Investigating Rare Earth Element Mine Development in EPA Region 8 and Potential Environmental Impacts

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Report Index

1.0 Abstract……………………………………………………………………………3

2.0 Background ……………………………………………………………………….3
2.1 Defining Rare Earth Elements………………………………………………3
2.2 Defining Key and Critical Materials……………………………………..…4
2.3 Uses………………………………………………………………………..4
2.4 Supply……………………………………………………………………...5

3.0 Active Exploration and Deposits in Region 8………………………………..6
3.1 Bear Lodge………………………………………………………………….7
3.2 Iron Hill……………………………………………………………………..9
3.3 Wet Mountains……………………………………………………………...9
3.4 Lemhi Pass…………………………………………………………….…10
3.5 Sheep Creek………………………………………………………………...10

4.0 Mining and Refining Processes…………………………………..……..…11

5.0 Geochemistry and Possible Contaminants…………………………………..12

6.0 Potential Risks to Human Health and the Environment………………………...14
6.1 China…………………………………………………………………….…14
6.2 Radionuclides……………………………………………………………….15
6.3 Rare Earth Elements………………………………………………………….15
6.4 Metals……………………………………………………………………….15
6.5 Mountain Pass Legacy……………………………………………………..18
6.6 Bear Lodge Case Study…………………………………………………….18

7.0 Conclusions……………………………………………………………………20

8.0 References...……………………………………………………………………22

9.0 Appendix………………………………………………………………………24

1.0 Abstract

Even though most people have not heard of rare earth elements, they govern man kind's modern lifestyle. The 17 periodic elements receiving rare earth designation encompass nearly all electronic, clean energy, and military technologies due to their unique physical and chemical properties. Despite world-wide usage of these elements, China succeeded in monopolizing the rare earth element industry two decades ago. Use of these elements has risen exponentially, while China has slashed rare earth element exports driving prices to record highs. The United States government has been reviewing the risks associated with rare earth element supply disruption due to their importance in modern technologies vital to economic growth and national defense. This prompted the U.S. Department of Energy (USDOE) to identify "key" and "critical" materials. Many of the key and critical materials are rare earth elements. The USDOE has even developed a strategic plan to achieve a globally diverse supply of these materials. This includes developing the United State's rare earth element resources.

Such a strategic plan, coupled with record high prices, has implications for Region 8 of the Environmental Protection Agency (Region 8), which is relatively enriched in economic occurrences of rare earth element minerals. Exploration activities and preliminary mining procedures indicate the real possibility of rare earth element mining within Region 8 at the Bear Lodge property of northeastern Wyoming within five years. Oversight of rare earth element production represents new challenges for government agencies, including Region 8, considering the lack of experience in dealing with these operations. If best management practices (BMP) are not used and/or operations are not carefully monitored, rare earth element production may put human health and the environment at risk. This comprehensive report strives to inform readers of all pertinent background information surrounding the rare earth element market, active exploration and deposits within Region 8, mining and refining processes, possible contaminants, and the potential risks for human health and the environment.

2.0 Background

2.1 Defining Rare Earth Elements

Rare earth elements represent the 15 periodic elements of the lanthanide family, which reside at the bottom of the periodic table in the top horizontal row of the f-block elements (Figure 1). Scandium and yttrium are also considered rare earth elements because they exhibit similar properties to the lanthanide family. Rare earth elements, sometimes referred to as rare earths or REE, can be further classified as "light" or "heavy" based on their relative atomic weights. The light rare earth elements include lanthanum, cerium, praseodymium, neodymium, promethium, samarium, and europium, while heavy rare earth elements describe gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium, and yttrium (Figure 2). According to the Institute for the Analysis of Global Security (IAGS), such distinctions are important considering light rare earth elements account for higher concentrations globally than heavy rare earth elements (IAGS, 2010).

The "rare earth" designation inaccurately portrays the likelihood of the 17 rare earth elements' natural occurrence. Rare earth elements are actually lithophile, meaning they are enriched in the Earth's crust. In fact, most rare earth elements exist in the Earth's crust in higher concentrations globally than silver or mercury (Castor and Hedrick, 2006). Rare earth elements are generally evenly concentrated throughout the Earth's crust resulting in few locations around the globe where they can be economically mined. The lack of rare earth element mines has the potential to create serious supply issues for these elements vital to electronic, clean energy, and military technologies (IAGS, 2010).

2.2 Defining Key and Critical Materials

In 2010, the USDOE identified “key” and “critical” materials. These materials are a collection of periodic elements, most of which are rare earth elements, vital to the economic growth and national security of the United States. For the purposes of this report, key materials and critical materials will be referred to as “key elements” and “critical elements” to clarify what these materials truly are. The distinction between key and critical elements is subtle yet important. Both key and critical elements are widely used in electronic, clean energy, or military technologies and both have supply risks; however, critical elements are essential to the production of clean energy technologies and have even greater supply risks associated with them than key elements. The supply risks result from a small global market, lack of supply diversity, and market complexities caused by coproduction and geopolitical risks associated these elements (USDOE, 2010).

The USDOE (2010) determined there to be 14 key elements (Figure 3). Within the group of 17 rare earth elements, nine of which received key element distinction. These rare earth elements include lanthanum, cerium, praseodymium, neodymium, samarium, europium, terbium, dysprosium, and yttrium. Five other periodic elements were labeled key elements as well. The five other periodic elements include lithium, cobalt, gallium, indium, and tellurium (USDOE, 2010).

The United States is currently experiencing a great increase in clean energy technology development. The same can be said for electronic and military technologies too, and these trends are expected to continue into the future. The USDOE was concerned the rising demand for key elements in electronic and military sectors could hamper the growth of the U.S. “green economy, ” or an economy based on renewable energy. The USDOE (2010) conducted a further assessment on the 14 key elements to determine how “critical” these elements are to the development of the United States green economy in the short (0-5 years) and medium (5-15 years) term. The assessment was solely based on each key element’s importance to the development of the green economy, the summation of supply risks, and the increasing demand for these elements in the electronic and military technology sectors. The USDOE (2010) rated dysprosium, neodymium, terbium, europium, yttrium, and indium critical in the short term. Dysprosium, neodymium, terbium, europium, and yttrium, all of which are rare earth elements, received critical designation in the medium term (USDOE, 2010).

For the remainder of this report, the key and critical elements will collectively be referred to as rare earths. However, it is important to note that lithium, cobalt, gallium, indium, and tellurium are not actually rare earth elements. The terms key and critical elements may still be used when specifically referring to elements receiving key or critical designation.

2.3 Uses

Rare earths comprise an enormous array of technological applications and are becoming widely used due to their unique catalyst, magnetic, and optical properties. For example, all cell phones and laptops contain rare earths. As developed nations modernize and transition to green economies, rare earth consumption for clean energy applications will become an ever increasing phenomenon and vital to successful conversions from traditional industrial economies. Such modern and clean energy technologies govern today’s societies to the extent experts consider rare earth usage significant economic indicators (Castor and Hedrick, 2006).

Permanent magnets represent the staple clean energy technology of future green economies. They constitute main components of lightweight, high powered motors and generators due to their production of a stable magnetic field without the need for an external power source. Permanent magnet motors power contemporary electric, hybrid electric, and plug-in hybrid electric vehicles, while permanent magnet generators produce electricity from wind turbines (USDOE, 2010). The key element derived samarium-cobalt permanent magnets dominate rare earth technology because they produce a magnetic field in a much smaller size. The samarium-cobalt permanent magnet also retains its magnetic strength at high temperatures making it ideal for clean energy and even military applications, including precision guided munitions and aircrafts (IAGS, 2010).

Permanent magnets work in conjunction with high efficiency rare earth based batteries to store energy in electric, hybrid electric, and plug-in hybrid electric vehicles (USDOE, 2010). Current generation hybrid electric vehicles use a battery with a cathode containing a host of rare earths including lanthanum, cerium, neodymium, praseodymium, and cobalt (Kopera, 2004). Each hybrid electric battery may contain several kilograms of rare earth materials (USDOE, 2010). Plug-in hybrid and electric vehicles require even greater storage capacity and higher power ratings than typical hybrid vehicles. In light of this, automakers will likely use the lithium ion battery, increasing demand for yet another key element. Scientists at the Argonne National Laboratory estimated one lithium ion battery contains 3.4-12.7 kilograms of lithium depending on proprietary design (USDOE, 2010).

Perhaps the fastest growing consumer of rare earth material is the phosphor production industry. In 2008, phosphors alone accounted for 7% of all rare earth usage by volume and 32% of total rare earth value. Phosphor materials produce luminescence essential to today's lighting technologies. Older generation fluorescent lighting used no rare earths, but rare earths make current fluorescent lighting phosphors more efficient and visually pleasing. Specific rare earths responsible for this include lanthanum, cerium, europium, terbium, and yttrium. Fluorescent lighting phosphor usage is expected to rise by 230% over current levels due to USDOE mandating increased efficiency ratings. Mass quantities of similar phosphor materials are produced for application in television screens, computer monitors, and electronic instrumentation, increasing demand for rare earth based phosphors (USDOE, 2010).

The clean energy technologies discussed to this point are expected to drive the U.S green economy in the short and medium term. Other clean energy applications using rare earth materials include grid storage batteries, fuel cells, nuclear power, electric bicycles, magnetic refrigeration, fluid cracking catalysts, and automotive catalytic converters. Despite the wide spread usage of rare earths in the clean energy sector, the largest user of rare earths remains the electronics sector. Rare earths are used in nearly all electronic device produced, ranging from iPods to calculators. The importance of rare earths to the military sector cannot be forgotten either. The United States military incorporates rare earths into many different technologies from guidance systems to night-vision goggles. Increasing implementation of rare earth materials will further strain an already fragile supply chain responsible for providing adequate amounts of rare earth materials to international electronic, clean energy, and defense technology sectors; all of which increase the overall supply concerns associated with rare earths (USDOE, 2010).

2.4 Supply

The bulk amount of rare earths needed globally per year remains small relative to other industrial materials; however, the rare earth supply chain recently developed larger, more internationally complex issues than other industrial materials. To fully understand the issues at hand, one must first understand the evolution of the rare earth element industry over the past 50 years. From 1965-1985, the United States was the major producer of rare earth elements until the Mountain Pass mine in southeastern California (Figure 4) ceased mining operations due to China flooding the market with low cost rare earth elements (Castor and Hedrick, 2006). Soon thereafter, China emerged as the main producer of rare earth elements and holds that title today with 95% of production in their control (USGS, 2010). The unparalleled Chinese dominance of the rare earth element market transpired because of their large, high quality reserves, coupled with minimal capital investment, low labor costs, and lack of environmental regulation (IAGS, 2010).

Even though China controls 95% of rare earth element production, they only possess 36% of identified global reserves (USGS, 2010). In recent years Chinese government officials realized rare earth elements are of, "urgent need of protection and utilization," and they must "protect and make rational use of China's superior natural resources." As a result, China restricted rare earth element exports, closed down smaller mining operations, consolidated larger ones, and stockpiled rare earth elements. In 2010, China restricted exports of dysprosium, terbium, thulium, lutetium, yttrium, gadolinium, holmium, erbium, and ytterbium (IAGS, 2010). This resulted in a 40% overall reduction of rare earth element exports from 2009 (USDOE, 2010).

Increased demand coupled with limited exports caused dramatic price increases of individual rare earth element oxides over the past two years. In July 2010, neodymium oxide cost $108 U.S. dollars per kilogram, but a year later in July 2011 the same neodymium oxide was selling for $245 U.S. dollars per kilogram. This represents a 226% price increase in one year. Similarly, the price of dysprosium oxide increased 200% in one year with one kilogram of dysprosium oxide now costing $1,200 U.S. dollars (mineralprices.com). These price trends can be observed with nearly all rare earth elements and prices are not expected to go down in the near future.

At the heart of these issues remains finding economical rare earth element occurrences and developing them into a profitable operation is difficult. The three main criteria in determining economic feasibility of a potential rare earth element mine include tonnage, grade, and the cost of refining rare earth minerals into useful materials for industry (USDOE, 2010). Rare earth element mine capacity and expansion lag behind increasing international demand for rare earth elements. Various deposits exist around the world (Figure 5), but estimates suggest an operational mine takes 2-10 years to begin production without any unforeseen setbacks (IAGS, 2010). During this time, continued exploration, process development, feasibility studies, permitting, construction, and commissioning must take place (USGS, 2010).

