GEOLOGY AND MINERAL DEPOSITS OF THE GALLINAS MOUNTAINS (GALLINAS DISTRICT), LINCOLN COUNTY, NEW MEXICO: PRELIMINARY REPORT

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ABSTRACT
Rare earth elements (REE) are used in the electronics, automotive, and metallurgical industries. Deposits containing REE are found throughout New Mexico. Minimal past production of REE in the 1950s, as bastnaesite, came from the Gallinas district, Gallinas Mountains, Lincoln County. Since then, several companies and the U.S. Bureau of Mines (USBM) have conducted various exploration programs to identify and delineate REE resource potential. Four types of deposits are found in the district: epithermal REE veins, Ce-REE-bearing veins, REEP breccia deposits, and igneous rocks. All are associated with Tertiary alkaline to calc-alkaline igneous intrusions. In 1991-1992, USBM calculated an inferred resource of 0.847 million metric tons with an grade of 2.95% total REE. Demand for REE, both domestically and globally, areas such as the Gallinas district in New Mexico are being re-examined for additional REE potential; preliminary results for the Gallinas district are in this report.

INTRODUCTION
Rare earth elements (REE) are increasingly becoming more important in our technological society and are used in many of our electronic devices. REE include the latest lanthanide elements (atomic number 57-71), yttrium (Y, atomic number 39), and scandium (Sc) and are commonly divided into two chemical groups, the light REE (La through Eu) and the heavy REE (Gd through Lu and Y). REE are lithophile elements (or elements enriched in the crust) that have similar physical and chemical properties, and, therefore, occur together in nature. Thorian (Th), uranium (U), niobium (Nb) and other elements typically are found with REE; most deposits are radioactive because of their Th and U content. The U.S. once produced enough REE for U.S. consumption, but since 1999 more than 90% of the REE required by U.S. industry have been imported from China. Recently, the Chinese government announced that it is examining the economic feasibility of continuing to export REE from their deposits.
REE deposits have been reported from New Mexico (McLemore et al., 1988a, b; McLemore, 2010), but were not considered important exploration targets because the demand in past years has been met by other deposits in the world. However, with the projected increase in demand and potential lack of available production from the Chinese deposits, these areas in New Mexico are being re-examined for their REE potential. One of these areas in New Mexico is the Gallinas mining district, also referred to as the Red Cloud Mining district, in the Gallinas Mountains.

The Gallinas Mountains are in northern Lincoln County where a series of alkaline volcanic rocks, including porphyry veins, calc-alkaline rocks, and shoshonites (i.e. volcanic equivalent to syenite), andesite, and basaltic lavas, have intruded Permain sedimentary rocks belonging to the Abo, Ysoco, and Glorieta Formations (Perhac, 1970; Schreiner, 1993). A small amount of bastnaesite ([Ce, La, (CO3)]F with 70-75% total REE oxide content), was recovered during processing for fluorite. Alteration includes brecciation, silicification, chloritization, and fenitization (Griswold, 1959; Woodward and Fulp, 1991; Schreiner, 1993). Carbonates are infilled at depth by the presence of fenitization, carbonatization of the breccias, presence of REE, and similarity of the intrusive rocks and mineralization to areas with carbonatites.

RE APPLICATIONS IN INDUSTRY
- Neodymium and lutetium are used in lasers and optical fibers
- Praseodymium is used in magnetic materials
- Cerium is used in electronic devices
- Terbium and dysprosium are used in light-emitting devices
- Lanthanum is used in automotive catalytic converters

MINERAL PRODUCE FROM THE GALLINAS MOUNTAINS DISTRICT, NM

Mining districts in New Mexico that contain REE deposits (modified from McLemore et al., 2005). In New Mexico, the North American Cordilleran alkaline igneous belt extends from the Sangre de Cristo Mountains near Raton, southward to the Cordilleran Mountains east of El Paso, Texas (North and McLemore, 1986, 1988; McLemore, 1996). Significant mineral production, especially gold and silver, has come from deposits spatially associated with Tertiary alkaline igneous rocks in the New Mexico alkaline-igneous belt (McLemore, 1996). These mineral deposits in New Mexico have been referred to as Great Plains Margin (GPM) deposits by North and McLemore (1986, 1988) and McLemore (1996).

