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-F veins, Cu-REE-F veins, REE-F breccias and iron skarn deposits; all are associated with Tertiary alkaline to alkalic-calcic igneous intrusions. In 1991-1992, USBM calculated an inferred resource of 0.487 million metric tons with an grade of 2.95% total REE. With the projected increase in demand of REE, 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 15 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. 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. 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 porphyritic latite, trachyte/phonolite (i.e. volcanic equivalent to syenite), andesite, and rhyolite laccoliths, dikes and plugs, have intruded Permian sedimentary rocks belonging to the Abo, Yeso, and Glorieta Formations (Perhac, 1970; Schreiner, 1993). A small amount of bastnasite ($[Ce, La, (CO_3)]F$ 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). 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.

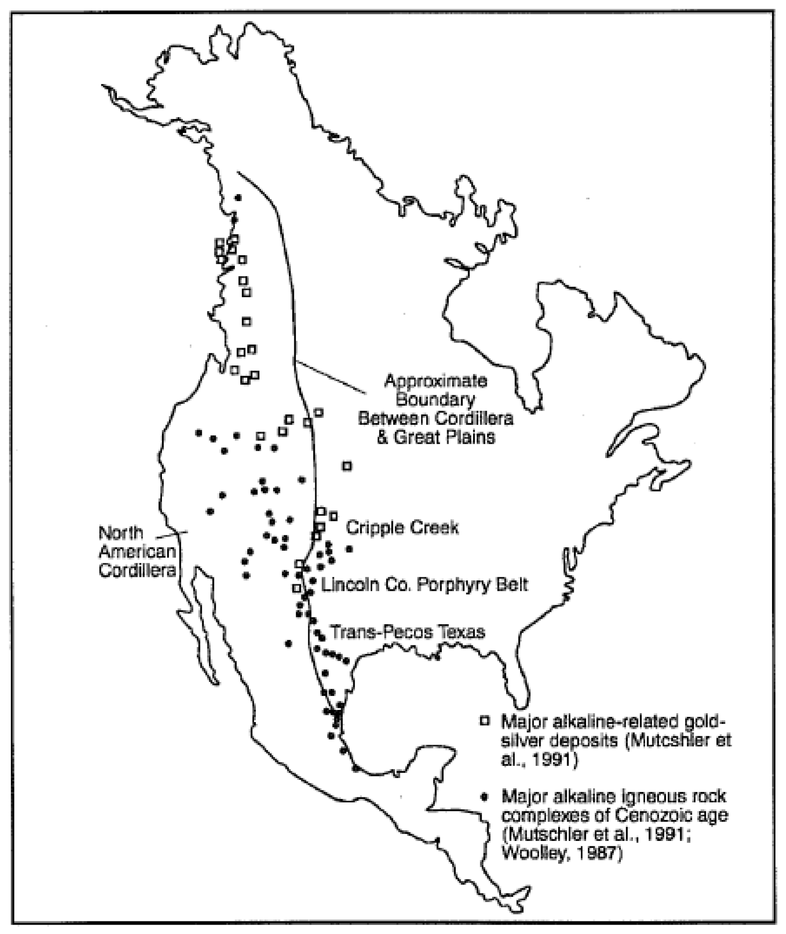
PURPOSE

- Compile and interpret available published and unpublished data from the Gallinas district
- Summarize the geology, geochemistry, resource potential and origin of the mineral deposits in the Gallinas district
- Relate mineral deposits to other REE deposits in New Mexico and elsewhere

