Iron Resources In Wyoming

Wayne M. Sutherland and Elizabeth C. Cola

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WYOMING STATE GEOLOGICAL SURVEY
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Banded Iron Formation within the Goldman Meadows Formation near South Pass, Wyo. *Photo by Elizabeth C. Cola, 2014.*

Cover photo: A view of the main pit at the Sunrise Iron Mine near Hartville, Wyo. *Photo by Elizabeth C. Cola, 2014.*

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ABSTRACT

Elemental iron (Fe) is the fourth most abundant element in the Earth's crust at about 5 percent and makes up a large portion of its core. At the surface, iron is most commonly found in the form of oxide minerals, particularly magnetite (Fe_3O_4) and hematite (Fe_2O_3). These iron-ore minerals, when processed, are extremely important to the functions of everyday life on a global scale from their uses in cosmetics to automobile construction. The demand for iron fluctuates as second and third world countries urbanize and continue developing. However, there will always be a need for this material. Currently, Wyoming has no active iron mines but produced more than 132 million tons of iron ore between 1899 and 1983. Iron deposits at South Pass and in the Hartville Uplift have not been mined out and still contain large amounts of iron-ore with economic potential. Numerous small iron occurrences are known across Wyoming and recent exploration has identified at least one potentially large and previously unknown deposit in the Rattlesnake Hills-Granite Mountain area.

Previous investigations into Wyoming iron occurrences have been conducted by the private sector, universities, the United States Geological Survey (USGS), the United States Bureau of Mines (USBM), and the Wyoming State Geological Survey (WSGS). However, the most recent of these was by the USBM in 1976, and little subsequent work has been done. Analyses in the earlier reports often lacked trace element information and have not been readily available to the public. This investigation strives to compile data from a multitude of historic reports and present current information from sites visited during field work. Samples were analyzed for major and trace elements and, in some cases, gold.

The scope of this investigation precluded collecting samples from all known or potential locations, nor was such collection necessary. Sites with iron-rich rocks occur in a variety of geologic environments across Wyoming, including **banded iron formation** (BIF), placer-type magnetite-ilmenite sandstones, concretions and more. Access to the results of this study, including analyses, locations, and geologic settings, can be found in the WSGS online database, Wyoming Database of Geology (Wyo-DOG). The data from this study will aid exploration across the state for iron and other potential resources.

INTRODUCTION

Elemental iron (Fe) is the fourth most abundant element in the Earth's crust and is most commonly found combined with oxygen in the form of iron oxide minerals, particularly magnetite (Fe_3O_4) and hematite (Fe_2O_3). In Wyoming, iron deposits include BIF or taconite, massive hematite, magmatic separations, concretionary iron, and paleo-placer magnetite-ilmentite black sands. Iron is extremely important to the functions of everyday life on a global scale. The demand for iron fluctuates as second and third world countries urbanize and continue developing, but iron will always remain a necessity. In the past decade, economic growth in China drove the price of iron up (The Lore of Ore, 2014). However, a recent slowing of construction has caused the price to drop to a five year low as supply exceeds demand (Trefis Team, 2014; Els, 2015). Currently, Wyoming has no active iron-mines but has significant in-place iron ore, and accompanying economic potential.

Records of iron deposits in Wyoming began in the mid-1800s (Pinnell and Marsh, 1954; Dow, 1961). Many of the deposits are undeveloped and small with an occasional prospect pit. Yet, exploration led to the development of two, moderate sized, iron-mining operations, the Atlantic City Iron Mine near South Pass and the Sunrise Mine near Hartville, as well as smaller operations in the Rawlins uplift and at Iron Mountain in the Laramie Range. Based on calculated and estimated in-place ore in many deposits, it is suggested that Wyoming may have hundreds of millions of tons of iron available, although numerous small deposits are scattered, and may never be mined. Nevertheless, recently, a team from Newstrike Resources and Innovation Exploration Ventures, LLC has reportedly discovered a potentially large, high-grade iron deposit in the Rattlesnake Hills-Granite Mountains area. All known iron occurrences from various resources have been compiled and summarized in sections of this report.

In early 2014, the Wyoming State Legislature allocated $252,488 to the WSGS for geological investigations and analyses of four potential industrial mineral resources within Wyoming: iron (Fe), rare earth elements (REE), zeolites, and lithium (Li). Of this allocation, $94,488 was designated for REEs from Abandon Mine Reclamation (AML) funds, with the remaining coming from the state's general fund. Of these funds, $35,241 were dedicated to a comprehensive summary of Wyoming's diverse iron resources, including historic mines, diverse occurrences, and analyses of iron quality and associated trace elements. In response to the legislative allocation and direction, the WSGS researched and compiled existing literature and began field work in the autumn of 2014. More than 40 samples were collected and analyzed from known, potential, and suspected iron-bearing rocks. Additional analyses of samples collected during previous WSGS projects are also included in this summary report. Sample descriptions and analyses are also publicly available in WSGS's online database (Wyo-DOG).

SCOPE AND RESULTS OF PROJECT

This report summarizes previous investigations of iron occurrences in Wyoming and provides some new investigations and elemental analyses where information was absent or incomplete. Samples were analyzed for iron content as well as for other potential economic elements. Although many samples were collected, sampling of all known or potential iron deposits was not possible during the time-frame of the project. An attempt was made for this report to address as many iron deposits noted in earlier literature as possible. However, for more recent WSGS samples, collected prior to this investigation, the authors did not address those with less than 20 percent Fe or about 28 percent Fe_2O_3 unless a sample potentially provided perspective on other similar occurrences.

Information from this project will provide individuals, consultants, and members of industry with a base for initiating iron exploration in Wyoming. Data, including sample analyses, locations, and geologic settings may aid in the identification of not only iron concentrations, but of other potentially economic associations as well. Educational institutions may use these data to better understand the often complex geologic environments in Wyoming. Decision makers at state and community levels may also find this information useful in identifying potential areas of economic development.

Products of our investigation include this summary report and related maps, a CD with all raw analytical data in an appendix, and a publicly available online database. The online Wyo-DOG database includes all elemental analyses along with brief write-ups and photographs for most samples. Wyo-DOG makes the results of this study available to a wide audience for exploration, evaluation, and education.

IRON OCCURRENCES AND DESCRIPTIONS

Locations, descriptions, and tonnages in this report may not directly coincide with those of earlier reports on iron in various locations. A detailed search through a great number of earlier references uncovered several errors that may have been caused by transposition of numbers, lack of detailed editing, single deposits with more than one name, or a lack of attention to detail. Data in this report was tracked back to original references wherever possible to ensure accuracy of locations and descriptions. Some early reports and letters describe a number of small iron deposits but failed to give locations; these iron occurrences were omitted from this report.

ACCESS FOR RESEARCH

Many areas described in this report may not be publicly accessible based on land ownership. Private lands may not be accessed without permission from the land owner. Descriptions of sites that occur on private land or on the Wind River Indian Reservation are compiled from historical sources. Access to the Wind River Indian Reservation can only be obtained through reservation officials. No sites were visited within the Wind River Indian Reservation. The WSGS does not investigate mineral rights, nor does it provide economic evaluation for specific properties. Evaluation of mineral rights and the economics of specific properties is left to private companies and individuals.

Mining claims may cover some areas of interest, and prospecting cannot be conducted on claims without the claimant's permission. Mining claim information, along with claimant contact information, should be available in the courthouse for the county in which the claim is staked. That information is also available at the U.S. Bureau of Land Management (USBLM), Wyoming State Office in Cheyenne. The phone number for the USBLM in Cheyenne is 307-775-6200, and their web page is http://www.blm.gov/wy/st/en.html. Contact information for claimants may also be found on claim posts that mark the claims on the ground.

Public lands administered by the State of Wyoming, the U.S. Forest Service (USFS), or the USBLM each have their own set of rules governing these activities in specific areas. Check with the proper agency before proceeding. USBLM information about exploration and development regulations for locatable minerals are found at http://www.blm.gov/wy/st/en/programs/mineral_resources/Surface.html.

The USBLM and USFS both produce maps that show general land ownership. The WSGS publications sales desk carries many of these maps (Ph 307-766-2286 or visit https://sales.wsgs.wyo.gov/catalog/index.php). However, up to date land ownership information can only be relied upon from the courthouse for a particular county.

TERMINOLOGY

Ore

The term "ore" generally refers to material from which minerals or elements of economic value can be extracted at a reasonable profit, and is often appended with the type of metal in the ore, such as iron ore (Neuendorf and others, 2005). This is also the historical definition of ore. However, in common usage, the term is often loosely applied to material from which someone hopes to derive economic gain. Descriptions of iron deposits within this report use the term ore, or iron ore, in its historical sense as the deposits were described in the referenced sources. No current economic extraction from these deposits is implied. The current potential for economic extraction of iron from these deposits can only be determined through detailed evaluations using modern exploration techniques.

Resources vs Reserves

Resources and reserves, as applied to the amounts of a valuable mineral commodity in any particular deposit, have often had a variety of meanings to geologists and mining engineers. The USGS (1980), in collaboration with the USBM, defined the terms resources and reserves, along with modifiers for subcategories of each, for more precise usage in relation to mineral deposits. A *resource* is a concentration of material in such form and amount that economic extraction of a commodity from the concentration is potentially or currently feasible. A *reserve* applies to a concentration of material that, using current technology, is demonstrated to be economically extractable. For clarity, geographic and geologic parameters, along with the author and date of the measurements or estimates must be included. Various modifiers may be applied to these terms to add more detailed meanings.

Since these terms have economic implications, the USGS and the USBM emphasized that the use of them must be continuously reassessed based on improving geologic knowledge, advances in technology, and changes in economic and political conditions. These terms were redefined, with minor modification, by the Canadian Institute of Mining, Metallurgy and Petroleum (Postle and others, 2000) to ensure uniformity of their usage and to clarify other definitions that are used in Canadian National Instrument 43-101 (NI 43-101).

NI 43-101 is a rule issued by the Canadian Securities Administrators, last updated in 2011, designed to promote public confidence in mining-related stocks through enhanced accuracy and integrity of public disclosures related to mining and to ensure that misleading or fraudulent data related to mineral properties is not presented to investors in stock exchanges under the Canadian Securities Authority. NI 43-101 governs public disclosures of scientific and technical information by publicly-traded mining companies, including oral statements, websites, and written documents. NI 43-101 is generally accepted internationally and several exploration and mining companies operating in Wyoming use this standard and are listed on Canadian stock exchanges.

In this report, metric tons (tonnes) or short tons (tons) at a particular grade have been cited from various references. The historic figures are all cited in their original unit of tons; the few modern figures include both tonnes and tons. Similarly, U.S. feet and miles are used from historical citations without metric conversions. One tonne is equal to 1000 kilograms (kg) or 2,204.62 pounds (lb); one ton is approximately equal to 0.907 tonnes or 2000 lbs or approximately 907.2 kg. The terms, "reserves" was used in many of these references but has been omitted to avoid confusion with current NI 43-101 or USGS definitions. Instead, the notation used will be, "resources (reserves)" to indicate historical use of the word. No statement as to the current economics, potential for development, or to the lack thereof for any deposit within this report is implied.

SAMPLES AND ANALYSES

Samples collected during this investigation are grab samples (i.e. small, unmeasured samples), not necessarily representative of a larger volume of material. Analyses of these grab samples can neither confirm nor deny the presence or absence of economic concentrations of iron or other elements. A grab sample only represents one small piece of evidence for the occurrence of a mineral concentration or deposit. The grab sample is not associated with nor does it indicate a volume of material greater than the size of the individual sample. The elemental concentrations associated with a grab sample may or may not extend into the outcrop from which the sample was collected.

A thorough assessment of a deposit, as opposed to a survey of occurrences as presented in this report, requires evaluation of multiple samples across the range of geologic environments that occur at a specific location. Each of those samples must represent a specific volume of relatively uniform material such that elemental concentrations can be converted to tonnage estimates across the deposit. Only then can the economic tenor of the deposit be estimated. No single sample can define, identify, or eliminate the possibility of an economic deposit. Analytical units are those expressed in the references cited or in values as received from an analytical laboratory. Iron content is often expressed as total iron or Fe. However, some sources cite oxides such as Fe_2O_3 or FeO; these are from the source referenced.

All sample analyses for this project were completed by ALS Chemex of Reno, Nevada. Analytical methods for historical samples included within this report or in Wyo-DOG are referred to as generic if either the laboratory or the method of analysis is not known. Geochemical analyses on samples included whole rock analyses (major element concentrations in the form of oxides) by inductively coupled plasma (ICP), atomic emission spectrometry or mass spectrometry, and atomic adsorption. These methods, when preceded by effective preparation techniques, can generally detect most elements in a sample from very low concentrations in the range of less than 0.1–5 parts per million (ppm) up to ore grade concentrations. To put this in perspective 1.0 percent is equal to 10,000 ppm.

IRON DEFINED

Iron is a chemical element and transition metal (fig. 1). It can be found in the Earth's crust, mantle, outer core, and inner core. Iron exists in oxidation states from -2 to +6, but most commonly occurs in the +2 (ferrous) and +3 (ferric) states. It has an atomic number of 26, atomic mass of 55.847, melting point of 1181 K (1563°C, 2862°F), density of 7.86 g/cm3, and resides in period 4 and group 8 on the periodic table.

IRON USES

Iron is integral to products we use every day from paperclips to cosmetics. Iron is typically combined with other elements to create various metal alloys, including iron carbide (cementite), carbon steel, stainless steel, cast iron, and wrought iron. The durability, strength, heat resistance, and rust prevention can all be improved when combining iron with carbon, chromium, nickel, manganese, tungsten, and more. Steel and other iron alloys are used in almost everything from the construction of buildings, cars, and appliances to cutlery, cookware, nails, and screws. Iron also contributes to red, yellow, brown, and black pigments used to color a wide range of products that include paints, polishes, tiles, fabrics, mulch, paper, food color, and cosmetics. Iron can also be used in mine reclama-

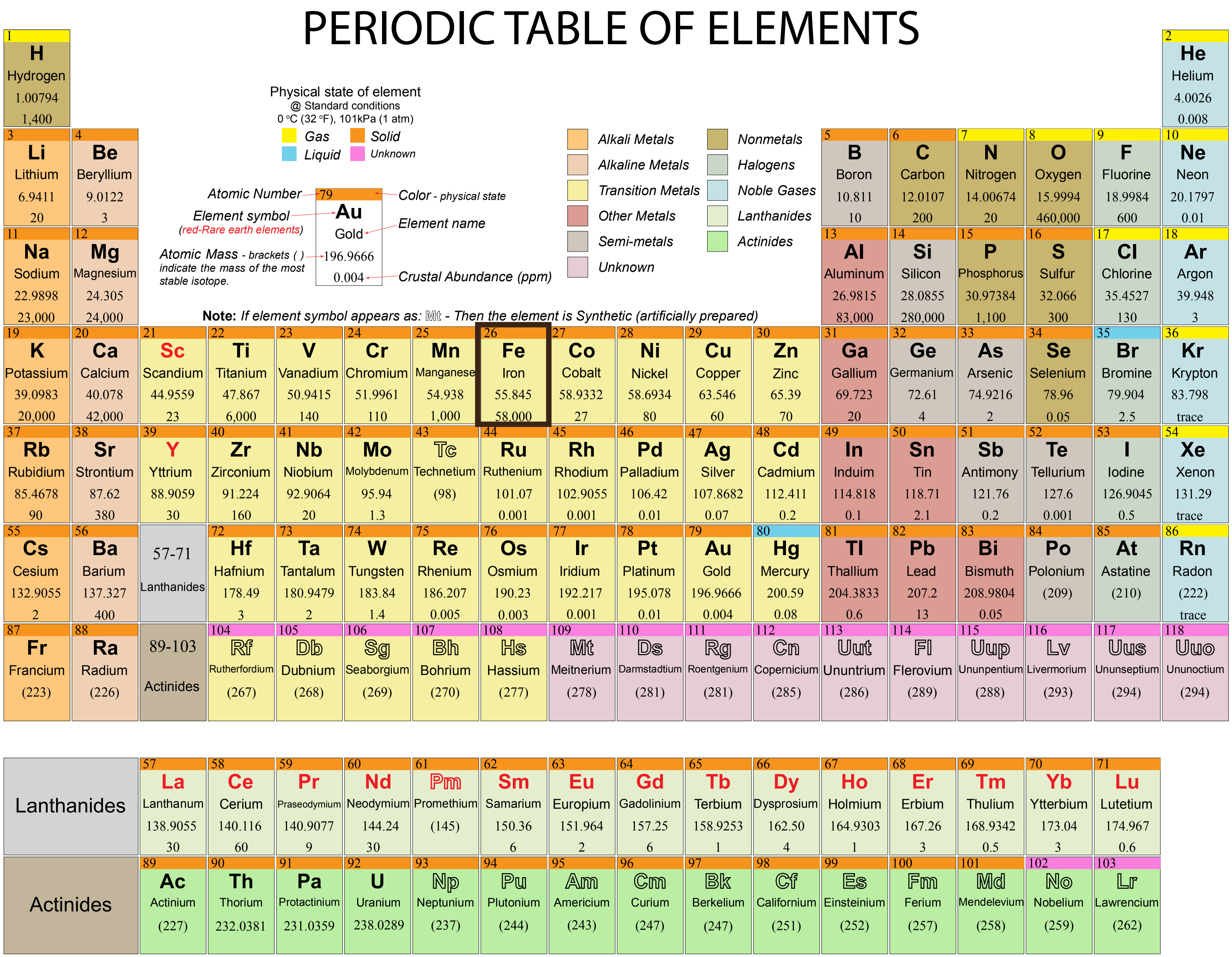


Figure 1. The Periodic Table of the Elements with iron highlighted in black. (Chart by James R. Rodgers, WSGS, 2015.)

tion and soil remediation to bind arsenic, lead, and other elements.

Iron based compounds can be included as additives in animal feed, pesticides, fertilizer, water/sewage treatment, pharmaceuticals, brake linings, polishing compounds, drilling muds, and much more. As with many rocks and minerals, iron-rich rocks and minerals are of minor use as decorative stone and in jewelry. Silicified banded iron formation (BIF), specular hematite, and magnetite have all been used in jewelry (Hausel and Sutherland, 2000). Table 1 displays many of the uses for iron, iron compounds, and iron metals; the list of products is seemingly endless, thus re-enforcing the importance and value of iron ore deposits (Minerals Education Coalition, 2013).

POLITICS AND SUPPLIES

The Iron Age is generally considered to date from about 1200 B.C., although the remains of iron ornaments date to about 4000 B.C. in Egypt (Schottman, 1983). Ancient civilizations in the Middle East, India, and China are known, from artifacts and writing, to have used iron. The Romans spread the technology of iron-making throughout Europe, but it was unknown in the Western Hemisphere until European colonization. Small local forges for iron-making began in the American Colonies in the early 1600s, with 16 blast furnaces and 19 hammer mills in operation by 1732. Production of pig iron, an intermediate smelting product, steadily increased with technology in the United States, reaching 22,000 tons in 1856 (Schottman, 1983).

In America, iron mining intensified during the post-Civil War era due to the emerging steel industry. Growth boomed in the 1870s-1880s. The need for steel continued as America industrialized and as capitalism increased. Inventions like the affordable automobile propelled the demand of iron by the average person, and recurring times of war also fueled the iron and steel industry (Schaetzl, 2008). From the mid-to late 20th century, iron usage plateaued as many countries slowly urbanized.

Recycling of scrap iron increased greatly during this period, which also limited the demand for raw ore. It was not until the early 21st century that a rapid industrializing of China caused a dramatic increase in demand. The iron industry is largely constrained by the prosperity and urbanization of countries. Trends in commodity prices are reflected in global growth trends, where times of global prosperity mean more consumption and more demand for base metals. For example, as mentioned earlier, the current level of growth in China is a huge factor affecting the global economy.

Politics and the stability of governments in various countries also affect iron exploration, production, and shipping. The variability of cost of labor, energy, and manufacturing in different countries under different governments can also affect production and trade (Kumar and Barua, 2014). A stable government, policy, and economy are the most conducive to development. Infrastructure for exploration, production, manufacturing, and shipping are also crucial to a successful mining operation.

Significant iron deposits have been found and developed around the world, including Minnesota, the Upper Peninsula of Michigan, Western Australia, eastern Canada, Sweden, Africa, Brazil, and more. Many of the deposits are owned and operated by Rio Tinto, BHP Billiton, Vale, and Fortescue Metals Group. Currently, the largest iron ore mine is the Vale-owned Carajas Mine in northern Brazil with 7.27 billion tonnes (8.01 billion tons) of proven and probable reserves, grading more than 66 percent iron, as of December 2012, and an extendable mine life to 2065 (The world's biggest iron ore mines, 2014). In contrast, about 75 percent of U.S. iron ore currently comes from low grade deposits in Minnesota that average close to 27 percent iron before bonification and upgrading to approximately 65 percent iron prior to being shipped (Minnesota Minerals Coordinating Committee, 2013). It is estimated that world iron resources exceed 208.7 billion tonnes (230 billion tons) of iron within more than 725.7 billion tonnes (800 billion tons) of crude ore, or unconcentrated ore. Of this total, 24.5 billion tonnes (27 billion tons) of iron contained within 99.8 billion tonnes (110 billion tons) of ore is located in the United States (Tuck, 2015). Current mine production and reserves for the highest producing countries can be found in figure 2.

Table 1. Iron can be used in various forms as well as in compounds with several elements. Below is a variety of iron compounds and their respective uses.

Iron (III) Acetate	dyes, mordants
Iron Arsenate	pesticides
Iron (III) Chloride	sewage treatment, dyes, animal feed additive, electronic etching, catalyst
Iron Hydroxide	water purifification systems
Iron (III) Phosphate	molluscicides, corrosion resistance/ rustproofing, adhesive, battery electrodes,
Iron (II & III) Sulfate	dyes/stains, black ink, treatment of anemia, sewage and water treatment, reducing agent, fertilizer, herbicide, food fortification, preservation of wood panelling
Cast Iron	frying pans, griddles, skillets, dutch ovens, waffle irons, pipes, auto parts, building construction, slurry pumps, ball mills, pulverisers
Metallic Iron	permanent and electro magnets
Stainless Steel	cutlery, surgical instruments, cookware, appliances, architecture, sculptures, railcars, automotive bodies, fibers, guns, watches
Steel	pipes, construction, heavy equiptments, furniture, steel wool, tools, armour, bolts, nails, screws, appliances, wire, railroad tracks, reinforcing mesh/bars, automobiles, trains, ships, magnetic cores
Wrought Iron	fences, furniture, home décor
Miscellaneous	coal washing, drilling mud/high density slurries, abrasives/polishing compounds, thermite/welding, magnetic tape and recordings, filtration, photocatalyst, calamine lotion ingredient

IRON PRICES

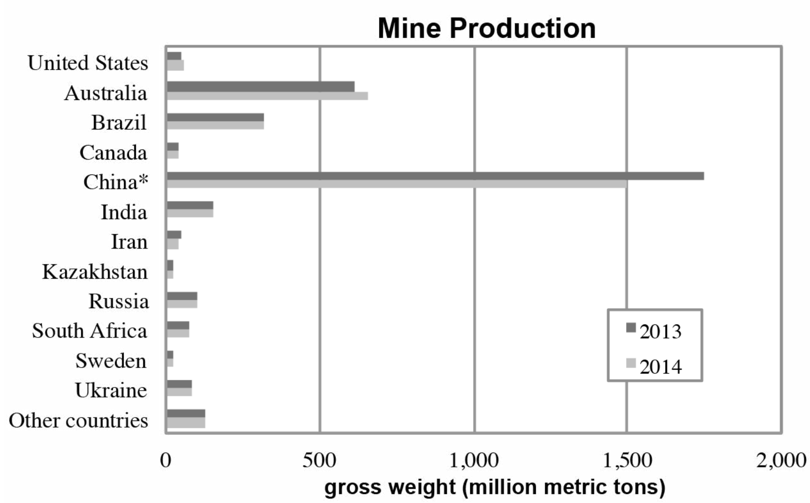
Through the 1980s and 1990s, iron prices were relatively stable, with a few minor fluctuations, around $11-$13/dry tonne, which is the material weight without moisture. Prices began to rise in the mid-2000s and almost doubled from an average price of $80/dry tonne in 2009 to $147 in 2010. Prices peaked at $187 in February 2011 and have overall declined, with some large fluctuations, to the present price of $63/dry tonne in February 2015. Prices by month from October of 1984 to February 2015 are presented in figure 3. Prices may to continue dropping through the near future as foreign urbanization slows. However, in the long term, overall iron ore demand is projected to increase as urbanization continues worldwide (The Lore of Ore, 2014).

EXTRACTION OF IRON

Most iron mines are surficial (open pit) operations as they are significantly more economical than underground shaft mines. To be competitive, mining must take place on a large scale with economic grade ore. Currently, a relative designation for high-grade ore is 55–65 percent or more iron, and the cut off for low grade ore is around 25–30 percent iron. Once establishing a site with an economic deposit, there are many requirements to start the mine. For a pig iron mine, there must be about 90.7 million tonnes (100 million tons) in reserves with an expected 2.7 million tonnes (3 million tons)/year extracted. The mine and facilities must have a 30-to 40-year life that can be paid off within 20 years (B. Avery, Wyoming Business Council, personal communication, 2014).

Country	Mine Production 2013	Mine Production 2014	Reserves Crude Ore	Reserves Iron Content
United States	53	58	6,900	2,100
Australia	609	660	53,000	23,000
Brazil	317	320	31,000	16,000
Canada	43	41	6,300	2,300
China*	1,750	1,500	23,000	7,200
India	150	150	8,100	5,200
Iran	50	45	2,500	1,400
Kazakhstan	26	26	2,500	900
Russia	105	105	25,000	14,000
South Africa	72	78	1,000	650
Sweden	26	26	3,500	2,200
Ukraine	82	82	6,500	2,300
Other countries	127	131	18,000	9,500
Wold total (rounded)	3,110	3,220	190,000	87,000

*China mine production based on crude ore instead of unusable ore.
Tuck (2015)



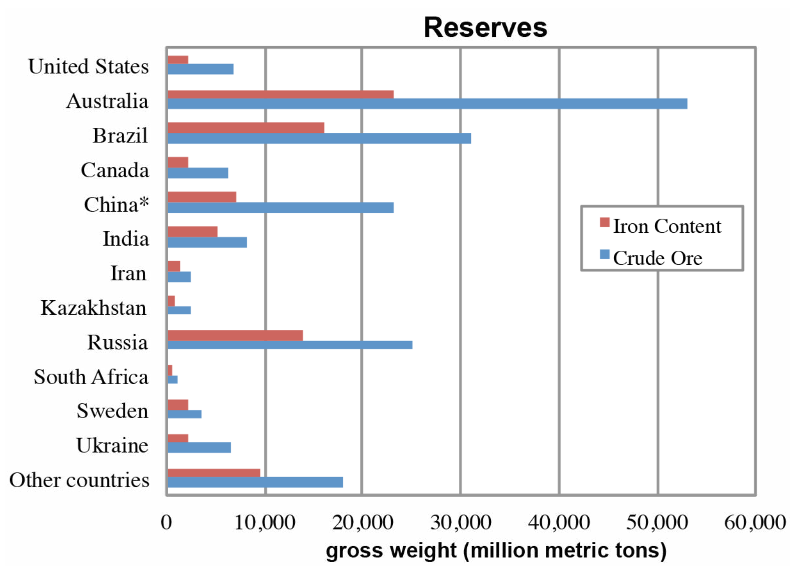
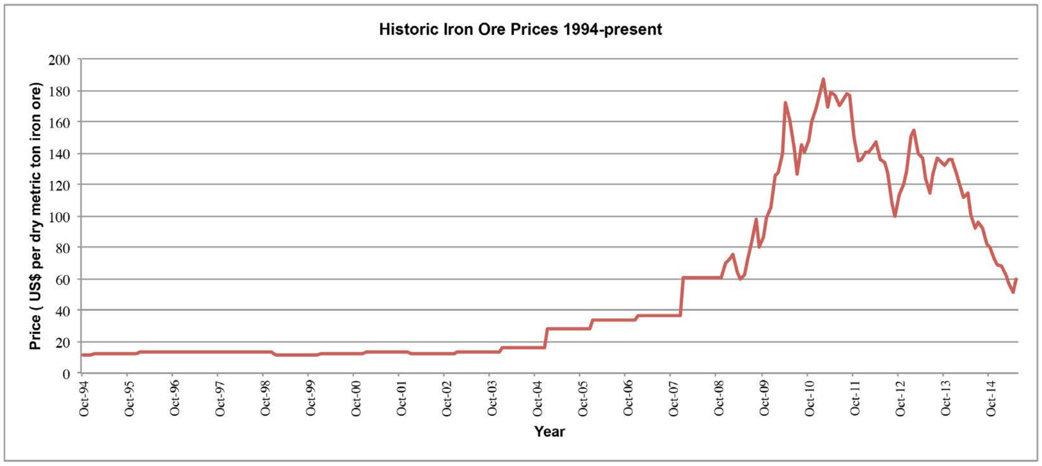


Figure 2. International iron mine production from 2013 and 2014 as well as current reserves in crude ore and iron content (Tuck, 2015).



www.indexmundi.com/commodities/?commodity=iron ore&months=360
www.ycharts.com/indicators/iron_ore_spot_price_any_origin

Figure 3. The fluctuation in price of iron from 1994 to present.

After mining the ore from the host rock, it is washed, crushed into a finer mixture by ball mills, and sorted in various ways. By using magnetic, heavy liquid, flotation, and spiral separation processes, impurities can be removed to concentrate the iron ore. Binding agents are often added to facilitate pelletization and to meet specific steel composition requirements. Pellets are formed in balling drums until they meet a size requirement, and are then dried and heated in a kiln for hardening (National Steel Pellet Co., 2003). Next, the pellets are transported to a blast furnace for smelting. This process releases iron from its chemical combination with oxygen by heating iron ore with charcoal as a reducing agent. The reduction process produces liquid iron or "hot metal," also known as pig iron when solidified, with slag and gas as by-products. Pig iron and/or hot metal can then undergo further processes to make various products (Walker, 2014).

Impurities like silica, aluminum, phosphorus, sulfur, and titanium can reduce the quality of iron ore and complicate the refining process. Many of these elements are removed during the smelting when silica, sulfur, and phosphorus are burned off. Sulfur can also be neutralized with the addition of the correct ratio of manganese (Rostoker and Bronson, 1990). However, aluminum and titanium have very high melting points and produce a viscous slag that can clog blast furnaces (Kato and Minowa, 1969; Rosenqvist, 1983; techhistory.co.nz, 2012). Fluxes are often used to counteract impurities, and the addition of lime can combat increased viscosity. Occasionally, impurities may be left in the mixture if it is desired for the final product. For example, phosphorus can increase the hardness and strength of the mixture and allow iron to stay molten longer if needed (Rostoker and Bronson, 1990). However, too much phosphorus and sulfur can lead to brittle, easily cracked iron. A typical economic-grade, magnetite-rich rock can yield 64 percent iron, contains less than 0.1 percent phosphorus, 3–7 percent silica, and less than 3 percent aluminum.

For industrial use and processing, iron ore is usually prepared and sold to steel makers as concentrate, fines, pellets, pig iron, and nuggets (Advanced Exploration Inc., 2008). Iron ore concentrate is an output product from processed ores that have been milled to separate deleterious elements and produce a higher quality product of 63 to 69 percent iron (Fe) compared to fines. It is sold to sinter and pellet plants and, due to its quality, usually commands a slight premium, but is overall priced competitively with iron ore fines. Iron ore fines are a screened small fraction of high-grade, direct-ship ore (DSO). The grade ranges from 56 to 66 percent Fe with the deleterious elements managed through ore blending. Fines are primarily sold to sinter plants and are typically the cheapest product available to steel industry blast furnaces.

The pelletizing of iron ore produces spheres of typically 8–18 mm (0.31–0.71 inch) diameter. Agglomeration and thermal treatment processes are combined to convert the raw ore into pellets with characteristics appropriate for use in a blast furnace and grades of 67 to 72 percent Fe. Additional materials are added to the iron ore (pellet feed) to meet the requirements of the final pellets. This is done by placing the blend in the pelletizer, which can hold different types of ores and additives, and mixing to adjust the chemical composition and the metallurgic properties of the pellets. In general, the following stages are included in this phase of processing: concentration/separation, homogenization of the substance ratios, milling, classification, increasing thickness, homogenization of the pulp, and filtering.

Pig iron is the intermediate product of smelting iron ore with coke, usually with limestone as a flux. It has a very high carbon content, which makes it very brittle and not useful directly as a material except for limited applications. Grades range from 90 percent Fe hot briquetted iron (HBI) to 96 percent Fe. HBI is a recently developed supplement for pig iron and is a compacted form of direct reduced iron (DRI) (Stena Metal Inc., 2011). The traditional shape of the molds used for these ingots was a branching structure formed in sand, with many individual ingots at right angles to a central channel or runner. Such a configuration is similar in appearance to a litter of piglets suckling on a sow. When the metal had cooled and hardened, the smaller ingots (the pigs) were simply broken from the much thinner runner (the sow), hence the name pig iron. As pig iron is intended for re-melting, the uneven size of the ingots and inclusion of small amounts of sand is insignificant compared to the ease of casting and handling. Pig iron contains varying amounts of contaminants such as sulfur, silicon and phosphorus. Its only significance is that of an intermediate step on the way from iron ore to cast iron and steel.

Iron nuggets are high in purity and iron content (>95 percent Fe). In the process of producing iron nuggets, all the iron oxide is reduced and no FeO remains in the nugget. The contents of silicon, manganese, and phosphorus in the product depend on raw material selection. The product sulfur level also depends on the sulfur contained in the feed reductant. However, it is often possible to reduce the sulfur level remaining in the nugget to an acceptable range (typically <0.03 percent). The final nugget product does not re-oxidize and does not generate fines. Therefore, it is easier than direct reduced iron and HBI products to handle and transport. The nuggets can be continuously fed to an electronic arc furnace (Minerals Education Coalition, 2013).

MINERALOGY OF IRON DEPOSITS

Iron deposits are found around the world as concentrations of various iron-bearing minerals and were formed in a wide variety of geologic settings. Magnetite, hematite, limonite, goethite, siderite, pyrite, ilmenite, and chamosite are important iron-bearing minerals (table 2).

Magnetite: Fe_3O_4

Magnetite is an iron oxide and member of the spinel mineral group. It contains both ferrous (Fe^{2+}) and ferric (Fe^{3+}) iron. The iron content is 72.36 percent, and it is the most magnetic naturally occurring mineral (webmineral.com, 2015).

Hematite: Fe_2O_3

Hematite is an iron oxide in the hematite group. It contains 69.94 percent iron in the ferric state (webmineral.com, 2015). It commonly pseudomorphs magnetite, and it can have a slight magnetism if magnetite is also in the rock. The easiest way to tell these minerals apart is by the streak color; magnetite has a black streak, and hematite has a dark-red streak. Hematite often accounts for the rusty oxidation of iron in rocks and soils.

Goethite FeO(OH)

Goethite is an iron-bearing hydroxide and a member of the diaspore group. It contains 62.94 percent iron in the ferric state (webmineral.com, 2015) and often forms due to weathering of other iron-rich minerals.

Limonite: $FeO(OH){\bullet}nH_2O$

Limonite is an iron-bearing hydroxide common in oxidized areas of iron deposits. The iron content

Table 2. The characteristics of iron minerals.

Mineral	Formula	% Fe	Color	Hardness	Streak	Density (cm^3)	Luster	Habit	Other
Magnetite	$Fe^{2+}Fe_2^{3+}O_4$	72.36	grayish black-black	5.5-6	black	5.15	metallic	massive, granular	magnetic
Hematite	$Fe_2^{3+}O_3$	69.94	red, blackish red	6.5	reddish-brown	5.3	earthy or metallic	massive, blocky, botryoidal	specular hematite has magnetite coating
Goethite	$Fe^{3+}O(OH)$	62.85	brown, yellowish-reddish brown	5-5.5	yellowish-brown	3.8	silky, adamantine	botryoidal, accicular/radial	
Limonite	$FeO(OH)*nH_2O$		yellow, orange, brown	4-5.5	yellowish-brown, red	2.7-4.3	earthy	massive, granular, botryoidal	term used for massive oxidized zones
Siderite	$Fe^{2+}CO_3$	48.2	yellowish brown	3.5	white	3.96	vitreous	botryoidal, massive	
Pyrite	FeS	46.6	brass-gold	6.5	greenish-black	5.01	metallic	cubic, drusy	fool's gold
Ilmenite	$FeTiO_3$	36.81	black	5-5.5	black-reddish brown	4.72	metallic-submetallic	massive	weak magnetism
Chamosite	$(Fe^{2+},Mg)_5Al(Si,Al)_4O_{10}(OH)_8$	29.61	greenish black	3	grayish green	3.2	dull-vitreous	granular, micaceous	

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can be variable, because the hydrated state can vary. However, it is commonly associated with altered goethite, pyrite, and other iron-bearing minerals. Limonite does not have a definitive chemical formula and crystal structure, which technically does not make it a true mineral by definition.

Siderite: $FeCO_3$

Siderite is an iron carbonate that forms a solid solution series with the minerals smithsonite ($ZnCO_3$), magnesite ($MgCO_3$), and rhodochrosite ($MnCO_3$). Siderite can contain 48.2 percent iron (webmineral.com, 2015) and often forms concretions in sedimentary rock units.

Pyrite: FeS_2

Pyrite, also known as fool's gold, is an iron-bearing sulfide containing 46.6 percent iron. Although it possesses a high concentration of iron, it is not usually considered an iron ore mineral due to its high sulfur content.

Illmenite: $FeTiO_3$

Ilmenite is a weakly magnetic oxide mineral containing ferrous iron. The iron content is 36.81 percent (webmineral.com, 2015) and the mineral is commonly found in metamorphic rocks or in black sand deposits. Although common with iron deposits, ilmenite is an important titanium ore mineral.

Chamosite: $(Fe, Mg)_5Al(AlSi_3O_{10})(OH)_8$

Chamosite is an iron-bearing phyllosilicate and member of the chlorite group. It contains 29.61 percent iron (webmineral.com, 2015) and, although uncommon, is found as a product of hydrothermal alteration of iron deposits, mafic rocks, and ultramafic rocks.

GENERAL GEOLOGY OF IRON DEPOSITS

One of the most common types of iron deposits worldwide is banded iron formation, BIF. BIFs are Precambrian age rocks with thin- to medium-bedded interlaminations of iron oxide, iron carbonate, or iron silicate materials, commonly chert or jasper. The term "taconite," originating in Minnesota's Mesabi iron range, is used specifically when describing a slate-like, iron-rich rock dominated by chert or jasper (Harrer, 1966). It is suitable for fine-grinding and magnetic separation to produce pellets containing 62–65 percent iron (Neuendorf and others, 2005). A BIF is considered a chemical sediment containing 15 percent or more iron with a sedimentary origin (James, 1954), but most economic formations contain at least 25–35 percent iron. BIFs can also be considered "ironstone" (Kimberley, 1978), which describes chemical sediments in a package of rocks with more than 15 percent iron. BIFs can be classified as Algoma-type or Superior-type deposits. Algoma-type deposits are Archean aged and related to submarine volcanic exhalative processes and spreading centers. Superior-type are Early Proterozoic aged and not necessarily volcanic. There are a number of theories explaining BIF formation. However, the most accepted theory relates the general age of BIFs, beginning about 1.8–2.5 billion years old (Ga), with the oxygenation of Earth's atmosphere and oceans around 2.0 Ga. It is thought that before the oxygenation of Earth's atmosphere and oceans, iron was dissolved in sea water under reducing conditions. As oxygen was introduced to the system, the iron oxidized and precipitated, forming iron-rich sediments on the ocean floor (Guilbert and Park, 1986). These layers of particles collected and were preserved during lithification. Direct Shipping Ore (DSO) deposits are typically composed of high-grade hematite and are primarily mined in South America, Australia and Asia. Most of these large hematite iron ore deposits come from the alteration of BIFs. DSO deposits are cheaper to mine and process as they require less beneficiation, usually only needing a simple crushing and screening before being exported (Gindalbie Metals Ltd., 2015).

Magmatic segregation (Kiruna-type) iron ore deposits are another important high-grade iron resource named for their discovery in Kiruna, Sweden. This deposit is sill-shaped with layers attributed to flow banding and sharp contacts with the host rock. The ore is composed of fine-grained magnetite, apatite, and rarely hematite. It is thought that the ore crystallized from an immiscible fluid fraction that evolved from a parent magma rich in magnetite and apatite. The fluid was highly mobile and intruded the host rock (Geijer, 1910; Guilbert and Park, 1986).

Hydrothermal iron deposits are often related to intrusive complexes especially when paired with calc-alkaline plutonism. These deposits are commonly found as skarn in the contact zone of hydrothermal metasomatism accompanying metamorphism of iron- and volatile-enriched residual magma. Magnetite is formed from the leaching of iron from igneous minerals and is deposited along veins, rock boundaries, and faults (Guilbert and Park, 1986).

