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GEOLOGY AND MINERAL DEPOSITS OF THE GALLINAS MOUNTAINS REE DEPOSIT, LINCOLN AND TORRANCE COUNTIES, NM; PRELIMINARY REPORT

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ABSTRACT

Rare earth elements (REE) are becoming more important in our society. REE deposits are found throughout NM. Some REE past production (1950s), as bastnaesite, came from the Gallinas Mountains district, Lincoln County, NM. Several companies and the U.S. Bureau of Mines (USBM) have conducted exploration programs to identify REE potential. Four types of deposits are found in the district: epithermal REE-F veins, Cu-REE-F veins, REE-F breccia pipe and iron skarn deposits; all are associated with Tertiary peraluminous, alkaline to alkalic-calcic volcanic rocks. District zonation is defined by base metals (REE-F-Cu veins) that form center of the district, surrounded by REE-F veins. The magmatic-hydrothermal breccia pipe 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. In 1991-1992, USBM calculated an inferred resource of 0.487 million metric tons with a grade of 2.95% total REE. With the projected increase in demand of REE, areas such as the Gallinas Mountains district in New Mexico are being re-examined for additional REE potential.

INTRODUCTION

Rare earth elements (REE) include the 15 lanthanide elements (atomic number 57-71), yttrium (Y, atomic number 39), and scandium (Sc; Table 1) and are commonly divided into two chemical groups, the light REE (La through Eu) and the heavy REE (Gd through Lu, Sc, and Y). REE are lithophile elements (or elements enriched in the crust) that have similar physical and chemical properties (Table 1), and, therefore, occur together in nature. However, REE are not always concentrated in easily mined economic deposits and only a few deposits in the world account for current production (Committee on Critical Mineral Impacts of the U.S. Economy, 2008; Hedrick, 2009). Thorium (Th), uranium (U), niobium (Nb) and other elements typically are found with REE. Most deposits are radioactive because of their Th and U content. Numerous deposits are found in New Mexico, but none are currently in production (McLemore et al., 1988a, b).

REE have many highly specialized applications in our industry, especially in our electronic devices, and for many applications there is no other known substitute (Naumov, 2008; Hedrick, 2009). Approximately 35% of the REE produced are used as catalysts in the refining of crude oil to improve cracking and in automobiles to improve oxidation of pollutants, although use of REE as catalysts is declining (Committee on Critical Mineral Impacts of the U.S. Economy, 2008). Europium is the red phosphor used in color cathode-ray tubes and liquid-crystal displays in computer monitors, cell phones, and televisions, with no known substitute (Committee on Critical Mineral Impacts of the U.S. Economy, 2008). Permanent magnets utilize Nd, Sm, Gd, Dy and Pr, which are used in appliances, audio and video equipment, computers, automobiles, communication systems, and wind turbines. All of the REE are used in manufacturing computer chips. 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 (Haxel et al., 2002). However, the projected increase in demand for REE in China, India, U.S., and other countries has resulted in increased exploration and ultimate production from future deposits in the U.S. and elsewhere.

Table 1. Description of rare earth elements (REE) (from Taylor and McClennan, 1985; Samson and Wood, 2005; Rudnick and Gao, 2005; Castor and Hedrick, 2006; and Hedrick, 2009). * Promethium does not occur naturally.

Rare Earth Element	Symbol	Oxide	Conversion factor (% element x conversion factor - % oxide)	Atomic Number	Abundance in the upper crust (ppm)
Scandium	Sc	Sc2O3		21	14
Yttrium	Y	Y2O3	1.269	39	21
Lanthanum	La	La2O3	1.173	57	31
Cerium	Ce	Ce2O3	1.171	58	63
Praseodymium	Pr	Pr2O3	1.17	59	7.1
Neodymium	Nd	Nd2O3	1.166	60	27
Promethium	Pm	*	*	61	*
Samarium	Sm	Sm2O3	1.16	62	4.7
Europium	Eu	Eu2O3	1.158	63	1.0
Gadolinium	Gd	Gd2O3	1.153	64	4.0
Terbium	Tb	Tb2O3	1.151	65	0.7
Dysprosium	Dy	Dy2O3	1.148	66	3.9
Holmium	Ho	Ho2O3	1.146	67	0.83
Erbium	Er	Er2O3	1.143	68	2.3
Thulium	Tm	Tm2O3	1.142	69	0.30
Ytterbium	Yb	Yb2O3	1.139	70	2.2
Lutetium	Lu	Lu2O3	1.137	71	0.31
Thorium	Th	ThO2	1.138	90	10.5
Zirconium	Zr	ZrO2	1.351	40	193
Niobium	Nb	Nb2O5	1.431	41	12

The Gallinas Mountains are in northern Lincoln County and southern Torrance County where a series of alkaline igneous bodies, including porphyritic latite, trachyte/syenite, andesite, and rhyolite laccoliths, flows, dikes, and plugs, have intruded Permian sedimentary rocks belonging to the Abo, Yeso, and Glorieta Formations (Perhac, 1961, 1970). A small amount of bastnaesite, a REE mineral, was recovered during processing for fluorite from the Gallinas Mountains. Alteration includes brecciation, silicification, chloritization, and fenitization (Griswold, 1959; Woodward and Fulp, 1991; Schreiner, 1993). Carbonatites are inferred 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 known carbonatites.

