Rare Earth Mineralization of Southern Clark County, Nevada

Jessica J. Bruns
Geological Sciences Department
California State Polytechnic University – Pomona

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ABSTRACT

Rare earth mineralization was first reported in the New York Mountains of southern Nevada and eastern California by Volborth (1962), 30 kilometers to the east of the rare earth carbonatite complex at Mountain Pass, California. This research examines the northern portion of this mineralized trend lying within southern Clark County, Nevada.

The New York Mountains are comprised of orthogneissic granitoids emplaced in a north-south-trending zone at about 1.80 to 1.65 Ga (Miller and Wooden, 1994). Greenschist to amphibolite grade metamorphism overlapped batholitic emplacement. XRF whole rock analyses indicate the host rocks are predominantly S-type granite to granodiorite typical of a continental arc. The rock suite is only slightly alkalic.

Alkali metasomatism, Na_2O addition and K_2O depletion, post-dated emplacement of rare earth mineralization, perhaps creating the series of albitite dikes and pegmatite bodies that act as hosts for the rare earths. The mineralization occurs along a 2.5 kilometer trend striking N20°E. Controls for the pegmatite bodies are enigmatic. Numerous northeast-striking normal faults have been mapped throughout the northern New York Mountains. In addition, many dikes closely parallel regional foliation.

XRF, XRD and thin section analyses reveal that mineralization occurs predominantly as rare earth fluorapatite with lesser monazite. A few grains of epidote (var. allanite) were present in hand sample. Bastnaesite was not observed. Rare earth geochemistry reveals the southern Nevada occurrences are dominated by heavy REEs and that the mineralizing hydrothermal fluids were of crustal origin.

Significant differences in host rocks, alteration, and rare earth mineralogy and geochemistry exist between southern Nevada and the Mountain Pass carbonate in eastern California. These differences make any link between the two areas tenuous at best. Two possible genetic models are presented for the southern Nevada rare earth deposits. The first links the mineralization to the Proterozoic Ivanpah orogeny. Intrusion of the 1800-1650 Ma granites was followed closely in time by pegmatite and rare earth emplacement along northeast-trending faults. The second model relates the rare earth mineralization, and perhaps the host pegmatites, to Mesozoic plate convergence and intrusion of the Jurassic-Cretaceous Ivanpah Granite. This model suggests the rare earth mineralization may be significantly younger than the pegmatite host and perhaps controlled by a series of local faults trending N 65-80°W.

INTRODUCTION

The rare earth elements (REEs) include the 15 Lanthanide elements (Z = 57 - 71), as well as scandium (Z = 21) and yttrium (Z = 39) which are chemically quite similar. The term “rare earths” stems from the fact that many of these elements were first isolated in the 18th and 19th centuries as oxides from very rare minerals. REEs are difficult to refine to pure metal, with efficient separation processes largely undeveloped until the 20th century.

All of the REEs were identified by 1945; promethium , the rarest was identified last. Commercial markets for REEs have arisen in only the past 50 years. During the 1970’s and 1980’s most rare earth’s were sold as phosphors for CRT television tubes and as glass polishing and tinting agents. With the advent of the Hi-Tech industry demand has accelerated over the past decade (Fig. 1) with application to the following products:

- Catalytic converts
- Hybrid automotive batteries
- Wind turbines
- Magnets
- Lasers
- LCD screens
- Electrical engines
- Medical imaging equipment
- Superconductors