Concretions are common in sedimentary units with siderite and hematite as the primary components of concretionary iron. Concretions form nodules, layers, intergranular cement, and irregular shapes by the nucleation and precipitation of a cement in concentric patterns and spheroidal masses. Chan and others (2007) link the precipitation of iron to the mixture of freshwater with water transporting reduced iron. When iron-rich water is oxidized, precipitation of concretionary masses occurs. As the conditions of the liquids change, variations in layers that are iron-rich and iron-poor may result. Frye (1967) theorized that nodules may have formed in shallow waters in a gelatinous state that later solidified contemporaneously with sedimentation. During dewatering and solidification of the nodules, shrinkage cracks and infillings produce, “alligator skin” type patterns, a common surficial feature on concretions (Franks, 1969; Biek, 2007)

Laterites are an iron-rich deposit formed over ferromagnesian, mafic-ultramafic, rocks in more humid environments. The combination of heavy rainfall and subdued topography dissolves siliceous rock components and concentrates iron, nickel, aluminum, and/or magnesium. If the iron deposit is relatively pure and easily accessible, small amounts of iron can be mined successfully (Guilbert and Park, 1986).

Black sandstones have a high content of heavy, dark minerals, especially magnetite. Houston and Murphy (1962) suggested these magnetite-rich sands originated as beach placers. First, magnetite-rich parent rocks erode and are deposited in a body of water. As regression occurs, the grains settle along beaches by wave action. Later, through the lithification process, grains become compacted and cemented to form a magnetite-rich sandstone layer.

Bog Iron is an example of biochemical precipitation of iron minerals. Bacteria breaks down humic iron in iron-rich bog waters to precipitate ferric oxides and hydroxides such as limonite. These are typically low-grade deposits, with many impurities, and of little economic importance unless found in very large amounts (Guilbert and Park, 1986).

IRON EXPLORATION AND PRODUCTION IN WYOMING

The earliest known mining of iron in Wyoming was by Paleo-Indians who used iron oxide dug from deposits near Hartville for paint or pigment(Frey, 1947). Clovis age artifacts associated with these early diggings indicate that mining took place between 8,000 and 13,000 years ago (Kornfeld and others, 2009; G. Frison, personal communication, 2014). It is also possible that the Rawlins Red hematite was used for ancient dyes and paints. However, development in the area, beginning in the 1870s, has eliminated any hard evidence for such use.

Wyoming iron ore occurrences were identified by the mid-1800s. One of the earliest published statements on iron in Wyoming was that of Captain Howard Stansbury, U.S. Army Corps of Engineers, on the titaniferous magnetite of the Laramie Range in Albany County in 1851 (Pinnell and Marsh, 1954; Dow, 1961). The Union Pacific Railroad (UPRR) was granted a title for much of the area in 1862, but little production has occurred. An 1890 report argued for the construction of a smelter, for pig iron production, in Cheyenne to take advantage of iron ores from several Wyoming sources, including Iron Mountain, Sunrise, Rawlins, and several occurrences of concretionary iron (Birkinbine, 1890); the facility was never built. A few tons of magnetite-ilmenite bearing rock were analyzed in 1898 and in 1956 (Dow, 1961), and the UPRR joined with the USGS and the USBM to conduct mapping and drilling. However, most attempts to smelt the iron, prior to 1957, failed due to the high amount of Titanium in the rock (Pinnell and Marsh, 1954). Plioflex Inc., formerly Magnetite Product Corp., operated an open pit for magnetite-ilmenite from 1962 to 1966, but production was not prolific and has been practically non-existent since 1966. Wyomex, LLC owned claims in the Iron Mountain area in the early 2000s but sold them to Titan Iron Corp. in 2011 (Business Wire, July 2011). Mountain Cement Co. also investigated and used some of the material as a weighting factor in heavy cement (A. McClugage, personal communication, 2009) but because of the small and erratic mining, the total production from the Iron Mountain area is unknown.

Iron deposits in the Seminoe Mountains and Rawlins area have been described since the early 1870s (Aughey, 1886; Anonymous, 1873). In the Seminoe Mountains, sporadic prospecting occurred over 70 years (Blackstone, 1965) and many claims were placed on lode and placer hematite deposits in 1902 (Harrer, 1966). By 1966, these claims were owned by Pattison Iron Co., Miller Estate Co., and Empire State Oil Co., but little production has occurred (Wilson, 1976). On the other hand, Rawlins Red hematite was produced from the Old Shaw Friend mines and was used for metallurgical flux and paint pigment. The UPRR gained ownership to the area and used the iron as paint pigment for their equipment. It was even used to paint the Brooklyn Bridge in 1883 (Boyle, undated; Lovering, 1929). Production eventually slowed and ceased. In 2014, Mountain Cement conducted limited exploration there for iron as an additive for heavy cement but did not find suitable material in quantity (A. McClugage, personal communication, 2014). Wilson (1976) estimated the total production from the Rawlins Red deposit to be 150,000 tons.

The Sunrise Mine in the Hartville area is one of two larger scale iron mining operations in Wyoming's history. Initially, the area was mined for copper from 1880 to 1887. However, further exploration led to iron ore production beginning in 1898 by Colorado Fuel and Iron Corp. Excavations included the main pit, Chicago Mine, Good Fortune Mine, and extensive underground workings between 1900 and 1975 (Frey, 1947). Between 1899 and 1980, the Sunrise Mine area, including the associated Iron Corporation Central ore body and the adjacent Chicago Mine, produced over 42 million tons of DSO and concentrate for CF&I's Pueblo, CO plant (MacCannon, 2003). The area is now owned by New Sunrise, LLC.

The second large scale iron mining operation in Wyoming was the Atlantic City Iron Mine. This deposit was known prior to 1911, and was described in 1916 (Harrer, 1966). Serious exploration of the BIF occurred from 1946 to 1958, and by 1962, U.S. Steel Corporation began shipping iron pellets (Bayley, 1963). This was the first taconite operation in the western United States, from which production continued until 1983 (Hausel, 1984). During this period, more than 90 million tons of iron ore were produced (Hausel, 1984). U.S. Steel reported remaining resources (reserves) of about 102.5 million tons plus 33.5 million tons in an unmined north pit and in waste rock with recoverable ore. This resource was left behind when the mine closed (Sandri and others, 1996). The current owner, JR Simplot Company, is reevaluating the mine for possible future operations (Storrow, 2014; D. Facer, personal communication, 2014).

The Owl Creek Mountains have been considered for potential iron resources. The year that iron deposits were discovered is unknown. However, gold and copper were mined from around 1900 into the 1920s. Tungsten was discovered and mined briefly in 1942, and uranium was prospected in the 1950s and 60s. In this area, iron is only represented by numerous prospect pits with no reported ore production (Duhling, 1971; Wilson, 1976; Hausel and others, 1985).

The Granite Mountains in central Wyoming were initially prospected for copper in the late 1800s to early 1900s, and iron there was not seen as having economic potential (Wilson, 1976). Ongoing investigations by Innovation Exploration Ventures, LLC and Newstrike Resources, Ltd. have reportedly discovered a deposit with possible economic grade and size. The company is currently in the exploration phase and remains optimistic (Innovation Exploration Ventures, 2014; Newstrike Resources, 2012).

GEOLOGY AND OCCURRENCES OF WYOMING IRON DEPOSITS

Although there are many different ways in which iron deposits form, only a few are observed in Wyoming. BIFs, magmatic segregations of magnetite, magnetite-rich sandstones, and iron concretions are present and were investigated for this report (fig. 4). Townships and ranges for site locations within this report are assumed to be on the 6th Principal Meridian unless otherwise noted to be based on the Wind River Meridian.

Banded Iron Formation

BIFs are relatively common in parts of Wyoming and account for the largest iron deposits in the state. Their presence is not surprising, because the existence of the Wyoming craton extends back into the Precambrian when the formation of BIFs was globally extensive. They are typically exposed at the edge of, and within, Laramide uplifts. Large continuous deposits have been reported in the Atlantic City-South Pass area, the Seminoe Mountains, the Owl Creek Mountains, and in the Granite Mountains area (fig. 4).

Silicified or jasperized BIF has been referred to as ironstone (which may refer to any iron-rich rock), jaspilite, or taconite. However, when it has aesthetically pleasing banding of alternating colors (tan, brown, caramel, red, gray, black) and contains sufficient silica to take a polish, it is useful for lapidary and decorative stones. This type of material is known in the vicinity of Bradley Peak in the Seminoe Mountains, near South Pass, and the Atlantic City Iron Mine (Hausel and Sutherland, 2000).

South Pass Area

Atlantic City Area, secs. 13, 23, 24, 25, 26, and 35, T. 30 N., R. 100 W., Fremont County

Precambrian iron deposits occur in folded and faulted metasediments and metavolcanics at the southern end of the Wind River Mountains. This area has undergone greenschist-amphibolite grade regional metamorphism and is folded into a regional synclinorium (Hausel, 1991). The metamorphosed units are flanked by Precambrian granite on the east and west, by moderately east-dipping Paleozoic sediments on the northeast, and by nearly horizontal Tertiary sediments on the south. The tight isoclinal folds in the Precambrian rocks strike northeast which contrasts the northwest trend of the Wind River Range (Bayley and others, 1973; Wilson, 1976).

The iron formation is a member of the Goldman Meadows Formation, a predominantly metasedimentary unit of quartzite, metapelite, amphibolite, and iron-bearing schist. The BIF is hard, dense, black schist consisting of alternating bands of magnetite- and quartz-rich layers. Ninety percent of the rock is formed of magnetite and quartz with lesser amounts of amphibole, chlorite, and garnet (Hausel, 1991). At the surface, weathering has replaced magnetite with hematite in an oxidized zone (Wilson, 1976). The average iron content is 33.5 percent with 50 percent silica. Locally, samples also include pyrite and chalcopyrite. The iron formation is structurally thickened by accordion-like folding, and repetition by faulting has increased the thickness of the unit nearly fourfold while shortening the strike length (Mining World, 1960; Harrer, 1966; Wilson, 1976; Hausel, 1984; 1991).

The partially reclaimed open pit mine at Atlantic City is located on the western limb of a syncline. The iron formation varies from 300–1,200 ft wide and 140–160 ft thick over a northeasterly strike length of more than 4,000 ft. These strongly foliated rocks, which range in dip from 30° SE to vertical, may extend in depth to as much as 4,000 ft (Harrer, 1966; Wilson, 1976).

The area was initially recognized primarily for gold until the beginning of Word War II. Subsequently, the need for steel shifted the focus from gold to iron. The presence of iron was known many years prior to 1911, and in 1916 a magnetic schist was described and sampled by the USGS (Harrer, 1966). Serious exploration of the BIF began in 1954 north of Atlantic City. Tonnage and grade figures for the ore body, at the opening of the mine in 1960, were 300 million tons, with indicated resources grading 22 to 35 percent iron, and 121 million tons of measured resources (reserves) grading 28 to 32 percent iron (Mining World, 1960).

In August 1962, U.S. Steel Corporation-Columbia-Geneva Steel Division shipped the first iron pellets from the Atlantic City open pit to Geneva Steel Works near Provo, Utah for smelting (Bayley, 1963). This was the first taconite operation in the western United States (Harrer, 1966). It had a design capacity of 4,000 tons of iron agglomerates per day, and produced 1,043,000 tons in 1962 and

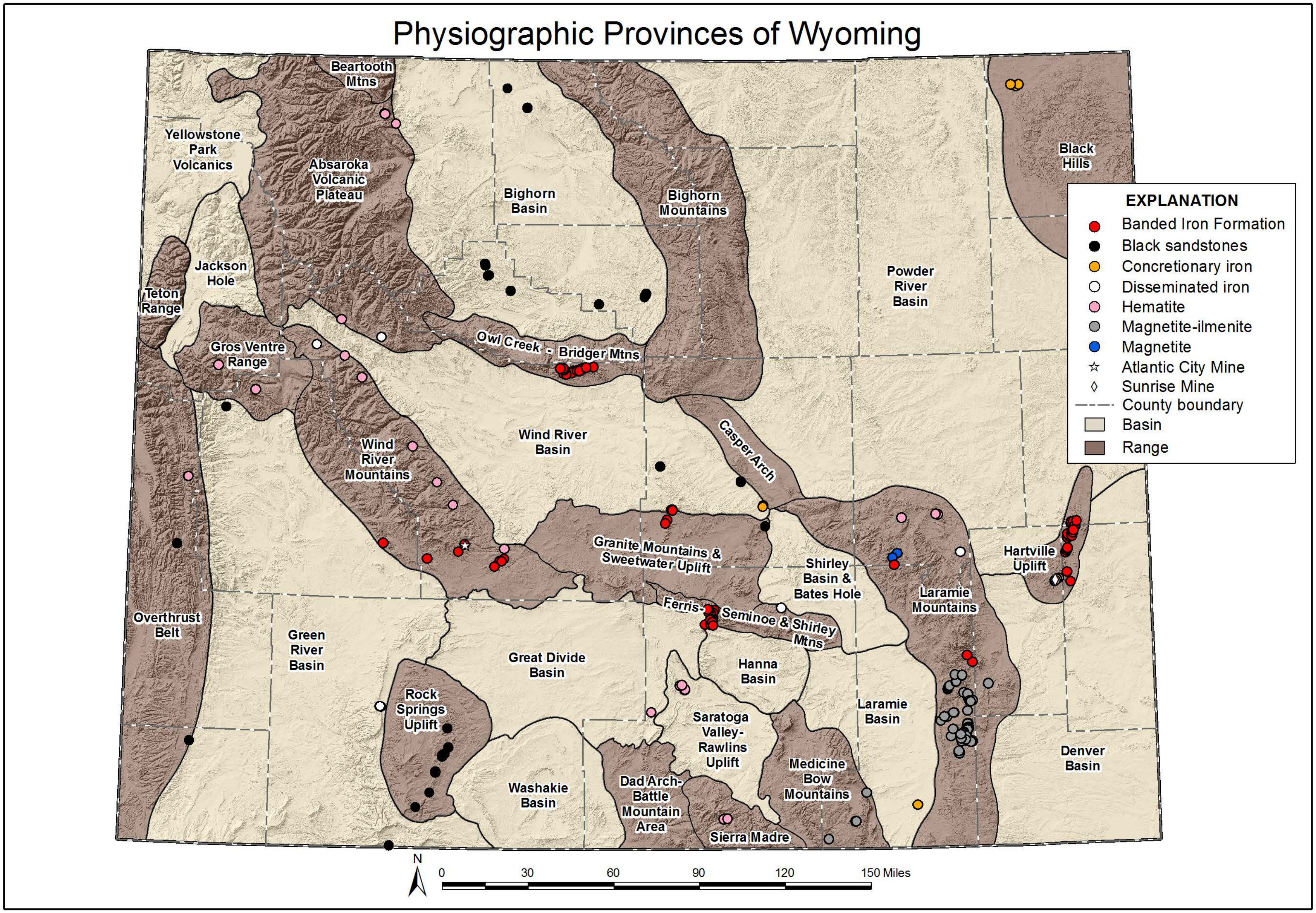

Figure 4. Different types of iron deposits around the state and their locations with respect to the physiographic provinces of Wyoming. Samples were taken at these localities for chemical analysis.

3,782,500 tons in 1963 (Osterwald and others, 1966). From 1962 until operations ceased in 1983, more than 90 million tons of iron ore were mined (Hausel, 1984) at about 5.5 million tons of ore per year when at full capacity (Osterwald and others, 1966; Hausel, 1991). Operations ceased in 1983 due to foreign competition, labor disputes, and high operating costs, leaving huge iron resources in place (Hausel, 1991). Around the time of closure, U.S Steel Corp estimated resources (reserves) of 102.5 million tons at 33.6 percent iron with an additional 33.5 million tons in an unmined north pit ore body and in low-grade waste rock that contains some recoverable ore. This assumed a mining depth

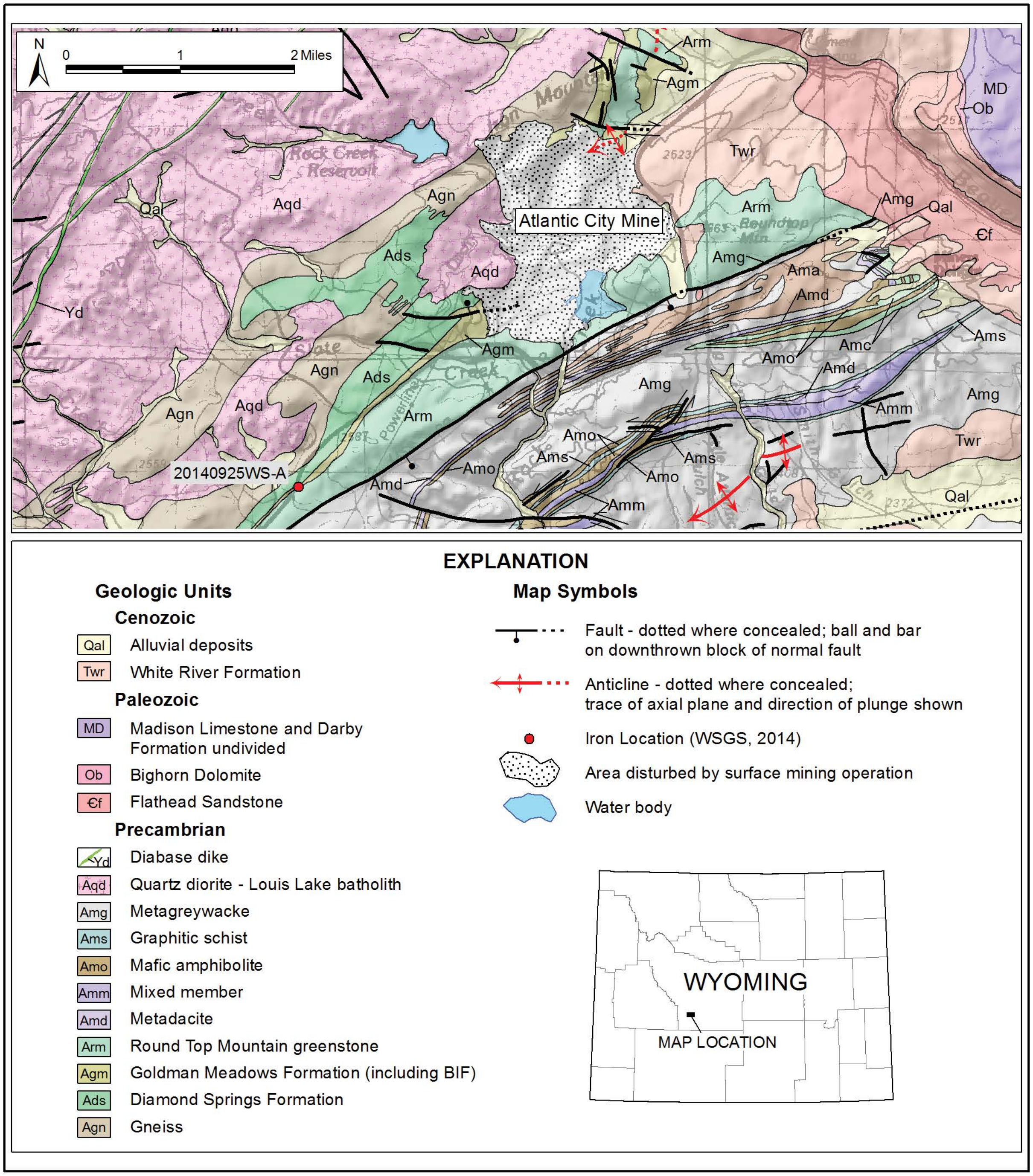

Figure 5. Sample location and geology of the southern Wind River Mountains near the Atlantic City Iron Mine. The sampled BIF occurs in the Goldman Meadows Formation. Map modified from Johnson and Sutherland (2009).

of about 600–700 ft below the east edge of the existing pit and did not account for higher grade ore that is projected to extend below the pit (Sandri and others, 1996). Currently, the owner, JR Simplot Company, is investigating the feasibility of reopening the mine (Storrow, 2014; D. Facer, personal communication, 2014).

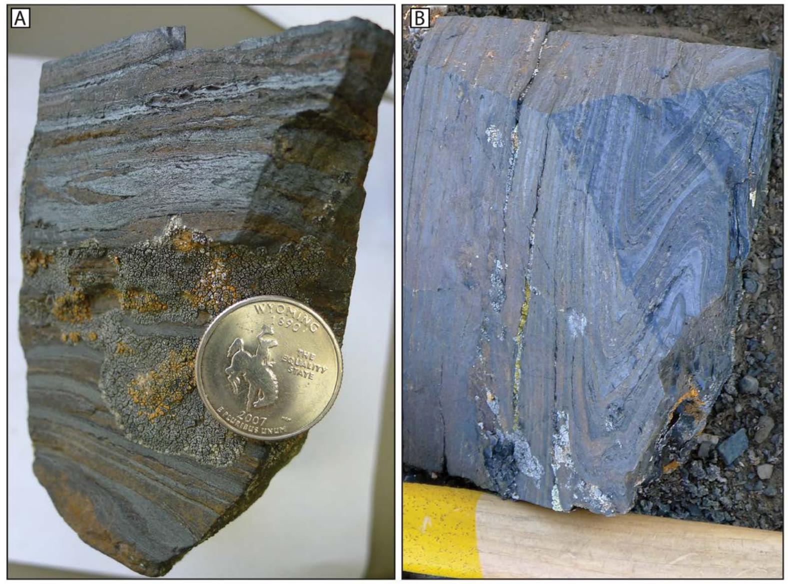

Figure 6. A and B) Banded iron formation from south of the Atlantic City Iron Mine (sample 20140925WS-A). Both images show metallic banding and recumbent folding.

During WSGS field investigations, BIF was sampled about 3.25 mi southwest of the Atlantic City Iron Mine on WY Hwy 28 (fig.5). Dark rock appears on either side of the road, however, magnetic iron formation was only encountered on the southeast side of the road. The formation was primarily covered with younger sediments and debris, but weather resistant ledges provided exposures of folded BIF with alternating magnetite and quartz layers. The rock was dense, hard, dark gray-black, metallic, and occasionally rusty (fig. 6). The sample, 20140925WS-A, yielded 52 percent Fe_2O_3 and 41.5 percent silica with no anomalous concentrations of other elements (table 3).

Upper Sweetwater River area, sec. 22, T. 29 N., R. 102 W., Fremont County

Hausel (1991) reports a deposit of BIF within a gneiss complex located near the Sweetwater River on the southwest flank of the Wind River Range.

Lewiston area, approx. sec. 5, T. 29 N., R. 98 W., Fremont County

The Lewiston area contains banded magnetite taconite similar to that in the Atlantic City-South Pass area. Harrer (1966) described an exposure 100 ft wide and 600 ft long along a southwestern strike. The area is covered by tertiary units and cross cut by granite.

Diamond Springs area, SW¼ sec. 19, T. 29 N., R. 97 W., and SE¼ sec. 25, T. 29 N., R. 98 W., Fremont County

In SW¼ sec. 19, T. 29 N., R. 97 W., south of Diamond Springs BIF occurs on a large fault block (Hausel, 1988; 1991). The iron formation is banded magnetite and silica with minor amphibole similar the Atlantic City open pit. To the west and south, the BIF is sheared with oxidization and hematite and contains quartz veins with copper mineralization. In SE¼ sec. 25, T. 29 N., R. 98 W., a thin grunerite schist outcrop containing 23.3 percent total iron as Fe_2O_3 is present. This same schist is seen in the Diana mine in the Miner's Delight Formation (Hausel, 1991).

Big Sandy and Little Sandy Creeks, T. 29, 30, and 31 N., R. 103, 104, and 105 W., Sublette County

Gersic and Nonini (1995) relate reports by Harrer (1966) of iron-bearing schists within Precambrian metasediments in the vicinity of Dutch Joe and Big Sandy Creeks. Specular hematite veins cutting granites are also reported on the upper drainage of Little Sandy Creek by Osterwald and others, (1966) and Endlich, 1879). The area around Dutch Joe and Big Sandy Creeks was examined by Sutherland in August of 2008 (personal field notes), but only large areas of well-foliated, medium-grained, rusty-weathering gneiss were observed along with very minor schist and no significant iron. The rock units that crop out along Little Sandy Creek are

Table 3. Analysis of the Goldman Meadows BIF.

Atlantic City-South Pass Area						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20140925WS-A	52.2	41.5	1.04	0.04	<0.01	0.07

essentially the same as in the Dutch Joe-Big Sandy area. The occurrence of small quartz or felsic veins with specular hematite may exist in these areas, but none were observed during field work. These observations combined with mapping and a written report by Worl and others (1984) suggest that there is little likelihood of any significant iron deposits in the Dutch Joe Creek-Big Sandy Creek area, or along the upper Little Sandy Creek.

Downs Mountain-Bear Basin area, E½E½ and NW¼ sec. 32, S½ sec 33, and S½ sec 34, T. 39 N., R. 107 W., Sublette County

This taconite iron occurrence is in the northern Wind River Mountains, of the Bridger Wilderness area, and has been referred to as the Clear Creek Area (Osterwald and others, 1966) and as the Union Pass District Magnetite (Harrer, 1966). This area was first mapped by Worl (1968) in 1964-1966, during investigations for his Ph.D. dissertation. Taconite bodies, two small and one large, are surrounded by amphibolite and quartz-plagioclase-biotite gneiss migmatite and grade laterally into amphibolite. Contacts between units are sharp and conformable. The largest body is composed of discontinuous lenticular taconites that vary from 2–30 ft thick and are as much as 500 ft long. Apparent relict sedimentary layering within each lens is evident in well-defined, continuous, but often contorted, layering parallel to the lenses, which are not contorted (Worl, 1968).

The taconite layers in the largest exposure are complexly folded and eroded into a u-shaped zone that is interpreted to be a relatively shallow sheet about 300 ft thick (Worl, 1968). This exposure is about 3,600 ft long and 2,500 ft wide, with taconite accounting for about 50 to 60 percent of the area (Gersic and Nonini, 1995; Ryan, 1982; Worl, 1968). Speculative resources based on geologic inference by Wilson (1976) are 252,264,000 tons averaging 25 percent iron. However, the deposit is probably not economic due to its remote location in a National Wilderness Area (Wilson, 1976). A similar, but smaller deposit, about 3 mi to the south, is reported by Harrer (1966), but no details are known.

The remote location of this iron deposit within the Bridger Wilderness Area and the Bridger-Teton National Forest, combined with low economic potential precludes this deposit from future consideration as a source of iron (Harrer, 1966; Wilson, 1976).

Hartville Uplift and Sunrise Area

The Hartville Uplift is an elongated north-northeast trending dome approximately 40 mi long. The area is bounded on the east by a high angle fault, in which the Hartville Uplift is the western, upthrown block (fig. 7). Rocks cropping out in the Sunrise-Hartville Uplift area include the Precambrian Whalen Group, overlain by the Mississippian-Devonian Guernsey Formation, which is overlain by the Pennsylvanian Hartville Formation. The iron-bearing formation occurs in the Whalen Group, a thick sequence of green schists, quartzites, dolomites, micaceous schists, and graphite schists (Wilson, 1976).

Frey (1947) described the country rock surrounding the iron ore as schist and an impure, hematite- and limonite-stained flint. Lenticular bodies of red iron ore are enclosed by schist, immediately above the uppermost limestone of the older Precambrian rocks; a thin layer of iron-stained, siliceous schist separates the iron ore from the limestone. Frey (1947) interpreted the iron ore to be a replacement of the schist and occurring in two varieties. The first variety is a fine-grained, generally schistose, soft, light-red, unit commonly referred to as "paint ore." The second is a fine-grained, hard, dark bluish-gray, compact ore with a smooth fracture, and referred to as "blue ore," which is the more

Table 4. Chemical analyses of samples in the Sunrise area. Other elements present at >5x crustal concentrations are W, As, Sb, U, Bi, Se, Ni, and Zn. For full details, see appendix.

Hartville Area-Sunrise Mine						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20140926WS-A	89.1	8.6	0.19	0.01	0.02	0.15
20140926WS-B	39.5	40.2	7.97	0.32	<0.01	0.17
20140926WS-C	57	16.95	6.99	0.24	0.02	0.15
20140624WS-C	8.46	65.7	13.55	0.58	0.01	0.13
20120322WS-3[1]	31.7	42.3	13.6	0.2	0.03	0.13
20120322WS-4[1]	75.2	12	5.2	0.12	0.05	0.17
20120322WS-6[1]	19.35	58	13.7	0.52	<0.01	0.05

[1]*Sutherland and others (2013)*

valuable of the two. A sample of each was collected for analyses (table 4). The "paint ore," which we refer to as ochre, has a deep red hue and is somewhat greasy to the touch (fig. 8B). It leaves a rusty, metallic stain on contact (sample 20140926WS-C). The ochre contains 57 percent Fe_2O_3 while the schist below it contains only 8.5 percent Fe_2O_3. The "blue ore," sample 20140926-A, is a dense, bluish-black hematite with a rusty surface and yields about 89 percent Fe_2O_3.

The USBM undertook an exploration effort using magnetometer and gravity-meter surveys around the Sunrise and Good Fortune mines during the 1940s. However, they failed to find a correlation between magnetic anomalies and either mineralization or structure and made no conclusions concerning the gravity surveys (Frey, 1947). Modern geophysical equipment and methods would most likely find those correlations.

Sunrise area: Main Ore Body, NW¼NE¼ sec. 7, T. 27 N., R. 65 W., Platte County

Osterwald and others (1966) describe the Sunrise Iron Mine as, "one of the most important iron mines west of the Mississippi." Copper ore was mined in the district from 1880 until 1887, with iron production by Colorado Fuel and Iron Co. (CF&I) beginning at the Sunrise Mine in 1898 after a 10-year period of prospecting and exploration (Frey, 1947). Hematite ore occurs in the lower part of the Good Fortune Schist which is faulted and part of a steeply east-plunging synform. Ore bodies appear localized in cross-folded zones superimposed on the synform in the thickest part of the Good Fortune Schist.

Archaeological investigations at the Sunrise mine site identified extensive Clovis age (8,000 and 13,000 years ago) artifacts co-mingled with red ochre. Although the site has been disturbed, the location is interpreted to be a prehistoric mine of the soft, fine-grained, red hematite (fig. 8B) with a suggested use as paint or dye by Native Americans during that time (Frey, 1947; Kornfeld, and others, 2009; G. Frison, personal communication, 2014).

Iron mining of the Sunrise property began in 1898–1899 and continued until 1980 when the mine closed. In 1947, the Sunrise and Chicago properties included a large open pit and underground mine. Other workings in the district were only shallow shafts, short adits, and some unconfirmed exploratory drilling (Frey, 1947). The mine consisted of the main, the open pit, and the central ore bodies (fig. 7; fig. 8A). The Main ore body is 50–600 ft thick, 1,600–2,100 ft long, and occurs as an S-shaped lens in a tight, south-plunging, synclinal fold. Sporadic, thinner ore bodies occur between the main body and dolomite footwall. The open pit ore body is continuous with the subsurface portion of the main ore body. The dip is steeply north suggesting isoclinal folding. The central ore body is smaller, less irregular and is composed of red, earthy hematite, and steel gray to bluish black, specular hematite. The wall rock contains

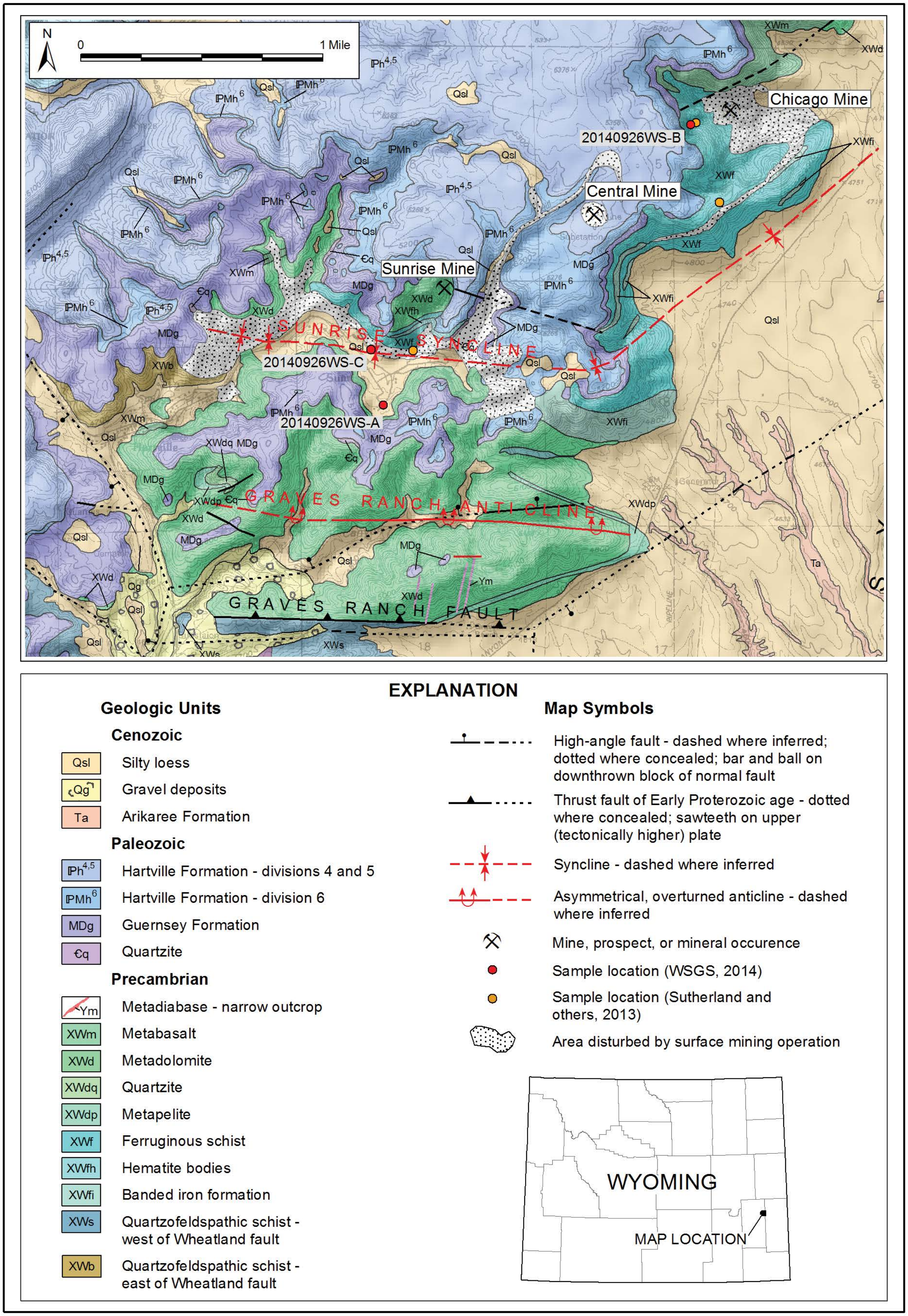

Figure 7. Geology of the Hartville Uplift area showing the Sunrise, Central, and Chicago mines along with WSGS sample locations. Map modified from Harris and others (2005).

Figure 8. Images from the Sunrise Mine near Hartville, Wyoming. A) The main pit now filled with water. The Mississippian Guernsey Formation is the cap rock overlying the Archean Ferruginous schist and Hematite members. B) Red ochre accompanied by greenish opaline chert sampled from an archeological site near the main pit. C.) Red, ultra-fine pond tailings (sample 20140926WS-C) held together by clay.

sharp and gradational contacts with low grade hematite. Total production during 1900–1980, from all ore bodies including the Chicago Mine, was about 42,454,000 tons (MacCannon, 2003). Wilson (1976) estimated that there were 118,000,000 tons of resources (reserves) at 55 percent iron.

A current estimate for iron in the Sunrise area includes an older CF&I in-place estimate of about 20 million tons averaging 55 percent Fe, one tailings pile of 3–3.5 million tons averaging 20–25 percent Fe, an old mine dump of about 1 million tons varying from 10 to 40 percent Fe, plus some other ore bodies of unknown size and grade. This would bring the total iron ore on-site to around 22.2 million tonnes (24.5 million tons) or more (J. Voight, personal communication, 2015).

Chicago Mine, NE¼NE¼ sec. 5, T. 27 N., R. 65 W., Platte County

The inactive open pit Chicago Mine (fig. 9) was cut into the northeasterly plunging synform developed in the Precambrian Good Fortune Schist. The north limb dips 75° SE while the south limb dips 80° NW. A shaft was sunk to 394 ft, but workings have since flooded. In 1880-1887 the area was explored and mined for copper. Initial iron production began in 1905 when 531,400 tons were shipped. The ore is similar to that from the Sunrise Mine and the total production from the Chicago Mine is unknown (Wilson, 1976). The face contains a variety of iron-rich rocks ranging from massive to schistose, rusty to metallic, or low to high magnetism. Multiple samples were taken (20140926WS-B) to acquire an average iron content of nearly 40 percent Fe_2O_3 (table 4).

Good Fortune Mine, NE¼SE¼ sec. 7, T. 27 N., R. 65 W., Platte County

A hematite iron ore zone occurs in the lower part of the Good Fortune Schist. It varies in thickness from 500–1,000 ft. The iron ore is in contact with and immediately overlies the Whalen Dolomite and the steeply north dipping beds are part of the south flank of an asymmetric antiform which plunges steeply to the east. The same rocks occur in the steeply plunging synform at the Sunrise Mine. The lenticular hematite zone in the mining area strikes about 290° with an average dip of 60° N. The iron ore zone is on average 50 ft thick but varies from 30–90 ft wide and is intermittently exposed along strike for 5,000 ft. Grade ranges from 33.4 to 63 percent iron with an average of 51.4 percent. The ore occurs as either soft, fine-grained, light red, hematitic schist or as hard, fine-grained, dark, bluish gray hematite. The latter contains a higher percent of iron. From 1898 to 1899, approximately 33,600 tons with an average of 62.4 percent iron ore were mined, and the waste dumps were shipped in 1953-1954. If resources (reserves) were calculated based on 51.4 percent average grade of iron, 100 ft depth, 5,000 ft length, and 53 ft width, the estimated total resources (reserves) are about 4,212,000 tons. If the all parameters were the same but the depth was changed to 200 ft, estimated resources (reserves) are about 8,421,000 tons. If the depth was changed to 300 ft, the estimated resources (reserves) are about 12,633,000 tons (Wilson, 1976). Thus, this area has some potential for renewed mining operations.

Muskrat Canyon, SW¼ sec. 13, W½ and SE¼ sec. 24, T. 30 N., R. 65 W.; W½ sec. 19, S½ sec. 18, NW¼ sec. 17, S½ and NE¼ sec. 8, T. 30 N., R. 64 W., Goshen County

Precambrian iron formation crops out discontinuously along the edge of a north-south trending fold near the headwaters of Wildcat Creek and the walls of Muskrat Canyon. The iron formation consists of hematite-rich quartzite and schist and crops out for about 5 mi along strike with a surface width up to 1,181 ft. In the west limb of the fold, most iron-bearing layers are about 20 ft thick, and layers on the east limb are up to 78 ft thick. Along the head of Wildcat Creek, abundant dark quartzites are interlayered with hematitic quartzite, schist, and dolomite. A grab sample contained 13.1 percent total iron (Wilson, 1976).

Muskrat Creek, S½ sec. 24, and NW¼ sec. 25, T. 30 N., R. 65 W., Goshen County

Small amounts of copper were mined in the late 1890s-early 1900s. However, only estimates have been made about iron potential. The iron-bearing formation, locally called the Muskrat Iron Formation in the Whalen Group, is 300–350 ft thick, folded, and with hematite, magnetite, goethite, and limonite in a quartzite host. The formation trends approximately north-south, with a hooked shaped structure at the northern end and dips from 70° E. to vertical (Wilson, 1976). CF & I Steel Corp. divided the formation into two mineable zones named the North and South Ore Bodies. The North Ore Body had an estimated 75,488,300 tons at an average 25.3 percent iron and the South Ore Body with 40,936,000 tons at an average 24 percent iron. However, Ackerman (1969) suggests both bodies would contain about 16.7 percent iron, because so much is locked up in silicate minerals. The stripping ratio at 3.12 tons waster/ton ore would be expensive for 50–150 ft of competent hard rock overburden.

Figure 9. Partial view of the Chicago Mine wall and location of sample number 20140926WS-B.

Haystack Range - Wildcat Hills

In the Haystack Range and Wildcat Hills, iron ore has been mined from hematite ore bodies that mostly occur in Precambrian phyllite above carbonate rocks (Osterwald and others, 1966). No hematite of economic significance was found north and west of the Chicago Mine, suggesting that ore bearing zones are absent or concealed. Considerable amounts of hematite occur in mica schists along the McCann fault near McCann

Pass, but on the west side of the pass and south side of the fault, hematite content was projected to be of little economic importance (Millgate, 1965). Two unmapped pod-like outcrops of hematitic schist occur on the south side of a small hill and are partially concealed by the Guernsey Formation. At the southern end of this outcrop, a belt of hematitic schist 50–70 ft wide trends east-west but is largely concealed to the south, east, and west (Millgate, 1965). Wilson (1976) discusses six occurrences, listed below, of iron formation in the Haystack Range and Wildcat Hills that vary in size, grade, and exposure.

Goshen-Niobrara County Sites

W½E½ sec. 23, T. 29 N., R. 65 W., Goshen County

Poorly exposed Precambrian iron formation crops out on the east flank of a north-plunging fold, which is thought to be overturned. The iron formation is red to black, very fine-grained quartzite up to 150 ft thick accompanied by hematite and minor magnetite. The iron formation is positioned about 100 ft above a thick dolomite and is underlain by iron poor quartzite.