REGIONAL GEOLOGIC AND TECTONIC SETTING
The North American Cordilleran belt of alkaline igneous rocks (Woodley, 1987; Mutschler et al., 1991; McLemore, 1996). Lindgren (1915, 1933) was one of the first geologists who noted that a belt of alkaline-igneous rocks extends from Alaska and British Columbia southeastward along the eastern New Mexico, Trans-Pecos Texas, and eastern Mexico and that these rocks contain relatively large quantities of fluophile (F), zirconium (Zr), rare-earth (REE) and other elements. Economic mineral deposits found within this bell have produced nearly 13% of the total lode gold production in the United States and Canada (Mutschler et al., 1991).

MINING AND EXPLORATION HISTORY
1818 first mining claims established
1885 early production for copper, silver, and lead
1942-1943 Fe ore produced from American Iron and Red Cliff mines
1942 fluorspar discovered in the district
1945 bastnaesite discovered with fluorspar
1951-1954 fluorspar produced from the Red Cloud and Conqueror mines
1950's ~142,000 lbs of bastnaesite was produced from Red Cloud mine
1956-1956 ~5,000,000 lbs of bastnaesite was produced from Red Cloud mine
1981 phosphorus added to the Skagit River mine
1980 Phelps Dodge drilled a 532-foot deep hole at the Rio Tinto mine
1980-1981 Molycorp, Inc. conducted geochemical survey, geophysical survey, and two drill holes on a magnetic high anomaly
1989 Canyon Resources examination
1991-1992 Hudson Mining Co. examination
1992 American Copper and Nickel, Inc. and Romarosa Resources
2009 Strategic Resources, Inc. staked claims and began exploration
Chemical analyses are from Schreiner (1993) and this report. Geochemical plots from Le Bas et al. (1986), de la Roche et al. (1980), and Frost et al. (2001).

Geochemical plots characterizing the igneous rocks in the Gallinas Mountains confirm this hypothesis. These data suggest a crustal source for the igneous rocks.

Separate magmatic event. Detailed dating and geochemical analyses are required to classification of breccia pipes is primarily based upon the mechanism of brecciation and these breccia pipes intrusive breccias. Intrusion breccias are formed directly from the proximal faults. The mineralized area of the Gallinas Mountains lies in a sandstones, siltstones, shales and limestones of the Abo, Yeso and Glorieta Formations. (exposed in Red Cloud Canyon) that are overlain by Permian arkoses, quartz sandstones, siltstones, shales and limestones of the Abo, Yeso and Glorieta Formations. Tertiary igneous rocks, as stocks and laccoliths, including latoir (also trachydatite to trachyandesite, Le Maitre, 1989), trachyte/phonolite, and rhyolite have intruded the Yeso and Abo Formations. Several magmatic-hydrothermal breccia pipes are hosted in the trachyte and Yeso Formations. Most of these breccia pipes are matrix-supported and are cemented by quartz, fayalite, and hematite along with small crystals of other minerals and rock fragments. However, two breccia pipes at the M and E No. 13 prospect are clast-supported. The mineralized area of the Gallinas Mountains lies in a low magnetic field low surrounded by magnetic high anomalies (McLemore, 2001). The classification of breccia pipes is primarily based upon the mechanism of brecciation and the involvement of water, magma, or tectonism (Sillitoe, 1985). Schreiner (1993) called these breccia pipes intrusive breccias. Intrusion breccias are formed directly from the subsurface movement of magmas (Sillitoe, 1985). Magmatic-hydrothermal breccias are formed by the release of hydrothermal fluids from the magma chamber and can include mafic, felsic, and basaltic breccias (Sillitoe, 1985). In the Gallinas breccia pipes, the breccia cement consists of hydrothermal minerals and mafic; therefore, magmatic-hydrothermal breccia pipe is a better term (Sillitoe, 1985).

petrochemistry of the igneous rocks

The igneous rocks in the Gallinas Mountains are mafic to peraluminous, alkaline volcanic rocks (Frost et al., 2001), and have chemical compositions similar to A-type granitoids (Whalen et al., 1987). A-type (anorogenic or anorogenic) granitoids typically are found along rift zones and within stable continental blocks and are characterized by high-Ti, high-Mg, and low-Mg.