The United States government is concerned about rare earth supply. The U.S. Department of Defense (USDOD) has special interest in maintaining a steady rare earth supply considering usage of these elements in various military technologies. The USDOE remains concerned over rare earth supply because these elements' necessity for producing clean energy technologies. In light if this, the United States government realized swift and strategic measures were needed to secure a long lasting rare earth supply chain. In 2010, the U.S Department of Energy received funding from Congress to develop a strategic plan to mitigate supply risks and place the U.S. green economy on a reliable and sustainable pathway. One aspect of the plan strives to improve recycling, reuse, and efficient use of critical elements. Such actions serve to stabilize the rare earth market in times of undersupply. Another point of the strategic plan declares appropriate rare earth substitutes must be identified to lessen the Chinese dependence of rare earth elements (USDOE, 2010). This could be accomplished by congressional and military commands placing more emphasis on education and awareness of rare earth (IAGS, 2010). Finally, the cornerstone of the plan stresses a globally diverse supply of rare earths is needed (USDOE, 2010). The Institute for the Analysis of Global Security suggests the United States should pursue rare earth mine ventures with nations of known reserves to increase the number of supply lines. Developing a diverse supply also means utilizing the United States' substantial reserves of rare earth elements. The United States is committed to nurturing the development of rare earth element mining in America by providing assistance and research collaboration when needed (IAGS, 2010). Such a strategic plan puts Region 8 in the middle of an American mining revolution.

3.0 Active Exploration and Deposits in Region 8

Even though rare earth elements are overall evenly concentrated throughout the Earth's crust, a wide range of geologic conditions are favorable for rare earth element enrichment. In fact, the United States Geological Survey (2010) has identified 29 "principle," or large, rare earth element deposits within the United States (Figure 6). Placers, iron ores, and alkaline igneous complexes constitute the major types of rare earth element deposits in the U.S. These deposits account for 13% of the world's identified rare earth element reserves and have the potential to supply the United States of its rare earth element needs for decades to come. Although the United States displays significant reserves, no rare earth element mines currently operate in America. The mine closest to rare earth element production is the Mountain Pass mine in California (Region 9), which plans to resume mining operations by 2012 after modernization of production facilities are completed. Many of the principle rare earth deposits in the United States, such as the Bokan Mountains in Alaska, Diamond Creek in Idaho, and the Bear Lodge Mountains in Wyoming, are now actively being explored for their mining potential in light of record high rare earth element prices (USGS, 2010).

Only three of the 29 principle rare earth element deposits reside within Region 8. With this said, Region 8 may seem to be an insignificant rare earth element stakeholder; however, Region 8 will most likely host the second operational rare earth element mine in the United States, a mine that could quite possibly become the largest rare earth element producer in America. In addition to the three principle rare earth element deposits, the USGS (2000) determined there to be over 10 rare earth element occurrences within Region 8. Record high rare earth element prices have resulted in a rare earth "ramp up" throughout Region 8. The focus of this next section will be on the exploration and resource potential of the three principle rare earth element deposits in Region 8, but it is important to note if China continues to cut exports and U.S. rare earth element demands are not met by other international suppliers, prices could rise to the extent even the minor rare earth element occurrences could be actively explored and mined in the future.

3.1 Bear Lodge

The Bear Lodge deposit has the most potential for rare earth element mining to develop in Region 8. The deposit is located approximately six miles northwest of the town of Sundance in northeastern Wyoming. The Bear Lodge property itself lies within the Bear Lodge Mountains in the Black Hills National Forest (Figure *7*). Rare earth element mineralization was first discovered at the Bear Lodge property in 1949 by geologists in search of uranium. Significant amounts of uranium were never found on the property, but interest in rare earth elements soon generated over the Duval Corporation's discovery of high grade rare earth element oxides in 1972 (USGS, 1983). Other exploration companies have found multiple high grade areas over the past 40 years increasing the potential for mining. Even though high grade rare earth element oxides were known to exist on the property, prices were not high enough to warrant mining activities. With prices higher than ever, rare earth element mining will most likely be a reality at the Bear Lodge property within the next five years.

Rare Element Resources Inc., a Wyoming cooperation based in Colorado, is poised to develop the Bear Lodge property into a world-class rare earth element mine. The company bought 100% ownership in the property comprising 90 unpatented federal lode claims and one state lease for a total of about 2,400 acres. Rare Element Resources began actively exploring the property for high grade rare earth element mineralization in 2004. Core drilling, geochemical analysis, and remote sensing techniques over the past six years have helped the company better understand the local geology and upgrade the resource reserve status. Spring 2011 National Instrument (NI) 43-101 results, which establish guidelines for companies trading in the Canadian stock exchange to disclose mineral resources to the public, increased the indicated rare earth element resources by 4.9 million tons, which now totals over 17 million tons of rare earth oxides grading at 3.46% (Rare Element Resources, 2011). Light rare earth elements account for much of the indicated resources at the Bear Lodge property (Pickarts, 2011). With additional drilling, it is thought that the Bear Lodge reserves could match or even out produce the Mountain Pass mine in California (Rare Element Resources, 2011).

The rare earth element resource at the Bear Lodge deposit is mainly found in a rare type of igneous rock called carbonatite (Figure 8). Carbonatites are characterized by containing 50% or more carbonate (CO_3^{2-}) minerals (USGS, 1983). Exotic carbonate minerals, such as bastnasite and ancylite, have rare earth elements in their crystal structure resulting in rare earth element enrichment of carbonatite rocks. Rare earth elements possess the same electrical charge and similar ionic radii's allowing for their wide spread substitution within a crystal lattice. This substitution explains why rare earth elements can be found throughout the Earth's crust and why many different rare earth elements occur within a single mineral (Castor and Hedrick, 2006). The greatest concentrations of rare earth element bearing minerals are generally found in carbonatite dikes, or sheet-like vertical rock structures, surrounding an alkaline igneous complex. This holds true at the Bear Lodge deposit.

Bear Lodge dike formation occurred when magmas enriched in alkaline materials intruded, or cross-cut, the existing rock 38 to 60.5 million years ago. The intrusions are responsible for what the USGS has described as the largest rare earth element deposit in North America (USGS, 1983).

Rare Element Resources is interested in developing three separate locations at the Bear Lodge property near the area known as “Bull Hill” (Figure 9). Two of the three locations, “Bull Hill southwest” and “Bull Hill northwest,” are known to have numerous carbonatite dikes present with some over 1,000 feet long and hundreds feet wide. Three separate mineralogical zones are present in these carbonatite dikes (Figure 10). Each mineralogical zone is defined by depth and the degree of weathering experienced by the dike. The carbonatite dikes are highly weathered near the surface into what the company refers to as an “iron oxide-magnesium oxide-rare earth zone” or “FMR” (Pickarts, 2011) (Figure 11). Weathering served to economically concentrate the rare earth element minerals (USGS, 2010). The loose, friable character and fine grain nature of rare earth element bearing minerals in the FMR allow a 90% recovery with a 19% rare earth element oxide grade by employing simple crushing, scrubbing, and screening processes. Chemical processing will be accomplished at an off-site facility (Pickarts, 2011).

Below the FMR zone, an incompletely weathered “carbonatite-oxide” mineralogical zone exists. Rare Element Resources plans to mine this bastnasite rich zone that extends hundreds of feet in the subsurface (Pickarts, 2011). The oxide material displayed favorable recovery in previous metallurgical testing (Rare Element Resources, 2011). The carbonatite-oxide zone of the dikes is also of mining interest because it is characterized by an absence of sulfides minerals. However, sulfides are found below the carbonatite-oxide zone in what Rare Element Resources terms the “transitional zone” and below (Pickarts, 2011). The transitional zone is described as a relatively flat-lying, thin layer where weathering has leached sulfides into a mixed carbonatite oxide-sulfide zone (Rare Element Resources, 2011). Below the transitional zone is an unoxidized carbonatite zone that contains all its original sulfide content. Rare Element Resources has no recovery plan for rare earth element bearing minerals found in this sulfide zone (Pickarts, 2011). Identifying the sulfide bearing geology is important because of potential acid mine drainage concerns at the mine.

The “Bull Hill southwest” location contains a large portion of the rare earth element resource where a dominant dike set and several minor dike sets are present. “Bull Hill northwest” displays similar characteristics to the “Bull Hill southwest” location. The third location, “Whitetail Ridge,” shows FMR stockwork, or rocks cut by a network of smaller mineralized dikes, near the surface. The stockwork displays low rare earth element oxide grades compared to the dikes. Stockwork zones grade between .5% and 2% rare earth element oxide, while FMR zones can grade close to 20% rare earth element oxide. Rare Element Resources is developing low cost physical processing methods to make stockwork more economical to mine (Pickarts, 2011).

Don Ranta, president of Rare Element Resources, has been quoted as saying, “the Bear Lodge project is advancing rapidly.” Rare Element Resources hopes to complete a pre-economic feasibility study by the first quarter of 2012 (Rare Element Resources, 2011). Metallurgical testing of mineralized core samples will continue throughout 2011 as will the design of their commercial processing (Rare Element Resources, 2011). The company plans to submit a Plan of Operation, or POO, to the United States Forest Service Sundance office by early 2012. The USFS will then have 30 days to accept or reject the POO. Modifications to the POO will incorporate comments received from the USFS (Pickarts, 2011). District Ranger Steve Kozel at the Sundance USFS office explained the USFS will not prohibit mining at Bear Lodge but will ensure mining and on-site processing are done so in an environmentally conscious manner. The National Environmental Policy Act (NEPA) process will be initiated by the USFS once the POO is accepted (Kozel, 2011). An EIS will then be developed and made available for EPA and public review.

3.2 Iron Hill

A smaller, yet still significant, Region 8 rare earth element deposit is known as Iron Hill. The Iron Hill deposit is located about 30 miles southwest of Gunnison in southwestern Colorado (Figure 12). A previously explored section of the deposit is near a community center and several houses. This deposit is underlain by carbonatite similar to the Bear Lodge deposit in Wyoming. The core of the Iron Hill deposit contains a massive plug, or neck, of carbonatite enriched in rare earth elements, niobium, thorium, and titanium. An adjacent igneous rock unit possesses rare earth elements too (USGS, 2010). Staatz and other (1979) calculated the Iron Hill deposit to contain nearly 2.9 million tons of rare earth element oxides, although Armbrustmacher (1983) found the carbonatite to only grade at an average of 0.5% rare earth element oxide. This grade is too low at the current time for economically feasible rare earth element production. Rare earth element oxide grades need to be at 2.5% or higher to be economically mined (Pickarts, 2011). However, some carbonatite dikes at Iron Hill studied by Olsen and Hedlund (1981) contain up to 3% rare earth element oxide, which are more attractive to mining companies.

The Iron Hill deposit is mainly known for its substantial titanium resources (USGS, 2010). Van Gosen and Lowers (2007) describe the Iron Hill deposit as the largest titanium resource in the United States. Teck Resources Inc. bought many of the patented claims within the Iron Hill deposit in 1990. The mining company's interest in the property resides in the substantial titanium resources, not the rare earth elements. No mineral resources have been produced to date, and Teck Resources is not actively conducting work at the Iron Hill property.

Environmental concerns regarding thorium and asbestiform mineral content could create expensive waste disposal measures to ensure these materials are handled in an environmentally friendly manner. The low rare earth oxide grades and immense investments needed for infrastructure development explain why Teck Resources has little interest in mining rare earth elements at the property. At this time, the company would not be able to compete with established rare earth element mines such as Molycorp's Mountain Pass mine in California (Van Gosen, 2011). For these reasons, it does not appear rare earth element mining will take place at Iron Hill in the near future. Although as with many rare earth element deposits, multiple mineral resources could be concurrently extracted at the Iron Hill property, which increases mining potential. A well coordinated mine and mill plan could make this realization possible (USGS, 2010). If rare earth element prices continue to rise and low grade rare earth element oxide recovery methods are developed, Iron Hill may be thoroughly explored for rare earth elements and subsequently mined in the future.

3.3 Wet Mountains

The third principle rare earth element deposit in Region 8 is the Wet Mountains deposit in the surrounding areas of Freemont and Custer counties in south-central Colorado (Figure 13). Multiple alkaline complexes formed in the area 500 million year ago during the cooling of the intrusive magmas. The deposit shows proven niobium, rare earth elements, and thorium resources. Niobium, rare earth element, and thorium mineralization can be found in the minerals ancylite, bastnaesite, monazite, synchysite, and thorite. The mineral resources are mainly found in quartz veins with lesser amounts in carbonatite dikes and fracture zones (Figure 14). Fracture zones and veins in the area have the highest economic potential for rare earth element recovery (USGS, 2010).

The USGS (1988) studied the Wet Mountain area extensively to determine the potential rare earth element resources in the area. The study even determined the light and heavy rare earth element fractions in the area. Potential light and heavy rare earth resources totaled 73,270 and 48,850 tons respectively with an average rare earth element oxide grade of 2.15%. Despite rare earth oxide grades close to economical percentages, mining seems unlikely due to land issues. Many of the fracture zones and veins reside on private land. Also inhibiting mining is the nature of the veins that contain the rare earth element minerals. The veins are not large and can extend long distances in the subsurface. These vein characteristics make mining costly. In addition, the thorium content of the mineralized veins could require expensive disposal (Van Gosen, 2011).