SE¼SE¼ sec. 14, T. 29 N., R. 65 W., Goshen County

Precambrian chlorite schist, magnetite quartzite, conglomeratic quartzite, and dolomite are exposed in a series of small folds that trend 35–50° and dip 35–80° SE. (Wilson, 1976). The iron-gray, black, and red magnetic quartzite is mostly thin-layered, very fine-grained, and composed chiefly of quartz, magnetite, and hematite. Wilson's (1976) grab samples contained 17.1 and 15.9 percent total iron.

NW¼ sec. 13, T. 29 N., R. 65 W., Goshen County

Precambrian hematitic quartzite and schist in thin layers are exposed along a 313° strike for about 1200 ft (Wilson, 1976). The iron-bearing rocks are light red to light gray, very fine- to fine-grained quartzites. The most abundant iron mineral is hematite, with minor magnetite. Wilson's (1976) grab sample contained 13 percent total iron.

SW¼ sec. 12, T. 29 N., R. 65 W., Goshen County

An outcrop of Precambrian hematitic schist and related surficial debris occurs along a distance of about 2,400 ft. The layers strike 202° and dip 80–85° NW. Most of the exposures are poor, however the iron formation is suspected to be in contact with chlorite and amphibole schist to the west and concealed by Tertiary rocks to the east. Hematite is the primary iron mineral, and the iron-bearing rocks are red to light gray, extremely fine-grained, and strongly magnetic in part.

Sec. 26, T. 28 N., R. 65 W., Goshen County

Iron occurs here in mica schist along the McCann fault in the vicinity of McCann Pass (Stensrud, 1963). No further details are available for this deposit.

SE¼NE¼ sec. 12, T. 27 N., R. 65 W., Goshen County

Millgate (1965) describes an east-trending belt of Precambrian hematitic schist about 50–75 ft wide transects a mica schist. The hematitic schist is mostly concealed and may be similar to the sites described above by Millgate (1965).

Rawhide Canyon, NW¼ sec. 4 and 5, T. 30 N., R. 64 W., Goshen County; S½ and NE¼ sec. 29, SE¼ sec. 30, NE¼ secs. 31-32, and SW¼ sec. 33, T. 31 N., R. 64 W., Niobrara County

Poorly exposed Precambrian granite with heavily oxidized and hematitic metamorphic remnants occurs along the headwaters of Rawhide Creek. These remnants may be weathered iron formation and form narrow, sinuous, shallow trenches which strike from 335° to 10° and dip 70° to 85° E. Most of these can be traced for 984 ft along strike before becoming concealed by tertiary rocks (Wilson, 1976).

NW¼ sec. 28, T. 31 N., R. 64 W., Niobrara County

A narrow band of poorly exposed Precambrian hematitic schists and quartzites at this location trends 20° and dips 85° SE to vertical. The northern end of the band includes some areas of red and black banding and jasperoid, while the southern end is primarily jasperoidal quartzites. The iron-bearing unit appears to be in contact with granite to the west and with a thick, buff to pink dolomite sequence on the east. The outcrop is discontinuous and partially buried by Paleozoic rocks (Wilson, 1976).

Laramie Mountains

Moonshine Peak-Elmers Rock area, sec. 7, SW¼ sec. 8, and NW¼ sec. 17, T. 23 N., R. 70 W., SE¼ sec. 11, SE¼ and SW¼ sec. 12, and NE¼, NW¼, and SW¼ sec. 14, T. 23 N., R. 71 W., Albany and Platte Counties

Several outcrops of BIF were mapped in detail within the Elmers Rock greenstone belt near Moonshine Peak in the central Laramie Mountains by Snyder (1984). An earlier report by Graff and others (1982) described this deposit as containing 40 percent iron in the form of folded magnetite, hematite, and quartz-amphibole layers up to 100 ft thick, with a length of 2 mi. The outcrops were described by Snyder (1984) as layered, gray granofels with more than 30 percent quartz-magnetite, along with quartz-grunerite-magnetite schist, and quartz-grunerite-garnet-magnetite iron formation. No iron sample analyses accompanied Snyder's description. Snyder's map showed the thickest outcrop, folded in a rough horseshoe shape centered in the SW¼ SW¼ of section 8, to vary from about 200 to 700 ft thick for a distance of about 2,000 ft along the fold. The longest outcrop, trending northeast across the northern half of section 14, appears to be about 200 ft thick for 0.6 mi, but its total length is almost 0.9 mi.

Fletcher Park area, sec. 2, T. 25 N., R. 71 W., secs. 6, 7, 17, 18, 19, 22, 26, 27, and 30, T. 26 N., R. 70 W., and secs. 24, 25, 26, 34, and 35, T. 26 N., R. 71 W., Albany and Platte Counties

Numerous scattered outcrops of BIF were mapped in detail within this area in the central Laramie Mountains by Snyder (1984). The largest outcrop trends NE for more than 0.5 mi in the SE¼ of section 24 and has a maximum width of more than 200 ft.

Rabbit Creek area, NE¼SE¼ sec. 22, T. 26 N., R. 70 W., Platte County

Precambrian quartz-magnetite iron formation, as much as 150 ft thick, is traceable from the vicinity of the old Black Powder graphite mine for a distance of 0.5 mi southeast along the North Laramie road. Although local strikes and dips vary, the general trend is southeast. Similar iron formation crops out in the Fish Creek area (Wilson, 1976) on the Riley, Weaver, and Clamp ranches about 6 mi to the northwest (Harrer, 1966).

Fish Creek, sec. 6, T. 26 N., R. 70 W., Albany County

Precambrian quartz-magnetite iron formation, up to 150 ft wide, crops out along the south bank of Fish Creek and reservoir for 1,000 ft, but thicknesses of individual iron-bearing beds are unknown. The trend is eastward with dips varying from 70° S. to vertical (Wilson, 1976). The iron formation is similar to, and may extend into, iron outcrops in the Rabbit Creek area, 6 mi to the southeast (Harrer, 1966).

Garrett area Banded Iron Formation, SW¼ NW¼NW¼ sec. 27 and NE¼SE¼ sec. 32, T. 25 N., R. 73 W., Albany County

The Garrett area is near the western edge of the Elmers Rock greenstone belt in the central part of the Laramie Mountains (Graff and others, 1982). Samples of BIF collected in this area by Hausel (1983) were analyzed at the time for gold and iron. All samples showed less than 0.34 g/tonne (0.01 oz/ton) gold. However, the sample (GA-306) from section 27 was described as magnetite-silica iron formation and showed 26.4 percent Fe. Two samples (GA-113A and GA-113C) from one location in section 32 were described as magnetite-amphibolite iron formation and showed 11.0 and 10.5 percent Fe, respectively (Hausel, 1983). Outcrops in the area generally trend northeastward, but details concerning the thickness and length of the BIF in this area are lacking. The outcrops here are mapped (Graff and others 1982) as layered mafic and ultramafic rocks with sample site GA-306 projected to be adjacent to outcrops of metasedimentary rocks.

Sierra Madre

Sierra Madre BIF, sec. 6, T.13 N., R. 84 W., sec. 1, T. 13 N., R. 85 W., sec. 11, 14, 16, 17, and 27, T. 13 N., R. 86 W., and sec. 34, T.14 N., R. 85 W., Carbon County

Several outcrops of BIF were mapped in these areas by Schmidt (1983). The two largest outcrops are in sections 16 and 34, which have respective lengths of more than 0.5 mi and about 1100 feet; maximum thicknesses of both are between 150 and 200 ft.

Seminoe Mountains-Bradley Peak Area

The Seminoe Mountains are a northwest-trending, Laramide-uplifted thrust wedge cored by Archean metamorphic and igneous rocks in central Wyoming (fig. 10). The highly folded and faulted uplift is flanked by steeply dipping Paleozoic and Mesozoic strata. The Bradley Peak Thrust Fault, a northeast-dipping, low-angle reverse fault, bounds the uplift on the southwest and places Archean rocks over sedimentary rocks as young as the Late Cretaceous Mesaverde Formation (Blackstone and Hausel, 1992). The Seminoe Mountains are bounded on the northeast by a normal fault, the Kortes Fault (Hausel, 1994b), which is the southeastern extension of the South Granite Mountains fault system.

The Seminoe iron ore deposits have been studied and prospected since 1870 (Aughey, 1886) and sporadic prospecting and sampling continued for more than 70 years (Blackstone, 1965). In 1902, seven lode claims (St. Louis, Calcator, Red Oxide, Domingo, New Year, Boston, Frozen Finger) were staked on hematite and four placer claims (Midnight Iron, Grant Iron, Greeley Iron, Hayes Iron) were located, all centering around Iron Hill (Harrer, 1966). By 1966, the claims were owned by the Pattison Iron Co., Miller Estate Co., and Empire State Oil Co. (Wilson, 1976). Although investigations were extensive, no known iron production has ever come from the Seminoe Mountains.

Banded iron formation crops out near the western end of the Seminoe Mountains and in the hanging wall near the Bradley Peak Thrust (fig. 10). The BIF is steeply dipping in general and outcrops in the northern part of the Seminoe Mountains and are separated from those along the southwestern flank by the northwest-trending Deweese Creek normal fault. Numerous smaller faults disrupt the southwestern BIF outcrops and major gravity slides have disrupted and displaced BIF southward from Bradley Peak a mile or more to the southern and western edges of Pattison Basin (fig. 10). These structures control the extent and thickness of the masses of iron formations (Blackstone and Hausel, 1992; Hausel, 1994). The extension of the iron formation at depth beneath the Bradley Peak Thrust is controlled by the attitude of the fault plane and is speculative at best. The entire area has been prospected extensively for both iron and gold (Blackstone, 1965; Harrer, 1966; Wilson, 1976; Hausel, 1994). However, no significant production has ever been reported.

The most common iron deposits are Archean magnetite-taconite BIF and siliceous hematite. The BIF comprises folded and banded layers of magnetite, amphibole, and quartz with black, yellow, and rusty coloration. Partial oxidation is common in most areas. This is most prevalent in the Bradley peak area. The siliceous hematite ore is common in the Pattison Basin. Bluish-black specularite-hematite is the result of magnetite oxidation and is accompanied by goethite and jasper (Blackstone, 1965; Harrer, 1966; Wilson, 1976). The locations of the deposits discussed further include the Bradley Peak area, the Junk Hill-Chimney Rock area, east of Deweese Creek, and the Pattison Basin area (fig. 10).

Taconite crops out in the Bradley Peak area, east of Deweese Creek, in the Junk Hill-Chimney Rock area, and numerous small outcrops in the gravity slide areas south and west of Pattison Basin (fig. 10). The iron-bearing unit here is estimated to be up to 300 ft thick. However, numerous faults, abundant tight folds, and cross cutting metagabbro bodies make the outcrops highly variable (Wilson, 1976). The basal Cambrian sandstones in this area of the Seminoe Mountains are also highly ferruginous (Harrer, 1966; Wilson, 1976).

Harrer (1966) estimated a potential iron ore tonnage of 1 million tons, averaging 30 percent

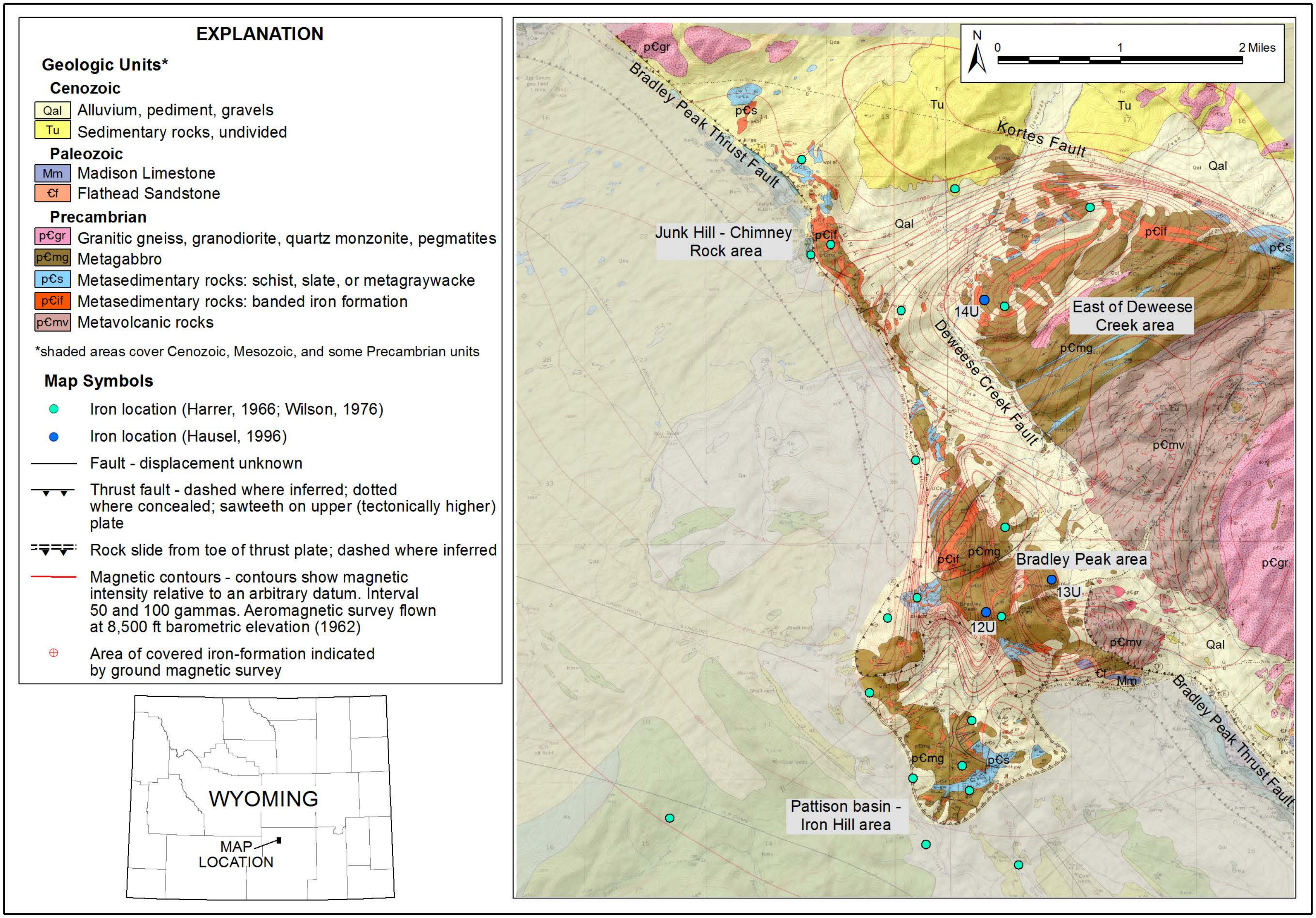

Figure 10. Iron-related geology of the Bradley Peak quadrangle in the Seminoe Mountains. Locations shown are approximate areas of deposits and include iron both in place and in landslide deposits. The map also displays magnetic contours from an aerial survey flown in 1962. Map modified from Bayley (1968).

iron, in the Bradley Peak area and the area east of Deweese Creek. Wilson (1976) estimated about 42 million tons in the largest outcrop based on dimensions and assuming 30 percent iron. Wilson also estimated 104,317,000 tons in the Junk Hill-Chimney Rock area based on outcrop dimensions and the assumption of 30 percent iron.

Harrer's (1966) estimate for the Pattison Basin area was about 200,000 tons of hematite varying from 31.4 to 68.72 percent iron. A *guess* of less than 1 million tons with 60 percent iron was made by Hendricks (1902) for the same area. Harrer (1966) also noted an *optimistic* estimate by the Wilson Exploration Co. in 1951 for the Pattison Basin-Iron hill area of "several million tons of ore grade material."

Wilson (1976) believed that the estimated iron resources (reserves) for the overall Seminoe Mountains area were 206,317,200 tons averaging 30 percent iron (Wilson, 1976).

Samples of BIF from the Seminoe Mountains and their analyses are shown in table 5. These were reported by Hausel (1994), and were secondary to his study emphasis on precious metals.

Bradley Peak area, sec. 6, T. 25 N., R. 85 W.; NE¼SE¼, SE¼NE¼, and NE¼NE¼ sec. 1, T. 25 N., R. 86 W.; SW¼ sec. 31, T. 26 N., R. 85 W.; E½E½ sec. 36, T. 26 N., R. 86 W., Carbon County

The largest taconite body, on the north side of Bradley Peak, can be seen at the head of Twin Creek as two bodies in the hanging wall of the Bradley Peak Thrust. These are separated by the Twin Creek Fault. The larger body, northwest of the fault, strikes northeast and is exposed along a steep, northeast-facing slope. The 60° SE. dipping iron formation is approximately 150 ft thick and is exposed for 3,500 ft along strike, with a maximum width of 1,056 ft (Wilson, 1976). The adjacent body can be traced for about 3,000 ft and has an exposed width of about 200 ft.

East of Deweese Creek, NE¼ and S½ sec. 19, N½, NE¼SE¼, and NW¼SW¼ sec. 20, and N½N½ sec. 30, T. 26 N., R. 85 W., Carbon County

Exposures of BIF that are close to 1 mi long and up to 400 ft wide form an arc across the northwestern part of the Seminoe Mountains between the Deweese Creek Fault to the south and the Kortes Fault to the north. One BIF analysis from near the Junk Creek prospect in the center of SW¼ section 20, Sample 14A (table 5), collected by Hausel (1994) showed 16.2 percent Fe.

Junk Hill-Chimney Rock area, SE¼, SE¼NW¼, and NE¼SW¼ sec. 14, E½E½ sec. 23, W½W½, and SE¼SW¼ sec. 24, and N½N½, SW¼NE¼, and SE¼ sec. 25, T. 26 N., R. 86 W., Carbon County

BIF outcrops in this area are scattered linearly along a northwest trend, parallel to and northeast of the Bradley Peak Thrust Fault. These outcrops have lengths of up to 2,300 ft and widths as much as 1,000 ft. The extreme width of some outcrops is due to both faulting and folding, which are extensive across the area.

Pattison (Patterson) Basin area, SW¼ and SW¼NW¼ sec. 7, NW¼ sec. 18, T. 25 N., R. 85 W.; SW¼SE¼ sec. 1, NE¼NW¼, S½NE¼,

Table 5. Analyses of iron formation in the Bradley Peak area by Hausel (1994).

	Bradley Peak Area					
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
12U	20.4	47.8	1.36	0.07	<0.02	0.29
13U	39	53.2	0.98	0.08	0.02	0.59
14U	40.1	54.9	0.36	0.03	0.07	0.44

Hausel (1994)

and E½SE¼ sec. 12, and E½NE¼ sec. 13, T. 25 N., R. 86 W., Carbon County

Many of the high-grade hematite occurrences in the vicinity of Pattison Basin are shallow, irregular, and comparatively small. One, or several, landslides from detachment along the Bradley Peak Thrust Fault have jumbled the area, but some outcrops have a large amount of bluish-black, specular hematite. These iron bodies occur in 75–100 ft wide, 800 ft long and 50 ft thick bands and contain 31.4–68.72 percent iron (Harrer, 1966).

Granite Mountains Area

The Granite Mountains are an east-trending complex assemblage of Archean granites, gneisses, and supracrustal rocks that were accreted onto the Wyoming Craton at approximately 2.6 Ga. The major Precambrian shear and continental accretion zone referred to as the Oregon Trail structural belt (Chamberlain and others, 2003; Grace and others, 2006) trends eastward across the Granite Mountains accompanied by multiple shear zones and igneous intrusions. Laramide deformation and uplift resulted in the east-trending Sweetwater arch and the northwest-trending Rattlesnake Hills anticline. This was followed by extensive late Tertiary basin fill, extension, and down-drop along the North and South Granite Mountains Faults (Love, 1970). The fault crosses the northern part of the Granite Mountains and affects emplacements of Tertiary alkaline volcanic and subvolcanic rocks, common in the Rattlesnake Hills area. Geologic units within the Granite Mountains (fig. 11) are dominated by those of Tertiary and Archean ages, with some Paleozoic sediments cropping out along the edges of the Rattlesnake Hills (Sutherland and Hausel, 2003). Tertiary rock unit exposures are dominated by the Miocene Split Rock Formation, the Eocene Wagon Bed Formation, and Tertiary alkalic igneous rocks. Archean rocks are represented by gneisses, schists, pegmatites, granites, and supracrustal rocks, which include BIF. The BIF is part of the Archean Barlow Springs Formation that also includes pelitic schist, quartzite, tremolite-chlorite schist, and metabasalt (Hausel, 1996).

Hausel (1996) described BIF from the Granite Mountains as poorly mineralized except where the iron formation has been modified by later deformation. The iron formation may be epigenetically mineralized, similar to modified BIFs in the South Pass and Seminoe Mountains.

Rattlesnake Hills, SE¼ sec. 23, SW¼ sec. 24, and NW¼ sec. 25, T. 32 N., R. 88 W., Natrona County

The northwestward trending Rattlesnake Hills are the eroded remnants of the northwest-plunging anticline on the north flank of the Sweetwater Arch. The area was initially prospected for copper in the 1890s-1900s. Rocks exposed include Precambrian igneous and metamorphic units, Paleozoic, Mesozoic, and Cenozoic sediments and Tertiary igneous rocks. Foliations trend northwest, with dips up to 80° NE. The iron formation crops out in a wedge shaped block approximately 10,800 ft long with a maximum width of 3,000 ft and contained a maximum of 49 percent Fe_2O_3 (Pekarek, 1974). The iron formation is overlain by pelitic schist and quartzite of the Barlow Springs Formation on the east-northeast, overlies metabasalt and quartzite to the south, is cut off by the Cottonwood Creek Fault to the southeast, and is buried beneath the Eocene Wagon Bed Formation to the northwest (Hausel, 1996). The BIF in the Barlow Springs Formation crops out on the up-thrown, north-side of the North Granite Mountains Fault and consists of oxide facies and magnetite alternating with layers of green silicate and iron-stained hornblende schist and grades from magnetite-rich schists to grunerite-rich schist. Samples by Hausel (1996) contained as much as 64.74 percent Fe_2O_3 and 23.13 percent SiO_2 but also showed as little as 15.62 percent Fe_2O_3 with 79.12 percent SiO_2 (table 6). A speculative resource based on geologic inference is 1,149,027 tons averaging 25.2 percent iron (Wilson, 1976). The conclusion reached by both Wilson (1976) and Hausel (1996) was that the known iron outcrops were too small for economic consideration at the time. However, Wilson (1976) suggested that exploration might be directed toward possible iron resources in the area concealed beneath Tertiary cover.

Barlow Gap area, SW¼NE¼ and NE¼SE¼ sec. 10; SE¼ sec. 16, and sec. 23, T. 31 N., R. 88 W., Natrona County

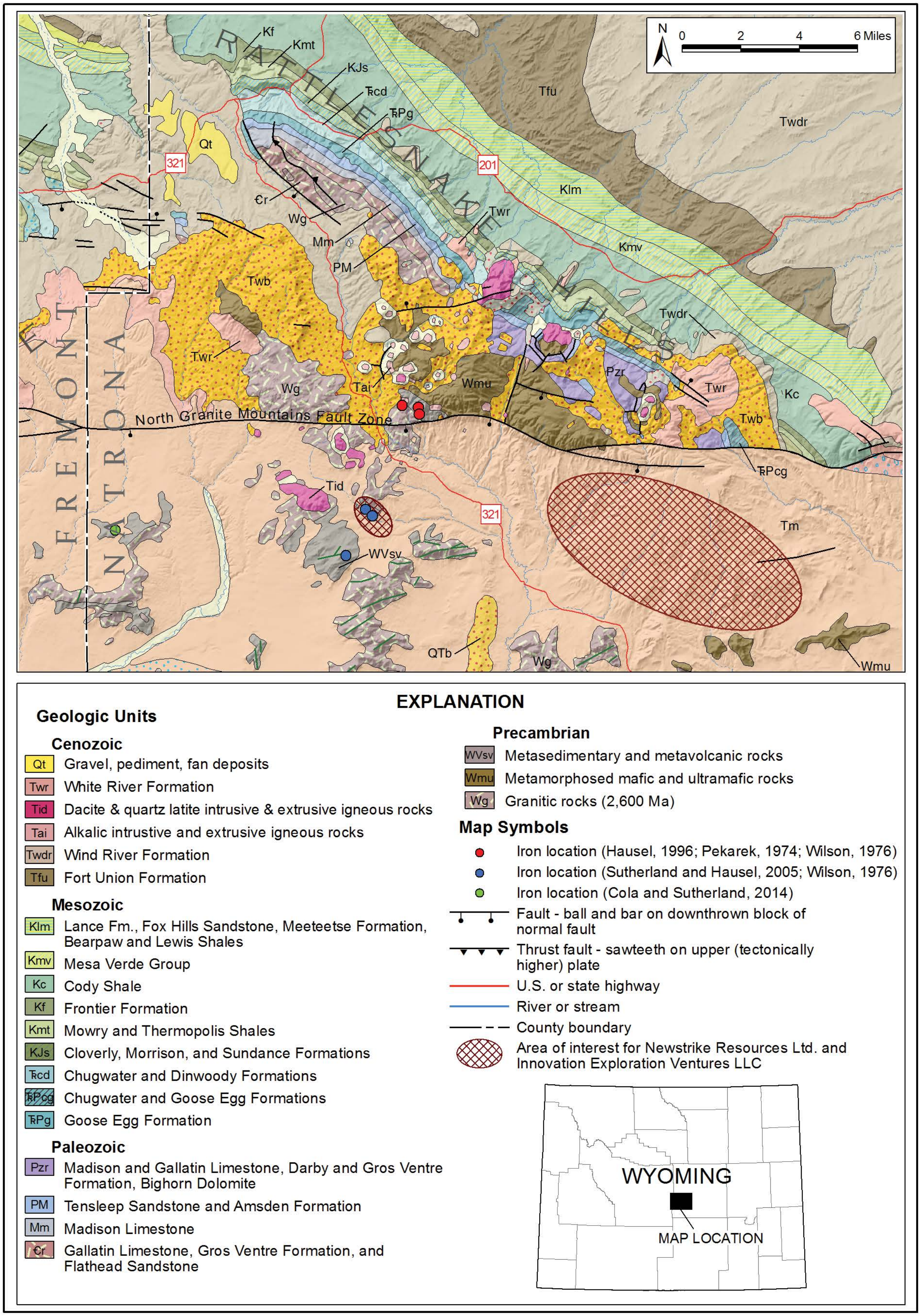

Figure 11. Geology of the Rattlesnake Hills-Granite Mountains area. BIF is found in metamorphosed Precambrian units. The area of iron resources being investigated by Newstrike Resources Ltd. and Innovation Exploration Ventures, LLC is emphasized. Map modified from Love and Christiansen (1985, 2014).

Iron formation crops out in section 10 in a narrow zone trending northwest for 2,650 ft at the contact between hornblende schist and granite gneiss. Iron formation layers are about 30–50 ft thick mixed with hornblende schist layers. Grab samples generally contained 21.0–29.5 percent iron; however, the largest deposit showed a maximum of 40.0 percent Fe_2O_3 (Wilson, 1976). Low grade BIF, 7.83–25.87 percent Fe_2O_3, sometimes brecciated and associated with gold, silver, and high silica, is located in the Barlow Gap area (Sutherland and Hausel, 2005). Similar BIF crops out within the Blackjack Ranch quadrangle (Sutherland and Worman, 2013) and within the McIntosh Meadows quadrangle, sample 20140507WS-B (Cola and Sutherland, 2014).

Innovation Exploration Ventures, LLC and Newstrike Resources, Ltd. conducted an airborne magnetic survey of part of the Granite Mountains and subsequently drilled an area they called Iron Valley in section 23, east of Barlow Gap. Their drill hole #SHW 5 intersected BIF at a depth of about 88 m (290 ft), and with the exception of one zone of about 1.5 m (5 ft), remained in BIF that showed more than 30 percent Fe_2O_3 to a depth of 172 m (565 ft). The exploration hole bottomed in ore when drilling was stopped due to equipment problems. The average grade from 94–172 m (310–565 ft) was 54.3 percent FeO_x (Innovation Exploration Ventures, 2014; Newstrike Resources, 2012; J. Davis, personal communication, 2015). A low-intensity magnetic separation of the composite drill sample yielded 70.7 percent Fe, free of impurities, with an 88 percent iron recovery. Further drilling is needed before the potential for this 2011-2012 iron discovery can be better defined.

Black Rock Mountain-Eastern Granite Mountains Iron Exploration, T. 31 N., R. 86 and 87 W., Natrona County

Recent exploration in the Black Rock Mountain-Eastern Granite Mountains area by Innovation Exploration Ventures LLC and Newstrike Resources Ltd. included aeromagnetic surveying followed up by limited drilling. Their drill hole BIF-3, in sec. 24, T. 31 N., R. 86 W., centered on a large magnetic anomaly with a length of 9.7–14.5 km (6–9 mi) and a width of 305–914 m (1,000–3,000 ft). Drill hole BIF-3 intersected greater than 30 percent Fe_2O_3, with 52.9 percent SiO_2, at a depth of 224 m (735 ft) and averaged 38.9 percent FeO_x, from various iron oxides, to a depth of 253 m (830 ft). The hole stopped in ore at 253 m (830 ft) due to technical problems (Innovation Exploration Ventures, 2014; Newstrike Resources, 2012; J. Davis, personal communication, 2015). Newstrike projects a very large iron resource for their 2011-2012 discovery, which needs confirmation through additional drilling.

Copper Mountain (Owl Creek Mountains)

Copper Mountain is an area of exposed Archean supracrustal and granitic rocks in the southeastern part of the Owl Creek Mountains, east of Wind River Canyon. The Owl Creeks are an east-trending, Laramide uplift that has been thrust southward over Phanerozoic sediments of the Wind River Basin. The Precambrian rocks underwent brittle

Table 6. Analyses of iron formation in the Granite Mountains area by Cola and Sutherland (2014) and Hausel (1996).

Granite Mountain-Rattlesnake Hills Area						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20140507WS-B[1]	22.8	72.9	0.3	0.01	<0.01	0.08
BG1-93[2]	25.87	69.03	0.18	<0.01	<0.02	<0.03
BG4-93[2]	17.72	74.8	0.19	<0.01	<0.02	<0.03
RH12-93[2]	17.38	47.92	13.84	2.04	0.02	0.15
RH14-92[2]	25.77	65.83	0.29	0.31	0.04	<0.03
RH25-92[2]	64.74	23.13	0.58	0.02	<0.02	<0.03

[1]*Cola and Sutherland (2014)*

[2]*Hausel (1996)*

deformation during thrusting, which resulted in intense fracturing and faulting of the thrust plate (Hausel and others, 1985). On the north flank of the Owl Creeks, Paleozoic and Mesozoic sediments dip steeply to the north and are unconformably overlain by Tertiary sediments that lap onto the Precambrian rocks.

Copper Mountain itself is made up of east-northeast-trending, steeply south-dipping supracrustal rocks, which were folded, intruded by granite, and metamorphosed about 2.7 Ga (Hausel and others, 1985). Near the western end of the mountain the rock units trend west-northwest. The up direction in the supracrustal sequence is speculated to be to the south by Millgate and Gliozzi (1966) and to the north by Hausel and others (1985); although both agree that insufficient evidence exists to determine a stratigraphic top. The supracrustal rocks are dominated by quartzofeldspathic gneisses and amphibolite schists, which are accompanied by metapelites, quartzites, BIF, and minor local pods of marble. These were intruded by Archean granitic rocks, including pegmatites, and later by Archean (and possibly Proterozoic) mafic dikes (Hausel and others, 1985).

Iron formation exposures extend discontinuously across Copper Mountain for more than 10 mi east-west (fig. 12, 13). Exposed magnetite iron formation is interlayered with other rock types in a zone that is locally as much as 2,500 ft wide. Iron formation outcrops are rusty brown to light yellowish brown, massive to slabby or slaty, and very fissile in part. Mineralogical and color banding are well developed throughout the iron formation and fairly intense minor folding is present (Millgate and Gliozzi, 1966).

BIF crops out in Wind River Canyon, about 3.5 mi west of the westernmost exposures on Copper Mountain in the Birdseye Pass area (Millgate and Gliozzi, 1966; Hausel and others, 1985). Details are lacking on this outcrop, which is probably a thin extension of the Copper Mountain iron formations.

Millgate and Gliozzi (1966) separated the iron formation into a lower and an upper series that assumes that the units are not overturned and stratigraphic bottom is to the north. The lower magnetic series varies from about 150–200 ft thick and is composed of black-gray, poorly banded, platy, very fine grained magnetite quartzite interlayered with dark gray to black amphibolite. Most iron-bearing quartzites within this unit are less than 30 ft thick. In the upper series, 125 ft of magnetite bearing quartzite and greenschist is distributed through a stratigraphic interval of 375 ft. In most places, the upper series hosts four distinct iron formation layers, within which the top two are generally separated by less than 20 ft of amphibolite and greenschist. The basal unit of the upper series is the thickest, with an aggregate iron formation thickness of 68 ft distributed over an interval of 91 ft. Iron formation in the central and eastern parts of Copper Mountain appears to have greater iron content than the upper magnetic series near the west end (Birdseye area).

Eight grab samples of iron formation from the Hoodoo Creek-West Fork Dry Creek area averaged 24.8 percent Fe and ranged from 20.1 to 30.4 percent (Millgate and Gliozzi, 1966). In the Birdseye Creek area in the western part of Copper Mountain, Millgate and Gliozzi (1966) assayed a series of 14 grab, composite, and chip samples from BIF. These varied from 6.6 to 19.1 percent iron oxide, with an average grade of the magnetic units, excluding intervening layers, of 9.5 percent Fe (13.1 percent Fe_3O_4 equivalent). In this current study, samples of varying grade were collected near the HooDoo-West Fork Dry Creek area and the East of Birdseye Ranch area. Additional details are below (fig. 12; table 7).

Millgate and Gliozzi (1966) concluded that the iron formation in the Copper Mountain area was too low in grade for direct shipment of iron ore but left open the question of its amenability to mining and concentration into a shippable product. Duhling (1971) made a rough tonnage calculation for the iron formation at Copper Mountain using assumed average values for cumulative length and width, and mining zone width, along with a factor for weight of ore vs waste, a stripping ratio of 5.33:1 (waste:ore), 80 percent recovery for a mining depth of 200 ft and a concentrating ratio of 3 to 1 (crude ore to concentrate). Duhling's (1971) calculations totaled 13,686,000 tons of iron concentrate at 54.7 to 58.7 percent Fe. Wilson (1976) was far more optimistic in his ore estimates of 753,667,200 tons grading 32.0 percent iron for the entire Copper Mountain area.

Wilson (1976) concluded that, although his estimated tonnage was large, the substantial amount of waste rock would prohibit economic mining at the time. This conforms to earlier investigations by Bolmer and Biggs (1965) and Gersic and Nonini (1995), who suggested that mining would only be viable in the large, exposed, iron lenses but would

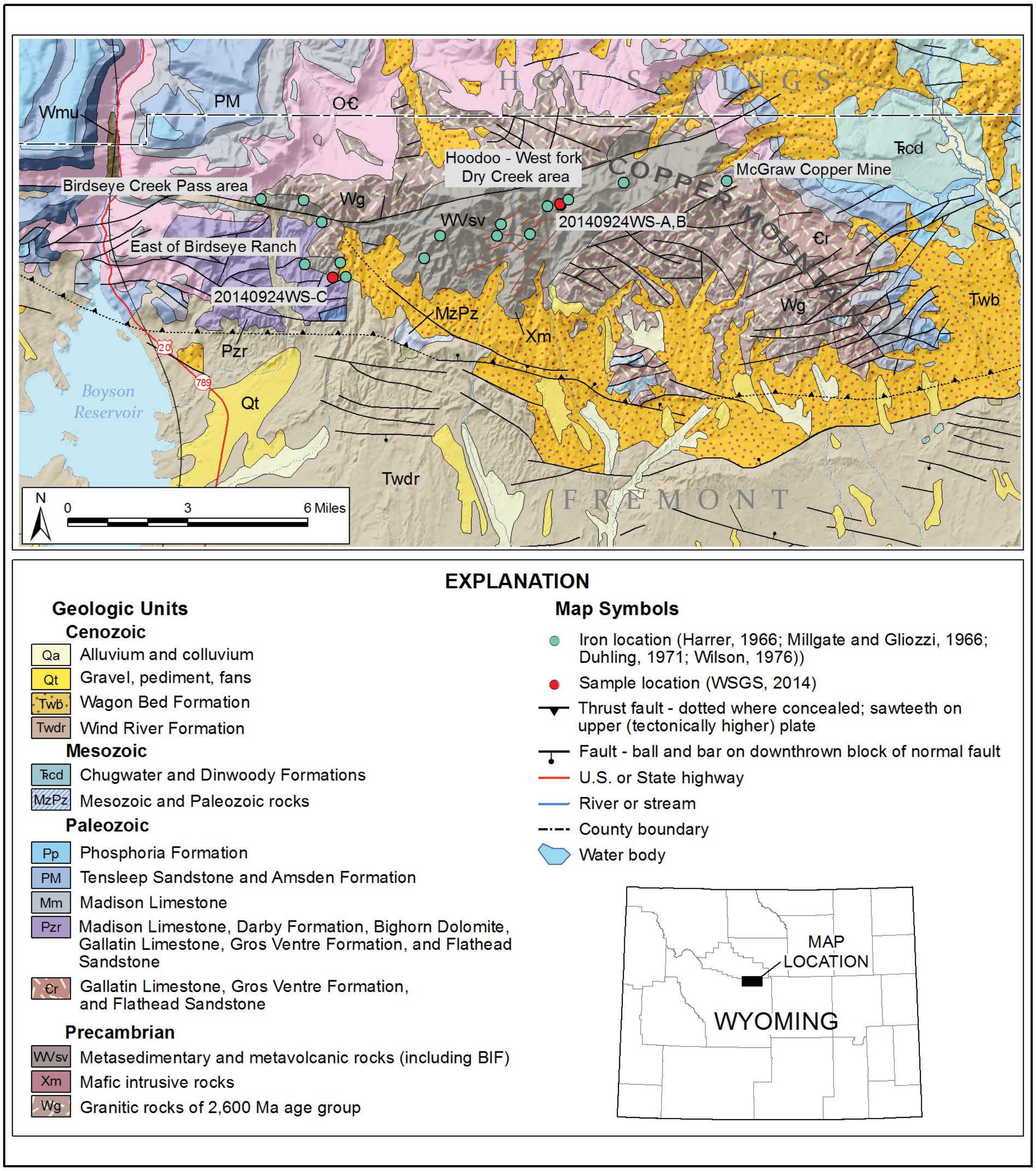

Figure 12. Geology of the Copper Mountain area. BIF occurs near the McGraw copper mine, the Hoodoo-West Fork Cry Creek area, east of Birdseye Ranch, and in the Birdseye Creek Pass area. Map modified from Love and Christiansen (1985, 2014).

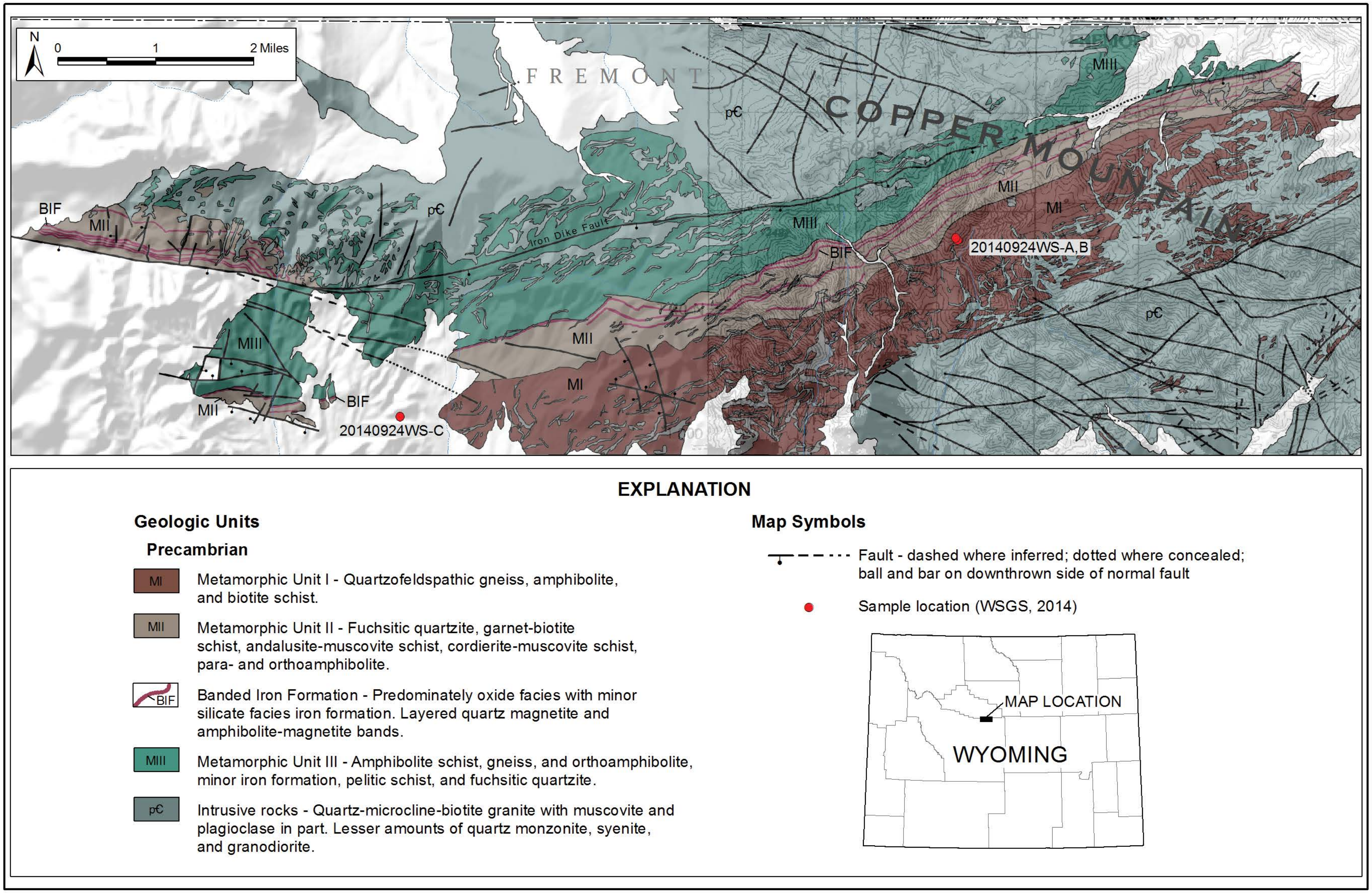

Figure 13. Geologic map of Copper Mountain in the Owl Creek Range with emphasis on iron formation. This area was subdivided into metamorphic units including iron formation surrounded by Archean granitic rocks. Map modified from plate 1 of Hausel and others (1985).

still not be economical. Hausel and others (1985) also reached the conclusion that the iron formations at Copper Mountain were too thin and too low grade for economic recovery at the time of their report.