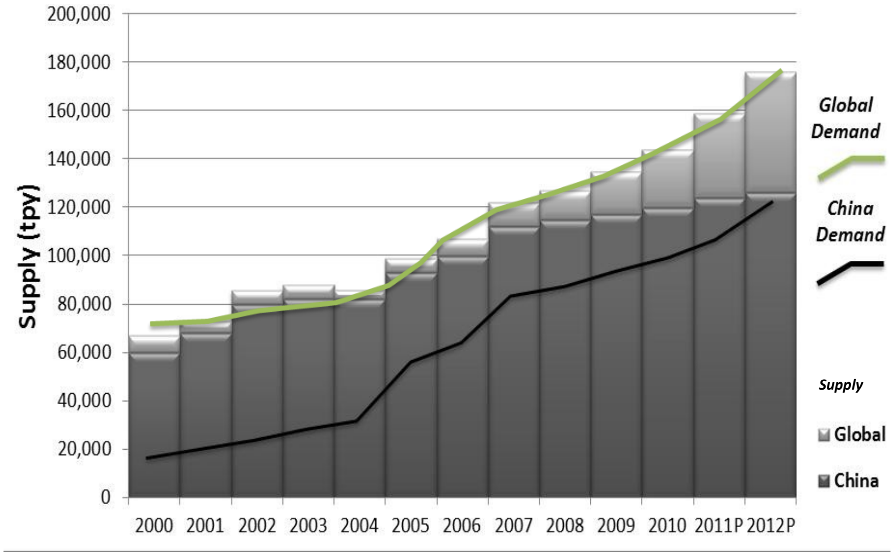

Figure 1. Supply and demand for rare earth elements 2000-2012P (projected). *Source: www.roskill.com*

REEs are not as uncommon as the name would imply. For instance, cerium (64 ppm), the most abundant REE (Table 1), comprises more of the earth’s crust than does copper (50 ppm) (USGS Fact Sheet 087-02, 2002). Many REEs are more common than tin and molybdenum and all but promethium are more common than silver or mercury (Taylor and McClennan, 1985). Lanthanide elements with low atomic numbers are generally more abundant in the earth’s crust than those with higher atomic numbers (Table 1). The lanthanide elements are subdivided into two groups: the light rare earth elements (LREEs)—lanthanum through europium (Z = 57 through 63) and scandium (Z = 21); and the heavy rare earth elements (HREEs)—gadolinium through lutetium (Z = 64 through 71). Yttrium is grouped with the chemically and physically similar HREEs.

Table 1. REEs, atomic numbers and abundances.

Element	Symbol	Atomic Number	Crustal Abundance ppm *
Scandium	Sc	21	22
Yttrium	Y	39	22
Lanthanum	La	57	30
Cerium	Ce	58	64
Praseodymium	Pr	59	7.1
Neodymium	Nd	60	26
Promethium	Pm	61	n/a
Samarium	Sm	62	4.5
Europium	Eu	63	0.88
Gadolinium	Gd	64	3.8
Terbium	Tb	65	0.64
Dysprosium	Dy	66	3.5
Holmium	Ho	67	0.80
Erbium	Er	68	2.3
Thulium	Tm	69	0.33
Ytterbium	Yb	70	2.2
Lutetium	Lu	71	0.32

*** *Source:* Taylor and McClennan, 1985**

REEs occur together naturally because all are trivalent (except for Ce+4 and Eu+2 in some environments) and have similar ionic radii. The similar radii and oxidation state allow the REEs to readily substitute for one another in crystal lattices. This substitution accounts for their wide dispersion in the earth's crust and the characteristic multiple occurrences of REEs within a single mineral.

Figure 1 shows the current global supply and demand trends for REEs. China currently produces 93% of all REEs. Beginning in 2005 there was a sharp increase in domestic demand and it is projected that by 2012 China will not be able to meet its own internal requirements. In May, 2011 the State Resource Council of China stated that it greatly increased rare earth taxes and refined its pricing mechanism to reduce the excessive profits in the rare earth mining industry. China will also raise the threshold for companies applying for export quotas, reducing the number of qualified exporters (*Source:* The Wall Street Journal, May 19, 2011). As a result, other nations will need to dramatically increase production to fulfill global demand.

This thesis examines a rare earth occurrence in southern Clark County, Nevada, 30 kilometers east of the Molycorp Mountain Pass Rare Earth Mine. The objectives are to:

1. **Examine host rock lithology and alteration.**
2. **Identify the rare earth-bearing mineral species.**
3. **Compare the Clark County occurrences to the "better known" Mountain Pass deposit.**
4. **Create a genetic model relating the two districts.**