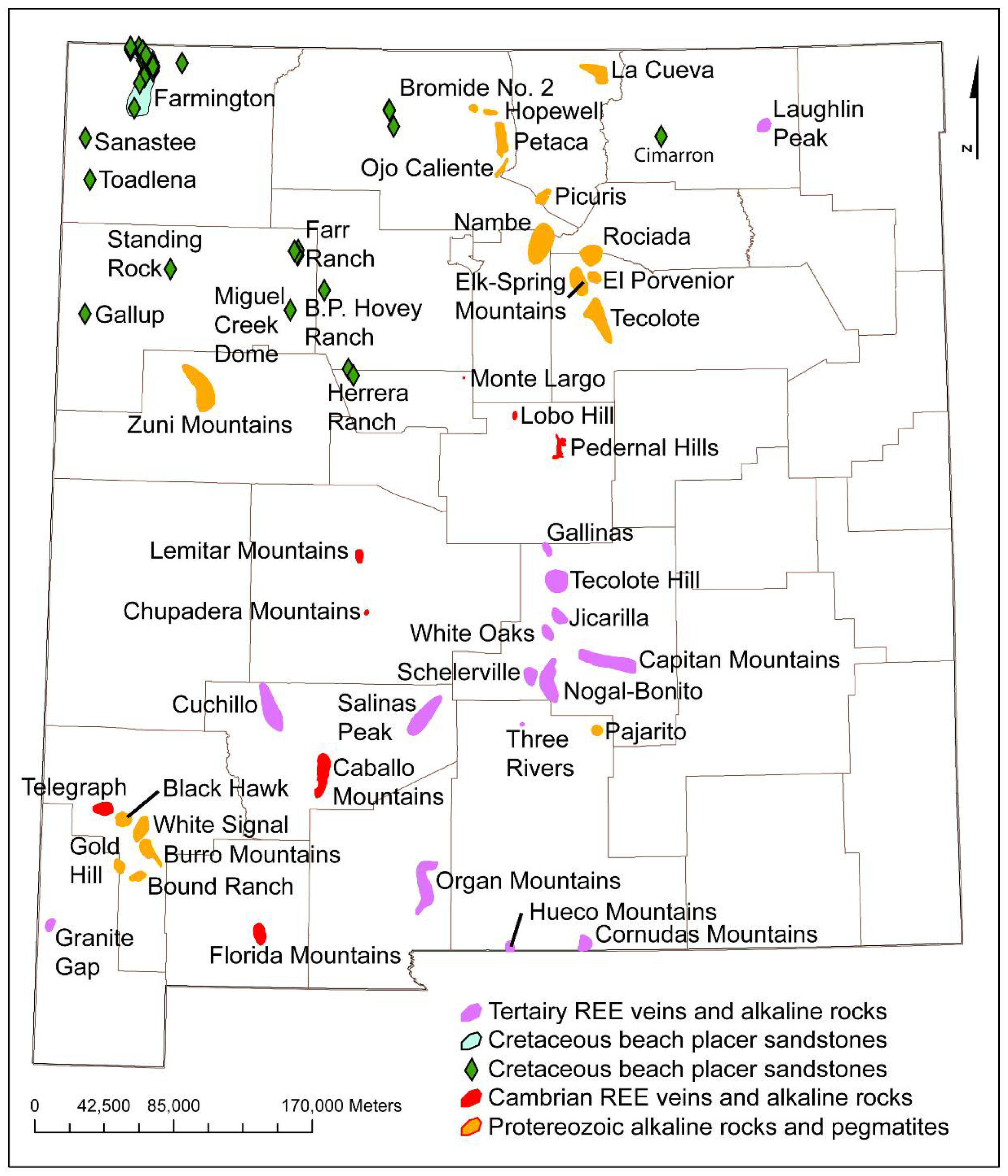
REE APPLICATIONS IN INDUSTRY

Eu	red phosphor in cathode-ray tubes (CRT), and liquid-crystal displays in computer monitors and televisions
Er	fiber-optic telecommunication cables, ceramics, dyes for glass, optical filters, and lasers
Nd, Sm, Gd, Dy, Pr	permanent magnets in appliances, computers, automobiles, communication systems, and wind turbines; Dy in hybrid car motors
La	rechargable lanthanum-nickel-hydrogen (La-Ni-H) batteries in computers, communication systems, automobiles; catalytic converters
Ce	magnetic switches in cell phones, polish for mirrors and lenses, catalytic converters
Y	fluorescent lamps, capacitors, CRT, phosphors, microwave filters, glasses, oxygen sensors, radars, lasers, structural ceramics, and superconductors
Sc	high strength aluminum-scandium alloys, electron beam tubes, metallurgical research, semiconductors, and speciality lighting (Hendrick, 2009)