Birdseye Creek area, S½NW¼, N½SW¼, and SE¼ sec. 13, S½N½ and N½S½ sec. 14, NE¼ and S½NW¼ sec. 15, T. 40 N., R. 94 W., Fremont County

Harrer (1966) and Wilson (1976) give similar descriptions of the Birdseye Creek area (Wilson's Area 3, and Duhling's (1971) Millgate Area). Wilson (1976) notes that the iron formation here, composed of magnetite-quartz-amphibole-pyroxene and oxidation, appears similar to the area East of Birdseye Ranch. However, he also states that these BIF units are wider and the area is more suitable for open pit mining operations. The four iron-bearing units crop out along a west-northwest strike for 2 mi and appear to bifurcate into seven thinner units at the east end of the mineralized zone. The iron formation appears to extend under Cambrian formations to the west as interpreted from similar

Table 7. Analyses of samples from the Owl Creek Mountains (Copper Mountain area). Other elements present at >5x crustal concentrations are W, Te, Bi, and Li. For full details see, appendix.

	Owl Creek Mountains						
Element	Fe	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20140924WS-A	-	41.6	55.3	0.24	0.02	<0.01	0.06
20140924WS-B	-	45.9	50.9	0.15	0.01	<0.01	0.06
20140924WS-C1	-	45.8	49.4	1.53	0.07	<0.01	0.18
20140924WS-C2	-	23.4	73.4	0.89	0.02	<0.01	0.16
Birdseye Pass[1]	36.8	-	48.9	-	0.16	0.03	-
Birdseye Pass[1]	23.1	-	52.2	-	0.25	0.04	-
Hoodoo Creek[1]	33.4	-	48.8	-	0.11	0.03	-
Hoodoo Creek[1]	31.0	-	46.3	-	0.29	0.03	-
Dry Creek[1]	32.3	-	49.5	-	0.19	0.03	-
Dry Creek[1]	31.1	-	50.4	-	0.19	0.03	-
McGraw Mine[1]	33.7	-	45.6	-	0.20	0.03	
Composit metallurgical sample, Owl Creek taconite[1]	32.4	-	50.1	-	0.19	0.03	-
IF-100-32[1]	28.17	-	-	-	-	-	-
IF-100-33[1]	25.86	-	-	-	-	-	-
IF-100-34[1]	30.40	-	-	-	-	-	-
IF-100-51[1]	20.06	-	-	-	-	-	-
IF-100-7[1]	22.09	-	-	-	-	-	-
IF-100-8[1]	24.94	-	-	-	-	-	-
IF-100-13[1]	25.23	-	-	-	-	-	-
IF-100-52[1]	21.62	-	-	-	-	-	-
CUMTN-2-83[1]	36.90	-	-	-	-	-	-
A1630[1]	33.90	-	-	-	-	-	-

[1]*Table 3 Hausel and others (1985)*

units that crop out along US Hwy 20. The entire zone of iron formation has a thickness of 2,000 ft, although only 35 percent of this is mineralized with the remainder being amphibolite, schist, and quartzite (Wilson, 1976).

In the same area, Harrer (1966) notes that iron formation, with magnetite, hematite, and limonite, trends east and dips 30–60° S. It can be traced for more than a mile east of the Birdseye Pass road, and he considered it to be continuous with outcrops further east. Surface exposures varied from 100–500 ft wide and the samples contained 36.8 and 23.1 percent Fe. These same samples also respectively showed 0.16 and 0.25% TiO_2, 0.07 and 0.075% P, 0.03 and 0.04% S, and 48.9 and 52.2% SiO_2. A sample from this area by Duhling (1971) showed 25.2 percent Fe and 56.0 percent SiO_2.

Both Wilson's (1976) and Harrer's (1966) descriptions interpret the Birdseye Creek taconite deposit to be continuous with localities to the east. However, mapping by Duhling (1971) and by Hausel and others (1985) shows these outcrops to be cut off on their southeastern end by an east-trending fault. About 1 mi east of the end of the Birdseye Creek area BIF outcrops, the fault, referred to by Hausel and others (1985) as the Iron Dike fault, extends northeastward for another 7 mi to the end of Precambrian outcrops in that direction. Wilson (1976) estimated 345,945,600 tons of iron ore present in the Birdseye Creek area at an estimated average grade of 32.0 percent iron. However, the high amount of waste rock would inhibit economic viability of iron mining (Wilson, 1976).

East of Birdseye Ranch, SE¼SE¼ sec. 23, S½S½ sec. 24, N½NE¼ and NE¼NW¼ sec. 25, T. 40 N., R. 94 W., Fremont County

Iron formation composed of magnetite, quartz, amphibole, pyroxene, and oxidation and can be projected southwestward on strike from the Hoodoo-West Fork Dry Creek area into the area east of Birdseye Ranch (fig. 12, 13). However, 1.2 mi between these areas is covered with Tertiary sediments. Wilson (1976) referred to this as Area 2, in which the iron formation is composed of two layers striking west-southwest for 1.2 mi that have been offset by southwest-trending, normal faults. These layers dip 75–80° S. and are exposed for a maximum width of 60 ft. Wilson (1976) estimated that 18,533,000 tons of iron ore at 32.0 percent Fe are present in this area. However, the large amount of waste rock would inhibit economic viability of iron mining (Wilson, 1976). A sample from this area by Duhling (1971) showed 31.9 percent Fe and 54.4 percent SiO_2. Iron formation crops out along Copper Mountain Road and was sampled (20140924WS-C) for this investigation. The rock is maroon to black to brown with some limonitic stain, noticeably magnetic, and is very sheared and folded (fig. 14). The large outcrop itself was primarily BIF with the exception of some small quartz veins cross-cutting the bedding plane (table 7).

Hoodoo Creek-West Fork Dry Creek area, SE¼ sec. 12., N½, N½SW¼, and SW¼SW¼ sec. 13, S½ and S½NE¼ sec. 14, S½SE¼ sec. 15., S½SE¼ sec. 16, SE½NE¼ and SE¼NW¼ sec. 20, N½N½ sec. 21, N½N½ sec. 22, N½NW¼ and NW¼NE¼ sec. 23, T. 40 N., R. 93 W., Fremont County

Harrer (1966) described magnetite iron formation that crops out at the head of Hoodoo Creek and is exposed for several miles toward Tough Creek and Dry Creek (fig. 12). Iron formation trends 74° and dips 65° S. It is made up of at least two bands of magnetite 50 ft and 100 ft thick that are separated by 50 ft of hard quartzite. The iron formation is platey and is dominated by magnetite and quartz with some amphibole, garnet, pyroxene, and chrysocolla. Samples contained 33.4 and 31.0 percent iron (Harrer, 1966). Two samples from this area by Duhling (1971) showed 30.7 and 32.1 percent Fe, and 52.0 and 54.4 percent SiO_2 respectively.

The eastern part of this area, west of the McGraw Copper Mine and near the head of Dry Creek, hosts at least 6 bands of 10–40 ft thick layers of iron formation separated by diorite and schist. Harrer (1966) described this as the Dry Creek area iron formation. He noted that the principle iron mineral is magnetite accompanied by quartz, amphibole, and pyroxene. He reported analyses here of 32.3 and 31.1 percent iron.

Hoodoo Creek-West Fork Dry Creek area is the same as Wilson's (1976) Area 1. He reports up to five iron-bearing units that dip from vertical to 50° S. The zone strikes northeast on the eastern end and curves to a east-northeast strike on the western end. The lowest of the five units is the widest and most persistent along strike extending about 5 mi. Overall, the outcrop width of the iron-bearing units is about 3,000 ft, but most of this is amphibolite, schist, and quartzite. Only 10.5 percent, or 315 ft is iron formation. Wilson (1976) estimates 389,189,000 tons of iron ore at 32.0 percent Fe in the Hoodoo Creek-West Fork Dry Creek area.

Current samples collected in the vicinity included two low grade BIFs. Sample 20140924WS-A is a schistose, quartzitic BIF located lower in section than sample 20140924WS-B. The latter contained less quartz layers, thin iron oxide layers, and exhibited heavier rusty weathering (table 7).

McGraw Copper Mine area, S½ and S½NE¼ sec. 7, W½NW¼ sec. 8, T. 40 N., R. 92 W., Fremont County

Three bands of fissile, folded, magnetite schist associated with white-gray quartzite, near the McGraw Copper Mine, have an overall width of 750 ft and are exposed for more than 1 mi (fig. 12, 13). The iron-bearing rock is mainly magnetite with limonite alteration cut by quartz veins and pegmatite. Bands of iron formation strike 100° to 120°, dip from 80° S. to vertical, and vary in thickness from 100–120 ft. A 10 ft width of distinctly banded magnetite is exposed in the McGraw Mine shaft. The same unit, 120 ft thick, crops out about 0.2 mi east of the shaft and continues eastward across section 7 (Harrer, 1966). Mapping by Hausel and others (1985) depicts the BIF continuing northeastward for more than 2 mi. The BIF contained 33.7 percent Fe which is comparable to a composite metallurgical sample of Owl Creek taconite at 32.4 percent Fe, table 7 (Bolmer and Biggs, 1965; Harrer, 1966).

West Bridger area, W½SW¼ Sec. 3, S½S½ and NE¼SE¼ sec. 4, S½SE¼ sec. 5, N½NE¼ and NE¼NW¼ sec. 8, T. 40 N., R. 92 W., Fremont County

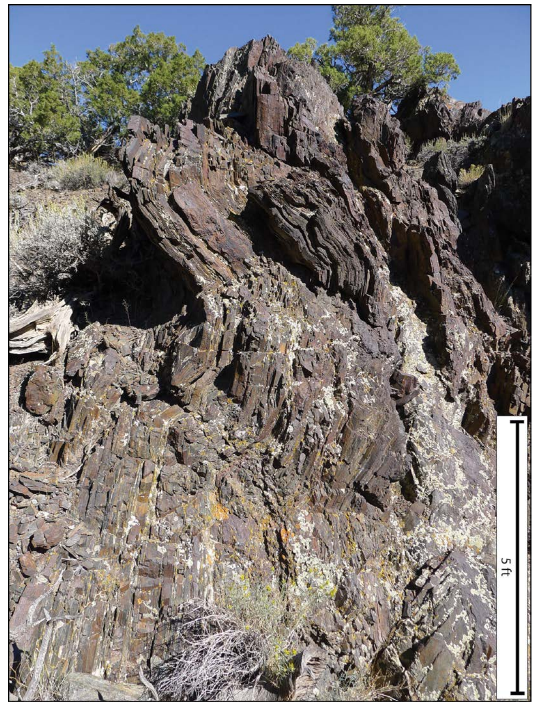

Figure 14. Intensely folded BIF at sample site 20140924WS-C near the East of Birdseye Ranch locality.

Mapping by Hausel and others (1985) (fig. 13) shows at least three bands of exposed BIF in this area that trend northeastward for about 1.8 mi. The iron formations extend to the northeastern end of Copper Mountain where they become buried beneath Phanerozoic sediments.

Buffalo Fork area, T. 45 and 46 N., R. 110 and 111 W., Fremont and Teton Counties

The exact location of this deposit is unknown but is reported to be toward the northwest end of the mountains in these townships on Buffalo Fork Creek and North Buffalo Fork Creek near the divide between Fremont and Teton Counties. Metasediments are reported in this area as well as samples of disseminated iron (Harrer, 1966). This may or may not correspond to an analysis in the WSGS files dated 1955 of "Teton County Titaniferous Ores." The undated analysis by Salem Engineering, Ltd. shows 51.2 percent total Fe and 10.53 percent TiO_2 but provides no location or name of the geologist responsible.

Magmatic Segregation Deposits

Magmatic segregations occur due to the crystallization of an immiscible fluid that evolved from a magmatic parent. In the case of titaniferous-magnetite deposits, the chemistry of the parent magma was rich in iron and titanium. Magmatic segregation iron ore deposits in Wyoming are dominated by massive and disseminated dike-like or irregular masses of titaniferous magnetite that cut or intrude anorthosite in the Iron Mountain area of the Laramie Mountains in southeastern Wyoming. Other iron segregations include layered mafic complexes in the Medicine Bow Mountains, and pegmatitic dikes with hematite that account for small occurrences in many areas of Precambrian igneous activity across the state. A few other iron occurrences are related to metamorphic events rather than to igneous segregation.

Iron Mountain Area

Titaniferous magnetite deposits occur within the Precambrian, 1.4 Ga Mesoproterozoic, crystalline core of the eroded, asymmetrical, anticlinal arch of the north-trending Laramie Mountains (Frost and others, 1993). The Precambrian is flanked by Paleozoic and Mesozoic sedimentary rocks and has been intruded by both anorthosite and granite bodies. Titaniferous magnetite deposits occur as massive and disseminated dike-like or irregular masses that cut or intrude the anorthosite in the Iron Mountain area (fig. 15). The ore grade bodies are believed to have been formed by differentiation and segregation in the parent anorthositic magma at depth and emplaced as magmatic, dike-like injections (Wilson, 1976). Locally, the magnetite-ilmenite is concentrated in patches and layers where it makes up a large percent of the rock. Most of the magnetite-ilmenite ore bodies occur near a major north-trending anticlinal axis within the anorthosite and are generally, but not exclusively, found near where the anticlinal axis changes direction (Newhouse and Hagner, 1957). Other local structures, including faults, may influence magnetite-ilmenite concentrations away from the anticlinal axis.

Titaniferous magnetite deposits in the Laramie Mountains have been known since the main deposit at Iron Mountain was first described in 1851 by Howard Stansbury, a U.S. Army officer (Pinnell and Marsh, 1954; Dow, 1961). Title was granted to the UPRR to a large part of the deposits in 1862 as part of the land grant that was given by the U.S. government as incentive to build the first transcontinental railroad (Dow, 1961).

Very little production came from the Iron Mountain deposits prior to 1961. In 1897 and in 1898, a few tons of massive magnetite-ilmenite were shipped by the Colorado Fuel and Iron, Corp. to their Pueblo, Colorado plant for testing. Increased demand for titanium and iron during WWII in the 1940s brought renewed interest and investigations to the Iron Mountain deposits (Pinnell and Marsh, 1954). The UPRR, in conjunction with the USGS, conducted geological mapping and geophysical investigations of the Iron Mountain titaniferous magnetite deposits between 1943 and 1945 and again between 1951 and 1953. The UPRR also conducted drilling programs in conjunction with the USBM during the same periods while the USBM and the Battelle Institute tested beneficiation and smelting. In 1956, the UPRR mined 50 tons of ore and shipped it to the Krupp Co. in Germany for testing by a process of direct iron reduction, but the results of the testing were not made public (Dow, 1961). Several attempts were made to smelt the titaniferous magnetite ore from the Iron Mountain area prior to 1957. These attempts failed due to difficulty in separating the intermixed magnetite and ilmenite, the lack of amenability of the ore to conventional ore-dressing methods and smelting practices, and the availability of larger and more suitable ore deposits for the eastern U.S. smelters (Pinnell and March, 1954).

Based on their studies, Pinnell and Marsh (1954) identified three types of ore: 1) massive magnetite-ilmenite averaging 45 percent iron and 20 percent titanium dioxide; 2) dense silicate ore averaging 34 percent iron and 16 percent titanium dioxide that contained olivine and occasionally plagioclase; and 3) a light to medium silicate ore with abundant ferromagnesian silicates, plagioclase, and disseminated magnetite-ilmenite that had an iron content of 17 percent and a titanium dioxide content of 7 percent. They estimated the presence of 120 million tons of the low-grade (light to medium silicate) ore, 28 million tons of the medium-grade (dense silicate) ore, and 30 million tons of the high-grade (massive magnetite-ilmenite) ore.

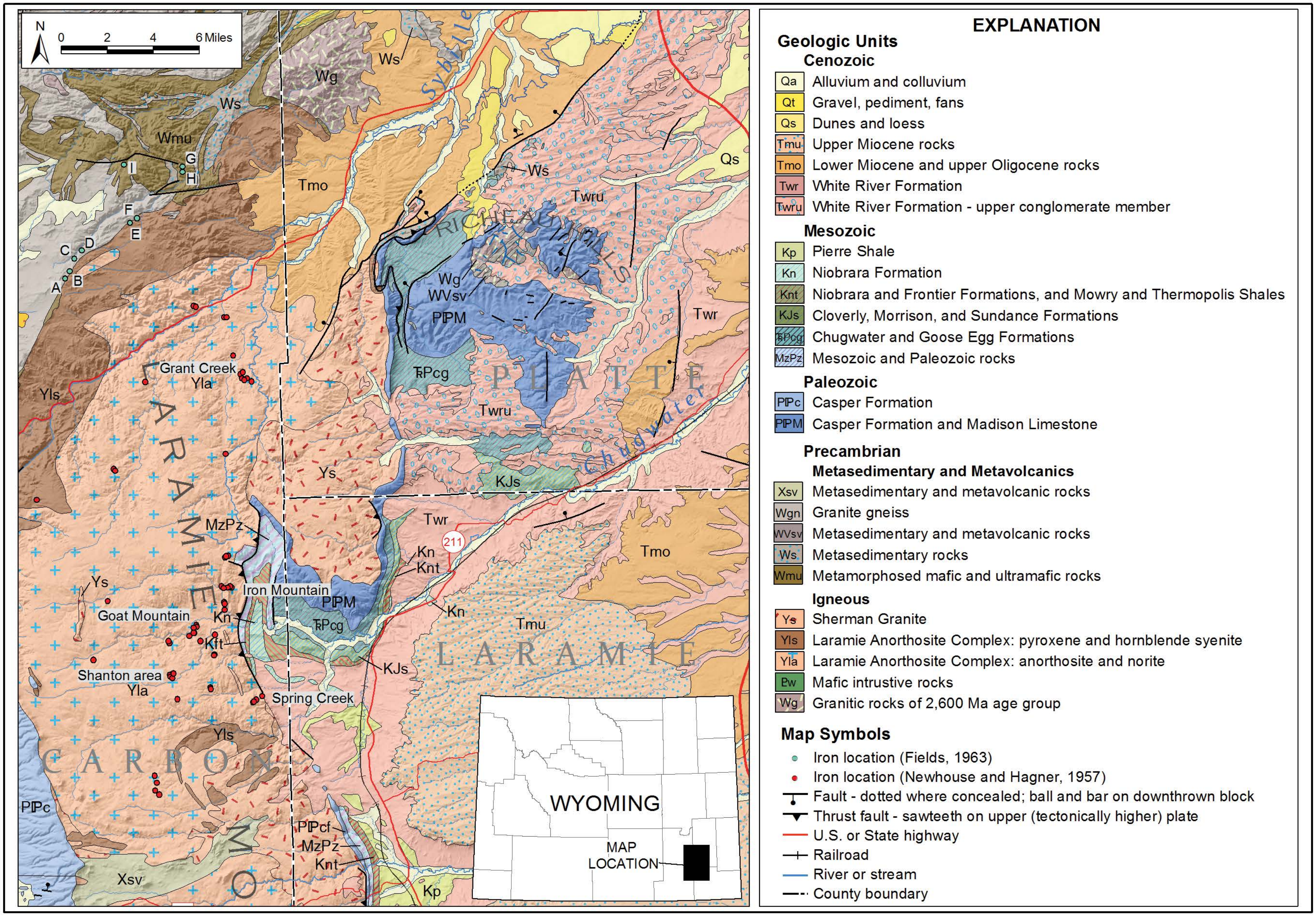

Figure 15. Geology of the Iron Mountain area in the northern Laramie Mountains. Many pods and lenses of magnetite-ilmenite rich rock have been recorded in the area. Some mining has occurred in the past, but no mines are known to be currently active. Map modified from Love and Christiansen (1985, 2014).

Dow (1961) combined Pinnell and Marsh's (1954) three types of ore into two general types: massive magnetite-ilmenite and disseminated magnetite-ilmenite with iron-bearing olivine and other silicates. He also noted that Pinnell and Marsh's (1954) resource estimates included the assumption that most of the ore could be mined by open-pit methods. Dow's (1961) report included detailed maps and interpretations for nine areas of magnetite-ilmenite concentrations, along with drill-hole data. His estimated resource figures for the Iron Mountain Area are the same as those used by Pinnell and Marsh's (1954), but he classifies them as massive magnetite-ilmenite [30 million tons averaging 45.0% Fe, 20.0% TiO_2, 0.64% V_2O_5, 10.0% SiO_2, and little or no phosphorous or sulphur], and disseminated magnetite-ilmenite [148 million tons averaging 20.2% Fe, 9.7% TiO_2, 0.17% V_2O_5, 35.6% SiO_2, 0.05% P, and 0.17% S].

Due to the complexities of the iron and titanium ore, accompanied by high silica in the low grades and an average of more than one percent V_2O_5 in the high-grade, Pinnell and Marsh (1954) concluded that more testing was needed to determine the most economical method of iron and titanium extraction to compete with higher-grade iron and titanium deposits elsewhere. Dow (1961) reiterated that the complexities of the magnetite-ilmenite ore had limited the development of these deposits. Although both iron and titanium have economic potential in the Iron Mountain area, neither have been commercially extracted for metallurgical use.

Plicoflex, Inc. (previously known as Magnetite Products, Corp.) was operating an open pit magnetite mine on the northwestern part of Iron Mountain, Albany County, until 1966. The magnetite was being shipped out of state for use as heavy aggregate in concrete specifically for coating underwater pipes and shielding fissionable materials. The amount of production between 1966 and 2015 is unclear, although some titaniferous magnetite was purchased by Mountain Cement Co. as a cement additive. Pinnell and Marsh (1954) estimated that total resources (reserves) were 178,000,000 tons. Wilson (1976) estimated speculative resources (reserves) with geologic projection and the inclusion of smaller deposits to total 267,000,000 tons. This included 29,994,000 tons of massive magnetite-ilmenite averaging 45.0 percent iron and 11.4 percent TiO_2 and 147,970,000 tons of disseminated magnetite-ilmenite averaging 20.2 percent iron and 9.7 percent TiO_2.

At the time of Wilson's (1977) report, much of the land was owned by the UPRR and by the Anaconda Company. Later, Wyomex, LLC owned property in the Iron Mountain area and in 2011 Titan Iron, Corp. acquired those claims covering 276.4 hectares (683 acres) (Business Wire, 2011). However, no current development is known. Mountain

Table 8. Chemical analyses of Iron Mountain samples from various sources.

	Iron Mountain Area						
Element	FeO (%)	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
sm[1*]	-	56.63	12.25	4.87	18.62	0.03	-
np1[1*]	-	53.24	15.18	4.64	16.43	0.03	-
sp1[1*]	-	52.66	16.73	4.79	14.55	0.04	-
sp2[1*]	-	48.26	19.27	7.11	13.88	0.03	-
sp3[1*]	-	49.99	18.58	5.44	13.75	0.04	-
Shanton Deposit[2]	32.66	38.34	0.26	5.13	19.56	0.03	0.01
Taylor Deposit[2]	36.31	26.15	0.36	3.1	30.84	0.01	<0.01

[1]*Mountain Cement Co.*

[2]*Osterwald and others (1966) from Newhouse and Hagner (1957)*

**reported as Fe (%), Si (%), Al (%), Ti (%), S(%)*

Cement Co. recently investigated the Iron Mountain titaniferous magnetite for use as a weighting factor in heavy cement mixtures. The average iron content of five of Mountain Cement's samples was 52.16 percent (A. McClugage, personal communication, 2009). The Iron Mountain area could not be sampled during this WSGS study due to lack of access at the time. However, other sources of chemical analyses are listed in table 8.

Newhouse and Hagner (1957) mapped 61 concentrations of titaniferous iron within the Laramie Anorthosite, of which 46 are found in the above described anorthosite (fig. 15). Twelve occurrences are found in noritic anorthosite, two in granulated anorthosite, one in olivine anorthosite, and one in fractured and altered anorthosite. Several other small concentrations were not mapped by Newhouse and Hagner (1957), but were mapped by Fields (1963) (fig. 15). The noritic anorthosite is massive to foliated and layered, coarse-grained gray plagioclase with magnetite-ilmenite and 10–50 percent orthopyroxene. The granulated anorthosite is made up of granulated, massive to poorly foliated, relatively fine-grained, light-gray plagioclase with generally less than five percent orthopyroxene and magnetite-ilmenite. The olivine anorthosite is massive to foliated and layered, medium- to coarse-grained, gray plagioclase, with or without orthopyroxene, but containing up to 50 percent olivine. The fractured and altered anorthosite is massive to foliated and layered, medium-grained, gray plagioclase with disseminated olivine and local magnetite-ilmenite.

The titaniferous iron occurrences mapped by Newhouse and Hagner (1957) are combined with those described by Osterwald and others (1966) in the descriptions that follow. Dow (1961) divided the area of titaniferous magnetite occurrences in the Laramie Mountains into a grid for his studies and referred to many occurrences by his grid area designations. Dow's grid area designations are included in area descriptions where they are known.

Iron Mountain Deposit, SE¼SE¼ and SW¼SE¼ sec. 22; SW¼SW¼ sec. 23; SE¼NE¼, SE¼SE¼, and NE¼SE¼ sec. 27, T. 19 N., R. 71 W., Albany County

The Iron Mountain deposit, referred to as Grid Areas 12S and 12W by Dow (1961), contains the largest known bodies of magnetite-ilmenite in the Laramie Mountains. The Iron Mountain deposit is described by Newhouse and Hagner (1957) as eight individual occurrences within anorthosite. Overlapping, lenticular, and discontinuous zones of massive and disseminated magnetite-ilmenite dip 40 to 60° SE and extend northward along the crest of Iron Mountain for more than 7,000 ft. The largest body, outcropping at the north end of Iron Mountain is 1,700 ft long, 250 ft wide, and extends down dip for over 800 ft. The second largest body, outcropping near the south end of Iron Mountain is 1,200 ft long, 200 ft wide, and extends down dip for about 700 ft (Dow, 1961). Osterwald and others (1966) relate ore estimates for three categories of ore as defined by Pinell and Marsh (1957):

- Grade 1: 3,000,000 tons indicated and 600,000 tons inferred of massive magnetite-ilmenite that consists of massive magnetite-ilmenite with 0 to 35 percent silicates (olivine and minor spinel) by volume and TiO_2 varying from 16 to 23 percent.

- Grade 2: 1,600,000 tons indicated and 1,310,000 tons inferred of dense silicate that consists of magnetite-ilmenite with 35 to 65 percent silicates (olivine, minor spinel, plagioclase, and hypersthene) by volume and TiO_2 varying from 10 to 16 percent.

- Grade 3: 900,000 tons indicated and 1,740,000 tons inferred of light to medium silicate that consists of magnetite-ilmenite with 65 to 85 percent silicates (largely plagioclase with minor olivine and hypersthene) by volume and TiO_2 varying from 5 to 10 percent.

Table 9 shows Osterwald and others' (1966) ore estimates for the Iron Mountain Ti-magnetite deposit.

Halleck Canyon area, T. 21 N., R. 72 W. and T. 22 N., R. 71 W., Albany County

The Halleck Canyon area was mapped by Fields (1963). He found numerous small pits dug into veins of massive magnetite that vary from 2 in–2 ft wide. Newhouse and Hagner (1957) did not depict any magnetite deposits or prospects in this area. Four of Fields' pits, prospects A, B, C, and D occur along a 10 ft wide shear zone that trends 40° and dips 70 to 80° SE. The shear separates quartz monzonite gneiss to the northwest from massive hornblende-andesine gneiss to the southeast. The magnetite veins, accompanied by minor copper staining, were generally continuous along the strike of the shear zone for almost 1 mi, suggesting to Fields that the shear zone controlled the location of the magnetite and that the veins may extend to depth. Magnetite within the veins, which range from 0.16 to 2 ft thick, is vuggy and often altered to dark brown limonite. Inter-grown with the magnetite are large euhedral feldspar grains that make up less than ten percent of the veins. X-ray fluorescence analyses of two samples from the larger veins showed 26 and 36 percent elemental iron, along with 0.02 percent nickel, accompanied by only trace amounts of copper and molybdenum (Fields, 1963).

Fields' pit A is approximately located in the NE¼NE¼ of section 15, T. 21 N., R. 72 W. and is roughly 4 ft square by 5 ft feet deep. Pit B is located in the SW¼SE¼ of section 10 in the same township and is caved in. Pit B is 15–20 ft wide and 10 ft deep and showed some small flakes of graphite on the dump, but none was noted in the outcrop (Fields, 1963). Fields also observed numerous small quartz veinlets intruding the thickest part of the iron-rich zone. Pit C is similar in size to pit A and is located in the NE¼ of section 10 in the same township. Pit D, similar to A and C, is 4 ft square by 5 ft deep and is located in the SW¼SW¼ of section 2 in the same township. Osterwald and others (1966) erroneously describe the pit D location as the Cobar No. 1 magnetite-ilmenite deposit, possibly due to a typographical error.

Specific locations and dimensions for Fields' pit designations are as follows:

- Pit A, NE¼SE¼ sec. 10, T. 21 N., R. 72 W., 4 ft^2 and 5 ft deep
- Pit B, SE¼NE¼ sec. 10, T. 21 N., R. 72 W., collapsed pit 20 ft wide and 10 ft deep
- Pit C, NE¼NE¼ sec. 10, T. 21 N., R. 72 W., similar to pit A
- Pit D, SW¼SW¼ sec. 2, T. 21 N., R. 72 W., similar to pit A
- Pit E, NW¼SW¼ sec. 31, T. 22 N., R. 71 W.
- Pit F, SE¼NW¼ sec. 31, T. 22 N., R. 71 W.
- Pit G, SW¼NE¼ sec. 21, T. 22 N., R. 71 W., 7 ft wide and 3 ft deep
- Pit H, SW¼NE¼ sec. 21, T. 22 N., R. 71 W., 20 ft long, 6 ft wide, and 3 ft deep

Fields' (1963) pits E and F are located in the central part of section 31, T. 22 N., R. 71 W., and occur within well-foliated quartz monzonite gneiss in the absence of any apparent shear zone. Pit E hosts a 1 ft thick zone of closely spaced and inter-layered magnetite and phlogopite veinlets that are about 0.1 in thick. This zone strikes 30°, dips 70 to 80° SE, appears conformable with, and grades into the surrounding gneiss. The magnetite zone appears to partially engulf an older quartz monzonite dike along the southeast side of the zone, where large potassium feldspar crystals are surrounded by massive magnetite. Grab samples of the veinlets by Fields (1963) showed 26 and 36 percent elemental iron, accompanied by minor amounts of copper and molybdenum. Similar veinlets were found in pit F, but these did not appear to extend along strike beyond the pits (Fields, 1963). Located in the east-central part of section 21, T. 22 N., R.

Table 9. Iron Mountain Deposit Estimates (short tons).

Ore Grade	Indicated	Inferred	Total
1	3,000,000	600,000	3,600,000
2	1,600,000	1,310,000	2,910,000
3	900,000	1,740,000	2,640,000
Totals	5,500,000	3,650,000	9,150,000

Osterwald and others (1966)

71 W., northeast of the McGill ranch, are Fields' (1963) prospect pits G and H. Pit G is 7 ft across by 3 ft deep, and H is 20 ft long by 6 ft wide by 3 ft deep. These pits expose small magnetite pods varying from 1–6 inches in diameter that discordantly cut across the foliation of highly altered hornblende-andesine gneiss. Both the magnetite and the gneiss are intruded by numerous small quartz veinlets. Fine-grained biotite is particularly abundant in the general area.

Cobar No. 1, SE¼NE¼ and NE¼SE¼ sec. 21, SW¼NW¼ and NW¼SW¼ sec. 22, T. 21 N., R. 71 W., Albany County

Osterwald and others (1966) refer to this as Deposit No. 1, and Wilson (1976) calls this Cobar No. 1. Wilson (1976) describes this as an irregular dike-like body of magnetite-ilmenite, which intrudes Precambrian gabbro and anorthosite, and strikes north for 400 ft with widths up to 100 ft. However, Osterwald and others (1966) describe the width as only 5–10 ft, which conflicts with aerial imagery of the site. Newhouse and Hagner (1957) noted two separate magnetite-ilmenite occurrences in the anorthosite, which conforms to the aerial imagery. This outcrop was also mapped by Snyder (1984).

Plicoflex, Inc. operated an open pit here from 1956–1960 for high density aggregate. Wilson (1976) estimated the total production from Cobar No. 1 at 106,900 tons. Osterwald and others (1966) reported a partial analysis of ilmenite-magnetite, which shows 0.34% V_2O_5, 19.0% TiO_2, 47.0% Fe, and 2.12% P_2O_5.

Shanton area, NE¼SW¼ and NW¼SE¼ sec. 8, T. 18 N., R. 71 W., Albany County

At this location are five known separate deposits of massive, granular-aggregate, magnetite-ilmenite striking north-northwest with near vertical dip. The two largest deposits are about 400 ft long and 60 ft wide, while the others are much smaller. These deposits cross-cut the anorthosite, suggesting that they are dike- or plug-like intrusions (Wilson, 1976).

Investigation of the deposit in 1946 by the USBM showed the character of the ore within the various bodies to be uniform. Seventy-one samples from jack-hammer holes assayed within the ranges of: 49.3 to 53.0% iron, 15.6 to 24.2% TiO_2, 0.66 to 0.86% V_2O_5, and 0.01 to 0.08% P_2O_5 (Osterwald and others, 1966). A later analysis (table 8) cited by Osterwald and others (1966) from Newhouse and Hagner (1957) showed 38.34% Fe_2O_3, 32.66% FeO, and 19.56% TiO_2.

Intermittent open pit mining was conducted in the Shanton area between 1958 and 1974. During this period, an estimated 29,990 tons of magnetite-ilmenite ore were produced primarily for shipment to the Gulf Coast for use as high density aggregate. None of this production was used for steel, titanium alloy, or titanium-based paint (Wilson, 1976). The amount of production from the Shanton area after 1974 is unknown.

Resource (reserve) estimates were compiled by Wilson (1976) based on Diemer's (1941) calculation of 11,890 tons of ore per 1 ft of depth for all the Shanton area deposits with an average grade of 51 percent Fe and 20 percent TiO_2. This grade corresponds with USBM drill holes (Dow, 1961). Wilson's tonnage estimates were 2,378,000 tons for a mining depth of 200 ft and 3,566,000 tons for a mining depth of 300 ft.

Taylor Deposit, SE¼ sec. 35, T. 21 N., R. 71 W., Albany County

The Taylor deposit is reported by Osterwald and others (1966) to include eight separate lenses of ilmenite-magnetite, three of which are 100–150 ft long and 50–75 ft wide; the other five lenses are smaller. The lenses contain up to 60 percent apatite and are relatively high in ilmenite. The Taylor deposit is noted by Newhouse and Hagner (1957) as only one occurrence within their granulated anorthosite. A sample analyzed by Wilson (1976) showed 47 percent Fe and 19 percent TiO_2, while an analysis by Newhouse and Hagner (1957) showed 26 percent Fe_2O_3, 36 percent FeO, and 31 percent TiO_2. The complete analysis is shown in table 8. The entire deposit is believed to contain approximately 2160 tons of ore per 1 ft of depth (Diemer, 1941).

Spring Creek (#14), SW¼ sec. 13 and SE¼ sec. 14, T. 18 N., R. 71 W., Albany County
This area includes 10 lenses of magnetite-ilmenite that crop out along northeast-trending ridges. One is a flat, low grade, dissemination deposit 900 ft long, 700 ft wide, and 250 ft thick. The other lenses of massive magnetite-ilmenite vary in length up to 400 ft with thicknesses of 10–60 ft, some of which are surrounded by rings of disseminated magnetite-ilmenite that grade into the surrounding anorthosite (Dow, 1961). Many of these contacts are covered. Newhouse and Hagner (1957) mapped only four outcrops in the NE¼SW¼ of section 13, three in anorthosite and one in fractured and altered anorthosite. This area is referred to by Osterwald and others (1966) as Deposit No. 14 and as Spring Creek (#14) by Wilson (1976). The 1961 USBM report by Dow refers to this deposit as Grid Area 1.

Goat Mountain area, SW¼, SE¼, and NE¼ sec. 33, T. 19 N., R. 71 W., and NW¼ sec. 4, T. 18 N., R. 71 W., Albany County
The Goat Mountain area includes Wilson's (1976) Near Iron Mountain (#10), Osterwald and others (1966) Deposit No. 10, and Dow's (1961) Grid Areas 7, 7S, 8, and 14.

Dow (1961) describes two north-northwest striking lenses of massive magnetite-ilmenite in section 4 that dip steeply southwest. The largest is 500 ft long and 100 ft wide. However, Newhouse and Hagner (1957) mapped only one magnetite-ilmenite deposit surrounded by anorthosite in section 4.

In section 33, Newhouse and Hagner (1957) separated the deposit into six lenses surrounded by anorthosite. However, Dow (1961) mapped in detail multiple irregular lenses of both massive and disseminated ilmenite-magnetite in section 33. Although both types are present, the disseminated magnetite-ilmenite dominates the outcrops and form lenses near the crest of an anorthosite knob. Dimensions are highly variable, but Wilson (1976) describes one as 110–150 ft wide, which strikes eastward for 330 ft then northward for another 350 ft. Part of the eastern most exposure is a lens of massive magnetite-ilmenite that forms the crest of Goat Mountain.

Section 3 Deposits, NW¼ and SW¼ sec. 3, T. 18 N., R. 71 W., Albany County
This area encompasses Deposit No. 11 of Osterwald and others (1966), Wilson's (1976) North Iron Mountain (#8), and Dow's Grid Area 3 and 4. It includes two north-striking, steeply east-dipping, lenses of massive magnetite-ilmenite within anorthosite along the crest of a high ridge. The largest of these is 150 ft long by 8 ft wide, while the smallest is only 15 ft long by 1 ft wide. Three unconnected, steeply dipping, narrow lenses of disseminated magnetite-ilmentite trend northeast. The largest is 500 ft long and 35 ft wide. Three other unconnected, steeply dipping, narrow lenses of disseminated magnetite-ilmentite trend northeast. The largest of these is 500 ft long by 35 ft wide. The USBM report by Dow (1961) refers to the area of these lenses as Grid Areas 3 and 4. Newhouse and Hagner (1957) mapped the area surrounding these lenses as anorthosite.

Middle Sybille Creek (#2), NE¼NW¼ sec. 26, T. 21 N., R. 71 W., Albany County
Newhouse and Hagner (1957) mapped two magnetite-ilmenite lenses in anorthosite in this area. Wilson (1976) and Osterwald and others (1966) both describe this as one lens that strikes east for about 600 ft and is 5–20 ft wide. Contacts with the surrounding anorthosite are covered, and the ore is similar to that at Iron Mountain. This outcrop is not shown in mapping conducted by Snyder (1984).

Grant Creek area, SW¼ sec. 1, and SE¼, SE¼NE¼ sec. 2, T. 20 N., R. 71 W., Albany County
Newhouse and Hagner (1957) mapped seven magnetite-ilmenite occurrences in anorthosite in this area. This includes Deposits No. 3 and 4 by Osterwald and others (1966), which are the same as Wilson's Deposit No. 3 and Grant Creek (#4). These poorly defined magnetite-ilmenite lenses strike 70–80° and are surrounded by anorthosite. The largest lens is about 75 ft long by 10 ft wide, while the smaller lenses are generally less than is 8 ft long by 5 ft wide (Osterwald and others, 1966; Wilson, 1976).