3.4 Lemhi Pass

The Lemhi Pass deposit resides in the central Beaverhead Mountains on the borders of Idaho and Montana a few miles away from Tendoy, Idaho. Even though nearly the entire deposit lies on Idaho state land, Region 8 should be aware of the deposit's existence and the issues surrounding the land because some of the area drains into Montana (Figure 15). Many parallels can be seen between Lemhi Pass and the Wet Mountains deposits. Both display the same general geology with thorium and rare earth element resources residing in numerous mineralized quartz veins (USGS, 2010) (Figure 16). Staatz (1972) and Staatz and others (1979) mapped over 200 mineralized veins in the district. These mineralized veins vary greatly in size from 1 to 1,325 meters in length and from a few centimeters up to 12 meters wide. The rare earth element oxide grades of the veins vary greatly as well. Samples from 31 mineralized veins showed rare earth element oxide grades between .073% and 2.20% (Staatz, 1972).

Despite some rare earth element oxide grades close to economical percentages, the overall grade average at Lemhi Pass was only .428% leaving little potential for mining (USGS, 2010). Thorium and land-use issues at Lemhi Pass inhibit the possibilities of mining similar to the Wet Mountains (Van Gosen, 2011). Lemhi Pass is more renowned for its thorium resources than rare earth element content. The area holds the largest thorium resource in the United States (Van Gosen and others, 2009). Previous exploration over the past decade has focused strictly on thorium targets by Thorium Energy Inc. (USGS, 2010).

The rare earth element resources at Lemhi Pass are in demand and very valuable. No thorium or rare earth elements have been produced at Lemhi Pass to date, although certain aspects of the deposit remain attractive to mining companies. Coproduction of thorium and rare earth elements cannot be ruled out. Also, the veins display unusual middle and heavy rare earth element enrichment with especially high neodymium enrichment (Staatz, 1972). Neodymium and other middle rare earth elements are classified under the USDOE's list of short and medium term key materials, while the heavy rare earth elements remain some of the most expensive rare earth products. Favorable market conditions may interest mining companies in reevaluating the rare earth element mining potential at Lemhi Pass. Additional exploration would be needed in the area to better define the total resources (USGS, 2010).

3.5 Sheep Creek

Each location discussed to this point was strictly a rare earth element deposit. The Sheep Creek deposit, which is located in central Montana approximately 60 miles south of Great Falls, does not contain rare earth elements but rather the key element cobalt (Figure 17). Mineral resources occur in extensive shale and bedded, or horizontally layered, zones (Figure 18). These zones can be found in multiple levels throughout 2,400 feet of rock. Some of the mineralized zones display long lateral extent in the subsurface and thicknesses of over 300 feet. Copper is the dominant metal found in the mineralized zones with the sulfide mineral chalcopyrite bearing the copper resources in its crystal lattice (Tintina Resources, 2011). Cobalt exists as a lining on the chalcopyrite (McCulloch, 2011).

A joint venture by Cominco and BHP explored the property in the 1980's. Tintina Resources now owns the property, which consists of long-term leases totaling nearly 6,000 acres on private ranch lands and federal mining claims. They have continued exploring and outlined an inferred resource of a mineralized zone near the surface. This mineralized zone is referred to as the "Upper Copper Zone" and totaled over 7 million tons of ore with a 2.4% and 0.12% grade of copper and cobalt respectively. The company is continuing to drill and expand the resource at additional areas of the property (Tintina Resources, 2011).

The large vertical, yet separated extent of the mineralized zones could lead to both surface and underground mining activities at the Sheep Creek property. Cobalt would be coproduced from the copper rich ores, although cobalt recovery would be difficult. Tintina Resources may only be able to extract 25% of the cobalt lining from the chalcopyrite (McCulloch, 2011). Feasibility studies need completed to see if cobalt can be economically produced from the copper rich ores. If cobalt prices continue to rise, this is a good possibility in the future.

4.0 Mining and Refining Processes

Each rare earth element body is unique and requires deposit specific processing (USGS, 2010). If substantial rare earth element resources are discovered in a location, extensive analytical analysis of the deposit's chemical composition is conducted to determine the rare earth element bearing minerals and individual rare earth element content. Analysis of this type is essential in determining the deposit's profitability. Such analysis also determines how the ore will be processed and how difficult it will be to separate the individual rare earth elements from each other (Castor and Hedrick, 2006). Production costs vary from deposit to deposit based on the ore content and rare earth element mineralogy (USDOE, 2010). If the results of the studies show potential for profit, advancements towards mining operations can occur. Some of these advancements include mine plan development, pilot plant metallurgical testing, permit applications, and conducting economic feasibility studies (USGS, 2010).

The Mountain Pass mine remains the only rare earth element mine ever to be developed in the United States. Much of the knowledge surrounding rare earth element mining resulted from observing operations at Mountain Pass (Castor and Hedrick, 2006). Carbonatite dikes hold the rare earth element resource similar to the Bear Lodge deposit. Molycorp used open-pit mining to extract the rare earth element bearing mineral bastnasite (Figure 19). In order to extract the bastnaesite at the Mountain Pass mine, heavy equipment excavated an open pit to a depth of about 400 feet (USGS, 2010).

Rare Element Resources is proposing the same kind of mining procedures at the Bear Lodge property. Specifically, the company plans to mine rare earth element bearing minerals down to depths of about 500 feet. The weak nature of the rocks does not allow for the possibility of underground mining. If geologic conditions allow, minerals may be extracted even deeper until the company comes within 30 feet of reaching the deep sulfide rich zone. This leaves a carbonate rich reaction front in place to ensure an acidic pit lake does not develop (Pickarts, 2011).

Extracting the ore from the Earth represents only a small portion of rare earth element production. Refining rare earth element bearing minerals into marketable products constitutes the major aspect of rare earth element production. Rare earth element bearing minerals may contain as many as 17 individual rare earth elements, where each must be refined and separated into their respective products. Separation may involve dozens of chemical processes to differentiate rare earth elements from one another and remove impurities. These processes can make rare earth element recovery much more expensive than other metals. In light of this, rare earth elements are often produced as byproducts or coproducts of other mineral commodities. The USGS estimates 44% of current global rare earth element production results from byproduction (USGS, 2010).

Past refining techniques at Mountain Pass facilities provide the model for processing bastnaesite into a rare earth element product (Figure 20). The first step of the refining process at Mountain Pass involved removing bastnasite out of the ore by crushing the rock into gravel size fractions and then further reducing the ore into smaller fractions via grinding (Castor and Hedrick, 2006). Once the rare earth element ore was reduced to a smaller size, the different mineral constituents in the ore could be separated from one another using "floatation." This was very important considering many minerals of little or no value exist in the ore. The flotation process at Mountain Pass involved adding an agent to a vat of bastnasite slurry where air bubbles were introduced through the bottom of the large container. Bastnasite bonded to the surfacing air bubbles and simply floated to the top of the container where it could be collected as froth (IAGS, 2010). Flotation at Mountain Pass resulted in a bastnaesite concentrate yielding a 60% rare earth element oxide product. The rare earth element oxide product would have undergone additional chemical processing in order to isolate the individual rare earth elements. Acid was employed at the facility to dissolve the trivalent rare earth elements and various solvent extraction steps served to separate the individual rare earth elements. After the elements were separated into their respective oxides, they were dried, stored, and shipped for further processing into alloys or other applications discussed earlier. The process took about 10 days from the time the ores were mined until the separate rare earth oxides were produced (IAGS, 2010). This process will be modernized when the mine reopens in 2012.

Even though Rare Element Resources will refine the same rare earth element bearing mineral as Molycorp, a different refining process will most likely be used to extract rare earth elements out of the ore from the Bear Lodge property. This highlights the unique refining methods employed at individual rare earth element deposits. High grade ores (>2.5%) recovered from carbonatite dikes will first be processed at the Bear Lodge property. Physical, on site, processing will include crushing and screening with water to mitigate dust pollution. Such processes are designed to concentrate the rare earth element bearing minerals and will overall resemble a gravel or mill operation. The low-grade ore (<2.5%) mined out of the pit will be stockpiled for future processing (Pickarts, 2011).

After the high grade ores are milled at the physical processing plant, they will be transported by truck to Upton Wyoming. Upton, which is about forty miles away from the Bear Lodge property, was chosen because it is an industrial park in close proximity to a viable railway and has existing infrastructure. The refining process about to be explained is simply proposed. Rare Element Resources is currently developing their pilot plant. At the Upton hydro-processing plant, the milled ores will be leached in four individual vats of heated 15% hydrochloric acid creating a rare earth element oxide slurry. Soda ash or caustic soda will be introduced into the slurry to raise the pH to 3. This precipitates the iron and hydroxides out of solution while keeping the rare earth elements in solution. Other wastes including low levels of thorium, uranium, and metals will also be contained in this iron hydroxide precipitate and will be disposed in a lined tailings facility. The pH of the remaining solution will then be further raised to around 6.5 in order to precipitate a rare earth element bearing carbonate for 90% rare earth element recovery. The carbonate bearing rare earth elements will be shipped to another refinery to separate the individual rare earth elements. Rare Element Resources plans to work within the boundaries of Nuclear Regulatory Commission (NRC) rules for construction of a tailing impoundment to properly dispose of their wastes in case thorium and uranium become concentrated enough to warrant regulation by the NRC (Pickarts, 2011).

5.0 Geochemistry and Possible Contaminants

Historical mining activities in the American West have created hundreds of thousands of environmental disturbances. Mining activities expose previously unexposed rocks to bacteria, oxygen, water, and wind. The summations of these weathering forces chemically and physically alter contaminant laden rocks that have been below the surface for millions of years (EPA, 1995). Chemical and physical alteration of natural constituents in rocks during mining can lead to environmental contamination; however, mining and milling itself is not the only means of contaminating the environment. Refining processes that accompany hardrock mining represent the same, if not worse, danger to the environment. While mining exposes contaminant laden rocks and increases the surface area of minerals, refining isolates and concentrates wastes. The chemicals and compounds used during refining could contaminate the environment too. Extreme care must be used in handling all the materials associated with rare earth element production to ensure they are not released into the environment. This section will introduce the possible contaminants from rare earth element production and the likely wastestreams of the possible contaminants.

One contaminant associated with rare earth element ores are radionuclides. Rare earth element bearing minerals such as monazite, xenotime, and bastnasite can contain low levels of primordial thorium-232, uranium-238, and their decay products. Uranium-235 is also present but in very low quantities. Thorium-232 and uranium-238 are rather benign, but some of the decay products can represent a danger to the environment due to the energetic particles and gamma rays released during radioactive decay. For example in the uranium-238 decay chain, bismuth-214 has a very energetic gamma release and produces radon-222 that can be inhaled and decay in the lungs (Argonne National Laboratory, 2005).

Radioactivity is not the only concern from rare earth element production. As many as 17 different rare earth elements could make their way into the environment during production from carbonate mineral dissolution. The trivalent charge of the rare earth elements makes it difficult for them to bond with natural compounds and come out of the environment. The toxicity of rare earth elements in the environment are not completely understood but are considered metals at their elemental level.

The overall metal content of rare earth element ores is another geochemical concern associated with rare earth element production. It is important to note rare earth element mining is hardrock mining, so any of the metal concerns associated with hardrock mining should be a concern with rare earth element mining as well. Metals such as aluminum, arsenic, cadmium, cobalt, copper, gold, iron, lead, manganese, silver, and zinc are often associated with hardrock mining. The dangers of metals in the environment are well documented. Metals of special concern at rare earth element mines include, but are not limited to, aluminum, arsenic, barium, beryllium, cadmium, copper, lead, manganese, and zinc. Each of these metals have negative impacts on the environment and may be found or present in elevated concentrations within rare earth element bearing minerals. Many of the potential metal contaminants reside within sulfide minerals that often accompany rare earth element ores. The dissolution of sulfide minerals, such as pyrite and chalcopyrite, can release these metals into the environment.

Sulfide mineral dissolution also creates a reaction where sulfuric acid is formed and causes acid mine drainage. Even if a mining company plans for a zero discharge mine, it is still important to analyze the possible concerns in case discharge occurs. Sulfuric acid lowers the pH of water resources aiding in further sulfide mineral dissolution, releasing more metals and acid into the environment. It represents a positive feedback loop that could affect the environment. However, one positive aspect associated with rare earth element ores is that sulfide minerals are usually not the main mineral constituents. Carbonate minerals are often the dominant minerals present in rare earth element ores, especially in Region 8. These minerals provide a natural buffer to acid generation and help neutralize acid generated during sulfide mineral dissolution. The dissolution of carbonate minerals can raise pH of a water system too. This serves to slow sulfide mineral dissolution, which helps prevent acid generation and the introduction of metals into water.