LOCATION and ACCESSIBILITY

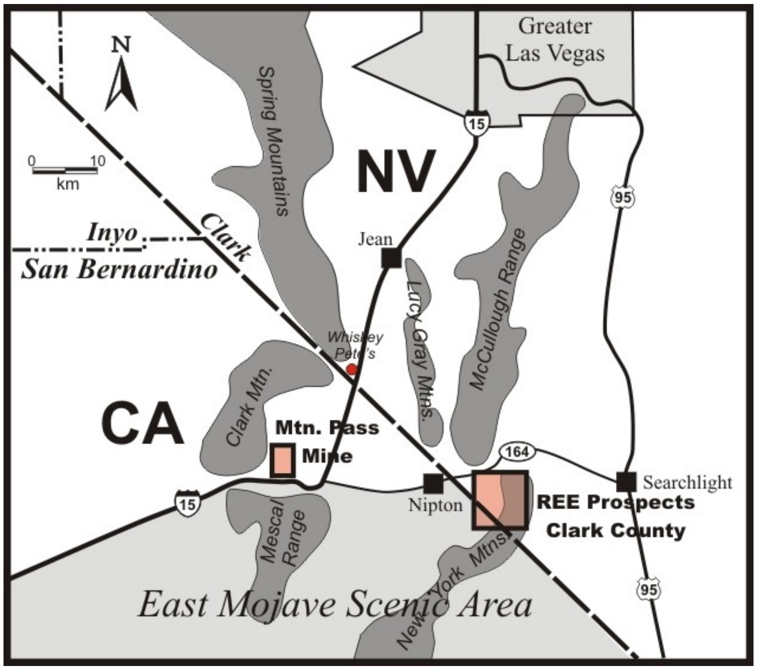

Figure 2. Index map showing the location of rare earth mineralization in southern Clark County, Nevada.

Volborth (1962) described several occurrences of rare earth mineralization in southern Clark County, near the California/Nevada state line, approximately 75 km south of Las Vegas, Nevada and 30 kilometers to the east of the Molycorp Mountain Pass Mine in San Bernardino County, California (Fig. 2). Access from Las Vegas is via U.S. Highway 95 south-southeast to the town of Searchlight, Nevada; then west via Nevada State Highway 164 for a distance of 26 km to a series of unpaved roads leading a few kilometers to the southeast to numerous prospect pits and trenches. The latter roads require 4WD during periods of inclement weather. Access from Cal Poly Pomona is via Interstate 15 North to the Nipton Road Exit (NV 164). Driving east through the town of Nipton, CA a distance of 25 kilometers leads to the aforementioned series of unpaved roads and access to the rare earth prospects.

The area of outcrop lies along the west flank of the New York Mountains with many of the prospect pits located in the broad Ivanpah Valley which extends westward into California. The terrain is typical of the eastern Mojave Desert Region and is part of the Basin and Range Physiographic Province, consisting of rugged hills ranging from 1,200 to 1,800 meters in elevation separated by basins ranging from 900 to 1,200 meters in elevation. The area of known rare earth mineralization stretches from Crescent Peak at the north end of the New York Mountains southward 10 kilometers to the Black Butte area in San Bernardino County, California.

This research study was restricted to rare earth occurrences in Nevada, as the California rare earth mineralization lies within the East Mojave Preserve and is off limits to prospecting and sampling. Specifically, the study area lies within what is termed the Thor REE Project of the Crescent Mining District in the northern New York Mountains. The project is comprised of 198 unpatented lode claims covering approximately 1,480 hectares (See Fig. 4). The claim block lies within the Crescent Peak and Hopps Well U.S. Geological Survey 7.5’ topographic quadrangles and includes all or portions of Sections 34 and 35 of R61E, T28S, and Sections 2, 3, 4, 5, 8, 9, 10, 11, 15 and 16 of R61E, T29S. The claims are staked by Elissa Resources Limited of Vancouver, Canada and are the site of ongoing geological prospecting and development.

CLIMATE and PHYSIOGRAPHY

Figure 3. View looking southeast toward the crest of the New York Mountains, Dark hills in the background are underlain by Proterozoic granitoids. Light-colored area in the foreground is alluvium with scattered outcrops.

The climate in southern Clark County, Nevada is arid desert (Fig. 3). There are two main periods of precipitation; one from December to March associated with the eastward passage of low pressure systems generated in the Gulf of Alaska and a second in July and August resulting from the northward flow of subtropical, monsoonal moisture. Average annual rainfall is 8.3 inches (21 cm) (Source: Western Regional Climate Center). Maximum average daytime temperatures of 97°F (36°C) occur in late July with the daily minimum of 53°F (11.6°C) around January 1st. The prevailing vegetation consists of mesquite and acacia, with creosote bushes and galletas in the basins, and Mojave shrubs and succulent plants, including Joshua trees, yucca and cacti, on the hillsides.