Deposit No. 5, SE¼ sec. 32, T. 20 N., R. 72 W., Albany County

This deposit, similar to Deposit No. 3, is another lens of magnetite-ilmenite striking east within Precambrian anorthosite along an east-trending ridge. It is 30 ft long by less than 3 ft wide (Osterwald and others, 1966; Wilson, 1976). Mapping by Newhouse and Hagner (1957) identifies the area as a hypersthene-rich syenite and did not include the magnetite-ilmenite lens.

Plumbago Canyon (#6), NW¼ and NE¼ sec. 4, T. 19 N., R. 72 W., Albany County

Wilson (1976) and Osterwald and others (1966) describe five separate magnetite-ilmenite lenses surrounded by anorthosite that are cut by quartz-syenite. Layering among the lenses contains variable amounts of labradorite, pyroxene, and apatite. The largest lens, 300 ft long by 100 ft wide, is located in the northeast quarter of the section. No magnetite-ilmenite occurrences are mapped in this area by Newhouse and Hagner (1957), because they mapped it as hypersthene syenite with very little anorthosite.

Plumbago Canyon (#7), NE¼ sec. 7, T. 19 N., R. 72 W., Albany County

Wilson (1976) and Osterwald and others (1966) describe the occurrence here as four discontinuous lenses up to 10 ft wide that extend 1,500 ft along strike on the southeast side of a northeast-trending ridge. Contact between the magnetite-ilmenite and the anorthosite is sharp and parallels schistosity in the anorthosite. Newhouse and Hagner (1957) did not map any occurrences in this area within the noritic anorthosite.

North Iron Mountain, SW¼NW¼ sec. 14, and NE¼SE¼ and SE¼NE¼ sec. 15, T. 19 N., R. 71 W., Albany County

Six lenticular to dike-like bodies of magnetite-ilmenite occur within massive Precambrian anorthosite near the border of section 14 and 15. Only three of these lenses were mapped by Newhouse and Hagner (1957). The longest dike extends eastward for about 250 ft, is cut by granite dikes, and generally has poorly exposed contacts with the surrounding anorthosite (Osterwald and others, 1966; Wilson, 1976). This is the same occurrence as Osterwald and others' (1966) Deposit No. 8, and Wilson's (1976) North Iron Mountain (#8).

Deposit No. 9, S½NE¼ sec. 26, T. 19 N., R. 72 W., Albany County

Patches of magnetite-ilmenite rock extend 400 ft along the west flank of a northward trending ridge with small stringers extending into anorthosite. Maximum width of the magnetite-ilmenite patches is 3 ft (Osterwald and others, 1966; Wilson, 1976). Newhouse and Hagner (1957) mapped the area as noritic anorthosite with no indication of magnetite-ilmenite present.

Grid Area 5, NW¼ and SW¼ sec. 5, T. 18 N., R. 71 W., Albany County

This is Dow's (1961) Grid Area 5. Three bifurcating, subparallel lenses of disseminated magnetite-ilmenite in anorthosite (Newhouse and Hagner, 1957) strike south to southeast and dip from vertical to 30° SW. Several small lenses of massive magnetite-ilmenite are erratically intermixed with the disseminated deposits. The largest disseminated lens is approximately 2,500 ft long and 300 ft wide with one offshoot almost as long. The other disseminated deposits are much smaller (Dow, 1961; Wilson, 1976).

Deposit No. 12, NW¼NW¼ sec. 15, T. 18 N., R. 71 W., Albany County

A dike-like lens of magnetite-ilmenite strikes north for 30 ft with widths varying between 3–25 ft. Contacts between the magnetite and anorthosite are sharp and dip outward near the south end of the lens (Osterwald and others, 1966; Wilson, 1976). Two magnetite-ilmenite lenses, rather than one, were mapped in this area by Newhouse and Hagner (1957).

Deposit No.13, NW¼SE¼ sec. 17, T. 18 N., R. 71 W., Albany County

A lens of magnetite-ilmenite in anorthosite strikes 20° for 180 ft and is 40–80 ft wide (Osterwald and others, 1966; Wilson, 1976; Newhouse and Hagner, 1957).

Deposit No. 15, SW¼SE¼ sec. 31, T. 18 N., R. 71 W., Albany County
This occurrence is a 50 ft long by 3 ft wide lens of magnetite-ilmenite that resembles the ore at Iron Mountain (Osterwald and others, 1966; Wilson, 1976). Contacts are not exposed between the magnetite-ilmenite and the surrounding noritic anorthosite mapped by Newhouse and Hagner (1957).

Unnamed Deposits
E½, NW¼NE¼, NW¼SE¼, and SW¼NE¼ sec. 6, T. 17 N., R. 71 W., Albany County
Newhouse and Hagner (1957) mapped six magnetite-ilmenite deposits in this area surrounded by noritic anorthosite.

SE¼SE¼ sec. 36, T. 18 N., R. 72 W., Albany County
One magnetite-ilmenite deposit was mapped by Newhouse and Hagner (1957) in this area surrounded by noritic anorthosite.

SW¼SW¼ sec. 2, T. 18 N., R. 72 W., Albany County
One magnetite-ilmenite deposit was mapped by Newhouse and Hagner (1957) in this area surrounded by olivine anorthosite.

SE¼SW¼ sec. 34, T. 19 N., R. 71 W., Albany County
Newhouse and Hagner (1957) mapped one magnetite-ilmenite deposit in this area surrounded by anorthosite.

NE¼NE¼ sec. 27, T. 20 N., R. 71 W., Albany County
Newhouse and Hagner (1957) mapped one magnetite-ilmenite deposit in this area surrounded by granulated anorthosite.

NW¼SE¼ sec. 25, T. 20 N., R. 72 W., Albany County
Newhouse and Hagner (1957) mapped two magnetite-ilmenite deposits in this area surrounded by noritic anorthosite. Snyder (1984) mapped several occurrences of anorthosite with irregular vein-like segregations of nearly pure magnetite-ilmenite and metagabbro that have been locally prospected for iron. These contain 3 to 30 percent interstitial magnetite-ilmenite. Five of Snyder's locations are described as follows:

SW¼NE¼, NE¼SE¼, and SE¼NW¼ sec. 6, T. 21 N., R. 71 W., Albany County
This is a west-northwest trending outcrop that is more than 300 ft wide and extends for more than 1,500 ft.

SW¼SW¼ sec. 7, T. 21 N., R. 71 W., and SE¼SE¼ sec. 12, T. 21 N., R. 72 W., Albany County
This west-southwest trending occurrence is nearly 200 ft wide at its widest and is exposed for a length of about 1,800 ft.

SE¼SE¼ sec. 8, and NE¼NE¼, NW¼NE¼ sec. 17, T. 21 N., R. 71 W., Albany County
The outcrop hosting magnetite-ilmenite is 100 ft wide and extends for about 1,700 ft.

NW¼NW¼ sec. 19, T. 21 N., R. 71 W., Albany County
This northeast-trending magnetite-ilmenite outcrop is about 100 ft wide by 400 ft long.

NE¼NW¼ sec. 29, T. 21 N., R. 71 W., Albany County
This irregular-shaped, north-trending magnetite-ilmenite outcrop extends for about 400 ft.

Medicine Bow Mountains
The Medicine Bow Mountains are a north-trending, Precambrian-cored, anticlinal, Laramide uplift, which is cut by the Mullen Creek-Nash Fork shear zone (Sutherland and Hausel, 2004). This shear zone is part of the Cheyenne belt suture, which represents a continental-arc collision zone (Graff, 1978; Hills and Houston, 1979) separating the Archean Wyoming Province to the north from cratonized (1.7 Ga) Proterozoic basement of the Colorado Province to the south. The Colorado Province south of the suture consists of volcanogenic island-arc basement rocks and intrusive granites and gabbroic complexes (Sutherland and Hausel, 2004). These gabbroic complexes include two of the larger

layered mafic complexes in the western US, the Lake Owen and Mullen Creek complexes.

Lake Owen Layered Mafic Complex, secs. 1-5, T. 13 N., R. 78 W.; secs. 19, 30, and 31, T. 14 N., R. 77 W.; secs. 15-17 and 20-36, T. 14 N., R. 78 W., Albany County

The Lake Owen layered mafic complex (fig. 16), in the east-central part of the Medicine Bow Mountains, is a Proterozoic gabbroic intrusion which hosts anomalous platinum group and other metals. Stensrud (1963) reported that magnetite, averaging 10 percent in some areas, occurs universally as an accessory mineral and is disseminated within gabbroic rocks. Stringers and uncommon fist-sized pods within the complex average 80 percent magnetite. These contain 29 percent Fe and 4.98 percent TiO2 (Harrer, 1966). Loucks and Glascock (1989) examined the vanadiferous magnetite horizons within the complex and estimated 1.4 billion tons of surface mineable oxide cumulates, not including titanium, platinum group, or other metals. However, speculative resources based on geologic inferences by Wilson (1976) suggested 716,440,032 tons averaging 10 percent iron.

Houston and Orback (1976) mapped and described multiple layers of magnetite gabbro within the Lake Owen complex that were later subdivided by Houston and others (2003) (fig. 16). Six of these subdivided layers that host notable magnetite are:

Unit - Xmgn: magnetite-gabbro and magnetite-norite, which ranges from norite with no magnetite to magnetite- gabbro with 15% magnetite;

Unit - Xomgn: dark-gray magnetite gabbro-norite, which hosts 7 to 18 percent magnetite plus ilmenite;

Unit 4 - Xmg4: dark purplish-gray to purplish-black magnetite gabbro, which hosts 13 percent magnetite plus ilmenite near the base to more than 20 percent near the top of the unit;

Unit 3 - (Xmg3): magnetite gabbro-norite, which hosts 7 to 18 percent magnetite plus ilmenite;

Unit 2 - (Xmg2): gabbro-norite, which hosts layers of magnetite gabbro near the top of the unit;

Unit 1 - (Xgn1 and Xmgn1): dark-brown to purple magnetite gabbro-norite with layers of gabbro-norite, which hosts 7 to 20 percent magnetite and additional layers of massive magnetite up to several inches thick. Some magnetite is cumulate. However, where magnetite is greater than 15 percent, it is interstitial, in microveinlets, or replaces silicate minerals.

Although the magnetite-iron resources within the Lake Owen complex are estimated to be extremely large, the overall average low grade of the deposit is probably not conducive to extensive economic development of iron. However, summaries of the iron resources in the Lake Owen area by Harrer (1966) and Wilson (1976) treated the southwestern part of the layered complex separately as the Lake Creek area. They identified a 3 ft layer of titaniferous magnetite within a 6 mi^2 area of Precambrian anorthosite from which a sample showed 55.6 percent iron and 11.0 percent TiO_2. This emphasizes variations within the well-vegetated and difficult to map complex may yet host potentially economic resources.

Mullen Creek Layered Mafic Complex, centered on T. 14 N., R. 80 W., Carbon County

The Mullen Creek layered mafic complex, 6 mi to the west of Lake Owen, covers about 60 mi^2 (Sutherland and Hausel, 2004). It is described by Loucks and others (1988) as lower crustal mafic cumulates derived from tholeiite magma associated with a Proterozoic intra-oceanic arc complex accreted to the Archean Wyoming Craton along the Cheyenne belt. The 1778 ± 2 Ma Mullen Creek complex (Loucks and others, 1988) is tilted on edge and has more than 21 cyclic units based on petrographic analyses (Loucks and Glasscock, 1989). It is similar to Lake Owen complex and the deposits may be related. However, in contrast to Lake Owen, magnetite within the

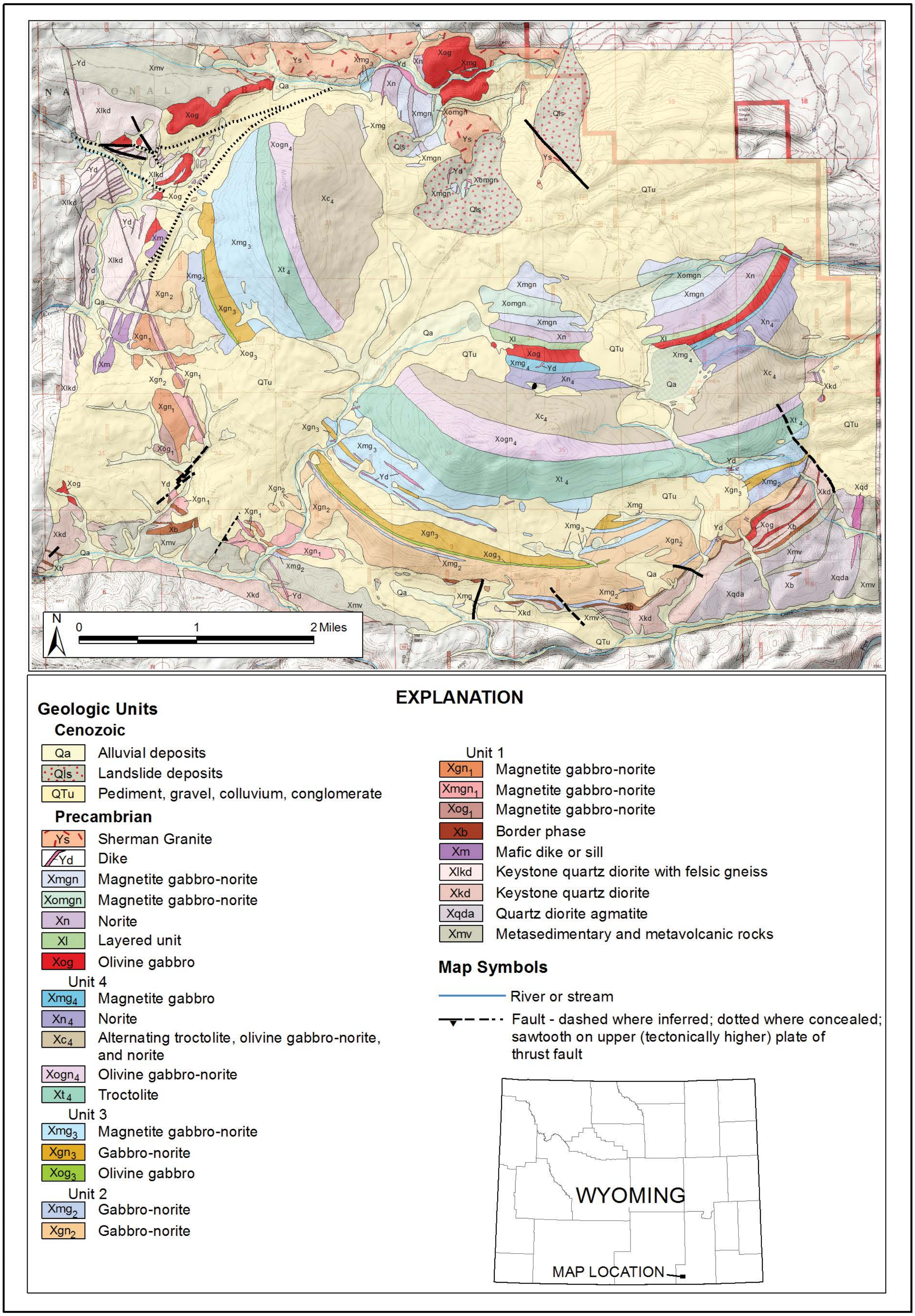

Figure 16. Geology of the Lake Owen complex in the Medicine Bow Mountains. The Lake Owen mafic complex consists of alternating layers of olivine and magnetite-rich gabbro and norite. Detailed unit descriptions can be found in text. Modified from an unpublished map by Houston and others.

Mullen Creek complex is reported only as an accessory mineral and not as a major component (Ruehr, 1961).

Pelton Creek, SW¼ sec. 33, T. 13 N., R. 79 W., Albany County
Magnetite and ilmenite occur here in a small, dark-colored peridotite. Analysis by X-ray fluorescence indicates 11 percent iron (Swetnam, 1961; Osterwald and others, 1966).

Quartz Veins and Specular Hematite

Shirley Hematite, E½ sec. 18, T. 26 N., R. 81 W., Carbon County
Hard, bluish-black, siliceous hematite occurs in pegmatite-like dikes associated with quartz and feldspar on the northern edge of the Shirley Mountains. The dikes vary in size from a few inches to 20 ft in width and from a few feet to 0.5 mi in length. Typically, the iron is best developed within pegmatitic quartz in the center of a dike and is locally disseminated within the adjacent syenite as specular hematite. One seam of massive, blue hematite varied from 1–2 ft wide, and some of the syenite adjacent to a dike contained 19.7 percent iron (Lovering, 1929).

The two largest hematite-quartz-feldspar dikes generally trend northward and are covered by three patented lode claims, the Bessemer 2, Bessemer 9, and Shirley Mountains 2 (Harrer, 1966). The eastern dike strikes 5 to 10° and can be traced for about 0.5 mi. It hosts a strong central seam of hematite-rich quartz that can be traced intermittently over this distance. A vertical dike to the west strikes 30° and is similar to the eastern dike. Hematite within the dikes occurs as small bodies of high-grade ore in veinlets, pockets, and as disseminations. The higher grade ore was found at a shaft near the south end of the Bessemer 2 claim, adjacent to a mass of syenite. At this location, the dike is 10–15 ft wide and consists of a central 1–2 ft thick lens of high-grade, bluish-black hematite, several 1–3 inches thick veinlets of hematite, and a leaner outer zone. The adjacent syenite contains abundant hematite, partly specularite, for more than 100 ft from the dike. A sample of the high grade hematite from the east dike contained 62.5 percent iron and 0.2 percent TiO_2 (Harrer, 1966). Locally, high-grade hematite appears to be associated with many pegmatites. However, the economic potential is reported to be low due to the spotty nature of the ore (Lovering, 1929) and the small resource of only a few thousand tons (Harrer, 1966).

Battle Hematite, sec. 28 and 29, T. 14 N., R. 85 W., Carbon County
Hard specularite, with metallic luster, and massive red hematite occur in small deposits in the Sierra Madre near the old town site of Battle, Wyoming. The hematite occurs in reddish Precambrian quartzites and greenstone schists that strike east to northeast and dip 40 to 45° S. The specularite occupies fractures in the hard quartzite while red hematite occurs in large masses. The massive, red hematite is 2–4 ft thick at the surface at the old Gertrude Mine in the E½ section 28, and is 9 ft thick at a depth of 80 ft. The hematite was reported to assay the equivalent of 0.37 ounce per ton (opt) gold (Spencer, 1904; Harrer, 1966; Hausel, 1997). These hematite deposits are small and there is no known production from them (Harrer, 1966).

Snowy Range area, T. 15 and 16 N., R. 80 W., Carbon County
Fractures within the Medicine Bow Peak and Sugarloaf metaquartzites are locally coated with specular hematite. The Precambrian Lookout Schist is reported to include some gray magnetite schist. Graphitic slate in the region is iron-rich in some areas, and other metasedimentary units in the central Medicine Bow Mountains host thin magnetite-rich beds (Houston and others, 1968; Harrer, 1966). These small occurrences are interesting but have no economic potential.

South French Creek area, sec. 21 and 22, T. 15 N., R. 80 W., Carbon County
Mineralization in the French Creek district is dominated by iron sulfides and iron oxides within siliceous and graphitic schist from the French Slate of the Early Proterozoic Libby Creek Group. Gold occurrences have also been reported, but these claims have turned out to be fraudulent (Hausel, 1989). A sample of black to gray, graphitic schist with disseminated pyrite, chalcocite, and minor chalcopyrite from this area was analyzed during

investigations of REE in Wyoming (Sutherland and others, 2013) and showed 34.7 percent Fe_2O_3.

Cooper Hill area, sec. 22, 26, 27, 28, and 34, T. 18 N., R. 77 W., Carbon County
Schoen (1953) reported a 8 ft band of layered hornblende gneiss on Cooper Hill that hosted 23 percent disseminated magnetite as well as one percent secondary hematite in veinlets (Harrer, 1966). Hausel (1994) sampled the area during his investigation of the geology and mineralization of the district. The highest iron content he found in the area was 13.47 percent Fe_2O_3 in metagabbro that he compared to a high-iron tholeiitic magma. Iron in the Cooper Hill area is of technical interest but has no economic potential.

Copper King Claim, SW¼ sec. 12, T. 29 N., R. 75 W., Converse County
Magnetite is described at the Copper King Claim, which is located along a 6 mi northeast trending mineralized zone (Harrer, 1966; Wilson, 1976).

Crazy Horse Creek area, sec. 26 (approx.), T. 29 N., R. 75 W., Converse County
Magnetite occurs as a 2 ft thick band in a 10 ft deep pit about 0.75 mi southwest of Crazy Horse Creek, a tributary at the head of La Prele Creek (Harrer, 1966).

Northwest of Warbonnet Peak, SW¼ sec. 35, T. 29 N., R. 75 W., Converse County
Two 80–100 ft wide schist outcrops, separated by 250 ft of granite, contain narrow veins of quartz and magnetite accompanied by chalcopyrite. This area, about 0.5 mi northwest of Warbonnet Peak and about 2.5 mi southwest of Crazy Horse Creek, was prospected by the Douglas Mining and Milling Company from 1902 to 1906 (Harrer, 1966; Wilson, 1976).

Magnetite Boulders, NE¼ sec. 22, T. 29 N., R. 75 W., Converse County
Magnetite boulders, up to 3 ft diameter, cover a 100 ft square area of green diabase schist. The schist is about 80 ft thick and is flanked by coarse granite (Harrer, 1966; Wilson, 1976).

Saul's Camp, SE¼ sec. 22, T. 29 N., R. 71 W., Converse County
At this location, an 8-inch wide band of magnetite and jasper is located in the center of a 2 mi wide hornblende schist at the head of Horseshoe Creek. A strong magnetic anomaly, about 300 ft wide, extends more than 1,000 ft to the northwest from about 400 ft east of the main shaft on the Tarsus No. 1 claim. Dump rock from several prospects here contains pyrite and magnetite (Spencer, 1916, Harrer, 1966; Wilson, 1976).

Trail Creek, center S½ sec. 10, T. 29 N., R. 71 W., Converse County
The Trail Creek claims encompass deposits about 2 mi north of Saul's Camp. Here, small to large masses of iron jasper occur in hornblende schist (Harrer, 1966; Wilson, 1976).

Copper Mountain Specular Hematite, NW¼ sec. 32, T. 40 N., R. 92 W., Fremont County
Specular hematite disseminated within Precambrian granite occurs in at least three separate outcrops on the south side of Copper Mountain. Two of these are lens- or pod-shaped bodies along the tops of small knolls. The largest is approximately 90 ft long by 20 ft wide with an exposed thickness of 15 ft, while the smaller lens is about 40 ft long with 20 ft of exposed thickness. A 7 ft wide zone of hematite-impregnated altered granite exposed in a 10 ft deep and partially caved shaft is the third outcrop (Osterwald and others, 1966).

Western Tin Cup Jasper, NE¼SW¼ sec. 27, T. 31 N., R. 93 W., Fremont County
The Tin Cup metals district in the western Granite Mountains contains amphibolite-grade Archean gneiss, schist, and amphibolite intruded by granite and cut by several northeast-trending faults. Although numerous prospects are found along the 6 mi long trend of the district, no significant metals deposits are known. Iron-rich massive jasper and jasperoid breccia from a shear zone exposed in a prospect pit showed 30.2 percent Fe (Sutherland and others, 2013).

Wind River Indian Reservation hematitic granite, SW¼NW¼ sec. 15, T. 7 N., R. 5 W.,

Wind River Meridian, Fremont County
Love (1934) described a brilliant red hematite deposit, which appeared to be a dike, just below an outcrop of the Cambrian Flathead Sandstone and partially covered by overlying variegated shales of the Wasatch Formation. The iron appeared to influence the color of the overlying Flathead Sandstone and Wasatch shales. The deposit was reported to contain up to 60 percent iron, but no analytical work was done to verify this, and no estimate of the deposits size was made. Love also described an extremely ferruginous sandstone near the middle part of the undivided Cambrian section which may be similar to the iron deposits near Rawlins.

Wildcat Creek, Union Pass area, SE¼ sec. 3, T. 41 N., R. 108 W., Fremont County
Located along a forest service road, magnetite is disseminated in a pegmatitic facies of coarse-grained, red, Precambrian granite. Exposures, visible in a road cut, indicate a 10 ft wide zone of disseminated magnetite extending easterly for 200 ft (Gersic and Nonini, 1995; Wilson, 1976). This area is also heavily faulted with a prevalent breccia zone around the pegmatite (fig. 17C). The rock is very iron-stained and magnetite rich, with some limonitic weathering (fig. 17B). Magnetite content appears to decrease with distance from the pegmatite. However, some samples, 20141016WS-A, contain banding and a granular appearance (fig. 17A) as if they were once BIF. It is suspected that this area may have been a BIF before heavy faulting and metasomatic alteration (Ullmer, 1983). Samples from this location, collected by the WSGS during investigations of potential REE resources in Wyoming during 2012 (Sutherland and others, 2013) varied from 5.22 to 25.9 percent Fe_2O_3. Analyses from this study can be found in table 10.

Concretionary Iron

Concretionary iron derives from surrounding sedimentary or fragmental rocks by water movement and has been concentrated by chemical precipitation. Concretionary iron may form pellets, nodules, spheres, layers, or irregular shapes as cementing material, void fillings, or replacements that often contrast strikingly with the surrounding rocks. Concretions are often, but not always, concentrically layered around a center of precipitation, such as a fossil, and are formed by many minerals other than iron, particularly amorphous silica and calcite. These concretions vary in size, shape, and composition. Some have an “alligator skin” texture, thick dark rinds, and/or magnetic qualities while others contain alternating layers of concretionary iron and siliceous material. Some concretionary iron may also take on the appearance of a broad red to brown to yellow area with poorly defined boundaries within a sedimentary rock unit. The most common concretionary iron minerals include hematite, siderite, limonite, and pyrite.

Concretionary iron occurs in many parts of Wyoming, but very little of it is found in quantities sufficient for more than incidental commercial use. One major exception is the Rawlins Red deposit in the Rawlins Uplift. The Rawlins Red deposit has been historically thought to be a Cambrian Flathead Sandstone occurrence (Hausel and others, 1992). However, it may have had a source in the Pennsylvanian-Mississippian Amsden Formation accompanied by remobilization along a fault. The Amsden Formation hosts concretionary hematite at various locations across the state (Biggs, 1951; Wilson, 1953; Harrer, 1966.) The Permian-Pennsylvanian Casper Formation also contains small nodules of concretionary iron (Hagner, 1942).

Several Cretaceous formations host iron concretions including: the Bacon Ridge Sandstone in northwestern Wyoming (Simons and others, 1988); the Mesaverde Group, notably the Rock Springs Formation and the Erickson Sandstone in southwestern Wyoming (Houston and Murphy, 1962); the Pierre Shale, Carlile Shale, Belle Fourche Shale, Skull Creek Shale, Fall River Formation, and Lakota Formation in northeastern Wyoming (Knechtel and Patterson, 1962; Robinson and others, 1964); the Thermopolis Shale in southeastern Wyoming; and the Cloverly Formation (fig. 18).

Tertiary formations that locally host concretionary iron include the Split Rock Formation, Wagon Bed Formation, Wind River Formation, Washakie Formation, and others with porous sandstones. The upper part of the Fort Union Formation in south central Wyoming includes hard black ironstone

Table 10. Wildcat Creek analyses.

	Wild Cat Creek-Union Pass area					
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20141016WS-A	50	48.2	1.12	0.14	<0.01	0.09
20121004JC-B.2[1]	13.05	79.6	1.67	0.36	0.08	<0.01

[1]*Sutherland and others (2013)*

beds that vary from 6–12 inches thick. In the Fort Union Formation-hosted Deacon's Prayer deposit in central Wyoming, the concentrated magnetite and hematite in the area may be partially derived from a depositional environment, but remobilized by later water movement through porous sandstone and local faults and fractures. The Wasatch Formation, which overlies the Fort Union, also contains some iron-rich beds (Swain, 1957).

The percentage of iron in most iron concretions is generally less than about 15 percent. However, some concretions host sufficient iron content to be of economic interest for limited, incidental uses. For example, Mountain Cement Co. has used concretionary iron from siliceous shale in the Thermopolis Shale as a weighting factor in heavy cement.

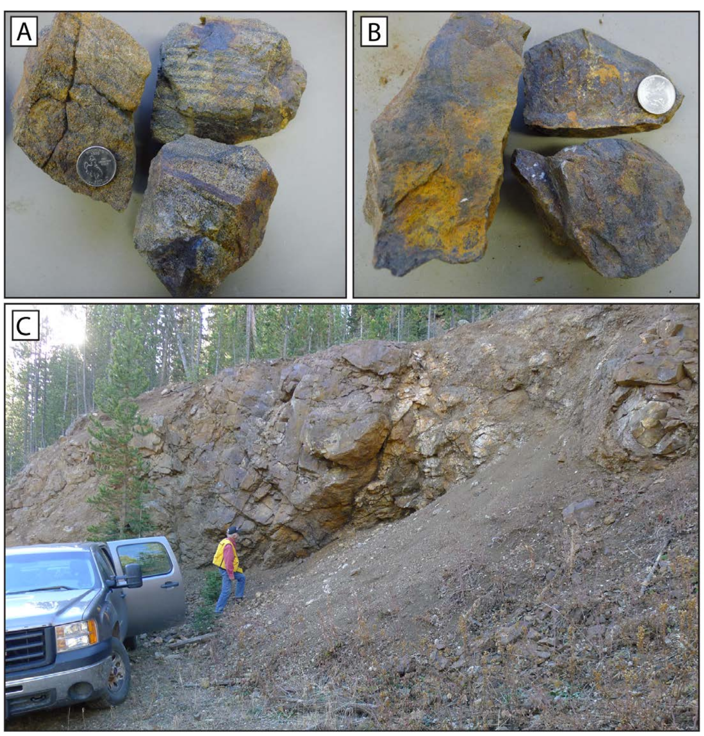

Figure 17. Wildcat Creek deposit (sample 20141016WS-A) with A) magnetite banding, possibly a metamorphosed BIF, B) a range of limonite and hematite staining and metallic sheen, and C) a view of the outcrop and fault zone.

Rawlins Uplift and the Flathead Sandstone

The Middle Cambrian Flathead Sandstone is the oldest sedimentary formation above the Precambrian in Wyoming and has a maximum thickness of about 560 ft in north central Wyoming (Kanizay, 1978). Most of the Flathead is thin- to thick-bedded and well-cemented with a general reddish-brown color that grades to purple, rusty-orange, yellow, or gray. It is dominantly quartz-rich, subangular, medium- to coarse-grained sandstone with large-scale cross-bedding. Non-quartz grains include abundant feldspar and crystalline lithic fragments typical of the underlying granite. Minor thin layers of red siltstone and red and green silty shale are typically interbedded with the sandstone in the upper part of the formation, while pebble conglomerate is common near the base. The Flathead represents a fluvial-marine transition zone along a north-south oriented shoreline with braided stream deposits as the conglomeratic base (Middleton, 1980).

Silica cement dominates the majority of the formation although calcite and iron cements are found in some areas. Middleton (1980) describes local, irregularly distributed hematite grain coatings and pore fillings and areas of hematite cement. The conglomeratic and arkosic lower part of the Flathead, varying from 20 to 50 ft in thickness (McKinney and Horst, 1953), locally represents braided stream

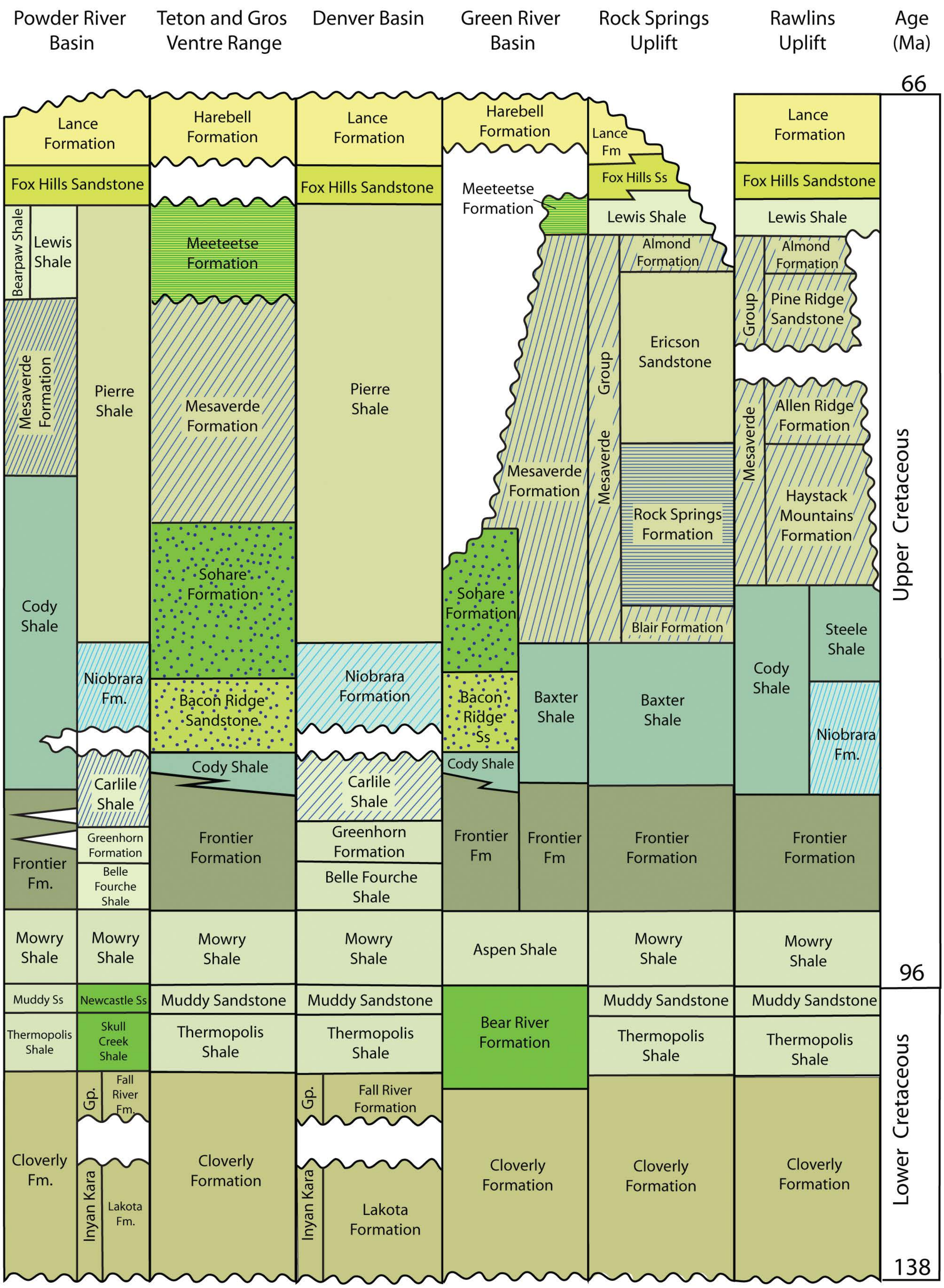

Figure 18. Stratigraphic columns showing the relationships of Cretaceous units across Wyoming. Modified from Love and others (1993), and colors updated to correlate with Love and Christiansen (1985, 2014).

environments. These braided stream deposits are quartz-rich, arkosic conglomerates with subangular to rounded clasts indicative of both a nearby source and a lack of reworking (Middleton, 1980; Hausel and others, 1992). Clast sizes are up to 2 inches in diameter with cementation varying from moderate silicic or limonitic to localized areas of quartzite. However, the majority of the formation was deposited in near-shore marine environments (Middleton, 1980). Fine placer gold is found in the lower Flathead conglomerates in the Bald Mountain area in the Bighorn Mountains (McKinney and Horst, 1953). A small amount of gold was identified within one sample from conglomerate in the lower Flathead Sandstone associated with the Rawlins Red hematite deposit (Hausel and others, 1992). Numerous samples were collected from the basal conglomerate layers by the WSGS during investigations of REE in Wyoming (Sutherland and others, 2013). Most of these contained less than 5 percent Fe. However, three samples in the Bald Mountain area showed between 5.71 and 15.25 percent Fe. One iron-stained sample from the lower part of the Flathead in the Union Pass – Warm Spring Area at the northern end of the Wind River Mountains showed 10.95 percent Fe.

Rawlins Red Deposit, common corner of secs. 4, 5, 8, and 9, T. 21 N., R. 87 W., Carbon County
The iron deposits occur on the east flank of the Rawlins Uplift, a large Laramide anticline trending north for a distance of 40 mi. Exposed rocks in the anticline include Precambrian, Cambrian, and Mississippian ages. These are unconformably overlain by Pliocene-Miocene formations. The regional attitude of the Paleozoic rocks near the iron deposits is a north-northwest strike with an 8–10° NE dip. Hematite is found in a 20 to 30 ft thick zone in both the upper shale of the Cambrian Flathead Formation and lower part of the Mississippian Madison Limestone (Lovering, 1929). Primary mineralization occurs in the Cambrian rocks, but early Tertiary northeast-trending faults appear to have controlled the emplacement of mineralization in the Mississippian limestone (Osterwald and others, 1966). Beds in the northern block at the fault contact strike nearly east-west and dip from 60–80° N. The trend of hematite mineralization appears to be 50°. Pods, lenses and irregular masses of hematite occur as hard, blue nodules and streaks of oolitic and pisolitic "grape ore," some local stalactitic ore, and as soft, ocherous hematite and limonite (Harrer, 1966; Wilson, 1976; Lovering, 1929). The iron ore here is sometimes referred to as "Rawlins red," "paint rock," or "paint ore."

One of the earliest descriptions of the Rawlins iron deposit is a collection of transcribed newspaper articles from the Sentinel and the Daily Independent from June of 1873 (Anonymous, 1873). The articles note that the red hematite iron ore exists in large quantities and has been commonly used as a flux for smelting silver in Utah and Colorado and addressed its use in paint. At that time, Friend and Co. was reported to be shipping 60 tons of ore per day from Rawlins to Utah for flux. At the same time, a paint mill in Rawlins, owned and operated by Ogg Shaw, was "running steady," and producing a very finely ground mineral paint with the consistency of lamp black that was in great demand at $80/ton at the mill. These newspaper articles primarily discuss fine gold associated with the hematite that was under suspicion as a scam at the time. However, Hausel and others (1992) confirmed traces of gold and concluded that fine paleoplacer gold may be erratically distributed between barren zones within the Flathead conglomerates. Hausel and others (1992) also found elevated REE in an arkosic conglomerate from the lower Flathead Sandstone. Later, the UPRR owned the deposits and mined them for use in metallurgical flux and for paint pigments starting in 1870, thus the name, "paint rock" (Lovering, 1929; Boyle, undated). In fact, Hague and Emmons (1877) stated the hematite was a valuable mineral for paint and flux because it was free from impurities, metallics, and created a brilliant vermillion powder. "Rawlins Red" was even used to paint the Brooklyn Bridge in 1883 (Lovering, 1929). Boyle (undated) noted that it was also used by the UPRR to paint many of its freight cars, road-way buildings, and bridges. Harrer (1966) stated that the last reported production was in 1945 for use as paint pigment and for a drilling mud constituent in Texas.

It is likely that this deposit was also of interest to Paleo-Indians for use as a pigment. However, excavations, prospect pits, and more recent development have probably obscured any early excavations or artifacts that might have indicated prehistoric use of the material.

The general geology of the area (fig. 19), combined with a lack of detailed geologic mapping of the Rawlins Red hematite deposits, leaves only suggestions as to their origin. Boyle (undated) suggests the deposits result from replacement of rock within the formation by iron oxide based on gradation of ore bodies in the country rock. Lovering (1929) states the iron is similar to that found in the Seminoe Mountains and was likely reworked by streams into iron-rich lenses and precipitated in solution cavities. Hausel and others (1992) agree that its source is likely nearby BIF which was eroded and re-deposited during Cambrian uplift.

Iron occurs in the lower part of the Flathead Sandstone around Wyoming, but only three areas, Bald Mountain, Wind River Canyon, and Union Pass, have shown greater than 10 percent Fe (table 11). This iron, at the base of the Cambrian, was likely derived in manner suggested by Hausel and others (1992). However, a maximum of 16 percent Fe is substantially less than the concentrations of 45 percent or more found near Rawlins. In addition, the massive hematite found in the Rawlins Red deposit is not observed in the Flathead Sandstone at any other location. However, massive, oolitic, pisolitic, and nodular hematite, similar to the Rawlins Red deposit, is found within the Amsden Formation at several locations across Wyoming.

Another hypothesis explaining the location of the iron is partial deposition from fluid movement along faults. Coincidentally, an east-northeast trending fault appears to parallel the trend of both the Rawlins Red and Rawlins North ore bodies. Samples taken by Hausel and others (1992) and recent drilling by Mountain Cement Co. (A. McClugage, personal communication, 2014) indicate increased iron content along the fault and a decrease in the orthogonal direction. Aerial imagery combined with regional geologic mapping (McLaughlin and Fruhwirth, 2008) indicate downward motion on the north side of the fault and show northeast dipping exposures of both Flathead Sandstone and Madison Limestone south of the fault. This could place part of the Amsden Formation, which overlies the Madison, at the surface north of the fault. With faults as conduits for fluid movement, hematite could have been re-mobilized from the Amsden and locally precipitated into slivers of Flathead within the fault zone. This would make the Amsden the major source of iron and would account for relationships between the Amsden hematite and the Madison Limestone as described by Lovering (1929) as well as the replacement deposits within the Flathead as suggested by Boyle (undated). Botryoidal and stalactitic hematite found at the deposit (sample CC136B) also indicate fluid deposition along a fault.