It is important to note the natural buffer of carbonate minerals in rare earth element ores can cause potential environmental concerns as well. Too much carbonate mineral dissolution represents just as much danger as sulfide mineral dissolution. Carbonate mineral dissolution introduces alkaline materials into water, where they can raise the pH of water to elevated levels. The dissolution of carbonate minerals can also introduce possible contaminants into the environment similar to how sulfide mineral dissolution can. Bastnasite is one of the carbonate minerals that can undergo dissolution. The dissolution of this carbonate mineral is what would release the rare earth elements into the environment. Another contaminant to be concerned about in carbonate mineral dissolution is fluorine. Fluorine is also a constituent of rare earth element bearing bastnasite. The dangers of fluorine in the environment are well documented. One last geochemical consideration associated with rare earth element ore is the presence of the mineral riebeckite. Some rare earth element deposits contain known occurrences of this asbestos mineral while others do not. This highlights the chemical uniqueness of every rare earth element deposit and the importance of extensive chemical analysis in determining environmental concerns at individual deposits.

The radionuclides, rare earth elements, metals, sulfides, carbonates, and other possible contaminants may be released into the environment at the mine site and refinery. The locations where the possible contaminants could be introduced into the environment represent likely “wastestreams.” All possible contaminants discussed, if they exist at a mine, will be exposed in the bottom and walls of an open pit, where they will interact with bacteria, oxygen, water, and wind. The possible contaminants will be exposed to these weathering conditions over the life of the mine. The longer the pit remains open, the more these possible contaminants can be released into the environment. The same can be said for the possible contaminants residing in wasterock piles at a mine site. In fact, it is more likely the possible contaminants from wasterock piles will be introduced into the environment considering these possible contaminants are not contained in a pit and only man-made barriers can prevent possible contaminants from being introduced into the environment. The mill itself represents a wastestream. Some rare earth element ores may unintentionally be lost during the milling process where they will collect outside the mill. Also, intentional wastes will be piled on-site. Unless the ores and wastes are carefully collected and monitored, contaminants could be easily introduced into the environment.

The possible contaminants can be found in the rare earth element products, byproducts, and waste materials (Castor and Hedrick, 2006). This makes the handling of materials associated with rare earth element production of utmost concern. Extreme care should be used to ensure the isolated and concentrated possible contaminants are not released into the environment. All of the materials produced from the refining process will have their respective holding piles. Each represents a likely wastestream. The chemicals and compounds used to isolate and concentrate possible contaminants should be of concern too. Various acids and bases are used to refine the rare earth element ores into marketable products.

6.0 Potential Risks to Human Health and the Environment

Mining, and the industries it supports, are among the building blocks of modern society. The benefits of mining to the United States have been many, but they come at great cost to the environment. Over the past century, there has been an increasing recognition that environmental protection is fundamental to a prosperous economy and healthy society. As mines have increased in size and complexity, environmental controls have become increasingly sophisticated. Modern mines are required to comprehensively evaluate environmental concerns at the earliest stages of mine planning and design. Environmental controls are now considered as an integral part of overall mine management (EPA, 1997). However, mining and refining of rare earth elements, if not carefully monitored, can pose threats to human health and the environment. Nowhere is this more apparent than in the nation dominating rare earth element production today.

6.1 China

According to the Chinese Society of Rare Earths, every ton of rare earth elements produced generates approximately 8.5 kilograms of fluorine and 13 kilograms of flue dust. Additionally, sulfuric acid refining techniques used to produce one ton of rare earth elements generates 9,600 to 12,000 cubic meters of gas laden with flue dust concentrate, hydrofluoric acid, sulfur dioxide, and sulfuric acid. Not only are large quantities of harmful gas produced, alarming amounts of liquid and solid waste also resulted from Chinese refining processes. They estimate at the completion of refining one ton of rare earth elements, approximately 75 cubic meters of acidic waste water and about one ton of radioactive waste residue are produced. The IAGS reports China produced over 130,000 metric tons of rare earth elements in 2008 alone (IAGS, 2010). Extrapolation of the waste generation estimates over total production yields extreme amounts of waste. With little environmental regulation, stories of environmental pollution and human sickness remain frequent in areas near Chinese rare earth element production facilities (Figure 21). United States government agencies, including EPA, can learn a lot from China’s environmental issues related to rare earth element production.

As discussed, mining and refining processes can introduce radionuclides, rare earth elements, metals, and other potential contaminants into the environment at unnaturally high rates. Once introduced into the environment, the potential contaminants can be redistributed through the three “environmental mediums.” These three mediums include air, soil, and water. Living organisms depend on environmental mediums with stable chemical properties for their survival. The release of the possible contaminants from rare earth element production could alter the properties of the three environmental mediums. The upcoming sections will discuss how the possible contaminants could be found in the environment and toxicology of the possible contaminants to organisms.

6.2 Radionuclides

Uranium-238, thorium-232, and their decay products could present a threat to human health and the environment. Radium-226 in the uranium-238 decay chain produces radon-222 gas and bismuth-214, which are dangerous radionuclides (Argonne National Laboratory, 2005). Due to the short half-lives of radon-222 and bismuth-214 from the radioactive decay of radium-226, these isotopes exhibit accelerated decay rates releasing energetic particles and rays in shorter time spans than other radioactive isotopes. This explains why radium-226 is often regulated as opposed to uranium-238 (Duraski, 2011). The energetic particles and rays from radioactive decay could represent a threat to human health and the environment as well. The energetic particles are essentially small fast moving pieces of atoms, while the energetic rays are a form of electromagnetic radiation. The energetic nature of these radioactive byproducts makes them dangerous. They have the potential to dislodge electrons from important biological molecules including water, protein, and DNA.

Ores containing uranium-238 and thorium-232 are very mobile as dust resulting in air and soil contamination, where radon-222 gas is constantly released (Argonne National Laboratory, 2005). Radionuclides released into the atmosphere can be carried by wind and travel long distances before settling in soil or water. Uranium is very soluble in water and radium, although less soluble, can also result in groundwater contamination. Thorium is generally insoluble and seldom a groundwater concern (Duraski, 2011). The radioactive materials reaching the ground can become incorporated by plants, which can then bioaccumulate in organisms eating plants, including humans. Various studies have shown low doses of radiation causes humans no harm, but massive amounts of ionizing radiation can cause detrimental health effects. Ionizing radiation from radioactive decay is known to be a human carcinogen. The decay products of radon-222 gas in air represent the greatest risk to developing cancer. The energetic particles can be inhaled and harm lung tissue to the extent cancerous cells can develop. These carcinogenic effects can be observed in all living organisms.

6.3 Rare Earth Elements

The threats to human health and the environment from radionuclides are well know, but the threats from rare earth elements are equally unknown. The movement of rare earth elements in the environment is generally lacking. The toxicology of rare earth elements to aquatic, human, and other terrestrial organisms is not well understood either. The toxicological effects would largely depend on the rare earth element compound and the dose of that compound.

6.4 Metals

Carbonate and sulfide minerals associated with rare earth element ores contain a host of other metals and metalloids (metals)in their crystal structure including aluminum, arsenic, barium, beryllium, cadmium, cobalt, copper, lead, manganese, and zinc. This list constitutes the metals of greatest concern to environmental contamination and organism health at rare earth element mines and refineries. These metals tend to adsorb to clays and organic matter in soils. Despite this characteristic, metals dissolution is pH dependant. They are very mobile at the right conditions in the environment, where they are often redistributed between air, soil, and water. This makes metals a contaminant concern at rare earth element production sites in all three environmental mediums as well as a toxicological concern for organisms depending on those mediums for survival. Metals cannot be destroyed in the environment and only change forms. The form of the metals dictates the severity of the toxicological affects in organisms. The dose of the compound is important as well. Discussions of why each individual metal is likely to be present within rare earth element ores, what mediums they likely to be found, and the toxicology of them to organisms will now be presented.

Aluminum is the most abundant metal and overall the third most abundant element in the Earth's crust. This makes aluminum widely distributed in rocks and tends to be a very reactive element in nature. Nearly all aluminum is found combined with other elements, which often include oxygen, silicone, and fluorine. These chemical compounds are commonly found in minerals and soils; however, small amounts of aluminum are found dissolved as ions in water and attached to very small dust particles in air. Most aluminum compounds do not dissolve in water unless the water is acidic or very alkaline (ATSDR, 2006). Considering aluminum can be found in all three environmental mediums, it represents a possible threat to many different life forms. Aquatic organisms are the most sensitive to aluminum toxicity with fish experiencing the greatest affects. Low doses of aluminum cause no harm in humans, but high levels of aluminum have been shown to cause pulmonary effects and possible developmental problems in children. Despite an abundance of aluminum compounds residing in soils, these compounds do not pose much of a threat to plants because they do not take aluminum into their systems (EPA, 2008).

Arsenic is widely distributed throughout the Earth's crust and commonly associated with economic mineral ores. It is often combined with other elements in the environment such as oxygen, chlorine, and sulfur. The arsenic compounds are found in soils and can make their way into air and water as well. Arsenic present in air may travel long distances before settling in soil or water. Despite arsenic's mobility in the water, most arsenic compounds remain in soil (ATSDR, 2007). The fact arsenic can be found in all three environmental mediums make it a health risk to humans and other organisms. Arsenic has been known to be a human toxin since ancient times. The Department of Health and Human Services (DHHS), EPA, and International Agency for Research on Cancer (IARC) have classified arsenic as a human carcinogen (ASTDR, 2007). Increases of skin cancer have been directly observed due to arsenic exposure. Chronic exposure of arsenic can also lead to fatigue, gastrointestinal discomfort, blood disorders, and neuropathy in humans. Ingesting very high levels of arsenic can even result in death. Low levels of arsenic can cause nausea, decrease production of white blood cells, and affect heart rhythm. Mammals display the same general health effects from arsenic exposure. Arsenic not only increases cancer rates in humans and mammals; it also causes cancer in aquatic organisms. Genetic mutations can result where the growth and development of aquatic organisms is inhibited. Arsenic in plants has been shown to cause wilting, dehydration, and death (EPA, 2008).

Barium is not high on the list of most abundant elements in the Earth's crust, but it is likely to be present in elevated concentrations at rare earth element mines considering barium has a 3+ charge like the rare earth elements. Barium should be considered a potential threat associated with rare earth element production because of the barium content in rare earth element bearing minerals and the adverse health effects barium has on mammals. Barium is relatively insoluble and typically not present in water, but barium compounds have been known to exist in groundwater near waste sites. Large amounts of soluble barium compounds, such as barium chloride and barium sulfide, in water can cause harmful muscular effects in humans, including changes in heart rhythm and even paralysis. The human kidney also shows sensitivity towards chronic ingestion of soluble barium compounds. Smaller amounts of barium ingestion in humans can result in gastrointestinal irritation (ASTDR, 2007). Barium toxicity in aquatic and other terrestrial organisms is not well understood (EPA, 2008).

Beryllium is naturally occurring in rocks and could be found in elevated concentrations at rare earth element mines because beryllium has a 2+ charge like calcium. Calcium is a chemical constituent of carbonate minerals that characterize carbonatites. Beryllium can make its way into air, water, and soil. In air, beryllium exists as very small particles that get carried by wind. Solubility of beryllium in water is dependent on the compound. Some beryllium compounds are soluble while others are not. Weathering processes can change insoluble compounds into soluble ones as well. A majority of beryllium compounds do not dissolve in water and remain bound to soils, where they can reside for thousands of years without moving into groundwater.

Water soluble beryllium compounds pose more of threat to organisms than insoluble forms, however the greatest threat to humans from beryllium is in air. Inhalation of beryllium can harm the lungs of humans and other terrestrial animals. Such damage is similar to pneumonia with reddening and swelling of the lungs. This condition is referred to as "acute beryllium disease." Lung damage stemming from beryllium inhalation can increase a person's risk of lung cancer. The DHHS and IARC have determined beryllium to be a human carcinogen, while EPA believes beryllium is a probable carcinogen (ASTDR, 2002).

Copper is a natural constituent of rocks and often present in elevated concentrations in carbonatite. Low levels can be measured in all air, soil, and water; therefore, copper is widespread in the environment. Copper strongly absorbs to organic matter and other components of soil. If copper is released from the organic matter and soil, it will not travel far in the environment before re-bonding and has little chance of reaching groundwater sources. Copper that does dissolve in water can be carried in the form of copper compounds, free copper, or attached to particles in suspension (ATSDR, 2004). Aquatic organisms are very sensitive to chronic copper exposure, which can ultimately result in death. Plants and animals depend on copper as a micronutrient vital to good health; however at elevated levels, copper becomes a toxic substance. Copper slows the growth and development in terrestrial organisms (EPA, 2008). Humans can be negatively affected by copper too. Breathing high levels of copper can cause irritation of your nose and throat. Ingesting high levels of copper can cause nausea, vomiting, and diarrhea. Very-high doses of copper can cause damage to your liver and kidneys, as well as cause death. It is uncertain whether copper is carcinogenic. EPA does not classify copper as a human carcinogen, but further research identifying the cancer causing potential of copper is needed (ATSDR, 2004).

