocks are termed metapelites. Many of these contain andalusite or other alumino-silicates. Metapelites include mica schists and gneisses that are strongly foliated and have abundant mica (muscovite and/or biotite) and some may also contain garnet. Some other minerals that may be found with andalusite include quartz, cordierite, sillimanite, and/or kyanite. Most andalusite found in Wyoming is poorly preserved and partially to completely replaced by sericite mica and quartz, or replaced by kyanite and/or sillimanite. Nearby aluminum-rich, silica-poor rocks that are devoid of primary quartz may contain aluminum oxides such as corundum (see **Corundum**).

Andalusite, kyanite, and sillimanite are polymorphs. In other words, they have identical chemical compositions, but different crystal structures. Each will recrystallize from one another depending on the pressure and temperature to which they were subjected. For example, kyanite forms at relatively high pressure and low temperature. Sillimanite is the higher pressure-temperature polymorph, and andalusite

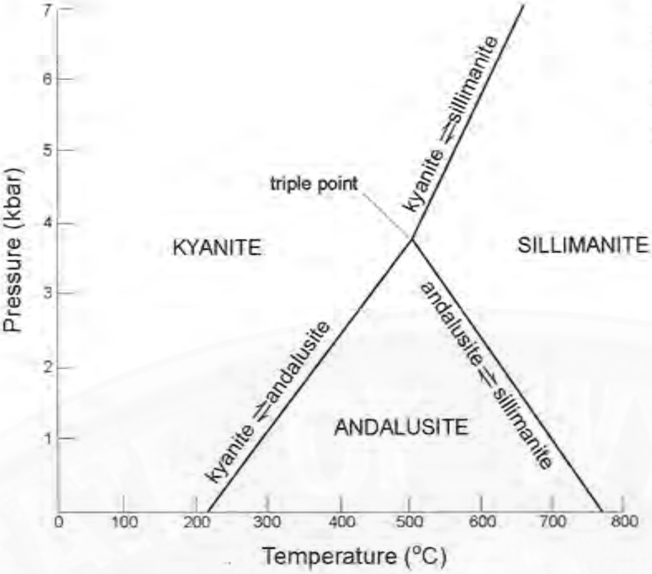


Figure 25. Ternary diagram showing pressure-temperature of the andalusite-kyanite-sillimanite polymorphs (redrafted from Figure 4.4, Gillen, 1982).

forms at moderate to low pressure and temperature (**Figure 25**). Where all three polymorphs are found in the same rock or in the same immediate area, such as in the central Laramie Mountains near Palmer Canyon and the Elmers Rock greenstone belt (Graff and others 1982), the host rocks were subjected to about 3.8 kilobars of pressure and 500°C of temperature. This is equivalent to a burial depth of about 7 to 8 miles. Thus, where these minerals are found together provides the geologist with information about the depth of burial: the host rocks would have been buried beneath 37,000 to 42,000 feet of rock sometime during the geological past prior to being uplifted along faults. Subsequent erosion would have later exposed the andalusite-bearing rocks.

Localities

Look for andalusite in Wyoming mountain ranges that exhibit thick successions of mica schist. Andalusite can usually be found where these schists occur with quartzite, metagraywacke, and/or other metasedimentary rocks. Andalusite has been identified in the Elmers Rock greenstone belt in the central Laramie Mountains near the Dodge Ranch north of Middle Sybille Canyon. In this region, all three Al_2SiO_5 polymorphs are found in the metapelites (mica–rich schists). In the southern portion of the Elmers Rock greenstone belt, metapelites contain andalusite and sillimanite. In the northern portion of the belt, the metapelites host kyanite and sillimanite (Graff and others, 1982).

Andalusite has also been identified in the South Pass greenstone belt of the Wind River Range (also see **Cordierite**). In the NE section 3, T28N, R98W, on the north bank of Strawberry Creek, muscovite schist is filled with two- to four-inch long prismatic crystals of andalusite (**Figure 26**). The map in the back of the publication by Hausel (1991) will show and aid in finding these rocks. Some muscovite schists near the Atlantic City iron ore mine on the northwest flank of the greenstone belt and in the vicinity of Anderson Ridge have brownish prisms that are also characteristic of andalusite. Andalusite has also been described in the Copper Mountain district in

Figure 26. Two- to four-inch long prismatic crystals of andalusite in muscovite schist from Strawberry Creek near Lewiston.

the Owl Creek Mountains (Hausel and others, 1985). Both Gliozzi (1967) and Hamil (1971) reported andalusite schist in Metamorphic Unit I of the Copper Mountain complex. The map in Hausel and others (1985) will show the locations of this rock unit.

ARSENOPYRITE
FeAsS

H = 5.5 to 6
SG = 6.07 (high heft)
Crystal system – Orthorhombic
Color – Silver gray
Luster – Metallic

Physical properties and crystal babit

Arsenopyrite forms distinct, silver-white to steel gray (**Figure 27**) metallic granular masses, and less commonly short prismatic crystals with striations. It will produce a black streak when scratched on a tile and yield a distinct garlic odor when struck with a hammer. Arsenopyrite alters to scorodite, a light lemon-yellow to yellow-green, arsenic-bearing limonite. Characteristics used to identify arsenopyrite include its common association with quartz veins in some gold mining districts, its steel-gray metallic color, association with yellowish-green scorodite (oxidized arsenopyrite) stains, and the distinct garlic odor emitted when powdered.

Localities

Arsenopyrite has been identified in some of the state's gold mining districts. Bayley

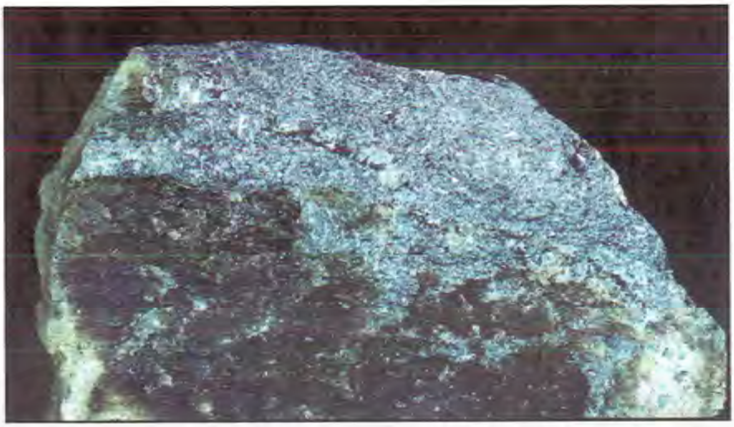


Figure 27. Tiny acicular prismatic metallic crystals of arsenopyrite scattered in massive arsenopyrite with limonite and scorodite (yellow) and hematite (dark red). Specimen collected near Garrett, Wyoming.

and others (1973) and Prinz (1974) reported a close association of gold with arsenopyrite at South Pass. However, Hausel (1991) was unable to verify this association and instead found arsenopyrite was weakly anomalous in silver rather than gold in this district. Gold was found to be more closely associated with disseminated pyrite and found as fracture fillings in quartz.

A few historical mines in the South Pass district contain some arsenopyrite in quartz. For example, massive specimens of arsenopyrite have been collected from two veins in a cliff on the north bank of the Sweetwater River in the SE section 9, T28N, R98W, of the Radium Springs Quadrangle (Hausel, 1988). Specimens with disseminated arsenopyrite are also scattered on the Dream mine dump about one hundred yards upstream from the veins. Specimens of massive arsenopyrite with interspersed short prismatic needles of arsenopyrite occur at Garrett in the central Laramie Range (sections 22 and 28, T25N, R73W). This area also has minor berthierite (see **Berthierite**).

Associated minerals

Arsenopyrite is often associated with native gold, pyrite, scorodite, and limonite.

ASBESTOS

H = 2.5 to 5
SG = 2.9 to 2.95 (low heft)
Crystal System – Monoclinic
Color – Green, white, gray
Luster – Silky or waxy
See **Amphibole** and **Serpentine**

Physical characteristics and crystal habit

Two forms of asbestos are recognized: (1) fibrous asbestiform amphibole referred to as crocidolite [$Na_2Fe_5Si_8O_{22}(OH)_2$] that is also known as rebeckite; and (2) the asbestiform of serpentine known as chrysotile [$Mg_3(Si_2O_5)(OH)_4$]. Asbestos may occur in shades of green, yellow, brown, and gray and exhibits a distinct silky, fibrous, or waxy luster. It has a hardness of 2.5 to 5, with low to medium heft and should exhibit a distinct fibrous habit.

Associated minerals and rocks

Asbestos is a fibrous form of serpentine or amphibole that is often associated with talc and occurs in some talc schists and serpentinites in Wyoming. Asbestos is a secondary mineral formed by alteration of mafic and ultramafic metamorphic rocks.

Localities

Some asbestos occurs with serpentinite and talc-tremolite schist near the entrance of the Atlantic City iron mine at South Pass in the Wind River Range (Hausel, 1984). However, some of the better Wyoming specimens have been found on Casper Mountain in sections 16 and 17, T32N, R79W, eight miles south of Casper (**Figure 28**). At this locality, 1/8- to 1/4-inch-wide cross-fiber chrysotile veinlets separate layers of massive serpentine. Other specimens have been collected at Smith Creek (SE section 19, SW section 20, NW section 29, NE section 30, T31N, R78W) southeast of Casper Mountain (Osterwald and others, 1966, p. 8-9).

Figure 28. Fibrous asbestos from Casper Mountain.

Asbestos is also reported to occur in lenticular serpentinite masses surrounded by granitic country rock south of Beaver Hill (section 19, T30N, R96W) near Highway 287, west of Jeffrey City. Some asbestos also occurs in the Halleck Canyon area in the central Laramie Mountains north of Sybille Canyon (section 18, T22N, R71W) (Graff and others, 1982).

AZURITE

$Cu_3(CO_3)_2(OH)_2$

H = 3.5 to 4
SG = 3.77
Crystal System – Monoclinic
Color – Blue
Luster – Vitreous to dull

Physical characteristics

Azurite forms distinct bright blue (**Figure 29**) crusts, coatings, and stains associated with green malachite on copper-bearing rocks. It has a dull to vitreous to earthy luster and less commonly occurs as vitreous botryoidal (rounded, grape-like) masses. Being a carbonate, azurite will strongly effervesce in cold dilute hydrochloric acid (10% HCl). Its reaction to acid, color, and association with other copper minerals are often distinctive enough to identify azurite.

Figure 29. Blue azurite with green malachite stains this schist from the American mine, Medicine Bow Mountains.

Occurrence

Azurite has been found with other copper minerals at several prospects and mines in Wyoming. In particular, azurite has been found at several locations in the Grand Encampment district in the Sierra Madre (Hausel, 1997). The Absaroka Range in northwestern Wyoming, known for its giant, low-grade, porphyry copper deposits, also has some azurite associated with other copper minerals (Hausel, 1982). Three good localities for azurite in Wyoming include the American mine (SW section 16, T12N, R78W) in the Medicine Bow Mountains, the DePass mine in the Copper Mountain district of the Owl Creek Mountains (Hausel and others, 1985), and the Griggs mine in the Lake Alice district of the Overthrust Belt. These properties are all described by Hausel (1997).

Associated minerals

Azurite is often associated with limonite (a hydrated iron oxide found in gossans). It is commonly found with other cupriferous minerals including malachite, tenorite, cuprite, and chalcopyrite.

AUTUNITE
$Ca(UO_2)_2(PO_4)_2 \bullet 10\text{–}12H_2O$

H = 2 to 2.5
SG = 3.1 to 3.2
Crystal System – Tetragonal
Color – Lemon-yellow to pale green
Luster – Vitreous
Other – Strongly radioactive

Physical characteristics and crystal habit

Autunite forms distinct, highly radioactive, bright lemon-yellow to pale green thin, tabular crystals and coatings on sand grains in sandstones. Autunite will fluoresce bright yellowish green or apple green under ultraviolet light and has a vitreous luster with perfect cleavage. The hardness of autunite is only 2 to 2.5 and will yield a yellow streak when scratched. It has a specific gravity of 3.1 to 3.2 and crystallizes within the tetragonal crystal system. However, since it is almost always found as coatings on sandstones in Wyoming, crystals are rarely found.

Similar minerals

Carnotite (potassium-uranium vanadate) is similar in appearance to autunite. However, carnotite has an dull earthy luster and is non-fluorescent.

Occurrence

Autunite is associated with other oxidized uranium minerals in sandstones in some of the state's basins, such as the Shirley and Wind River basins. It has been found associated with carnotite and uranophane.

BARITE
$BaSO_4$

H = 3 to 3.5
SG = 4.5 (relatively high heft)
Crystal System – Orthorhombic
Color – White, gray, blue
Luster – Vitreous

Physical characteristics and crystal habit

Figure 30. (a) Pale blue tabular barite crystals on calcite and quartz from the Sheep Creek area near Crystal Hill in the Shirley Basin. The largest crystal is approximately 1 inch in length.

Barite often forms colorless, white, gray, brown, or blue tabular rhombohedral crystals or massive granular concretions with vitreous to resinous luster. It is often opaque, but may occur as translucent to transparent crystals with good basal and prismatic right angle cleavage. It is a relatively soft mineral with a hardness of only 3 to 3.5 and it can be readily scratched with a pocketknife. It will produce a white to grayish streak on a streak plate. The specific gravity is notably high at 4.5, thus massive specimens (particularly barite concretions) will have a noticeably high heft.

Localities

Barite has been reported at several locations in the state (Osterwald and others, 1966). Excellent specimens of blue transparent barite (**Figure 30a**) are found in the Sheep Creek area at Crystal Hill along the eastern margin of the Shirley Basin, 30 miles northeast of Medicine Bow (section 10, T26N, R75W). These are excellent, transparent, thin, tabular clear to light-blue orthorhombic crystals compressed along the c-axis. The crystals have beveled to chisel-tipped edges with excellent cleavage parallel to (001), (210), and (010). They occur with calcite and quartz in vugs and in fractures in the host rock Casper Formation limestone.

Scattered barite concretions are reported elsewhere in the Shirley Basin. These will

Figure 30. (b) White massive barite with tawny limonite from fault gouge from the Hog Park area of the Sierra Madre (NW section 2, T12N, R85W). The massive specimen, in particular, has very noticeable high heft unlike the blue barite crystal specimen that has considerable pore space.

weakly fluoresce under long-wavelength ultraviolet light and exhibit a distinct high heft. Other localities for barite include transparent to translucent barite wedges near Hanna (NE section 23, T24N, R81W). Other barite crystals have been collected in the Wiggins Fork in Fremont County, near Newcastle, the Shoshone Canyon area west of Cody (SE section 5, T52N, R102W), from the New Rambler Mine in the Medicine Bow Mountains (SW section 33, T15N, R79W), and at Hog Park in the Sierra Madre (**Figure 30b**). The Hog Park occurrence, in section 2, T12N, R85W, is massive barite that contains tabular white crystals cemented in a limonitic to hematitic matrix found in a shear zone in quartz monzonite.

BERTHIERITE
$FeSb_2S_4$

H = 2 to 3
SG = 4.64 (relatively high heft)
Crystal System – Orthorhombic
Color – Dark steel-gray
Luster – Metallic

Physical characteristics and crystal habit

Berthierite is a rare mineral and has been described at only one locality in Wyoming. Berthierite forms short, vertically-striated, prismatic crystals that are metallic steel-gray, opaque, massive to granular. It may show indistinct b(010) cleavage.

Locality

The only known locality for berthierite in Wyoming was identified by the author at Garrett in the central Laramie Range (sections 22 and 28, T25N, R73W) 35 miles northeast of Medicine Bow and verified by XRD (Hausel, 1989). The berthierite is uncommon, but found associated with massive arsenopyrite and interspersed short prismatic needles of arsenopyrite. Berthierite is similar in appearance to massive arsenopyrite, but has a bright silvery metallic sheen with associated blood-red hematitic alteration. One sample of berthierite collected near the Garrett School House assayed 0.25 ounce of gold per ton.

BERYL
$Be_3Al_2Si_6O_{18}$

H = 7.5-8
SG = 2.6-2.9
Crystal System – Hexagonal habit (commonly as hexagonal prisms with basal terminations)
Color – Yellow-green, blue, green
Luster – Vitreous

Physical characteristics and crystal habit

Much of the beryl that has been found in Wyoming occurs as greenish-yellow translucent to opaque crystals with six-sided hexagonal prisms and basal terminations (**Figure 31**). Some beryl recovered from the Casper Mountain quarry was a gem-variety known as helidor, a distinct, transparent yellow-green beryl (Hausel, in press).

A few varieties of gem-quality transparent to translucent light-blue aquamarine beryl have been found and only one grass-green transparent beryl has been reported in the state that purportedly came from the Sierra Madre (Larry Clark, personal communication). Beryl has a vitreous luster on fresh surfaces with a conchoidal to uneven fracture. Cleavage is imperfect basal c(0001) and due to its hardness, beryl has a white streak. It also has a low to moderate heft and a relatively low specify gravity of 2.6 to 2.9. When found in transparent crystals, beryl is often gem quality and with a variety of possible colors (**Table 8**). To date, only helidor and aquamarine have been found in Wyoming, but the geology of parts of the state suggest there is a very good possibility for finding emerald.

Figure 31. Translucent to opaque yellow-green beryl crystal from the Casper Mountain quarry.

Associated minerals and rocks

Beryl is restricted to simple granite pegmatites in Wyoming (Harris and Hausel, 1986). As such, beryl is found in ancient Precambrian terrains and associated with the traditional pegmatitic minerals quartz, biotite, and potassium feldspar.

Table 8. Varieties of gem beryl and the trace coloring agents (chromophores) responsible for the colored gemstone.

Variety	Color	Chromophores
Emerald	Chrome-green	Cr, V, Fe^{2+}, Fe^{3+}
Aquamarine	Light blue, sea green	Fe^{2+}, Fe^{3+}
Maxixe beryl	Blue (fades in sunlight)	Fe^{2+}, Fe^{3+}
Chrysolite	Yellow-green	Fe^{2+}, Fe^{3+}
Golden beryl	Golden-yellow	Fe^{2+}, Fe^{3+}
Heliodor	Greenish-yellow	Fe^{2+}, Fe^{3+}
Morganite	Pink-orange, pale pink	Mn^{2+}, Mn^{3+}
Bixbite	Dark red	Mn^{2+}, Mn^{3+}
Goshenite (rosterite)	None	Colorless

Source: Hausel and Sutherland, in press.

Localities

Beryl has been found in crystals ranging from less than 1 inch to more than 3 feet in length in Wyoming at several localities. The reader should examine the maps published in Hausel and Sutherland (2000) for many locations of known beryl deposits. The majority of the specimens are yellowish green to green. Excellent, but rare, gem-quality aquamarine beryl has been reported from Anderson Ridge in the Wind River Range (Hausel, 1991) and has also been found in pegmatites near Hoodoo Creek along the southern flank of Copper Mountain in the Owl Creek Mountains (McLaughlin, 1940).

Several pegmatites in the Hartville uplift near Guernsey contain beryl (Millgate, 1965). Excellent specimen-grade crystals, several inches to more than 3 feet in length, have been mined from Precambrian pegmatite on Casper Mountain south of the Hogadon ski area (Knittel, 1978, p. 60) in sections 17, 18, 19, and 20, T32N, R79W. Some fence-post-size specimens from Casper Mountain have been greenish yellow, with zones of transparent gem-quality heliodor.

An excellent transparent green beryl (emerald) was found in the Sierra Madre at an undisclosed location (Larry Clark, personal communication). The beryl was grass-green, transparent, and approximately 0.5 inch in length. Several other beryl localities are known and described by Hausel and Sutherland (2000).

BORNITE
Cu_5FeS_4

H = 3
SG = 5.08
Crystal System – Tetragonal
Color – Red, bronze (tarnishes to distinctive iridescent purple)
Luster – Metallic

Physical characteristics and crystal habit

Bornite occurs in metallic masses and disseminated grains associated with quartz veins and some altered and mineralized volcanic and metamorphic rocks. Bornite typically is found as a bronze-colored to copper-red-colored metallic sulfide with a distinctive iridescent purplish tarnish (**Figure 32**). The streak of the mineral is a light grayish black. It may exhibit octahedral (111) cleavage. It is typically found with other copper minerals.

Associated minerals

Bornite is found with other copper sulfides including copper carbonates and copper oxides, which may include chalcopyrite, chalcocite, malachite, and tenorite.

Localities

Some bornite has been collected from the Hercules mine dump (W/2 SW section 29, T14N, R85W) in the Sierra Madre. Certain fractures in these samples contain well-crystallized radiating prisms of malachite with masses of chalcopyrite, minor chalcocite, minor tenorite, and traces of bornite. Samples collected from the nearby Portland mine dump (E/2 SE section 30, T14N, R85W) (Hausel,

Figure 32. Bornite specimen from the Ferris-Haggarty mine in the Encampment district of the Sierra Madre. Distinct multi-colored bornite found with green malachite, bronze, metallic pyrite, and chalcopyrite all in deformed metaconglomerate.

Figure 33. Copper ore from the Ferris-Haggarty mine, Sierra Madre. Massive malachite, bornite, chalcocite, covellite, and chalcopyrite form the matrix of Precambrian metaconglomerate.

1997) consist of milky quartz with disseminated chalcocite, bornite, minor malachite, and tiny disseminated pyritohedrons. Trace amounts of bornite have also been collected from the Charter Oak mine dump north of Encampment.

The Kurtz-Chatterton mine dumps (S/2 section 29, T14N, R84W) along Copper Creek 5 miles southwest of Encampment contain specimens of milky quartz with disseminated to massive chalcopyrite, bornite, chalcocite, and malachite. This is a good place to find a variety of copper sulfides.

Some of the better specimens of bornite have been collected within the ore zone of the Ferris-Haggarty mine (section 16, T14N, R86W) in the Sierra Madre. Sheared specimens and mineralized metaconglomerates contain sericitized quartz and quartzite pebbles in a mineralized matrix of malachite, chalcocite, and massive chalcopyrite and bornite, with bornite replacements of chalcopyrite (**Figure 33**).

CALCITE
$CaCO_3$

H = 3
SG = 2.71 (low heft)
Crystal System – Hexagonal
Color – White or gray
Luster – Vitreous

Physical characteristics and crystal habit

Calcite often forms rhombohedral or scalenohedral crystals and may occur as finely crystalline masses with perfect rhombohedral cleavage, in masses with rhombohedral cleavage, or as stains (**Figure 34**). Typically, it is white or gray and less often yellow, brown, pink, green, or black. It has vitreous luster with a white to grayish streak. Some distinct characteristics include rhombohedral crystal habit, effervescence in cold dilute hydrochloric acid, and possible white, red, yellow, pink, or blue fluorescence in ultraviolet light.

Occurrence

Limestones and marbles are rocks that are formed almost entirely of massive calcite. Good rhombohedral calcite crystals may be found in some vugs in limestone, or in quartz veins that contain appreciable calcite and siderite (iron carbonate). Brown to yellow-brown siderite may accompany calcite in some veins.

Figure 34. Calcite rhombohedral crystals with minor chlorite and polybasite from Cooper Hill, Medicine Bow Mountains. Note the distinctive calcite rhombohedrons reflecting light near the center of the photo.

Localities

Calcite is found at a number of places in the state. Some good specimens of calcite rhombs have been found with polybasite on Cooper Hill in the NE section 34, T18N, R78W, west of Arlington near the North Fork of Cooper Creek in the Medicine Bow Mountains (Hausel, 1994a). Specimens of calcite onyx (Mexican onyx) are found in the Hartville uplift in eastern Wyoming. One of the better Mexican onyx localities is found in section 2, T27N, R66W.

CASSITERITE

SnO_2

H = 6 to 7
SG = 7 (high heft)
Crystal System – Tetragonal
Color – White, brown
Luster – Adamantine (bright) to dull

Physical characteristics

Cassiterite occurs in different shades of brown to brownish-black (occasionally gray, white, or yellow) short prismatic tetragonal crystals, bipyramids, or fine granular or botryoidal masses. It often forms contact or penetration-twinned crystals with high specific gravity. The mineral has a white streak.

Locality

The only known locality in Wyoming where cassiterite has been identified is in the Mineral Hill district in the Black Hills of Crook County. Tin placers are associated with gold in this area. Nearby, a few cassiterite-bearing pegmatites have been identified that are assumed to be the source of the placer cassiterite.

Granite pegmatite on a ridge between Bear Gulch and Sand Creek contains 1/8 to 1/2 inch diameter anhedral (formless) cassiterite, although some well-developed euhedral crystals have been found. The cassiterite occurs as inclusions in feldspar and less often in quartz and mica. The cassiterite content of the pegmatites rarely exceeds 2% (Welch, 1974).

Cassiterite has been identified in placers in Bear Gulch, Sand Creek, and at Sand Creek Crossing. Here the cassiterite occurs as subangular fragments. Some samples up to 1 inch in size have been reported. Cassiterite grains in black sand concentrates are intermixed with garnet, magnetite, columbite-tantalite, wolframite, gold, and rare minute topaz grains (Irving and Emmons, 1904, p. 95-97).

CHALCEDONY
SiO_2

H = 7
SG = 2.57 to 2.64 (low heft)
Crystal System – Hexagonal
Color – Varied (nearly every color of the rainbow)
Luster – Vitreous

Physical characteristics and crystal habit

Chalcedony occurs as masses of microcrystalline quartz found in a wide variety of colors. Because of its chonchoidal fracture, many native Americans used chalcedony to manufacture arrowheads. Today, lapidaries use chalcedony in the manufacture of some varieties of jewelry and as ornamental stones (see Hausel and Sutherland, 2000).

Locality

Localities for chalcedony are shown in **Figure 35**.

Varieties

There are several varieties of chalcedony. *Agate* is common chalcedony with concentric banding that occurs in cavities such as geodes or in veins. *Moss agate* is an unbanded agate with irregular dendritic markings. Other varieties of chalcedony include *onyx* (alternating layers of dark and light chalcedony), *sard* (yellowish and reddish brown translucent chalcedony), *chrysoprase* (apple-green translucent chalcedony), *jasper* (dark red to yellowish brown opaque chalcedony), *prase* (dull green chalcedony), *bloodstone* (green chalcedony with red jasper spots), *chert* (dull black, white, or gray opaque chalcedony), and *flint* (dull gray to black opaque chalcedony) (**Figure 36a**).

Opal is a submicroscopic silicon dioxide containing some water that is found in cavity fillings and sometimes exhibits brilliant internal color dispersion. *Banded agates, moss agates,* and *petrified wood* are popular collectors' items in Wyoming. *Rainbow* or *iris agate* diffract ordinary light into the colors of the rainbow when thinly sliced. Iris agate is found along the Wind River near Riverton. *Wood-cast agate* is chalcedony that has filled and taken on the external form of cavities created by the rotting and removal of buried limbs, roots, and trunks of trees. Wood-cast agate is collected in the Wiggins Formation of the Absaroka Range. In contrast, *petrified wood* is formed by mineral replacement of the organic material as it lies in the ground, with retention of some of the internal features characteristic of wood. The Wiggins Formation of the Absaroka Range is a good source for agate-filled casts of tree trunks and limbs. Much of this material is gray to white and has either concentric or horizontal banding (Root, 1977).

Dryhead agate is an attractive red and white banded agate found in the Phosphoria Formation south of the Pryor Mountains. The agate also occurs in Dryhead Creek

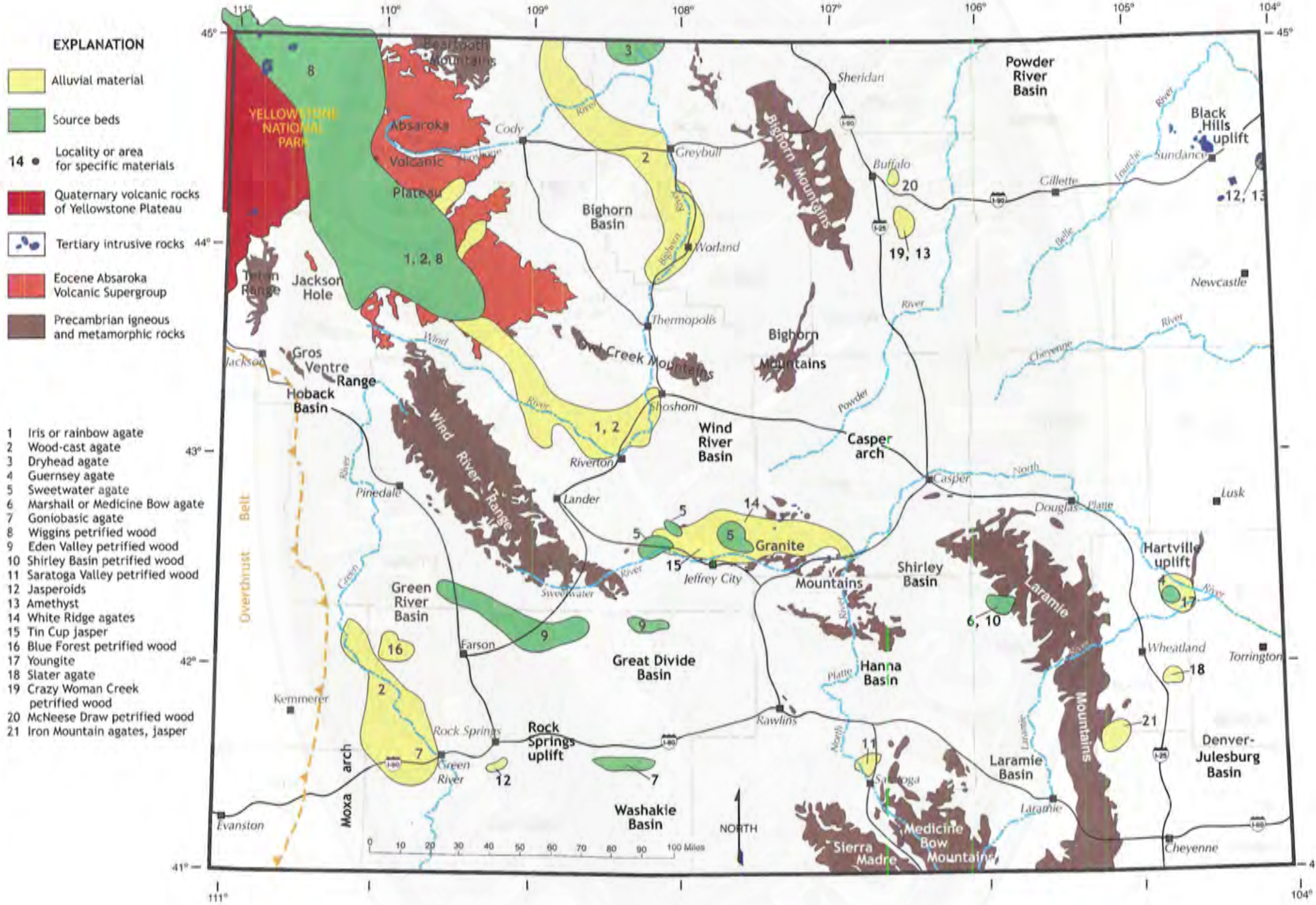


Figure 35. Quartz, chalcedony, and petrified wood localities in Wyoming.

and along the Bighorn River northeast of Lovell (Wilson, 1965). Seams of agate in Guernsey Formation limestones near Hartville (Platte County) were mined commercially in the early part of the century. These are white moss agates and cream-colored banded agate (Root, 1977).

Youngite agate consists of a mixture of drusy quartz and banded agate encrusting pink breccia (**Figure 36b**). It is found in natural caves in Mississippian limestone near Guernsey and Glendo reservoirs a few miles northwest of Guernsey. This popular agate will fluoresce light-green in both long- and short-wave ultraviolet light.

One common variety of agate popular in Wyoming is the Sweetwater moss agate (**Figure 36c**). This agate is dark gray-blue with clusters of black manganese dendrites. Some of the best localities lie along Sage Hen Creek northeast of Jeffrey City. *In situ* Sweetwater moss agate was found in the White River Formation near Beaver Rim in section 7, T31N, R94W, by the author. Small pebbles of the agate are also collected along the Sweetwater River where it parallels US. Highway 287 near Jeffrey City (Love, 1970). Some agates from this region will fluoresce yellow-green in short-wave ultraviolet light (Vanders and Kerr, 1967).

White moss agate is found in the Casper Formation near Marshall in Albany County and occurs with jasper in gravels southwest of Marshall. Some moss agate and clear chalcedony occur in outcrops of the Bridger Formation north of Wamsutter. At Steamboat Mountain in the Leucite Hills (sections 9, 10, 15, and 16, T23N, R102W), the orendite and wyomingite lava flows have amygdules that are sometimes lined with crusts of chalcedony (Wilson, 1965).

Goniobasis agate is a dark-brown siliceous rock filled with shells of the fossil snail, *Goniobasis*. This rock takes a high polish and produces very attractive specimens of brown agate filled with agatized snail shells. *Goniobasis* agate may be found capping some buttes south of Interstate 80 between Green River and Granger. Some of these specimens weakly fluoresce white, yellow, or light blue in long-wave ultraviolet light.

Petrified wood is an organic woody material that has been replaced by microcrystalline quartz or opal. Most Wyoming petrified wood formed 30 to 40 million years ago, when trees were buried under volcanic ash. A few large petrified trees may be seen in Yellowstone National Park at Specimen Ridge and Amethyst Mountain and in the Absaroka Range to the east. The Wiggins Formation in the Absaroka Range contains abundant petrified wood locally; some petrified pine cones and seed clusters have also been preserved (Root, 1977).

Some of the most attractive petrified wood in the state is found northeast of Farson, just south of the Wind River Range (**Figures 36d** and **36e**). This is the famous Eden Valley wood which is black to dark gray. Petrified wood has also been identified along the old Casper Road about 35 miles north of Medicine Bow and on the flats along State Highway 130 14 miles south of Walcott Junction.