In the field, WSGS coal geologist Chris Carroll collected four samples (table 11) and noted a red-brown, fine-medium grained arkosic sandstone rich with iron oxide (fig. 20). The iron appears dark brown to black and metallic but not magnetic. Sample CC134, from an old iron pit, represents some of the more concentrated, high-grade hematite, as does Sample CC135. Sample CC136 was collected from an exposure in an abandoned iron pit and is similar to previous samples but appeared to contain higher concentrations of two types of iron that were separated out for analyses. CC136A is massive red iron oxide within, or replacing shale, and CC136B is soft, massive, botryoidal to stalactitic hematite with minor limonite; suggestive of deposition through fluid movement, possibly related to the nearby fault.

Historic mining methods included shallow pits, inclines, and underground rooms to access ore bodies, which were generally small and irregular (Boyle, undated). The largest ore body varied in thickness from 2–3 ft, and was mined for 300 ft down dip at a trend of 43° (Wilson, 1976), which is roughly parallel to the afore-mentioned fault. Lovering (1929) addressed this, presumably the same, ore body as accessed by an inclined shaft, extending 200 ft down dip to the northeast. He also reported that UPRR drilled a series of holes 200 ft north of an inclined shaft in the southwest corner of section 5 and did not intersect iron. However, he also pointed out the linearity of the iron-rich trend at 50°.

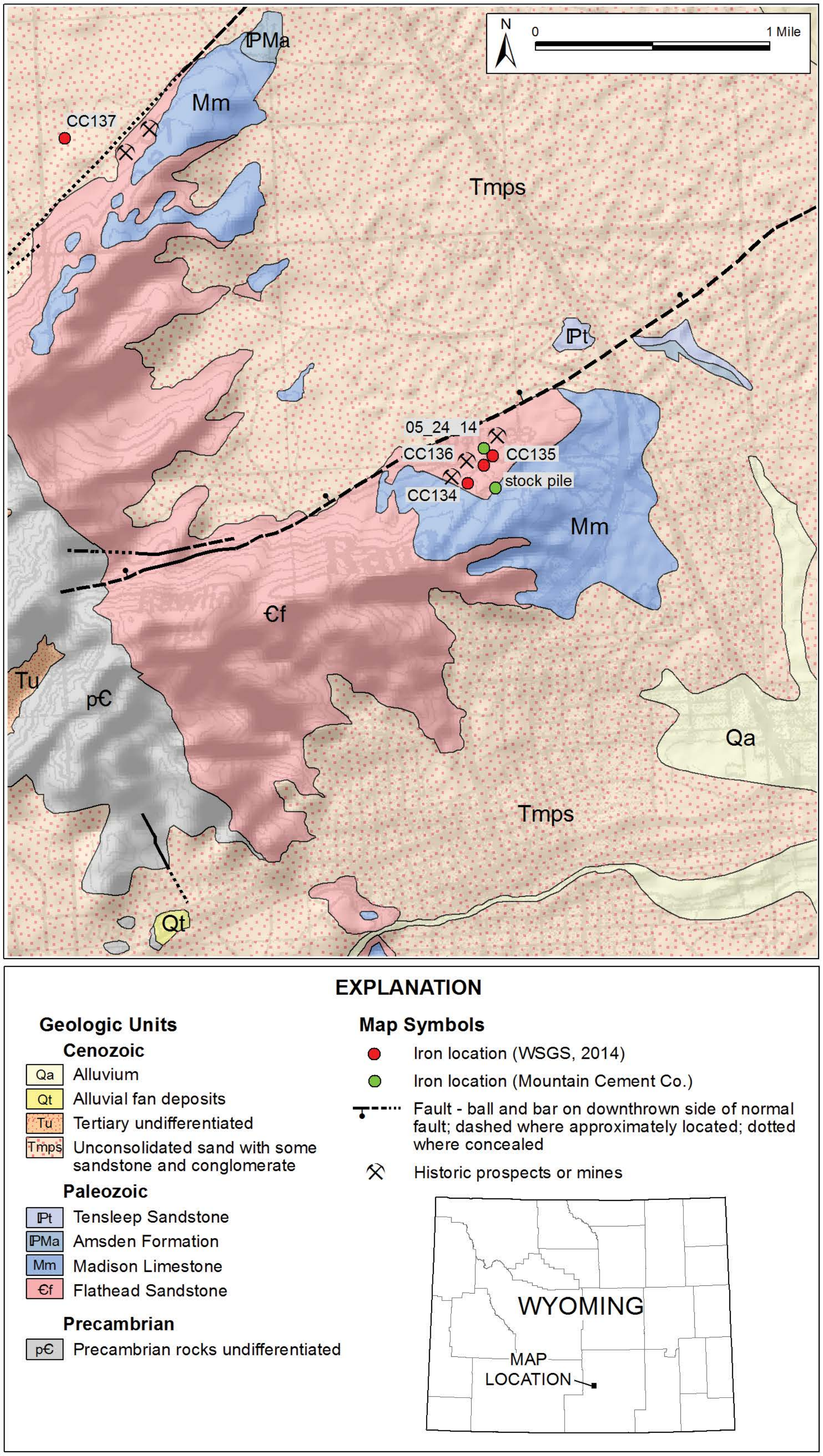

Figure 19. Geology of the Rawlins area where hematite deposits occur just north of the city. Some samples reside within the historic Rawlins Red mine area. Map modified from McLaughlin and Fruhwirth (2008).

Table 11. Rawlins Area analyses. Other elements present at >5x crustal concentrations are Ce, La, Nd, Pr, Se, Sm, Sr, As, Mo, and Bi. For full details, see appendix.

Rawlins Area						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
CC134	30.8	57.1	5.17	0.16	0.13	1.47
CC135	90.5	3.87	0.3	0.01	<0.01	0.08
CC136A	5.37	1.38	0.28	0.02	0.01	0.02
CC136B	89.2	1.62	0.48	0.01	<0.01	0.03
Rawlins Hematite 3[1]	79.91	13.17	3.69	0.09	0.03	0.02
Rawlins Hematite 4[1]	92.43	3.66	1.14	0.04	0.02	0.02
Rawlins Hematite 5[1]	87.73	6.51	2.07	0.07	0.03	0.03
05_24_14[1]	25.58	2.47	1.67	0.04	0.23	-
05_24_14[1]	21.55	1.30	0.86	0.00	0.21	-
Pile from highwall 9[1]	20.67	64.18	2.79	0.30	0.17	-
Stockpile surface 10[1]	21.79	8.46	0.79	0.01	0.20	
old test pit 11A[1]	41.99	2.37	0.87	0.02	0.19	-
RA1-91[2*]	65.36	-	-	-	-	-
RA4-91[2*]	13.48	-	-	-	-	-
RA9-91[2*]	*16.14*	-	-	-	-	-
RA14-91[2*]	*47.9*	-	-	-	-	-
1[3*]	64.64	3.16	-	-	0.011	0.013
2[3*†]	51.47[†]	20.03[†]	-	-	-	0.021[†]
3[3*]	62.25	-	-	-	-	0.016
4[3*]	62.25	-	-	-	-	0.013
5[3*]	63.05	-	-	-	-	0.037
6[3*]	64.75	-	-	-	-	0.01
7[3*]	67.05	-	-	-	-	0.013
8[3*]	66.40	-	-	-	-	0.014
9[3*]	66.85	-	-	-	-	0.006
10[3*]	61.10	-	-	-	-	0.004
11[3*]	66.35	-	-	-	-	0.004

[1]*Mountain Cement (2014)*

[2]*Table 4 Hausel and others (1992)*

[3]*Lovering (1929)*

**reported as Fe (%)*

[†]*average of four samples*

In 2014, Mountain Cement Company investigated the Rawlins hematite for use in heavy cement mixtures. During their investigation, some samples produced significant Fe_2O_3 content but failed to show potentially useful volumes of material (A. MacClugage, personal communication, 2014) (table 11). At least one of the Mountain Cement Co. drill holes appears to have been very near to or on trend with historic mining, with other holes arrayed north of the fault. However, their having not intersected significant iron reinforces the form of the ore as irregular deposits and lends credence to the idea that those deposits may be concentrated along the fault rather than extending any distance from it.

Lovering (1929) estimated that more than 100,000 tons of ore was mined prior to 1890. In 1976, Wilson estimated that 150,000 tons of iron ore had been produced. Harrer (1966) indicated a known 500 tons of high grade ore remaining in 1957, with an estimated 1 million tons at 55.2 percent iron and 0.20 percent TiO_2, although the basis for this estimate is unknown. The most recent investigations of the Rawlins Red deposit suggest that any remaining hematite resource is relatively small.

Eleven samples were collected by Hausel and others (1992) from hematitic conglomerate (table 11) from both mine dumps and outcrops in sections 5 and 8 (fig. 20), in the vicinity of excavations and prospects. The Flathead Sandstone for these samples consists of rusty-red, earthy to specular hematite cement surrounding quartz pebbles. Total iron content in these samples ranged from 1.51 to 47.9 percent Fe; a split of panned concentrate in sample RA1-91 assayed 63.36 percent Fe. Table 11 also shows early analyses reported by Lovering (1929). The first (undated) represents nine rail car loads of ore and indicates that the average material shipped was 64.94 percent iron.

Rawlins Red Hematite North, NE¼SW¼ sec. 31, T. 22 N., R. 87 W., and sec. 35, T. 22 N., R. 88 W., Carbon County

Several iron prospect pits are dug into red to dark brown outcrops mapped as Flathead Sandstone, but records of any production are lacking (Anonymous, 1873; Boyle, undated.; Hauge and Emmons, 1877; Hausel and others, 1992; Lovering, 1929). Smaller prospect pits are found in outcrops of iron-rich Flathead Sandstone in section 35, T. 22 N., R. 88 W., but no production is known from these.

Amsden Formation pisolitic or oolitic hematite deposits

Biggs (1951) described pisolitic hematite in the Mississippian-Pennsylvanian Amsden Formation as limited to a discontinuous thin layer, about 20 to 35 ft above the basal sandstone of the Amsden (Darwin Sandstone Member). Sando and others (1975) refer to the shaly unit hosting the pisolitic hematite within the Amsden as the Horseshoe Shale Member. In some areas, any indications of the pisolitic hematite are absent. At a few of these locations, Biggs described disseminated pyrite, both macroscopic and microscopic, within much of the formation. The pisolitic layer, where present, varies from several inches to 3 ft thick. In the Wind River Mountains and vicinity (fig. 21), the pisolitic layer is generally divided into two units separated by a thin yellow shale. The pisolites consist of concentric spherical layers around a center of anhydrite, gypsum, or rarely a

Figure 20. Rawlins hematite shown as rusty red to dark, blackish blue ore.

sand grain within a matrix of red shale, anhydrite, and/or massive hematite. The thickest layers may be massive, whereas the thinner layers are well-bedded and pisolitic. Biggs also noted that small hematite concretions may occur in other parts of the Amsden section. Biggs (1951) concluded that the pisolitic iron within the Amsden Formation was not economic at the time of his study. The same conclusion was reached by Gersic and Nonini (1995).

The Amsden is equated to the lower Minnelusa Formation in the Black Hills and to the lower part of the Wells Formation in western Wyoming (Biggs, 1951; Sando and others, 1975). The depositional environment of the Horseshoe Shale Member is interpreted by Sando and others (1975) as off-shore or lagoonal deposits, although they also cite other views suggesting that the Horseshoe is a reworked regolith after weathering of the Madison Limestone. The source of the hematite remains in debate as to whether it has a depositional or post depositional origin (Biggs, 1951; Sando and others, 1975).

Pat O'Hara Mountain King area, SW¼ sec. 9, T. 54 N., R. 103 W., Park County

Hematite oolites, pisolites, nodules, and pods are irregularly scattered in the soft red shales and sandstone in the lower part of the Amsden Formation. The site is in a depression between hogbacks of the upper Amsden and the upper part of the Madison Limestone (fig. 21). Seven mining claims (Iron King No. 1 through 7) covered the area when it was examined by Wilson (1953). A 23 ft thick zone contains the iron at a site about 1,400 ft above Pat O'Hara Creek where the Amsden strikes 314° and dips 35° NE. The iron includes hard, blue, hematite nodules referred to as "buckshot ore" and soft, brownish-red, "paint rock," bedded, nodular hematite. Analyses in 1952 showed 45.6 percent Fe for the buckshot ore and 47.6 percent Fe for the bedded nodular ore. The deposit was investigated and rejected by Colorado Fuel and Iron. Although some areas appear high grade and the deposit extends for 1.5 mi along strike, the relative narrowness, combined with its spotty nature and overall low grade negated commercial development (Wilson, 1953, 1976; Harrer, 1966).

"North" Pat O'Hara Mountain, NW¼SW¼ sec. 26, T. 55 N., R. 104 W., Park County

By tracing the reddish Amsden Formation at the Pat O'Hara Mountain King deposits to the north, more hematitic outcrops were identified. At this sample site, the Amsden Formation outcrops along a road cut between Pat O'Hara Mountain and Dead Indian Hill. The rusty-red outcrop (fig. 22C) contained pisolitic, hard, bluish rock (fig. 22A and B). Two samples, 20141015WS-B and C, were collected for geochemical analysis (table 12). It is possible that locating the Amsden Formation in the Absarokas and Cody area could lead to the discovery of more hematite deposits. However, the size and grade cannot be predicted.

Sheep Creek Canyon, SW¼ sec. 11, T. 33 N., R. 116 W., Lincoln County

A zone of hematite and limonite pebbles on the north side of Sheep Creek Canyon is thought to be hosted by the Amsden Formation (Harrer, 1966). The zone includes a 4 ft thick conglomerate and an underlying 7 ft thick iron-bearing shale that can be traced in an east-west direction for about 0.5 mi. These beds are overlain by bluish gray sandstone and underlain by white sandstone (Osterwald and others, 1966; Wilson, 1976). Analyses of hematite accretions and pebbles showed 60.44 percent iron, the conglomerate showed 34.81 percent iron, and the shale showed 11.33 percent iron" (Harrer, 1966).

During field investigations for this study, one outcrop was identified in this area as iron-rich. On a steep slope about 100 ft above the creek, a reddish maroon, iron-rich shale, sample 20141016WS-B, (fig. 23A) with various amounts of hematite and magnetite underlies shale with purple, green, red, orange, and yellow coloration (fig. 23C). Above the variegated shale lies a pisolitic layer, sample 20141016WS-C, with a similar variation of color (fig. 23B). Although the outcrop is suspected to be the Amsden Formation, a cursory field investigation could not confirm the stratigraphy. Table 13 lists the chemical analyses for this sample site.

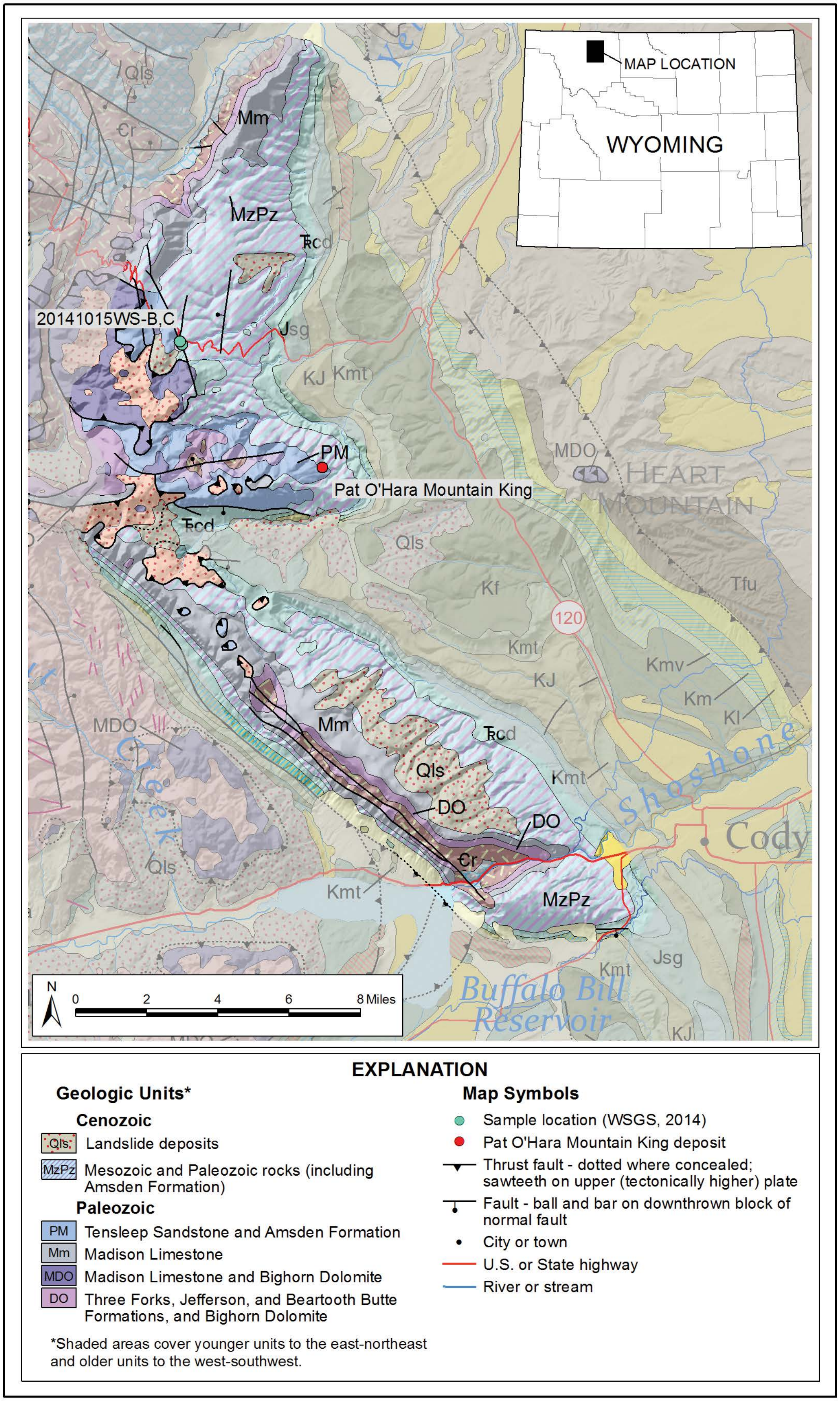

Figure 21. Geology of the eastern edge of the Absaroka Mountains near Cody, focusing on the Paleozoic formations. Iron occurs locally within the Amsden Formation. Sampling was based on potential continuity with the Pat O'Hara Mountain King deposit. Map modified from Love and Christiansen (1985, 2014).

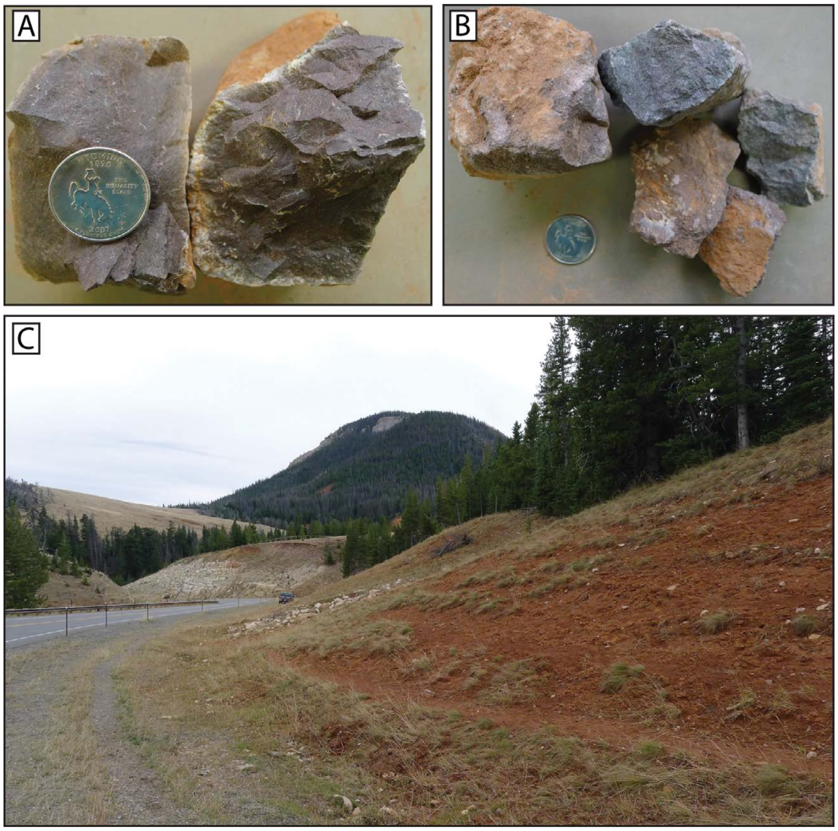

Figure 22. Hematite-rich Amsden Formation occurs near Pat O'Hara Mountain. A) Concretionary hematite with a maroon hue. B) Concretions with bluish-black color and a slight metallic luster (sample 20141015WS-B). C) The outcrop of Amsden Formation with a southeast view toward Pat O'Hara Mountain.

Gros Ventre Hematite, W½SW¼ sec. 13 and NW¼NW¼ sec. 24, T. 40 N., R. 114 W., Teton County

Investigation of the Gros Ventre Wilderness Study Area by Simons and others (1988) noted a concentration of hematite nodules in the Amsden Formation at one locality on the top of a ridge between Bunker Creek and Box Creek (fig. 24). Hematite nodules and disseminated grains are accompanied by limonite pisolites up to 0.25 in diameter in a discontinuous layer of red-brown shale. The area where the nodules are concentrated is about 150 ft east-west by 100 ft north-south and includes two small prospect pits less than 2 ft deep by 6 ft in diameter. The hematite nodules contain 50 percent iron but are diluted by the enclosing shale. Grab samples from the prospect dumps showed 13.6 and 7.5 percent Fe. The limonite pisolites, when concentrated and separated from the enclosing shale, showed 39.9 percent Fe. Simons and others (1988) determined the deposit to be of little economic importance.

Tosi Creek, secs. 30-31, T. 39 N., R. 111 W., Sublette County

A pisolitic hematite zone crops out in the basal red shale of the Amsden Formation (fig. 24), just above the Darwin Sandstone Member on the east side of Tosi Creek Basin (W.R. Keefer oral communication to Osterwald and others, 1966). The zone, which is at an elevation of 9,500–10,000 ft, is continuously exposed along a bluff for 1–1.5 mi and is approximately 10 ft thick. These pisolitic beds also crop out at the base of Hodges Peak on the west side of Tosi Creek Basin (Osterwald and others, 1966; Wilson, 1976).

Wagner Pass area, sec. 12, T. 29 N., R. 117 W., Lincoln County

A 5 to 6 ft thick bed of pisolitic hematite is reported from the lower part of the Pennsylvanian Wells Formation (Amsden equivalent) at this location (Fruchey, 1962; Osterwald and others, 1966).

Table 12. "North" Pat O'Hara sample analyses.

Pat O'Hara Mountain area						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20141015WS-B	7.44	62	15.1	0.74	<0.01	0.27
20141015WS-C	4.32	33.7	8.76	0.41	0.04	0.39

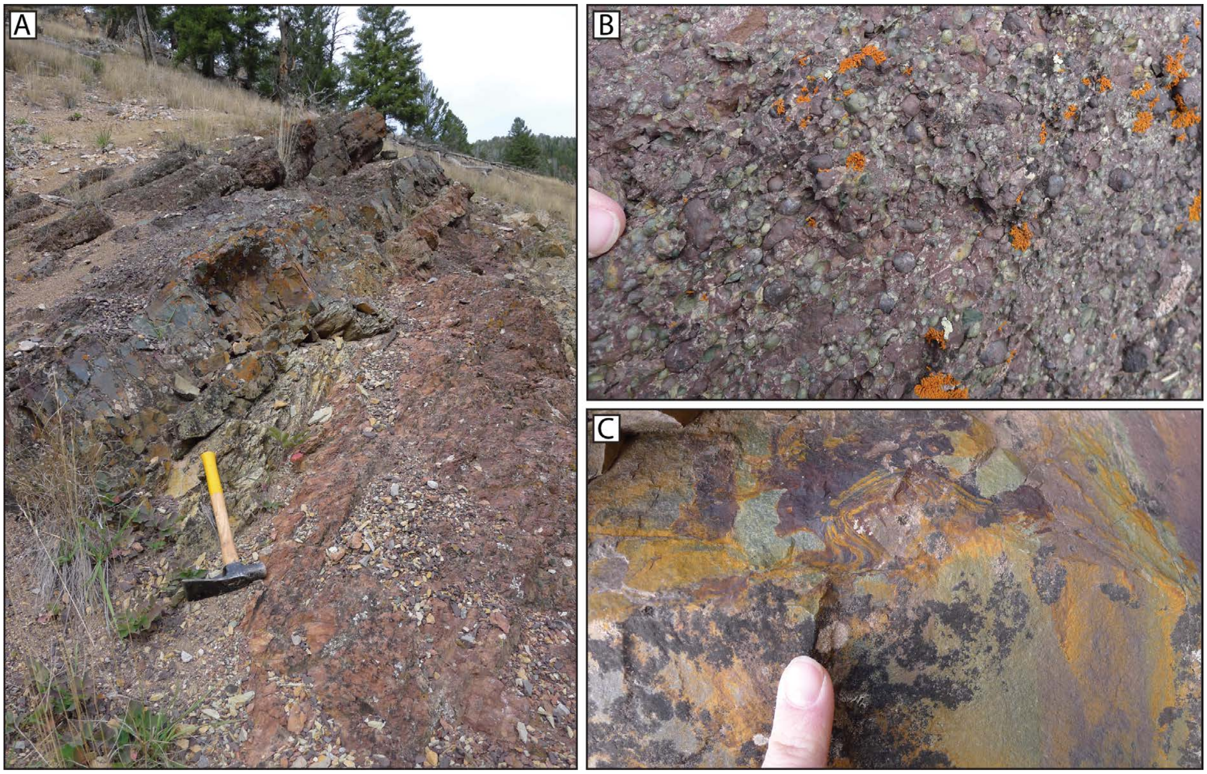

Figure 23. Sheep Creek Canyon locality in the Western Wyoming Range. A) The bottom layer is a hard, red, silty shale (sample 20141016WS-B), the middle layer is fissile, variegated shale, and the top layer a variegated pisolite (sample 20141016WS-C). B) A close up of the pisolite. C) A close up of the variegated shale.

Red Creek area, secs. 32 and 33, T. 40 N., R. 105 W., Fremont County

In the Red Creek area along the Wind River Range (fig. 24), the Amsden Formation contains thin discontinuous layers of pisolitic and oolitic hematite and limonite nodules that can be traced for miles. These occur in red shale in the lower part of the formation and in a red, marly limestone, which Harrer (1966) thought was above the contact with the overlying Tensleep Sandstone. A composite sample of a 1–7 ft thick bed containing oolitic limonite nodules analyzed 13.3 percent iron and 18.6 percent Fe_2O_3. Other samples from the same layer, taken over a 2-12 ft width, contained 2.4 to 19.6 percent iron (Biggs, 1951; Harrer, 1966; Osterwald and others, 1966).

Jakey's Fork, NE¼ sec. 29, T. 41 N., R. 106 W., Fremont County

At this location, (fig. 24) Biggs (1951) noted that the outcrop, which strikes 120° and dips 15° NE, is similar to that at Horse Creek. However, here the lower sandstone in the Amsden Formation (Darwin Sandstone) is much redder than in any other location he examined. Due to poor exposures, Biggs did not provide a description of the hematite layer, but noted that the basal (Darwin) sandstone was very hematitic.

Table 13. Sheep Creek sample analyses. Other elements present at >5x crustal concentrations are Hf, Th, U, Zn, As, Bi, Sb, and Te. For full details, see appendix.

Sheep Creek						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20141016WS-B	20.5	63.1	7.77	2.12	<0.01	0.08
20141016WS-C	42.9	40.4	10.05	0.74	<0.01	0.04

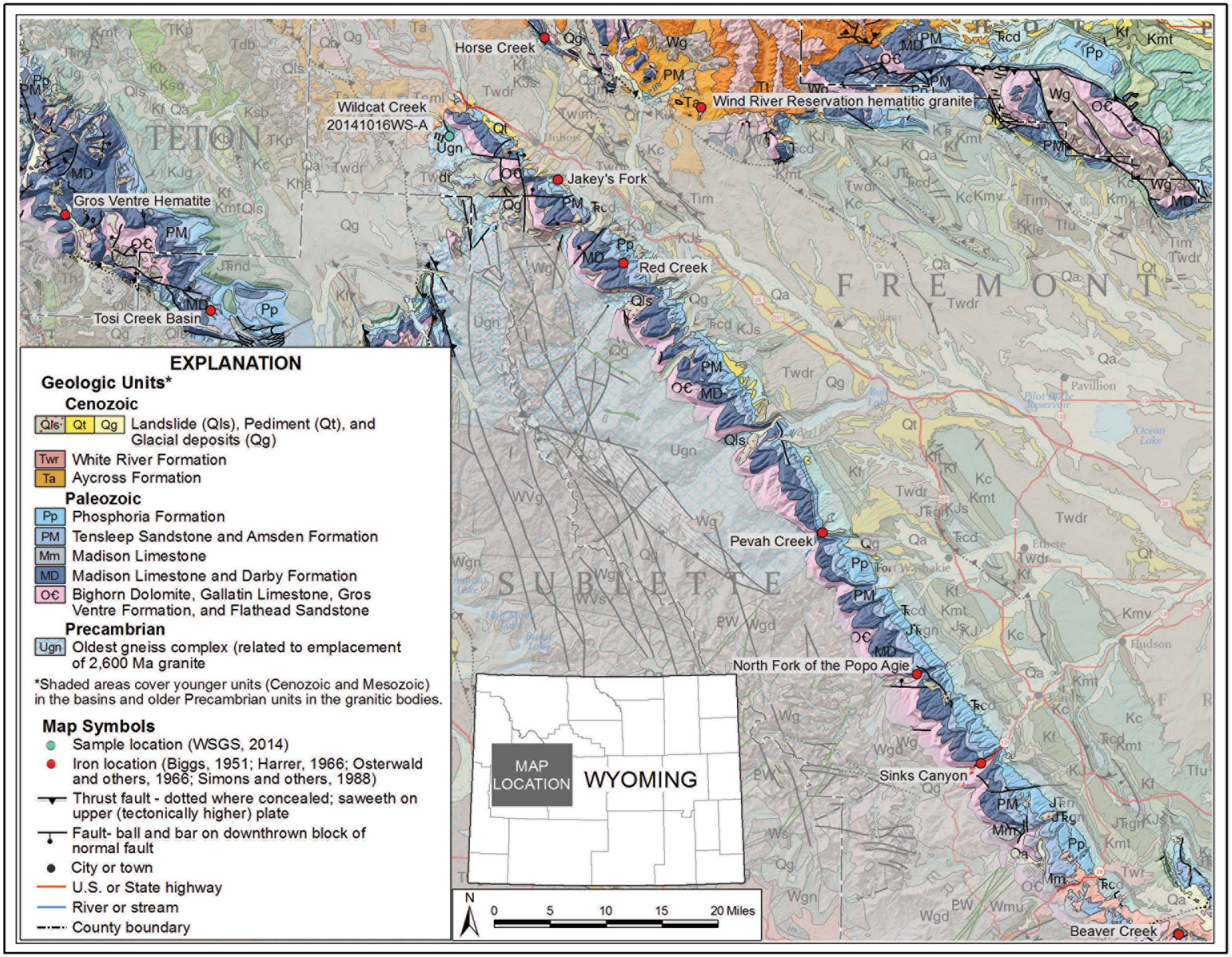

Figure 24. Iron locations and geology along the Wind River Mountains, the Gros Ventre Range, and the southern Absarokas/western Owl Creeks. Large areas of the map have been shaded for simplification of the geology. Map modified from Love and Christiansen (1985, 2014).

Horse Creek, SW¼ sec. 19, T. 43 N., R. 106 W., Fremont County

The Amsden here (fig. 24) strikes 156°, dips 85° SW to vertical, and hosts prominent pisolitic nodules. Pisolitic iron within a shale matrix is locally more than 4.5 ft thick and may be entirely "buckshot iron ore." However, the unit rapidly grades laterally into areas of only scattered red nodules (Biggs, 1951).

Pevah Creek, NE¼ sec. 28, T. 1 N., R. 3 W., Wind River Meridian, Fremont County

Biggs (1951) measured red pisolitic hematite in the Amsden Formation near the head of Pevah Creek on Wind River Indian Reservation (fig. 24) where it strikes 336° and dips 6° NE. The dip increases to 71° NE in the upper part of the formation. The iron varies from two thin hematite stringers separated by a thin yellow shale to more than 3 ft of pisolitic hematite. Scattered concretionary hematite pisolites occur in shale below the primary iron layer, and microscopic botryoidal hematite is found in the shale above it.

North Fork of the Popo Agie, SE¼ sec. 5, T. 33 N., R. 101 W., Fremont County

Two beds of pisolitic hematite occur in the Amsden Formation where it strikes 336° and dips 12° NE along the north side of the canyon of the North Fork of the Popo Agie River (fig. 24). Each of the beds is about 2 ft thick at the top of a mottled red and yellow shale unit. The pisolites have yellow interiors with dark red exteriors and are set within a matrix of gypsum and anhydrite (Biggs, 1951).

Sinks Canyon, SE¼ sec. 18, T. 32 N., R. 100 W., Fremont County

The Amsden Formation is exposed in the north wall of the Middle Fork of the Popo Agie River Canyon (Sinks Canyon) (fig. 24) where it strikes 331° and dips 14° NE. Two beds of very hard, round, hematite concretions at this location are each about 2 ft thick (Biggs, 1951).

Beaver Creek, NW sec. 6, T. 29 N., R. 97 W., Fremont County

The Amsden Formation at this location (fig. 24) strikes 329° with a dip of 16° NE. Concretionary hematite is found in two generally consistent thin zones totaling 4–5 ft in thickness. These are within a red to lavender gypsiferous shale that is almost entirely gypsum in some areas but grades laterally into concretionary hematite (Biggs, 1951).

Olin Brothers hematite, sec. 8, T. 31 N., R. 74 W., Converse County

Loose and compact hematite is hosted by the Amsden Formation and exposed in two pits, one 6 ft by 6 ft, and the other 6 ft by 3 ft by 12 ft deep. The ore is irregular and appears to both coat and replace chert. The pits are about 900 ft apart along an east-west trend with three smaller pits between them in the west-central part of the trend. The amount of chert is less in the three small pits (Hagner, 1942a).

Sheep Mountain, sec. 4 and SE¼NE¼ sec. 5, T. 31 N., R. 72 W., Converse County

Southeast of Schofield Pass, hematite is interbedded with sandstone in the Casper or Amsden Formation. This hematite occurrence is briefly described in a 1942 field report (Hagner, 1942b). The report cites the location in sections 4 and 5 in the Casper Formation, but aerial imagery clearly locates hematite in the SE¼NE¼ of section 5. The 1:100,000 scale geologic map covering the area (McLaughlin and Ver Ploeg, 2008) puts the location in the Madison Limestone, which includes paleokarst, just south of Casper Formation outcrop. It is likely, but not certain, that this site is within a thin layer of the Amsden Formation.

The area was formerly known as the American Mining Co. Property and the Douglas iron deposit, and several samples showed 57-68 percent iron (Harrer, 1966). Ore occurs erratically as hard, blue-black to reddish hematite, and iron-rich chert for a distance of 0.75 mi with a north to northwest trend. Dips vary from near horizontal to 30° SW. Prospect pits indicate a maximum thickness of 5 ft of hematite enclosed within a sandstone bed that is overlain by limestone. No production is known from this deposit (Harrer, 1966).

Deer Creek–Little Deer Creek, T. 32 N., R. 76 W., Converse County
This occurrence does not have an accurate location. Wilson (1976) described angular fragments of hematite, up to 4 inches in diameter, imbedded in red, shaly sandstone about 60 ft above the contact of the Casper and Madison Formations. He suspected this to be in the Amsden Formation equivalent.

Koch prospect, sec. 21, T. 32 N., R. 79 W., Natrona County
Red hematite is associated with chert in the Casper Sandstone at the prospect. It is largely masked by soil but exposed in several shallow pits (Hagner, 1942; Harrer, 1966).

Black Hills and Powder River Basin Cretaceous and Tertiary Concretions

The Black Hills and Powder River Basin area in northeastern Wyoming contains a wealth of iron concretions found throughout Cretaceous shale units (fig. 25 and 26). These include the Pierre Shale, Carlile Shale, Belle Fourche Shale, Skull Creek Shale, Fall River Formation, and Lakota Formation (Knechtel and Patterson, 1962; Robinson and others, 1964). Ricketts (1880) described large pieces of magnetic iron ore float in Crook County. He also noted that "clay iron ore" is abundant at several locations in shales of the Colorado Group (outdated nomenclature). The Colorado Group includes units from the Lower Cretaceous Skull Creek (Thermopolis) Shale upward through the Upper Cretaceous Niobrara Formation; early usage may have included the Pierre Shale. However, clay or shale associated iron is so common that it attracts little attention and has had little development. This clay iron also occurs as nodules and irregular layers within shale in southern Wyoming near Rock Creek Station along the UPRR and in the Late Cretaceous Fort Benton Group northwest of Elk Mountain as described by A. Hayne (Ricketts, 1880). The Fort Benton Group is a stratigraphic term, no longer used in Wyoming, which included the Mowry Shale, Belle Fourche Shale, and the Greenhorn Formation.

Within the Pierre Shale, the upper part of the Mitten Black Shale Member contains small, red-weathering ferruginous concretions, and the Gammon ferruginous member host several beds of orange to dark-red weathering, tabular, closely-spaced, ferruginous concretions up to a many feet long in all but the lower-most 100 ft of the member (Robinson and others, 1964). The upper part of the Pool Creek shale member of the Carlile Shale contains clay ironstone concretions and white-weathering, phosphatic claystone nodules (Knectel and Patterson, 1962). Red to purplish-black siderite concretions occur in the lower third of the Skull Creek Shale. One to 2 inch thick silty, or finely sandy, dark-brown, iron-rich beds and nodules are scattered within the thicker sandstones of the Fall River Formation; the thinner sandstones in the Fall River often host dark-brown to reddish-brown, resistant seams and thin iron oxide cemented layers. Siderite concretions are also found as a minor component of the Lakota Formation (Robinson and others, 1964).

The Upper Cretaceous Belle Fourche Shale, about 850 ft thick, is dominated by nonresistant, black to dark-gray bentonitic shale containing minor limestone lenses. It overlies the Clay Spur Bentonite, which is the uppermost layer in the underlying Mowry Shale (Sutherland, 2008). Dark-red to purplish-black weathering, irregularly rounded, slightly magnetiferous siderite concretions, ranging up to 5 ft in their longest dimension, are hosted within soft grayish-black shale characterizing the basal 50 ft of the Belle Fourche Shale. In the upper part of the formation, thin, very fine, friable sandstone and siltstone laminae host scattered red-weathering ironstone concretions along with numerous, gray- to yellow- and red-weathering, septarian limestone concretions (Knechtel and Patterson, 1962; Robinson and others, 1964). Radiometric anomalies distinguish the Belle Fourche from surrounding units (DeWitt and others, 1989).