Lead is a naturally occurring metal in the environment and commonly present in small concentrations within hardrocks. It binds strongly with soil particles where it may reside for years. Small amounts of lead can make their way into water and travel into streams. This is more pronounced on acidic or very basic landscapes. If introduced into solution, the lead will eventually bind strongly to sediments. Concentrations of lead in soils can build to the extent it is taken up by plants. With elevated lead levels in soil, plants showed a decrease in growth, photosynthesis, and water absorption (EPA, 2008). Lead is also known to exist in the air floating as tiny particles. Although the effects of lead exposure are a concern for all humans, children under the age of seven are most at risk. The health effects of lead in humans are the same whether inhaled or ingested. Lead toxicity negatively impacts the cardiovascular, endocrine, muscular, nervous, reproductive, and respiratory systems and may ultimately result in death. No conclusive evidence suggests lead is a human carcinogen, but the DHHS, IARC, and EPA agree lead is a probable human carcinogen (ATSDR, 2007). Birds, fish, and mammals display similar health effects as humans from lead exposure (EPA, 2008).

Manganese is a natural constituent of hardrocks that is known to be mobile moving between the three environmental mediums. The type of soil and manganese compound determines the rate at which manganese travels in the soil column. Manganese in solution tends to attach to particles floating in solution and settle into the sediment. At low levels, manganese is considered a trace element essential to maintaining health in humans and other mammals (ATSDR, 2008). However, too much manganese has been shown to impair neurobehavioral, muscular, and gastrointestinal function. Manganese is vital for normal physiologic functioning in all animal species. Several disease states in humans have been associated with both deficiencies and excess intakes of manganese. The EPA concluded not enough scientific information exists to determine if manganese is a human carcinogen (ATSDR, 2008). Manganese toxicity towards aquatic and terrestrial organisms is generally lacking.

Zinc is released from hardrock sources and found naturally in air, soil, and water. It is labeled as an essential element to many different organisms, where too little zinc can cause as much health problems as too much zinc intake. The concern is that elevated zinc concentrations could be released into the environment making zinc harmful rather than helpful (ATSDR, 2005). Toxic amounts of zinc in water have resulted in reduction of growth and reproduction rates of aquatic plants and animals with increased mortality rates of both groups. Elevated levels of zinc in mammals can cause health problems too. Cardiovascular and nervous systems can be negatively affected. At high levels, zinc has caused liver and kidney problems in humans that are then amplified by hematological affects (EPA, 2008).

6.5 Mountain Pass Legacy

The Mountain Pass mine and refinery began operation in 1952, when historically few environmental controls existed. Due to lower rare earth element prices and competition from China, mining at Mountain Pass halted in the mid 1980's (Castor and Hedrick, 2006). The site contains an open-pit mine, overburden stockpiles, a crusher and mill/flotation plant, a separation plant, a mineral recovery plant tailings storage area, on-site evaporation ponds, and off-site evaporation ponds, as well as laboratory facilities to support research and development activities, offices, warehouses and support buildings (Figure 22). Groundwater and soil contamination is known to exist around the facility. Contaminants include barium, gross alpha, gross beta, nitrate, sodium lignin sulfonate, strontium, total dissolved solids, total lanthanides, total petroleum hydrocarbons (kerosene/diesel), total radium, total thorium, and total uranium. Claims have been brought under environmental laws, regulations, and permits for toxic torts, natural resource damages and other liabilities, as well as for the investigation and remediation of soil, surface water, groundwater and other environmental media (Environmental Audit, 2010).

On September 30, 2008, Molycorp Minerals LLC acquired the Mountain Pass, California rare earth deposit and associated assets from Chevron Mining Inc. through Rare Earth Acquisitions LLC (which was later renamed Molycorp Minerals, LLC). The mine and refinery at Mountain Pass will reopen in 2012 after modernization to its production facilities are completed. Molycorp proposes to expand the open-pit mine both laterally to the west, southwest and north as well as deepening it. In addition to the existing overburden stockpile located west of the pit, which will serve as the initial overburden stockpile when mining recommences, additional overburden stockpiles will be constructed to the north or east of the pit to provide additional storage capacity sufficient to accommodate the remaining overburden material for the existing permitted life of the mine. New facilities, including the construction of a control lab, additional warehousing and raw material storage facilities, and a new mill are proposed in the modernization and expansion project (Environmental Audit, 2010).

6.6 Bear Lodge Case Study

The Bear Lodge and Mountain Pass properties exhibit somewhat similar geology and contain the same dominant rare earth element bearing mineral, bastnasite. Analyzing the environmental issues associated with rare earth element production at Mountain Pass provides the model for identifying potential risks at the Bear Lodge property. Any of the environmental concerns at Mountain Pass should be a concern at the Bear Lodge property along with some unique concerns specific to the Bear Lodge property. Some of possible contaminants associated with mining at Bear Lodge include, but are not limited to, radionuclides, rare earth elements, metals, sulfides, carbonates, and other elements such as fluorine.

Water represents the environmental medium of overall greatest concern at Bear Lodge. Not only can the possible contaminants go into solution, a great deal of water is consumed during rare earth element mining and processing. Such issues generate both water quality and quantity concerns that will heavily depend on what management practices are put into place. Pit lake water represents a potential environmental concern, however Rare Element Resources does not intend for a pit lake to develop because the pit will be above the water table and surface water will be diverted away from the pit. Even though the company is taking these measures, the environmental concerns of pit lake water must be analyzed because it remains a possibility until the mine is opened and proven not to be an issue. This could be the most dangerous water issue at the mine if the pit is opened to depths where sulfide minerals are present considering the constant contact water would have with sulfides at depth. Water will also be in constant contact with carbonate minerals in the carbonatite dikes.

Meteoric water will come into contact with stockpiled rare earth ores while being saved for future production. Depending on how much ore is piled, how long they remain piled, and what management practices are put in place will determine the extent of contaminant release into the environment. To prevent contamination from these likely wastestreams, the runoff needs to be captured and stormwater controls put in place. The waters produced from the physical processing plant may pose an environmental threat as well (Kozel, 2011).

The hydrology of the Bear Lodge area is not well understood. However, the Madison formation remains the prominent aquifer in the region that is often hundreds of feet from the surface (Wyoming State Geological Survey, 2008). The Bear Lodge area is a recharge zone for the regional aquifer responsible for providing drinking water to people in Sundance and the surrounding areas of northeastern Wyoming and western South Dakota. According the National Oceanic and Atmospheric Administration, northeastern Wyoming receives on the order of 15-20 inches of rain every year. The streams in the area are predominantly ephemeral with some surface springs present (Timm, 2011). The lack of surface water leaves no choice but for Rare Element Resources to use water from the Madison formation in rare earth element production at the property. Rare Element Resources believes the aquifer can handle the company's planned water extraction, but it is not clear how aquifer usage will affect surface spring behavior at the Bear Lodge property (Pickarts, 2011). These springs provide the most reliable water source for animals in the area. Elevated water extraction from the Madison could dry the springs or they may not be affected. Rare Element Resources plans to recycle 100% of water used during physical processing and collect runoff from tailings piles to be used at the mill. Such a strategy may address some of the water quality and quantity issues at Bear Lodge and could prevent the Madison aquifer from overuse.

Surface waters at the Bear Lodge property need to be protected since the proposed mine location resides at the headwaters of Beaver Creek, which eventually flows into Cook Lake. This is a popular recreation area for locals who value being able to use the water resource at their leisure. The contaminants from the Beaver Creek headwaters could make their way to Cook Lake affecting the water quality. Rare Element Resources understands the risks to ground and surface waters in the area and employs of the services of Knight Piesold consulting in matters related to environmental monitoring. An immense database of background data of the surface and ground waters in the Bear Lodge area exists because of previous exploration and monitoring of the atomic power station nearby. Knight Piesold is also actively taking water samples on site to better understand the natural environment and gauge how future mining affects the area. A total of 14 ground water monitoring wells are established on the property. There will also be two piezometers in the mining pit once it is opened. Currently, surface waters are being tested monthly, while the ground water wells are tested quarterly (Pickarts, 2011).

Water is a dominant concern at most mine sites, not just at the Bear Lodge property. Rare earth element mining presents various water issues of concerns. Specific concerns include contamination of groundwater, surface water, and surface water run-off. Most of these concerns result from the chemical constituents of the rare earth element ores. Oxidation and dissolution of these constituents have the potential to release contaminants and cause environmental hazards. Such processes are accelerated by increasing the surface area of the rock by crushing, milling, and processing. This is especially true in rare earth element ores that often contain greater amounts of minerals that can undergo dissolution. Rare Element Resources and the USFS office in Sundance do not anticipate any acid drainage issues at the Bear Lodge property, but acid mine drainage is a concern at many mine sites and needs to be monitored for the long-term at the Bear Lodge property. Additionally, the natural buffer in the carbonatite may help mitigate acid concerns. The natural buffer in carbonatite also explains why Rare Element Resources will leave at least a 30 foot reaction front directly above the sulfide rich zone. The reaction front ensures enough carbonate is present to prevent an acid lake from forming in the pit (Pickarts, 2011).

Air quality issues associated with mining and processing are of concern too. Dust can be created during physical processing, and fumes can be generated from chemical processing. This is certainly the case at the Bear Lodge property and Upton processing plant. The mining and milling processes at Bear Lodge may also cause deposition of particulates off-site if proper precautions are not put in place. The collection of organic and inorganic particles that make up dust have the potential to harm human health and the environment. Airborne radionuclides represent an air quality concern at the Bear Lodge property. Alarming concentrations of radionuclides are not known to exist at Bear Lodge, but the physical processing of rare earth ores onsite could cause radionuclides present in the ore to become airborne. This is why Rare Element Resources will use water to ensure excess dust is not created during the crushing and grinding of rare earth ores. Knight Piesold has also established four air monitoring stations around the property to record possible airborne radionuclide (Pickarts, 2011). The fumes bound to be created by chemical refining of the rare earth element ores will need to be addressed as well. Radionuclides could be released into the atmosphere near Upton Wyoming. Metals and other elements such as have the potential to be released into the air as well. Rare Element Resources will need an air permit in compliance with the clean air act.

Another important oversight of mining is to ensure soil quality and quantity is maintained during and after mining occurs. Possible contaminants of the rare earth ore, such as radionuclides, metals, and rare earth elements, can become incorporated into the soils as a result of weathering or during rare earth element production. Metals, rare earth elements, and radionuclides can come out solution and precipitate in soils. The contaminants can reside in the soils for extended time periods depending on weathering and future land use. Contamination at Bear Lodge has yet to be seen. A robust monitoring program and well designed production plan at the Bear Lodge property and Upton chemical processing plant should prevent, or at least address, any problems caused by the possible contaminants and environmental concerns discussed.

7.0 Conclusions

Attention towards rare earth elements, including key and critical elements, will only grow as governments around the world scramble to address serious supply issues as a result of increased global usage and decreased export quotas of rare earth elements by China over the past few years. The United States government is concerned about rare earth element supply considering the elements are vital to electronic, clean energy, and military technology production. Each sector either directly influences the U.S. economy or national defense. The USDOE conducted a study to determine which periodic elements are essential to maintaining the integrity of the United States where key and critical materials were identified. Nine of the 14 key elements are rare earth elements. The rare earth elements receiving key designation include lanthanum, cerium, praseodymium, neodymium, samarium, europium, terbium, dysprosium, and yttrium. The five other key elements are elements scattered throughout the periodic table and include lithium, cobalt, gallium, indium, and tellurium. Critical elements describe key elements that are necessary for clean energy technology production and have even greater supply risks than the key elements. The key elements receiving critical designation in the short term (0-5 years) were dysprosium, neodymium, terbium, europium, yttrium, and indium. Critical materials in medium term (6-15 years) include dysprosium, neodymium, terbium, europium, and yttrium. All are rare earth elements. The same USDOE report has even outlined a strategic plan to explore substitution of key and critical elements in future technologies, recycling from waste electronics, and developing a globally diverse supply of these elements.

Record high rare earth element prices have already resulted in increased investments for exploration and development of rare earth element deposits in the United States. Companies are rediscovering the mining potential of rare earth element deposits across the nation from the Bokan Mountains in Alaska to the Bear Lodge Mountains in Wyoming. Favorable market conditions and a promising deposit could put a Region 8 state at the center of rare earth element mining. The realization of rare earth element production in Region 8 is real and fast approaching. Within five years, Rare Element Resources plans to have the second operating rare earth mine in United States at the Bear Lodge property. This northeastern Wyoming deposit has the potential to become the largest producer of rare earth elements in America.

As with any mine or refinery, rare earth element production could contaminate the environment if best management practices are not used and the operation is not closely monitored. Federal and state agencies must determine how to best oversee the Bear Lodge project to ensure this operation does not put human health and the environment at risk. Many potential contaminants reside within rare earth element bearing rocks and minerals. The possible contaminants include, but are not limited to, radionuclides, rare earth elements, metals such as barium, beryllium, copper, lead, manganese, and zinc, sulfide minerals, carbonate minerals, and other potential contaminants such as fluorine and asbestos minerals. Mining exposes these possible contaminants, while refining isolates and concentrates the possible contaminants. Rare earth element mining is hardrock mining, so any of the environmental concerns associated with hardrock mining could be a concern with rare earth element production.