A number of previous reports have examined the geology and mineral resources of the Gallinas Mountains, but few examined the resource potential for REE and re-examination of the Gallinas Mountains is warranted in light of today's potential economic importance of REE. Therefore, the purposes of this report are 1) to compile and interpret available published and unpublished data from the Gallinas Mountains and 2) to summarize the geology, geochemistry, resource potential, and origin of the mineral deposits in the Gallinas Mountains

LORZEB AND KNESS (1992), METHODS OF STUDY

Published and unpublished data were inventoried and compiled on existing mines and prospects within the Gallinas Mountains. Mineral databases were examined, including the Mineral Resource Data System (MRDS) of the U.S. Geological Survey (Mason and Arndt, 1996), the Minerals Industry Location System (MILS) of the U.S. Bureau of Mines (U.S. Bureau of Mines, 1995), U.S. Forest Service Abandoned and Inactive Mines database, AMLIS (U.S. Bureau of Land Management), and unpublished files at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR). Using these data, mineral occurrences, deposits, mines, prospects, and mills were identified, plotted on base maps, and compiled in the New Mexico Mines Database (McLemore et al., 2005a, b). More details are in McLemore (2010). Mineralized areas were examined and sampled in 1980 and 2009-2010 by the author and in 1991-1992 by the U.S. Bureau of Mines (Korzeb and Kness, 1992; Schreiner, 1993). Mineral production by commodity and year since the late 1880s is in McLemore (2010).

A geologic map was compiled in ARCMAP@ using U.S. Geological Survey topographic maps as the map base and by modifying Kelley et al. (1946), Perhac (1961, 1970), Fulp and Woodward (1991), Korzeb and Kness (1992), Schreiner (1993), and field reconnaissance by the author (1980, 2009-2010). Samples were collected and analyzed and compared with published data (McLemore, 2010). Igneous rock lithologies were identified on the basis of mineralogy and chemistry as defined by LeMaitre (1989).

Any resource or reserve data presented here are historical data and are provided for information purposes only and do not conform to Canadian National Instrument NI 43-101 requirements.

MINING AND EXPLORATION HISTORY AND PREVIOUS INVESTIGATIONS

The Gallinas Mountains mining district is in the central Gallinas Mountains, mostly in Lincoln County and also is known as the Corona, Iron Mountain, Red Cloud, and Gallinas districts (File and Northrop, 1966). The Gallinas Mountains were first examined for base and precious metals about 1881 when the Red Cloud, Buckhorn, Deadwood, and Summit mining claims were established; production started around 1885 for copper, silver, and lead (File and Northrop, 1966). Small quantities of ore were sent to Socorro for smelting (Jones, 1904), but there are no early production records remaining. The first recorded production for base metals was in 1909, which continued until 1955 (McLemore, 2010). By 1920, the ore was shipped to El Paso for refining at the smelter. Iron ore was found by 1904 (Jones, 1904) and in 1942-1943, iron ore was produced from the American Iron and Red Cliff mines (Kelley, 1949). Kelley et al. (1946) and Kelley (1949) mapped the geology and described the iron resources.

Fluorite was discovered in the Gallinas Mountains before the 1930s (Johnston, 1928; Perhac, 1970). In 1951-1954, fluorite was produced from the Red Cloud and Conqueror mines. Bastnaesite was discovered in the area about 1943 (Glass and Smalley, 1943; Dean, 1944; Soulé, 1943, 1946) and approximately 142,000 lbs of bastnaesite was produced from the Red Cloud mine in the 1950s (Zandra et al., 1952). Between 1954 and 1956, the New Mexico Copper Corp. set up a small mill facility near Carrizozo, NM and produced 55,000 lbs of bastnaesite. Phelps Dodge drilled a 532-ft deep hole at the Rio Tinto mine in 1980 and Molycorp, Inc. conducted a more extensive exploration program in 1980-1981, including a geochemical survey, geophysical survey, and two drill holes on a magnetic high anomaly (Schreiner, 1993). Other companies examined the area in 1989-1992, including Canyon Resources (in 1989), Hecla Mining Co. (in 1991-1992), American Copper and Nickel, Inc. and Romana Resources (in 1992). Woodward and Fulp (1991) reported gold assays as high as 183 ppb in brecciated trachyte/syenite sills that intruded Yeso sandstone in Sawmill Canyon. The U.S. Bureau of Mines conducted extensive mapping and sampling of the REE deposits in 1991-1992 (Schreiner, 1993). Williams-Jones et al. (2000) and associates (Gagnon et al., 2003; Salvi and William-Jones, 2005; Samson and Wood, 2005) examined the geochemistry of selected deposits in the Gallinas Mountains. Strategic Resources, Inc. staked claims in 2009 and began exploration activities (http://www.strategicresourcesinc.ca/index.php, accessed 5/14/2010).

REGIONAL GEOLOGIC AND TECTONIC SETTING

Lindgren (1915, 1933) was one of the first geologists who noted that a belt of alkaline-igneous rocks extends from Alaska and British Columbia southward into eastern New Mexico, Trans-Pecos Texas, and eastern Mexico (Fig. 1) and that these rocks contain relatively large quantities of fluorine (F), zirconium (Zr), REE, and other elements. Since then, the North American Cordilleran alkaline-igneous belt has been explored and exploited for numerous types of mineral deposits, especially gold and silver (Mutschler et al., 1985, 1991; Clark, 1989), fluorite (Van Alstine, 1976), and REE (Woolley, 1987).