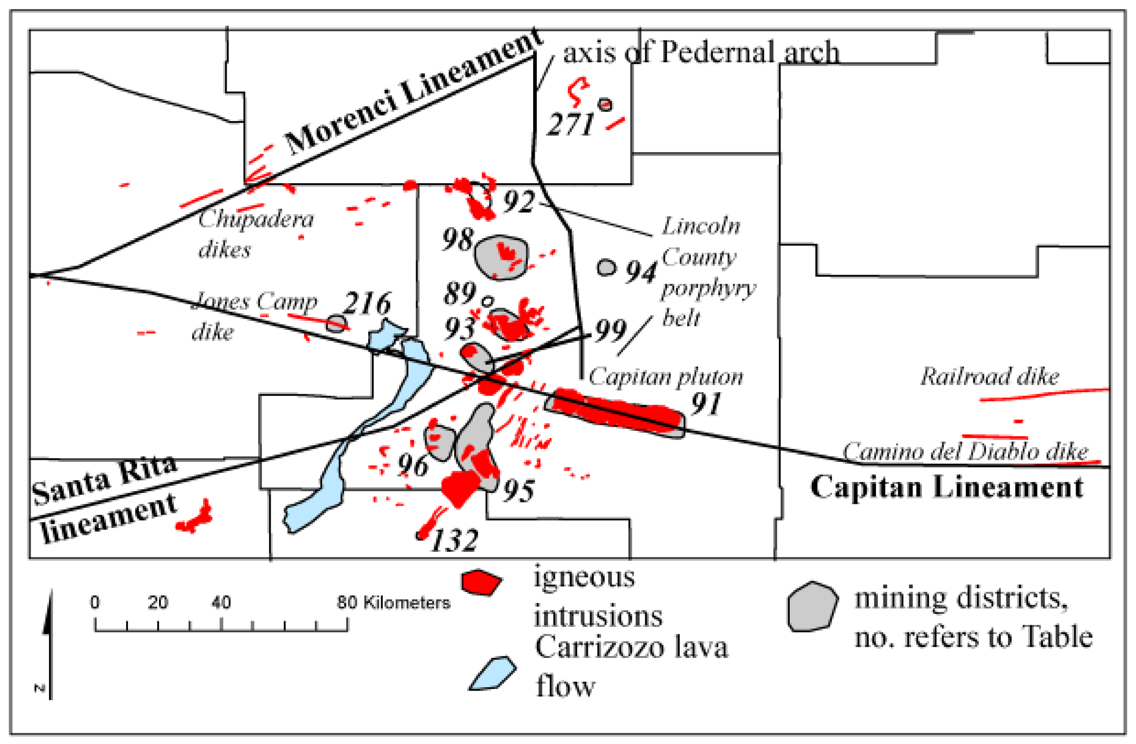
REGIONAL GEOLOGIC AND TECTONIC SETTING



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

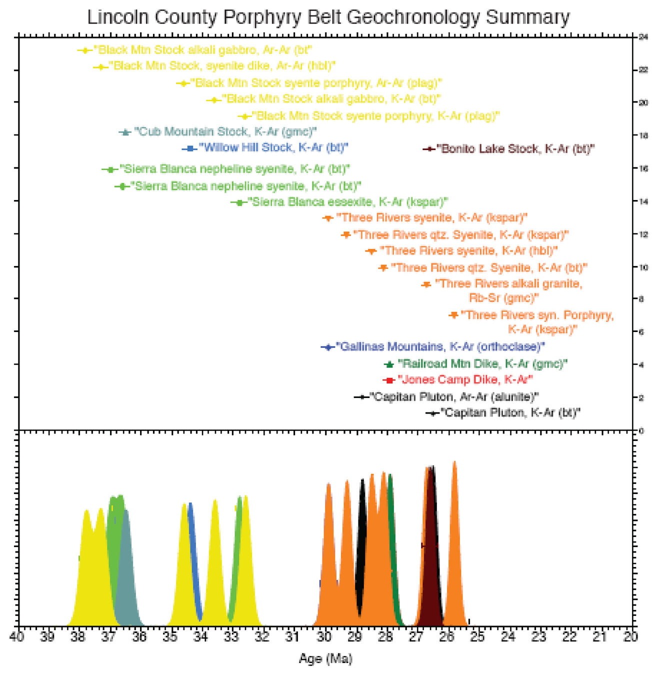


Mining districts in New Mexico that contain REE deposits (modified from McLemore et al., 2005). In New Mexico, the North American Cordilleran alkaline-igneous belt extends from the Sangre de Cristo Mountains near Raton, southward to the Cornudas Mountains east of El Paso, Texas (North and McLemore, 1986, 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).



Mining districts and igneous intrusions forming the Lincoln County porphyry belt (LCPB; McLemore and Zimmerer, 2009). The mining district numbers are prefaced with DIS, come from the New Mexico Mines Database. 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 (Table; Kelley and Thompson, 1964; Kelley, 1971; Allen and Foord, 1991; McLemore and Zimmerer, 2009). 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 (Segerstrom and Ryberg, 1974; McLemore and Phillips, 1991; Thompson, 1991). K-Ar and sparse Ar^{40}/Ar^{39} 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 (Allen and Foord, 1991).

The diversity of igneous rocks and associated mineral deposits within this belt (McLemore, 1996) suggests that the boundary between the Great Plains and Rocky Mountains and Basin and Range provinces is a region of highly fractionated and differentiated magmas (Thompson, 1991; Allen and Foord, 1991). The association of lineaments and other major structures with igneous rocks and mineral deposits in New Mexico suggests that near vertical deep-seated fracture systems probably channeled the magmas and resulting fluids. Once the magmas reached shallow levels, local structures and wall rock compositions determined the final character and distribution of intrusions and mineralization.



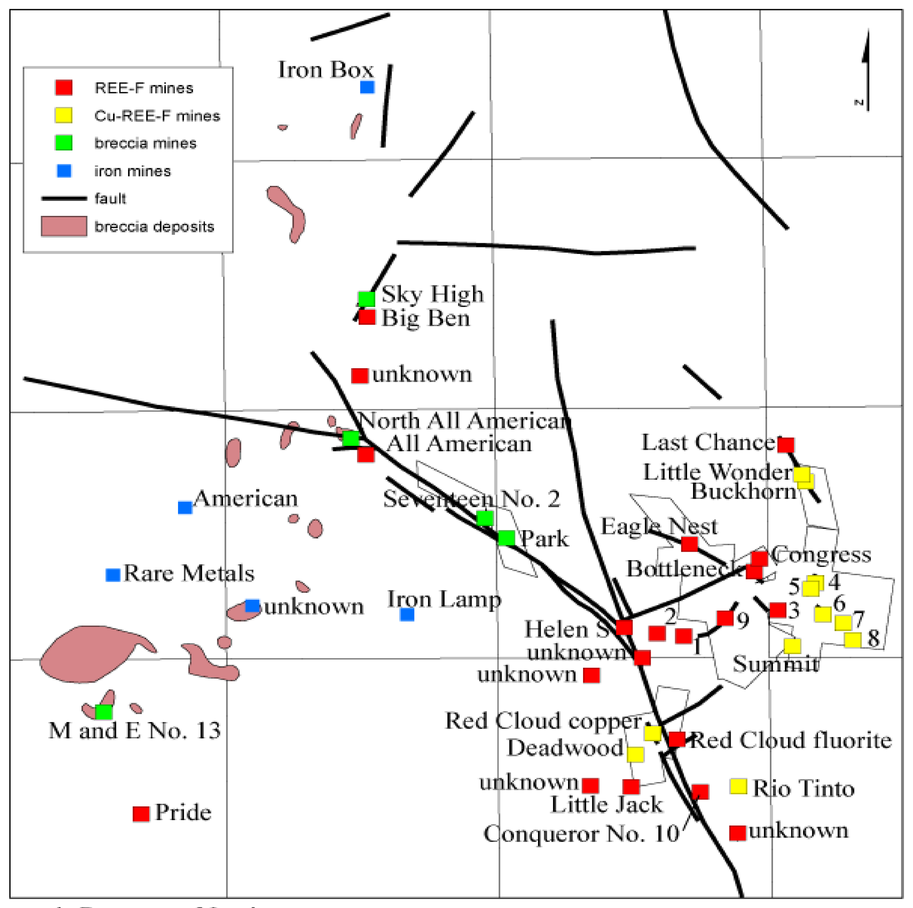
Ideogram of K/Ar, Rb/Sr, and Ar^{40}/Ar^{39} ages of igneous rocks in the LCPB area. $^{40}Ar/^{39}Ar$ ages have been recalculated using the new decay constant (modified from McLemore and Zimmerer, 2009). The Gallinas Mountains trachyte was dated by K/Ar methods as 29.9 Ma (Perhac, 1970).