The possible contaminants cause negative effects towards aquatic and terrestrial organisms in addition to humans. Some of the radionuclides and metals contaminants are even classified as human carcinogens by international and federal health agencies. Others possible contaminants increase the mortality rates of aquatic and terrestrial organisms. Cooperation between all government agencies designed to protect the environment and companies responsible for rare earth element production will prove invaluable in ensuring these operations do not pose a threat to human health and the environment in the United States. Even though mining at the Bear Lodge property is early in the planning stages, cooperation and communication between Rare Element Resources, Wyoming Department of Environmental Quality (WDEQ), and USFS seem strong. Areas of China have suffered the consequences of haphazard rare earth element production. The stronger the communication lines between the different parties, the better off the surrounding environment and human population will be.

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9.0 Appendix

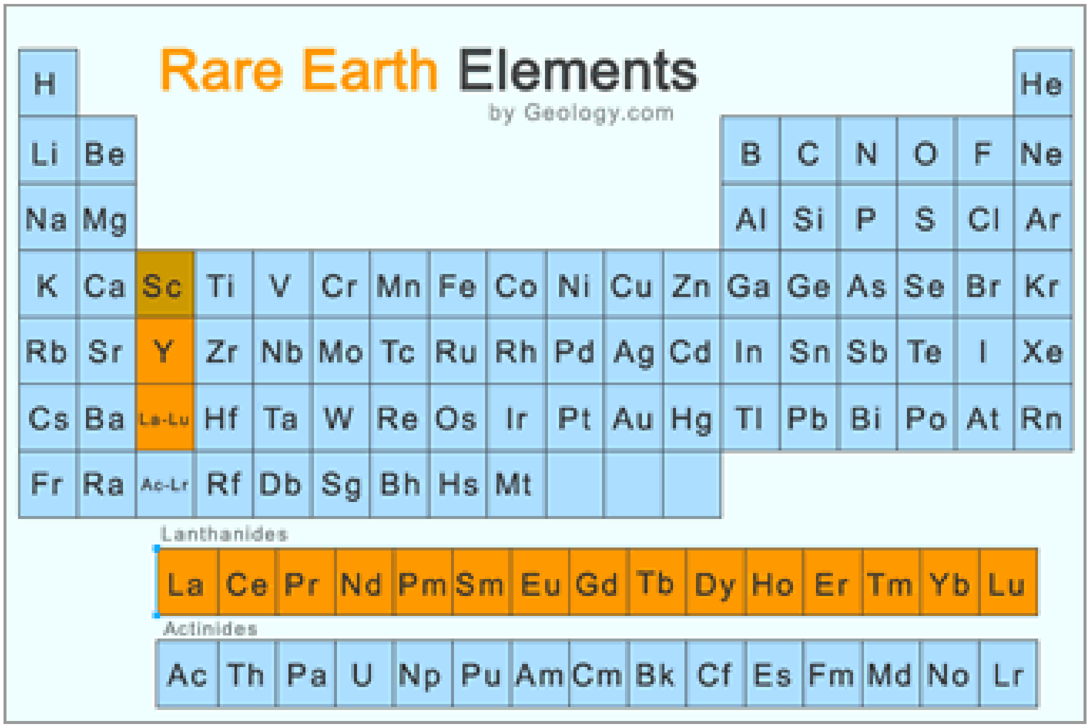

Figure 1: *Periodic table highlighting all 17 rare earth elements in orange. Figure adapted from geology.com.*

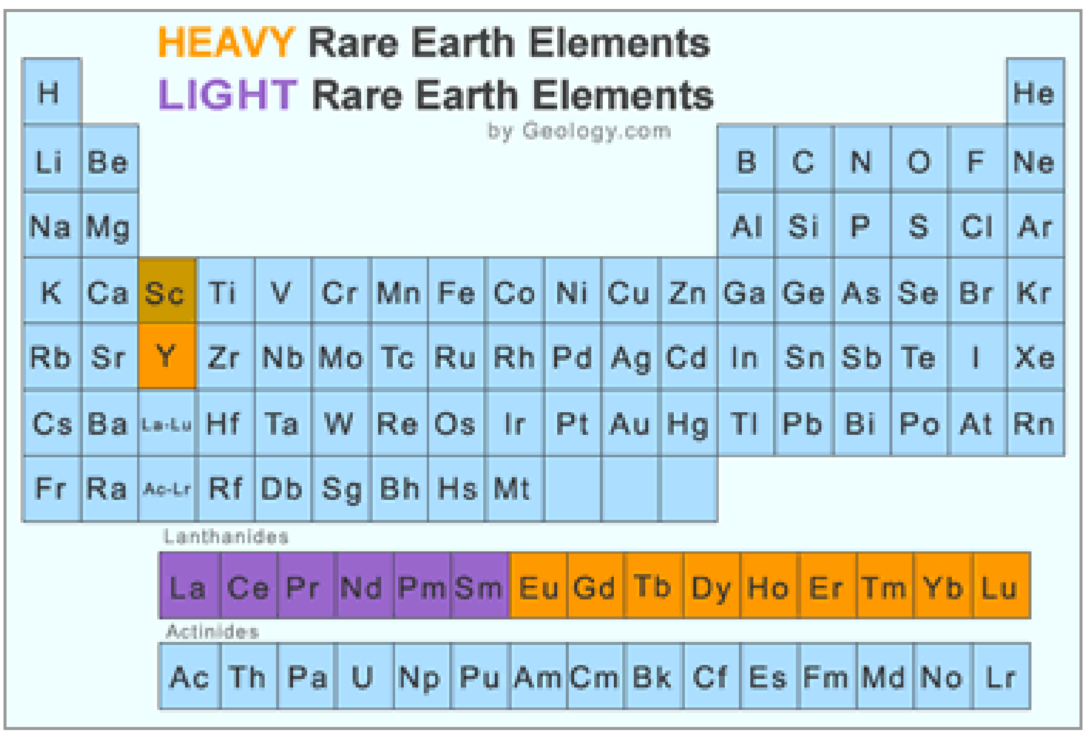

Figure 2: *Periodic table designating "light" and "heavy" rare earth elements. The periodic elements highlighted in violet represent the "light" rare earth elements, while the orange highlight elements are "heavy" rare earth elements. Figure adapted from geology.com.*

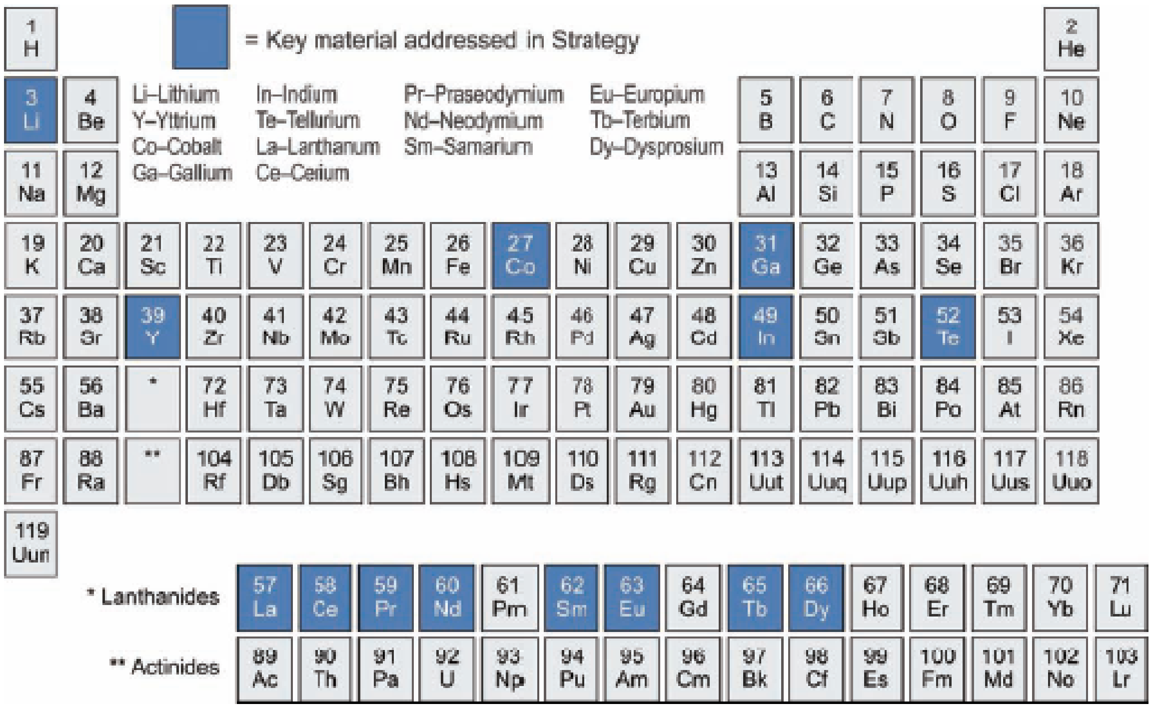

Figure 3: *Periodic table with the 14 key materials described by the USDOE highlighted in blue. Figure adapted from USDOE (2010) "Critical Materials Strategy" report.*

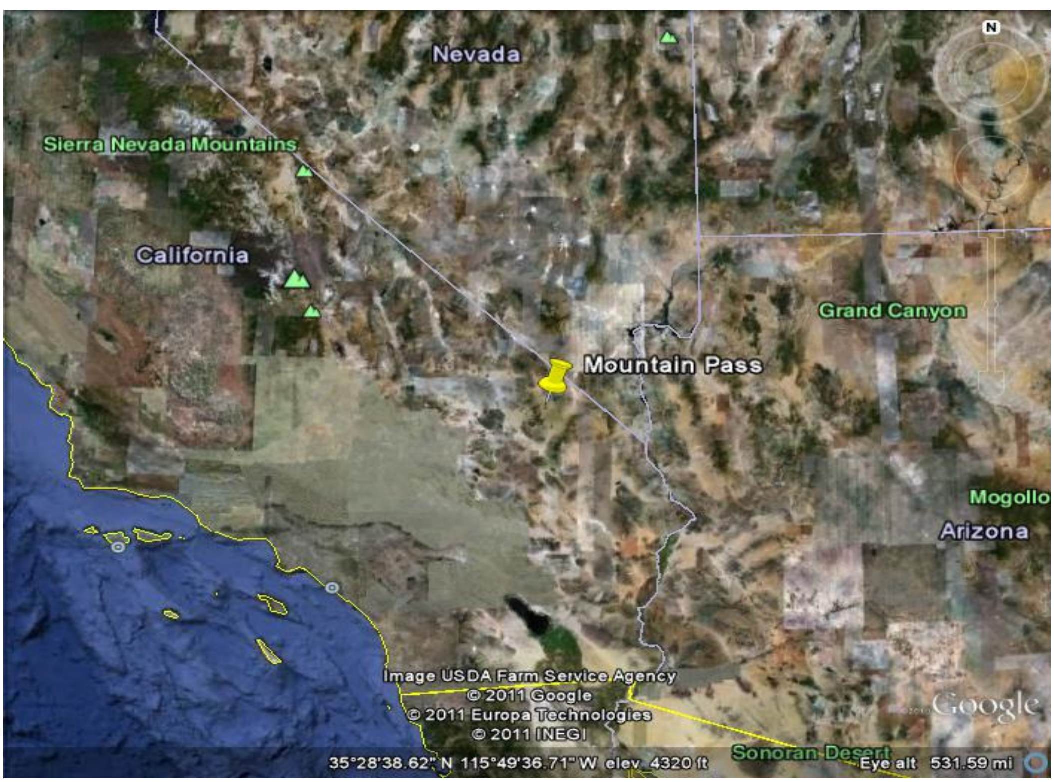

Figure 4*: Google Earth map showing the location of Molycorp's Mountain Pass mine.*