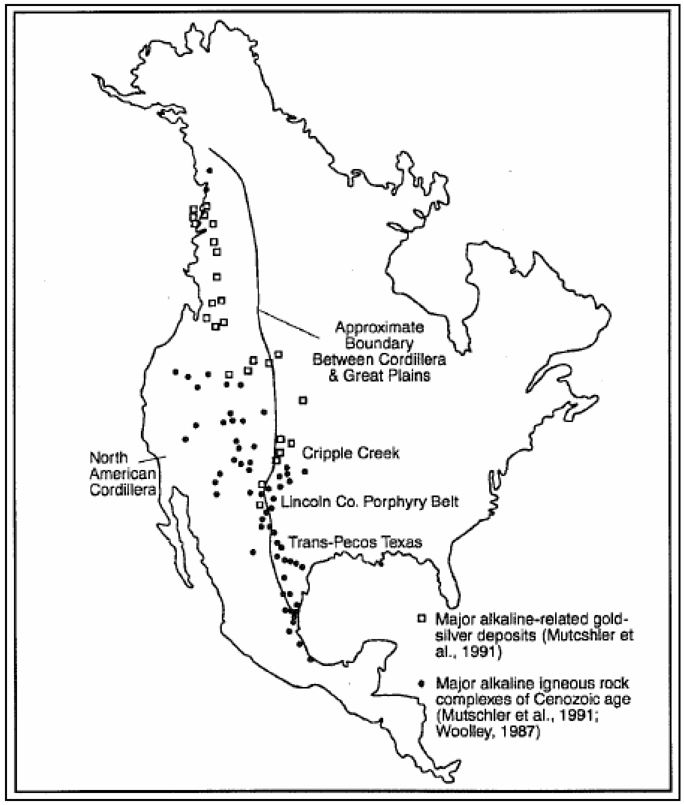

Figure 1. North American Cordilleran belt of alkaline igneous rocks (Woolley, 1987; Mutschler et al., 1991; McLemore, 1996).

In New Mexico, the North American Cordilleran alkaline-igneous belt extends from the Sangre de Cristo Mountains near Raton, southward to the Cornudas Mountains, east of El Paso, Texas (North and McLemore, 1986, 1988; McLemore, 1996, 2001). 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, 2001). 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, 2001). Alternative classifications by other workers include alkalic-gold or alkaline-igneous related gold deposits (Fulp and Woodward, 1991; Thompson, 1991a, b; Bonham, 1988; Mutschler et al., 1985, 1991; Richards, 1995), porphyry gold deposits, and Rocky Mountain gold province.

The Lincoln County porphyry belt (LCPB) in central New Mexico is part of the North American Cordilleran alkaline-igneous belt and is at the intersection of the north-trending Pedernal arch and the east-west-trending Capitan lineament in Lincoln County, which appears to have localized magmatic and volcanic activity in the LCPB (Kelley and Thompson, 1964; Kelley, 1971; Allen and Foord, 1991; McLemore and Zimmerer, 2009; McLemore, 2010). Alkaline to subalkaline igneous rocks are found in all districts in the LCPB, but mineralization is locally associated with silica-saturated (monzonite) or oversaturated (quartz monzonite) rocks (Seagerstrom and Ryberg, 1974; McLemore and Phillips, 1991; Thompson, 1991a, b, c). K-Ar and sparse 40Ar/39Ar dating suggests the LCPB likely represents two stages of magmatism, an early alkaline belt emplaced along a N-S trend (Pedernal uplift) between 38 and 30 Ma and a younger bimodal suite emplaced along an E-W trend between 30 and 25 Ma (Fig. 2; Allen and Foord, 1991). Although the Gallinas Mountains rocks were reported as belonging to the older magmatic event by Allen and Foord (1991), a K-Ar date of 29.9 Ma (Perhac, 1970) suggests that the igneous rocks in the Gallinas Mountains represent a transition between the two magmatic events or are part of the younger magmatic event. More dating is required.

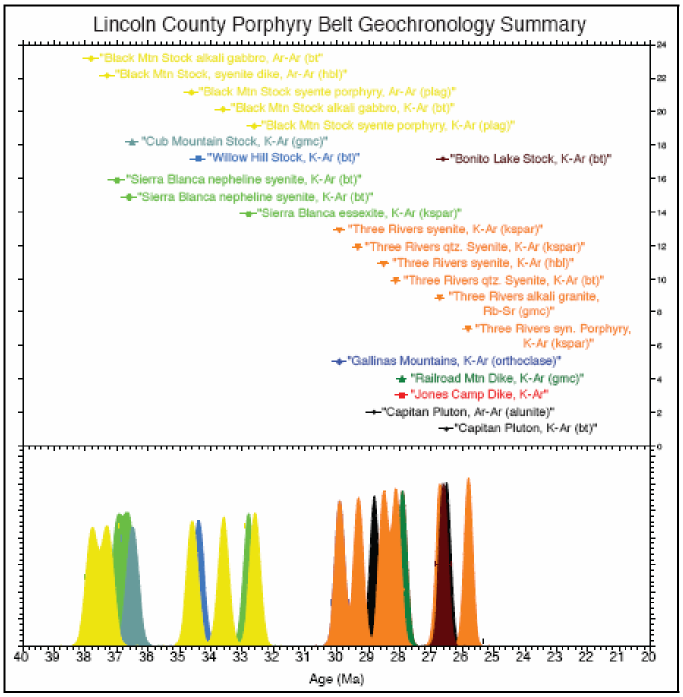

Figure 2. Ideogram of K/Ar, Rb/Sr, and Ar40/Ar39 ages of igneous rocks in the LCPB area. 40Ar/39Ar ages have been recalculated using the new decay constant (modified from McLemore and Zimmerer, 2009). References are cited in McLemore (2010). The Gallinas Mountains trachyte/syenite was dated by K/Ar methods as 29.9 Ma (Perhac, 1970).

LOCAL STRATIGRAPHY

The oldest rocks in the Gallinas Mountains are altered Proterozoic gneisses and granites exposed in Red Cloud Canyon that are overlain by arkoses, quartz sandstones, siltstones, shales and limestones of the Permian Abo, Yeso and Glorieta Formations. Proterozoic granite and granitic gneiss are exposed by faulting in three places in the Gallinas Mountains (Fig. 3). Permian Abo Formation consists of a basal arkosic conglomerate, a middle arkose, siltstone, and shale sequence, and an upper shale unit. Most of the Abo rocks are a distinctive brick-red color. The Yeso Formation unconformably overlies the Abo Formation and consists of 1500 ft of tan to orange, thinly-bedded sandstone, siltstone, shale, limestone, and dolomite. The gypsum facies, commonly found in the Yeso Formation elsewhere in central New Mexico, is absent in the Gallinas Mountains (Kelley, 1949; Perhac, 1961, 1970). The more resistant Glorieta Sandstone, is as much as 250 ft thick, overlies the Yeso Formation, and caps many of the mesas and ridges in the Gallinas Mountains. The igneous rocks intrude the Proterozoic and Permian rocks.