MINING AND EXPLORATION HISTORY

1881	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	fluorite discovered in the district
1943	bastnaesite discovered with fluorite
1951-1954	fluorite produced from the Red Cloud and Conqueror mines
1950's	~142,000 lbs of bastnaesite was produced from Red Cloud mine
1954-1956	NM Copper Corp.-mill near Carrizozo, NM , produced 55,000 lbs of bastnaesite
1980	Phelps Dodge drilled a 532-ft 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 (Schreiner, 1999)
1989	Canyon Resources examination
1991-1992	Hecla Mining Co. examination
1992	American Copper and Nickel, Inc. and Romana Resources
1991-1992	U.S. Bureau of Mines conducted extensive mapping and sampling of the REE deposits (Schreiner, 1993)
2009	Strategic Resources, Inc. staked claims and began exploration

MINERALS PRODUCTION FROM THE GALLINAS MOUNTAINS DISTRICT, NM

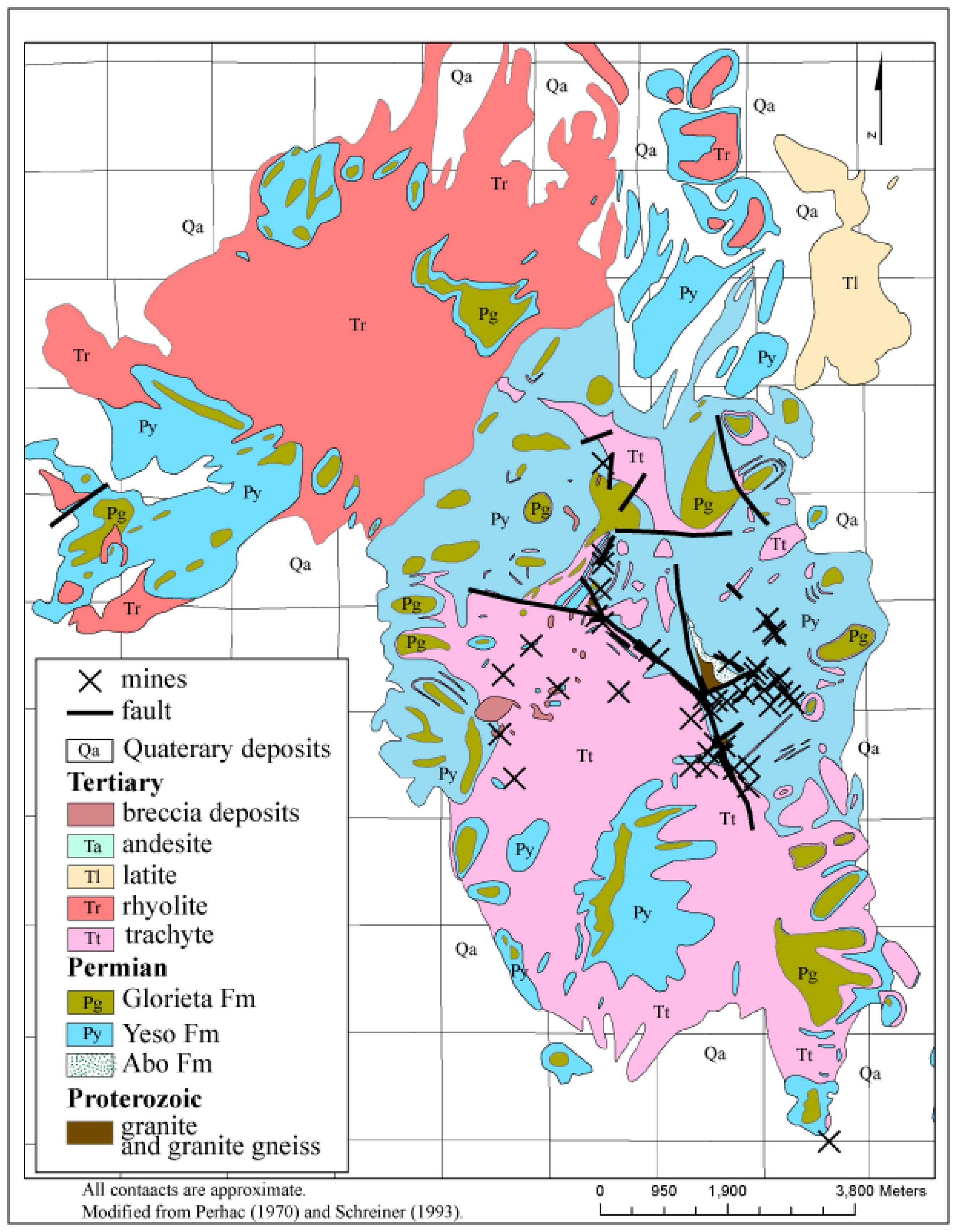
Mineral Produced	Mine name	Years of production	Amount (short tons)	Grade %	Reference
Copper	various	1909-1953	192.7		McLemore (1991)
Gold	various	1913-1955	6.58 ounces		McLemore (1991)
Silver	various	1909-1955	23,723 ounces		McLemore (1991)
Lead	various	1909-1055	863.4		McLemore (1991)
Zinc	various	1948-1953	8.7		McLemore (1991)
Iron ore	American	1942-1943	3,944	55.7	Kelly (1949)
	Gallinas	1942	6,410	48.7	Kelly (1949)
	Other mines		3,326		Kelly (1949)
Total iron ore		1942-1943	10,354		
Fluorite	All American	1951-1954	129		Griswold (1959), McAnulty (1978)
	Conqueror (Tinto)	1951-1954	300		Griswold (1959), McAnulty (1978)
	Red Cloud	1951-1954	1,000		Griswold (1959), McAnulty (1978)
Total fluorite		1951-1954	1,608		
Bastnaesite	Conqueror No. 9	1954-1955	60		Griswold (1959)
	Conqueror No. 10	1956	11		Griswold (1959)
Total bastnaesite		1954-1956	71		



1-Conqueror No. 4
2-Conqueror Apex
3-Hoosier Girl N
4-Hoosier Girl N
5-Old Hickory
6-Hoosier Boy
7-Eureka
8-White Oaks
9-Hilltop