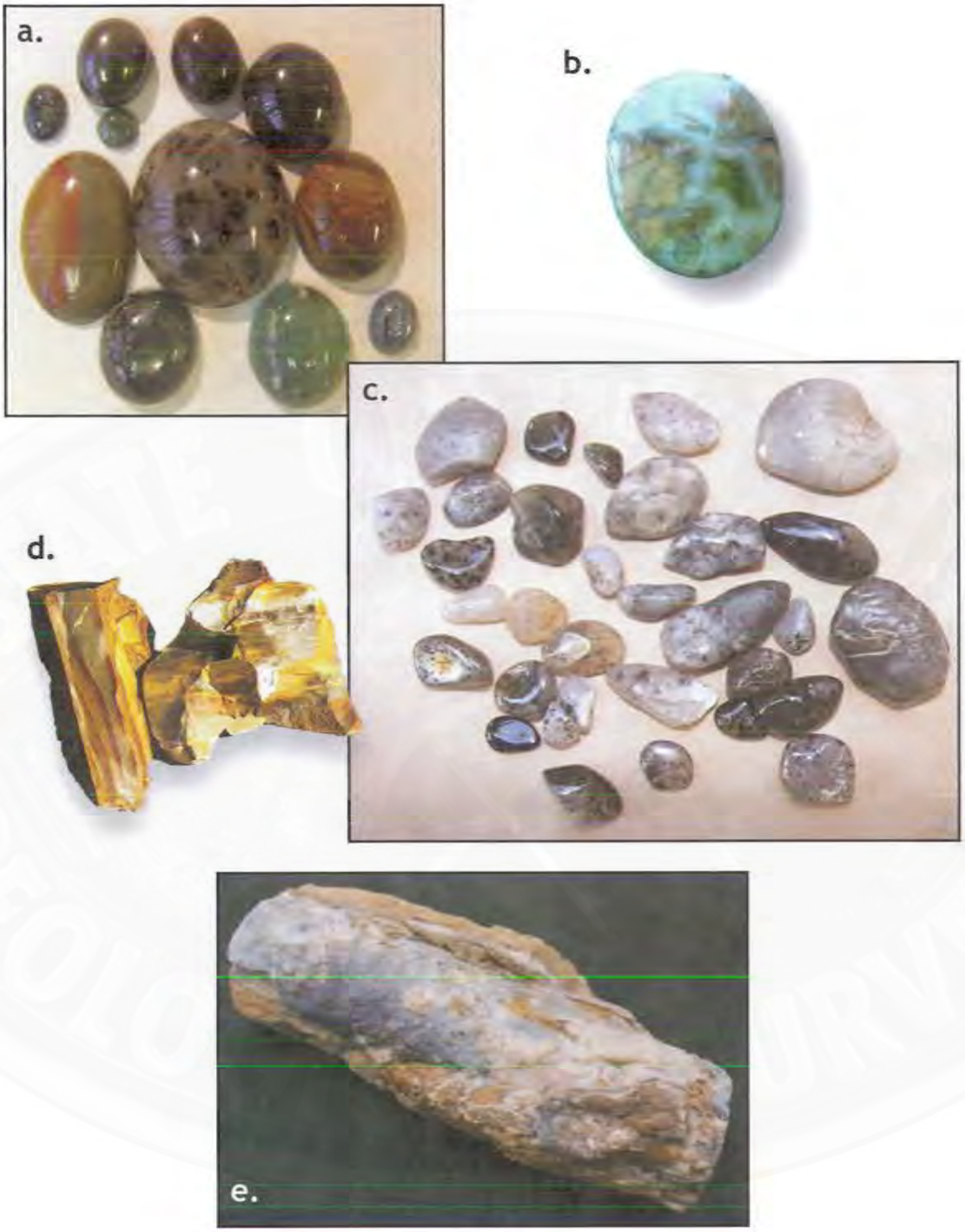


Figure 36. Group of cabochons (including some chalcedonies) from Wyoming. (a) Clockwise, starting from left center: banded jasperoid from Quaking Aspen Mountain; blue kyanite and green quartzite from the Laramie Range; steel-gray specularite from Sunrise mine; brown limonite followed by a second brown limonite from Charter Oak mine; tawny to reddish silicified banded iron formation from the Seminoe Mountains; small blue kyanite from Laramie Mountains; green quartzite from Snowy Range; and silver metallic specularite from Charter Oak mine, all surrounding a Sweetwater agate in center. (b) Youngite agate cabochon from Glendo area. (c) Group of Sweetwater agates from Granite Mountains (photograph by Meg Ewald). (d) Jasperoids from Quaking Aspen Mountain near Rock Springs. (e) Silicified wood from the Farson area from the Wayne Sutherland collection (photograph by Meg Ewald).

CHALCOCITE
Cu_2S

H = 2.5 to 3
SG = 5.5 to 5.8
Crystal System – Orthorhombic
Color – Black
Luster – Metallic to Dull

Physical characteristics

Chalcocite is a soft, black to lead-gray metallic, subsectile mineral that forms masses and is associated with other copper minerals, most notably malachite (**Figure 37**). It will yield a shining dark lead-gray streak and has conchoidal fracture. Typically, chalcocite is lead-gray and readily tarnishes to a dull black color with a thin film of malachite. A common field test is to place a few drops of 10% hydrochloric acid on the black mass and rub a well-used rock hammer over the acid-coated mass. If the specimen is chalcocite, rusted areas on the rock hammer will be partially replaced by native copper.

Figure 37. Massive specimen of steel gray to blue metallic chalcocite from New Mexico.

Localities

Chalcocite is found is some of the old mine dumps associated with a few historical mines in the Encampment district of the Sierra Madre. The Kurtz-Chatterton mine along Copper Creek southwest of Encampment has some chalcocite mixed with chalcopyrite, bornite and malachite. Another mine, the Doane-Rambler (section 25, T14N, R86W), is reported to have some chalcocite with chalcopyrite, bornite, covellite, malachite, azurite, cuprite, and chrysocolla (Spencer, 1904). Chalcocite has also been reported on some mine dumps in the Medicine Bow Mountains. These include the Cuprite mine (NW section 11, T14N, R79W) in the Keystone district, the Blanche mine (SE section 32, T15N, R79W) and the New Rambler mine (SW section 33, T15N, R79W) in the New Rambler district (also see **Sperrylite**). Some chalcocite from this area is reported to be platinum-bearing.

CHALCOPYRITE
$CuFeS_2$

H = 3.5 to 4
SG = 4.1 to 4.3
Crystal System – Tetragonal
Color – Bronze with blue and green iridescent metallic sheen.
Luster – Metallic

Physical characteristics

Figure 38. Massive bronze-colored chalcopyrite with quartz from the Ferris-Haggarty mine, Sierra Madre.

Chalcopyrite, sometimes referred to as copper-pyrite, forms metallic bronze, compact masses with a distinct violet, greenish to blue sheen on the surface of the mineral. Uncommon distinct cleavage (011) may be seen on some specimens. The mineral is brittle, has uneven fracture, and will produce a greenish black streak. Twinning on the (112) and (012) is common. Nearly all of the chalcopyrite found in Wyoming has been massive or disseminated grains with no obvious crystal form. Typically it is found with other copper minerals including chalcocite, malachite, and bornite (**Figure 38**).

Occurrence

Chalcopyrite has been found in all of Wyoming's copper districts. Some good massive specimens have been recovered from the Hercules and Portland mines (SW section 29, T14N, R85W) near Battle in the Sierra Madre (see Osterwald and others, 1966), the Charter Oak mine (section 24, T15N, R85W), the Kurtz-Chatterton mine (S/2 section 29, T14N, R84W), and the Ferris-Haggarty mine (section 16, T14N, R86W) (see Hausel, 1997).

CHERT (see CHALCEDONY)

CHROMITE

$FeCr_2O_4$

H = 5.5
SG = 4.3 to 4.6
Crystal System – Isometric
Color – Black
Luster – Submetallic

Physical Characteristics

Chromite (**Figure 39**) is a member of the spinel group of minerals that includes several mineral species. The spinel group consists of the following mineral species:

Spinel, $MgAl_2O_4$
Hercynite, $FeAl_2O_4$
Gahnite, $ZnAl_2O_4$
Galaxite, $MnAl_2O_4$
Magnesioferrite, $MgFe_2O_4$
Magnetite, $FeFe_2O_4$

Figure 39. Black octahedral chromite crystals in a greenish matrix from Casper Mountain.

Franklinite, $ZnFe_2O_4$
Jacobsite, $MnFe_2O_4$
Magnesiochromite (chrome spinel), $MgCr_2O_4$
Chromite, $FeCr_2O_4$

There is a nearly complete substitution of the divalent elements and limited substitution of the trivalent elements in the spinel crystal lattice, which results in a whole spectrum of spinel group minerals with various chemical compositions. The pure end-members of the spinel species are rare due to substitution and the hybrid minerals are more common.

Chromite is typically found as octahedrons sometimes with dodecahedral truncations, and rarely as cubes. Twinning is common on the octahedral face *o*(111), known as spinel twins. Cleavage is imperfect parallel to the octahedral plane—*o*(111) and the fracture is conchoidal (Dana and Ford, 1949) although Bauer (1968) and Kievlenko (2003) indicated that cleavage is absent or very imperfect at best.

Chromite forms black, submetallic granular grains and less commonly octahedral grains. It may be found in serpentinite and similar ultramafic rocks. In hand specimen or under the microscope, chromite appears similar to magnetite. However, chromite will be weakly to nonmagnetic, while magnetite is strongly magnetic. Chromite will yield a brown streak.

Localities

Chromite has been reported at a few localities in Wyoming. These include Halleck Canyon east of Mill Creek in the central Laramie Mountains (section 13, T22N, R72W). In this area, chromite veinlets and disseminated chromite occur in serpentinite (Fields, 1963; Graff and others, 1982).

In Deer Creek canyon (section 11, T31N, R77W) about 15 miles southwest of Glenrock, a serpentinite belt contains fine-grained compact masses of chromite in layers ranging from 2 to 5 feet wide (Spencer, 1916; Beckwith, 1939). A rare chromium chlorite mineral, kammererite, was also identified in this deposit (Diller, 1920). On Casper Mountain in the SW section 16, SE section 17, and NE section 20, T32N, R79W, disseminated chromite, along with lenses and pods of chromite, is scattered throughout the talc schist (Beckwith, 1939).

CHRYSOCOLLA
$CuSiO_3 \bullet 2H_2O$

H = 2 to 4
SG = 2 to 2.8
Crystal System – Cryptocrystalline
Color – Azure blue
Luster – Vitreous

Physical characteristics and crystal habit

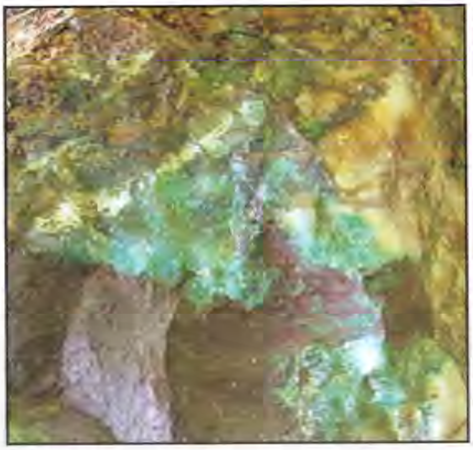


Figure 40. Blue-green chrysocolla with massive red cuprite from the Sunday Morning prospect, Seminoe Mountains, Wyoming.

Chrysocolla has not been found at many places in Wyoming. Where found, it produces distinct azure-blue compact masses and crusts associated with other copper minerals. It is sometimes mistaken for azurite, but unlike azurite, chrysocolla will not react to hydrochloric acid, since it is a silicate. Chrysocolla also has a distinct vitreous luster unlike azurite which is dull blue. Chrysocolla has also been mistaken for turquoise, but chrysocolla has an inferior hardness compared to turquoise (H = 5 to 6) and turquoise has not been identified in Wyoming.

Locality

Chrysocolla has been reported at several prospects and mines in the state including the Rogers Canyon prospects (sections 10, 15 & 22, T16N, R72W) and the Wallrock Canyon prospect (section 36, T19N, R73W) in the Laramie Range, the DePass mine (section 23, T40N, R92W) in the Owl Creek Mountains and the Doane-Rambler mine (NE section 25, T14N, R86W) in the Sierra Madre. Some of the better samples consist of coatings and crusts on cuprite in milky quartz that have been found at the Sunday Morning prospect (SE section 29, T26N, R85W) (**Figure 40**) in the Seminoe Mountains (Hausel, 1994b).

CLINOPTILOLITE
$(Na,K,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36} \bullet 12H_2O$

H = 3.5 to 4
SG = 2.1-2.2
Crystal System – Orthorhombic
Color – White to light-green
Luster – Earthy

Physical properties

Clinoptilolite forms lightweight, white to light-green earthy granular masses with good water-absorbing and ion-exchange properties. A wet tongue tends to stick to this mineral because of its excellent water-absorbing capacity. Since it is formed from the alteration of ash fall tuffs, this mineral is typically found in some localized areas in the Wyoming basins.

Zeolites, a generic term for a group of minerals including clinoptilolite, have been used in water softeners, in the manufacture of catalysts for oil refining, and for kitty litter because of their effective odor-absorbing ability. Large regions south of Tipton in the Greater Green River Basin are underlain by bedded clinoptilolite that occurs in the Laney Shale Member of the Green River Formation.

COLUMBITE –TANTALITE
$(Fe,Mn)(Ta,Nb)_2O_6$

H = 6 to 6.5
SG = 5.15 to 8.2 (increasing density with increasing Ta_2O_6 towards the tantalite end member)
Crystal System – Orthorhombic
Color – Black to brownish black
Luster – Submetallic

Figure 41. Single crystal of columbite-tantalite from the Big Creek district, Carbon County, from the Ralph E. Platt collection (photograph by Mel Dyck).

Physical characteristics and crystal habit

Columbite-tantalite may occur as thin to thick tabular, equant, prismatic crystals (less commonly pyramidal) with good side pinacoidal cleavage, or as compact masses in granite pegmatites. Typically, it is found as compact masses in Wyoming. Twinning on (201) is common. It may be heart-shaped with pinnate striations parallel to (010), or as pseudohexagonal *trillings* (cyclic crystal twins consisting of three individuals). Cleavage is distinct on (010) and less distinct on (100). The mineral is black to brownish black, opaque, submetallic to weakly vitreous, typically with an iridescent tarnish. It produces a black, brownish black, or reddish brown streak.

Localities

Several pegmatites in the Big Creek district of the North Platte Valley contain rare-earth minerals. The Platte pegmatite (SW section 3, T13N, R81W) is an exceptional rare-earth-rich pegmatite. It has a central core of quartz-mica-feldspar-rare-earth minerals and an outer rim of feldspar. Rare-earth minerals occur as large individual crystals and as crystal aggregates, and include columbite-tantalite associated with euxenite and monazite. Euxenite is the most common, followed by monazite and columbite (Houston, 1961). Some exceptional specimens of columbite-tantalite were recovered from the Platt pegmatite (**Figure 41**).

CORDIERITE
$(Mg,Fe)_2Al_4(Si_5O_{18})$

H = 7-7.5
SG = 2.6-2.66
Crystal System – Orthorhombic
Color – Gray, blue, violet, brown
Luster – Vitreous
Also see **Kyanite**, **Sillimanite**, **Andalusite**

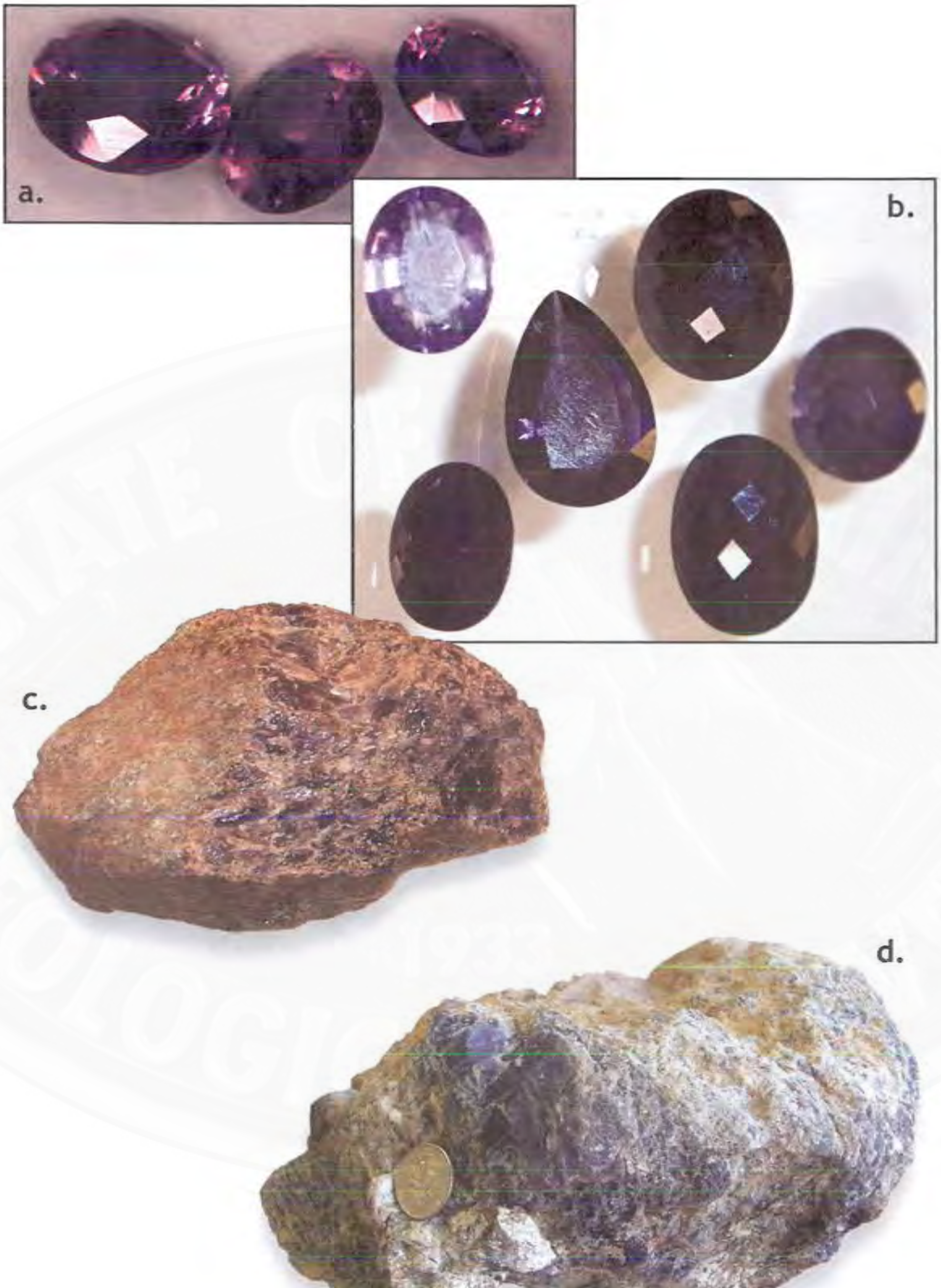


Figure 42. (a) Faceted iolite gems from material collected from Palmer Canyon (photo by Robert W.Gregory). (b) Beautiful large (4 to 6 carat) iolite gemstones from Palmer Canyon (specimens from the Vic Norris collection (photograph by Robert W. Gregory). (c) Large 1,750-carat rough iolite from Wyoming. (d) Massive transparent 24,500-carat cordierite (iolite) from Grizzly Creek.

Physical characteristics and crystal habit

Cordierite typically forms orthorhombic (pseudohexagonal) crystals with short prismatic habit that are found in mica-rich gneiss or schist. Where found in Wyoming, the crystal habit is often rounded, small, pebble-like grains, massive nodules, and/or disseminated grains. Due to alteration, cordierite may be partially replaced by sericite and quartz, or it may occur as translucent to transparent dark-gray, smoky, blue to violet crystals. Transparent grains are strongly pleochroic with vitreous luster and may produce very attractive gemstones (**Figures 42a** and **42b**).

The mineral is brittle, has conchoidal fracture, and may have poor cleavage parallel to b(010) and parting parallel to c(001). It ranges in hardness from 7 to 7.5 and has a specific gravity of 2.55 to 2.75. Cordierite is sometimes referred to as dichorite due to its strong pleochroism, which results in transparent to translucent minerals that appear to change shades of color depending on the angle viewed. In one direction, the mineral will appear sapphire-blue. When rotated, it may appear light grayish-blue to grey.

Occurrence

Cordierite forms distinct porphyroblasts in muscovite schists in some metamorphosed sedimentary rocks known as metapelites. The mineral is sometimes found in these aluminosilicate-rich rocks in metamorphic terrains in the Precambrian cores of some of Wyoming's mountain ranges.

Associated Minerals

Cordierite is often found with other aluminosilicates such as muscovite, sillimanite, andalusite, and/or kyanite. Sometimes corundum (sapphire and ruby) are found in adjacent aluminum-rich, quartz-poor rocks such as vermiculite (glimmerite) or serpentinite. Cordierite may be mistaken for andalusite.

Localities

Specimens of oval-shaped cordierite and quartz-sericite pseudomorphs after cordierite that are locally referred to as "peanuts" or "almonds" occur in metagreywacke schist near South Pass City in the southern Wind River Range. Where found, these are elongated in the plane of foliation and consist of dark-gray to black, opaque cordierite enclosed in a yellow-brown reaction rim (envelope). The rim is comprised of sericite and quartz, which partially to completely replaces the host mineral. According to Bayley and others (1973), these porphyroblasts were originally andalusite. XRD analysis of samples collected in the vicinity of the Rose gold mine at South Pass produced patterns characteristic of cordierite (Hausel, 1991).

Several miles southeast of the Rose mine, near the Sweetwater River, good tabular black crystals with square cross sections occur. These cross sections average 1/2 to 1/4 inch in diameter. These crystals are found in a narrow band of schist in the extreme southeastern corner of section 24, T29N, R98W, (Lewiston Lakes Quadrangle) within the Goldman Meadows Formation (Hausel, 1988b). Some of these exhibit prisms with pseudohexagonal cross section and are probably cordierite.

In the Palmer Canyon area of the Laramie Mountains, west of Wheatland, cordierite gneiss is found in association with spectacular kyanite schist containing minor sillimanite. Some of the cordierite was faceted producing flawless, transparent iolite gemstones. Nearby, a corundum-mica-kyanite-schist contains 0.1 to 1 inch long prismatic porphryoblasts of red, white, and pink corundum, some of which have also been faceted (Hausel, 2002). Additionally, much of the kyanite is gem-quality and of cabochon grade. Similar gem-quality cordierite (iolite) has been found in the Grizzly Creek area (NE section 35, T24N, R71W), where spectacular massive transparent cordierite weighing a few thousand carats was recovered by the author. Transparent cordierite is also found in anorthosite-syenitic rocks near Sherman Mountain along the North Fork of Horse Creek. Some cordierite has also been reported north of Palmer Canyon at Owen Creek (sections 9 and 10, T25N, R71W) (Hausel and Sutherland, 2004).

Sinkankas (1959) mentioned gem-quality iolite found in Wyoming, including a deposit with an estimated 500,000 tons. Unfortunately, no location was given nor did he mention how the tonnage estimate was derived. If valid, this iolite occurrence could potentially host 2.7 trillion carats (Hausel and Sutherland, in preparation). It is speculated that the deposit is either the Grizzly Creek or more likely the Horse Creek. Either way, the Wyoming iolite resources represent the largest in the world. The two largest iolite gemstones were found in Wyoming by the author. These included the Palmer Canyon Blue Star of 1,750 carats (**Figure 42c**) and the Grizzly Creek Blue Giant of 24,500 carats (**Figure 42d**) (Hausel and Sutherland, in preparation).

CORUNDUM
Al_2O_3

H = 9
SG = 4 to 4.1
Crystal System – Hexagonal
Color – Gray, white, blue, violet, pink, brown, and red
Luster – Adamantine to vitreous

Physical characteristics and crystal habit

Corundum is considered to be the second hardest naturally occurring mineral. Only diamond is harder. Corundum occurs as barrel-shaped hexagonal prisms with rough, rounded surfaces (**Figure 43a**) and often exhibits distinct parting. Because of good rhombohedral and basal parting, corundum prisms often terminate at basal pinicoids and display striations due to repeated twinning (**Figure 43b**).

Corundum exhibits a variety of colors including gray, grayish green, blue, pink, brown, red, and purple. Some corundum is used to produce extraordinary gemstones. Ruby is the deep pigeon's-blood red translucent to transparent variety of corundum; sapphire includes all other colors (**Figure 43c**). Corundum will display a striking adamantine to vitreous luster that is more noticeable in faceted gemstones. Corundum's high specific gravity is favorable for concentration of the mineral in black sand concentrates in streams. For example, during sampling in the central Laramie Mounatins, panners from the Wyoming State Geological Survey identified corundum in a small group of sample concentrates in that region.

Occurrence

Corundum, a high-pressure aluminum oxide, is generally found with silica-poor aluminum-rich metamorphic rocks within areas containing metapelites. The metapelites typically contain a variety of aluminosilicate porphyroblasts such as mica, kyanite, sillimanite, andalusite, vermiculite, and cordierite. The corundum itself is typically found in vermiculite and/or aluminum-rich serpentinites.

Localities

Corundum has been found at a number of places in Wyoming (Hausel and Sutherland, 2000). One of the better known localities lies northwest of Jeffrey City. At this location, known as the Red Dwarf deposit (sections 13 and 24, T30N, R93W), corundum gneiss and schist were mapped over a 5,000-foot strike length with widths of 20 to 50 feet (Hausel, 1996b). The rock has 1 to 10% corundum porphyroblasts encased in fuchsite reaction rims and also contains considerable fuchsite and zoisite pseudomorphs after corundum.

The corundum may be light purplish-pink, lavender, or reddish-purple, and individual minerals range from millimeter size to more than 2 inches across. Some gem-quality corundum has been found on the property (Love, 1970). Partially replaced specimens of ruby provide evidence for rubies up to 5 inches in length. A nearby serpentinite discovered to the west of the ruby schist by Robert Odell contains tiny (millimeter-size), light-blue, translucent to opaque corundum. Locally, the serpentinite has 20 to 40% corundum (Hausel, personal field notes, 1995). At the Aberna-

Figure 43. (a) Hexagonal rough corundum (pink sapphire) prism in schist from Palmer Canyon. This specimen is estimated to be 50+ carats. (b) Ruby cabochon (3 carats) from North Platte Valley exhibiting distinct rhombohedral parting (photograph by Meg Ewald). (c) Group of blue iolites with a square cut oriental sapphire, red rubies, and pink sapphires (from the Vic Norris collection). (d) High-quality faceted 1.1 carat transparent ruby cut from Palmer Canyon corundum (photograph courtesy of Chuck Mabarak).

thy deposit (section 26, T30N, R96W) near Sweetwater Station, pale-blue and white corundum is found in mica schist. The corundum is abundant and occurs as 1-inch diameter nodules in the schist (Love, 1970).

Another corundum deposit is associated with vermiculite schist (glimmerite) west of Wheatland in Palmer Canyon. This deposit (N/2 section 18, T24N, R70W) is associated with kyanite, cordierite, and sillimanite schist and gneiss. The corundum forms small hexagonal pink, red, purplish-red, and white grains from about 0.1 to 0.3 inches across. Many of the grains have well-developed parting which limits the size of facetable material. Even so, a significant percentage of specimens have excellent color and are transparent (**Figure 43d**) (W.D. Hausel, personal field notes, 1997). Locally, the schist may contain more than 20% corundum. Small amounts of corundum have also been identified at the Grizzly Creek iolite (cordierite) deposit to the south and other localities to the north.

Some corundum has also been identified in vermiculite schist in the North Platte River Valley between the Medicine Bow Mountains and Sierra Madre. Another notable corundum locality is located in the Big Sandy opening along the southern margin of the Wind River Range. Prospectors (Russ and Joe Sims, personal communication) have collected hundreds of corundum crystals weighing up to 90 carats from the Squaw Creek placer. The source of this corundum undoubtedly is somewhere nearby as schist specimens with gem-quality ruby have been found nearby.

COPPER

Cu

H = 2.5 to 3
SG = 8.95
Crystal System – Isometric
Color – Metallic copper-red
Luster – Metallic

Physical characteristics and crystal habit

Native copper forms distinct copper-red metallic grains, dendrites, or masses that are noticeably heavy (**Figure 44**). It will produce a shining metallic copper streak and is always found with other copper minerals such as malachite and cuprite.

Localities

Native copper is not common in Wyoming presently. However, large masses of native copper were found during the initial copper mining rushes in the state in the late 1800s. These large masses of copper were found near the surface in supergene enriched zones in the Hartville and Encampment districts (Dyck and others,1994).

Figure 44. Group of native copper crystals and masses with a single cubic crystal in the center of the photograph (about 1 inch in diameter) from the Big Creek mine (NW section 9, T13N, R81W). Ralph E. Platt, Jr. collection (photograph by Mel Dyck).

COVELLITE
CuS

H = 1.5 to 2
SG = 4.68
Crystal System – Hexagonal
Color – Dark indigo-blue
Luster – Submetallic to dull

Physical characteristics and crystal habit


Figure 45. Iridescent metallic blue and violet covellite.

Covellite is a dark indigo-blue copper sulfide that is typically foliated. As crystals, covellite may occur as thin, hexagonal plates flattened on the (0001) crystallographic axis while exhibiting hexagonal striations on the basal pinacoid. It will produce a shining, gray-black streak (**Figure 45**).

Localities

Covellite is not common in the state, but has been reported at a few copper deposits. For example, it has been reported in the Lake Alice district in the Overthrust Belt in western Wyoming, in the New Rambler district in the Medicine Bow Mountains, and in the Encampment district in the Sierra Madre. The most notable deposit was the New Rambler mine (SW section 33, T15N, R79W) (see **Sperrylite**) where platinum-bearing covellite and platinum-bearing chalcocite were discovered in the supergene enriched zone at depth. The other notable deposit is the Ferris-Haggarty mine (section 16, T14N, R86W) in the Sierra Madre.

Covellite found at the Ferris-Haggarty mine was common in the ore zone in underground mine workings. It is associated with chalcopyrite, pyrite, malachite, chalcocite, and bornite in a gangue of quartz and limonite. It occurs as distinct, foliated, submetallic to earthy masses on fractures in the sheared and unsheared metaconglomerate host rock.

CUPRITE
Cu_2O

H – 3.5 to 4
SG – 5.8 to 6.2
Crystal System – Isometric
Color – Earthy red
Luster – Earthy

Physical characteristics and crystal habit

Cuprite forms brittle, earthy, red masses with high heft and also occurs as stains on cupriferous rocks associated with other copper minerals (**Figure 46**). It is often found with malachite and tenorite on many copper mine dumps in Wyoming. It has an uneven to conchoidal fracture.

Chemical identification

Pouring muriatic acid (dilute hydrochloric acid) on a suspected specimen of cuprite and rubbing a well-used rock pick on the material will yield a reddish brown mud. When the mud is wiped off, native copper will be seen replacing the surface of the hammer. This same test can be used for several other cupriferous minerals including tenorite.

Figure 46. Massive earthy red cuprite with minor green malachite and black tenorite stains from the Junk Creek mine, Seminoe Mountains.

Localities

Several mine dumps in the Encampment district of the Sierra Madre contain cuprite. Within the Huston Park area in the southwestern Sierra Madre, a group of historical mines and prospect pits were originally developed for copper and zinc. Several of these in the vicinity of the Itmay mine (section 14, T13N, R86W) and prospect 9999 (W/2 section 15 and E/2 section 16, T13N, R86W) have scattered occurrences of pyrite, tenorite, cuprite, and marmatite (Hausel, 1997).

Although limited in quantity, some of the better cuprite specimens collected by the Wyoming State Geological Survey were found in the Seminoe Mountains north of Sinclair. A large (5-inch diameter) massive piece of solid cuprite was collected from a prospect near the Junk Creek mine (SW section 20, T26N, R85W). The Junk Creek mine and nearby prospects have some malachite, bornite, chrysocolla, and chalcopyrite along with occasional specimens of cuprite. Other specimens of massive cuprite filling fractures in milky quartz with crusts of chrysocolla were found on the Sunday Morning prospect (SE section 29, T26N, R85W), also in the Seminoe Mountains (Hausel, 1994b).

DIAMOND
C

H = 10
SG = 3.52
Crystal System – Isometric
Color – Colorless, green, brown, yellow, black
Luster – Adamantine

Physical characteristics and crystal habit

Diamonds occur as colorless, pearly-white, brown, yellowish-brown, green, black, and rarely pink or blue crystals. They may be transparent to translucent or even opaque with brilliant adamantine to greasy luster. They exhibit perfect octahedral cleavage and conchoidal fracture. Even though diamond is hard, it is brittle and will easily break. The primary crystal habit of diamond is that of an octahedron (eight-sided bipyramid), but many modifications are seen in the diamond crystal habit including dodecahedrons and other modifications (**Figure 47**). Most diamonds found in Wyoming are clear (less often black to brown) octahedrons, dodecahedrons, macles, twins, and irregular crystals.

Diamond crystals tend to have etched triangles visible on the octahedral (111) crystal faces. Many diamonds are weakly fluorescent. Diamonds are also hydrophobic (nonwettable) and naturally attracted to grease. In other words, uncoated diamonds will tend to adhere to grease. Diamonds can also be induced to float on water, even though they are 3.5 times heavier than water (Hausel and others, 1985).

Associated minerals

Diamondiferous kimberlite often contains a host of rare minerals, including abundant minerals that are known as kimberlitic indicator minerals. These include pyrope garnet, chromian diopside, chromian enstatite, picroilmenite, and chromite. The pyropes and chromian diopsides are sometimes gem in character.

Occurrence

Diamonds have been reported in many different rock types around the world (Erlich and Hausel, 2002). The more common diamondiferous host rocks are kimberlite and lamproite, both of which are relatively abundant in Wyoming (Hausel, 1998). For instance, Wyoming hosts the largest field of lamproites in North America (Leucite Hills) and also includes the two largest kimberlite districts in the nation (Iron Mountain and State Line districts) (Hausel and others, 1979, 1995a, 1995b, 2000, 2003; Coopersmith and others, 2003). In addition, other diamondiferous rocks, assumed to have lamprophyre affinity, are found near Cedar Mountain in the Greater Green River Basin (Hausel and others,1999).