Tertiary igneous rocks

The nomenclature of igneous rocks in this report conforms to the International classification proposed by LeMaitre (1989), where the primary classification of igneous rocks is based upon mineralogy and, if too fine-grained to determine mineralogy, by the use of whole-rock geochemical analyses using the TAS (Le Bas et al., 1986) and R1-R2 (de la Roche et al., 1980) diagrams. According to the definition of volcanic and plutonic rocks proposed by LeMaitre (1989), the igneous rocks in the Gallinas Mountains are mostly volcanic (i.e. aphanitic texture) and not plutonic (i.e. coarse-grained rock), except for portions of the trachyte/syenite. Kelley et al. (1946), Poe (1965), Perhac (1961, 1970), and Schreiner (1993) used the volcanic terminology, which is used in this report. Allen and Foord (1991) and Williams-Jones et al. (2000) used the plutonic terminology for these rocks; i.e. syenogabbro, quartz syenite, syenodiorite, and alkali rhyolite. The volcanic rocks are mostly extrusive or shallow intrusive as interpreted from their texture.

The igneous rocks are generally poorly exposed and the contacts are generally covered and not well exposed. Cougar Mountain, in the northeastern portion of the Gallinas Mountains, consists of a porphyritic latite stock (Kelley et al., 1946; Poe, 1965; Perhac, 1970). The northern portion of the Gallinas Mountains consists of a rhyolite stock. The southern portion of the Gallinas Mountains consists of porphyritic trachyte (trachytic texture) to syenite (equigranular texture). These igneous rocks have intruded Permian Yeso and Abo Formations. Poe (1965) determined from thermal states of feldspar that the latite is the oldest, followed by the trachyte/syenite, and the youngest is the rhyolite. This requires confirmation by isotopic age dating.

The age of the igneous rocks is mid-Tertiary and likely similar in age to other igneous rocks in the LCPB. A sample of trachyte/syenite has been dated as 29.2 Ma by K-Ar dating methods on feldspar (Perhac, 1970), but Allen and Foord (1991) believed the igneous rocks in the Gallinas Mountains are older than 32 Ma on the basis of chemical data. Additional age dating is required.

The mineralized area of the Gallinas Mountains lies in a magnetic low surrounded by magnetic high anomalies (Fig. 4). Similar magnetic anomalies are characteristic of some alkaline complexes associated with mineral deposits (Woolley, 1987).

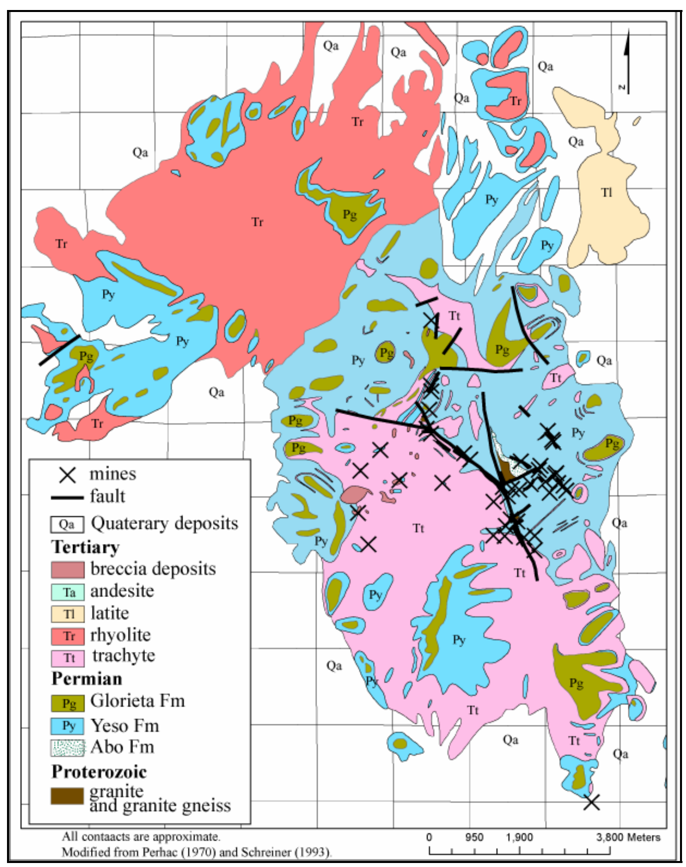

Figure 3. Geologic map of the Gallinas Mountains, Lincoln and Torrance Counties, New Mexico (modified from Kelley et al., 1946;

Kelley, 1949, 1971; Perhac, 1961, 1970; Woodward and Fulp, 1991; Schreiner, 1993; McLemore, 2010; field reconnaissance by the author).