Mines and prospects in the Gallinas Mountains, Lincoln County

DESCRIPTION OF GALLINAS DISTRICT



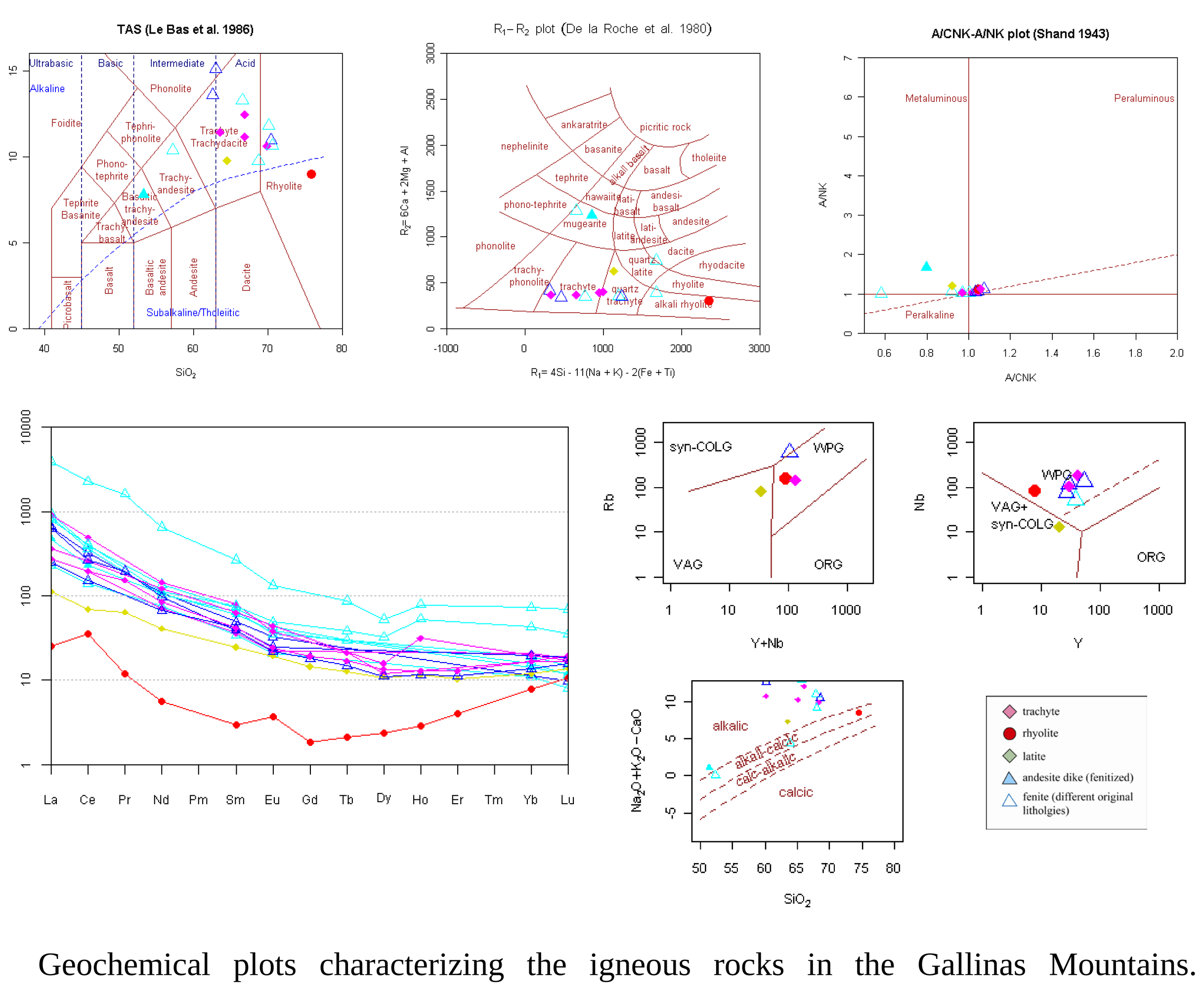
Geologic map of the Gallinas Mountains, Lincoln County, New Mexico (modified from Kelly et al., 1946; Perhac, 1961, 1970; Woodward and Fulp, 1991; Schreiner, 1993; field reconnaissance by the authors)

LOCAL GEOLOGY

The oldest rocks in the Gallinas Mountains are altered Proterozoic gneisses and granites (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 latite (also trachydacite 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 Formation. Most of these breccia pipes are matrix-supported and are cemented by quartz, fluorite, and hematite along with small crystals of other minerals and rock fragments. However, two breccias pipes at the M and E No. 13 prospect are clast-supported. The mineralized area of the Gallinas Mountains lies in a magnetic low surrounded by magnetic high anomalies (McLemore, 2010). The classification of breccia pipes is primarily based upon the mechanism of brecciation and the involvement of water, magma, or tectonics (Sillitoe, 1985). Schreiner (1993) called these breccias 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 magmatic, meteoric, connate, or ocean waters (Sillitoe, 1985). In the Gallinas breccia pipes, the breccia cement consists of hydrothermal minerals not magma; therefore, magmatic-hydrothermal breccia pipe is a better term (Sillitoe, 1985).