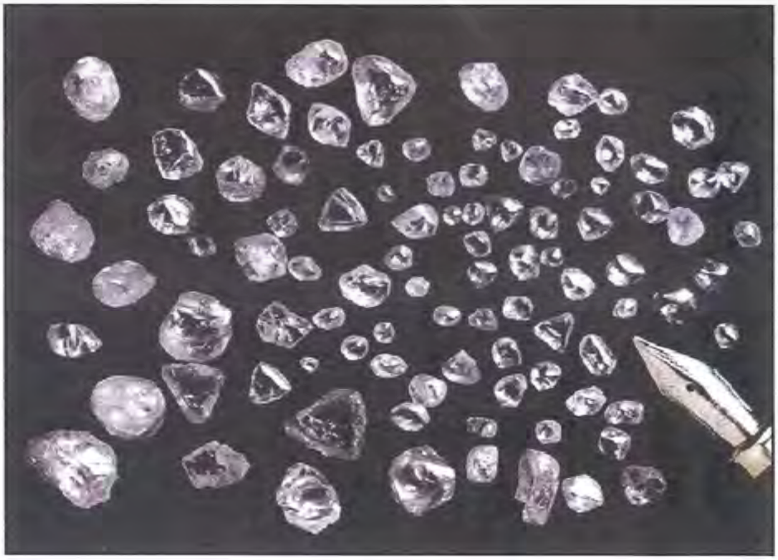


Figure 47. Gem-quality diamonds with various crystal habits from the Kelsey Lake diamond mine, Colorado-Wyoming State Line district (photograph courtesy of Howard Coopersmith).

The largest verified diamond from Wyoming weighed 6.2 carats (Howard Coopersmith, personal communication, 1997) and was recovered in Fish Creek in the Colorado-Wyoming State Line district south of Laramie. Larger (unverified) diamonds have been reported in the state including a large stone (0.5 inch in diameter) reportedly found in the Wind River Range and a 7- to 9-carat gemstone from the Gros Ventre Range (J.D. Love, personal communication).

A short distance south of the Colorado-Wyoming state line, gem-quality diamonds weighing more than 28 carats have been recovered from kimberlite at the Kelsey Lake mine in Colorado and an octahedral fragment from a diamond estimated to weigh up to 80 carats was also recovered (Howard Coopersmith, personal communication, 1997). This same kimberlite is part of a cluster extending a few miles north into Wyoming. Thus, one would expect to see similar diamonds in some kimberlites in Wyoming.

The gem-quality diamonds have an unusually high percentage of beautiful brilliant white colors. Of all of the diamonds recovered in Wyoming, 50% are gem quality. Industrial diamonds are frosted, contain numerous mineral inclusions, or are badly flawed in some other way to make them unsuitable for gems. *Bort diamonds* are granular to microcrystalline diamonds that are often colored brown, gray, or black. These are poor-quality stones that are crushed and used for abrasives. *Carbonado* is a black opaque bort composed of amorphous carbon and diamond. *Grit* consists of broken diamond fragments with sharp edges. Of the industrial diamonds recovered in Wyoming, the greatest number are better-grade stones that can be used for drill bits and other cutting tools. Only a small percentage of these are classified as bort.

Localities

Diamonds have been recovered from kimberlite 20 miles south of Laramie. More than 130,000 diamonds were found in the State Line district in this area in the past. Several kimberlites intrude Sherman Granite a short distance west of Highway 287 near the Colorado-Wyoming state line. These rare volcanic rocks occur in sections 5, 8, 9, 16, and 21, T12N, R72W (Hausel and others, 1979, 1981).

Diamonds have also been recovered from the northern Medicine Bow Mountains. Two octahedral diamonds were found in Cortez Creek in N/2 NW section 2, T16N, R81W. The larger of these two stones weighed approximately 0.1 carat. These were good-quality clear stones with minor mineral inclusions. The source of the diamonds was never found, but several kimberlitic mineral indicator anomalies were identified nearby that provide physical evidence for undiscovered kimberlites in the area.

At least one macro-diamond and some micro-diamonds were recovered from kimberlite in the Iron Mountain district (Coopersmith and others, 2003). Several diamonds have been recovered from mantle-derived breccia pipes on Cedar Mountain in the Greater Green River Basin (Richard Kucera, personal communication, 1995). Other diamonds have been reported from Butcherknife Draw of the Green River Basin, the Wind River Range, the Granite Mountains, and the Gros Ventre Range (Hausel, 1998).

DOLOMITE
$CaMgCO_3$

H = 3.5-4
SG = 2.85 (low heft)
Crystal System – Hexagonal
Color – White, gray, brown
Luster – Vitreous to dull
Also see **Calcite**

Physical characteristics and crystal habit

Dolomite is found as white, gray, or brown masses and rhombohedral crystals, often with curved faces. Dolomite exhibits a vitreous to dull luster and perfect rhombohedral cleavage. When scratched, it will produce a white streak. One method of identification involves testing the crushed, powdered mineral with cold, dilute hydrochloric acid. Powdered dolomite will react weakly with the acid, producing effervescence that is not as dramatic as calcite (**Figure 48**).

Occurrence

Dolomite is found in sedimentary and metasedimentary environments often associated with limestone and/or marble.

Localities

Dolomite has been reported at several places in Wyoming (Osterwald and others, 1966). One very distinct dolomite (metalimestone) occurs in the Nash Fork Formation in the Medicine Bow Mountains. This unit is Precambrian in age and contains several well-preserved algal domes and reefs (Hausel, 1993). Other dolomites are reported by Osterwald and others (1966) in the Casper, Phosphoria, Amsden, and Darby formations: the Bighorn Dolomite and Madison Limestone.

Figure 48. Dolomite partially replaced by epidote from the Bighorn Dolomite, southern Bighorn Mountains, Wyoming (photograph by Kathy Walker).

Dolomite has also been reported as a gangue mineral in some veins. For example, in the Medicine Bow Mountains (SW section 35, T15N, R80W), poorly exposed, 1- to 3-foot wide copper veins are found in Precambrian granite. The vertical veins were exposed in several trenches and two shafts and have a northerly strike. In one quartz vein, mineralization included malachite, azurite, and chrysocolla. Gangue minerals included potassium feldspar, dolomite, hematite, and limonite. This prospect lies a short distance west of the New Rambler district.

EPIDOTE

$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$

H = 6-6.5
SG = 3.2-3.5
Crystal System – Monoclinic
Color – Distinct pistachio green
Luster – Vitreous

Figure 49. Pistachio green veinlet of epidote in Sherman Granite from the Silver Crown district, Laramie Range.

Physical characteristics and crystal habit

Epidote occurs as distinctive pistachio green veinlets and replacements of mafic minerals (i.e., biotite, amphibole) and feldspars in many granitic and metamorphic rocks in Wyoming (**Figure 49**). It has a vitreous luster with perfect basal cleavage and a hardness of 6 to 6.5.

Occurrence

Epidote is found in many of Wyoming's mountain ranges and is typically associated with a late retrograde metamorphic event which resulted in the replacement of primary minerals in the host metamorphic and plutonic rocks due to the interaction of metamorphic fluids with the rocks. Pervasive epidotization found locally suggests that the affected rocks were hydrothermally altered. This type of pervasive alteration is seen in the state's porphyry copper, silver, gold, zinc, and lead deposits in the Absaroka Range (i.e., Kirwin, Stinkingwater, Eagle Creek, Sunlight Basin, and others) (Hausel, 1982) as well as in the Copper King copper-gold porphyry in the Silver Crown district of the Laramie Mountains west of Cheyenne.

Associated minerals

Where rocks are altered to epidote with chlorite and calcite (known as propylitic alteration), some disseminated pyrite is often found.

Localities

Epidote can be found in most mountain ranges in Wyoming. A few areas with pervasive epidote include the Copper King mine (NW section 36, T14N, R70W) in the Silver Crown district of the Laramie Range. The Copper King mine is thought to represent a Precambrian gold-copper porphyry deposit and epidote is accompanied by low-grade copper and gold mineralization. Epidote is also prominent in the Rambler prospect (E/2 SE NE section 22, T14N, R70W) in Curt Gowdy State Park. Here, pervasive epidote occurs with chlorite, calcite, pyrite, chalcopyrite, limonite, minor sphalerite, and specularite (Hausel, 1997). Epidote is also commonly found with nephrite, chlorite, and zoisite in the vicinity of many jade deposits in the Tin Cup district near Jeffrey City (Hausel, 1996b) (see **Nephrite**).

Propylitic alteration is also associated with many porphyry copper deposits in the Absaroka Range. The intensity of the alteration, which includes common epidote, increases towards the porphyry centers (Hausel, 1982). Intensive pervasive propylitic alteration (with chlorite, epidote, and some copper sulfides) occurs at Black Rock Gap in the Granite Mountains (S/2 section 32, T31N, R91W) of central Wyoming.

Here, a wide variety of minerals are found, but only a cursory reconnaissance of the mineralized area has been conducted by the Wyoming State Geological Survey.

EUXENITE
$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$

H = 6.5
SG = 4.7-5.0
Crystal System – Isotropic (pseudo-orthorhombic)
Color – Brownish black
Luster – Vitreous

Physical characteristics and crystal habit

Euxenite is an extremely rare complex radioactive oxide that forms masses and rarely crude pseudo-orthorhombic crystals (**Figure 50**). It is ordinarily coated with pale-yellow, earthy alteration products and is typically found in some rare-earth bearing pegmatites. It shows perfect basal cleavage, yields a white streak, and is found as replacements of former minerals or as fibrous masses.

Figure 50. Single crystal of euxenite from the Platt mine, Big Creek district, Ralph E. Platt, Jr. collection (photograph by Mel Dyck).

Occurrence

World-class specimens of euxenite were once recovered from the Platt (Uranium King) mine in the Big Creek district of the Medicine Bow Mountains. Many of these now reside in the Ralph E. Platt, Jr. collection.

FELDSPAR
aluminosilicates of sodium, potassium, and calcium

H = 6-6.5
SG = 2.56 to 2.59 (K-feldspars); 2.62 to 2.76 (Na-Ca feldspars)
Crystal System – Monoclinic or triclinic
Color – Colorless, yellow, pink, green, white
Luster – Vitreous

Physical characteristics and crystal habit

The feldspars represent one of the most common groups of minerals found in the Earth's crust. Only quartz is thought to be more common at the surface. The feldspars are represented by two groups of solid solution aluminosilicates. One group, known as the alkali feldspars, is potassium-rich and forms a solid solution with albite (sodium-rich feldspar), such that substitution of sodium for potassium occurs in the crystal chemistry. The second group, the plagioclase feldspars, is dominated by albite as the sodium-rich feldspar member and anorthite as the calcium-rich member. The remaining plagioclase feldspars are hybrids that exhibit variable amounts of both calcium and sodium. Plagioclase feldspar typically forms tabular crystals, whereas the potassium feldspars produce prismatic crystals (**Figures 51a** and **51b**).

Alkali Feldspars	**Plagioclase feldspars**
Orthoclase, $KAlSi_3O_8$	Albite $NaAlSi_3O_8$
Microcline, $KAlSi_3O_8$	Oligioclase $(Na,Ca)AlSi_3O_8$
Sanidine, $KAlSi_3O_8$	Andesine $(Na,Ca)AlSi_3O_8$
Albite $NaAlSi_3O_8$	Labradorite $(Ca,Na)AlSi_3O_8$
	Bytownite $(Ca,Na)AlSi_3O_8$
	Anorthite $CaAlSi_3O_8$

Orthoclase, a common potassium feldspar found in granites, forms monoclinic crystals indicating that one set of crystal faces are inclined to the others (i.e. *mono* meaning one, and *clinic* meaning inclined). Microcline is triclinic such that all crystal faces are inclined to one another (*tri* meaning three). Due to perfect cleavage and relatively low hardness, the feldspar minerals are fragile.

Plagioclase (unlike the potassium feldspars) tends to twin repeatedly to produce distinct and marked striations on the crystal faces perpendicular to the twin planes. The striations are often visible under a microscope or with a hand lens. Striations are particularly notable in cleavelandite, a bladed variety of albite feldspar. Cleavelandite is often found in some gem-bearing pegmatites, as well as in labradorite where the striations appear as thin streaks showing color differences (Sinkankas 1959).

Feldspars have good prismatic cleavage and exhibit perfect to near perfect cleavage in one direction, while the second cleavage is less perfect. According to Sinkankas (1959), the term *orthoclase* is taken from the Greek for *right cleave* suggesting that the cleavage planes intersect one another at right angles. And *microcline* is also taken from the Greek *micro* and *cline*, indicating a very small inclination of its cleavage planes from 90°. The term *plagioclase* was taken from the Greek *oblique cleavage,* indicating that the plagioclase group of feldspars show a departure from right angle cleavage. For the plagioclase series, the specific gravity is lowest (2.62) for the sodium end member (albite) and gradually increases to 2.76 for the calcium end member (anorthite).

Feldspars are typically white, gray, or creamy to light pink in color and are found in a variety of host rocks. Less common colors include smoky gray, yellowish, and greenish to greenish-blue tints. The plagioclase series feldspars are typically white. Less often, specimens may be yellowish to slightly greenish.

Figure 51. (a) Microcline specimen from Copper Mountain. b) Sanidine twin from Utah.

Some labradorite is light to dark gray to black, whereas other labradorite feldspars have a distinctive fire, making them a semi-precious gemstone. The potassium feldspars may be white to salmon-pink in color.

Feldspars are common rock-forming minerals typically found as major to minor mineral constituents of many rocks. Rarely do feldspars have attractive colors, sheens, or transparency and thus few are used as gemstones. But when they do exhibit these characteristics, they are responsible for a variety of gemstones, which include moonstone, amazonite, sunstone, and labradorite (**Table 9**).

Table 9. Gemstone Feldspars

Alkali Feldspars	Gem Varieties
Orthoclase (Adularia)	Moonstone (water opal), sunstone, larvikite
Sanidine	Transparent smoky-brown gemstone
Microcline	Amazonite
Albite	Moonstone, peristerite
Plagioclase Feldspars	Gem varieties
Albite	Moonstone, peristerite, larvikite
Oligioclase	Sunstone, moonstone
Andesine $(Na,Ca)AlSiO_3O_8$	
Labradorite $(Ca,Na)AlSi_3O_8$	Labradorite, spectrolite
Bytownite $(CaNa)AlSiO_3O_8$	
Anorthite $(Ca,Al)SiO_3O_8$	

Source: Hausel and Sutherland, in press.

Occurrence

Plagioclase feldspar is best seen in the Laramie anorthosite-syenite complex in the central Laramie Mountains, particularly in outcrops along State Highway 34 through Sybille Canyon. Anorthosite is an igneous rock composed almost entirely of plagioclase feldspar. The Laramie Anorthosite Complex is exposed over nearly 350 square miles and samples can be collected over a wide region. The anorthosite crops out along the Ninth Street Road in Rogers Canyon 11 miles northeast of Laramie, and specimens can be gathered along Highway 34 in Sybille Canyon north of Laramie.

The potash or potassium-rich feldspars include microcline and orthoclase. Large crystals of potash feldspar are common in granites and associated pegmatites at many sites in Wyoming. A variety of potassium feldspar known as microcline, which forms at relatively low temperatures, was once mined on Casper Mountain in sections 17, 18, and 20, T32N, R79W. Microcline was also mined on Copper Mountain north of Shoshoni and was recovered from several pegmatites in the Laramie Range along U.S. Highway 287 south of Laramie. The feldspar was used as an abrasive filler for household products and ceramics. It was also used to manufacture false teeth.

FLINT (see CHALCEDONY)

FLUORITE
CaF_2

H = 4
SG = 3.18
Crystal System – Isometric
Color – Violet, purple, green, or blue
Luster – Vitreous

Physical characteristics and crystal habit

Fluorite typically forms violet to dark purple cubic crystals or granular masses. When associated with radioactive minerals, fluorite tends to be dark purple to black. Fluorite has moderate heft, which means that some may be captured with black sands in a gold concentrator (such as a gold pan). It exhibits subconchoidal to splintery fracture and has perfect octahedral cleavage. It is relatively soft and easily crushed to a fine, white powder. Most fluorite will luminesce violet blue under ultraviolet light.

Figure 52. Purple to violet fluorite in tawny limonite boxworks from the Bear Lodge Mountains north of Sundance.

Localities

Fluorite is found in the Bear Lodge Mountains in northeastern Wyoming. Here it occurs as massive granular replacements of Pahasapa Limestone (**Figure 52**). Some small cubic crystals may be found in vugs in altered limestone in the same area. The Bear Lodge fluorite occurs near Tertiary intrusives where it is often found along the contact of the intrusive margin with limestone. Some good specimens have been found in sections 15, 23, 27, and 28, T52N, R68W.

Purple fluorite grains have also been found in a pegmatite near Pole Mountain in the Laramie Mountains (SW NW section 5, T15N, R70W; Osterwald and others, 1966). In this same area, the Wyoming State Geological Survey recovered several fluorite grains in stream sediment sample concentrates over a 30- to 40-square-mile area during diamond exploration. The principal use for fluorite is in the manufacture of hydrofluoric acid. In metallurgy, it is used as a flux and an electrolyte.

FUCHSITE (see MICA)

GALENA
(PbS)

H = 2.5
SG = 7.58
Crystal System – Isometric
Color – Lead gray
Luster – Metallic

Physical characteristics and crystal habit

Galena is a sulfide mineral often found with copper, zinc, and silver. It forms soft, lead-gray cubes and masses that have a noticeably high heft. It has subconchoidal fracture and a lead gray streak (**Figures 53a** and **53b**). The massive metallic material is cleavable parallel to perfect c(001) cleavage. Galena also has twinning on (111), (114), and (144). Galena may contain some silver within its crystal structure. Silver-rich (argentiferous) specimens will exhibit noticeable rounding or bowing of the cubic crystal faces.

Localities

Galena has been found at the Esterbrook mine (SE section 9, T28N, R71W) in the northern Laramie Mountains. Historical reports indicate that the mine workings intersected six foot wide ore shoots of solid galena. The galena was weakly argentiferous (Spencer, 1916). When the mine dump was examined in 1980, only scattered specimens of galena were found. These consisted of fracture fillings of galena in milky quartz. Parsons (1937) reported that galena was found with a variety of ore minerals in the Sunlight district in the Absaroka Range in northwestern Wyoming.

At Black Butte in the Black Hills, minor amounts of galena occur with hemimorphite, minor fluorite, jasper, and wulfenite. These are found as contact replacement deposits in limestone and limestone breccias of the Pahasapa Limestone (Mississippian) where intruded by trachyte. The mineralization occurs at the Black Butte prospect (NE section 26, T50N, R62W).

A minor amount of argentiferous galena is found at the Albion mine on Cooper Hill (W/2 section 27, T18N, R78W) in the Medicine Bow Mountains. The galena occurs in limonite-stained milky quartz and is found as fracture fillings in the quartz. The galena forms masses but cubes of galena are visible. In addition to galena, the mine also contains some chalcopyrite, chalcocite, and bornite.

Some galena at the Gold Coin prospect in the Sierra Madre is also found in limonitic milky quartz veins. It is found with pyrite, malachite, and chalcopyrite. The galena forms masses and occurs as cubes in lenses and pockets in the quartz.

At the Broadway Mine (SW section 32, T13N, R83W) in the Sierra Madre, a large gossan exposed on the side of the hill contains some

Figure 53. (a) Galena filling fractures in limestone from Black Buttes area, Black Hills. (b) Galena cube.

chalcopyrite, chalcocite, and bornite, as well as massive sphalerite and some galena in a host pyroxenite.

Some prospects in the Medicine Bow Mountains (SE SE section 34, T15N, R80W) also have some galena. McCallum and Kluender (1983) reported that several galena-bearing samples were collected from prospect pits in this area that contained anomalous silver. The samples assayed from 1.17 to 46.6 opt (ounces per ton) Ag (silver), with 1.0 to 2.0% Pb (lead), and 0.05% to 0.5% Zn (zinc). One sample also contained 0.13 opt Au (gold).

GARNET GROUP

H = 6.5-7.5
SG = 3.5-4.3 (to high heft)
Crystal System – Isometric
Color – Red-brown, reddish purple, black
Luster – Vitreous to resinous

Physical characteristics and crystal habit

Garnet is a common accessory mineral in many micaceous metamorphic rocks in Wyoming and has also been found in several kimberlites. When found in host metamorphic or pegmatitic rocks, garnets typically can range from a few millimeters to single minerals as large as 5 to 6 inches in diameter. Many Wyoming garnets are purplish-red, yellow-orange, or reddish-brown in color.

Six pure end-member garnet subspecies are recognized by mineralogists. These will vary in color, specific gravity, chemistry, and index of refraction. The subspecies include pyrope [$Mg_3Al_2(SiO_4)_3$], almandine [$Fe_3Al_2(SiO_4)_3$], spessartine [$Mn_3Al_2(SiO_4)_3$], grossularite [$Ca_3Al_2(SiO_4)_3$], andradite [$Ca_3Fe_2(SiO_4)_3$], and uvarovite [$Ca_3Cr_2(SiO_4)_3$]. However, in nature, garnets form solid solutions or mixtures of the end members. The pure end member compositions are uncommon. Thus, garnets are often described as solid-solutions.

Names have been given to some garnet species of intermediate composition in the solid solution series (**Table 10**). An additional example is the rose-red to purple *rhodolite* garnet, which has a chemical composition averaging a 2:1 mixture of pyrope to almandine. Another intermediate variety of garnet with a composition between pyrope and almandine (1:1 mixture of pyrope to almandine) is referred to

Table 10. Some Hybrid Garnets

Calderite	$Mn_3Fe^{3+}{}_2(SiO_4)_3$
Goldmanite	$Ca_3V_2(SiO_4)_3$
Hydrogrossular	$Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}$
Hibschite	$Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}$ (where $x=0.2$ to 1.5)
Katoite	$Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}$ (where $x>1.5$)
Kimzeyite	$Ca_3(Zr,Ti)_2[(Si,Al,Fe^{3+})O_4]_3$
Knorringite	$Mg_3Cr_2(SiO_4)_3$
Majorite	$Mg_3(Fe,Al,Si)_2(SiO_4)_3$
Morimotoite	$Ca_3Ti^{4+}Fe^{2+}(SiO_4)_3$
Schorlomite	$Ca_3(Ti^{4+},Fe^{3+})_2[(Si,Ti)O_4)]_3$

Source: Hausel and Sutherland, in press.

as *pyrope-almandine* (also known as Mozambique garnet). It exhibits a striking dark orange-red to red color. In Wyoming, almandine, pyrope-almandine, spessartine, and pyrope have been identified to date.

Garnets have relatively high specific gravity (3.5 to 4.3) and hardness (6.5 to 7.5). The high specific gravity results in garnets showing up in the heavy black sand concentrates in placer deposits. Garnets crystallize in the isometric crystal system, have no cleavage, and may show parting. They are typically transparent to translucent and often exhibit well-formed dodecahedral or trapezohedral habit. Garnets are used for abrasives, although excellent museum-quality garnets are often found. Some transparent to translucent garnets are used as semiprecious gemstones (**Figure 54a**).

Pyrope

Pyrope garnet is red to purple-red, but may also be yellow-orange when it contains some spessartine in solid solution. It has a specific gravity of 3.50 to 3.80 and exhibits a distinct rounded habit with no visible crystal faces. Pyrope has relatively high magnesium and chromium content and is associated with ultramafic igneous and metamorphic rocks. To date, essentially all pyrope garnets found in Wyoming have occurred as xenocrysts in kimberlite in the State Line and Iron Mountain districts of southeastern Wyoming, or have occurred as porphyroblasts in garnet peridotite xenoliths (nodules) hosted by the kimberlite. They have also been found as detrital grains in stream sediment samples over vast regions of the state, in anthills, and in sedimentary rocks eroded from kimberlitic pipes. In addition, pyropes have been found in some mafic breccia pipes (lamprophyres) along Cedar Mountain and in nearby anthills in the Butcherknife Draw area of the southern Green River Basin (**Figure 3**). The largest pyrope-almandine garnet found in Wyoming was about 5 inches across and found in kimberlite in the State Line district south of Laramie.

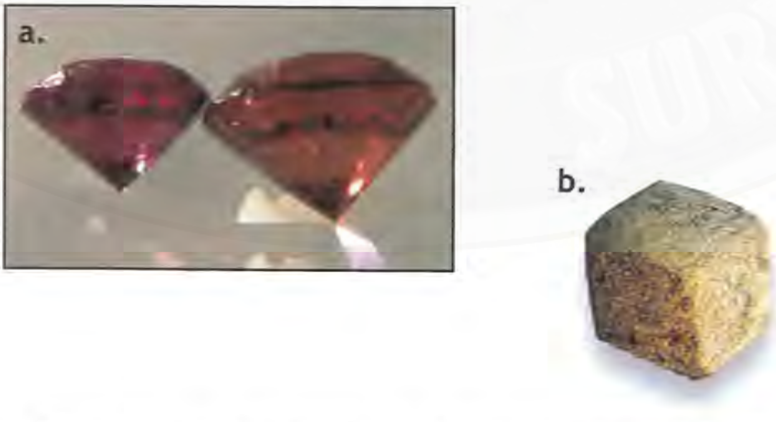


Figure 54. (a) Two pyrope gem garnets faceted from specimens collected from anthills in the Butcherknife Draw area of the Green River Basin (photograph by Robert W. Gregory). (b) Large (3-inch diameter) green chlorite pseudomorph after almandine garnet from the Oldman property near Encampment. Larger garnets up to 5 to 6 inches across have been found in granitic pegmatites near Tie Siding.

Almandine

Almandine garnets are red to reddish brown and have specific gravities of 3.85 to 4.32. Almandine garnets often exhibit good dodecahedral habit (**Figure 54b**).

Spessartine

Spessartine garnets are orange-red, orange, or yellow-orange with a specific gravity of about 4.2. Garnets of this type have been described in granite pegmatite in the Eagle Rock-Happy Jack area of the southern Laramie Mountains and in pegmatites at Copper Mountain in the Owl Creek Mountains.

Occurrence

Garnet is a common mineral in many metamorphic environments, particularly where the rocks have been metamorphosed to amphibolite grade and are aluminum-rich. Such rocks typically contain abundant black mica and may also have some amphibole with periodic porphyroblasts of garnet.

Localities

A number of garnet localities have been reported. These include translucent to opaque almandine garnets with good dodecahedral habit from the Teton Range and chlorite pseudomorphs after garnet from the Sierra Madre near Encampment. These latter pseudomorphs exhibit excellent dodecahedral habit, are opaque, and are completely to nearly completely replaced by chlorite mica, even though they retain a dodecahedral crystal habit. Some excellent 3- to 4-inch diameter crystals have been collected from a narrow schist at the Oldman prospect (NE section 14, T14N, R84W). The deposit, located south of Encampment along the Copper Creek road, forms a narrow chlorite schist (more than 10 feet wide) on both sides of the road about 1/2 mile south of the Oldman Ranch. The garnet-chlorite-schist crops out over a distance of approximately 2,000 feet, and contains large dodecahedral chlorite pseudomorphs after garnet. Several 0.5- to 3-inch diameter garnet pseudomorphs have been collected from this area. The interiors of many of the pseudomorphs contain primary, reddish-brown almandine garnet.

Some extraordinary pyrope-almandine garnet megacrysts have been found in kimberlite in the Colorado-Wyoming State Line district (T12N, R72W). Some rounded megacrysts as large as 5 to 6 inches across have been found in this region. Due to assimilation in the kimberlite magma during emplacement, these large garnets never exhibit any crystal faces and are always rounded with smooth surfaces.

In the same area, near Tie Siding (section 11, T12, R72W), several pegmatites were quarried for feldspar during the 1940s along U.S. Highway 287 east of the State Line diamond district. These pegmatites contain uncommon euhedral garnet (Osterwald and others, 1966). At one of these quarries, about 500 feet east of Highway 287, some fractured, fist-size, opaque, euhedral, reddish-brown almandine garnets were recovered by the author (Hausel, personal field notes, 1979).

Hundreds of rounded pyrope and almandine garnets have been found in breccia pipes in the Greater Green River Basin near Cedar Mountain and in anthills near Butcherknife Draw. These are small, transparent pyrope and pyrope-almandine garnets (typically less than 8 mm in diameter) that are found in anthills in association with emerald-green chromian diopside and chromian enstatite. Some collectors have faceted some of these stones, producing attractive emerald-green, yellow-orange, and reddish-purple gems.

Figure 55. (a) A 34-ounce nugget from the Rock Creek placer at South Pass. Specimen is approximately 2.5 inches across (photograph courtesy of the Los Angeles Museum of Natural History). (b) Placer gold from Rock Creek at South Pass (from the Gerald Stout collection).

GOLD (Native)
Au

H = 2.5 to 3
SG = 15 to 19.3 (pure)
Crystal System – Isometric
Color – Golden yellow
Luster – Metallic

Physical characteristics and crystal habit

Native gold forms distinct golden yellow, silvery yellow, or reddish yellow specks, flakes, and rounded nuggets in some quartz veins, shear zones, and stream placers (**Figure 55a** and **55b**). Gold has a very high heft and produces a hackly fracture. It is soft, malleable, and can be easily scratched with a pocketknife. Gold is quite distinctive and can be identified by its color, malleabiity, sectility, and specific gravity. It is insoluble in ordinary acids, but soluble in aqua regia (a very strong acid that is a mixture of nitric and hydrochloric acid at a ratio of about 1:3).

Occurrence

Gold is sometimes found in fractures in quartz veins and may be associated with pyrite. It is sometimes found with limonite derived from the oxidation and weathering of pyrite. Specimen-grade samples are often found in limonite-stained boxworks (honeycomb structures) (see **Limonite**) (Hausel, 1999).

Localities

A number of reports indicate that specimen-grade gold was found in several mines in the South Pass area in the southern Wind River Range (Hausel, 1989, 1991). Good specimens of gold-bearing quartz have also been found at the Carissa, Duncan, Mary Ellen, Miners Delight, Mint, Gold Leaf, and other mines.

Nuggets are still found by modern prospectors in streams, old mine dumps, and in historical dredge tailings in the South Pass region (Hausel, 2001). During the 1990s, prospectors and treasure hunters recovered a few hundred nuggets from the South Pass area including a 7.5-ounce nugget (Hausel and Sutherland, 2000). Today, some of the better places to search for gold nuggets lie in creeks immediately downstream from a group of gold-bearing shear zones mapped near South Pass City and Atlantic City (Hausel, 2001). These include Willow Creek, Rock Creek, Strawberry Creek, Big Atlantic Gulch, and Smith Gulch.

Some notable gold placers in the state besides those at South Pass include Sand Creek in the Mineral Hill district of the Black Hills and the Douglas Creek district in the Medicine Bow Mountains. Statistics indicate that several 1/2-inch-long nuggets were found in stream gravel in the Mineral Hill district of the Black Hills (Welch, 1974). Several nuggets have also been found on Douglas Creek, including a 3.4-ounce nugget. Another area to search for gold is the Sierra Madre. Several samples of quartz with visible gold were found in the Purgatory Gulch area by the author a few years ago, and a treasure hunter reportedly found 299 nuggets in the northwestern portion of this mountain range.

Some rare specimen-grade gold is found in the Gold Hill district of the Medicine Bow Mountains. Past samples from the Acme mine in the Gold Hill district reportedly assayed as high as 2,100 ounces of gold per ton (Hausel, 1989; Hausel, 1993a). Specimen-grade gold samples have also been recovered from the historical Keystone and Florence mines along Douglas Creek. Other places where one might search for visible gold in veins includes the Penn Mine area of the Seminoe Mountains and the Treadwell Open cut mine in the Mineral Hill district of the Black Hills.

GYPSUM

$CaSO_4 \cdot 2H_2O$

H = 2
SG = 2.32
Crystal System – Monoclinic
Color – White
Luster – Vitreous to earthy

Physical characteristics and crystal habit

Figure 56. Twinned gypsum crystal from Wyoming.

Gypsum typically forms white to transparent, vitreous to earthy, massive, prismatic, or tabular crystals that exhibit at least one well-formed flat surface (**Figure 56**). Some gypsum is also found as parallel fibrous crystals (called satin spar) and as *fish tail* twin crystals. The coarsely crystalline form is called selenite; the massive earty form is called alabaster. Gypsum exhibits good cleavage in three directions and perfect in one direction. Gypsum is easily scratched with a fingernail. It also has distinctively low heft and tends to bend and will break with a splintery fracture.

Occurrence

Gypsum may be found associated in siltstones and shales in red-bed environments. It has been found in Permian,Triassic, and Jurassic red beds along the flanks of several of the state's uplifts. The Goose Egg, Chugwater, and Gypsum Spring Formations commonly host gypsum beds. Near Cody and Lovell, the Gypsum Spring Formation has been a source of gypsum for manufacturing sheet rock.

GRAPHITE

C

H = 1 to 2
SG = 2.09-2.23
Crystal System – Hexagonal
Color – Steel gray to black
Luster – Dull to submetallic

Physical characteristics and crystal habit

Graphite is a soft, sectile mineral that is greasy to the touch and will stain hands black. It has perfect basal cleavage and commonly occurs as disseminated grains and also as foliated masses resembling molybdenite.

Figure 57. Shiny, hexagonal grains of graphite are visible in this rock specimen.

Localities

Graphite is found at several places in the Laramie Mountains and Hartville uplift. These locations include Halleck Canyon in the Laramie Mountains west of Wheatland (section 26, T22N, R71W) where it occurs as irregular narrow seams of amorphous graphite cutting metalimestone in gneissic country rock (**Figure 57**). It has also been found in Plumbago Canyon to the south (section 12, T19N, R72W) in schist and in metalimestone. Graphite has also been identified in graphitic schist at several locations in the Haystack Hills of Goshen County, including the McCann Pass area, Muskrat Canyon, and Rawhide Buttes.

HEMATITE

Fe_2O_3

H = 5.5 to 6.5
SG = 4.9 to 5.3
Crystal System – Hexagonal
Color – Red to steel gray
Luster – Earthy to metallic

Physical characteristics and crystal habit

Figure 58. 'Kidney ore' specimen (4 inches across) showing more than one generation of hematite with some yellow limonite.

Hematite, an iron oxide (essentially rust), forms rusty-red to steel-gray earthy masses with dull, earthy to submetallic luster (**Figure 58**). A variety of hematite known as specularite occurs as shiny, steel-gray, metallic masses, botryoidal metallic masses, and micaceous to platy metallic coatings or flakes. It has subconchoidal habit and is brittle. Hematite has a distinct rusty red to dark red streak and can be identified by its streak, habit, and relatively high specific gravity.