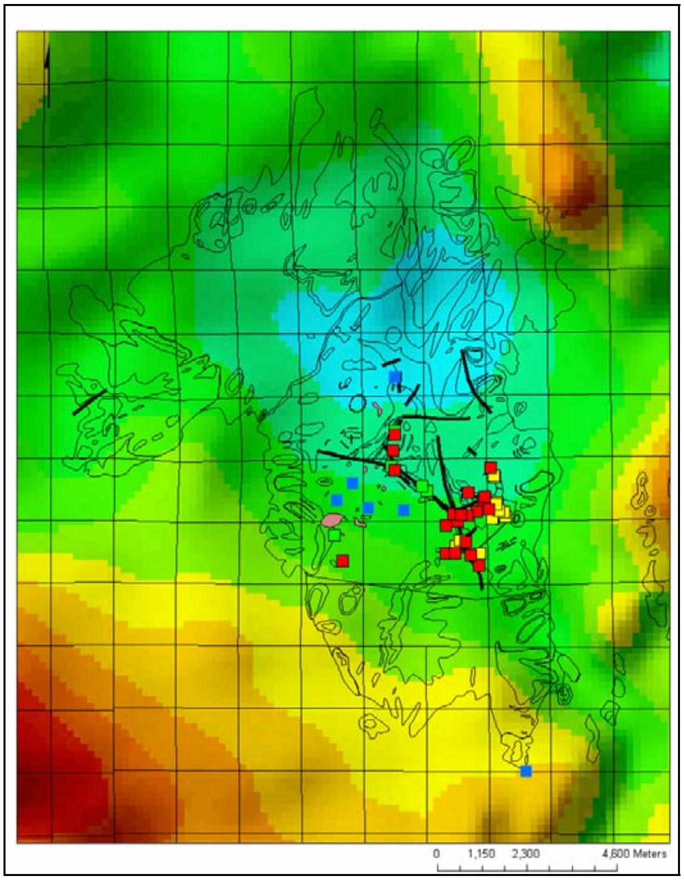

Figure 4. Aeromagnetic map of the Gallinas Mountains area, from Kucks et al. (2001). Note the aeromagnetic high (red) southeast of the Gallinas Mountains, which could be indicative of an intrusion in the subsurface. The blue in the center of the Gallinas Mountains is a magnetic low anomaly. The magnetic high anomaly in the northeastern portion of the map could be indicative of subsurface continuation of the latite. See Figure 3 for the geologic map.

Latite

The latite is in the northern Gallinas Mountains (Fig. 3) and ranges in lithology from latite to trachydacite to trachyandesite, according to the classification by LeMaitre (1989). The latite is light to medium gray, holocrystalline to porphyritic, matrix supported and consists of euhedral plagioclase and hornblende phenocrysts in a medium- to fine-grained matrix of plagioclase, orthoclase, hornblende, titanite (sphene), apatite, magnetite, and quartz (Poe, 1965; Perhac, 1961, 1970). The porphyritic texture is produced by large plagioclase and hornblende phenocrysts surrounded by a fine-grained matrix. The nearby Yeso sedimentary rocks are nearly flat lying, suggesting that the latite is a stock. An aeromagnetic high anomaly to the northeast could indicate additional latite in the subsurface (Fig. 4).

Trachyte/syenite

The trachyte/syenite (called syenite by some workers) is found in the southern Gallinas Mountains (Fig. 3) and is associated with the mineral deposits. The trachyte/syenite consists of tan to buff to light gray holocrystalline-porphyritic trachyte with trachytic texture to porphyritic-holocrystalline syenite with equigranular texture. It consists of albite and K-feldspar phenocrysts in an aphanitic groundmass consisting of albite, K-feldspar, biotite or hornblende (now altered to hematite and limonite) and trace amounts of apatite, quartz, zircon, and hematite.

Rhyolite

The rhyolite is found in the northwestern Gallinas Mountains (Fig. 3) and is more than 500 ft thick at Gallinas Peak. The rhyolite is tan to pinkish gray to white, fine-grained to aphanitic to porphyritic and contains small miarolitic cavities (few millimeters in diameter) containing small crystals of quartz and feldspar. The groundmass consists of orthoclase, quartz, albite, and trace biotite, aegirine-augite, apatite, titanite, magnetite, ilmenite, zircon, and muscovite. Albite phenocrysts form the local porphyritic texture.

Andesite

An altered andesite dike intruded the Yeso sandstone near the Sky High prospect. The andesite is dark gray to dark brown, porphyritic and consists of hornblende, pyroxene, plagioclase, K-feldspar, and trace amounts of sericite, calcite, apatite, and biotite.

Magmatic-hydrothermal breccia pipes

Several breccia pipes are hosted in the trachyte/syenite and Yeso Formation and consist of angular to subrounded fragments of sandstone, shale, limestone, granite, granitic gneiss, and trachyte/syenite that are as much as 1 m in diameter. The contacts are covered and are not well exposed, but the pipes appear to be roughly elliptical in shape. Most of the breccia pipes are matrix-supported and are cemented by quartz, feldspar, fluorite, and hematite along with small crystals of other minerals and rock fragments. The matrix locally has a trachytic or porphyritic texture (Schreiner, 1993). Two breccia pipes at the M and E No. 13 prospect are clast-supported. The magmatic-hydrothermal breccia pipes form a north-east-trending belt, approximately 2-3 miles long and 0.5 mile wide (Fig. 3). Most of the breccia pipes are strongly altered and weathered to hematite and locally carbonate. Fenitization of mineralized breccia pipes was identified by Schreiner (1993).

PETROCHEMISTRY OF THE IGNEOUS ROCKS

The igneous rocks in the Gallinas Mountains are metaluminous to peraluminous, alkaline volcanic rocks (Frost et al., 2001; McLemore, 2010), and have chemical compositions similar to A-type granitoids (Whalen et al., 1987; McLemore, 2010). A-type (anorogenic or anhydrous) granitoids typically are found along rift zones and within stable continental blocks and the identification of A-type granitoids is based upon both tectonic setting and chemical characteristics. Many ore deposits are associated with A-type granitoids (Lindgren, 1933; Mutschler et al., 1985, 1991; McLemore, 1996). The trachyte/syenite and latite samples plot within the within-plate granite tectonic field of Pearce et al. (1984; WPG, Fig. 5), whereas the rhyolite sample plots within the volcanic-arc granite field (VAG, Fig. 5). Trachyte/syenite and latite are possibly related, but the rhyolite could be a separate magmatic event (McLemore, 2010). Detailed dating and geochemical analyses are required to confirm this hypothesis. The rocks exhibit typical light REE enriched condrite-normalized REE patterns of alkaline rocks (Fig. 6). The geochemical characteristics of the Gallinas Mountains are consistent with a crustal source for the igneous rocks.