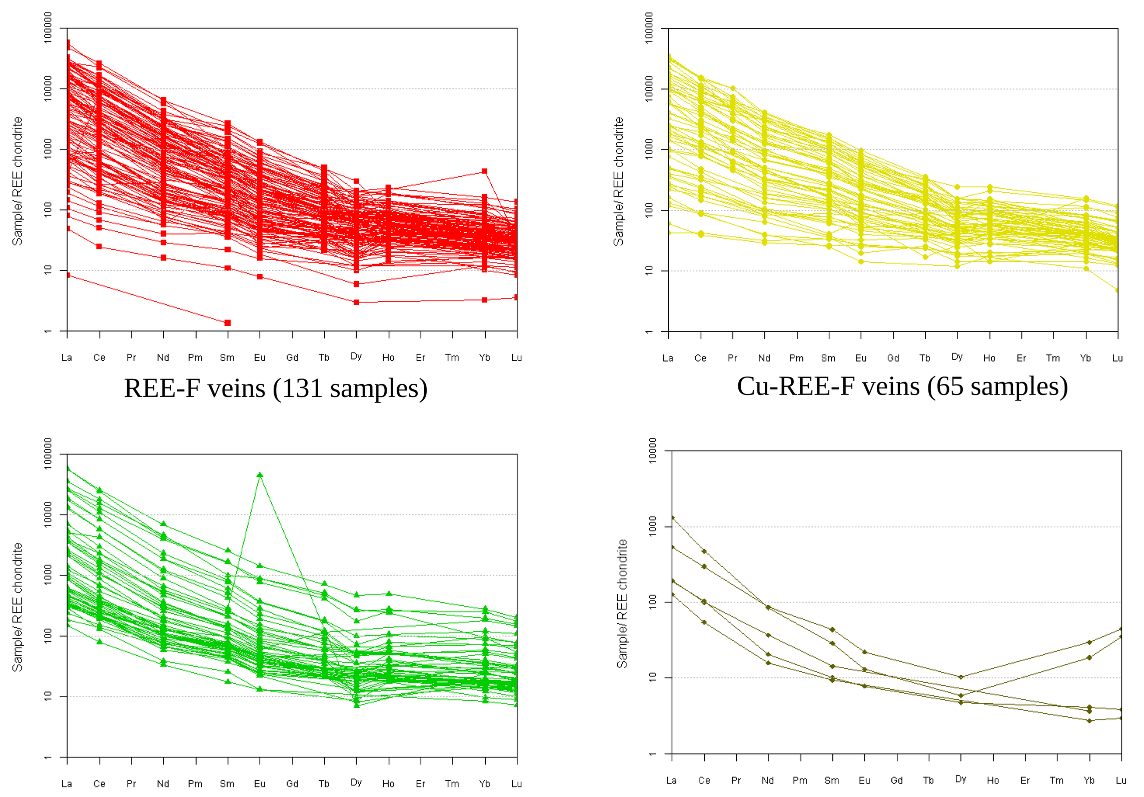
PETROCHEMISTRY OF THE IGNEOUS ROCKS

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 (Whalen et al., 1987). 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. The trachyte and latite samples plot within the within-plate granite tectonic field of Pearce et al. (1984; WPG), whereas the rhyolite sample plots within the volcanic-arc granite field (VAG). Trachyte and latite are possibly related magmatically, 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.

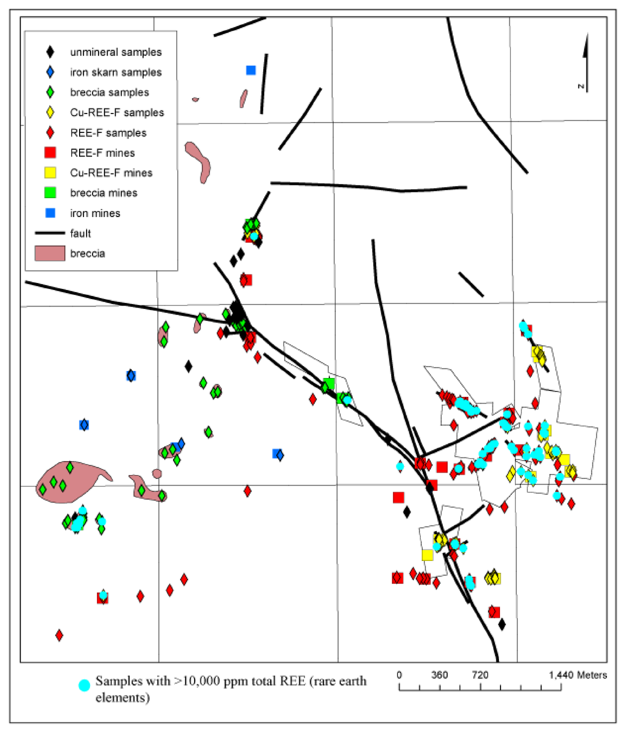


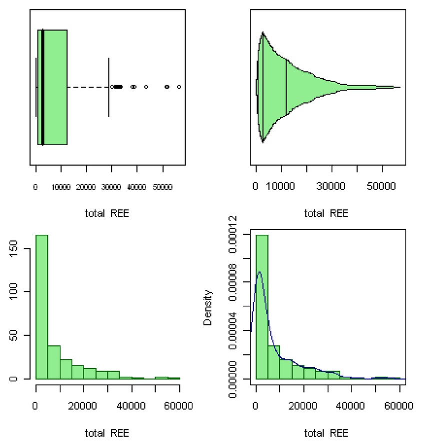
Geochemical plots characterizing the igneous rocks in the Gallinas Mountains. Chemical analyses are from Schreiner (1993) and this report. Geochemical plots from Le Bas et al. (1986), de la Roche et al. (1980), and Frost et al. (2001).