Localities

Hematite is relatively common in Wyoming. Rock units such as the Chugwater Formation have a distinct rusty color and contain abundant hematite as cementing material in the rocks. In the past, some hematite ore bodies were mined in the Hartville uplift in eastern Wyoming and also along the northern edge of Rawlins.

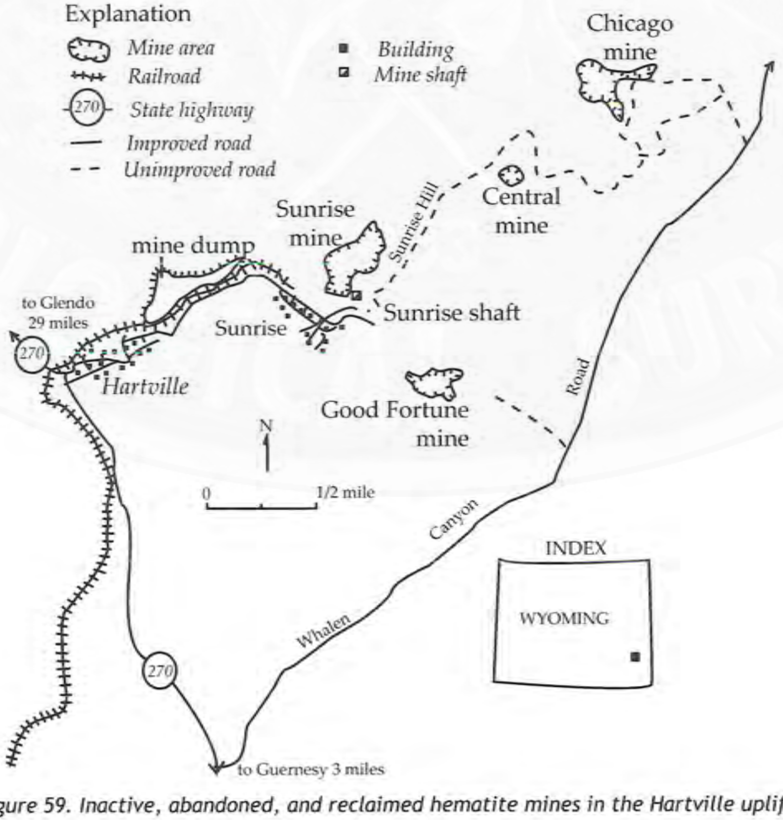


Figure 59. Inactive, abandoned, and reclaimed hematite mines in the Hartville uplift.

Earthy hematite was historically mined north of Rawlins and used as a paint pigment. The paint was termed "Rawlins Red" and used by the Union Pacific Railroad for painting cabooses and boxcars. The Rawlins hematite occurs as replacement deposits in the Flathead Sandstone and Madison Limestone (Harrer, 1966) in sections 4, 5, 8 and 9, T22N, R87W immediately north of Rawlins and west of U.S. Highway 287.

Both specularite (metallic steel-gray hematite) and massive red earthy hematite are found in the Sunrise area of the Haystack Range iron district in the Hartville uplift of eastern Wyoming. Hematite in the Sunrise area was mined for nearly one hundred years and the mines produced millions of tons of hematite ore and small amounts of copper. Hematite was produced from a group of mines in this area including the Sunrise, Chicago, Good Fortune, and Central mines (**Figure 59**). Ore extracted from this area was shipped to blast furnaces in Pueblo, Colorado until 1981. In addition to specularite and earthy hematite, some botryoidal hematite is found in this area.

Excellent specimens of massive specularite with chalcopyrite, goethite, and malachite are found at the Charter Oak mine in the Puzzler Hill area of the Sierra Madre north of Encampment. These have been collected on the mine dump in section 24, T15N, R85W. In addition to massive specularite, some specularite samples exhibit prismatic habit. In the past, hematite was found in some gossans with limonite in several oxidized ore bodies in Wyoming. One of the better known gossans included massive, earthy, red hematite at the New Rambler mine in the Medicine Bow Mountains. The hematite was found with limonite and copper carbonates (see **Sperrylite**).

HEMIMORPHITE
$Zn_4Si_2O_7(OH)_2 \bullet H_2O$

H = 4.5 to 5
SG = 3.4 to 3.5
Crystal System – Orthorhombic
Color – White
Luster – Vitreous to silky

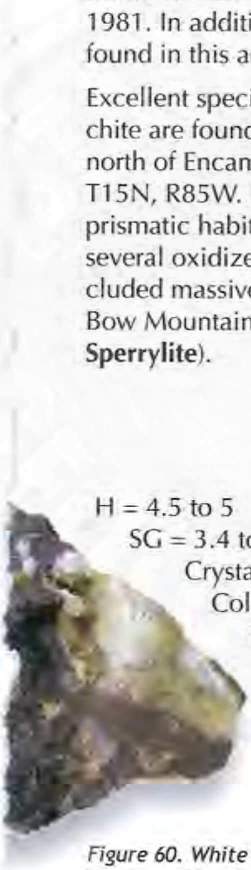


Figure 60. White radiating hemimorphite from Black Buttes, Black Hills area.

Physical characteristics and crystal habit

Hemimorphite forms white, radiating, tabular masses and stalactitic crystal aggregates (**Figure 60**). It produces a white streak and exhibits vitreous luster.

Locality

The only locality where hemimorphite has been found in Wyoming, to date, is at Black Butte in the Black Hills of northeastern Wyoming. Along with hemimorphite, some fluorite, jasperoid, and wulfenite occur at the prospect in NE section 26, T50N, R62W. The mineralization is found in a silicified zone in the Pahasapa Limestone.

ILMENITE
$FeTiO_3$

H = 5 to 6.5
SG = 4 to 5.2
Crystal System – Hexagonal
Color – Black to steel gray
Luster – Metallic

Physical characteristics and crystal habit

Ilmenite occurs as brown to black, dense, rounded masses with high heft and exhibits metallic to submetallic luster. It may be weakly magnetic to non-magnetic and will have a black streak. Many samples of ilmenite found within the anorthosite complex in the central Laramie Mountains are very heavy, metallic gray, rounded cobbles that are quite often mistaken for meteorites. Much of the ilmenite in this area is complexly mixed with magnetite, which produces a highly magnetic massive mixture of the two minerals.

Occurrence

Three types of ilmenite have been recognized in Wyoming. One is an iron-rich variety that is found as disseminated grains in some layered gabbroic complexes, such as the Lake Owen and Mullen Creek complexes in the Medicine Bow Mountains. Ilmenite has also been described in minor amounts in some titaniferous black sandstone deposits scattered around the state (Houston and Murphy, 1962).

The Laramie anorthosite batholith, located northeast of Laramie in the Laramie Mountains, contains large masses of black metallic rock known as titaniferous magnetite. This material is a complex mixture of both ilmenite and magnetite. Magnetism, high heft, black metallic luster, and association with anorthosite are diagnostic characteristics. The material produces large rounded boulders and cobbles of massive material. Locally, sulfides with up to several percent pyrite and pyrrhotite may be associated.

During the 1960s and 1970s, titaniferous magnetite was mined from a group of deposits at Iron Mountain in the central Laramie Mountains. The ore was used as a heavy-mineral aggregate in concrete for underwater pipes and for the shielding of fissionable materials. Since the ore contains appreciable titanium, there has been considerable interest in separating the titanium for use in paint pigments and for the manufacture of titanium steel.

Titaniferous magnetite deposits are scattered all over the Iron Mountain region. One of the largest, the Iron Mountain deposit (sections 22, 26, 27 and 28, T19N, R71W), includes a 5,000-foot-long outcrop of massive ilmenite-magnetite exposed by now-defunct open-pit mine operations. Further descriptions of these deposits are in Osterwald and others (1966).

A third type of ilmenite found in Wyoming is known as picroilmenite. This ilmenite contains significant substitution of magnesium for iron in the ilmenite crystal structure, such that it tends to mask any magnetism. Picroilmenite forms small, rounded, black metallic grains and may contain a distinct white coating or crust that has a similar appearance to elk droppings (Paul J. Graff, personal communication, 1999).

Some large picroilmenite megacrysts (3 to 4 inches in diameter) have been found in the State Line district south of Laramie. Picroilmenites are rare and associated only with kimberlite (see **Kimberlite**).

ILSEMANNITE
$Mo_3O_8 \bullet xH_2O$

H = Not determined
SG = Not determined
Crystal System – Unknown
Color – Black, blue-black, blue
Luster – Metallic

Physical characteristics and crystal habit

Massive as crusts, stains, or pigment associated with the alteration of primary molybdenum-bearing minerals. This mineral has not been adequately described in the literature (**Figure 61**).

Figure 61. Blue-gray ilsemannite with green malachite in white quartz from Sheep Mountain, Medicine Bow Mountains.

Location

The only known Wyoming locality for this mineral is at the Barber mine on Sheep Mountain in the Medicine Bow Mountains W/2 SE sec. 15, T14N, R77W. At this mine, massive ilsemannite was found by the author as fracture fillings in a quartz vein with malachite, chalcopyrite, chalcocite, molybdenite, bornite, and traces of cuprite. Some of the granite found on the mine dump also contained traces of fluorite (Hausel, 1997). The ilsemannite was verified by XRD (Robert W. Gregory, personal communication).

JADE (see NEPHRITE)

JASPER (see CHALCEDONY)

KAMMERERITE (see CHROMITE)

KYANITE
Al_2SiO_5

H = 5 parallel to length; 7 across length
SG = 3.52-3.65 (moderate heft)
Crystal System – Triclinic
Color – Light blue, white, green
Luster – Vitreous
Also see **Andalusite** and **Sillimanite**

Physical characteristics and crystal habit

Kyanite forms light-blue to sky-blue bladed crystals with good basal parting (**Figure 62a**). Less commonly, it may occur as white, tan, reddish, or green bladed crystals. Some crystals may be fibrous. It has vitreous luster with perfect pinacoidal cleavage. One distinct characteristic is its hardness. Parallel to the length of the crystal, it will scratch with moderate difficulty with a pocketknife, but across the length it will not scratch. It has a moderate heft and a specific gravity of 3.52 to 3.65. The combination of the crystal habit, color, and variable hardness are diagnostic. Kyanite is often associated with one or more of the following minerals: mica, staurolite, garnet, rutile, andalusite, corundum, and sillimanite.

Occurrence

Kyanite is trimorphous with andalusite and sillimanite and is essentially restricted to metamorphic terrains in the mountains. Being an aluminum-rich mineral, it is

Figure 62. (a) Sky-blue kyanite from Grizzly Creek. (b) The author stands adjacent to large boulder of kyanite schist (note the numerous kyanite blades) at Grizzly Creek (photographs by Wayne M. Sutherland). (c) Cabochon kyanite gems cut from material from Palmer Canyon (photograph courtesy of Vic Norris).

commonly found in metapelites and is often found as abundant, large prismatic porphyroblasts (**Figure 62b**).

Localities

Good kyanite crystals have been found at Copper Mountain in the Owl Creek Mountains. For further information on this locality, refer to Hausel and others (1985).

Some of the better samples of kyanite found in the state occur along the margin of the Elmers Rock greenstone terrain in the surrounding gneiss complex (Graff and others, 1982). For example, the Grizzly Creek prospect in the Laramie Mountains (section 35, T24N, R71W) contains abundant kyanite and sillimanite in gneiss and schist. Some spectacular specimens of kyanite schist also occur in the Palmer Canyon area a few miles north of the Grizzly Creek prospect, as well as in the Cooney Hills to the south (**Figure 62c**).

Rocks near the headwaters of Cottonwood Creek in the Encampment District of the Sierra Madre are rich in kyanite (section 20, T14N, R83W). Some of the kyanite crystals in this area are as large as 6 inches in length and range from white to light blue in color. At one location, disseminated emerald green kyanite is reported (Osterwald and others, 1966).

Some rare kyanite-eclogite xenoliths (nodules) have also been recovered from some kimberlites in the State Line district south of Laramie (see **Diamond**) (section 16, T12N, R72W). These kyanite eclogites contain garnet, chromian diopside, and small tabular grains of blue kyanite. The crystal habit of kyanite in these eclogites is quite different from the bladed grains found in metamorphic terrains. Only a handful of these nodules have been found in Wyoming.

LEUCITE
$K(AlSi_2O_6)$

H = 5.5-6
SG = 2.42
Crystal System – Tetragonal
Color – White to gray
Luster – Vitreous to dull

Physical characteristics and crystal habit

Leucite occurs in a rare rock type known as lamproite. It is white to gray with vitreous to dull luster and forms pseudo-cubic trapezohedral mineral grains. Some crystal faces of leucite may be finely striated due to twinning on (110). Where found in the Leucite Hills of Wyoming, the leucite is abundant but occurs as microscopic mineral grains; thus a petrographic microscope is almost always necessary in the identification of this mineral. Minerals found associated with leucite may include phlogopite, microcline, and richterite.

Localities and occurrence

Leucite occurs in abundance in potassium-rich lava flows and plugs of the Leucite Hills north of Rock Springs and Superior. Large crystals in these rocks are rare and leucite occurs predominantly as an aphanitic mineral in the volcanic rocks (also see **Wyomingite** in **Wyoming Rocks** section). In the past, these leucite-bearing lavas have been considered a potential potash resource.

In the Black Hills of northeastern Wyoming, phonolite and related alkalic volcanic rocks (see **Wyoming Rocks** section) contain large alkali feldspar and some pseudoleucite crystals enclosed in a fine-grained (microscopic) groundmass. These rocks are well exposed throughout Devils Tower National Monument and in the Bear Lodge Mountains.

LIMONITE

FeO(OH)

H = 1 to 5.5
SG = 2.7 to 4.3
Crystal System – Amorphous
Color – Yellow, brown, red, tawny
Luster – Vitreous, dull, earthy

Physical characteristics and crystal habit

Limonite is a hydrated iron oxide produced from the weathering and oxidation of iron-rich minerals. It occurs in a wide variety of colors such as yellowish-brown, red, yellow, and dark brown. It forms dull to vitreous earthy to porous masses including boxworks (porous honeycomb masses). Some minerals found with limonite particularly in historical mining districts may include pyrite, pyrrhotite, chalcopyrite, chalcocite, malachite, and azurite.

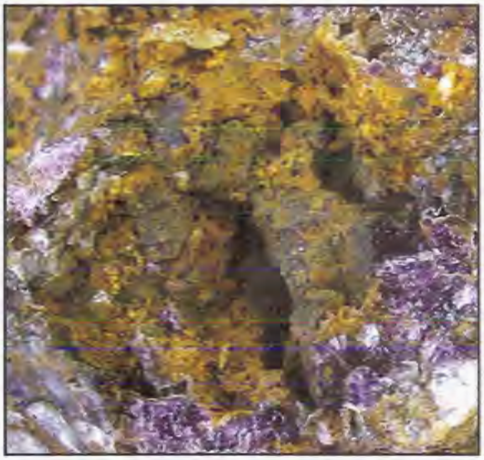


Figure 63. Tawny limonite with purple fluorite from the Bear Lodge Mountains.

Occurrence

Limonite (**Figure 63**) forms as a residue from the oxidation and leaching of iron-rich minerals including copper and iron sulfides. Massive limonite produces caps called gossans that are found associated with many iron-copper sulfide deposits. Some very distinct porous specimens, called boxworks, may be found in these gossans. Boxworks may sometimes contain visible gold, as some boxworks result from decomposition and leaching of pyrite. If the pyrite was auriferous (gold-bearing), the sulfur is usually leached, leaving behind porous, hydrated iron oxide along with any gold. Boxworks and limonite gossans are considered so important in mineral exploration that an entire book was written on their interpretation (see Blanchard, 1968).

Localities

Limonite is found almost anywhere where copper sulfides and iron sulfides occur. Some areas where limonite can be found include the Encampment district, all of the copper porphyry districts in the Absaroka Range and the Gossan Hill (sections 23, 26, and 27, T28N, R65W) area in the Hartville uplift of eastern Wyoming (Hausel, 1997). Gossan Hill contains a large limonite zone approximately 300 by 3,000 feet in size.

LORANDITE

$TlAsS_2$

H = 2 to 2.5
SG = 5.53
Crystal System – Monoclinic
Color – Carmine red
Luster – Metallic adamantine

Physical characteristics and crystal habit

Lorandite forms translucent to transparent, cochineal (scarlet) to carmine red granular masses, veinlets, and encrustations that have a dark grayish coating with ocher-yellow powder. In crystalline form, it will exhibit perfect cleavage on the (100) and distinct cleavage on (201) and (001). Crystals are flexible and will readily separate into cleavage fibers. Lorandite may form tabular or short prismatic crystals with striations parallel to the b or c crystallographic axes. It will yield a dark cerise (cherry) red streak and has brilliant metallic luster.

Occurrence

This mineral is found in the New Rambler mine encrusting massive fine-grained pyrite associated with realgar and orpiment.

Locality

The only known locality for lorandite in Wyoming is in the copper-palladium ores at the New Rambler mine (section 33, T15N, R79W) in the Medicine Bow Mountains (see **Sperrylite**).

MAGNETITE

Fe_3O_4

H = 5.5 to 6.5
SG = 5.2
Crystal System – Isometric
Color – Black
Luster – Metallic to dull

Physical Characteristics & Crystal Habit

Magnetite may form iron black, metallic to dull, highly magnetic masses or octahedral grains. Its relatively high heft is responsible for significant quantities of magnetite ending up in the black sand concentrates of streams and rivers. When found, it may exhibit good octahedral parting and will yield a black streak (**Figure 64a**).

Figure 64. (a) Cumulate textured, black magnetite in serpentinite from Lake Owen area, Medicine Bow Mountains.

Occurrence

Prospectors worldwide speak of black sands (sand-sized dark mineral grains including magnetite) when discussing placer gold. Magnetite is a relatively heavy mineral and occurs as finely disseminated mineral grains in many rocks. These magnetite-bearing rocks break down through weathering and erosion. Magnetite (along with lighter minerals such as quartz and feldspar) tends to migrate downslope into nearby drainages. Once in the drainage, water in the streams will favor the separation of magnetite from lighter minerals due to the difference in specific gravity.

Figure 64. (b) Typical banding in isoclinally folded taconite showing alternating layers of chert and magnetite.

Abundant black sands (including magnetite) in a placer implies a good placer trap where heavy minerals are favorably concentrated. If available, gold, which has very high specific gravity, will concentrate with magnetite and other dense minerals. Typical host rocks for magnetite in Wyoming include banded iron formation, which is formed primarily of alternating layers of magnetite and chert, anorthosite, some layered gabbroic complexes, and titaniferous black sandstones.

Localities

There are several known magnetite deposits in Wyoming. From 1962 to 1983, U.S. Steel Corporation produced iron ore from the Atlantic City mine at South Pass, south of Lander. The ore was taconite (banded iron formation), a metamorphic rock with alternating bands of magnetite and chert (**Figure 64b**). Other Precambrian banded iron formations have been identified in the Owl Creek Mountains (Hausel and others, 1985), in the Seminoe Mountains (Harrer, 1966; Hausel, 1994b), and in the Rattlesnake Hills (Hausel, 1996a). Titaniferous black sandstone deposits, which are interpreted as paleobeach placers, are found at a number of locations in the state (Houston and Murphy, 1968). Many of these are hosted by Cretaceous sandstones now exposed near the margins of some Wyoming basins.

MALACHITE

$Cu_2CO_3(OH)_2$

H = 3.5 to 4
SG = 4
Crystal System – Monoclinic
Color – Green
Luster – Earthy to vitreous

Physical characteristics and crystal habit

Malachite forms green coatings or crusts on other cupriferous minerals and is rarely found as botryoidal masses or acicular prismatic crystals (**Figure 65a** and **65b**). It

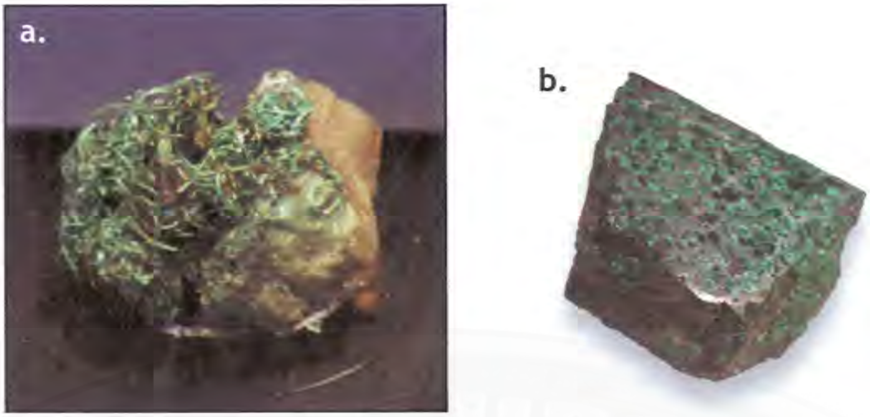


Figure 65. (a) Rare malachite wires (about 0.5 inch long) on quartz from the Big Creek mine, Carbon County, from the Ralph Platt collection (photograph by Mel Dyck). (b) Spherical malachite in quartz from the Sunrise Mine, Hartville uplift from the Steve Caligore collection (photograph by Mel Dyck).

produces a pale green streak and will effervese in muriatic acid. The association of malachite with other cupriferous minerals such as chalcopyrite, chalcocite, azurite, tenorite, and/or cuprite and its reaction with muriatic acid are enough for positive identification.

Localities

Malachite is a common copper mineral found in Wyoming's copper districts (**Figure 66**). Details on Wyoming's copper mines and districts are described by Hausel (1997). Mine dumps in the Absaroka Range (Kirwin, Sunlight Basin, Stinkingwater, and other districts), Sierra Madre, Lake Alice district, Copper Mountain, and Jelm Mountain commonly have malachite. Good crystalline malachite is uncommon in Wyoming and most malachite occurs as stains on mineralized rock.

MICA GROUP
hydrated silicates

H = 2.5 to 3
SG = 2.7 to 3.4
Crystal System – Monoclinic
Color – Black, green, bronze, pinkish-purple
Luster – Vitreous

Physical characteristics and crystal habit

The mica group includes biotite, muscovite, phlogopite, fuchsite, lepidolite, sericite, and chlorite. All of these have been found in Wyoming. The micas form layers, sheets, or plates known as mica books that have perfect basal cleavage (**Figure 67**). Individual crystals form flat, six-sided plates that are flexible. The micas are monoclinic, even though they commonly exhibit six-sided pseudohexagonal crystals.

Occurrence

Biotite is a black mica found in schists and granites. Muscovite forms a white to

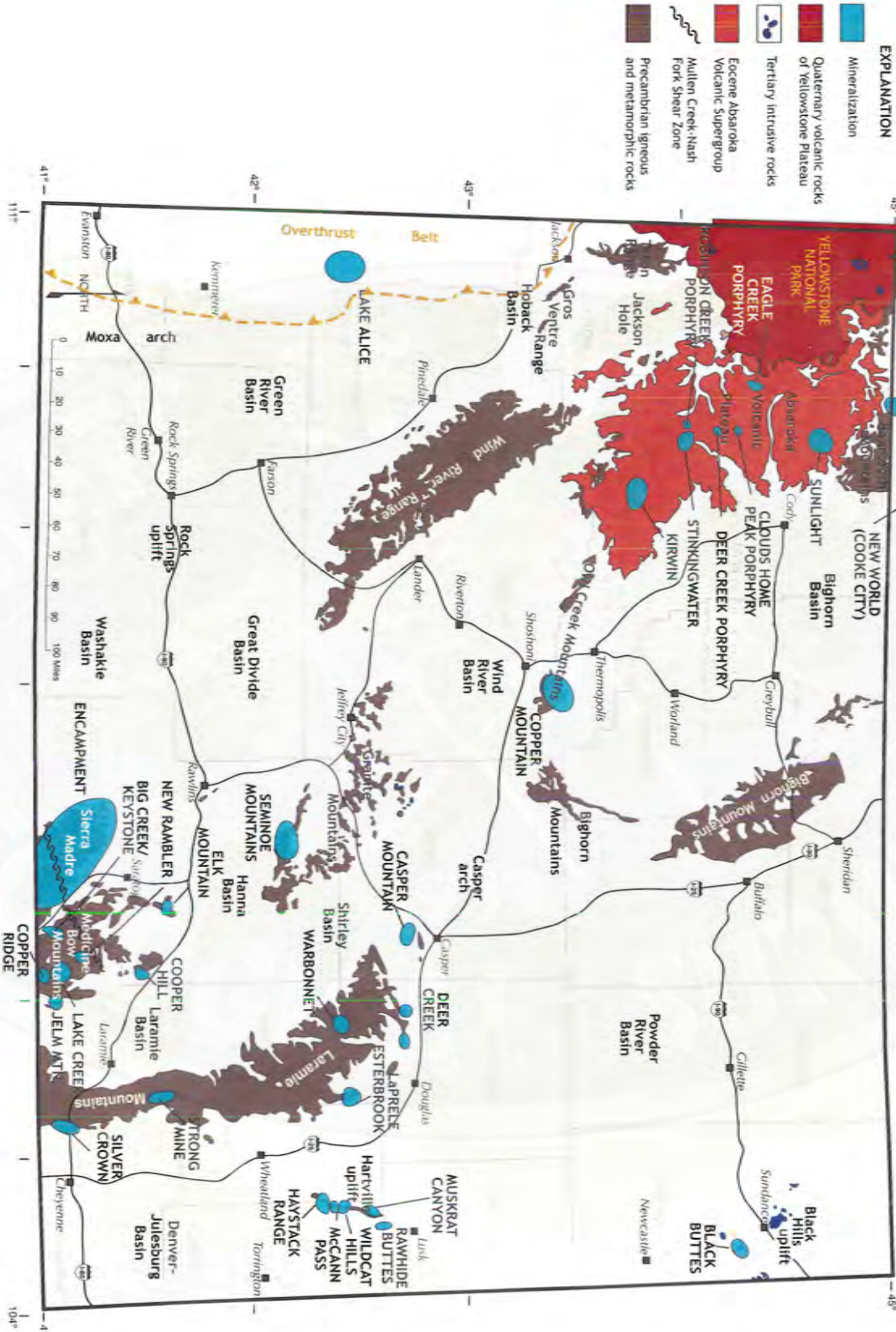


Figure 66. Wyoming's copper districts.

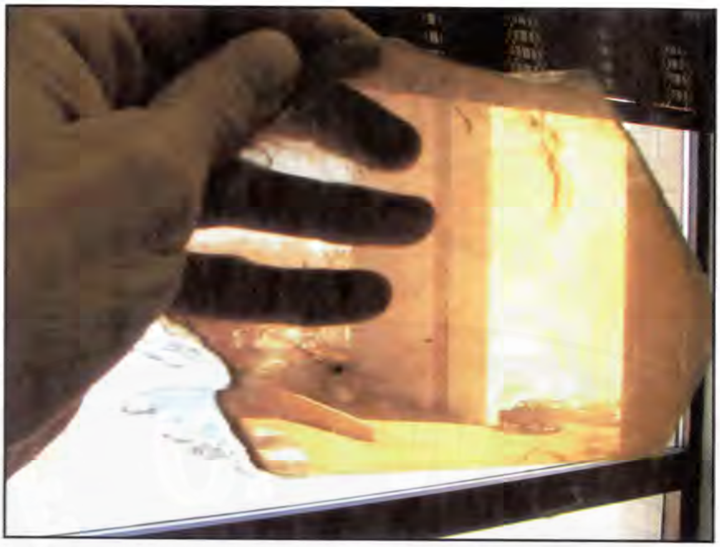


Figure 67. Muscovite mica forms pseudohexagonal masses separated by numerous cleavage planes.

colorless mica found in many granites, pegmatites, schists, and gneisses. Because of its bronze-white color and its tendency to break down into small thin golden-white flakes, many people have mistaken fine-grained muscovite (sericite) mica for gold. In Mark Twain's classic *Roughing It,* this was an error he, too, made during his first prospecting venture in Nevada. One distinguishing characteristic of muscovite is that it is brittle, whereas gold is malleable.

Phlogopite is a bronze-colored mica that occurs in kimberlite, lamproite, and other related igneous rocks. A very good place to collect phlogopite is from the volcanic rocks in the Leucite Hills north of Rock Springs. Fuchsite forms a distinct light-green muscovite mica that contains up to 5% chromium. Some good specimens of fuchsitic quartzite have been collected near Gold Hill in the Medicine Bow Mountains. Lepidolite is a pink to lilac, lithium-rich mica associated with lithium-rich pegmatites. Lepidolite pegmatites crop out along the southern edge of Copper Mountain in the vicinity of Hoodoo Creek (sections 22 and 27, T40N, R93W). Chlorite forms a dark green to almost black mica. Chlorite has been found in many schists in Precambrian terrains in the mountains of Wyoming.

MICROCLINE (see FELDSPAR)

MONAZITE

$(Ce,La,Y,Th)PO_4$

H = 5 to 5.5
SG = 4.6 to 5.4
Crystal System – Monoclinic
Color – Yellow, reddish-brown
Luster – Vitreous, waxy or resinous

Physical properties

Monazite occurs as small, radioactive, yellow to reddish brown grains with a vitreous to resinous luster and thin to thick tabular crystals. Monazite mineral grains are often equant with rough or striated crystal faces. It will produce a conchoidal to uneven fracture. It has good basal parting and good cleavage in one direction.

Occurrence

Monazite is found in some granites, pegmatites, and gneisses. Due to its relatively high heft, monazite often concentrates with black sands in placer deposits downstream from monazite-bearing rocks.

Locality

The basal conglomerate of the Flathead Sandstone at Bald Mountain (T56N, R91W) is one of the better known monazite localities in Wyoming. Some gold occurs with the monazite.

MOLYBDENITE

MoS_2

H = 1 to 1.5
SG = 4.62 to 4.73
Crystal System – Hexagonal
Color – Shining steel-gray
Luster – Metallic

Physical properties

Molybdenite occurs as silver-gray to lead-gray, soft, sectile, foliated masses with scales and disseminations that have a greasy feel. Less often, molybdenite will be found as rough hexagonal tabular crystals or granular masses with perfect basal cleavage. It exhibits a shining gray streak and will rub onto your fingers, staining them dark gray. Molybdenite is the principal ore of molybdenum, which is used as a steel alloy to increase the strength and hardness of steel at high temperatures.

Localities

Molybdenite is reported only from a few scattered localities in Wyoming. Molybdenum-bearing veins and stockworks are reported along Temple Peak (section 24, T32N, R103W) in the Wind River Range. Significant low-grade molybdenum resources are also associated with porphyry copper deposits in the Absaroka Range east of Yellowstone National Park.

NEPHRITE (JADE)

$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

H = 6 to 6.5
SG = 2.8-3.5
Crystal System – Monoclinic
Color – Green to black
Luster – Vitreous to waxy

Figure 68. (a) A variety of high-quality jade from the Jeffrey City region (specimens from the Jay Sundberg collection). (b) Large jade boulder from the Green Mountain area.

Physical characteristics and crystal habit

Nephrite jade (or "Wyoming Jade") almost never shows external structure, except where the mineral rarely pseudomorphs the crystal habit of another mineral. For example, in the Granite Mountains of central Wyoming near Jeffrey City, some nephrite pseudomorphs quartz. These specimens are pseudohexagonal (six-sided prism) and are uncommon.

Typically, nephrite jade occurs in irregular masses lacking cleavage (**Figure 68a** and **68b**). Microscopically, nephrite will exhibit a mass of matted, intricately interwoven fibers. This form makes nephrite extremely tough and resistant to fracturing. As a result, unless the rock has a schistose (foliated) fabric, rounded boulders of nephrite are nearly impossible to break with a hammer.

Nephrite (jade) consists of submicroscopic, intricately interwoven, actinolite-tremolite mineral fibers that produce a massive and extremely tough gemstone (see **Actinolite**). Nephrite forms as a result of the alteration of pyroxene in metamorphic terrains. The nephrite form of actinolite-tremolite is one of the toughest minerals known.

Nephrite can be confused with a number of other minerals and special care must be taken for accurate field identification. Positive identification almost always requires testing by x-ray diffraction. The following rules of thumb are useful for field identification of jade, according to Root (1977) and Hausel and Sutherland (2000):

(1) Nephrite is heavier than the average rock of the same size.

(2) Nephrite cannot be scratched with an ordinary knife blade (if it scratches, it is probably serpentine or chlorite, or another similar-looking mineral.

(3) Nephrite has a smooth, almost waxy appearance.

(4) If the end is ground off a suspected Wyoming jade specimen, the fresh surface should not sparkle or glitter in the sun. If it sparkles, it is not jade.

(5) Nephrite should not be magnetic (if it is magnetic, it is probably serpentine, which is quite often mistaken for nephrite).

(6) Nephrite is associated with a very distinct alteration assemblage that includes pink zoisite, bleached white sericitized granite, pistachio-green epidote, and dark-green chlorite.

Rocks often mistaken for nephrite include fine-grained quartzite, serpentinite, epidotite, and even metadiabase. These occur in the same geologic environment as nephrite. Quartzite can be distinguished by its granular texture that tends to sparkle on a freshly broken surface. Serpentinite and epidotite are softer and can be scratched with a knife. Most serpentinite also will have some magnetite and exhibit small areas, or lenses of magnetism. Close inspection of metadiabase should reveal the presence of numerous individual crystal grains that are not seen in nephrite.

Occurrence

Nephrite occurs primarily in central Wyoming within the Granite Mountains. It has also been reported at scattered localities from the Wind River Range to the northern Laramie Mountains in a narrow east-west band that encloses the Granite Mountains north of Jeffrey City (**Figure 69**).

Pockets of jade that are associated with distinct alteration minerals mentioned above are sometimes found in the mountains. Nephrite has also been found as pebbles and boulders in alluvial fans and in soils near source rocks. Jade also is periodically found pseudomorphing quartz. These pseudomorphs consist of jade replacing quartz and retaining the original hexagonal crystal habit of quartz. Individual jade localities are described by Hausel and Sutherland (2000). Many of these are found within the Tin Cup district northwest of Jeffrey City (T30N, R92-93W) and are marked by old prospect pits in the granite and gneiss (Hausel, 1996b).