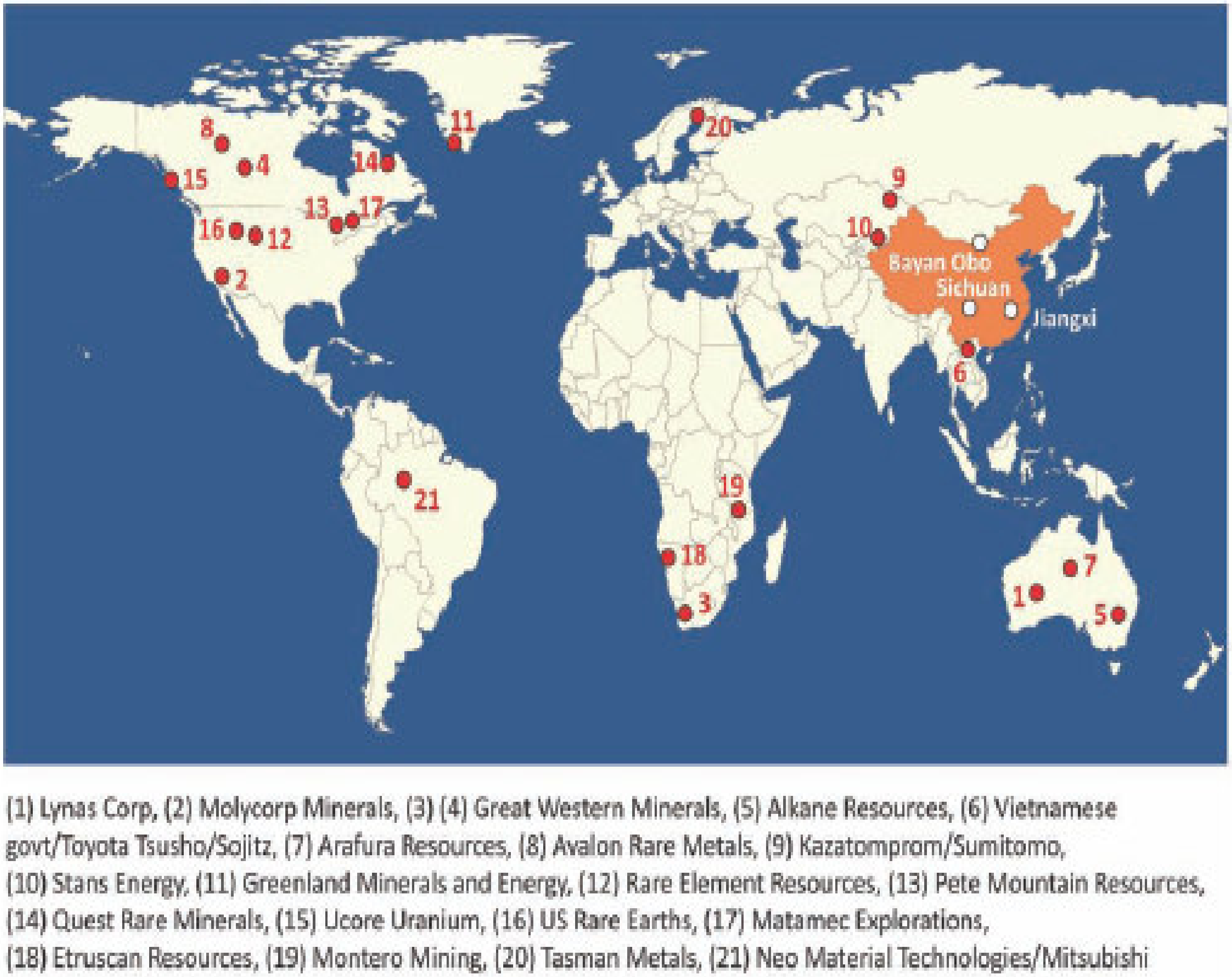

Figure 5*: World map labeling the prominent rare earth element deposits owned by mining companies. Figure adapted from USDOE (2010) "Critical Materials Strategy" report.*

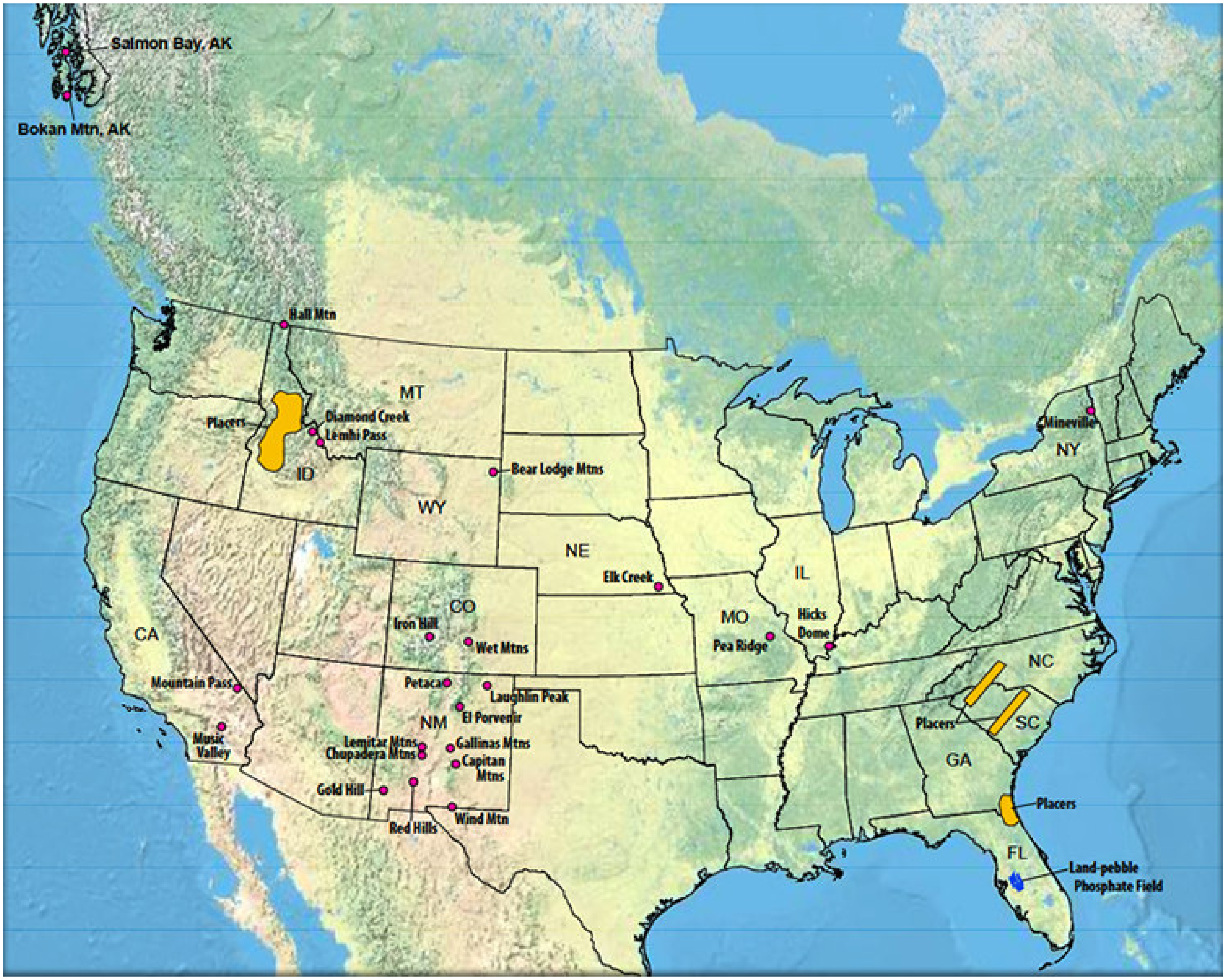

Figure 6: *Map with principle United States rare earth element deposits labeled. Figure adapted from United States Geological Survey (2010) "Principle Rare Earth Elements Deposits of the United States-A Summary of Domestic Deposits and a Global Perspective" report.*

Figure 7: *Google Earth map showing the location of the Bear Lodge property.*

Figure 8*: Picture displaying a sample of carbonatite from Brazil.*

Figure 9*: Photo of Bull Hill (center) taken during site visit June 22, 2011.*

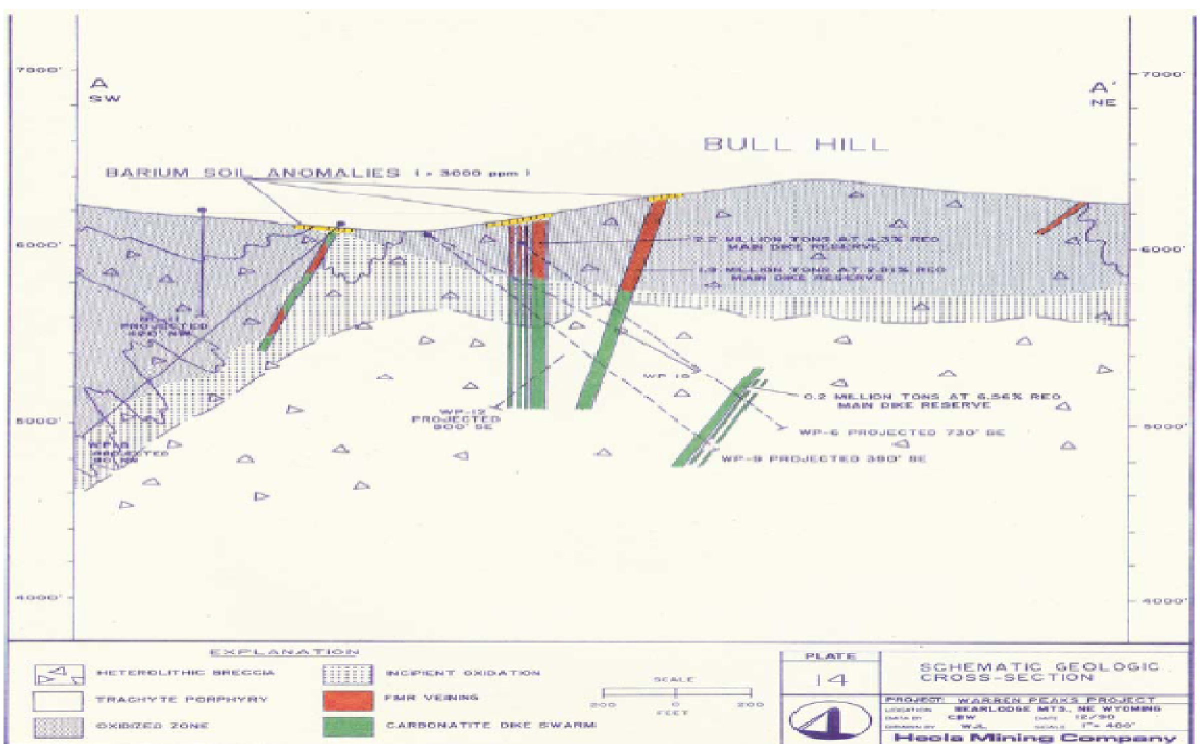

Figure 10*: Geologic cross-section constructed by Hecla Mining Company depicting the carbonatite dikes near Bull Hill and the respective mineralogical zones. FMR zones are shown in red and the carbonatite-oxide zone is represented by green. The dark blue area displays where the subsurface rocks have been oxidized and the lighter area depicts where oxidation is beginning to happen. Figure adapted from Rare Element Resources "Bear Lodge Summary" document.*

Figure 11: *Image of FMR core sample at Rare Element Resources core shed in Sundance Wyoming. Photo was taken during site visit June 22, 2011.*

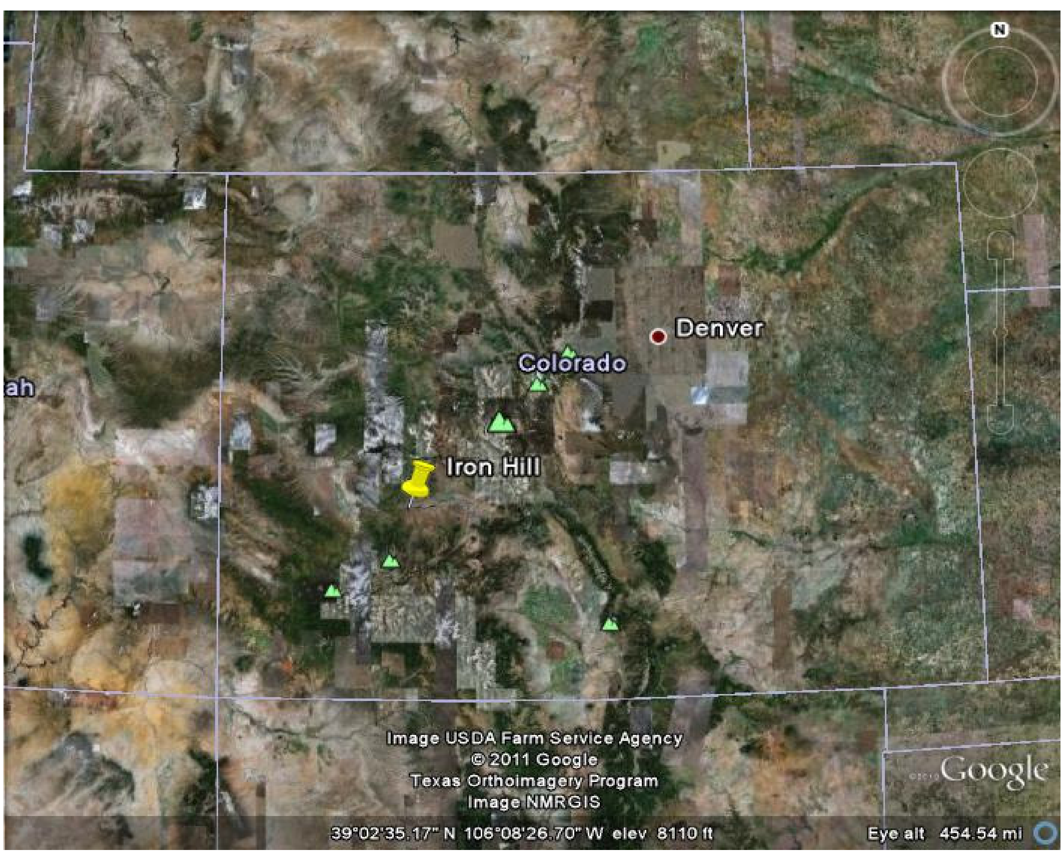

Figure 12*: Google Earth map displaying the Iron Hill deposit resides.*

Figure 13: *Google Earth map showing where the Wet Mountains deposit is located.*