GEOCHEMISTRY OF THE GALLINAS REE DEPOSITS

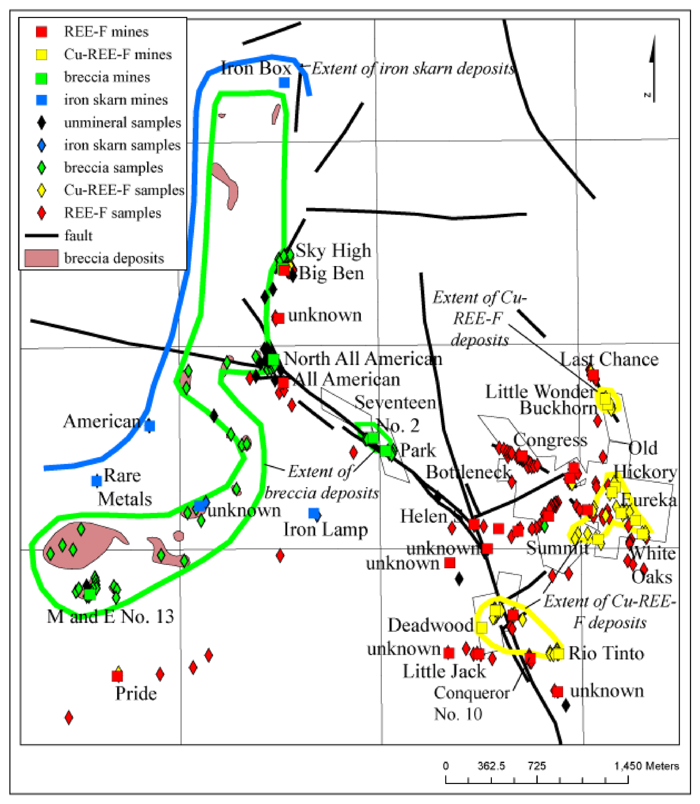


The geochemical data for this area consists of 279 samples that were collected and analyzed for various elements by Schreiner (1993) and by the authors for this report. Chondrite-normalized REE plots of mineralized samples from the Gallinas district are shown above. Chondrite values are from Nakamura (1974). Geochemical anomaly maps (below) 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.

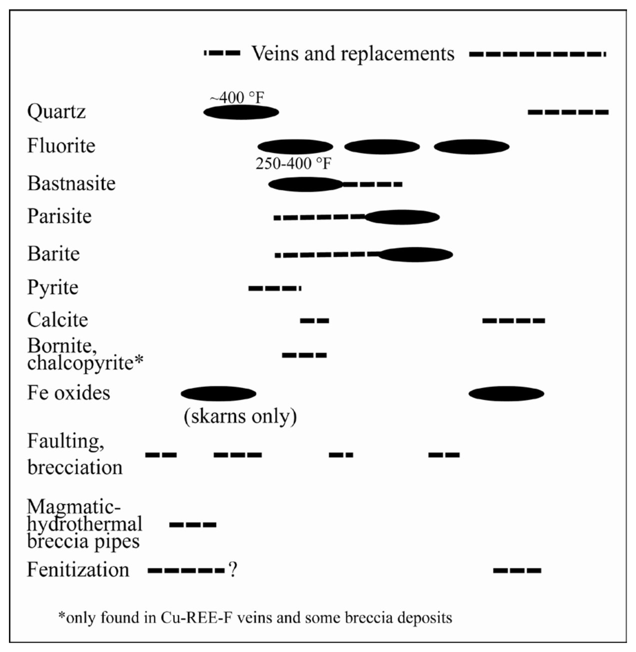




Geochemical anomaly map and statistical plots (box plots, histogram, cumulative frequency distribution plot for all samples) of total REE (rare earth elements, ppm) of samples from the Gallinas Mountains. Chemical analyses are from Schreiner (1993) and this report.



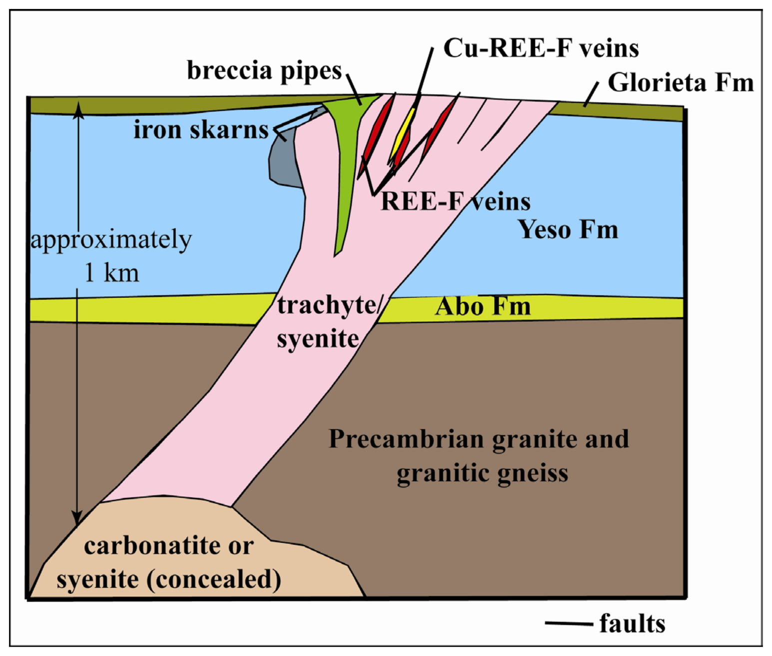
Mineral zoning in the Gallinas Mountains, Lincoln County, New Mexico, based upon predominant mineralogy and chemistry of the known deposits.



Simplified paragenesis of the REE deposits in the Galliinas Mountains (modified from Perhac, 1970, Schreiner, 1993, William-Jones et al., 2000, and field observations by the author). Temperature estimates are from Williams-Jones et al. (2000).

SEQUENCE OF EVENTS

- •Intrusion of the trachyte/phonolite
- •Fenitization
- •Deposition of the iron skarns
- •Faulting and brecciation
- •Formation of the magmatic-hydrothermal breccia pipes
- •Continued fenitization
- •Additional brecciation
- •Deposition of the REE-F and Cu-REE-F veins
- •Late stage deposition of quartz



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).