OLIVINE
$(Mg, Fe)_2SiO_4$

H = 7
SG = 3.3
Crystal System – Orthorhombic
Color – Green, yellow-green, red, orange-red
Luster – Vitreous

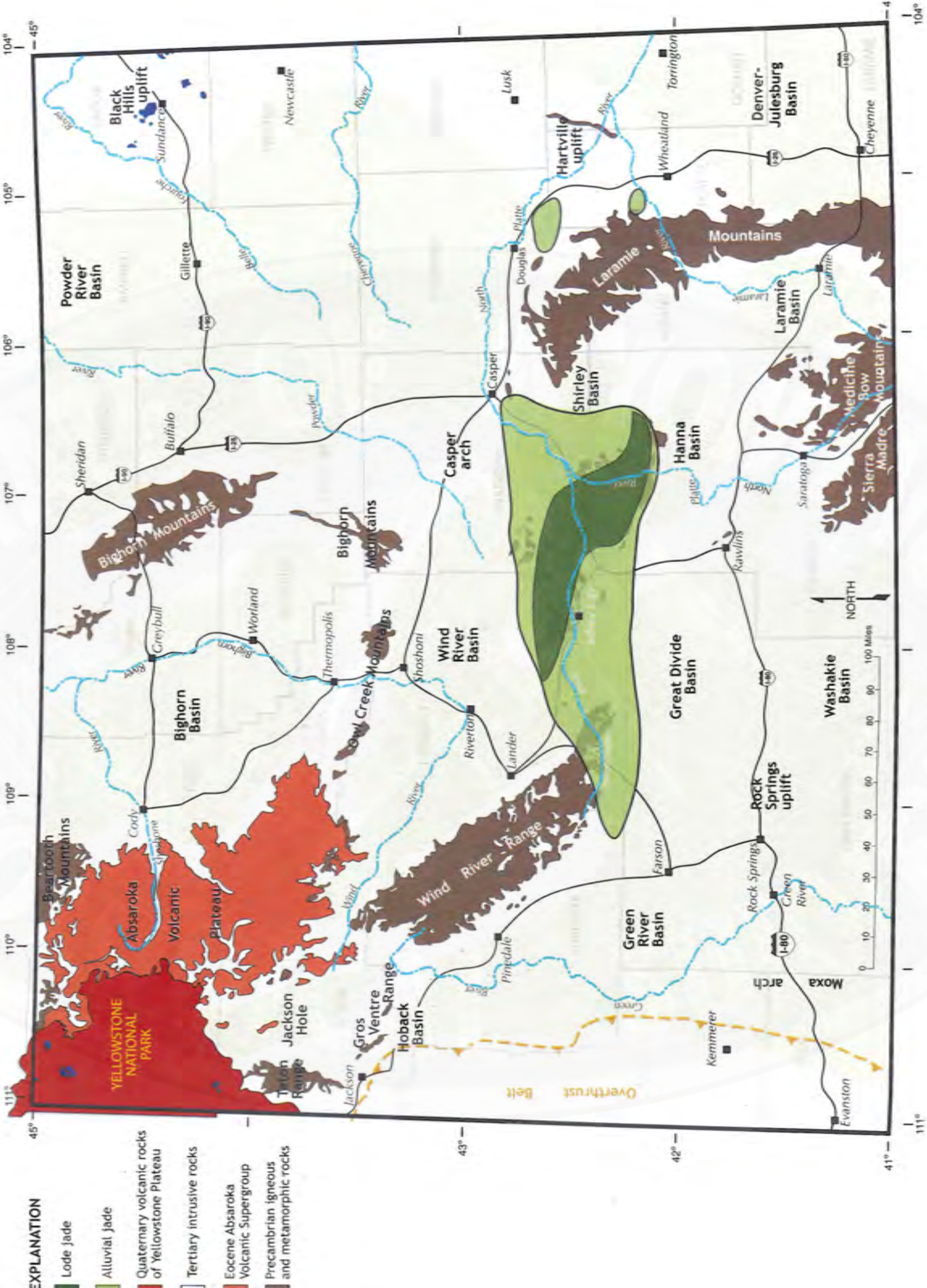


Figure 69. Principal jade localities in Wyoming.

Physical characteristics and crystal habit

The olivine found in Wyoming typically occurs as olive green, sometimes reddish rounded mineral grains with vitreous luster and conchoidal fracture. When transparent, olivine can be used to produce gem material known as peridot. Olivine grains are brittle, may have visible vertical striations, twinning parallel to (100) (less commonly parallel to (011)), and an uncolored streak.

Occurrence

Olivine is found associated with mafic and ultramafic igneous rocks. In Wyoming, olivine has been found in some basalts, gabbros, lamproites, kimberlites, pyroxenites, and peridotites. Much of the olivine in Wyoming is serpentinized, but good preserved specimens occur in the Leucite Hills (**Figure 70a**).

Localities

Olivine is found as fine-grained to aphanitic (microscopic) grains in some basalt flows in the Absaroka Range near Yellowstone. Entirely serpentinized olivine grains occur in some dunites and serpentinites in the South Pass greenstone belt along the southern tip of the Wind River Range (Hausel, 1991). The grains have been found in similar rocks in the Seminoe Mountains (Hausel, 1995). Partially to entirely serpentinized olivine is also found in kimberlites in the State Line district in the southern Laramie Mountains south of Tie Siding and in the Iron Mountain district near Chugwater (Hausel and others, 2000). Some of the black, mafic gabbros in the

Figure 70. (a) Rough olivine recovered from anthills in the Leucite Hills of Sweetwater County surrounding faceted olivine gems (peridot) from the same locality. (b) Faceted transparent gem-quality peridot collected from the Black Rock area of the Leucite Hills (photograph by Robert W. Gregory).

Lake Owen and Mullen Creek area of the Medicine Bow Mountains also have tiny olivine grains.

The best locality for preserved olivine is the Leucite Hills north of Rock Springs. A few lamproitic volcanoes and flows in the northeastern portion of this volcanic field contain olivine. Most notable is the Black Rock lamproite, as well as nearby anthills. More than 13,000 carats of olivine, mostly peridot (**Figure 70b**) were found in two anthills along the western flank of Black Rock by the author. The largest of the grains was 8 mm in length. Some well-preserved dunite and peridotite xenoliths at Black Rock include relatively large olivine grains (as large as 0.25 inch) (Hausel and Sutherland, 2000). Also, the soils near Black Rock should contain considerable olivine.

ORPIMENT (see LORANDITE and SPERRYLITE)

ORTHOCLASE (see FELDSPAR)

PHLOGOPITE (see MICA)

PYROXENE GROUP

complex calcium, iron, magnesium and aluminum silicates

H = 5-6
SG = 3.2-3.5 (moderate heft)
Crystal System – Monoclinic (clinopyroxenes); Orthorhombic (orthopyroxenes)
Color – Green, black, white
Luster – Vitreous to dull

Physical characteristics and crystal habit

Pyroxene is a common rock-forming mineral found in many volcanic rocks. It occurs as fine grains in basalt and gabbro that are barely visible to the unaided eye; however, many andesites have larger prismatic crystals. A pyroxene cut parallel to the basal section will produce a square cross section with near right-angle cleavage (**Figure 71**), whereas amphiboles, which are similar and often mistaken for pyroxene, have diamond-shaped cross sections with faces intersecting at 56° and 124°. Pyroxenes crystallize in two crystal systems: orthorhombic (orthopyroxenes) and monoclinic (clinopyroxenes).

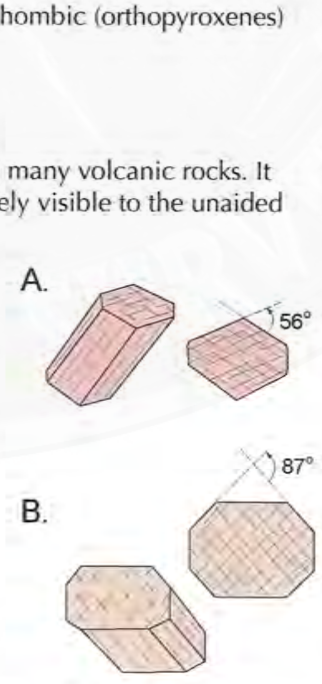


Figure 71. (A) Typical amphibole cleavage. (B) Pyroxene cleavage.

Occurrence

The most common pyroxenes found in Wyoming include diopside, augite, and enstatite. In addition, one locality containing relatively large spodumene pyroxenes is a popular site for mineral collectors in the state. Rare, dark green, salitic pyroxene $[CaFeMg(SiO_3)_2]$ is also found in some lamproites

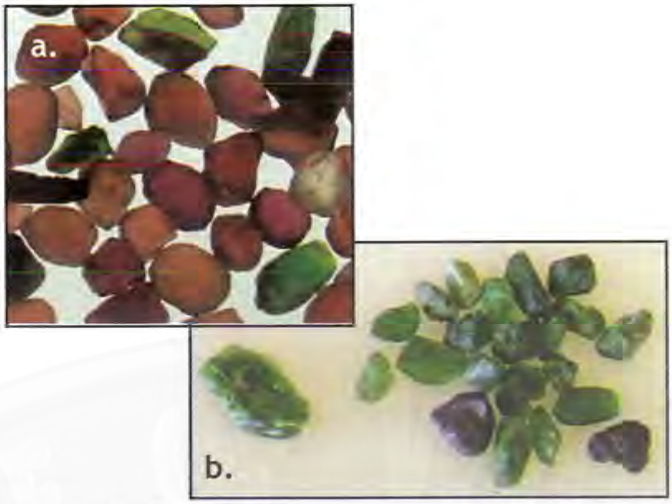


Figure 72. (a) Emerald green chromian diopside mixed with pink, orange, violet to purple pyrope garnets collected from anthills at Butcherknife Draw, Green River Basin. (b) Emerald green chromian diopside, some with flat cleavage surfaces, mixed with two gray, metallic grains of picro-ilmenite, a magnesium rich ilmenite, from the Colorado-Wyoming State Line district (photographs by Robert W. Gregory).

in the Leucite Hills. These form tiny, 1- to 2.5-mm-long crystals that are often enclosed by diopside rims. Some other salitic pyroxenes have been recovered from a few pyroxenite xenoliths trapped in the lamproites. Mitchell and Bergmann (1991) reported that the Leucite Hills occurrence is the only known paragenesis of this type in the world.

Clinopyroxenes (monoclinic pyroxenes)

The following clinopyroxenes have been found in Wyoming:

Augite $Ca(Mg,Fe,Al)(Al,Si)_2O_6$

Augite is a jet black, opaque mineral with square to eight-sided cross sections. It has been found primarily in the Absaroka volcanic field in basalts and andesites. Typically it occurs as small (1 to 6 mm) black phenocrysts.

Diopside $CaMg(SiO_3)_2$

Diopside is of interest to prospectors and geologists who search for diamonds. A rare diopside, known as chromian diopside, forms a distinct, emerald-green diopside with distinct inclined cleavage (**Figure 72a** and **72b**). Trace amounts of chrome (up to 2%) substitute for the calcium in chromian diopside, giving it its distinct color. Chromian diopside is found in kimberlite intrusives (or related rare mantle-derived, ultramafic intrusives). In Wyoming, chromian diopside has been found in the State Line district south of Laramie, in the Iron Mountain district north of Cheyenne, and in breccia pipes and nearby anthills along the southwestern edge of Cedar Mountain in the Greater Green River Basin southwest of Green River (Hausel, 1998). The numerous anthills in the Butcherknife Draw area of the Green River Basin typically contain several grains of chromian diopside and some pyrope garnet.

Spodumene $LiAl(Si_2O_3)_2$

Spodumene occurs as long, striated prismatic crystals with steep terminations. Spodumene in Wyoming is typically large and frequently has a wood-like surface alteration. It is found as white, buff, or grayish translucent to opaque crystals with perfect prismatic cleavage intersecting at 87° and 93°. The only known locality in Wyoming is along the north edge of Black Mountain in the Rattlesnake Hills (section 1, T32N, R89W). At this locality, the Black Mountain pegmatite contains large (0.5 to 1.5 feet long) bluish gray, greenish to lavender spodumene crystals. Tourmaline and apatite occur as accessory minerals in the pegmatite (Osterwald and others, 1966).

Orthopyroxenes (orthorhombic pyroxenes)

Enstatite $Mg_2(SiO_3)_2$

Enstatite typically occurs in tiny, black, prismatic translucent to opaque crystals in some basalts in the Absaroka Range in northwestern Wyoming. It has two well developed cleavages intersecting at 87° and 93°. A rare form of dark, emerald-green enstatite, known as chromian enstatite, has been found in the Butcherknife Draw and Cedar Mountain area of the Greater Green River Basin. In this region, the mineral is found in anthills with chromian diopside and pyrope garnet. It has also been recovered from breccia pipes along the southwestern margin of Cedar Mountain. The enstatite is typically a darker green than the diopside in this region.

PHENAKITE

Be_2SiO_4

H = 7.5 to 8
SG = 3.0
Crystal System – Hexagonal
Color – Colorless, white and sometime bluish
Luster – Vitreous

Physical characteristics and crystal habit

Phenakite forms flat complex rhombohedral crystals that are sometimes prismatic, vertically striated, and may resemble quartz. Its name is derived from the Greek for *deceiver*, as it is often mistaken for quartz. Flat transparent to translucent complex crystals are characteristic with poor prismatic cleavage.

Associated minerals

Phenakite is often found associated with beryl and chrysoberyl in pegmatites and is reported on Casper Mountain in Natrona County.

PLAGIOCLASE (see FELDSPAR)

PLATINUM (Native)

Pt

H = 4 to 4.5
SG = 14 to 19 (very high heft)
Crystal System – Isometric

Color – Steel gray to silver gray
Luster – Metallic

Physical characteristics and crystal habit

Native platinum forms steel-gray, sectile, and malleable grains, scales, and less often nuggets with very high heft and hackly fracture. It may be weakly magnetic depending on iron content. Platinum is primarily associated with dark mafic to ultramafic igneous rocks and may also occur with black sands and gold in stream placers. In particular, platinum is often associated with pyroxenites, peridotites, dunites, troctolites, and gabbros in layered mafic complexes.

Platinum and palladium are typically associated with other platinum-group metals (i.e. iridium, osmium, rhodium, ruthenium) and are used in jewelry, thermocouples, and in chemical and electrical equipment. In particular, they are indispensable in some computer chips and are used as catalysts in vehicles and in the petroleum refining process.

Localities

Platinum and palladium were discovered and mined at the New Rambler mine in 1900. Some platinum and palladium has sporadically been recovered with gold from Douglas Creek and Centennial Ridge districts in the Medicine Bow Mountains.

McCallum and Orback (1968) reported that platinum group metals were found in sheared and altered mafic and ultramafic rocks in the New Rambler district (sections 32 and 33, T15N, R79W). Some rare crystals of a platinum-sulfide known as sperrylite (see **Sperrylite**) were also identified in the ore. Platinum and palladium are also reported in the Centennial Ridge district immediately west of the town of Centennial (McCallum, 1968). In recent years, platinum and palladium have been detected at a number of localities in the Lake Owen and Mullen Creek mafic complexes in the Medicine Bow Mountains. They have also been found associated with significant anomalies in the Puzzler Hill pyroxenite massif in the Sierra Madre (Hausel, 2000b). Some platinum anomalies have also been reported in association with black shales in the Overthrust Belt of western Wyoming.

PYRITE
FeS_2

H = 6 to 6.5
SG = 5
Crystal System – Isometric
Color – Brass yellow
Luster – Metallic

Physical characteristics and crystal habit

Pyrite, commonly referred to as fool's gold, forms metallic, brass

Figure 73. Pyrite cubes in quartz from the Lost Muffler mine, Rattlesnake Hills. Note the distinctive bronze metallic luster and crystal habit.

yellow, massive specimens, disseminated grains, cubes with striated faces, octahedrons, pyritohedrons, and combinations of these forms (**Figure 73**). Pyrite yields a greenish black streak, is brittle, and crushes to a greenish black powder. Pyrite is of no value except as a mineral specimen or where the sulfide contains appreciable gold. Some pyrite grains may contain several parts per million (ppm) in gold within the crystal lattice. In rare cases, some pyrite (outside of Wyoming) has been reported to host as much as 2,000 ppm gold.

Occurrence

Pyrite may be found associated with chalcopyrite, sphalerite, galena, gold, and/or arsenopyrite in many mining districts in Wyoming. Marcasite, a polymorph of pyrite, has been reported in some sedimentary uranium deposits as finely disseminated grains.

Localities

In the South Pass-Atlantic City district, good specimens of massive and crystalline pyrite are found at the Snowbird mine (section 6, T29N, R99W) northeast of Atlantic City. Samples from the mine include a distinct massive pyrite zone (with minor chalcopyrite) sandwiched between a layer of calcite and white quartz. The massive pyrite includes individual crystals of cubic and octahedral pyrite with some mixed combinations.

Some excellent pyrite cubes (as large as 0.2 inch) have been found in the Lost Muffler prospect (SW section 16, T32N, R87W) in the Rattlesnake Hills. The pyrite occurs in a siliceous zone in metabasalt and metagabbro that was traced over a distance of about 4,800 feet. Some gold is associated with the pyrite (Hausel, 1996).

Massive pyrite samples with chalcopyrite occur in magnetite iron formation at the Itmay mine (section 14, T13N, R86W). The colliform texture of the samples shows large, rounded pyrite grains (0.2 to 0.4 inch in diameter) surrounded by a mantle of chalcopyrite in a magnetite matrix. Elsewhere in the Sierra Madre, Osterwald and others (1966) reported several pyrite localities.

Massive pyrite is found with some gold deposits in the Gold Hill district (T16N, R80W) and without gold in the French Creek area (sections 11, 12, 15, 21, and 22, T15N, R80W). The pyrite at Gold Hill occurs as fracture fillings in milky quartz in veins along the contact between amphibolites and the country rock. In the French Creek area, pyrite occurs with pyrrhotite in gossaniferous siliceous and graphitic schists.

PYRRHOTITE

$Fe_{1-x}S$

H = 3.5 to 4.7
SG = 4.5 to 4.7
Crystal System – Hexagonal
Color – Brass yellow
Luster – Metallic

Physical characteristics and crystal habit

Figure 74. Pyrrhotite from the Sierra Madre.

Pyrrhotite forms brass yellow, metallic, granular masses and platy to tabular or bipyramidal crystals with twinning. Pyrrhotite may be weakly to highly magnetic and have distinct basal parting. Pyrrhotite is similar in appearance to pyrite, but will produce a grayish-black streak and is magnetic (**Figure 74**).

Localities

Massive specimens of pyrrhotite have been collected in the Esterbrook district north of Laramie Peak. The Maggie Murphy mine (section 22, T28N, R71W) and the Three Cripples mine (NW section 16, T28N, R71W) in the Esterbrook district contain massive pyrrhotite in veins (Osterwald and others, 1966). The Maggie Murphy mine workings intersected 10- to 40-foot wide veins containing disseminated chalcopyrite and malachite with pyrrhotite. Some pyrrhotite has also been reported from Iron Creek in the French Creek region of the Medicine Bow Mountains (see **Pyrite**).

QUARTZ
SiO_2

H = 7
SG = 2.65 to 2.67
Crystal System – Hexagonal
Color –White, black, gray, green, yellow-green, red, orange-red
Luster – Vitreous

Physical characteristics and crystal habit

Quartz is a common rock-forming mineral with vitreous luster, conchoidal fracture, and moderate heft. It typically forms opaque, translucent to transparent pieces of

Figure 75. Quartz from various localities including amethyst, clear, smoky, and rose quartz (photograph by Meg Ewald).

massive material, or may occur as hexagonal prisms capped by a single pyramid (**Figure 75**). Compact microcrystalline quartz (chalcedony, chert, agate, jasper, etc.) is also found in the state as irregular masses *(*see **Chalcedony***)*.

Quartz is the most common rock-forming mineral on the surface of the Earth. Many metamorphic, sedimentary, and igneous rocks contain significant amounts of quartz. Some sedimentary and metamorphic rocks (sandstone and quartzite) are formed almost entirely of quartz. Its ubiquitous nature commonly results in the development of quartz veins in metamorphic and igneous rocks.

The two varieties of quartz, coarsely crystalline and cryptocrystalline, are quite varied and occur in many colors. Coarsely crystalline varieties of quartz may include beautiful six-sided pyramids. These well-formed crystals may occur in geodes (hollow, crystal-lined nodules), in vugs, or in fractures in some rocks.

Colored varieties include milky white (bull quartz), purple (amethyst), pink (rose quartz), black (smoky quartz), colorless and transparent (rock quartz), and yellow to reddish brown (citrine). Quartz with brown to red inclusions is termed ferruginous quartz. Cryptocrystalline varieties of quartz include jasper and agate—both of which are widespread in Wyoming (see Hausel and Sutherland, 2000).

Localities

Well-formed, iron-stained quartz crystals have been found in Precambrian pegmatites along U.S. Highway 287 south of Tie Siding. Many of these consist of well-developed prisms capped by a pyramid, but are somewhat unattractive because of the iron staining. Other nicely crystallized specimens have been recovered from pegmatites, veins, and related rocks in the Granite Mountains of central Wyoming, north of Jeffrey City.

Amethyst is not common in the Cowboy State, although one large, 310-pound, amethyst-lined geode was found in southern Wyoming several decades ago. Some other amethyst was found in the Mineral Hill district of northeastern Wyoming by the Wyoming State Geological Survey. Chalcedony (cryptocrystalline quartz) is much more common in Wyoming and is often used in jewelry. Localities for chalcedony are described by Hausel and Sutherland (2000).

REALGAR (see LORANDITE)

SCHEELITE

$CaWO_4$

H = 4.5 to 5
SG = 6.1
Crystal System – Tetragonal
Color – White
Luster – Dull to vitreous

Physical characteristics and crystal habit

Scheelite occurs as white, dull to vitreous, disseminated to massive granular material. It rarely occurs as tabular crystals with diagonal striations. Twinning on (110) is common. The mineral has distinct fluorescence: it will fluoresce a bright light-blue to white under short-wave ultraviolet light but will not fluoresce under long-wave ultraviolet light. Scheelite also has a relatively high specific gravity, making it favorable as a concentrate in black sand placers. Essentially all of the scheelite examined in Wyoming occurs as disseminated grains in milky quartz or in quartzofeldspathic gneiss. Scheelite is an ore of tungsten and is used as an alloy to harden steel. Tungsten also has important applications and strategic uses including the manufacture of armor plating (**Figure 76**).

Figure 76. Milky white scheelite (circled) in sheared gneiss with milky white quartz from the Strong Mine, Laramie Mountains. Scheelite can be distinguished from quartz by its strong fluorescence.

Localities

Scheelite is found at: (1) the Strong mine (section 4, T16N, R71W, and section 32, T17N, R71W) along the Ninth Street Road northeast of Laramie; (2) Copper Mountain in the Owl Creek Mountains; and (3) the Burr mine (section 8, T28N, R98W) in the Lewiston gold district in the South Pass greenstone belt along the southeastern tip of the Wind River Range.

Of these, Copper Mountain appears to be the most extensively mineralized. Several prospects (T40N, R93W) at Copper Mountain exhibit stratiform scheelite in quartzofeldspathic gneiss. During World War II, these deposits were examined as a potential source for tungsten. Scheelite at the Strong Mine is associated with copper, gold, molybdenum, and nickel anomalies in a contact zone between granite gneiss and anorthosite. The scheelite occurs in granite gneiss and is closely associated with milky quartz veins. At the Burr mine, scheelite is closely associated with quartz veinlets in metagreywacke of the Miners Delight Formation.

SCHROECKINGERITE (Dakeite)
$NaCa_3UO_2SO_4(CO_3)_3F \cdot 10H_2O$

H = 2.5
SG = 3.1 to 3.2
Crystal System – Triclinic
Color – Greenish yellow
Luster – Vitreous

Physical characteristics and crystal habit

Schroeckingerite forms greenish yellow, vitreous, thin tabular triclinic crystals, or coatings on sand grains in some sandstones. It has perfect cleavage in one direction and a hardness of 2.5. It has a moderate specific gravity of 3.1 to 3.2 and is highly radioactive and fluorescent. It will yield a bright yellowish-green or occasionally light bluish-green fluorescence under ultraviolet light.

Localities

Schroeckingerite was found in the Lost Creek area (sections 29 through 33, T26N, R94W) within the Cyclone Rim fault. The mineral occurs as a cementing agent in some sandstones in the area.

SERPENTINE GROUP
$Mg_3(Si_2O_5)(OH)_4$

H = 2.5 to 5
SG = 2.2 to 2.6
Crystal System – Monoclinic
Color – Shades of green, yellow, red, white, and black (but most commonly green)
Luster – Waxy, greasy to silky
Also **see Asbestos**, **Talc** and **Actinolite**

Physical characteristics and crystal habit

Serpentine occurs as a distinctive greenish mineral that is easily scratched with a pocketknife or rock hammer. The serpentine group includes a variety of massive forms known as antigorite, chrysotile, clinochrysotile, lizardite, and pecoraite (**Figure 77**). Serpentine in general is translucent and will have a waxy to greasy feel. In some cases, it will appear silky.

Figure 77. Serpentine from Granite Mountains.

Occurrence

Serpentine is a hydrothermal and deuteric alteration product of ultrabasic, ultramafic, and mafic igneous rocks. It is the result of the alteration of olivine and pyroxene. It may occur in amphibolites, tremolite schist, talc schist, or in rocks completely formed of serpentine known as serpentinites and found in some metamorphic terrains in Wyoming. Kimberlites are essentially serpentinized breccias. Some serpentinites may host narrow veins of cross-fiber chrysotile asbestos.

Localities

Serpentine has been found in some of Wyoming's metamorphic greenstone terrains such as South Pass, Seminoe Mountains, Rattlesnake Hills, and Elmers Rock. It also occurs in some high-grade supracrustal rocks such as those in the Tin Cup district in the Granite Mountains.

One notable locality is in the Diamond Springs Formation at South Pass (section 33, T30N, R100W). Near the entrance of the Atlantic City iron ore mine, cumulate-textured serpentinite crops out. The serpentinite exhibits numerous tiny (1mm) rounded grains that give the appearance of sand. These grains are serpentine pseudomorphs after olivine and have entirely replaced the former olivine grains. Some cross-fiber asbestos is found locally in the serpentinite (see **Asbestos**) (Hausel and Love, 1991).

Serpentinite found at the Red Dwarf ruby deposit (section 13, T30N, R93W) includes light-gray, massive serpentinite composed almost entirely of serpentine. This material is easily scratched with a rock hammer with the exception of many very hard, light-blue resistant mineral grains. These hard grains may compose as much as 20% of the serpentinite and are composed of corundum (sapphire) (Robert Odell, personal communication, 1996).

SHERIDANITE
$(Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$

H = 2 to 3
SG = 2.68 to 2.8
Crystal System – Monoclinic (Pseudohexagonal)
Color – Greenish white
Luster – pearly
(see **Mica**)

Physical characteristics and crystal habit

Sheridanite is a mica with pseudohexagonal habit that is greenish white to yellow. Sheridanite produces foliated crystals with perfect basal cleavage (001) and twinning on (001) and (310). The diagonostic characteristics for Sheridanite include well-foliated to massive, talc-like chlorite with a greasy feel in schists.

Locality

Sheridanite is restricted to Precambrian terrains and was named after the type locality in Sheridan County, Wyoming. Sheridanite was discovered on the Little Falls claim in section 10, T53N, R84W, about 150 yards downstream from the lower falls of North Piney Creek.

SILLIMANITE
Al_2SiO_5

H = 6.5 to 7.5
SG = 3.28 to 3.27
Crystal System – Orthorhombic
Color – White, colorless, gray, light-brown, or bluish
Luster – Vitreous to silky
See **Andalusite**

Physical characteristics and crystal habit

Sillimanite is a high-pressure and high-temperature metamorphic mineral that is trimorphous with andalusite and kyanite (**Figure 78**). It forms distinct, long, prismatic, translucent and principally white fibrous crystals or

Figure 78. Fibrous sillimanite in schist.

masses and is essentially restricted to metapelites. It primarily occurs as tiny fibrous crystals, but where found with larger diameter it will display a square cross section with vertical striations and perfect pinachoidal cleavage (010).

Occurrence

Sillimanite is found in micaceous schists with garnet. Other minerals that are sometimes found in association with sillimanite include andalusite, cordierite, kyanite, corundum, and muscovite. Sillimanite-bearing schists are restricted to the high-pressure amphibolite-grade metamorphic environments within the cratonic rocks in the mountainous regions of Wyoming.

Localities

Hand specimens of sillimanite schist with 0.5-inch long sillimanite crystals (porphyroblasts) and minor kyanite occur along Mill Creek (section 19, T29N, R101W) north of Anderson Ridge in the South Pass region of the Wind River Range. The Grizzly Creek prospect in the Laramie Mountains also has some sillimanite along with the kyanite-rich schists (see **Kyanite**). Sillimanite with kyanite and andalusite also occur in metapelites in the Palmer Canyon area west of Wheatland (Graff and others, 1982). In this area, samples of gem-quality cordierite, sapphire, and ruby are found associated with sillimanite and kyanite (Hausel and Sutherland, 2000).

SPECULARITE (see HEMATITE)

SPERRYLITE

$PtAs_2$

H = 6 to 7
SG = 10.46 to 10.6
Crystal System – Isometric
Color – Tin-white
Luster – Metallic

Physical characteristics and crystal habit

Sperrylite forms brittle, heavy, metallic cubic to cubo-octahedral crystals associated with dark mafic to ultramafic rocks. It is opaque with conchoidal fracture and has a bright, shiny, tin-white color and a black streak.

Occurrence

Sperrylite was first identified in Wyoming in covellite-rich ores at the New Rambler mine in the Medicine Bow Mountains and was later identified at some other nearby mines.

Localities

The New Rambler mine (SW section 33, T15N, R79W) was developed in hydrothermally altered metapyroxenite, metagabbro, and in shear zone tectonites and mylonitic gneiss of the Mullen Creek layered mafic complex. Coarsely crystalline, sheared, epidotized Rambler granite was found on the property. Diorite and peridotite were also intersected in the mine shaft (McCallum and Orback, 1968).

The New Rambler deposit is considered to be a classical supergene enriched deposit with complex mineralogy. The property has an overlying porous spongy limonite and jaspilite gossan which capped a 75-foot-thick oxidized zone. Minerals of the oxidized zone include malachite and azurite with lesser cuprite, tenorite, chalcotrichite, and chalcopyrite. Dendrites and nuggets of native copper with atacamite, chalcanthite, tetrahedrite, and bornite are sparsely distributed. This oxidized assemblage grades downward into the supergene-enriched zone consisting of platinum-bearing covellite and chalcocite. Orpiment, realgar, and lorandite were reported by Rogers (1912) in this zone. Deeper than 100 feet, the supergene minerals grade into the primary mineralized rock containing quartz-pyrite-chalcopyrite veins with minor sperrylite (McCallum and Orback, 1968).

At the nearby Blanche mine (SE section 32, T15N, R79W) west of the New Rambler, mineralization included malachite, chalcocite, cuprite, chalcopyrite, pyrite, hematite, and limonite in sheared felsic gneiss, metagabbro, and metadiorite. Two samples collected from the dump were reported to contain limonite, abundant malachite, and cuprite with traces of chalcocite and sperrylite (Loucks, 1976).

SPHALERITE
ZnS

H – 3.5 to 4
SG – 3.9 to 4.1
Crystal System - Isometric
Color – Reddish brown
Luster – Resinous

Physical characteristics and crystal habit

Figure 79. Sphalerite from the Broadway mine in the Sierra Madre.

Sphalerite occurs as a resinous massive to granular mineral often associated with galena and various copper minerals. It typically has a variable habit and color that can range from amber to reddish brown to black, and rarely to green and colorless. It is typically brittle with a conchoidal fracture and may occur in cleavage masses (it has perfect dodecahedral habit). It will dissolve in HCl and give off a distinct hydrogen sulfide odor.

Occurrence

Typically, sphalerite is found with other ore minerals such as galena, pyrite, chalcopyrite, and limonite.

Localities

Sphalerite, a zinc ore, has been reported only at a few localities in Wyoming. Most notable is the Broadway mine in the Sierra Madre of the Encampment district. According to Hausel (1997), massive to banded reddish-brown sphalerite (**Figure 79**) was found in the ore dump on the property in the SW section 32, T13N, R83W. In addition to sphalerite, minor galena with disseminated chalcopyrite, chalcocite, and covellite was found on the property with small amounts of secondary malachite and chrysocolla. The ore minerals are apparently along the contact of pyroxenite, gneiss, gabbro, and diorite. Minor amounts of sphalerite are also described at the Black Butte prospect in the Black Hills of Wyoming (NE section 26, T50N, R62W). Here sphalerite was found with galena, hemimorphite, wulfenite, minor fluorite, and jasperoid. Minor amounts of zinc, presumably as sphalerite, are also found in the Sunlight district of the Absaroka Range and in the Griggs mine of the Overthrust Belt.

SULFUR
S

H = 1.5 to 2.5
SG = 2.05 to 2.09
Crystal System – Orthorhombic
Color – Yellow
Luster – Resinous to earthy

Physical characteristics and crystal habit

Sulfur occurs as distinct yellow, resinous to earthy masses that may be translucent to opaque. The material is very soft and emits a distinctive sulfur odor. When scratched, it will produce a pale yellow streak. Sulfur is used in the manufacture of sulfuric acid, paper, gunpowder, and rubber (**Figure 80**).

Figure 80. Sulfur on limestone from Aspen Mountain, Green River Basin.

Occurrence

Sulfur occurs in many hot springs including some along the Yellowstone highway a few miles west of Cody. It also occurs in some altered limestone along Wyoming Highway 120, 3.5 miles northwest of Thermopolis (Root, 1977). Wyoming is a source for sulfur, much of which is recovered from natural gas containing hydrogen sulfide (known as sour gas).