Belle Fourche Concretionary area, NW¼SW¼ sec. 12, NW¼NW¼ sec. 14, T. 56 N., R. 67 W., Crook County
This location is in the northeastern Powder River Basin where Cretaceous formations dip gently to the northwest off of the flank of the Black Hills

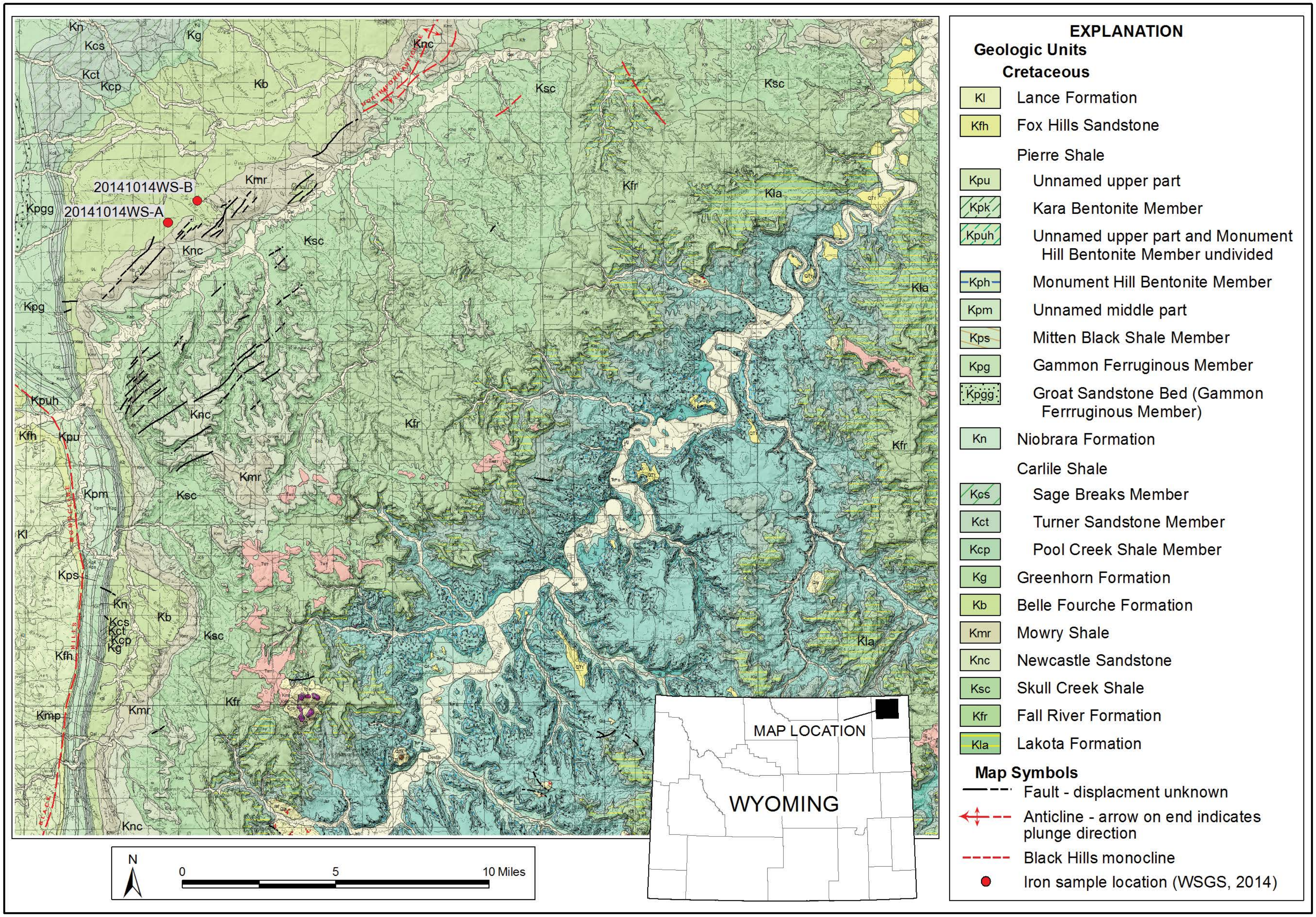

Figure 25. Geology in the Crook County area of northeast Wyoming with emphasis on Cretaceous units, because iron concretions are common in these formations. Map modified from Sutherland (2008).

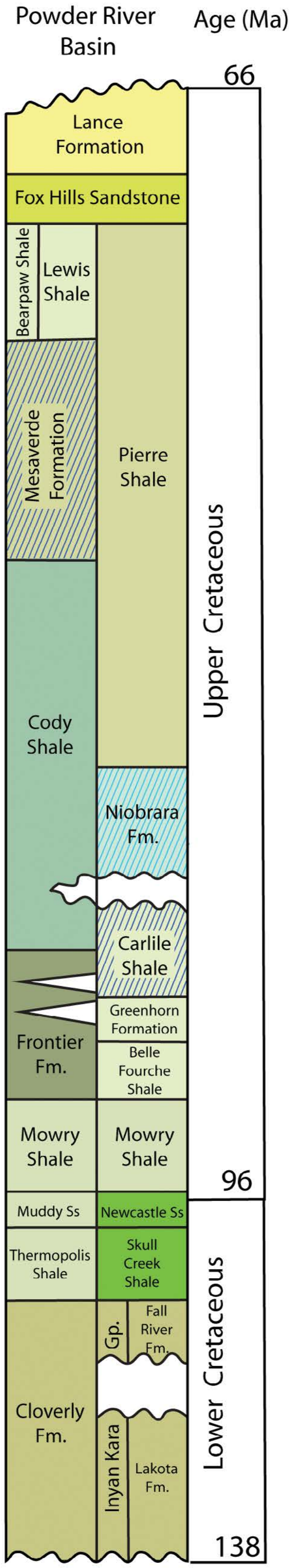

Figure 26. Stratigraphic column showing the relationships of Cretaceous units in the Power River Basin in northeast Wyoming. Modified from Love and others (1993), and colors updated to correlate with Love and Christiansen (1985, 2014).

uplift. Iron concretions are prevalent in this area of the formation. The maroon-black concretions are found in a black shale and gray bentonitic mud. Rusty to orange staining is common. They occur in a variety of sizes and shapes (fig. 27B) and often display unique textures referred to as "alligator skin" (fig. 27A). In cross section, the concretions have a black rind of varying thickness and a dark gray interior. They are occasionally magnetic and contain alternating layers of concretionary iron and siliceous material. Samples 20141014WS-A and 20141014WS-B are from these iron concretions (fig. 25). Table 14 displays chemical analyses of samples collected during field work.

Other Concretionary Iron

Thermopolis Shale concretionary iron, SE¼NE¼ sec. 3, T. 14 N., R. 74 W., Albany County

Iron concretions are present in the upper part of the Cretaceous Thermopolis Shale above a thin bentonite layer. The concretions, sample 20140917WS-A, are dark brown to black and concentric (fig. 28A) as well as solid concretionary layers up to a foot or more in thickness (fig. 28B). These concretions host sufficient iron content to be of limited economic use.

The siliceous shale from the Thermopolis is used in part of the normal cement manufacturing process. The concretionary iron must be screened out of the shale before the shale is crushed. The iron is set aside and ground separately to be added to the cement at a later stage in the process. The concretions, which would otherwise be a liability, are then combined with additional iron from other sources to get the proper chemistry and desired physical properties. See table 14 for chemical analyses.

Deacon's Prayer Group Claims, NW¼SW¼ and SW¼NW¼ sec. 17, SE¼SE¼ sec. 18, T. 32 N., R. 82 W., Natrona County

The Deacon's Prayer location occurs in the Fort Union Formation, which generally strikes northwest but is locally disrupted by folds and faults. The Fort Union hosts several heavily iron-stained layers and is overlain to the southwest by high hills of light-colored sandstones and conglomerates in the Wind River Formation. The sandstone in the

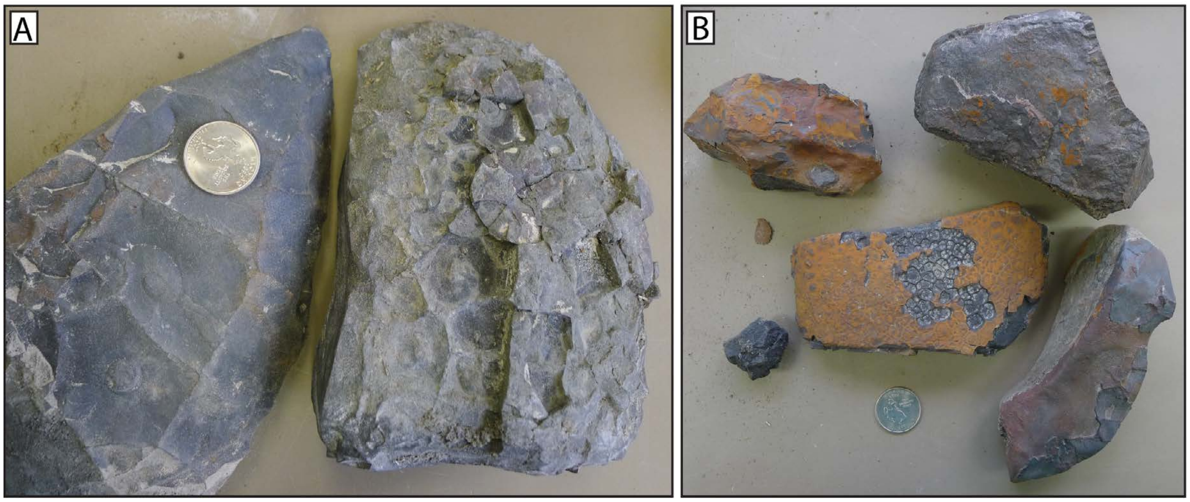

Figure 27. Iron concretions (samples 20141014WS-A & B) collected from the Belle Fourche Formation in northeastern Wyoming. A) "Alligator skin" texture and B) a variety of shapes, textures, and coloration of concretions.

Wind River Formation hosts large iron concretions greater than 6 ft across, which were sampled by the WSGS in 2012 in conjunction with an investigation of REE in Wyoming. Rinds on the concretions, 4 to 8 inches thick, are composed of dark brown to yellow, very coarse-grained, subangular, limonite-cemented, lithic arkose. The insides of the concretions are tan to yellow, very coarse-grained, subangular, calcite-cemented, limonitic, lithic arkose. Analysis of the interior of the concretions showed no significant REE enrichment, and only 1.26 percent Fe and 0.075 percent Ti. However, the concretionary rind contained 11.45 percent Fe and 0.094 percent Ti, accompanied by weak enrichment in most REE, yttrium, and uranium (Sutherland and others, 2013).

During this investigation, dark black-brown layers within the Fort Union Formation were sampled (sample 20141023WS-A) as well as magnetite-rich iron concretions (samples 20141023WS-B and -C, fig. 29A, C), which are also in the Fort Union. Red, hematitic sandstone (sample 20141023WS-D) with metallic banding was also found in some of the layers (fig. 29B). The rock layers in the area are vertical-subvertical and undulating. It is possible that the iron-mineralized area built up and was thickened by large scale folding and accompanying faulting. The concentrated magnetite and hematite here may be derived in part from a depositional environment but remobilized by subsequent fluid movement through porous sandstone and local faults and fractures. Iron concentrations were higher in the black, concretionary layers than in the hematite-rich and iron-stained layers (table 15).

Mule Creek area, SW¼SE¼ sec. 1, T. 38 N., R. 61 W., Niobrara County

This location was examined by the WSGS during investigations of REE in Wyoming (Sutherland and others, 2013). A grab sample analysis of tan to red laminated siltstone with moderate hematite and

Table 14. Chemical analyses of concretionary iron samples. Other elements present at >5x crustal concentrations are As, Bi, Te, and Cd. Se is present at >100x crustal concentrations. For full details, see appendix.

	Iron Concretions					
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20140917WS-A	46.6	23.9	8.39	0.29	0.12	0.17
20141014WS-A	67.2	5.95	2.02	0.07	0.07	0.78
20141014WS-B	58.3	11.65	3.97	0.14	0.07	0.55

limonite staining in the Cretaceous Pierre Shale showed 36.3 percent Fe_2O_3 along with elevated concentrations of some REE and thorium.

Red Gulch area, SW¼SE¼ sec. 18, T. 52 N., R. 91 W., Big Horn County
A sample collected from dark brown, sandy, iron concretions in the Jurassic Morrison Formation by the WSGS during investigations of REE in Wyoming (Sutherland and others, 2013) showed 19.35 percent Fe. The concretions weathered out from surrounding black to brown and gray, weathered, bentonitic, sandy shale interlaminated with brown, fine- to medium-grained, poorly cemented sandstone. These surrounding sediments contained only 2.53 percent Fe.

Figure 28. Iron concretions (sample 20140917WS-A) in the Thermopolis Shale at the Mountain Cement Company quarry south of Laramie, Wyoming. A) Concentric iron concretions and B) a concretionary iron layer.

Black Sandstone Deposits
The term, "black sandstone" describes a sedimentary rock composed of dark, heavy minerals that have typically accumulated in an ancient beach environment. These sands originate from crystalline sources rich in heavy minerals. When the source rock was exposed and eroded, the debris was deposited off shore. Continued settling, sorting, and erosion increased the concentration of minerals, and waves and currents deposited the sands in and along bars, where they remained as the sea regressed.

Black sandstone horizons are relatively common in the lower part of the Late Cretaceous Mesaverde Formation across Wyoming, Colorado, and New Mexico, and in the Mesaverde Group in Arizona (Houston and Murphy, 1962; 1970). The Wyoming deposits (fig. 30) occur at the top of the formation's basal sandstone (Houston and Murphy, 1962). The basal sandstone of the Mesaverde is typically a tan to buff, fine-grained sandstone overlain by a succession of interbedded sandstone, shale, carbonaceous shale, and coal or, in some areas, by black shale. The Mesaverde Formation is underlain by black shale of the Cretaceous Cody Shale. Together, the Cody and the Mesaverde represent a generally regressive sequence that transitioned from a deep marine to near-shore terrestrial environment over the depositional history of the two units. The black shale, which in places overlies the basal sandstone of the Mesaverde, represents a short-lived transgressive event (Houston and Murphy, 1962). The black sandstones of interest, which are titaniferous and host abundant magnetite, occur at or near the top of the basal sandstone and are

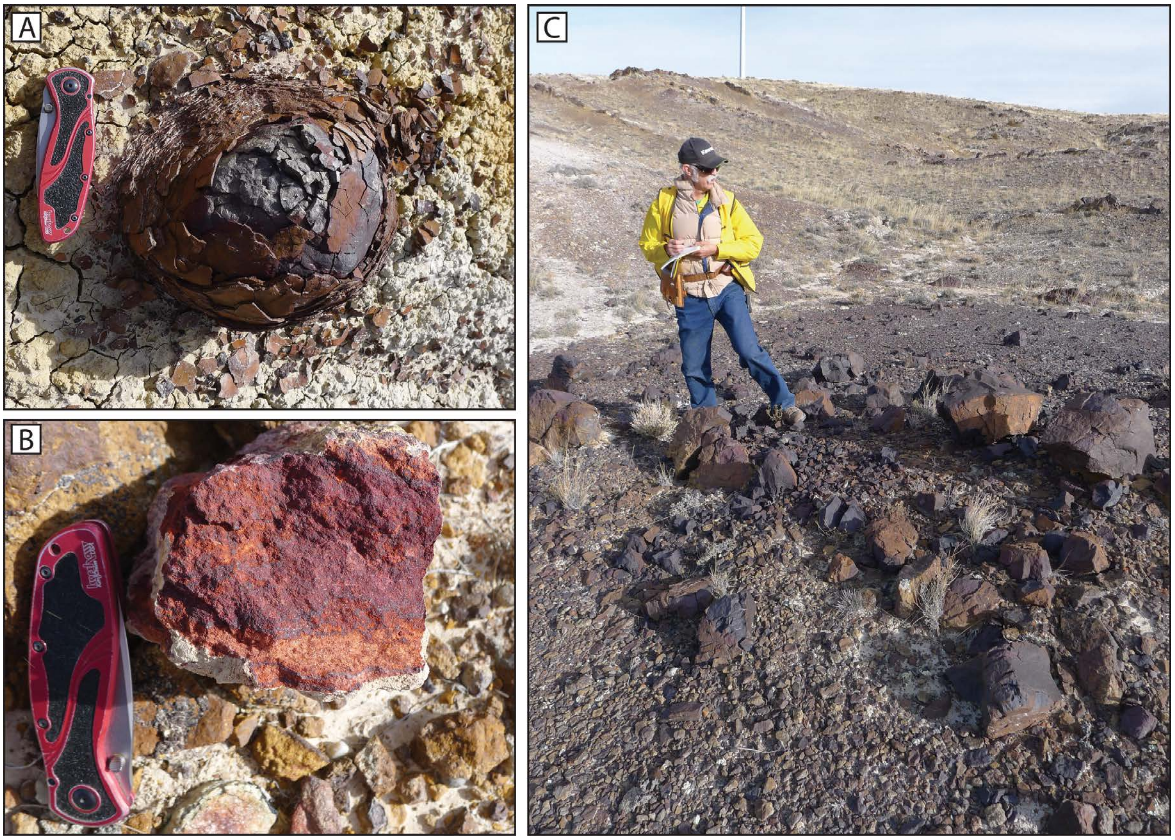

Figure 29. Iron deposits at the Deacon's Prayer Group claim. A) Concentric, cannonball-type iron concretion. B) Hematite-rich sandstone with thin metallic banding (sample 20141023WS-D). C) Geologist Wayne Sutherland investigates a concretionary iron layer (sample 20141023WS-B).

thought to be paleo beach placers analogous to modern, heavy mineral-rich, black sand beaches found in Australia (Houston and Murphy, 1962; 1970).

In Wyoming, heavy black sandstone deposits crop out within, or along the peripheries of intermontane basins and are dominated by occurrences within the Cretaceous Mesaverde Formation (fig. 30). A lesser number of heavy black sandstone deposits are found in the Cretaceous Frontier Formation and in the Jurassic Stump Sandstone. The Late Cretaceous black sandstone deposits all have very similar characteristics and stratigraphically are almost always associated with rocks deposited in a normal regressive sequence. The original long axes of the deposits were parallel to the direction of the strand lines of the Late Cretaceous sea, and individual black sandstone deposits are elongate lenticular bodies resembling the accumulation of sands along modern beaches. In cross-section, the deposits generally have a flat upper surface and a convex lower

Table 15. Chemical analyses of the Deacon's Prayer deposit.

Deacon's Prayer Group Claim						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20141023WS-A	28.4	54.2	4.17	0.2	0.01	0.36
20141023WS-B	37.5	47.5	5.45	0.28	0.02	0.14
20141023WS-C	38.6	47.9	2.46	0.14	0.04	0.11
20141023WS-D	22.9	68.5	3.89	0.21	0.05	0.05

surface. The overall mineralogical characteristics are the same from one deposit to another regardless of the geographic locality. However, the size and shape of the deposits are often difficult to estimate because of the younger strata cover (Houston and Murphy, 1962).

Heavy minerals within the black sandstones of the Mesaverde Formation were studied in detail by Houston and Murphy (1962; 1970) and are dominantly volcanic in origin. The heavy mineral fraction of the black sandstone consists of 79 to 97 percent opaque minerals, mostly iron-titanium oxides, including ilmenite and magnetite. The presence of titanium in these deposits has earned them the title of titaniferous black sandstones. The remaining heavy mineral fraction is composed of varying amounts of amphiboles, apatite, biotite, chlorite, epidote, garnet, monazite, rutile, sphene, spinel staurolite, tourmaline, and zircon. Zircon and garnet are the most abundant of the translucent heavy minerals, and radioactive elements within the monazite and zircon cause anomalous radioactivity associated with these deposits (Houston and Murphy, 1962). Several of the black sandstone deposits are known to host elevated concentrations of rare earth elements (Sutherland and others, 2013). Analyses of samples collected by the WSGS from the Mesaverde Formation in Wyoming are presented in table 16. Although both iron and titanium are present in these paleoplacers, neither metal has been commercially extracted for metallurgical use.

The black sandstone deposits in this report have been grouped by location in northern, central, or southern Wyoming. Deposits in the Bighorn basin are near Cowley and Lovell, Grass Creek, and Tensleep. Three deposits are exposed in the eastern part of the Wind River Basin, and outcrops occur at Sheep Mountain in the Laramie Basin. There are at least four deposits along the margins of the Rock Springs Uplift and one near Cumberland Gap. The Cliff Creek deposit in northwest Wyoming is unique in that it's in Late Jurassic rocks.

Northern Wyoming

Cowley Deposit, sec. 1, T. 56 N., R. 97 W., Big Horn County

The Cowley deposit is a magnetite-ilmenite bearing sandstone, which appears to be an erosional remnant of a much larger deposit. This black sandstone deposit is in the basal sandstone of the Mesaverde Formation and is covered by alluvium to the south. The Mesaverde strikes 120°, dips 9° SW, and appears to thin toward the south. The maximum black sandstone outcrop length is 900 ft along strike in a northwest direction. It has a maximum thickness of 3.5 ft and an average thickness of 1 ft. Analysis of a single sample showed 33.8 percent total Fe_2O_3 and 3.0 percent TiO_2 (Houston and Murphy, 1962).

Lovell Deposit, sec. 7, T. 55 N., R. 95 W.; sec. 12, T. 55 N., R. 96 W., Big Horn County

This magnetite-ilmenite bearing sandstone consists of two erosional remnants with a combined length of 5,000 ft. The south remnant, and larger of the two, is 3,000 ft long in a northwest direction and averages about 3 ft thick, with maximum thickness of 4 ft at the north end. This sandstone is a rusty brown layer within the light buff, fine-grained basal unit of the Mesaverde Formation that strikes 326° and dips 11° SW. This is probably the same unit that, with a similar strike and dip, hosts the Cowley deposit, about 11 mi to the northwest. An analysis of a select, high-grade sample contained 71.08 percent total Fe_2O_3 and 15.10 percent TiO_2 (Houston and Murphy, 1962; Wilson, 1976).

A WSGS sample (20120801WS-A, fig. 31) from the Lovell deposit was collected in 2012 for a study of REE. This is a dark brown to purple, thin-bedded, fine-grained sandstone up to 4 ft thick. Analysis of this sample showed 36.1 percent Fe_2O_3, 3.18 percent TiO_2, and weak enrichment in the LREE, gadolinium, and niobium (Sutherland and others, 2013). A 2014 sample, 20141015WS-A2, for this investigation showed an average 44.9 percent Fe_2O_3 and 5 percent TiO_2, while a high-grade sample, 20141015WS-A1, contained 60.6 percent Fe_2O_3 and 11.9 percent TiO_2 (table 16).

Grass Creek area, (North Deposit) E½SE¼ sec. 8, SW¼SW¼ sec. 9, NW¼NW¼ sec. 16, T. 46 N., R. 98 W.; and (South Deposit) S½NE¼ sec. 33, S½NW¼ sec. 34, T. 46 N., R. 98 W., Hot

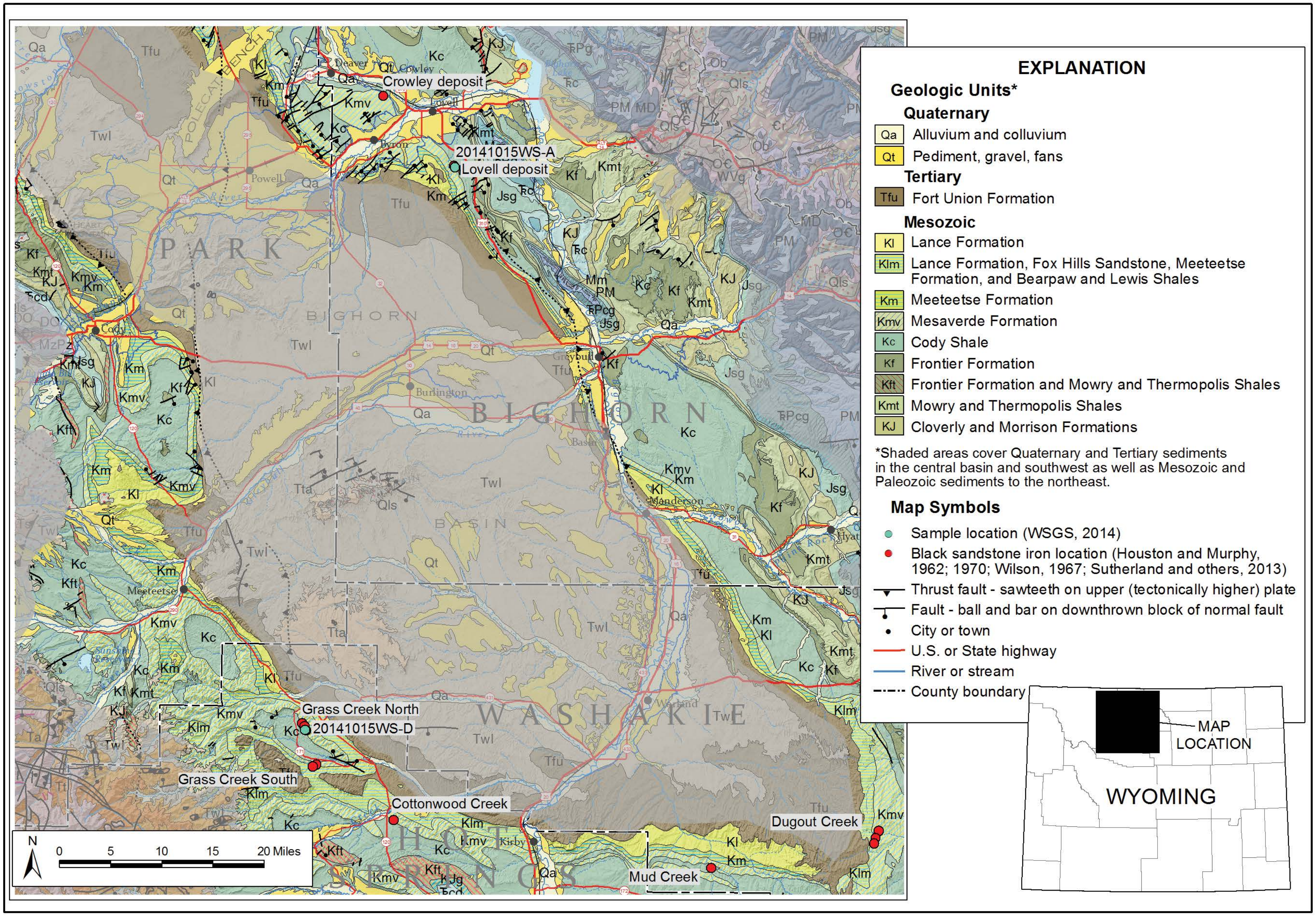

Figure 30. Geology of the Big Horn Basin with emphasis on Cretaceous formations and black sandstone deposits within the Mesaverde Formation. Map modified from Love and Christiansen (1985, 2014).

Table 16. Chemical composition of black sandstone deposits. Many other elements are present at >5x crustal concentrations including As, Ce, Cr, Dy, Er, Gd, Ho, La, Lu, Nb, Nd, Pr, Sn, Tb, Tm U, Y, Yb, Zr, Zn, Bi, and Se. Elements present at >100x crustal concentrations are Hf and Th. For full details, see appendix.

	Black Sandstones					
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20141015WS-D	40.5	5.58	0.9	28.5	0.02	0.27
20141015WS-A1	60.6	9.56	2.12	11.9	0.07	0.43
20141015WS-A2	44.9	31.7	3.26	5.01	0.05	0.29
20141017WS-D	0.7	96.2	0.18	0.07	0.2	0.02
20141023WS-E	62.2	4.9	1.72	7.99	0.02	0.32
20120730WS-A[1]	17.5	75.7	1.67	0.1	0.03	0.02
20120731WS-A[1]	10.85	65.3	3.43	0.19	0.1	0.17
20120731WS-B[1]	14.75	66	3.33	0.2	0.27	0.2
20120731WS-C[1]	37.5	34.7	2.89	5.51	0.87	0.73
20120731WS-H[1]	44.7	24.5	2.9	12	0.03	0.24
20120731WS-G[1]	15.2	67.7	7.44	0.37	0.7	0.17
20120801WS-A[1]	36.1	39.7	3.66	3.18	0.1	0.2

[1]*Sutherland and others (2013)*

Springs County
According to Houston and Murphy (1962), these are the largest high-grade titaniferous black sandstone deposits in Wyoming. They occur at the top of the basal part of the Mesaverde Formation. The magnetite-ilmenite bearing sandstone deposit crops out in two isolated segments: one on either side of the Grass Creek anticline. The deposit is believed to be two erosional remnants of a once continuous deposit (Houston and Murphy, 1962). The northern segment (fig. 32), although partially covered by overlying strata up to 100 ft thick, is about 5,600 ft long, a maximum of 680 ft wide, and averages about 10–12 ft thick. The exposed deposit trends 345° within strata that strike 335° and dip 15° NE (Houston and Murphy, 1962). The southern segment, on the south side of the Grass Creek anticline, strikes 100°, dips 30–35° S, and is poorly exposed. These outcrops are disrupted by faults and appear sporadically over a distance of more than 1,600 ft in an east-west direction. The black sandstone has a maximum exposed thickness of 3.5 ft near the eastern end of the outcrop and is at least 5 ft thick in a partial exposure at the western end. The average chemistry of 25 samples from both the northern and southern outcrops showed 23.0 percent Fe_2O_3 and 16.0 percent TiO_2 (Houston and Murphy, 1962).

Two undated samples from the WSGS files, representing both the northern and southern outcrops, were analyzed during an investigation of REE in Wyoming. Specific outcrop locations for these are unknown. Analyses showed 31.1 percent Fe and 0.116 percent Ti for the northern outcrop. The southern outcrop sample showed 33.6 percent Fe, 10.0 percent Ti, elevated concentrations of most REE plus yttrium and niobium (Sutherland and others, 2013). The northern outcrop was sampled again for this study. Due to field conditions at the time, samples of black, heavy, magnetite-rich sandstone were collected from the talus rather than from the cap rock outcrop. Sample 20141015WS-D contained 40.5 percent Fe_2O_3 and 28.5 percent TiO_2 (table 16).

Cottonwood Creek (Waugh) Deposit, SE¼ sec. 26, T. 45 N., R. 97 W., Hot Springs County
This magnetite-ilmenite bearing sandstone deposit is about 10 mi southeast of the Grass Creek deposit and located on the northeast flank of the Waugh anticline. The deposit forms an irregular patch,

Figure 31. Lovell deposit black sandstone with A) concentric banding and differential weathering surfaces and B) magnetite pebble debris with a magnet attracted to a piece (sample 20141015WS-A).

thought to be an erosional remnant of a larger deposit, which extends 150 ft in a northwest direction and 150 ft in a northeast direction (Houston and Murphy, 1962; Wilson, 1976). The maximum exposed thickness is 9 ft. This deposit occurs 5.5 ft above the basal sandstone of the Mesaverde Formation, separated from it by a layer of gray shale and thin coal partings. This dark brown to black and rusty-brown, fine- to medium-grained, cross-bedded sandstone forms discontinuous outcrops that strike 317° and dip 20° NE.

Four samples analyzed by Houston and Murphy (1962) averaged 38.4 percent total Fe_2O_3 and 9.7 percent TiO_2. Three of these came from the lower 2 ft of the deposit, which is a light buff to tan sandstone and averaged 35.4 percent Fe_2O_3 and 7.4 percent TiO_2 in material that superficially appeared to be barren. The fourth sample, collected 4 ft below the top of high-grade rock, contained 47.2 percent Fe_2O_3 and 16.8 percent TiO_2.

Three WSGS samples (20120731WS-A, B, & C) were collected from the Cottonwood Creek deposit in 2012 for a study of REE. Sample 20120731WS-A is a dark-brown heavy sand layer about 3 ft thick that appears to be a channel sand. The darkest material is an exterior desert varnish over a rusty-brown interior. The other two samples represent several dark brown, iron-rich, fine- to medium-grained, lenticular sandstone bodies in this area. Analysis of sample 20120731WS-A showed only 10.85 percent Fe_2O_3 and 0.19 percent TiO_2. Sample 20120731WS-B showed 14.75 percent Fe_2O_3 and 0.2 percent TiO_2, while sample 20120731WS-C showed 37.5 percent Fe_2O_3 and 5.51 percent TiO_2, indicating that the distribution of heavy minerals here may be erratic in some places. 20120731WS-C was also the only sample to show any REE enrichment (Sutherland and others, 2013).

Dugout Creek Deposit, secs. 34 and 35, T. 45 N., R. 89 W.; secs. 2 and 11, T. 44 N., R. 89 W., Washakie County

This is the largest black sandstone deposit reported in Wyoming and occurs in the uppermost unit of the basal sandstone in the Mesaverde Formation (Houston and Murphy, 1962). The magnetite-ilmenite bearing sandstone extends about 2.7 mi in the north-northeast direction with maximum width of 1,500 ft. The body dips northwest beneath younger rocks, and the thickness ranges up to 25 ft, but averages 10–15 ft. The strike of the bedding of this deposit is 195°, with a dip of 3–5° NW. Samples collected by Houston and Murphy (1962) averaged 38.9 percent Fe_2O_3 and 5.9 percent TiO_2. However, two select, high-grade samples averaged 62.2 percent Fe_2O_3 and 10.5 percent TiO_2.

A WSGS sample (20120731WS-H) from the Dugout Creek deposit was collected in 2012 for a study of REE. This sample consists of fine- to medium-grained, dark-brown to purple and orange, cross-bedded sandstone about 3 ft thick that overlies a yellowish brown sandstone. Analysis of this sample

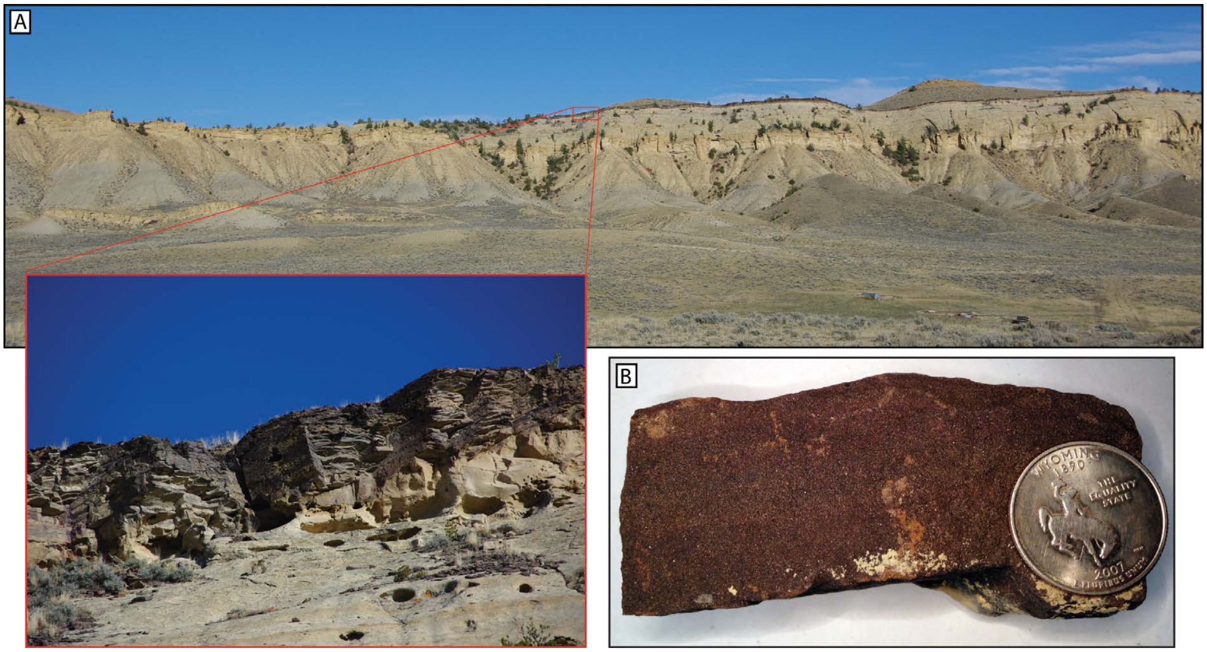

Figure 32. A) Panorama of the Grass Creek North black sandstone deposit and location of sample 20141015WS-D. The dark, magnetite-rich layer can be seen at the top with varying thickness. The inset photo shows the layer in more detail. B) Close up of the black sandstone with varying color and slight layering.

showed 44.7 percent Fe_2O_3, 12 percent TiO_2, and slight enrichment in all REE except dysprosium and holmium (Sutherland and others, 2013).

Mud Creek Deposit, sec. 19, T. 44 N., R. 91 W., Washakie County

Located in the center of section 19, this magnetite-ilmenite bearing black sandstone has an exposed length of 1,500 ft in a west-northwest direction parallel to the 290° strike of the Mesaverde Formation. This exposed length is believed by Houston and Murphy (1962) to be close to the true width of the Cretaceous strand line, which trended within 20° of true north at the time of deposition. The deposit forms the uppermost part of the Mesaverde's basal sandstone and has an outcrop width of about 100 ft. The strata dip 10° northward into the Bighorn Basin, in which this is the southernmost black sandstone deposit. There are two high-grade zones each underlain by a rusty, barren zone about 3 ft thick. The upper high-grade zone at the eastern end of the deposit is 4.5 ft thick, and the lower high-grade zone is 3.0 ft thick (Houston and Murphy, 1962). The average composition of three samples from the high-grade zones contained 30.0 percent iron and 8.0 percent TiO_2 (Wilson, 1976).

Cliff Creek, S½S½ sec. 33, T. 38 N., R. 114 W., Sublette County

The Cliff Creek deposit is one of the few magnetite-ilmenite bearing black sandstone deposits not found in the Cretaceous Mesaverde Formation. Instead, it occurs in the upper part of the Stump Sandstone of Late Jurassic age and is generally thought to be a beach placer laid down during a transgressive rather than regressive sequence. However, Houston and Murphy (1962) opine that there were some oscillations during the advance of the Jurassic sea and that the black sandstones here mark a short-lived regression. The deposit is 3.7 ft thick and varies from low grade near the base to high grade at the top. The host rock is a dark gray to red weathered, hard, limy, oolitic, fine- to coarse-grained, greenish sandstone with hematitic partings. Grains are 50 percent quartz, 30 percent oolitic calcite, and the remainder is composed of hematite, limonite, and glauconite (Sutherland and others, 2013). Four samples varied from 5.7 to 54.9 percent total Fe_2O_3 and 0.70 to 20.15 percent TiO_2 (Houston and Murphy, 1962).

Two samples (20121003JC-D & E) were collected by the WSGS from the Cliff Creek deposit in

2012 for a study of REE. Sample 20121003JC-D is representative of the fine-grained material and 20121003JC-E is coarse-grained sandstone. These samples showed 3.5 and 2.87 percent Fe_2O_3, and 0.27 and 0.1 percent TiO_2 respectively; neither sample showed any REE enrichment (Sutherland and others, 2013).

Central Wyoming

Coalbank Hills Deposit, sec. 5, T. 34 N., R. 88 W., Natrona County

This magnetite-ilmenite bearing sandstone is exposed as the cap rock on two buttes about 700 ft apart. If the localities were connected, the length would be in excess of 1,400 ft with a thickness of about 5 ft. The deposit occurs in the uppermost unit of the basal sandstone in the Mesaverde Formation and strikes 320° with a dip of 23° NE (Houston and Murphy, 1962). Five outcrop samples averaged 30.1 percent iron and 12.5 percent TiO_2 (Wilson, 1976).

Poison Spider, NE¼NE¼ sec. 1, T. 33 N., R. 84 W.; SE¼SE¼ sec. 36, T. 34 N., R. 84 W., Natrona County

This magnetite-ilmenite bearing sandstone deposit is the only one reported to occur in the Lewis Shale. It is positioned about 375 ft above the base of the Lewis near the top of a marine tongue, just below a tongue of continental rocks of the Meeteetse Formation. The lithology of this deposit is similar to the Mesaverde Formation and represents an early regression of the interior seaway. The bedding strikes 138° and dips 70° SW. The deposit is up to 7 ft thick and extends for about 300 ft. However, overlying cover, erosion, and cross-cutting faults make it difficult to estimate the entire size. The average of 13 analyses of weathered rock was 21.7 percent total Fe_2O_3 and 5.2 percent TiO_2, but a less altered sample from a depth of 17 ft in a prospect pit contained 63.7 percent Fe_2O_3 and 7.9 percent TiO_2 (Houston and Murphy, 1962). In the field, a large prospect pit exposes a rusty-maroon, magnetite-rich, highly faulted area (fig. 33), which was sampled (20141023WS-E) for this investigation. Chemical analyses found 62.2 percent Fe_2O_3 and 7.99 percent TiO_2 (table 16).

Clarkson Hill Deposit, NE¼NE¼ sec. 20, T. 31 N., R. 82 W., Natrona County

This deposit occurs in the upper part of the Parkman Sandstone Member which is a basal unit of the Mesaverde Formation. The magnetite-ilmenite bearing sandstone deposit has an exposed length of about 150 ft in an east-west direction, a maximum width of about 20 ft, and a maximum exposed thickness of 5.6 ft. The unit strikes 260° and dips 38° N. Chemical analysis of one sample showed 26.1 percent Fe_2O_3 and 4.8 percent TiO_2 (Houston and Murphy, 1962).

Southern Wyoming

Cumberland Gap area, sec. 25, T. 18 N., R. 117 W.; secs. 18, 19, and 30, T. 18 N., R. 116 W., Uinta County

Numerous prospect pits dot this 2.5 mi long by several hundred-foot wide zone of heavy mineral-hosting black sandstones in the lower part of the Cretaceous Frontier Formation. These black sandstones are best identified by radiation detection, in which the anomaly is about five times higher than background. The deposit consists of two main ledges and several minor ledges of magnetite-ilmenite bearing sandstone that are not visually apparent due to lack of contrast with the surrounding dark rocks. The black, heavy mineral sandstones are interbedded with siltstone and shale, along with minor amounts of coal and bentonite. The upper ledge of sandstone appears to be a regressive marine deposit, or beach placer, while the depositional provenance of the lower main ledge is unknown (Houston and Murphy, 1962).

The tops of the two, major, heavy mineral bearing sandstone beds lie about 120 ft and 355 ft above the basal contact of the Frontier Formation with the underlying Aspen Shale. The longest exposure is about 600 ft parallel to the strike of the bedding at 42°, and about 15 ft thick. The host rock dips 15° NW. Average analysis for two samples from the upper black sandstone was 20 percent total Fe_2O_3 and 9.5 percent TiO_2. Two samples from the lower black sandstone averaged 7.1 percent TiO_2 and 27 percent total Fe_2O_3 (Houston and Murphy, 1962).