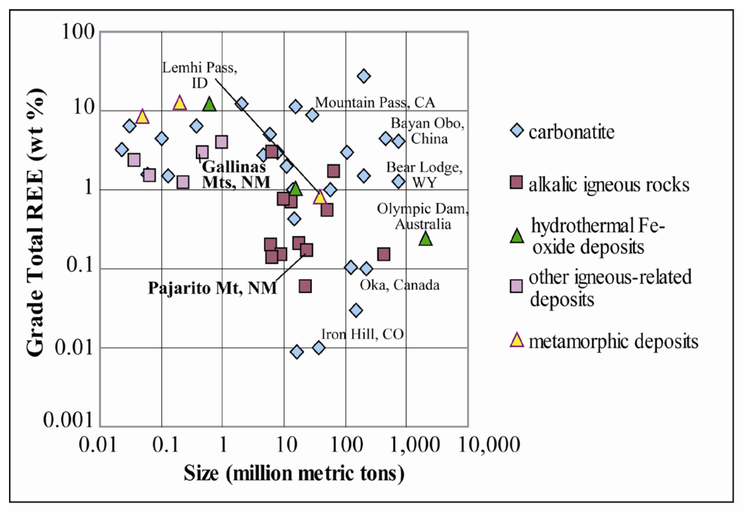
DESCRIPTION OF MINERAL DEPOSITS

Four types of deposits have been identified in the Gallinas district, as defined by McLemore (1996) and the U.S. Geological Survey (Cox and Singer, 1983):

1. GPM iron skarn deposits (U.S. Geological Survey classification, iron skarn, 18d)
2. GPM breccia pipe deposits
3. REE-F veins (GPM REE-Th-U±Cu, F) hydrothermal veins (U.S. Geological Survey classification, thorium-rare-earth veins, 10b)
4. Cu-REE-F veins (GPM REE-Th-U±Cu, F) hydrothermal veins (U.S. Geological Survey classification, thorium-rare-earth veins, 10b)

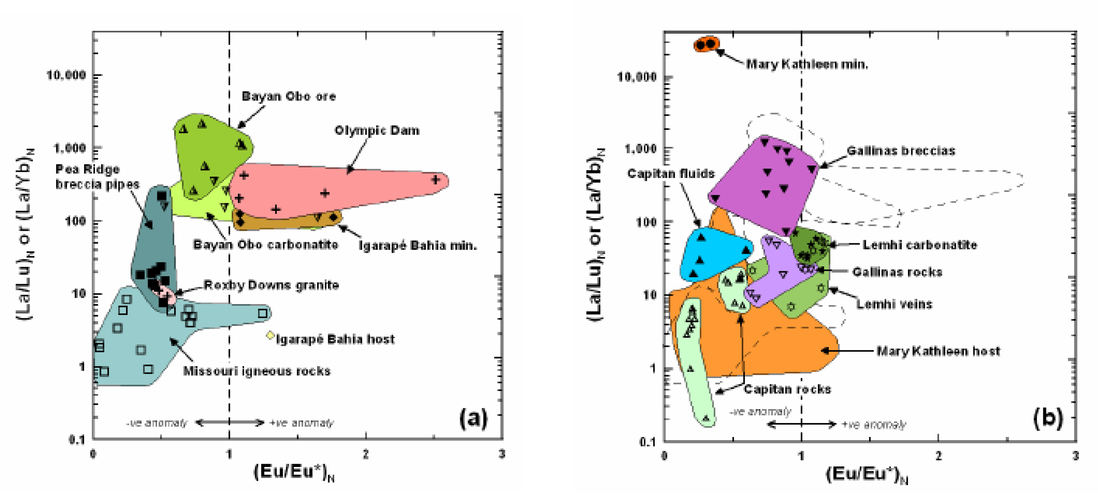
A fifth type of deposit, carbonatite deposits (Cox and Singer, 1986), could be in the subsurface as suggested by previous drilling, but no samples have been obtained for precise determination of the lithology. The mineralogy in the district is diverse and includes fluorite, quartz, barite, pyrite, iron 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, 1970; Perhac and Heinrich, 1964; McAnulty, 1978; DeMark, 1980). 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). Nb_2O_5 ranges from 8-148 ppm (Moore, 1965; Schreiner, 1993).

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



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 REE deposits in the Gallinas district are among the highest 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. Chemically, samples from the Gallinas district are similar in REE chemistry to Bayan Obo, Lemhi Pass, and Olympic Dam deposits and different from Capitan deposits.



Differentiation of different types of REE deposits by normalized La/Lu and normalized La/Gd verses normalized Eu/Eu* (from Samson and Wood, 2005; Gillerman, 2006). Samples from Gallinas Mountains are similar in REE chemistry 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, Capitan).

PRELIMINARY CONCLUSIONS

- •The igneous rocks in the Gallinas Mountains are metaluminous to peraluminous, alkaline volcanic rocks, and have chemical compositions similar to A-type granitoids. Trachyte and latite are possibly related magmatically, 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.
- •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.
- •District zonation is defined by REE-base metals (REE-F-Cu veins) that form center of the district, surrounded by REE-F 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. The iron skarns are probably related to the REE-F veins and breccias because they typically contain bastnaesite and fluorite.
- •Some fenites are more enriched in REE than unaltered igneous rocks.
- •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.
- •A genetic model is summarized by intrusion 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.

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 outcrop geologic 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 zonation. Additional geochemical studies, including isotopic studies, of igneous rocks, mineralization, and alteration will aid in a better understanding of the systematics of igneous intrusion and mineralization in the Gallinas Mountains. REE and radiometric isotope analyses are invaluable in differentiating between mantle and crustal sources.

ACKNOWLEDGEMENTS

This work is part of ongoing research of the economic and environmental geology of mineral resources in New Mexico at NMBGMR, Peter Scholle, Director and State Geologist. Mark Mansell provided technical assistance. This work was funded by the NMBGMR and Strategic Resources, Inc. (http://www.strategicresourcesinc.ca/, accessed 5/14/2010). Matt Zimmerer provided the geochronology summary. Finally, I would like to thank Russ Schreiner for his work in the area and sharing his insights and information over the years.

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