TALC
$Mg_3(Si_4O_{10})(OH)_2$

H = 1
SG = 2.58 to 2.83
Crystal System – Monoclinic
Color – White to green
Luster – Pearly to greasy

Physical characteristics and crystal habit

Talc is very soft and has a distinctive greasy to talcum-powder feel when rubbed between one's fingers. It is easily scratched with a knife, and is found primarily as translucent, light-green masses with perfect basal cleavage (**Figure 81**). When talc

Figure 81. Talc (fibrous) veins in chlorite schist from Tin Cup district, Granite Mountains.

is suspected, the mineral is pulverized with a rock hammer and the resulting powder placed between the finger tips to test for a talcum-powder feel. It is a metamorphic mineral formed by alteration of magnesium silicates and is commonly found with serpentine and actinolite-tremolite associated with dark-green to bluish green ultramafic schists, such as tremolite-talc-chlorite schists. An ingredient in ceramics and paints, talc also has other industrial uses. Two well-known products of talc are crayons and talcum powder.

Localities

Talc schists have been found west of the Atlantic City iron mine at South Pass (section 34, T30N, R100W) and north and west of Lewiston Lakes (section 19, T29N, R97W) near Radium Springs. Similar talc schists occur in Halleck Canyon (section 13, T22N, R72W) of the Elmers Rock greenstone belt and in the Garrett region (sections 29 and 32, T25N, R73W) north of the Elmers Rock greenstone belt.

TENORITE
CuO

H = 3 to 4
SG = 6.5
Crystal System – Monoclinic.
Color – Black
Luster – Vitreous, submetallic to earthy

Physical characteristics and crystal habit

Tenorite is found in some of Wyoming's copper districts. It forms black stains on mineralized rocks and has a vitreous, submetallic, to earthy luster (**Figure 82**). It is easily scratched and will yield native copper replacement when a well-used rock hammer is rubbed across a specimen wetted with dilute hydrochloric acid. It is often found associated with malachite and cuprite.

Figure 82. Tenorite (black) with azurite (blue) and altered sandstone from the Griggs mine, Lake Alice district, western Wyoming.

Localities

Tenorite has been identified with other oxidized copper minerals on some mine dumps and in mineralized veins and shear zones, including several historical mines on Jelm Mountain and in the southern Sierra Madre. It is also reported in the Lake Alice district in the Overthrust Belt.

Some good specimens are found in the Huston Park area of the Sierra Madre. For example, tenorite is found on mineralized samples at Prospect 9999 in the W/2 section 15, and E/2 section 16, T13N, R86W of the Encampment district (Hausel, 1997). Tenorite is probably more widespread than originally thought and most likely has been overlooked in the past because of its nondistinctive black color stains. It is often misidentified as pyrolusite (manganese oxide).

TETRAHEDRITE

$Cu_{12}Sb_4S_{13}$

H = 3 to 4.5
SG = 4.6 to 5.1
Crystal System – Cubic
Color – Black
Luster – Metallic

Physical characteristics and crystal habit

Found as steel gray, opaque, metallic massive and coarse granular to compact material. Rarely found as tetrahedral (3-sided) crystals. Contact or penetration twins are common (111). Yields a black, brown, or dark-red streak.

Localities

Tetrahedrite has been reported in some of the state's copper districts. Tetrahedrite was reported at the New Rambler mine in the Medicine Bow Mountains (see **Sperrylite**) and at the nearby Duchess mine (SW section 32, T15N, R79). At the Duchess mine, shear zone tectonites and strongly sheared metagabbro and metadiorite were intersected in the old mine workings. The recovered ore contained traces of copper associated with pyrite, hematite, limonite, and gold-bearing tetrahedrite (McCallum and Orback, 1968; Loucks, 1976).

Tetrahedrite is reported in some cupriferous veins in the Absaroka Range. Within the Kirwin district near the headwaters of the Wood River (Ts 45 and 46N, R104W) southwest of Meeteetse, the following minerals were identified on various mine dumps around the Kirwin copper porphyry: pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, molybdenite, stephanite, limonite, malachite, azurite, cuprite, native gold, specular hematite, siderite, barite, calcite, quartz, and dolomite (Hewett, 1912).

Tetrahedrite is also reported at the Crater Mountain copper porphyry (section 18, T47N, R106W) on the confluence of Needle Creek and the South Fork of the Shoshone River near the center of the southern Absaroka volcanic field. Here, chalcopyrite is the major disseminated mineral in the altered zone, followed in abundance by molybdenite and minor bornite. Beyond the central chalcopyrite-molybdenite zone, pyrite is dominant and associated with low copper-molybdenum values.

Chalcopyrite and molybdenite also occur in narrow quartz veinlets and coat fractures in the area of disseminated sulfide minerals. Vein mineralization extends outward and the veins are commonly 1 to 2 inches wide and reach a maximum of 1 foot locally. These contain galena, chalcopyrite, sphalerite, pyrite, minor arsenopyrite, and tetrahedrite in quartz, calcite, dolomite, and minor siderite gangue. The veins are commonly crustiform, banded, and considered simple fracture fillings (Fisher, 1972).

In the Sunlight district to the north, stockwork mineralization consists of 1-inch-wide veins and veinlets containing chalcopyrite, bornite, covellite, and chalcocite in quartz and calcite gangue. Ore minerals reported by Parsons (1937) include chalcopyrite, pyrite, galena, tetrahedrite, sphalerite, gold, sylvanite ($AgAuTe_4$), bornite, famatinite (Cu_3SbS_4), enargite (Cu_3AsS_4), wolframite [$(Fe,Mn)WO_4$], proustite (Ag_3AsS_3), stromeyerite ($AgCuS$), bournonite ($CuPbSbS_3$), magnetite, limonite, malachite, azurite, covellite, anglesite ($PbSO_4$), cerussite ($PbCO_3$), cerargyrite ($AgCl$), chalcocite, quartz, siderite ($FeCO_3$), ankerite [$Ca(Fe,Mg)(CO_3)_2$], calcite, adularia, and barite.

TOURMALINE
$Na(Mg,Fe,Mn,Li,Al)_3Al_6(Si_6O_{18})(BO_3)_3(OH,F)_4$

H = 7 to 7.5
SG = 3.03 to 3.25
Crystal System – Hexagonal
Color – Predominantly black and less commonly green
Luster – Vitreous to translucent

Physical characteristics and crystal habit

Tourmaline crystals are typically elongated prisms with triangular cross sections and striations parallel to (001). Many tourmaline crystals also display basal fractures perpendicular to the striations. Tourmaline has moderate heft. Most tourmaline found in Wyoming has been black schorl tourmaline that is opaque with vitreous luster (**Figure 83**).

Figure 83. Prismatic black tourmaline with triangular cross-sections in quartz from Anderson Ridge, Wind River Range.

Occurrence

Tourmaline is found in some granite pegmatites in Wyoming. These pegmatites may also contain some muscovite, bull quartz, beryl, and feldspar.

Localities

Tourmaline has been identified in several granite pegmatites in Wyoming. Pegmatites in the Anderson Ridge area near South Pass contain abundant tourmaline with lesser beryl. A few pegmatites in sections 30 and 31, T29N, R101W, in the Anderson Ridge area are enriched in tourmaline. Collectors have recovered some specimens up to 1 foot in length. Tourmaline (schorl) is also reported with beryl in pegmatites of the Hartville uplift of eastern Wyoming.

TRONA
$Na_3H(CO_3)_2 \bullet 2H_2O$

H = 2 to 3
SG = 2.14
Crystal System – Monoclinic
Color – Tan to white
Luster – Vitreous to earthy

Figure 84. Flattened massive fibrous trona from the Green River Basin.

Physical characteristics and crystal habit

Trona is tan to white in color, with vitreous to earthy luster and flattened fibrous to massive prismatic crystals (**Figure 84**). It has perfect cleavage in one direction (100) and an alkaline taste. Most trona in Wyoming is light brownish-yellow, vitreous, and massive bedded material.

Occurrence

Trona is an alkaline mineral of unusual abundance in the Green River Basin of southwestern Wyoming. The world's largest resource of natural trona occurs in 42 beds of the Green River Formation west of Green River. Estimated trona resources total 134.4 billion tons (Burnside and Culbertson, 1979).

The trona was precipitated from a relatively shallow saline lake during periods of intense evaporation. The prehistoric lake which produced the Wyoming trona beds is known as Lake Gosiute. It covered a large area in southwestern Wyoming, northeastern Utah, and northwestern Colorado during the Eocene.

Today, five underground mines produce trona from depths as great as 1,700 feet. These mines lie north and south of Little America along Interstate 80. The mined trona is processed and used in the glass, paper, soap, petroleum refining, and textile industries. Bicarbonate of soda (baking soda) is one of the better known household products made from Wyoming trona.

URANINITE
UO_2

H = 5 to 6
SG = 7.5 to 10
Crystal System – Cubic
Color – Black to grayish black
Luster – Submetallic

Physical characteristics and crystal habit

Uraninite forms highly radioactive brown to black submetallic grains that have a greasy to dull luster. It has a hardness of 5 to 6, will produce a brown, black, or gray streak, and has a very high heft. Typically, it forms cubes or octahedrons (isometric crystal system), but most commonly occurs in a massive form.

Occurrence

Uraninite has been identified in uranium roll fronts in Tertiary sedimentary rock units in some Wyoming basins, including the Shirley and Powder River basins and the Gas Hills area of the Wind River Basin.

Similar minerals

Coffinite, a hydrous uranium silicate, is similar in appearance to uraninite and most often occurs in fine aggregates and rarely as tetrahedrons.

Uranium

Although uranium is found in metamorphic and igneous rocks, the great majority of the state's resources are hosted by sandstone within the Wyoming basins. During the uranium boom of the late 1970s, uranium was mined from several districts (**Figure 85**).

Uranium minerals are numerous and chemically complex, but can be differentiated into two groups on the basis of color and degree of oxidation. Most Wyoming uranium is tied up in chemically reduced (unoxidized) black to brown minerals, such as uraninite and coffinite. Oxidized uranium minerals are brightly colored and are found near the surface where oxygen-rich groundwater combines with uranium. Carnotite, autunite, schroeckingerite, and tyuyamunite are typical oxidized uranium minerals. All uranium minerals naturally emit beta and gamma rays detectable by scintillometers and Geiger counters.

During the past, much of the uranium produced in Wyoming occurred in roll fronts in fluvial (stream-deposited) sandstone. The *roll fronts* are concentrations of uranium located at a chemical interface. Uranium is relatively mobile when oxidized. Thus, on the upslope side of a roll front, the groundwater and associated minerals are typically oxidized. On the downslope side of the roll fronts, the uranium and groundwater are chemically reduced (unoxidized). It is thought that oxygen-rich groundwater traveled downslope through the fluvial sandstone, picking up and oxidizing the uranium until much of the oxygen in the water was depleted. At this point, uranium precipitated.

These types of sandstone uranium deposits are found in the Powder River Basin, the Shirley Basin, the Great Divide-Washakie Basin and the Wind River Basin. Detailed information on the location of many of these deposits is available in Osterwald and others (1966).

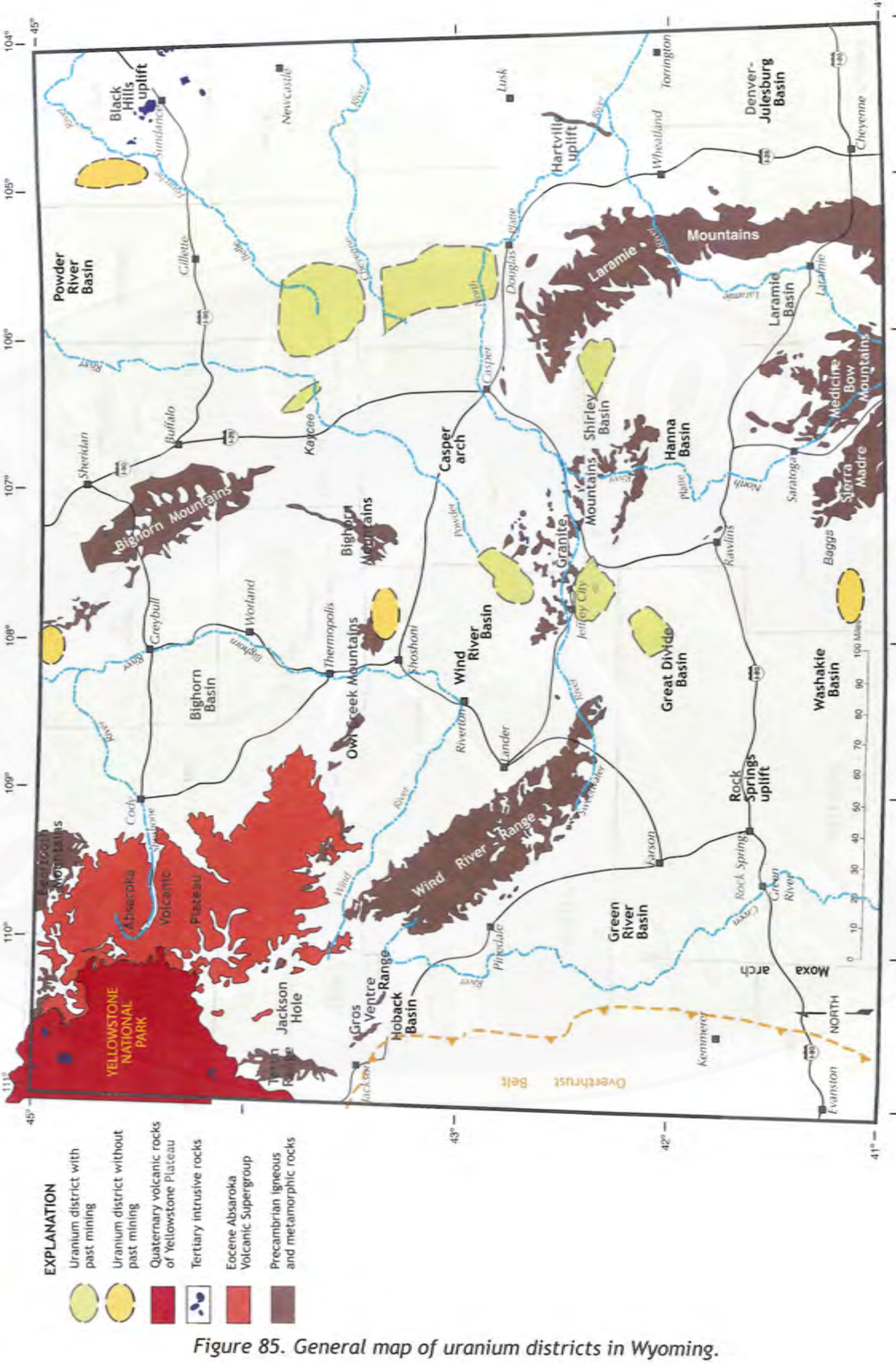


Figure 85. General map of uranium districts in Wyoming.

VARISITE
$AlPO_4 \cdot 2H_2O$

H = 3.5 to 4.5
SG = 2.57
Crystal System – Orthorhombic
Color – Pale to emerald green
Luster – Vitreous, waxy to dull

Figure 86. Varisite from the Cody area.

Physical characteristics and crystal habit

Varisite occurs as massive crusts or nodules apparently associated with minyulite [$KAl_2(PO_4)_2(OH,F) \cdot 4H_2O$] in the Phosphoria Formation of western Wyoming (**Figure 86**). Specimens of both minerals from the Cody area were verified by XRD at the Wyoming State Geological Survey.

Locality

Varisite has been reported at two separate locations in western Wyoming. One locality is at Cedar Mountain near Cody and a second locality has been reported farther south near Cokeville.

VERMICULITE
$(Mg,Fe,Al)_3(Al,Si)_4O_{10}(OH)_2 \cdot 4H_2O$

H = 1.5
SG = 2.3
Crystal System – Monoclinic
Color – black brown to golden brown
Luster – pearly

Physical characteristics and crystal habit

Figure 87. Vermiculite with micaceous cleavage from the North Platte River Valley.

Vermiculite is a group of micaceous minerals that vary somewhat in composition. They form as a result of alteration of biotite and phlogopite mica and retain the original crystal habit as well as the micaceous cleavage (**Figure 87**). Vermiculite is soft and pliable, and ranges in color from white to yellow to brown. When heated, it will expand to as much as 30 times its original volume. Many Wyoming vermiculites are hosts for corundum (sapphire and ruby). In the past, vermiculite was well suited for insulation and fireproofing and was mined from several small deposits in Wyoming.

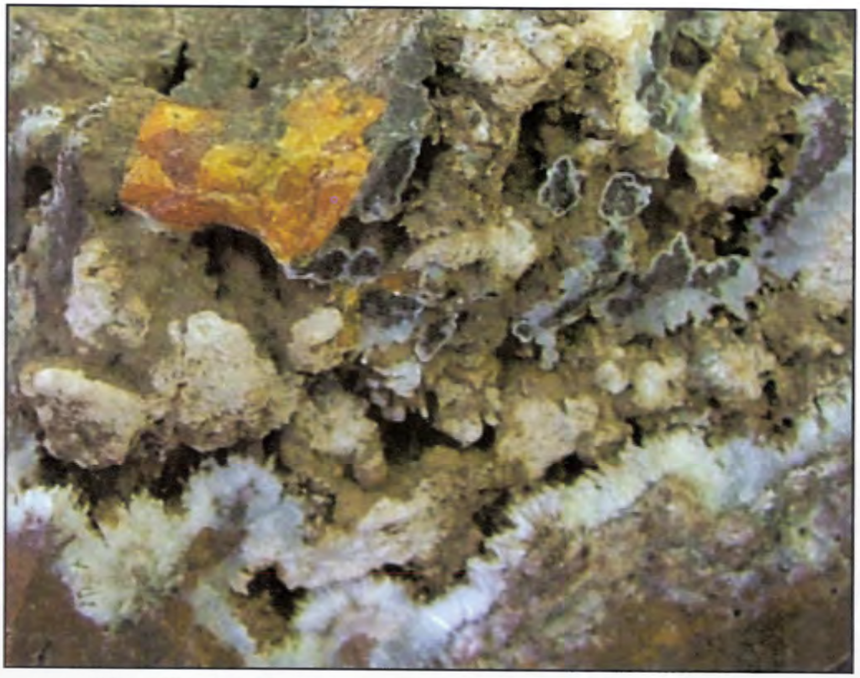


Figure 88. Wulfenite (yellow-orange) on jasperoid, Black Butte area.

WULFENITE
$PbMoO_4$

H = 2.75 to 3
SG = 6.5 to 7
Crystal System – Tetragonal
Color – Shades of orange and yellow
Luster – Resinous to adamantine

Physical characteristics and crystal habit

Wulfenite occurs as distinctly resinous, yellow-orange, translucent rounded to tabular masses and octahedral mineral grains (**Figure 88**).

Locality

Wulfenite is found at Black Butte (NE section 26, T50N, R62W) with hemimorphite and jasperoid in a silicified zone in the Pahasapa Limestone.

WYOMING ROCKS

Rocks are aggregates of minerals formed by various geologic processes. Three basic rock groups are recognized—metamorphic, igneous, and sedimentary. Metamorphic rocks form by recrystallization of pre-existing rocks which were subjected to high temperatures and pressures. Metamorphic rocks are classified into three types: regional, contact, and dislocation. Regional metamorphic rocks occur in most of Wyoming's mountain ranges and are formed from pre-existing sedimentary and igneous rocks that were buried under a thick sedimentary sequence for eons of time. Under the tremendous weight of the sediments, new minerals and rock textures that were stable at the elevated temperatures and pressures replaced the former minerals and textures.

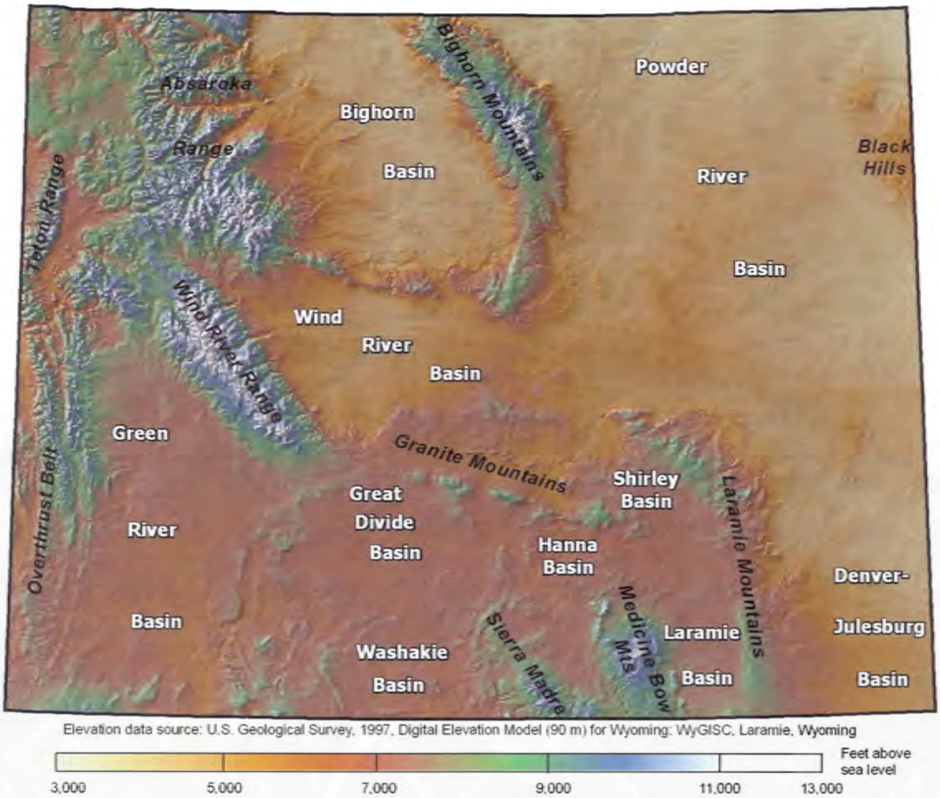
Contact metamorphic rocks are uncommon in Wyoming. However, at a few locations, such as in the Rattlesnake Hills of the Granite Mountains, several alkalic igneous intrusives invaded both the metamorphic terrain and the adjacent sedimentary rocks along the edge of the Wind River Basin. Where the hot igneous rocks came in contact with limestone in the basin, carbonate rocks were altered to low-grade marble, producing a narrow zone of contact metamorphism.

Tectonic forces before, during, and after uplift of the metamorphic belts resulted in fracturing of the terrains. Localized dislocation metamorphic zones (shattered, broken and granulated rock) are recognized by the presence of cataclastic and mylonitic textures. These rocks are especially well developed in shear zones and faults. Several good examples of ultramylonites (cherty looking rocks that have been granulated to a fine powder) occur in the South Pass area near the Gold Dollar and Miners Delight mines.

Igneous rocks form at high temperatures at depth. These can originate from depths as great as 200 miles to less than several miles below the surface. Some of this hot magma will erupt at the surface from volcanic vents. Following eruption, the magma will cool rapidly and produce finely crystalline igneous rock. Where the molten material slowly cooled and solidified beneath the Earth's surface however, coarsely crystalline plutons, batholiths, and dikes formed.

Sedimentary rocks formed at the Earth's surface by the erosion and deposition of particles of pre-existing rocks, or by chemical and biochemical precipitation from ancient lakes or oceans. Some sedimentary rocks contain fossils of creatures that lived millions of years ago and were preserved in various ways to become part of the rock.

A relief map of Wyoming (**Figure 89**) is useful for demonstrating where these three rock groups are most likely to occur. Many of Wyoming's mountain ranges formed during the tectonic events that uplifted thick sections of rock along faults. Where uplift was greatest, erosion has stripped away most, or all of the sedimentary cover. Most of these ranges are cored by some of the oldest metamorphic rocks in the U.S.



Elevation data source: U.S. Geological Survey, 1997, Digital Elevation Model (90 m) for Wyoming: WyGISC, Laramie, Wyoming

Figure 89. Relief map of Wyoming. Digital cartography by D.W. Lucke, 2005.

and are favorable places to search for precious stones, precious metals, and base metals. Metamorphic rocks in these mountains range in age from about 1.7 billion years old to more than 3 billion years old. Large regions in Wyoming's mountains were intruded by plutons and batholiths. These intrusive rocks are igneous and are dominantly granites that cooled and crystallized at depth.

In northwestern Wyoming, a large field of volcanic rocks erupted between 51 and 43 million years ago from several volcanoes along the eastern edge of Yellowstone National Park. These volcanic rocks now form the Absaroka Range. Some (geologically) young volcanoes are well preserved in the Leucite Hills north of Interstate 80 and north of Rock Springs. These volcanoes erupted only 1 to 3 million years ago and this area should be considered a possible site for future eruptions, as should Yellowstone National Park. The volcanic rocks which form the Leucite Hills volcanoes are finely crystalline igneous rocks. Some igneous rocks in Wyoming are potential sources for large base and precious metal deposits.

The basins in Wyoming are predominantly underlain by sedimentary rocks. During the Paleozoic and part of the Mesozoic, ancient seas covered Wyoming and rocks such as limestone and other marine strata were deposited. Later, sediments eroded from uplifted mountains were carried downslope into nearby basins. Through time, these sediments were compacted and cemented to produce sandstones, siltstones, shale, and other related detrital sedimentary rocks. The basins are known sources for many industrial minerals, coal, oil, and natural gas. With these geographic relationships in mind, each of the three rock groups can be discussed more thoroughly. The *Geologic Map of Wyoming* (Love and Christiansen, 1985) shows this general distribution of rock types.

METAMORPHIC ROCKS

According to Mason (1978, p. 3), "Metamorphic rocks are those whose characters have been changed since their original formation by processes operating within the Earth." These changes in character that Mason spoke of are changes in texture, mineralogy, or both. They result from temperature and pressure increases and alteration by solutions.

Many metamorphic rocks have distinct textures; the classification of these is based primarily on texture and to a lesser extent on mineralogy. Textures observed in metamorphic rocks are of two general types—foliated and nonfoliated.

Foliated rocks contain abundant mica flakes, amphibole prisms, or other prismatic minerals that are arranged parallel to one another. When foliation is highly developed throughout a rock, the texture is called *schistose*. In some metamorphic rocks, narrow dark schistose layers alternate with coarsely crystalline bands that may be lighter in color with different minerals. Such a banded texture is termed *gneissic*. Schists and gneisses are the most common metamorphic rocks in Wyoming.

Nonfoliated metamorphic rocks are described with a variety of textural classifications. Many of these rocks formed from minerals with interlocking grains and may look like some igneous rocks. Because metamorphism tends to form crystals of the same grain

Table 11. Simplified Classification of Metamorphic Rocks

Texture or grain size	Principal mineral	Rock name	Original rock type
Equigranular (equal grain size)	Quartz	Quartzite	Sandstone
Equigranular to foliated	Calcite or dolomite	Marble	Limestone and/or dolomite
Broadly foliated parallel layers or bands	Feldspar, mica, quartz, amphibole, garnet	Gneiss	Granite, rhyolite, shale, etc.
Thinly foliated	Feldspar, mica, amphibole, quartz	Schist	Andesite, basalt, rhyolite, shale, etc.
Very thinly foliated	Mica, quartz, clay (these minerals normally cannot be seen with the naked eye)	Slate	Shale

size, a significant portion of metamorphic rocks have equant grain sizes (**Table 11**).

Gneiss

Figure 90. Gneiss from Copper Mountain.

Gneiss (pronounced "nice") is a metamorphic rock with coarse-grained, light-colored mineral layers that alternate with dark schistose layers (**Figure 90**). The light minerals may be quartz and feldspar while the dark minerals may be mica, amphibole, or pyroxene.

Gneiss forms by the deformation and recrystallization of igneous and sedimentary rocks at great depth in the crust. A large percentage of gneiss in Wyoming is chemically equivalent to the igneous rock granodiorite. A significant portion of metamorphic rocks in the state are gneisses.

Schist

Schist is a metamorphic rock characterized by finely laminated foliation. The surfaces of schists (in particular mica schists) tend to reflect sunlight (like a mirror) due to the abundant platy or prismatic crystals that form in parallel bands (**Figure 91**).

Schists are usually described and named by listing their principal mineral constituents. For example, a schist composed of biotite with some garnet would be named garnet-biotite schist. A schist with abundant andalusite would be an andalusite schist. Schists are relatively common in Wyoming's mountains.

Quartzite

Quartzite is a hard compact rock composed almost entirely of cemented, rounded, relatively equant quartz grains. It is the metamorphic equivalent of sandstone. During metamorphism, fine-grained sand tends to dissolve, filling pore spaces between sand grains and coating larger sand grains. The tendency is to create a rock of equal grain size. When struck, quartzite breaks across individual grains unlike sandstone, which breaks around grains. When struck by a hammer, quartzite will ring, while

Figure 91. Chlorite-talc-actinolite schist showing distinct schistose layering. Sample from the Carissa mine, South Pass.

sandstone will yield a dull thud.

Many quartzites in Wyoming are pure white, but some are brown (stained by iron oxide) and some are light green (filled with fuchsite, a green chromium-rich mica). Quartzites are fairly common in the Medicine Bow Mountains and Sierra Madre. A gray, micaceous-rich quartzite with some lithic (rock) fragments is also found in Wyoming, particularly in the South Pass, Elmers Rock, and Rattlesnake Hills greenstone belts. These quartzites are referred to as metagreywackes.

Marble

Marble consists of calcite or dolomite and is the product of metamorphosed carbonate sedimentary rocks (limestones and dolomites). Marbles are generally white to light gray and are distinguished from their sedimentary counterparts by a greater degree of crystallinity and coarser grain size.

Marbles are not very common in Wyoming, although several outcrops are reported in the Medicine Bow Mountains, Haystack Range, and Laramie Mountains. At White Mountain in the Sunlight Basin of the Absaroka Range, limestone in contact with volcanic rock was baked and metamorphosed to marble. Marbles found in the Snowy Range of the Medicine Bow Mountains were originally limestones deposited about 2 billion years ago and recrystallized under increased pressures and temperatures at depth before being uplifted to their present position at the earth's surface. These rocks, even though metamorphosed, still have an appearance of limestone in hand specimen and are often referred to as metalimestone.

Amphibolite

Amphibolites are black to greenish black metamorphic rocks formed of amphibole minerals with lesser quantities of other minerals. Amphibolites that are the metamorphosed products of sedimentary rocks are termed para-amphibolites, and amphibolites formed from pre-existing igneous rocks are called orthoamphibolites.

These rocks are common in many of the state's historical base and precious metal mining districts. Some para-amphibolites will contain specks of reddish-brown almandine garnet. Notable occurrences of both para- and orthoamphibolites were mapped in the Copper Mountain area of the Owl Creek Mountains (Hausel and others, 1985).

IGNEOUS ROCKS

Igneous rocks form by the solidification of molten magma that originated from melted or melting rock at depth. Magma that erupts at the surface of the Earth from a volcano or similar vent is termed *extrusive* or *volcanic* (**Figure 92**). Much of the heat from the extrusive magma dissipates upon contact with the Earth's atmosphere or ocean bottom and the rock cools rapidly, producing a fine-grained texture.

Magma that does not reach the surface, but slowly cools at depth in the earth's crust, is termed *intrusive* igneous rock. Slow cooling allows crystals to grow to a relatively large size. Thus most intrusives, such as granite, have a coarser-grained texture than most extrusive igneous rocks. The mineral grains are randomly arranged in most igneous rocks.

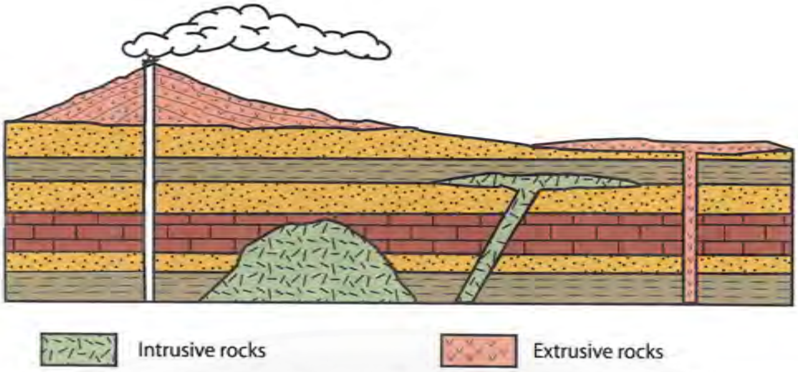


Figure 92. Cross section illustrating the relationships between intrusive and extrusive igneous rocks and bedded sedimentary rocks.

Igneous rocks with *porphyritic* texture have an uneven grain size with larger, randomly oriented crystals (phenocrysts) enclosed by a fine-grained groundmass. The porphyritic texture resulted from cooling rate changes as the molten rock approached the surface and erupted. The phenocrysts formed slowly in the magma before extrusion and the fine-grained material crystallized relatively quickly upon extrusion.

Igneous rock classification is based on chemistry. The minerals of the rocks are essentially solid chemicals, so in a sense, the rocks are also classified by their mineralogy. As seen in **Table 12**, the relative amount of feldspar and the presence or absence of quartz are important criteria for naming igneous rocks. The distinction between plagioclase and potassium feldspar is most easily made in the field by noting the presence or absence of fine twinning striations on the crystal faces by using a 10-power magnifying lens. Plagioclase typically has twinning striations, whereas potassium feldspar does not. Some potassium feldspar is also pink, while most plagioclase has a white to cream color. Quartz almost always has an irregular mineral shape with conchoidal fracture, but is translucent and may have a greasy to glassy luster.

Fine-grained igneous rock is difficult to classify in the field because individual minerals cannot be identified without the use of a special petrographic microscope. In the field, the classification of these rocks must be based on texture and color. Generally, the lighter colored rocks contain more potassium feldspar and quartz. The darker colored rocks contain mafic minerals (amphibole and pyroxene) with little to no quartz.

Basalt-Gabbro

Basalt is a fine-grained, black, greenish black, and less often reddish brown mafic volcanic rock (**Figure 93**). Individual minerals are seldom large enough to distinguish with the naked eye, and a

Figure 93. Basalt porphyry.

petrographic microscope is usually required for mineral identification. Some varieties of basalt were saturated with volcanic gas and developed numerous gas cavities, called *vesicles*. Some of the rare lamproite volcanic rocks in the Leucite Hills also contained considerable gas, which produced some vesicular volcanic rocks (**Figure 94**).