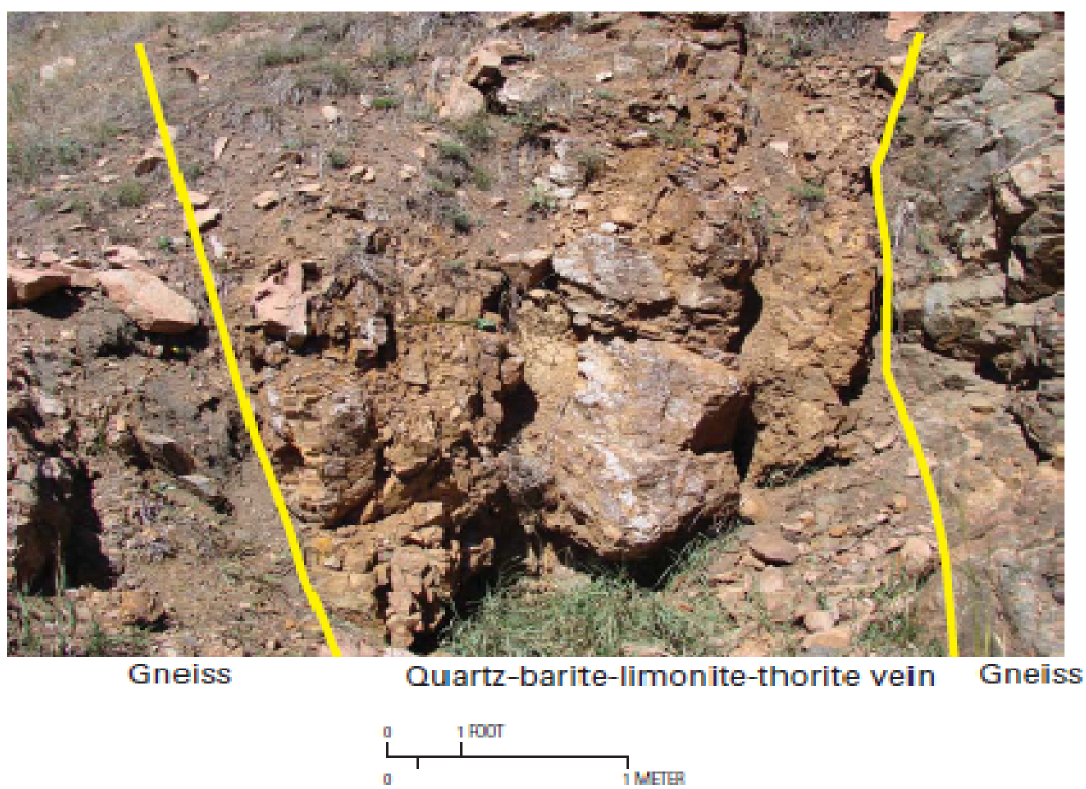

Figure 14*: Photo of mineralized quartz veins at the Wet Mountains Deposit. Figure adapted from United States Geological Survey (2010) "Principle Rare Earth Elements Deposits of the United States-A Summary of Domestic Deposits and a Global Perspective" report.*

Figure 15: *Google Earth map displaying where the Lemhi Pass deposit resides.*

Figure 16*: Photo of mineralized quartz veins at Lemhi Pass. Figure adapted from United States Geological Survey (2010) "Principle Rare Earth Elements Deposits of the United States-A Summary of Domestic Deposits and a Global Perspective" report.*

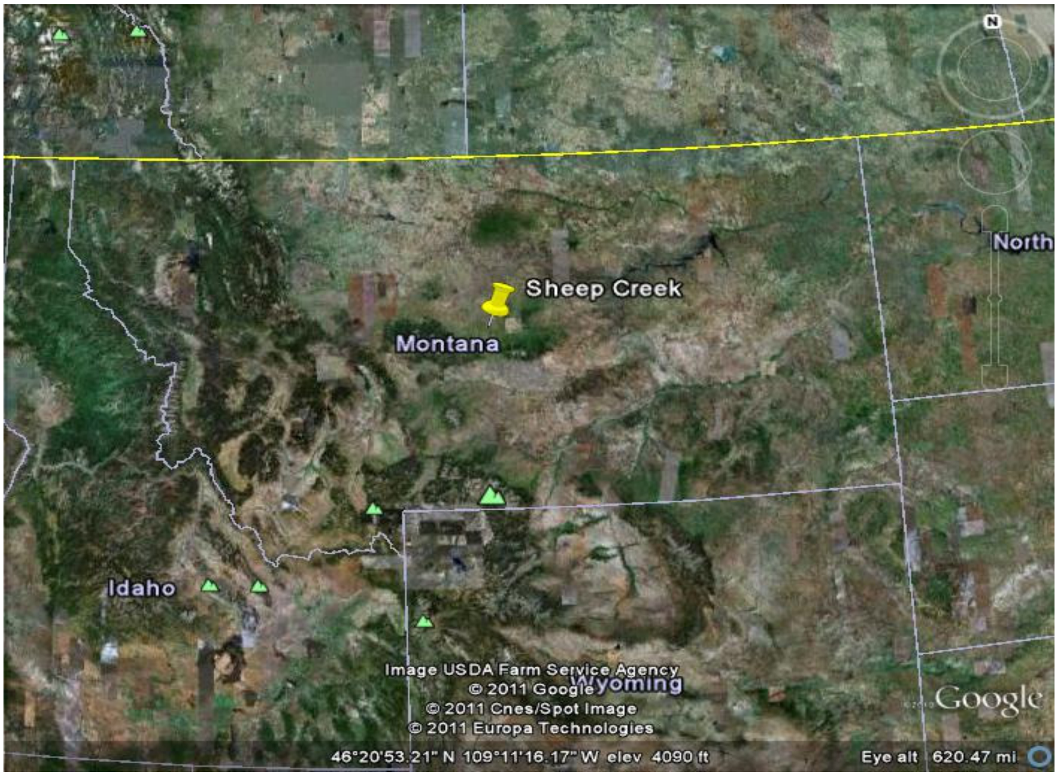

Figure 17: *Google Earth map showing the location of the Sheep Creek project.*

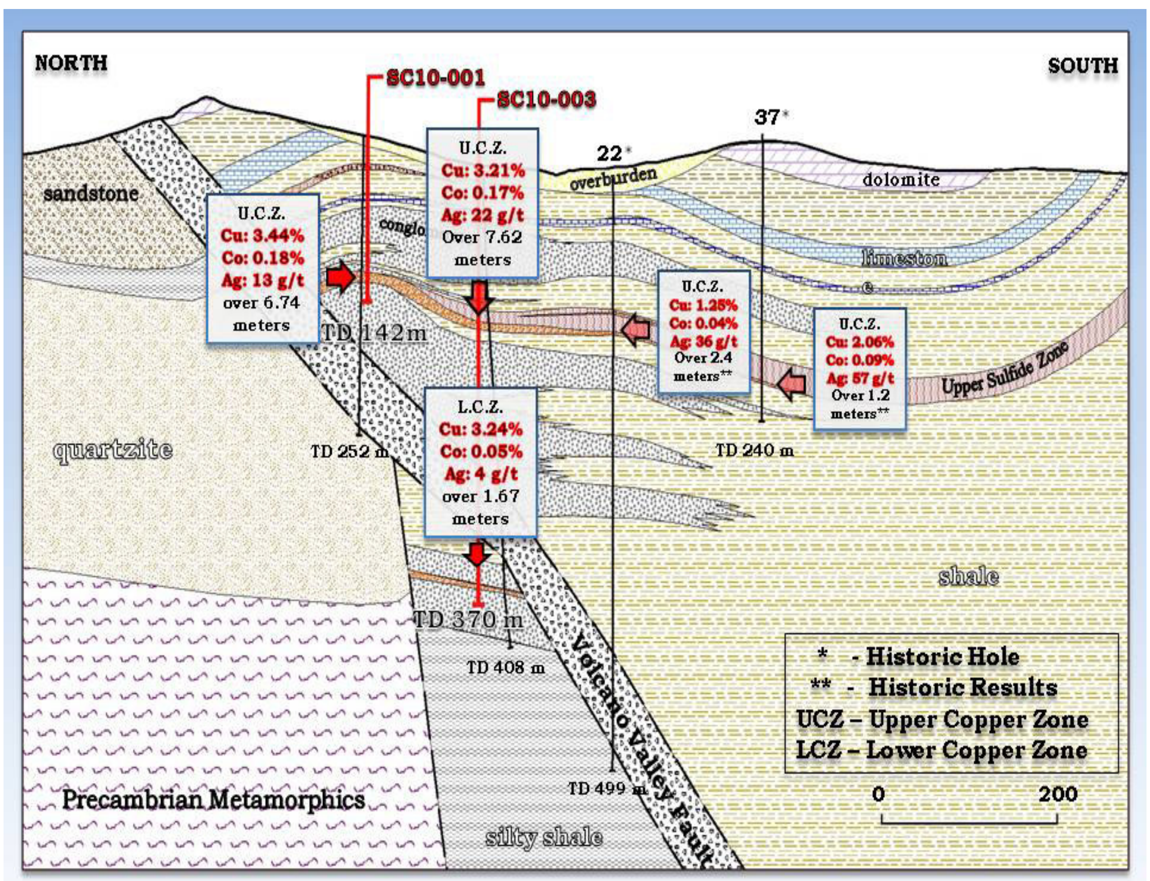

Figure 18*: Geologic cross-section at Sheep Creek property. Adapted from Tintina Resources' website.*

Figure 19: *Photo of Molycorp's Mountain Pass open-pit mine in southeastern California.*

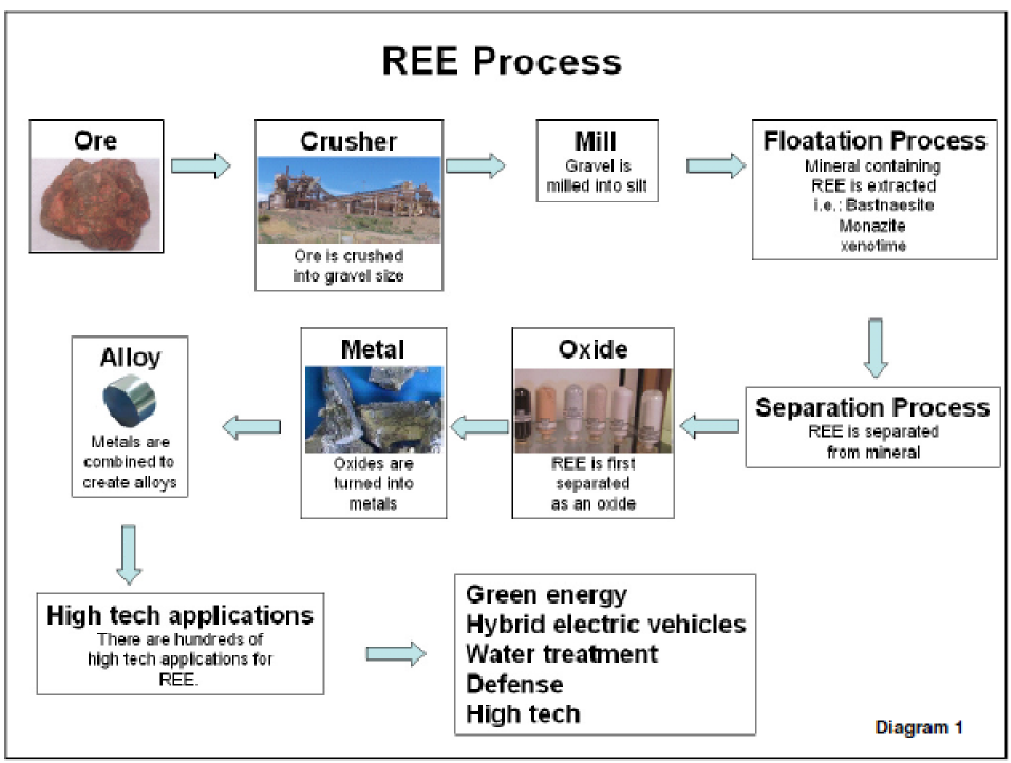

Figure 20: *Flowchart depicting the rare earth element refining process. Figure adapted from IAGS (2010) report.*

***Figure 21**: Google Earth image of the Bayan Obo mine in China.*

***Figure 22**: Google Earth image of Mountain Pass mine displaying the components of the mine, refinery, and support buildings.*