Characteristics. Many ore deposits are associated with A-type granitoids. The trachyte and latite samples plot within the within-plate granite tectonic field of Pease et al. (1984, WPG), whereas the rhyolite sample plots within the volcanic-arc granite field (VAG). Trachyte and latite are possibly related magnetically, but the trachyte could be a separate magma. The geochemical data for this area consists of 279 samples that were collected and analyzed for various elements by Schreiner (1993) and by the authors for this report. The differentiation of the igneous rocks in the Gallinas Mountains are shown above. Chondrite values are from Nakamura (1974). Geochemical anomaly maps (below) were constructed using ARClAPF and indicate that the higher concentrations of REE, Cu, Pb, and Au are found along faults filled with Cu-REE veins and REE veins and the M and E breccia deposits.

geochemistry of the gallinas REE deposits

Geochemical anomaly map and statistical plots (box plots, histogram, cumulative frequency distribution plot for all samples) of total REE (rare earth elements, ppm) of samples from the Gallinas Mountains. Chemical analyses are from Schreiner (1993) and this report.

Schematic model of formation of the mineral deposits in the Gallinas Mountains, Lincoln County, New Mexico (modified in part from Schreiner 1993; Richards, 1995; Williams-Jones et al., 2000).

mineral zoning in the Gallinas Mountains, Lincoln County, New Mexico, based upon predominant mineralogy and chemistry of the known deposits.

GEOCHEMISTRY OF THE GALLINAS REE DEPOSITS

4. Differentiation of different types of REE deposits by normalized La/Lu and Ba/Lu ratios is similar to Bayan Obo, Lemhi Pass, and Olympic Dam deposits and different from Capitan deposits. Note also that there are different compositions within some districts (i.e. Lemhi Mountains, Gallinas District).

PRELIMINARY CONCLUSIONS

The igneous rocks in the Gallinas Mountains are mafic to peraluminous, alkaline volcanic rocks, and have chemical compositions similar to A-type granitoids. Trachyte and latite are possibly related magnetically, but the trachyte could be a separate magmatic event. Detailed dating and geochemical analyses are required to confirm this hypothesis. These data suggest a crustal source for the igneous rocks.

• Resources amount to at least 0.487 million metric tons of 2.95% total REE (not NI-43-101 compliant; Jackson and Christiansen, 1993; Schreiner, 1993). Drilling is required identify a better resource estimate.

DISTINCT ionation is defined by REE-based REE-Cu veins that form center of the district, surrounded by REE veins. The magmatic-hydrothermal breccia deposits form a belt partially surrounding the veins. Iron skarns formed at the top and edge of the trachyte intrusion and are likely the earliest stage of mineralization. Intrusive iron skarns are probably related to the REE veins and breccias because they typically contain basaltic and carbonatite.

• Some features are enriched in REE, but unthinned igneous rocks.

The igneous rocks in the Gallinas Mountains are metaluminous to peraluminous, alkaline volcanic rocks (Frost et al., 2001), and have chemical compositions similar to A-type granitoids. Trachyte and latite are possibly related magnetically, but the trachyte could be a separate magmatic event. Detailed dating and geochemical analyses are required to confirm this hypothesis. These data suggest a crustal source for the igneous rocks.

• Intrusion of the trachyte/phonolite
• Formation of the magmatic-hydrothermal breccia pipes and veins
• Continued fuctionalization
• Additional brecciation
• Formation of the REE-F and Ca-REE-F veins
• Late stage deposition of quartz

relationship of the mineral deposits in the Gallinas District to other REE deposits in New Mexico and elsewhere

The REE deposits in the Gallinas District are among the most extensive potential in New Mexico. The Gallinas deposits are similar in size and grade to small- to medium-size deposits found elsewhere in the world (Figure). Resources amount to at least 537,000 short tons of 2.95% total REE (not NI-43-101 compliant; Jackson and Christiansen, 1993; Schreiner, 1993). Drilling is required identify a better resource estimate. However, the district has not been extensively drilled and future exploration could identify additional resources. Chemicals, samples from the Gallinas district are similar in REE chemistry to Bayan Obo, Lemhi Pass, and Olympic Dam deposits and different from Capitan deposits.

RECOMMENDATIONS FOR FUTURE STUDIES

The most important future research activity is the precise dating of the volcanic rocks in the Gallinas Mountains to fully understand the temporal relationships and to better delineate the timing of igneous activity and associated mineralization and alteration. Additional detailed and regional scale geological mapping is needed in the Gallinas Mountains to better define the local structural framework and to establish the framework for interpretations of the temporal relationships. Any additional geologic mapping also should be focused on defining the extent of the alteration and defining any cogenesis. Additional geochemical studies, including isotopic studies, of igneous rocks, mineralization, and alteration will aid in a better understanding of the systems of igneous intrusion and mineralization in the Gallinas Mountains. REE and radiometric isotopic analyses are invaluable in differentiating between mantle and crustal sources.

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