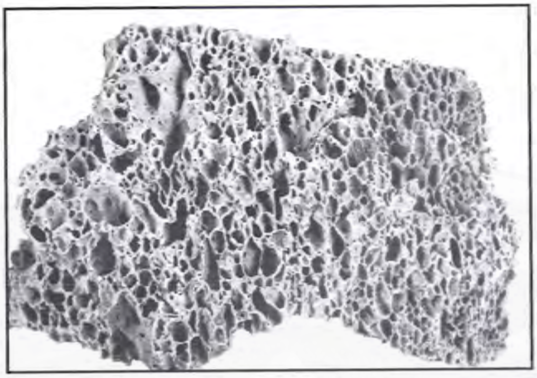


Figure 94. Vesicular volcanic rock (Wyomingite) from Leucite Hills.

Table 12. Simplified Classification of Igneous Rocks

Rock type	Texture or grain size	Mineral Composition				
		Light-colored. Principal minerals: orthoclase feldspar, some biotite or amphibole		Medium-colored. Principal minerals: plagioclase & orthoclase feldspar, amphibole, biotite, pyroxene		Dark-colored. Principal minerals: plagioclase feldspar, pyroxene, amphibole, olivine
		With quartz	No quartz	With quartz	No quartz	No quartz
Intrusive	Very coarse grained	Pegmatite				
	Coarse to medium grained	Granite	Syenite	Granodiorite, quartz diorite	Diorite	Gabbro, pyroxenite (pyroxene only), peridotite (olivine-rich with no feldspar).
Extrusive	Fine grained[1]	Rhyolite	Trachyte	Dacite	Andesite	Basalt
	Porous	Pumice		Pumice		Scoria
	Glassy	Obsidian				
	Fragmental or broken	Fine-grained ash or tuff. Coarse-grained breccia.				

[1] If mixed grain or crystal sizes occur, then the rock is called a porphyry. Example: andesite porphyry.

Highly vesicular, dark-colored volcanic rock is termed *scoria* (**Figure 95**). Pumice is similar to scoria; however, it is often lighter colored and sufficiently buoyant to float on water (see **Pumice**). Another igneous rock found that commonly has vesicular texture found in the state is lamproite. However, lamproite is not a basalt, but is instead a very rare mafic, ultrapotassic igneous rock (see **Lamproite**).

Figure 95. Scoria with vesicles from the Leucite Hills.

Gabbro is the coarse-grained equivalent of basalt. It formed at depth and cooled slowly. The major minerals that form both basalt and gabbro are plagioclase feldspar, pyroxene, and sometimes olivine.

The Absaroka Range of northwestern Wyoming has large regions dominated by Tertiary basalt and andesite. Many of the state's historical gold mining districts also have basalts, but these are very old and metamorphosed. Some of these basalts and gabbros retain relict volcanic textures and are termed metabasalt or metagabbro. Even though they are clearly metamorphic rocks, they still retain characteristics of the former igneous rocks. Others are sufficiently metamorphosed so that they no longer retain any relict textures. These are termed amphibolites, or more specifically orthoamphibolites, and are considered former basalts and gabbros based on their chemistry and geologic setting.

Andesite and Dacite – Diorite and Granodiorite

Andesites are fine-grained to porphyritic gray to green volcanic rocks whose major minerals are plagioclase feldspar, amphibole, and pyroxene (**Figure 96**). Some potassium feldspar and mica may be present in small amounts. If quartz is present in visible amounts, the rock is termed *dacite* rather than andesite. *Diorite, quartz diorite* and *granodiorite* are coarse-grained intrusive rocks that are chemically equivalent to andesite and dacite.

Andesites and dacites are found in the Absaroka Range and Yellowstone National Park of northwestern Wyoming. In some of the state's gold mining districts such as South Pass, metamorphosed 2.8-billion-year-old andesites are called meta-andesites. Elsewhere, such as at Copper Mountain in north-central Wyoming, metamorphism was sufficiently intense to change both the mineralogy and texture of what are thought to be metamorphosed andesites. These highly metamorphosed rocks are chemically similar to andesites and dacites, but they are now texturally gneisses.

Figure 96. Andesite porphyry from Sunlight Basin, Absaroka Range.

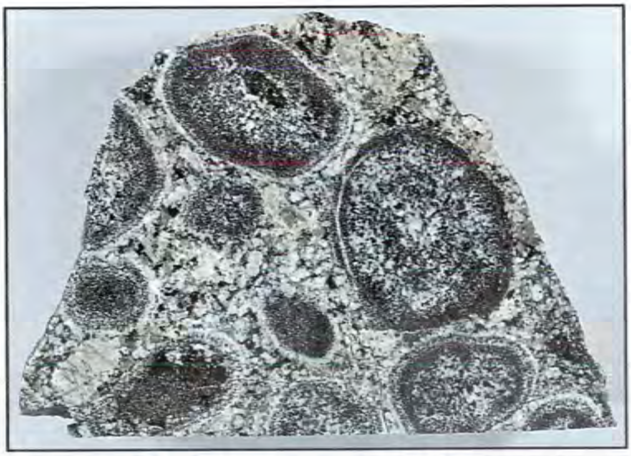


Figure 97. Orbicular granodiorite from the Ferris Mountains.

Granodiorite and quartz diorite intrusive rocks also occur near and within many of the state's gold districts and within the Absaroka Range. In the Ferris Mountains north of Rawlins is a very unusual granodiorite coveted by rock hounds and geology students. This is the Ferris Mountains orbicular granodiorite (**Figure 97**) (Master, 1977).

Rhyolite-Granite

Rhyolites are light-colored, gray, white to red volcanic rocks consisting of quartz, potassium feldspar, and mica, with minor plagioclase feldspar. Texturally, they are fine-grained porphyritic to *aphanitic* (mineral components not distinguishable with the unaided eye) rocks and many exhibit flow banding. Tertiary-age rhyolites occur as extrusive flows, flow breccias, intrusive plugs, and dikes in the Absaroka Range. Only a small proportion of the Absaroka-Yellowstone volcanics are rhyolites.

Granites are coarse-grained intrusive equivalents of rhyolite. Precambrian granite plutons occur in most Wyoming mountain ranges. For example, Interstate 80 between Cheyenne and Laramie cuts through several miles of Sherman Granite. The Vedauwoo recreation area near Buford is located within this granite (**Figure 98**). The Granite Mountains in central Wyoming are named for their major component, Precambrian granite.

Pumice

Pumice is a lightweight (commonly lighter than water) frothy appearing rock largely composed of volcanic glass. The chemical composition of pumice is much like that of obsidian, and the frothy texture is due to numerous vesicles produced by escaping

Figure 98. Granite in the Vedauwoo picnic area near Buford. Rounded weathering surface and prominent joint pattern are characteristic of this rock type (Photograph by Richard W. Jones).

volcanic gas when it was molten.

Pumice is often developed on the upper surface of lava flows or occurs as fragments of volcanic rock blown out of volcanoes. It is generally white or gray and has a mineral composition similar to rhyolite, andesite, or dacite. Pumice fragments are found in the Yellowstone-Absaroka volcanics and in the Leucite Hills north of Rock Springs.

Obsidian

Obsidian is a dense volcanic glass produced by extremely rapid chilling or cooling of magma at the Earth's surface. Obsidian commonly is black and has a conchoidal fracture. Chemically, most obsidian is equivalent to rhyolite. The color of obsidian is due to impurities in the volcanic glass: black obsidian is colored by disseminated magnetite, red obsidian is colored by hematite.

The Tertiary lava flows in Yellowstone National Park contain some obsidian. Obsidian Cliff in the northwestern part of Yellowstone is a popular tourist site.

Tuff

Tuff is a light colored, fine-grained volcanic rock composed of volcanic ash, small fragments of pumice, and broken crystals. During explosive volcanic activity such as the eruption of Mount St. Helens, volcanic ash and debris are thrown into the air and blanket the surrounding landscape. When solidified, they are termed tuffs or ash-fall tuffs.

Tuffs containing large angular fragments of rock are called *tuff breccias*. Some breccias contain angular fragments of volcanic rock and may be cemented by other volcanic material or tuffs. These may be called *fragmental volcanics* or *volcanic breccias*. Such rocks generally form at the vent of a volcano.

Some volcanic eruptions yield small, hot particles that settle on the ground and build up to a thickness such that the particles tend to flatten and weld together due to the intrinsic heat. These rocks are termed *welded tuffs*. Welded tuffs are difficult to distinguish from many rhyolite flows without a microscope. Tuffs and volcanic breccias are common in the Yellowstone-Absaroka volcanic field.

SEDIMENTARY ROCKS

Sedimentary rocks form at or near the Earth's surface by a variety of mechanical, chemical, or organic processes. Many of these rocks are composed of detrital mineral and rock fragments that were weathered and eroded from preexisting rocks, mineral matter organically or inorganically precipitated from solutions, and other organic materials. Sedimentary rocks are usually characterized by layering or bedding. Their classification is based primarily on mineral content and grain size (**Table 13**). The following discussion of sedimentary rocks is modified from Root (1977).

Chert

Chert is a fine-grained, dense, hard cryptocrystalline quartz. It occurs in a wide variety of colors including black, white, yellow, gray, green, brown, and red. Dark gray to black varieties are commonly called flint (see **Chalcedony**).

Chert forms by the organic and/or inorganic precipitation and recrystallization of silica dissolved in groundwater or sea water. Many Phanerozoic cherts contain siliceous skeletal parts of small organisms. Siliceous sponge-spicule-bearing chert is common in the Permian Phosphoria Formation of western Wyoming and chert beds or nodules are found in some limestones. Cherts of Precambrian age are reported in many metamorphic terrains in the state. Many of these cherts are considered to be exhalites related to submarine volcanic activity and are often termed metachert. Iron formation at South Pass is a banded rock with alternating layers of magnetite and chert. The South Pass iron formation is also considered by many geologists to be an exhalite. Banded iron formations are reported in a few of Wyoming's metamorphic terrains (Harrer, 1966).

Coal

Coal is a rock consisting almost entirely of compressed, partially decomposed plant material. This organic material is originally deposited as peat in swamps, marshes, and bogs where it accumulated beneath water and was rapidly covered and compacted. Following burial, heat changed the peat into coal (**Figure 99**).

Figure 99. Coal.

Coals and other organic debris are classified or ranked according to the proportions of moisture, volatile matter, fixed carbon and heating value. Ranks of coal from lowest to highest include peat, lignite, sub-

Table 13. Simplified Classification of Sedimentary Rocks

Grain size	Chief mineral	Cement	Rock name
Clastic Rocks			
1/16 inch or greater	Any rock or mineral fragment	Silica, calcite, iron oxide, clay, sand, silt	Breccia (angular) Conglomerate (rounded)
Less than 1/16 inch but still visible	Quartz, feldspar	Silica, calcite, iron oxide, clay, gypsum, anhydrite	Sandstone (coarser) Siltstone (finer)
Too small to see with the naked eye	Clay minerals	----	Shale (bedded, fissile) Claystone (more massive)
Chemical and Organic Rocks			
Variable	Calcite	Calcite	Limestone
	Dolomite	Dolomite	Dolomite
	Gypsum, anhydrite	Not applicable	Gypsum, anhydrite
	Halite	Not applicable	Rock salt
Too small to see with the naked eye	Silica	Not applicable	Chert
Not applicable	Carbon	Not applicable	Coal

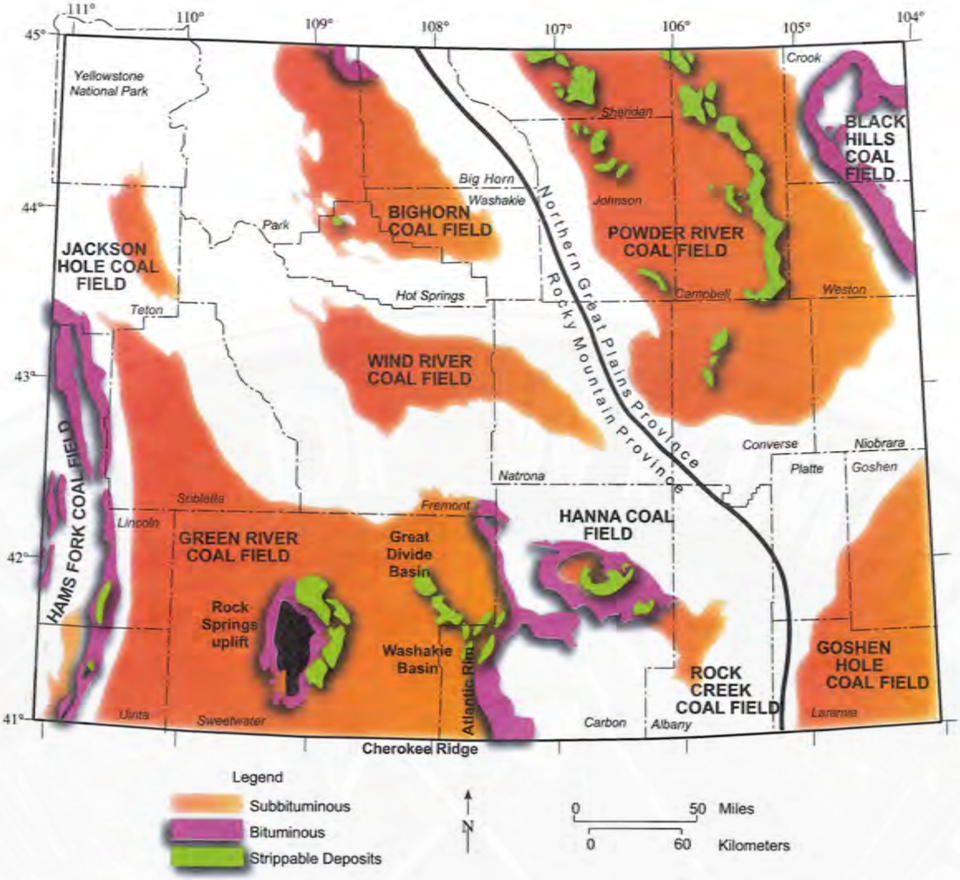


Figure 100. Map of the coal-bearing areas of Wyoming.

bituminous coal, bituminous coal, and anthracite coal. The highest-rank coals have been subjected to the highest temperatures during burial. This tends to drive off water (oxygen and hydrogen), enriching the coal in carbon relative to the other two major chemical elements.

Enormous resources of bituminous and subbituminous coal of Cretaceous and Tertiary age occur in Wyoming (**Figure 100** and **Figure 101**). More than 1.6 trillion tons of coal resources, the second largest in the U.S. only after Alaska, are estimated for the Wyoming coal fields (Ayers, 1986; Glass, 1984). The Wyodak coal bed is more than 100 feet thick in the Powder River Coal Field near Gillette, Wyoming. Another coal, the Lake DeSmet bed near Buffalo, Wyoming, is more than 200 feet thick.

Environmentally, Wyoming coals are attractive because they are relatively low in sulfur compared to coal mined in the eastern U.S.. Burning Wyoming coal is not considered to contribute significantly to the introduction of sulfur dioxide into the atmosphere. Additionally, the Wyoming coals are a source of significant coalbed natural gas resources.

Figure 101. Clovis Point Mine with view of the entire Wyodak coal seam (photograph by R.W. Jones).

Conglomerate

Conglomerate is a coarse-grained, detrital sedimentary rock formed of rounded to subangular pebbles, cobbles, or boulders in a fine-grained sandy matrix (**Figure 102**). The clasts (rock particles) are of one or several rock types.

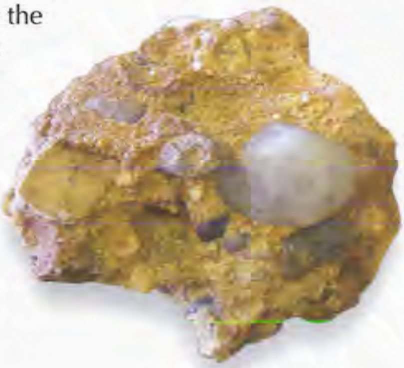


Figure 102. Tertiary conglomerate that flanks the south side of the Seminoe Mountains.

In Wyoming, some conglomerate beds are well developed in the Cambrian Flathead Sandstone on the flanks of several mountain ranges adjacent to Precambrian rocks. Good exposures of the Flathead conglomerate occur on the north edge of Copper Mountain and along the northeast flank of South Pass. Conglomerates are also common in upper Paleozoic rocks that flanked the ancestral Rocky Mountains and in Cretaceous and Tertiary rocks that formed from debris shed off mountain ranges that rose during the Laramide orogeny.

Many enormous Tertiary conglomerates have been mapped and identified at several locations in the state. In general these are poorly consolidated and some contain large cobbles and boulders. A significant portion of these conglomerates are mineralized in gold and represent paleoplacers. Some notable Tertiary conglomerates are found near South Pass (Love and Antweiler, 1978) and near the Miracle Mile along the northern flank of the Seminoe Mountains (Hausel, 1994).

Metamorphosed conglomerates retain their textural characteristics, but may be very hard and silicified. Such rocks are termed *metaconglomerates*. Several metaconglomerates (also termed quartz-pebble conglomerates) were mapped in the Medicine Bow Mountains and Sierra Madre of southeastern Wyoming. These rocks represent former stream beds deposited 2.0 to 2.5 billion years ago and like some streams today, they may have some placer (paleoplacer) gold.

Figure 103. Limestone composed primarily of shells of invertebrate fossils including brachiopods (B) and corals (C).

Because of the lack of oxygen in the Earth's atmosphere prior to two billion years ago, some of the metaconglomerates (paleoplacers) also contain placer uranium and thorium (Houston and Karlstrom, 1979). Another unusual metaconglomerate was mined at the Ferris-Haggarty mine in the Sierra Madre in the early 1900s (Hausel, 1997). This metaconglomerate is unique in that the matrix is replaced by copper, which surrounds numerous unmineralized pebbles (Hausel and Sutherland, 2000).

Limestone

Limestone is a sedimentary rock composed primarily of calcite. Most limestones are white, gray or buff, but some are brown. Limestones range in grain size from microcrystalline (crystal grains visible only under high magnification) to coarsely crystalline. Many limestones are primarily composed of shells and shell fragments (**Figure 103**).

Although some limestone is precipitated chemically under evaporative conditions, most limestones are directly or indirectly the product of organic activity. Many organisms extract calcium carbonate from the water in which they live and use it to build shells or internal hard parts. When the animal or plant dies, it is incorporated in the accumulating calcareous sediment. Other organisms influence the deposition of limestone by less direct means. In the process of living, any organism will cause small, local changes in the chemical environment. These local changes in the chemistry of sea or lake water can cause the precipitation of calcium carbonate as a fine mud. Most limestones are deposited in marine water, but some are formed in fresh water lakes.

In Wyoming, limestones are most abundant in Paleozoic rocks such as the Madison Limestone and the Casper Formation. Limestone is most readily identified in the field by its strong reaction to cold, dilute hydrochloric acid. Limestone is used to make cement and lime, in beet sugar refining, and as a building stone.

Travertine

Figure 104. Travertine terraces at Hot Springs State Park, Thermopolis. (Photograph courtesy of Wyoming Travel Commission.

Travertine is a chemical sedimentary rock composed almost entirely of calcite and aragonite. Often, limonite will stain the travertine yellowish brown. These rocks are generally porous and are light gray to yellowish brown depending on the amount of limonite. Travertine is deposited from spring water that is supersaturated in calcium carbonate; many travertine deposits form by precipitation of carbonate from thermal springs. Well-known travertine deposits in Wyoming include the terraces at Hot Springs State Park in Thermopolis (**Figure 104**) and the massive travertine cliffs associated with Mammoth Hot Springs in Yellowstone National Park.

Phosphorite

Phosphorite, also referred to as phosphate rock, is a rare sedimentary rock that occurs in relative abundance in the Permian Phosphoria Formation of western Wyoming. Phosphate is generally dark (brown, gray, or black), but on the outcrop it may have a bluish coating or bloom. Phosphate rock may be dense and fine-grained, pelletal, nodular, or fossiliferous.

The mineralogy of phosphate rock is complex and poorly understood, but most of the phosphatic material appears to be hydrous tricalcium phosphate with varying amounts of calcium carbonate and fluoride. Phosphate rock of the Phosphoria Formation also contains abnormally anomalous amounts of vanadium and other rare metals including gold and silver (Love, 1984).

The Permian phosphate deposits of Wyoming were precipitated from marine water in the region between a deep oceanic trough in Idaho, and a broad, shallow marine shelf that covered most of Wyoming. Slightly different chemical conditions in the deeper waters on the margin of the shelf prevented the accumulation of carbonate rock and favored the precipitation of phosphate. The rock is interlayered with dark organic shales and cherts. Organic processes probably played a major role in the formation of phosphate deposits. This same suite of rocks is believed to be the source of major oil accumulations in Wyoming (Peterson, 1984, p. 59-62). The phosphate is used mainly for manufacturing fertilizer and was once mined in western Wyoming.

Sandstone

Sandstone is a sedimentary rock composed of detrital sand-size grains. The grains are cemented together by silica, calcite, or iron oxide or are set in a matrix of clay and other fine-grained material. Almost any mineral or rock fragment may be found among the detrital grains of sandstone, but the more resistant types like quartz, chert, and feldspar are more common minerals.

Sandstone is common in Wyoming. Sandstones are formed in a wide variety of terrestrial and marine environments. Desert sand dunes, river-channel sand bars, alluvial fans, deltas, beaches, and deeper-water sand bodies are all represented by sandstones in the geologic record (**Figure 105**).

Porous sandstones, whose grains are not completely surrounded by cement or matrix material, form the reservoirs that contain most of Wyoming's oil and natural gas reserves. Sandstones of Cretaceous and Tertiary age form the host rocks for many of the state's uranium deposits. Sandstone from the Casper Formation has also been used in many buildings on the University of Wyoming campus in Laramie. Some extremely pure quartz sandstones (silica sands) in the Casper Formation are a potential silica resource for glass making.

Shale

Shale is the most abundant sedimentary rock type. It is a mixture of extremely fine-grained quartz, other detrital grains, and clay minerals. Shales are finely laminated or thinly bedded. Common colors are gray, brown, black, green, and red. Red shales of the Triassic Chugwater Formation and Permian Goose Egg Formation form some of the most colorful outcrops in the state. Clay-rich shales of the Cretaceous Frontier Formation and Mowry Shale are mined for abundant Wyoming bentonite. *Bentonite* is a type of clay produced from volcanic ash decomposition in a marine environment. Other shales are used as sources of clay for brick, tile, and clay pipe.

Clinker

In the Powder River Basin of northeastern Wyoming, many hills and buttes are capped by reddish clinker or natural slag. *Clinker* is a rock formed by heating and baking of pre-existing rocks by the spontaneous burning of underlying coal beds. Clinker beds are generally brightly colored, usually red, yellow, brown, or purple. In some cases, the rocks actually melt. giving a dark, massive or scoriaceous, appearance similar to some basalts. Some of this natural slag is used for road and railroad bed material.

Figure 105. Cross-bedded sandstone in eolian dune environment, Boulder Ridge, north end of Casper Formation outcrops (photograph by Alan Ver Pleog).

Oil Shale

Oil shale is a very fine-grained rock that is a mixture of quartz and other small detrital grains, clay, calcium carbonate, and organic matter. It yields petroleum upon heating. Most oil shale is brown to gray and finely laminated such that individual minerals are not visible to the unaided eye. Oil shale deposits are extensive in the Tertiary Green River Formation of southwestern Wyoming. These deposits are a unique accumulation of lake sediments that also represent a potential petroleum resource. These rocks are known for their excellent fossils of fish and other life.

SOME UNUSUAL ROCKS FOUND IN WYOMING

Phonolite

Phonolite is an uncommon porphyritic to fine-grained volcanic rock that occurs in the Black Hills of northeastern Wyoming and the Rattlesnake Hills southwest of Casper. These rocks are low in silica and enriched in sodium and potassium. They have no quartz, but contain sodium-rich feldspar. They are also known to contain potassium-rich pseudoleucite crystals (see **Leucite**). Both feldspar and pseudoleucite occur as large phenocrysts in an aphanitic groundmass. Devils Tower in the Black Hills is composed of phonolite.

Lamproite

Lamproite is one of the rarest rock types on earth, if not the rarest. These rocks are found in the Leucite Hills of southwestern Wyoming, north of the towns of Rock Springs and Superior (Hausel and others, 1995a, b). Lamproite forms rare high-potassium (ultrapotassic) lamproite volcanoes, flows, and plugs (**Figure 106**).

Figure 106. Gray lamproite lava flow at Zirkel Mesa sits on reddish baked tawny shale. The red color of the shale is the result of the intense heat of the lava when it erupted nearly a million years ago (photograph by Sharon Hall).

These rocks were initially called wyomingite, orendite, and madupite. However, equivalent rock types found in Australia were also given local names. As a result, it has been recommended that the local terminology for lamproites be dropped in favor of mineralogical modifiers. For example, wyomingite consists of mica (phlogopite) phenocrysts in a fine-grained matrix (groundmass) of leucite, pyroxene, apatite, and volcanic glass. This rock may or may not contain olivine. Thus, the wyomingite would better be termed a phlogopite-leucite lamproite.

Within the past few decades, some of the lamproites in Australia have become important source rocks for

Figure 107. Kimberlite breccia containing large (1 inch long) chromian diopside megacryst. Sample from the Sloan kimberlite, Colorado-Wyoming State Line district.

diamond. These include the Argyle and Ellendale olivine lamproites in Western Australia. The Argyle lamproite, in particular, has been a tremendous source for diamonds over the past two decades, producing as much as 30 to 40% of the world's diamonds in some years. Another important diamond-bearing lamproite is found at Murfreesburo, Arkansas. Unfortunately, the search for diamonds in the Leucite Hills has been very limited, even though the region is considered to have good potential for discovery (Erlich and Hausel, 2002).

Kimberlite

Kimberlite is also a very rare igneous rock that sometimes contains accessory diamonds. Initially identified in Kimberley, South Africa, kimberlite hand specimens consist of green, brown, and/or gray serpentinized and carbonate-rich porphyritic rocks that may contain large rounded crystals of pyrope garnet, green chrome pyroxene, black picroilmenite, and bronze to brownish phlogopite mica (**Figure 107**). Many kimberlites exhibit a distinctive breccia texture or a porphyritic texture. Most kimberlites contain enough carbonate that they react to a drop of dilute hydrochloric acid, much like a limestone.

Rounded mantle rocks (nodules) and some more angular country rock fragments (xenoliths) are also commonly found in kimberlite (**Figure 108**). These may be quite varied in mineralogy and appearance and include xenoliths of country rock, granite, gneiss, schist, garnet peridotite, eclogite, and pyroxenite (see **Diamond** and **Olivine**). Kimberlites are essentially serpentinized dunites (olivine-rich rocks). The two largest kimberlite fields in the U.S. have been identified in southeastern Wyoming (Hausel, 1998).

Figure 108. Rounded nodule of kyanite, chromian diopside eclogite recovered from a Wyoming kimberlite.

Komatiite

Komatiite is another rare volcanic rock first identified along the Komati River in South Africa. It is a magnesium-rich volcanic rock that often exhibits a very distinct volcanic texture known as spinifex texture. The spinifex texture consists of long blades of amphiboles (often pseudomorphing pyroxene or olivine) arranged in a parallel pattern similar to the appearance of spinifex grass found in Australia and South Africa.

Many komatiite flows are capped by spinifex-textured volcanic rock that grades downward into a fine-grained aphanitic rock, which in turn grades downward into cumulate-textured rock. The cumulate texture is formed of tiny, rounded olivine or serpentinized olivine grains and the cumulate is usually dark green to black. Komatiite has been identified in the South Pass and Seminoe Mountains greenstone belts (Snyder and others, 1989; Blackstone and Hausel, 1991).

MAPS

If you plan to spend any time looking for rock and mineral specimens on public land in the state, it may be worth your while to familiarize yourself with U.S. Bureau of Land Management (BLM) offices. The BLM keeps records on mining claims and land ownership that can help determine what areas are accessible for collecting. Land status maps are also available from the BLM or the Wyoming State Geological Survey.

Generalized maps of the state are great aids during the initial stages of planning a collecting trip or vacation. One such map, the *Metallic and Industrial Minerals Map of Wyoming* (Harris and others, 1985) shows the location of mountain ranges, principal roads, towns, mining districts, and significant mineral occurrences. The *Geologic Map of Wyoming* (Love and Christiansen, 1985), shows all major rock units, and is very helpful for identifying rock types. After locating areas of interest on these maps, the locations of the nearest towns, roads, mining districts, and rock units in relation to your area of interest are quickly visualized. Once the area is outlined, more detailed maps can often be obtained. These more detailed topographic and geologic maps are listed on various map indexes by name and location (see additional information in **References Cited**).

Topographic and geologic maps are available from the Wyoming State Geological Survey, from the U.S. Geological Survey, and locally throughout the state from private distributors. Topographic maps show streams, lakes, cabins, houses, improved and unimproved roads, and other cultural features in relation to hills, valleys, and other topographic features. These maps essentially show three dimensions: length, breadth, and relief. Relief is expressed by contour lines that show lines of equal altitude above sea level.

Most topographic maps have been surveyed, so locations on the maps are easily found by legal description. Township and range are found printed in the map's margin. Each township and range block is usually subdivided into 36 sections (section numbers are printed in the centers of sections). Sections are further subdivided into four quarters: the northeast, northwest, southeast, and southwest. The quarters are frequently found in legal descriptions but are not generally printed on maps.

Figure 109. A part of the U.S. Geological Survey Miners Delight topographic map. Township 30 North (T30N) is labeled in the right margin and Range 99 West (R99W) in the lower margin. Sections are numbered and a portion of section 11 occurs at the upper right. The southwest quarter is the lower left hand portion of section 11.

Further subdivisions are based on continuing the 4-quarters system. To find a spot described as SW section 11, T30N, R99W, first find the boxed-in area on the map where Township 30 North and Range 99 West intersect. The spot you are looking for is in the southwest quarter of Section 11 in that box (**Figure 109**).

Geologic maps are a geologist's interpretation of the distribution and attitudes of rock bodies and unconsolidated sediments. The base for these maps may be two dimensional without relief, but most geologic maps published recently are printed on a topographic base map (**Figure 110**).

The geologic map can be a valuable aid when searching for a particular mineralized rock, ornamental stone, etc. For example, suppose it was reported that rock outcrops of the Phosphoria Formation in the SW section 11, T20N, R99W, contained some thin beds of agate. Using a topographic map, you can narrow the area down to a square one quarter mile on a side. Using a geologic map, the outline of the Phosphoria Formation further restricts the area necessary to search for the agates.

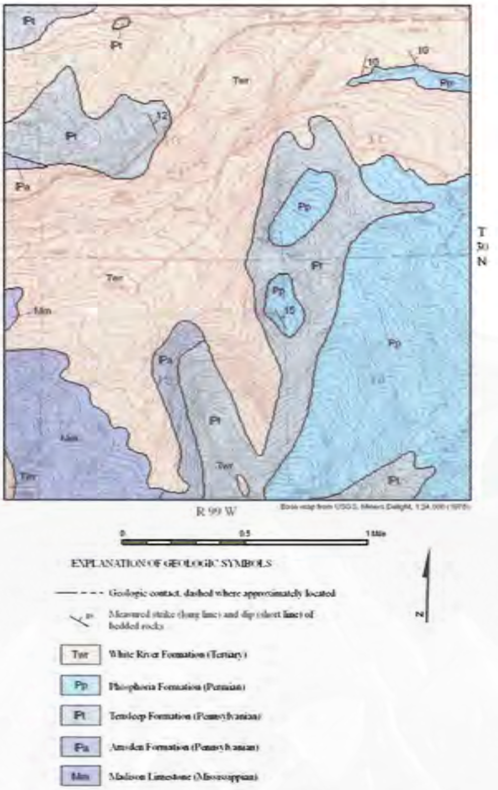


Figure 110. A part of a geologic map of the Miners Delight Quadrangle showing the same areas in Figure 109 but with the geology added. In the SW ¼ section 11 is an oval-shaped exposure of the Phosphoria Formation.

CONCLUDING REMARKS

Mineral and rock identification is not always easy and requires patience, practice, and experience. There are a few thousand mineral and rock species and many have several variations. Becoming a good mineralogist requires knowledge of a large portion of these specimens. The *Encyclopedia of Minerals* (Roberts and others, 1974) lists more than 2,200 mineral species alone, but many of these are rare. Usually you will only encounter a small number of rocks and rock-forming minerals. So first learn the characteristics of the common rock forming minerals, the common ore minerals, and the common rocks.

One of the greatest aids to a mineralogist is the knowledge of rock and mineral associations. For example, a rock sample containing chalcopyrite will usually have some other sulfides such as pyrite. The pyrite will oxidize with time and produce limonite (hydrated iron oxide), and chalcopyrite may oxidize to tenorite (copper oxide) or to cuprite (another copper oxide). If the host rock sample contains some carbonate, the copper will react to form copper carbonate (for example azurite or malachite). On the other hand, if the chalcopyrite is in a quartz vein, the copper may react with quartz (silicon dioxide) to produce a copper silicate such as chrysocolla.

Because chalcopyrite is a sulfide that forms in hot solutions, a trained mineralogist will also look for similar high-temperature sulfides in the rock specimen such as galena (lead sulfide) or sphalerite (zinc-sulfide). Such knowledge comes only with experience, familiarity with mineral and rock associations, and familiarity with the geology of the collecting area. Many of the most common associations are listed in this book along with the mineral and rock descriptions.

If you find what appears to be a new mineral in Wyoming, the Wyoming State Geological Survey is always interested in hearing about the discovery. Since the 1980s, the Survey and private collectors have identified dozens of new localities of minerals and rocks in the state. We expect to see more discoveries and welcome any new information.

REFERENCES CITED

Ayers, W.F., Jr., 1986, Coal resources of the Tongue River Member, Fort Union Formation (Paleocene), Powder River Basin, Wyoming and Montana: Wyoming State Geological Survey Report of Investigations No. 35, 23 p.

Bauer, M., 1968, Precious stones: Dover Publications, Inc., New York, New York, 627 p.

Bayley, R.W., Proctor, P.D., and Condie, K.C., 1973, Geology of the South Pass area, Fremont County, Wyoming: U.S. Geological Survey Professional Paper 793, 39 p.