DESCRIPTION OF MINERAL DEPOSITS

Introduction

Four types of deposits have been identified in the Gallinas Mountains (Fig. 7; McLemore, 2010), as defined by mineralogy and chemistry:

1. GPM iron skarn deposits
2. GPM breccia pipe deposits
3. GPM REE-F hydrothermal veins
4. GPM Cu-REE-F (±Pb, Zn, Ag) hydrothermal veins

A fifth type of deposit, carbonatites (Cox and Singer, 1986), could be in the subsurface as suggested by previous drilling, but no samples have been obtained for precise determination of the lithology. Carbonatites are inferred 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.

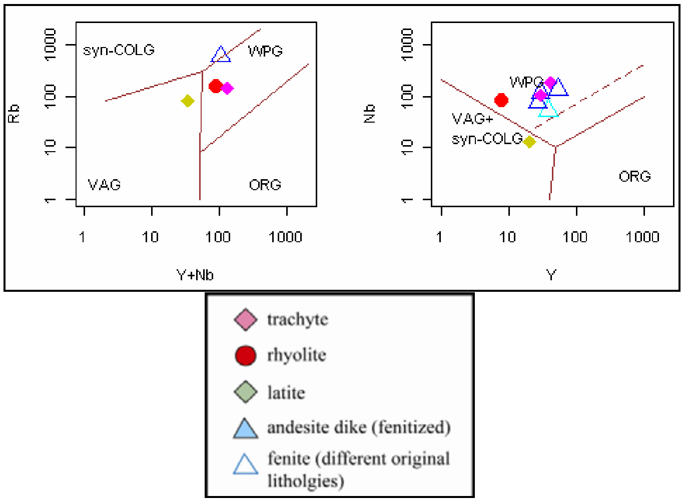

Figure 5. Tectonic classification of igneous rocks from the Gallinas Mountains, i.e. within plate granites. Chemical analyses are in McLemore (2010).

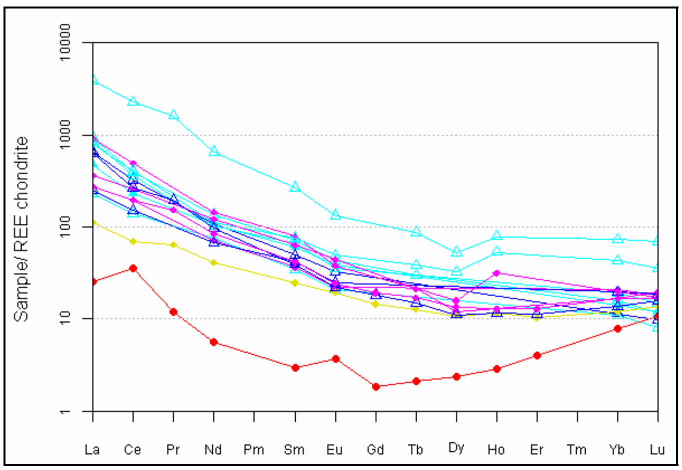

Figure 6. Enriched light-REE chondrite-normalized patterns (with no Eu anomaly) of igneous rocks in the Gallinas Mountains. Key is in Fig. 5. Chemical analyses are in McLemore (2010).

The mineralogy in the Gallinas Mountains is diverse and includes fluorite, quartz, barite, pyrite, iron oxides and accessory bastnaesite, calcite, chalcedony, galena, bornite, chalcocite, pyromorphite, anglesite, chrysocolla, malachite, and azurite and rare agardite (yttrium-arsenic oxide), mimetite, wulfenite, vanadinite, mottramite, cerusite, among others (Perhac, 1964, 1968, 1970; Perhac and Heinrich, 1964; McAnulty, 1978; DeMark, 1980; DeMark and Hlava, 1993; McLemore, 2010). Geothermometric fluid-inclusion studies indicate a temperature of formation of 250-400°C with salinities of approximately 15 NaCl eq. wt% at pressures of 1-2 kbar (Perhac, 1970; Williams-Jones et al., 2000). Nb2O5 ranges from 8-148 ppm (Moore, 1965; Schreiner, 1993).

Great Plains Margin-iron skarn (or pyrometasomatic iron) deposits

The GPM iron skarn deposits are spatially associated with the igneous rocks and typically consist of magnetite, hematite, limonite, and martite in a gangue of calcite, quartz, fluorite, tremolite, actinolite, pyrite, fluorite, phlogopite, and locally bastnaesite. The iron ore grade is typically less than 50% (Harrer and Kelly, 1963).

Great Plains Margin-breccia pipes

Many GPM breccia pipe deposits are circular or oval in plan view and possibly formed by intrusion, gaseous explosions, or collapse (Griswold, 1959). Schreiner (1993) calls the Gallinas breccia pipes intrusive breccias, but they are better described as magmatic-hydrothermal breccias pipes (Sillitoe, 1985; McLemore, 2010).

Cu-REE-F (±Pb, Zn, Ag) hydrothermal vein deposits

The Cu-REE-F (±Pb, Zn, Ag) hydrothermal vein deposits were first developed and mined in the Gallinas Mountains and consist of fissure and fracture filling brecciated hydrothermal veins. Fluorite, barite, and quartz are major minerals along with many copper and lead minerals (McLemore, 2010).