Frontier Formation, Spring Gap, NE¼SW¼ sec. 8, and SE¼NW¼ sec. 30, T. 16 N., R. 117 W., Uinta County

An altered sandstone in the lower part of the Cretaceous Frontier Formation exhibits an elemental assemblage typical of beach placer deposits and contains limonite, pyrite, leucoxene, and an unidentified REE-bearing mineral. This area was examined by the WSGS during an investigation of REE in Wyoming in 2012. An exploration trench in section 30 exposes light green to yellow weathered, angular to sub-angular, medium- to coarse-grained sandstone (sample 20121128JC-E) that is overlain by a dark green to dark brown, angular, medium- to coarse-grained laminated sandstone (sample 20121128JC-D). The lower, light green sandstone is not significantly enriched in REE, and contains only 4.82 percent Fe_2O_3 and 0.28 percent TiO_2. However, the upper, dark green to dark brown sandstone contains 28.1 percent Fe_2O_3, 4.03 percent TiO_2 and is enriched in all of the REE as well as scandium, yttrium, and niobium (Sutherland and others, 2013). The same altered Frontier Formation sandstone as in sec. 30 crops out in section 8. The exposure in a prospect pit there is similar to that of sample 20121128JC-D. This dark green to dark brown, angular, and medium- to very coarse-grained sandstone (sample 20121128JC-F) is enriched in REE plus scandium, yttrium, and niobium and contains 15.25 percent Fe_2O_3 and 2.18 percent TiO_2 (Sutherland and others, 2013).

Figure 33. Sample locality 20141023WS-E, the Poison Spider black sandstone deposit. Outcrop is part of an old excavation pit and reveals a fault zone along the entirety of the exposure.

White Mountain Disseminated Iron, central sec. 18, T. 20 N., R. 105 W., Sweetwater County

The White Mountain area is of interest because native iron was reported in the vicinity of the contact between the Wasatch Formation and the overlying Green River Formation. A sample of white-buff sandstone containing millimeter-sized silver beads was brought to the WSGS by prospector Jack Krmpotich of Rock Springs in 2007. These beads were later identified as pure iron by X-ray diffraction. No pure iron was found during field work. However, white sandstone with millimeter-size, rusty, weathered-out spots were found (sample 20141017WS-A, fig. 34C). It is presumed this could be the weathered version of the rock once containing pure iron. Also, areas with strong hematite and limonite staining were sampled (samples 20141017WS-B and C1, fig. 34A). These areas often contained concretions varying in size from less than 6.4 mm to 5 cm (<0.25 in to 2 in). Some concretions appeared limonitic and generally round, and some appeared metallic and angular (sample 20141017WS-C2, fig. 34B). Table 17 displays the analyses of the various sandstones and concretions sampled in the area.

Union Pacific Railroad Co. Deposits, sec. 19, T. 19 N., R. 101 W.; sec. 11, T. 17 N., R. 102 W., Sweetwater County

Two black sandstones in the basal unit of the Ericson Sandstone comprise the Union Pacific Railroad Co. deposits. The Ericson is part of the Mesaverde Group, equivalent to the Mesaverde Formation in northern and central Wyoming. The larger of the two magnetite-ilmenite bearing sandstones is entirely exposed in section 19, with a length of 2,700 ft, an average thickness of 7 ft, and an average width of 150 ft. The deposit trends 40° and is cut by a fault normal to this trend. The fault has dropped the northeasterly third of the mineralized zone about 60 ft below the southwestern part of the deposit. Samples collected from a shaft and along the outcrop averaged 20.2 percent iron and 21.2 percent TiO_2 (Wilson, 1976).

The smaller deposit, in section 11, caps a ridge for a distance of 2,500 ft, varies in width from 50 to 100 ft, and has an average thickness of 4 ft. This deposit strikes 50° and dips 6° SE. An average of three samples contained 18.4 percent iron and 22.2 percent TiO_2 (Wilson, 1976).

Black Butte (Zalenka) Deposit, sec. 30, T. 18 N., R. 101 W.; sec. 1, T. 17 N., R. 102 W., Sweetwater County

Two magnetite-ilmenite sandstone deposits are found in the Black Butte area. Both deposits occur in the Ericson Sandstone which is a part of the Mesaverde Group, and there is a possible correlation with the Red Creek and Murphy deposits to the south. The larger of the two deposits crops out sporadically in section 30 and is exposed in prospect pits at each end of the deposit. The deposit trends northeast with a length of 1,500 ft and is 3–4 ft thick. Bedding in the adjacent rocks strikes 40° and dips 7° SE. The smaller deposit, in section 1, caps a low ridge, is poorly exposed, and is about 1 ft thick. The average of three analyses for the larger deposit was 15.0 percent total Fe_2O_3 and 14.0 percent TiO_2 while one sample from the smaller deposit showed 35.8 percent Fe_2O_3 and 28 percent TiO_2 (Houston and Murphy, 1962).

Figure 34. Sample 20141017WS-D from the Murphy No. 2 deposit vicinity. The dark rocks have a metallic appearance with limonite and hematite stain.

Murphy Deposit No. 2, sec. 8, T. 16 N., R. 102 W., Sweetwater County

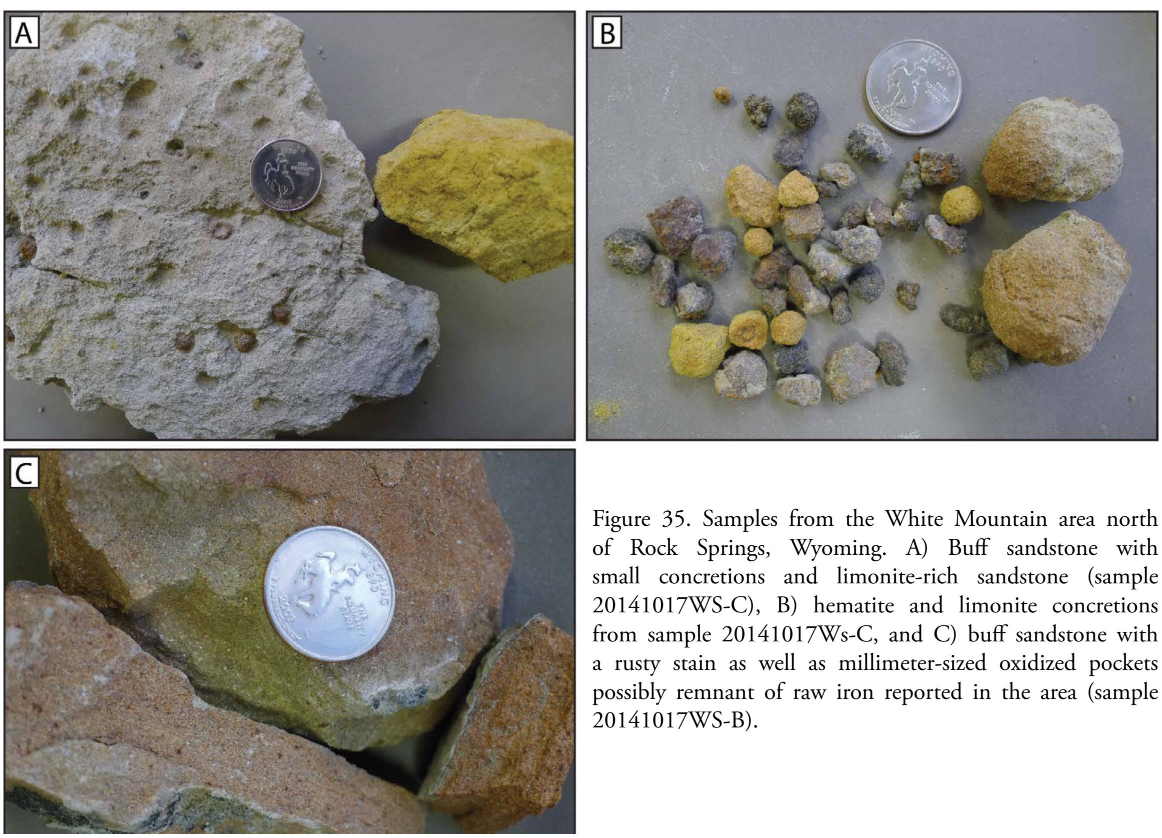

Figure 35. Samples from the White Mountain area north of Rock Springs, Wyoming. A) Buff sandstone with small concretions and limonite-rich sandstone (sample 20141017WS-C), B) hematite and limonite concretions from sample 20141017Ws-C, and C) buff sandstone with a rusty stain as well as millimeter-sized oxidized pockets possibly remnant of raw iron reported in the area (sample 20141017WS-B).

Table 17. Analyses of the White Mountain area samples. Other elements present at >5x crustal concentrations are U, Sb, and Se. Arsenic is present at >100x crustal concentrations. For full details, see appendix.

White Mountain Area						
Element	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	S (%)	P_2O_5 (%)
20141017WS-A	34.9	52.2	2.75	0.25	0.15	0.18
20141017WS-B	3.38	72.4	8.11	0.24	0.13	0.08
20141017WS-C1	10.2	73.4	7.58	0.29	0.14	0.22
20141017WS-C2	35.5	48.7	5.2	0.28	0.38	0.09

Similar to the Yenko deposit, this magnetite-ilmenite bearing sandstone deposit is exposed on the north slope of a mesa for 450 ft and is a channel fill within the Ericson Sandstone. The rocks strike 25° and dip 7° SE. The average thickness of the deposit is 3 ft. Samples averaged 15.4 percent iron and 19.7 percent TiO_2 (Wilson, 1976).

This site was visited during this investigation, but due to the steep slope it was not possible to approach the outcrop. However, iron-rich debris was collected in the talus. Pieces are colored by heavy black desert varnish, rusty hematite, and limonite staining (fig. 35). Some samples are dense and slightly magnetic but vary in appearance from sedimentary to concretionary. Overall, the samples collected were not iron-bearing at 0.7 percent total Fe_2O_3 (table 16).

Yenko Deposit, sec. 13, T. 15 N., R. 103 W., Sweetwater County

The Yenko magnetite-ilmenite bearing black sandstone deposit is hosted in the basal part of the Ericson Sandstone. The deposit crops out on the west wall of a mesa and trends northeast until disappearing under a 200 ft thick cover of younger sediments. It has a width of 250 ft and an average thickness of 5.5 ft. The average composition of four samples from the deposit included 16.3 percent iron and 22.4 percent TiO_2 (Wilson, 1976).

Salt Wells Creek Deposit (Murphy No. 1), SE¼ sec. 7, T. 14 N., R. 103 W., Sweetwater County

This magnetite-ilmenite bearing sandstone deposit is a northeast-trending, lens-shaped outcrop about 250 ft long and up to 3 ft thick. Bedding adjacent to the deposit strikes 82° and dips 5° S. The black sandstone is similar to the Red Creek deposit, about 17 mi southwest, and appears as a channel fill at the top of massive, white to buff, littoral marine sandstone within the Ericson Sandstone. Chemical analyses of two samples showed an average of 25.5 percent total Fe_2O_3 and 22.5 percent TiO_2 (Houston and Murphy, 1962).

Red Creek Deposit, NE¼ sec. 22, T. 12 N., R. 105 W., Sweetwater County

The Red Creek deposit is an irregular shaped lens which fills a channel cut into the underlying, 60 ft thick, white basal sandstone of the Ericson Sandstone. The exposed part of the magnetite-ilmenite bearing sandstone measures a maximum 800 ft in an easterly trend, but the concentration of heavy minerals is limited to about 125 ft of this distance. The higher-grade rock averages about 6 ft thick at the western end of the exposure, while the eastern end is mostly lower grade rock and thins out from 4 ft. Bedding in rocks adjacent to the black sandstone strike due west and dip 20° N. Eight samples from this deposit averaged 19.0 percent total Fe_2O_3 and 14.3 percent TiO_2 (Houston and Murphy, 1962).

Sheep Mountain, SE¼ sec. 10, T. 15 N., R. 77 W., Albany County

This is one of the eastern-most magnetite-ilmenite bearing sandstone deposits. It is surrounded by alluvium and exposed at intervals over a distance of about 1,900 ft in a northwest trend. The maximum outcrop width of about 50 ft and a maximum thickness of 17 ft were measured in a prospect pit by Houston and Murphy (1962). However, the unit thins toward the southeast to about 2 ft. The stratum containing the deposit is poorly exposed but is thought to be the Mesaverde basal sandstone. It strikes 315–330° and dips 25–35° NE. Seven samples collected from a prospect pit averaged 40.4 percent total Fe_2O_3 and 15.6 percent TiO_2 (Houston and Murphy, 1962).

Separation Rim, SE¼NW¼ sec. 22, T. 24 N., R. 89 W., Northwestern Carbon County

A black to dark brown, fine-grained, iron-stained sandstone crops out along a hogback ridge in the Separation Rim quadrangle. This black sandstone had not been previously investigated and is located just above the Haystack Mountain Formation in the lower part of the Allen Ridge Formation within the Mesaverde Group. An analysis of this black sandstone, sample 20120730WS-A, collected by the WSGS during investigations of REE in Wyoming, showed 17.5 percent Fe_2O_3, 0.1 percent TiO_2, and no REE enrichment (Sutherland and others, 2013).

CONCLUSIONS

Iron has been a significant resource in the history of Wyoming, providing raw material, jobs, and economic development. The earliest iron mining and use was by Paleo-Indians in the Sunrise area for iron oxide pigment between 8,000 and 13,000 years ago. In the late 1800s, Wyoming produced concretionary hematite from the Rawlins area for use as paint pigment and smelting flux. Titaniferous magnetite, identified prior to 1850, has been mined sporadically from magmatic segregation deposits in the Iron Mountain area for use as a weighting additive in cement. Archean BIF mined in both the Hartville Uplift, between 1899 and 1980, and near South Pass, from 1962 to 1983, accounted for more than 132 million tons of iron ore, shipped out of state for iron and steel manufacture. Over time, numerous smaller deposits across the state have also been investigated as potential sources of iron.

Although numerous small iron deposits exist, relatively large iron resources are needed to justify expenditures by the business community to rebuild older established and new iron mining infrastructure. Additional funding and planning are also necessary to process iron ore into saleable products. However, iron will continue to be an important resource necessary for global urbanization and consumerism. This investigation has added data and compiled historical occurrences to improve the information on iron deposits in Wyoming, and recent exploration in the Granite Mountains of central Wyoming may have identified a new major deposit of BIF. That iron deposit, combined with remaining iron ore in both the Sunrise and South Pass areas, and the information gathered from this report may encourage exploration and provide the motivation needed to again turn Wyoming into an iron-producing state.

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REFERENCES

Ackerman, W.C., 1969, Mineral Patent Application of the C.F.&I. Steel Corporation Pueblo, Colorado for the Muskrat Lodes: U. S. Department of the Interior Bureau of Land Management Mineral, Report No. W-0325358, 106 p.

Advanced Exploration Inc., 2008, Iron Ore Product, at http://www.advanced-exploration.com/industry/io_products/, accessed Sept. 15, 2014.

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

Aughey, S., 1886, Annual Report of the Territorial Geologist to the Governor of Wyoming: Cheyenne,Wyo., 61 p.

Bayley, R.W., 1963, A preliminary report on the Precambrian iron deposits near Atlantic City, Wyoming: U.S. Geological Survey Bulletin 1142-C, p. C1-C23.

Bayley, R.W., 1968, Geologic map of the Bradley Peak quadrangle, Carbon County, Wyoming: U. S. Geological Survey Geologic Quadrangle Map GQ-733, scale 1:24,000.

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.

Biek, B., 2007, Concretions and nodules in North Dakota: North Dakota Geological Survey, at https://www.dmr.nd.gov/ndgs/ndnotes/concretions/concretions.asp, accessed Nov. 10, 2014.

Biggs, C.A., 1951, Stratigraphy of the Amsden Formation in the Wind River Range and adjacent areas in northwestern Wyoming: Laramie, University of Wyoming, M.A. thesis, 121 p.

Birkinbine, J., 1890, Report upon the manufacture of pig iron at Cheyenne, Wyoming: Report to the Cheyenne Board of Trade, unpublished, 28 p.

Blackstone, D.L., 1965, Gravity thrusting in the Bradley Peak Seminoe Dam quadrangles, Carbon County, WY and the relationship to the Seminoe iron deposits: Geological Survey of Wyoming [Wyoming State Geological Survey], Preliminary Report No. 6, 13 p.

Blackstone, D.L., and Hausel, W.D., 1992, Field guide to the Seminoe Mountains, in Frost, B.R., and Roberts, S., eds., Mineral Resources of Wyoming: Wyoming Geological Association 42nd annual field conference, Guidebook, Geological Survey of Wyoming (Wyoming State Geological Survey), Reprint No. 48, p. 201-210.

Bolmer, R. L., and Biggs, P., 1965, Mineral resources and their potential on Indian Lands, Wind River Reservation, Fremont and Hot Springs counties, Wyoming: U.S. Bureau of MinesPreliminary Report 159, 103 p.

Boyle, A.C., Jr., undated, circa 1920s, Excerpt from report of A.C. Boyle, Jr., Geologist, Union Pacific System, on the Rawlins, Wyo. iron ore deposits: Geological Survey of Wyoming [Wyoming State Geological Survey] Mineral Report UN-10, 34 p.

Business Wire, July 2011, Titan Iron Ore Corp. completes acquisition of option on Wyoming iron complex, at http://www.businesswire.com/news/home/20110707006856/en/Titan-Iron-Ore-Corp.-Completes-Acquisition-Option, accessed Dec. 5, 2014.

Chamberlain, K.R., Frost, C.D., and Frost, B.R., 2003, Early Archean to Mesoproterozoic evolution of the Wyoming Province – Archean origins to modern lithospheric architecture: Canadian Journal of Earth Sciences, v. 40, no. 10, p. 1357-1374.

Chan, M.A., Ormo, A. J., Stich, M., Souza-Egipsy, V., and Komatsu, G., 2007, Models of iron oxide concretion formation: field, numerical, and laboratory comparisons: Geofluids 7, p. 13.

Cola, E.C., and Sutherland, W.M., 2014, Preliminary geologic map of the Mc Intosh Meadows 7.5' quadrangle, Fremont and Natrona counties, Wyoming: Wyoming State Geological Survey Open File Report 14-2, 39 p., scale 1:24,000.

Dewitt, E., Redden, J.A., Bruscher, D., and Wilson, A.B., 1989, Geologic map of the Black Hills area, South Dakota and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1910, scale 1:250,000.

Diemer, R. A., 1941, Titaniferous magnetite deposits of the Laramie Range, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Bulletin 31, 23 p.

Dow, V.T., 1961, Magnetite and ilmenite resources, Iron Mountain area, Albany County, Wyoming: U.S. Bureau of Mines Information Circular 8037, 133 p.

Duhling, W.H., Jr., 1971, Precambrian banded iron formation at Copper Mountain: Laramie, Wyo., Geological Survey of Wyoming [Wyoming State Geological Survey] Mineral Report MR#71-1, and Natural Resources Research Institute of University of Wyoming, , p. 25.

Els, F., 2015, "Another day another iron ore price drop," Mining.com, at http://www.mining.com/another-day-another-iron-ore-price-drop-31353/?utm_source=digest-en-mining-150127&utm_medium=email&utm_campaign=digest, accessed Jan. 2015.

Endlich, F.M., 1879, Report on the geology of the Sweetwater district, in Hayden, F.V., Eleventh annual report of the U. S. Geological and Geographical Survey of the Territories embracing Idaho and Wyoming, being a report of exploration for the year 1877: Washington, D.C., United States Government Printing Office, p. 3-158.

Fields, E.D., 1963, Precambrian rocks of the Halleck Canyon area, Albany County, Wyoming: Laramie, Wyo., University of Wyoming, M.S. thesis, 91 p., scale 1:12,000.

Franks, P.C., 1969, Synaeresis features and genesis of siderite concretions, Kiowas Formation (Early Cretaceous), north-central Kansas: Journal of Sedimentary Petrology, v. 39, no. 3, p. 799-803.

Frey, E., 1947, Hartville iron district, Platte County, Wyoming: U.S. Bureau of Mines, Report of Investigations 4086, 3 p., 16 figs.

Frost, B.R., and Frost, C.D., Lindsley, D.H., Scoates, J.S., and Mitchell, J.N., 1993, The Laramie Anorthosite Complex and Sherman batholith: geology, evolution, and theories of origin, in Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., eds., Geology of Wyoming: Wyoming State Geological Survey Memoir 5, p. 118-161.

Fruchey, R.A., 1962, Overthrusting in the Mt. Thompson and adjacent areas, Sublette and Lincoln counties, Wyoming: Laramie, Wyo., University of Wyoming, M.A. thesis, 77 p.

Frye, Charles, I., 1967, The Hell Creek Formation in North Dakota: unpublished UND, Ph.D. dissertation, 411 p.

Geijer, P., 1910, Igneous rocks and iron ores of Kiirunavaara, Luossavaara and Tuolluvaara, Geologie des Kirunagebiets, v. 2, 278 p.

Gersic, J., and Nonini, L.G., 1995, Sand/gravel, gypsum, and iron resources on the Wind River Indian Reservation, Wyoming: Wyoming State Geological Survey Reprint No. 61, p. 15-18. (Republished by Administrative report to the Bureau of Indian Affairs and Shoshone – Arapahoe Tribes Report BIA 8-II, Part 2 (Wind River), 1985).

Gindalbie Metals Ltd., 2015, Magnetite vs Hematite, at http://www.gindalbie.com.au/investor___media_centre/magnetite_vs_hematite.phtml, accessed Feb. 17, 2015

Grace, R.L.B., Chamberlain, K.R., Frost, B.R., and Frost, C.D., 2006, Tectonic histories of the Paleoarchean to Mesoarchean Sacawee block and Neoarchean Oregon Trail structural belt of south-central Wyoming Province: Canadian Journal of Earth Sciences, v. 43, no. 10, p. 1445-1466.

Graff, P.J., 1978, Geology of the lower part of the Early Proterozoic Snowy Range Supergroup, Sierra Madre, Wyoming: Laramie, Wyo., University of Wyoming, Ph.D. dissertation, 85 p.

Graff, P. J., Sears, J. W., Holden, G. S., and Hausel, D., 1982, Geology of the Elmers Rock greenstone belt, Laramie Range, WY: Geological Survey of Wyoming [Wyoming State Geological Survey] Report of Investigations No. 14, 23 p.

Guilbert, J. M., and Park, C. F., Jr., 1986, The Geology of ore deposits. Long Grove: Waveland Press, Inc., 985 p.

Hagner, A.F., 1942, Koch hematite: Geological Survey of Wyoming [Wyoming State Geological Survey], unpublished field notes, MR42-26, 1 p.

Hagner, A.F., 1942a, Olin Brothers hematite: Geological Survey of Wyoming [Wyoming State Geological Survey], unpublished field notes, MR42-27, 1 p.

Hagner, A.F., 1942b, Douglas iron: Geological Survey of Wyoming [Wyoming State Geological Survey], unpublished field notes, MR42-28, 1 p.

Hague, A., and Emmons, S.F., 1877, Descriptive geology – Rawlings Peak, in King C., Report of the geological exploration of the Fortieth Parallel: Professional Papers of the Engineer Department, U.S. Army, v. 2, no. 18, p. 161.

Harrer, C.M., 1966, Wyoming iron-ore deposits: description, beneficiation processes, and economics: U.S. Bureau of Mines, Information Circular 8314, 114 p.

Harris, R.E, McLaughlin, J.F., and Jones, R.W., 2005, Geologic map of the Guernsey quadrangle, Platte and Goshen counties, Wyoming: Wyoming State Geological Survey Map Series 68, scale 1:24,000.

Hausel, W.D., 1983, Report on iron formation samples from the Garrett 7.5' quadrangle, Laramie Range: Geological Survey of Wyoming [Wyoming State Geological Survey] mineral files, unpublished, 2 p., scale 1:24,000.

Hausel, W.D., 1984, Tour guide to the geology and mining history of the South Pass gold mining district, Fremont County, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Public Information Circular 23, folded pamphlet.

Hausel, W.D., 1988, Revised geologic map of the South Pass City quadrangle, Fremont County, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Open File Report 88-2, scale 1:24,000.

Hausel, W. D., 1989, The geology of Wyoming's precious metal lode and placer deposits: Geological Survey of Wyoming [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: Geological Survey of Wyoming [Wyoming State Geological Survey] Report of Investigations No. 44, 129 p., scale 1:48,000.

Hausel, W.D., 1994, Geology and mineralization of the Cooper Hill mining district, Medicine Bow Mountains, southeastern Wyoming: Wyoming State Geological Survey Report of Investigations No. 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. scale 1:24,000.

Hausel, W.D., 1996, Geology and gold mineralization of the Rattlesnake Hills, Granite Mountains, Wyoming: Wyoming State Geological Survey Report of Investigations No. 52, 28 p., scale 1:24,000.

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., Graff, P.J., and Albert, K.G., 1985, Economic geology of the Copper Mountain supracrustal belt, Owl Creek Mountains, Fremont County, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Report of Investigations No. 28, 33 p., 3 pls, scale 1:24,000.

Hausel, W.D., Marlatt, G.G., Nielsen, E.L., and Gregory, R.W., 1992, Preliminary study of metals and precious stones in southern Wyoming: Wyoming State Geological Survey Mineral Report 92-1, 63 p., 2 pls, scales 1:12,000 and 1:84,480.

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.

Hauser, J. and Hauser, U., 2005, The Hamersley Range, at http://www.wefly4fun.com/Australia05-03-Hamersley.html, accessed Feb. 4, 2015.

Hendricks, C. E., 1902, Report on the Eastman properties, Wyoming: Wyoming State Geological Survey files, 5 p.

Hills, F.A., and Houston, R.S., 1979, Early Proterozoic tectonics of the central Rocky Mountains, North America: Laramie, Wyo., University of Wyoming, Contributions to Geology, v. 17, no. 2, p. 89-109.

Houston, R.S., McCallum, M.E., and Patchen, A.D., 2003, Geologic map of a portion of the Lake Owen and Albany quadrangles, Albany County, Wyoming, showing major lithologic subdivisions of the Lake Owen Mafic Complex: Wyoming State Geological Survey Open File Report 03-5, scale 1:24,000.

Houston, R.S., and Murphy, J.R., 1962, Titaniferous black sandstone deposits of Wyoming, Geological Survey of Wyoming [Wyoming State Geological Survey] Bulletin No. 49, 55 p.

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

Houston, R.S., and Orback, C.J., 1976, Geologic map of the Lake Owen quadrangle, Albany County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map GQ-1304, scale 1:24,000.

Houston, R.S., and others, 1968, A regional study of rocks of Precambrian Age in that part of the Medicine Bow Mountains lying in southeastern Wyoming – with a chapter on the relationship between Precambrian and Laramide structure (reprinted, 1978): Geological Survey of Wyoming [Wyoming State Geological Survey] Memoir No.1, 167 p., 5 pls, scale 1:63,360.

Innovation Exploration Ventures, LLC, Projects and Discoveries, 2014, at http://www.innovationexplorationventures.com, accessed Dec. 5, 2014.

James, H.L., 1954, Sedimentary facies of iron formation, Economic Geology, v. 49, p. 235-293.

Johnson, J.F., and Sutherland, W.M., 2009, Geologic map of the Lander 30' x 60' quadrangle, Fremont County, Wyoming: Wyoming State Geological Survey,Map Series 87, scale 1:100,000

Kanizay, S.P., 1978, Preliminary geologic map of the Sheridan area, northwestern Powder River Basin, Wyoming: U.S. Geological Survey Map MF-1043, scale 1:50,000.

Kato, M., and Minowa, S., 1969, Viscosity measurement of molten slag- properties of Slag at elevated temperature (Part 1): Transactions of the Iron and Steel Institute of Japan, v. 9, p. 31-38.

Kimberley, M.M., 1978, Paleoenvironmental classification of iron formation, Economic Geology, v. 73, p. 215-229.

Knechtel, M.M., and Patterson, S.H., 1962, Bentonite deposits of the northern Black Hills district, Wyoming, Montana, and South Dakota: U.S. Geological Survey Bulletin 1082-M, 137 p., scale 1:48,000.

Kornfeld, M., Frison, G.C., and Larson, M.L., 2009, Prehistoric hunter-gatherers of the High Plains and Rockies (Third Edition): Walnut Creek, CA, Left Coast Press, 668 p.

Kumar, N., and Barua, A., Jan. 2014, "The boom and beyond: Managing commodity price cycles," Deloitte University Press, at http://dupress.com/articles/global-economic-outlook-q1-2014-the-boom-and-beyond-managing-commodity-price-cycles/, accessed Nov. 10, 2014.

"The Lore of Ore," Oct. 2014, The Economist, at http://www.economist.com/node/21564559, accessed Nov. 2014.

Loucks, R.R., and Glascock, J.W., 1989, Petrology and PGE mineralization of the Early Proterozoic synorogenic Lake Owen layered mafic intrusion, southern Wyoming, USA: unpublished report, 31 p., scale 1:12,000.

Loucks, R.R., Premo, W.R., and Snyder, G. L., 1988, Petrology, structure, and age of the Mullen Creek layered mafic complex and age of arc accretion, Medicine Bow Mountains, Wyoming: Geological Society of America Abstracts with Programs, v. 20, p. A73.

Love, J.D., 1934, The geology of the west end of the Owl Creek Mountains, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Bulletin 24, 33 p.

Love, J.D., 1970, Cenozoic geology of the Granite Mountains area, central Wyoming: U.S. Geological Survey Professional Paper 495-C, 154 p., 4 pls, scale 1:125,000.

Love, J.D, and Christiansen, A.C., 1985, Geological map of Wyoming: United States Geological Survey (Wyoming State Survey release 2014), 3 pls, scale 1:500,000.

Love, J.D., Christiansen, A.C., and Ver Ploeg, A.J., 1993, Stratigraphic chart showing Phanerozoic nomenclature for the state of Wyoming: Wyoming State Geological Survey Map Series 41., 1 p.

Lovering, T.S., 1929, The Rawlins, Shirley, and Seminoe iron deposits, Carbon County, Wyoming: U.S. Geological Survey Bulletin 811-D, and Contributions to Economic Geology, Part I, p. 203-235.

MacCannon, R.W., 2003, Sunrise – A chronology of a Wyoming mine: Pueblo, CO, The Bessemer Historical Society, 413 p.

McKinney, A.A., and Horst, H.W., 1953, Deadwood conglomerate, Bald Mountain deposit, Sheridan and Bighorn counties, Wyoming: U.S. Atomic Energy Commission Technical Report RMO-1546, 47 p.

McLaughlin, F., and Fruhwirth, J., 2008, Preliminary geologic map of the Rawlins 30' × 60' quadrangle, Carbon County, Wyoming: Wyoming State Geological Survey Open File Report 08-4, scale 1:100,000.

McLaughlin, J.F., and Ver Ploeg, A.J., 2008, Geologic map of the Douglas 30' x 60' quadrangle, Converse and Platte counties, Wyoming: Wyoming State Geological Survey Map Series 83, scale 1:100,000.

Middleton, L.T., 1980, Sedimentology of the Middle Cambrian Flathead Sandstone, Wyoming: Laramie, Wyo., University of Wyoming, Ph.D. dissertation, 182 p.

Millgate, M. L., 1965, The Haystack Range Goshen and Platte counties: Geological Survey of Wyoming [Wyoming State Geological Survey] Preliminary Report No. 5, 1 pl, 9 p.,

Millgate, M.L., and Gliozzi, J.P., 1966, Reconnaissance of iron formation in the Copper Mountain area, Fremont County, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Mineral Report 66-1, 65 p., scale 1:12.000.

Mindat.org, 2015, Online mineral database, at http://www.mindat.org/, accessed Nov. 10, 2014.

Minerals Education Coalition, 2013, Iron, at http://www.mineralseducationcoalition.org/minerals/iron, accessed Jan. 9, 2015.

Mining World, 1960, Wyoming taconite project to get underway: Mining World, v. 22, no. 8, p. 27.

Minnesota Minerals Coordinating Committee, 2013, Explore Minnesota: Iron ore, 3 p. at http://mn.gov/irrrb/images/IronOre.pdf, accessed March 25, 2015.

National Steel Pellet Company, 2003, Iron Ore Processing for the Blast Furnace, 7 p., at http://www.steel.org/~/media/Files/AISI/Making%20Steel/Article%20Files/ironore.PDF, accessed Jan. 9, 2014.

Neuendorf, K.K.E., Mehl, J.P., Jr., and Jackson, J.A., 2005, Glossary of Geology: Alexandria, VA, American Geological Institute, 5th ed., 779 p.

Newhouse, W.H., and Hagner, A.F., 1957, Geologic map of anorthosite areas, southern part of Laramie Range, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map 119, scale 1:63,360.

Newstrike Resources Ltd., 2012, “The Wyoming Projects,” at www.newstrikeresources.com, accessed Dec. 5, 2014.

Osterwald, F.W., Osterwald, D.B., Long, L.S., Jr., and Wilson, W.H., (revised by Wilson), 1966, Mineral resources of Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Bulletin 50, 287 p.

Pekarek, A.H., 1974, Structural geology and volcanic petrology of the Rattlesnake Hills, Wyoming: Laramie, University of Wyoming, Ph.D. dissertation, 111 p., scale 1:50,000.

Pinnell, D.B., and Marsh, J.A., 1954, Summary geological report on the titaniferous iron deposits of the Laramie Range, Albany County, Wyoming: unpublished report,U.P. Oil Dev., 13 p.

Postle, J., Haystead, B., Clow, G., Hora, D., Vallée, M., and Jensen, M., 2000, CIM Standards on mineral resources and reserves – Definitions and guidelines: Canadian Institute of Mining, Metallurgy and Petroleum, Standing Committee on Reserve Definitions, 26 p.

Ricketts, L.D., 1880, Report on iron from Annual Report of the Territorial Geologist of Wyoming, 4 p.

Robinson, C.S., Mapel, W.J., and Bergendahl, M.H., 1964, Stratigraphy and structure of the northern and western flank of the Black Hills uplift, Wyoming, Montana, and South Dakota: U.S. Geological Survey Professional Paper 404, 134 p., scale 1:96,000.

Rosenqvist, T., 1983, Principles of extractive metallurgy, 2nd ed. McGraw-Hill Book Company, 506 p.

Rostoker, W. and Bronson, B., 1990, Pre-Industrial iron: Its Technology and Ethnology, Philadelphia: Archeomaterials Issue 1, 232 p.

Ruehr, B.B., 1961, Geology of the Devils Gate area, Albany and Carbon counties, Wyoming: Laramie, Wyo., University of Wyoming, M.S. thesis, 48 p., scale 1:24,000.

Ryan, G.S., 1982, Mineral investigation of the Bridger Wilderness and Green-Sweetwater RARE II Wilderness Recommendation Area, Sublette and Fremont counties, Wyoming: U.S. Bureau of Mines, MLA 125-82, 12 p., 2 pls, scale 1:169,171.

Sando, W.J., Gordon, M., Jr., and Dutro, J.T., Jr., 1975, Stratigraphy and geologic history of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming: U.S. Geological Survey Professional Paper 848-A, 83 p., 11 pls.

Sandri, H., Dempsey, J., and Peters, M., 1996, The Atlantic City iron carbide project – Phase I scoping study evaluation, Unpublished report prepared for KN Energy, 134 p.

Schaetzl, R., 2008, Iron Mining: where and why?, 4 p., at web2.geo.msu.edu/geogmich/iron.html, accessed Feb. 4, 2015.

Schmidt, T.G., 1983, Precambrian metavolcanic rocks and associated volcanogenic mineral deposits of the Fletcher Park and Green Mountain areas, Sierra Madre, Wyoming: Laramie, Wyo., University of Wyoming, M.S. thesis, 113 p., scale ~1:24,000.

Schottman, F.J., 1983, Iron and Steel- Mineral facts and problems: U.S. Bureau of Mines Bulletin 675, p. 405-424.

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

Simons, F.S., Love, J.D., Keefer, W.R., Harwood, D.S., Kulik, D.M., and Bieniewski, C.L., 1988, Mineral resources of the Gros Ventre Wilderness Study Area, Teton and Sublette counties, Wyoming: U.S. Geological Survey Bulletin 1591, 66 p., 4 pls.

Snyder, G.L., 1984, Preliminary geologic maps of the central Laramie Mountains, Albany and Platte counties, Wyoming – Part E, Sheet 1, Geologic map of the Moonshine Peak 7.5' quadrangle, Wyoming: U.S. Geological Survey Open File Report 84-358 (Parts A through M), 15 p., 11 maps, scale 1:24,000.

Spencer, A.C., 1904, The copper deposits of the Encampment district, Wyoming: U.S. Geological Survey Professional Paper 25, 107 p., scale 1:84,480.

Spencer, A.C., 1916, The Atlantic gold district and the north Laramie Mountains, Fremont, Converse, and Albany counties, Wyoming: U.S. Geological Survey Bulletin 626, 85 p.

Stena Metal Inc., 2011, "Hot Briquetted Iron (HBI)." At http://stenametalinc.com/Global/Footer-links/Privacy/, accessed March 25, 2015.

Stensrud, H.L., 1963, Geology of the Lake Owens mafic complex, Albany County, Wyoming: Laramie, Wyo., University of Wyoming, M.A. thesis, 46 p., scale 1:24,000.

Storrow, B., Nov. 2014, "Wyoming Business Council, JR Simplot Co. study reopening Fremont County iron mine," Casper Star-Tribune, at http://trib.com/business/energy/wyoming-business-council-jr-simplot-co-study-reopening-fremont-county/article_026fea42-7af5-586c-a48b-d323ec4c97a9.html, accessed Jan. 9, 2015.

Sutherland, W.M., 2008, Geologic map of the Devils Tower 30' x 60' Quadrangle, Crook County, Wyoming, Lawrence and Butte counties, South Dakota, and Carter County, Montana: Wyoming State Geological Survey Map Series 81, 29 p., scale 1:100,000.

Sutherland, W.M., Gregory, R.W., Carnes, J.D., and Worman, B.N., 2013, Rare earth elements in Wyoming: Wyoming State Geological Survey Report of Investigations No. 65, 82 p.

Sutherland, W.M., and Hausel, W.D., 2003, Geologic Map of the Rattlesnake Hills 30' x 60' quadrangle, Fremont and Natrona counties, Wyoming: Wyoming State Geological Survey Map Series 61, 28 p., scale 1:100,000.

Sutherland, W.M., and Hausel, W.D., 2004, Preliminary Geologic Map of the Saratoga 1:100,000 scale quadrangle: Wyoming State Geological Survey Open File Report 04-10, 3 pls., 34 p.

Sutherland, W.M., and Hausel, W.D., 2005, Geologic map of the Barlow Gap quadrangle, Natrona County, Wyoming: Wyoming State Geological Survey Map Series 67, scale 1:24,000.

Sutherland, W.M., and Worman, B.N., 2013, Preliminary geologic map of the Blackjack Ranch quadrangle, Natrona County, Wyoming: Wyoming State Geological Survey,Open File Report 13-3, 24 p., scale 1:24,000.

Swain, B.W., 1957, Fort Union Formation, west flank of the Sierra Madre, Carbon County, Wyoming: Laramie, Wyo., University of Wyoming, M.A. thesis, 123 p., 16 pls.

Swetnam, M.N., 1961, Geology of the Pelton Creek area, Albany and Carbon counties, Wyoming: Laramie, University of Wyoming, M.S. thesis, 78 p., scale 1:15,500.

Techhistory.co.nz, 2012, Titanium, at http://www.techhistory.co.nz/IronSands/Titanium.htm, accessed Jan. 30, 2015.

Trefis Team, March 2014, The latest iron ore price slump: causes and effects, Forbes, at http://www.forbes.com/sites/greatspeculations/2014/03/14/the-latest-iron-ore-price-slump-causes-and-effects/, accessed Jan. 30, 2015.

Tuck, C. A., 2015, Iron and Steel: U.S. Geological Survey Mineral Commodity Summary Report, 2 p., at http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel/mcs-2015-feste.pdf, accessed Feb. 17, 2015.

Ullmer, E., 1983, Precambrian iron-rich pods and uranium mineralization near Warm Spring Creek, Fremont County, Wyoming: Laramie, Wyo., Contributions to Geology, University of Wyoming, , v. 22, no. 2, p. 75-82.

U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, 5 p.

Vale, 2015, Iron ore and Pellets, at http://www.vale.com/en/business/mining/iron-ore-pellets/pages/default.aspx, accessed Feb. 4, 2015.

Walker, R. D., 2014, "Iron Processing," Encyclopedia Britannica Online, Encyclopedia Britannica Inc., at http://www.britannica.com/EBchecked/topic/294507/iron-processing, accessed Nov. 10, 2014.

Webmineral.com, 2015, Mineralogy Database, at http://webmineral.com/, accessed Nov. 10, 2014.

Wilson, W.H., 1953, A hematite deposit on Pat O'Hara Mountain, Park County: Geological Survey of Wyoming [Wyoming State Geological Survey] Mineral Report 52-2, 4 p.

Wilson, W.H., 1976, Wyoming iron resources summary report, unpublished report, U.S. Bureau of Mines, Contract No. J0265005, 56 p.

Worl, R.G., 1968, Taconite in the Wind River Mountains, Sublette County, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Preliminary Report No. 10, 15 p., scale 1:36,000.

Worl, R.G., Lee, G.K., Long, C.L., and Ryan, G.S., 1984, Mineral resource potential of the Bridger Wilderness and the Green-Sweetwater Roadless Area, Sublette and Fremont counties, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-1636-A, 36 p., scale 1:250,000.

"The world's biggest iron ore mines," Feb. 2014, at http://www.mining-technology.com/features/featurethe-worlds-11-biggest-iron-ore-mines-4180663/, accessed Feb. 4, 2015

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