Beckwith, R.H., 1939, Asbestos and chromite deposits of Wyoming: Economic Geology, v. 84, no. 7, p. 812-843.

Berry, L.G., and Mason, B., 1968, Elements of Mineralogy: W.H. Freeman and Company, San Francisco, 550 p.

Blackstone, D.L., Jr., 1988, Traveler's guide to the geology of Wyoming: Wyoming State Geological Survey Bulletin 67, 130 p.

Blackstone, D.L., and Hausel, W.D., 1991, Field guide to the Seminoe Mountains, in Frost, B.R., and Roberts, S., editors, Mineral Resources of Wyoming: Wyoming Geological Association 42nd Annual Field Conference Guidebook, p. 201-210.

Blanchard, R., 1968, Interpretation of leached outcrops: Nevada Bureau of Mines Bulletin 66, 196 p.

Burnside, M.J., and Culbertson, W.C., 1979, Trona deposits in the Green River Basin, Sweetwater, Uinta and Lincoln Counties, Wyoming: U.S. Geological Survey Open File Report 79-737, 10 p.

Bruton, E., 1978, Diamonds, Second Edition: Chilton Book Company, Radnor, Pennsylvania, 532 p.

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

Coopersmith, H.G., Mitchell, R.H., and Hausel, W.D., 2003, Kimberlites and lamproites of Colorado and Wyoming, USA: Field Excursion Guidebook for the 8th International Kimberlite Conference, Geological Survey of Canada, 24 p.

Dana, E.S., and Ford, W.E., A Textbook of Mineralogy: John Wiley and Sons, Inc., New York, New York, 822 p.

DeBruin, R.H., Lyman, R.M., Jones, R.W., and Cook, L.W., 2001, Coalbed methane in Wyoming: Wyoming State Geological Survey Information Pamphlet 7, 23 p.

Diller, J.S., 1920, Recent studies of domestic chromite deposits: American Institute of Mining and Metallurgical Engineers Transactions, v. 68, p. 105-149.

Dyck, H.M., Hausel, W.D., and Dyck, G., 1994, The Sunrise iron mine near Hartville, Wyoming: Rocks and Minerals, v. 69, no. 3, p. 163-168.

Erlich, E.I., and Hausel, W.D., 2002, Diamonds: Origin, exploration and history of discoveries: Society of Mining, Metallurgy and Exploration of the American Institute of Mining, Metallurgical, and Petroleum Engineers, 374 p.

Fields, E.D., 1963, Precambrian rocks of the Halleck Canyon area, Albany County, Wyoming: M.S. thesis, University of Wyoming, Laramie, 91 p.

Fisher, F.S., 1972, Tertiary mineralization and hydrothermal alteration in the Stinkingwater mining region, Park County, Wyoming: U.S. Geological Survey Bulletin 1332-C, 33 p.

Gillen, C., 1982, Metamorphic geology – an introduction to tectonic and metamorphic processes: George Allen and Unwin Ltd., London, England, 144 p.

Glass, G.B., 1975, Analyses and measured sections of 54 Wyoming coal samples: Wyoming State Geological Survey Report of Investigations 11, 219 p.

Glass, G.B., 1984, Description of seams [Wyoming]: Keystone Coal Industry Manual, McGraw-Hill, New York, New York, p. 637-663.

Gliozzi, J., 1967, Petrology and structure of Precambrian rocks of the Copper Mountain district, Owl Creek Mountains, Fremont County, Wyoming: Ph.D. dissertation, University of Wyoming, Laramie, 141 p.

Graff, P.J., Sears, L.W., Holden, G.S., and Hausel, W.D., 1982, Geology of the Elmers Rock greenstone belt, Laramie Range, Wyoming: Wyoming State Geological Survey Report of Investigations 14, 22 p.

Grande, L., 1984, Paleontology of the Green River Formation, with a review of the fish fauna: Wyoming State Geological Survey Bulletin 63, 333 p.

Hamil, M.M., 1971, Metamorphic and structural environment of Copper Mountain, Wyoming: Ph.D. dissertation, University of Missouri, Rolla, 87 p.

Harlow, G.E., 1998, The Nature of Diamonds: Cambridge University Press, Cambridge, United Kingdom, 278 p.

Harrer, C.M., 1966, Wyoming iron-ore deposits: U.S. Bureau of Mines Information Circular 8314, 114 p.

Harris, R.E., and Hausel, W.D., 1986, Wyoming pegmatites, *in* Colorado Pegmatite Symposium: Colorado Chapter, Friends of Mineralogy, May 30th-June 2nd, p. 101-108.

Harris, R.E., Hausel, W.D., and Meyer, J.E., 1985, Metallic and industrial minerals map of Wyoming: Wyoming State Geological Survey Map Series MS-14, scale 1:500,000.

Hausel, W.D., 1982, General geologic setting and mineralization of the porphyry copper deposits, Absaroka volcanic plateau, Wyoming, *in* Reid, S.G., and Foote, D.J., editors, Geology of Yellowstone Park area: Wyoming Geological Association 33rd Annual Field Conference Guidebook, p. 297-313.

Hausel, W.D., 1984, Tour guide to the geology and mining history of the South Pass gold mining district, Fremont County, Wyoming: Wyoming State Geological Survey Public Information Circular 23, folded pamphlet.

Hausel, W.D., 1986, Minerals and rocks of Wyoming: Wyoming State Geological Survey Bulletin 66, 117 p.

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

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

Hausel, W.D., 1993, Guide to the geology, mining districts and ghost towns of the Medicine Bow Mountains and Snowy Range Scenic Byway: Wyoming State Geological Survey Public Information Circular 32, 53 p.

Hausel, W.D., 1994a, Economic geology of the Cooper Hill mining district, Medicine Bow Mountains, southeastern Wyoming: Wyoming State Geological Survey Report of Investigations 49, 22 p.

Hausel, W.D., 1994b, Economic geology of the Seminoe Mountains mining district, Carbon County, Wyoming: Wyoming State Geological Survey Report of Investigations 50, 31 p.

Hausel, W.D., 1996a, Geology and gold mineralization of the Rattlesnake Hills, Granite Mountains, Wyoming: Wyoming State Geological Survey Report of Investigations 52, 28 p.

Hausel, W.D., 1996b, The Tin Cup district, central Wyoming — A rock hound's paradise: International California Mining Journal, v. 65, no. 8, p. 65-68.

Hausel, W.D., 1997, Copper, lead, zinc, molybdenum, and associated metal deposits of Wyoming: Wyoming State Geological Survey Bulletin 70, 229 p.

Hausel, W.D., 1998, Diamonds and mantle source rocks in the Wyoming craton, with a discussion of other U.S. occurrences: Wyoming State Geological Survey Report of Investigations 53, 93 p.

Hausel, W.D., 1999, Gold fever: International California Mining Journal, v. 68, no. 12, p. 17-19.

Hausel, W.D., 2000a, Diamond fever: International California Mining Journal, v. 69, no. 6, p. 13-15.

Hausel, W.D., 2000b, The Wyoming platinum-palladium-nickel province: geology and mineralization, *in* Winter, G.A., editor, Classical Wyoming Geology ib the New Millenium: Wyoming Geological Association 51st Field Conference Guidebook, p. 15-27.

Hausel, W.D., 2001, The South Pass gold placers, western Wyoming: International California Mining Journal, v. 70, no. 8, p. 29-35 and 41-42.

Hausel, W.D., 2002, A new source of gem-quality cordierite and corundum in the Laramie Range of southeastern Wyoming: Rocks and Minerals, v. 76, no. 5, p. 334-339.

Hausel, W.D., in press, Diamonds, *in* Industrial Minerals and Rocks: Society for Mining, Metallurgy and Exploration of the American Institute of Mining, Metallurgical, and Petroleum Engineers.

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

Hausel, W.D., Graff, P.J., and Albert, K.G., 1985, Economic geology of the Copper Mountain supracrustal belt, Owl Creek Mountains, Fremont County, Wyoming: Wyoming State Geological Survey Report of Investigations 28, 33 p.

Hausel, W.D., Gregory, R.W., Motten, R.H., and Sutherland, W.M., 2000, Economic geology of the Iron Mountain kimberlite district, Wyoming, *in* Winter, G.A., editor, Classical Wyoming Geology in the New Millenium: Wyoming Geological Association 51st Field Conference Guidebook, p. 151-164.

Hausel, W.D., Gregory, R.W., Motten, R.H., and Sutherland, W.M., 2003, Geology of the Iron Mountain kimberlite district and nearby kimberlitic indicator mineral anomalies in southeastern Wyoming: Wyoming State Geological Survey Report of Investigations 54, 42 p.

Hausel, W.D., and Jones, R.W, 1984, Self-guided tour of the geology of a portion of southeastern Wyoming: Wyoming State Geological Survey Public Information Circular 21, 44 p.

Hausel, W.D., Kucera, R.E., McCandless, T.E., and Gregory, R.W., 1999, Mantle-derived breccia pipes in the southern Green River Basin of Wyoming (U.S.A.): *in* Gurney, J.J., and others, editors, Proceedings of the 7th International Kimberlite Conference, Capetown, South Africa, p. 348-352.

Hausel, W.D., Love, C.M., and Sutherland, W.M., 1995, Road log — Leucite Hills, Green River Basin, Wyoming, *in* Jones, R.W., and Winter, G.A., editors, 1995 Field Conference Road Logs: Wyoming Geological Association, Resources of Southwestern Wyoming, p. 45-53.

Hausel, W.D., and Love, J.D., 1991, Field guide to the geology and mineralization of the South Pass region, Wind River Range, Wyoming, *in* Frost, B.R., and Roberts, S., editors, Mineral Resources of Wyoming: Wyoming Geological Association 42nd Annual Field Conference Guidebook, p. 181-200.

Hausel, W.D., McCallum, M.E., and Roberts, J.T., 1985, The geology, diamond testing procedures and economic potential of the Colorado-Wyoming kimberlite province — A review: Wyoming State Geological Survey Report of Investigations 31, 22 p.

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: Wyoming State Geological Survey Report of Investigations 19, 29 p.

Hausel, W.D., and Sutherland, W.M., 2000, Gemstones and other unique minerals and rocks of Wyoming — A field guide for collectors: Wyoming State Geological Survey Bulletin 71, 268 p.

Hausel, W.D., and Sutherland, W.M., 2004, Geological reconnaissance of the Grizzly Creek gemstone deposit, Laramie Mountains, Wyoming — Potential source for iolite, sapphire, ruby and kyanite: Wyoming State Geological Survey Open File Report 04-14, 8 p.

Hausel, W.D., and Sutherland, W.M., in preparation, Gemstones of the World - Geology, Occurrence, and Exploration:

Hausel, W.D., Sutherland, W.M., and Gregory, R.W., 1995, Lamproites, diamond indicator minerals, and related anomalies in the Green River Basin, Wyoming: Wyoming Geological Association 1995 Field Conference Guidebook, p. 137-151.

Hewett, D.F., 1912, The ore deposits of Kirwin, Wyoming: U.S. Geological Survey Bulletin 811-A, p. 121-132.

Houston, R.S., 1961, The Big Creek pegmatite area, Carbon County, Wyoming: Wyoming State Geological Survey Preliminary Report 1, 11 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 Open File Report GJBX-1'80, 510 p.

Houston, R.S., and Murphy, J.F., 1962, Titaniferous black sandstone deposits of Wyoming: Wyoming State Geological Survey Bulletin 49, 55 p.

Hurlbut, C.S., Jr., and Switzer, G.S., 1979, Gemology: John Wiley and Sons, New York, New York, 243 p.

Irving, J.D., and Emmons, S.F., 1904, Economic resources of the northern Black Hills: U.S. Geological Survey Professional Paper 26, part II, 222 p.

Kievlenko, E.Y., 2003, Geology of Gemstones: Ocean Pictures, Ltd., Littleton, Colorado, 432 p.

Kerr, P.F., 1959, Optical Mineralogy: McGraw-Hill Book Company, New York, New York, 442 p.

Knittel, P., editor, 1978, A field guide to the Casper Mountain area: Wyoming Field Science Foundation: Wyoming State Geological Survey Reprint 45, 80 p.

Kraus, E.H., and Slawson, C.B., 1947, Gems and Gem Materials: McGraw-Hill Book Company, New York, New York, 332 p.

Loucks, R.R., 1976, Platinum-gold-copper mineralization, central Medicine Bow Mountains, Wyoming: M.S. thesis, Colorado State University, Fort Collins, Colorado, 290 p.

LeGrand, D.S., 2003, Gemology – Learning the craft: Rock and Gem, Miller Magazines, Inc., Escondido, California, v. 33, no. 2, p. 80-83.

Love, J.D., 1970, Cenozoic geology of the Granite Mountains area, central Wyoming: U.S. Geological Survey Professional Paper 495-C, 154 p.

Love, J.D., 1984, Gold, silver, and other selected trace elements in the Phosphoria Formation of western Wyoming *in* Goolsby, J., and Morton, D., editors, The Permian and Pennsylvanian Geology of Wyoming: Wyoming Geological Association 35th Annual Field Conference Guidebook, p. 383-387.

Love, J.D., Antweiler, J.C., and Mosier, E.L., 1978, A new look at the origin and volume of the Dickie Springs-Oregon Gulch placer gold at the south end of the Wind River Mountains *in* Boyd, R.G., Olson, G.M., and Boberg, W.W., editors, Resources of the Wind River Basin: Wyoming Geological Association 30th Annual Field Conference Guidebook, p. 379-391.

Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey Map, scale 1:500,000.

Mason, R., 1978, Petrology of the metamorphic rocks: George Allen and Unwin Ltd., London, England, 254 p.

Master, T., 1977, Rock and mineral occurrences in the Ferris Mountains, Wyoming: M.S. thesis, University of Wyoming, Laramie, 147 p.

McCallum, M.E., 1968, The Centennial Ridge gold-platinum district, Albany County, Wyoming: Wyoming State Geological Survey of Wyoming Preliminary Report 7, 13 p.

McCallum, M.E., and Kluender, S.E., 1983, Mineral resource potential of the Savage Run Wilderness, Wyoming; U.S. Geological Survey Miscellaneous Field Studies Map MF-1638A, 10 p.

McCallum, M.E., and Orback, C.J., 1968, The New Rambler copper-gold-platinum district, Albany and Carbon Counties, Wyoming: Wyoming State Geological Survey Preliminary Report 8, 12 p.

McCandless, T.E, 1984, Detrital minerals of mantle origin in the Green River Basin, Wyoming: Society of Mining Engineers of AIME Preprint 84-395, 6 p.

McCandless, T.E., Nash, W.P., and Hausel, W.D., 1995, Mantle indicator minerals in ant mounds and conglomerates of the southern Green River Basin, Wyoming, *in* Jones, R.W., editor, Resources of Southwestern Wyoming: Wyoming Geological Association 1995 Field Conference Guidebook, p. 153-163.

Millgate, M.L., 1965, The Haystack Range, Goshen and Platte Counties: Wyoming State Geological Survey Preliminary Report 5, 9 p.

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

Osterwald, F.W., Osterwald, D.B., Long, L.S., Jr., and Wilson, W.H., (revised by Wilson), 1966, Mineral resources of Wyoming: Wyoming State Geological Survey Bulletin 50, 287 p.

Parsons, W.H., 1937, The ore deposits of the Sunlight mining region, Park County, Wyoming: Economic Geology, v. 32, no. 6, p. 832-854.

Peterson, J.A., 1984, Permian stratigraphy, sedimentary facies, and petroleum geology, Wyoming and adjacent area, *in* Goolsby, J., and Morton, D., editors, The Permian and Pennsylvanian Geology of Wyoming: Wyoming Geological Association 35th Annual Field Conference Guidebook, p. 25-64.

Phillips, K.A., and Greeley, M.H., 1978, Uranium — A prospector's guide: Arizona Department of Mineral Resources Special Report SR-1, 34 p.

Prinz, W.C., 1974, Map showing geochemical data for the Atlantic City gold district, Fremont County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-865, scale 1:20,000.

Roberts, W.L., Rapp, G.R., Jr., and Webert, J., 1974, Encyclopedia of minerals: Van Nostrand Reinhold Company, New York, New York, 693 p.

Root, F.K., 1977, Minerals and rocks of Wyoming: Wyoming State Geological Survey Bulletin 56, 84 p.

Sinkankas, J., 1964, Mineralogy for amateurs: Van Nostrand Reinhold Company, New York, New York, 585 p.

Snoke, A.W., Steidtmann, J.R., and Roberts, S., editors, 1993, Geology of Wyoming: Wyoming State Geological Survey Memoir 5, 937 p.

Snyder, G.L., Hausel, W.D., Klein, T.L., Houston, R.S., and Graff, P.J., 1989, Precambrian rocks and mineralization, Wyoming Province: 28th International Geological Congress Guide to Field Trip T-332, July 19-25, 48 p.

Spencer, A.C., 1904, Copper deposits of the Encampment district, Wyoming: U.S. Geological Survey Professional Paper 25, 107 p.

Spencer, A.C., 1916, The Atlantic City gold district and the North Laramie Mountains: U.S. Geological Survey Bulletin 626, 85 p.

Stokes, W.L., 1966, Essentials of Earth History: Prentice-Hall Inc., Englewood Cliffs, New Jersey, 2nd edition, 468 p.

Vanders, I., and Kerr, P.K., Mineral recognition: John Wiley and Sons, Inc., New York, New York, 316 p.

Walton, L., 2004, Exploration criteria for coloured gemstone deposits in the Yukon: Yukon Geological Survey Open File Report 2004-10, 184 p.

Welch, C.M., 1974, A preliminary report on the geology of the Mineral Hill area, Crook County, Wyoming: M.S. thesis, South Dakota School of Mines, Rapid City, 88 p.

Wilson, W.H., 1965, A field guide to the rocks and minerals of Wyoming: Wyoming State Geological Survey Bulletin 51, 72 p.

GLOSSARY

Alluvial	Refers to alluvium, or recent stream-deposited gravels, sands and clays that have not been cemented together.
Altered rock	One that has undergone chemical and mineralogical changes since its original formation.
Amygdule	A gas cavity or vesicle in an igneous rock.
Anticline	A rock structure in which layered rocks dip in opposite directions like the roof of a house.
Aphanitic	A texture of igneous rocks in which individual minerals are too small to be identified with an unaided eye.
Breccia	A course-grained clastic rock, composed of angular broken rock fragments held together by mineral cement or in a fine-grained matrix.
Brittle	Easily broken.
Contact metamorphic	Refers to changes that take place in rocks near their contact with an igneous rock body.
Crossbedding	Lamination oblique to the main stratification of sedimentary rock layers.
Crystalline	The texture of a rock consisting of interlocking crystals or crystal fragments; usually refers to igneous or metamorphic rocks.
Detrital	Pertaining to loose rock and mineral material.
Dike	A tabular-shaped body of igneous rock that cuts across (intrudes) the structure of adjacent rocks.
Dunite	A peridotite formed principally of olivine.
Earthy	Earth-like appearance.

Eclogite	A metamorphic rock formed by extremely high pressure and temperature. Composed of pyroxene and garnet, sometimes contains diamond.
Euhedral	A well-formed mineral grain.
Exhalite	Chemical sediments of predominantly volcanic exhalative origin. Deposits precipitated from hydrothermal fluids from submarine volcanic emanations. Common forms are chert and iron formation.
Fault	A displacement of rocks in the Earth's crust along a fracture(s).
Fibrous	Thead-like appearance.
Fissure	An extensive crack (fracture) in the rocks.
Float	A displaced fragment of rock.
Fold	A bend in layered rock.
Formation	A group of sedimentary rocks that is used as a geological map unit and named after a geographic locality, i.e., Tensleep Sandstone, Thermopolis Shale, etc.
Gangue	The valueless rock and mineral materials in ore.
Gossan	An iron rich outcrop formed primarily of hematite and limonite (may contain some copper carbonates and oxides) that represents the weathering product of sulfide minerals along with the leaching of some of the metals and sulfur. Prospectors always focused on these gossans as some were enriched in gold.
Groundmass	The fine-grained to glassy matrix of a rock.
Hydrothermal	Refers to ore deposits that have been formed by heated fluids or emanations derived from magmatic (igneous) rocks.
Iridescent	A surface film, similar to oil on water, that forms on some minerals and produces an array of prismatic colors that masks the true color of that mineral.
Laccolith	An igneous body that has intruded generally horizontally or concordant with layering and domed up layered rocks.

Lamproite	A group of dark-colored intrusive or extrusive alkaline igneous rocks such as wyomingite and madupite.
Macle	A flat, triangular, rough twinned diamond.
Mafic rock	Refers to an igneous rock composed dominantly of dark-colored ferro-magnesian minerals.
Magmatic segregation	A process by which different rock or ore deposits are derived from a single parent magma.
Malleable	Refers to a mineral that is capable of being extended or shaped by pounding with a hammer without breaking.
Metapelite	A mica schist that is rich in aluminum-bearing minerals that may include mica, cordierite, andalusite, sillimanite, kyanite, and/or garnet.
Micaceous	A mineral that will separate into very small sheets.
Orogeny	Period of mountain building.
Orbicular	Igneous texture characterized by numerous orbicules (more or less spherical bodies composed of concentric bands of alternating light and dark minerals.
Pegmatite	An exceptionally coarse-grained granitic rock.
Phenocryst	A large conspicuous crystal in an igneous rock.
Placer	Refers to a mineral deposit that has been weathered from a vein, or other type of deposit, and concentrated by gravity and water in the gravels and sands of stream and river channels.
Pleochroic	The property of a mineral to differentially absorb various wavelengths of white light in different crystallographic directions. Thus, as the mineral is rotated in white light it will appear to change color showing different colors in different directions. Most pleochroic minerals are not apparent to the visible eye other than those that are strongly pleochroic such as the gem-variety of cordierite known as iolite, which can be observed to change color from a violet blue to a light blue to a gray-blue as it is rotated in transmitted light.
Plug	An intrusive mass of solidified igneous rock.

Porphyroblast	Large, distinct, scattered crystals in a metamorphic rock.
Plutonic	A general term applied to granite-like rocks that have crystallized at great depth beneath the surface of the Earth.
Prismatic	Pencil-like or lath-like shape.
Prospect	Undeveloped mineral deposit.
Pseudomorph	In this report, a mineral crystal that has the outward form of another mineral.
Pyramidal	Pyramid shape or form.
Replacement	The process by which a new mineral(s) of partly or wholly different chemical composition may grow in the body of an old mineral or mineral aggregate.
Schist	A metamorphic rock that has very distinctive linear to layered texture. A metamorphic rock with strongly foliated texture that can often be easily split into slabs using a rock hammer.
Sectile	Refers to a mineral that is capable of being carved or cut by a knife.
Sediment	A term applied to material deposited by streams, lakes, seas, wind, and ice.
Serpentinite	A rock composed of serpentine.
Strata	Sedimentary beds or layers of sedimentary rock.
Striations	Parallel lines or grooves.
Sulfide	In this report, the term is applied to a mineral that is composed of sulfur and a metal (such as copper).
Supergene	A mineral deposit (or enrichment of a deposit) formed near the surface, commonly by descending oxidizing solutions.
Syncline	Opposite of anticline. Folded rocks in which the rocks on both sides dip downward toward the center of the fold.
Translucent	Partly transparent.

Ultramafic rock	An igneous rock composed essentially of dark colored mafic minerals (pyroxenes). Usually dark colored and heavy. These rocks completely lack felsic minerals (quartz and feldspar) unlike mafic rocks which often have some feldspar.
Vein	A fracture (or crack) in the Earth's crust filled with mineral matter.
Volcanic vent	An opening in the Earth's crust, out of which volcanic material was erupted to the surface.
Weathering and erosion	Weathering is the mechanical breakdown of rocks, while erosion is the progressive removal of such particles by wind, water, or both.
Xenocryst	A large crystal in an igneous rock that is not related to the genesis of the igneous rock (foreign crystal).
Xenolith	A fragment or block of rock in an igneous rock that is not related to the genesis of the igneous rock (foreign rock).

ABOUT THE AUTHOR

W. Dan Hausel is a nationally recognized geologist who is passionate about and dedicated to his profession, a passion exemplified by his commitment to sharing his knowledge with others. He has authored or co-authored more than 500 books, professional papers, geologic maps, and general interest articles. Further, he has shared his expertise with thousands of people around the nation by presenting more than 400 lectures, field trips, and short courses. He is currently the Senior Economic Geologist for the Wyoming State Geological Survey where he conducts investigations related to precious and base metals, gemstones, mineralogy, mining districts, Archean greenstone belts, and diamondiferous host rocks.

During the past 28 years, Dan has mapped more than 600 square miles of Precambrian geology and historical mining districts. These include the two largest kimberlite districts in the U.S. (State Line and Iron Mountain), the largest lamproite field in North America (Leucite Hills), and the largest gold district and greenstone belt in Wyoming (South Pass). His work resulted in the discovery of some diamond, colored gemstones, several base and precious metal occurrences and deposits, as well as a previously unrecognized gold district in Wyoming (Rattlesnake Hills). Some of his more important gemstone discoveries include several diamondiferous kimberlites as well as two significant multi-gem deposits that include the world's largest iolite gemstones.

Dan's dedication to sharing his life's work has earned him numerous awards. In 2004, Dan received the prestigious Distinguished Service Award for Contributions to the Understanding of the Geology of Wyoming from the Wyoming Geological Association (WGA). In 1992, he was presented with the President's Award from the Energy Minerals Division of the American Association of Petroleum Geologists and the WGA's Certificate of Appreciation for Outstanding Endeavors and Contributions. In 2003, he was elected to the Colorado Chapter of the International Order of Ragged Ass Miners. In 2001, he was elected to the National Rock Hound and Lapidary Hall of Fame and received the Education Award for his contributions to the education of rock hounds and amateur mineralogists. In 1998, he received the Prospector's Best Friend Award by the Rocky Mountain Prospectors and Treasure Hunters. Dan has also served as a Distinguished Lecturer for both the University of Wyoming, Department of Geology and Geophysics, and the Laramie Lyceum.

Dan's hobbies include martial arts and fine art. Dan is considered one of the top martial arts instructors in North America and has achieved the rank of 10th Dan/Soke or Grandmaster. He is the founder of Seiyo Shorin-Ryu style and is an instructor and club advisor for UW's campus Shorin-Ryu Karate and Kobudo Club. Dan is also an accomplished artist. His striking and unique artwork appears in publications, galleries, on book covers, and Web sites.

RECOMMENDED READING

Bulletin 67—Traveler's guide to the geology of Wyoming (1988).

Bulletin 68—The geology of Wyoming's precious metal lode and placer deposits (1989).

Bulletin 70—Copper, lead, zinc, molybdenum, and associated metal deposits of Wyoming (1997).

Bulletin 71—Gemstones and other unique minerals and rocks of Wyoming - A field guide for collectors (2000).

Information Pamphlet 2—Geology of Wyoming (1999).

Information Pamphlet 9—Searching for gold in Wyoming (2002).

Information Pamphlet 11—Guide to prospecting and rock hunting in Wyoming (2004).

Memoir 5—Geology of Wyoming, 2 volumes and map pocket (1993).

Public Information Circular 23—Tour guide to the geology and mining history of the South Pass gold mining district (1984).

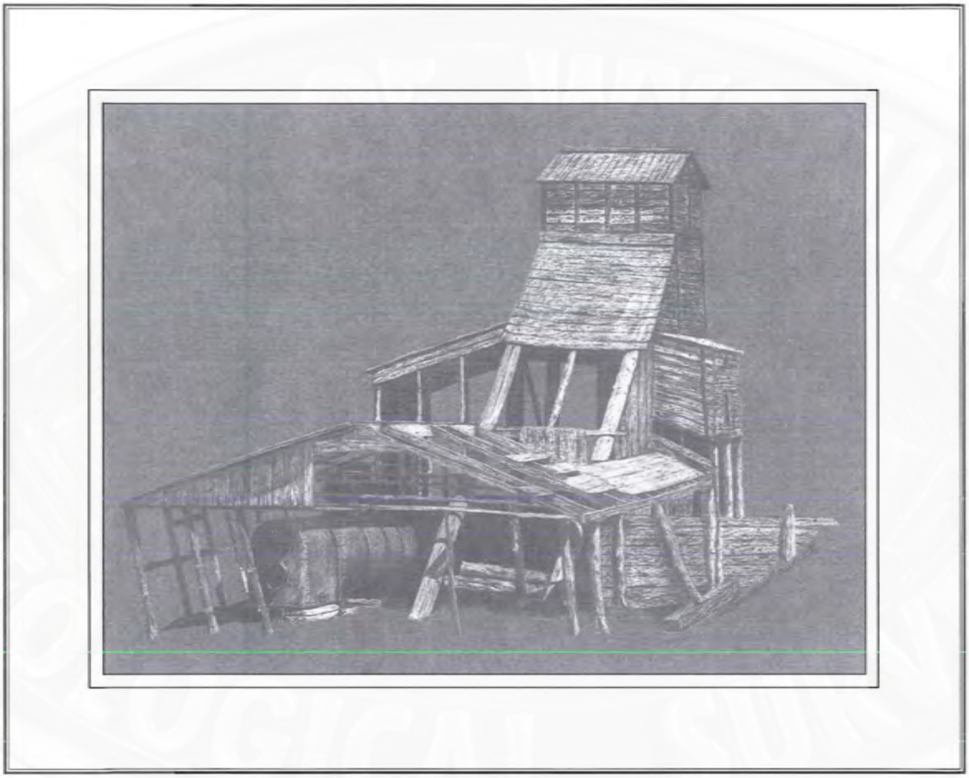
Public Information Circular 32—Guide to the geology, mining districts, and ghost towns of the Medicine Bow Mountains and Snowy Range scenic byway (1993).

Report of Investigations 44—Economic geology of the South Pass granite-greenstone belt, southern Wind River Range, Wyoming (1991).

Geologic map of Wyoming—U.S. Geological Survey, 1:500,000-scale color map (1985).

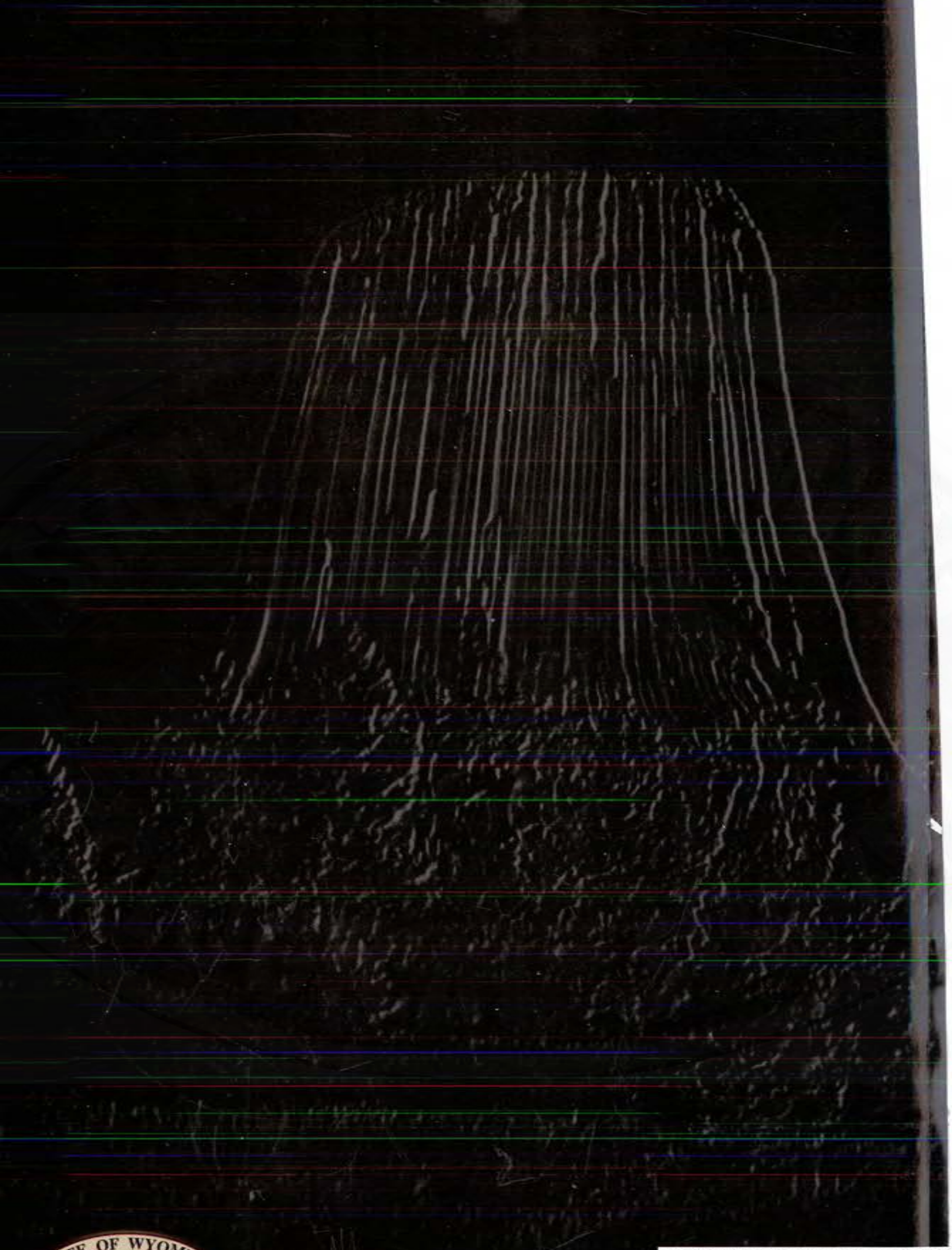
Wyoming Geologic Highway Map—GTR Mapping, 1:1,000,000-scale color map (2006).

For current prices, a free publications catalog, or to order any of these publications, contact the Wyoming State Geological Survey at the address on the inside front cover.



The Red mask mine, circa 1955, in the Medicine Bow Mountains. Pencil sketch by W. Dan Hausel, 2002.

Back cover: Devils Tower, in northwestern Wyoming, is a phonolite porphyry igneous rock approximately 600 feet tall. Photo illustration by Meg Ewald from a photograph by R.W. Jones.



STATE OF WYOMING
1933
GEOLOGICAL SURVEY

Geology – Interpreting the

WS GS - B72 - 06