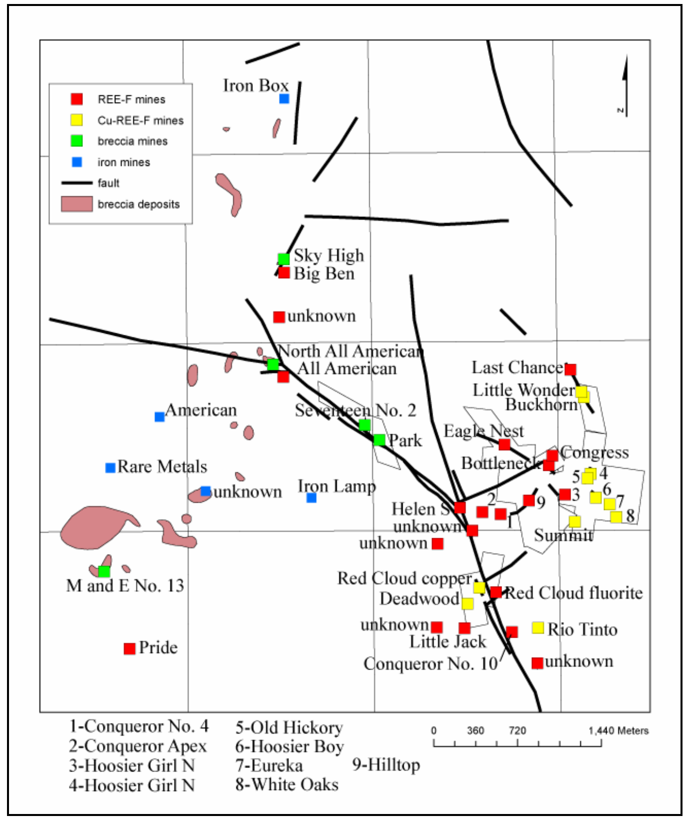

Figure 7. Mines and prospects in the Gallinas Mountains, Lincoln County.

REE-F hydrothermal vein deposits

The REE-F hydrothermal vein deposits were developed and mined for fluorite and consist of fissure and fracture filling brecciated hydrothermal veins. Fluorite, barite, and quartz are major minerals (McLemore, 2010). veins, similar to the Cu-REE-F (±Pb, Zn, Ag) hydrothermal vein deposits. Fluorite, barite, and quartz are major minerals; only trace amounts, if any, base and precious metals are found (McLemore, 2010).

ALTERATION

Schreiner (1993) described the alteration associated with the mineralization in the Gallinas Mountains in detail. The trachyte/syenite, Proterozoic granite and granitic gneiss, and magmatic-hydrothermal breccia pipes have been altered locally by two separate periods of fenitization; sodic followed by potassic fenitization. Sodic fenitization is characterized by replacement of feldspars and other minerals by albite. Potassic fenitization is characterized by replacement of feldspars, including older albite, and other minerals by K-feldspar. Temperatures ranging from 400 to 700°C are estimated for fenitization (Eckerman, 1966; Kresten and Morgan, 1986; Haggerty and Mariano, 1983; Le Bas, 1987).

GEOCHEMISTRY OF THE GALLINAS REE DEPOSITS

Geochemical data for this area consists of 279 rock and mineralized samples that were collected and analyzed for various elements by Schreiner (1993) and the author for this report (McLemore, 2010). Geochemical anomaly maps were constructed using ARCMAP@ and indicate that the higher concentrations of REE, Cu, Pb, and Au are found along faults filled with Cu-REE-F and REE-F veins and the M and E breccia deposit (McLemore, 2010). Descriptive statistics are in McLemore (2010).

MINERAL ZONATION, SEQUENCE OF EVENTS AND PARAGENESIS OF THE MINERAL DEPOSITS

The mineral zonation for the Gallinas Mountains was determined by mineralogy and chemistry of the individual deposits (McLemore, 2010) and is shown in Figure 8. The sequence of events in the Gallinas Mountains is summarized as:

- Emplacement of the trachyte/syenite about 30 Ma
- Sodic fenitization
- Deposition of the iron skarns
- Faulting and brecciation
- Formation of the magmatic-hydrothermal breccia pipes
- Potassic fenitization
- Additional brecciation
- Deposition of the REE-F and Cu-REE-F veins
- Late stage deposition of quartz and calcite

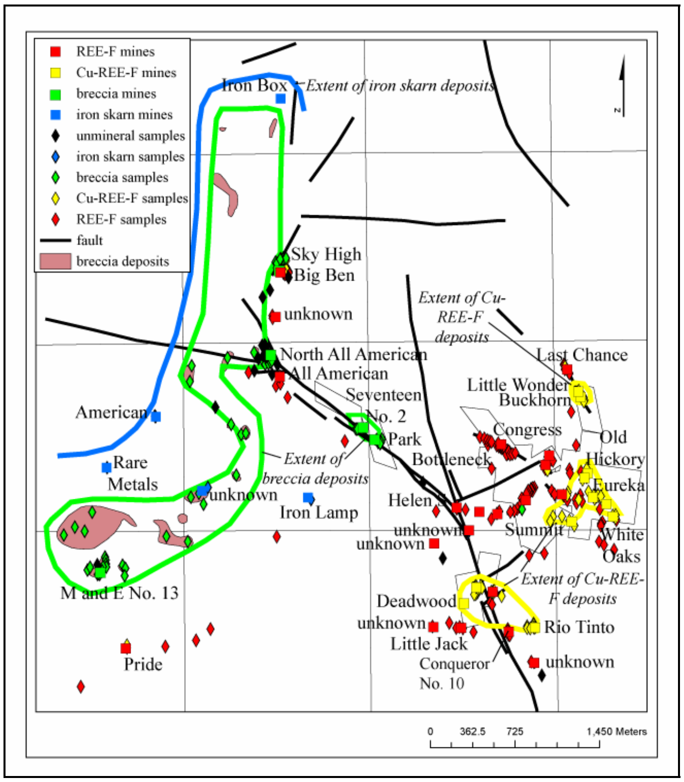

Figure 8. Mineral zoning in the Gallinas Mountains, Lincoln County, New Mexico, based upon predominant mineralogy and chemistry of the known deposits.

A schematic model showing the formation of the deposits in the Gallinas Mountains is shown in Figure 9.

PRELIMINARY CONCLUSIONS

- The REE deposits in the Gallinas Mountains are among the highest potential for REE in New Mexico. Chemically, samples from the Gallinas Mountains are similar in REE chemistry to Bayan Obo, Lemhi Pass, and Olympic Dam deposits and are different from Capitan REE deposits (McLemore, 2010).
- The Gallinas Mountains deposits are similar in size and grade to small- to medium size deposits found elsewhere in the world (Fig. 10). Estimated 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 Gallinas Mountains has not been extensively drilled and future exploration could identify additional resources.

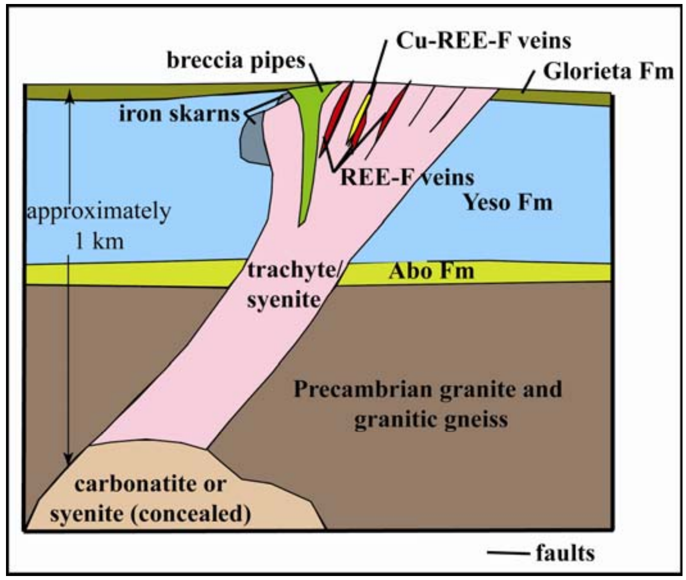

Figure 9. Schematic model of formation of the mineral deposits in the Gallinas Mountains, Lincoln County, New Mexico (modified in part from Schreiner, 1993; Richards, 1995; Williams-Jones et al., 2000).

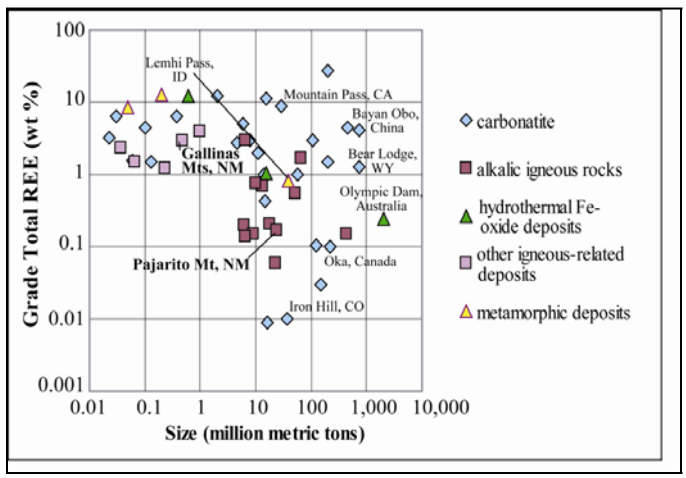

Figure 10. Grade and size (tonnage) of selected REE deposits, using data from Oris and Grauch (2002) and resources data from Schreiner (1993) and Jackson and Christiansen (1993) for the Gallinas Mountains. Deposits in bold are located in New Mexico.

- The igneous rocks in the Gallinas Mountains are metaluminous to peraluminous, alkaline volcanic rocks, and have chemical compositions similar to A-type granitoids (McLemore, 2010). Trachyte/syenite and latite are possibly related, but the rhyolite 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.
- District zonation is defined by Cu-REE-F (±Pb, Zn, Ag) hydrothermal veins that form center of the district, surrounded by REE-F hydrothermal veins (Fig. 8). The magmatic-hydrothermal breccia pipe deposits form a belt partially surrounding the veins. Iron skarns formed at the top and edge of the trachyte/syenite body and are likely the earliest stage of mineralization. The iron skarns are probably related to the REE-F and REE-F-Cu veins and breccias because they typically contain bastnaesite and fluorite and are similar in trace element geochemistry (McLemore, 2010).
- Most fenites are more enriched in REE than unaltered igneous rocks (McLemore, 2010).

- Sequence of events:
  - Emplacement of the trachyte/syenite about 30 Ma
  - Sodic fenitization
  - Deposition of the iron skarns
  - Faulting and brecciation
  - Formation of the magmatic-hydrothermal breccia pipes
  - Potassic fenitization
  - Additional brecciation
  - Deposition of the REE-F and Cu-REE-F veins
  - Late stage deposition of quartz and calcite
- The paragenesis is defined by four stages of brecciation and faulting with three stages of fluorite deposition. REE minerals were deposited during the 1st and 2nd stage of fluorite deposition (McLemore, 2010).
- A genetic model is summarized by intrusion/extrusion of crustal-derived igneous source rock in an extensional terrain possibly related to alkaline-carbonatite complex with mineralization related to mixing of magmatic-hydrothermal and formation fluids (Fig. 9).

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