The northern New York Mountains are comprised of a series of peaks of moderate elevation 500-700 meters above the floor of Ivanpah Valley. Crescent Peak at 1828 meters is the highest point within the northern New York Mountains. Drainage is southwestward toward Nipton, California and Ivanpah dry lake. The area of outcropping rare earth mineralization is generally at the base New York Mountains in a series of low hills and gently, southwest-dipping alluvial fan deposits averaging 1300 to 1400 meters in elevation.

Las Vegas, Nevada (pop. 583,000 Source: U.S. Census Bureau 2010); lies 100 kilometers from the Thor rare earth property by road. It is a major metropolitan area offering full service facilities, daily commercial air flights to major cities and a great way to lose your spending money. The town of Searchlight (pop. 1,000, 35 kilometers by road) offers limited facilities including food, lodging, and fuel. Nipton, California (pop. 26), eight kilometers to the southwest of the Thor property offers bare bones lodging and the best blue cheese and bacon burger in the Mojave Desert.

Most rare earth outcrops and prospect pits are located on public land administered by the U.S. Bureau of Land Management (BLM) and are open for public access and mineral claim staking. The Thor property is currently staked by Elissa Resources of Vancouver, Canada.

HISTORY

While the Goodsprings District near, Jean, Nevada was a significant producer of lead and zinc from 1856 to 1957, and gypsum mines around Las Vegas continue to be major producers, southern Clark County has never produced significant mineral commodities, As such, published literature on the history of mining and exploration is minimal.

Vanderburg (1937), in a county report on Clark County mentions the mining of turquoise near Crescent Peak that had probably been going on for hundreds of years. Total turquoise production is estimated to have exceeded $1,000,000 (Morrissey, 1968). Gold and silver were also discovered in the district in the early 1900's, with ensuing periods of mining activity in 1905-1907, 1911, 1930 and 1934-1941 (Hogge and others, 2010). Principal producers were the Nippeno, Big Tiger, (Lily, and Double Standard mines). Total production was only about $62,000 (Longwell and others, 1965).

In more recent times, the district has been intermittently explored for gold, silver, copper, lead and molybdenum. Kennecott, in the early 1950's identified Crescent Peak as a possible porphyry Cu-Mo target and drilled several exploration holes. The prospect was re-examined by Utah International, ASARCO, Homestake and U.S. Borax in the period from 1955 to the late 1970's but no development work was undertaken. During the 1980's and 1990's Tenneco Minerals and other companies, spurred by the discovery of the Castle Mountain gold deposit in the Hart Mining District, explored the area in and around the New York Mountains for various types of gold deposits, including detachment-related gold, but no discoveries were made. In 1988, platinum group metals were discovered by the Nevada Bureau of Mines and Geology along the flank of Crescent Peak (Lechler, 1988), but the discovery has warranted no further evaluation.

Following WWII and the development of the atomic bomb there was a prospecting rush throughout the Mojave Desert. Weekend prospectors would often gather at the general store in Jean, Nevada and then head off to the nearby mountains (Jessey, 2011 pers. com.) In April 1949, a couple of prospectors noted modest radioactivity on their Geiger counter at Sulphide Queen Hill near Mountain Pass, California, about 60 kilometers west of Jean. They grabbed samples of the radioactive rock and took it to the U.S. Bureau of Mines in Boulder City, Nevada. Analyses of the samples by the Bureau of Mines, revealed that while uranium and thorium were present in small amounts, the rock was rich in bastnaesite—a rare earth–fluorocarbonate. The prospectors staked a claim and in February 1950 Molybdenum Corporation of America (later "Molycorp") purchased the claims. In 1952, Molycorp began mining and processing the ore body.

Occurrences of radioactive minerals, mainly thorium with associated rare earth elements (REE), were discovered in the New York Mountains, southwest of Crescent Peak, and in an area 3 miles south of Crescent Peak extending southward into California in the early 1950's. U.S. Atomic Energy Commission geologists reported a sample containing 0.15% ThO_2 and 1.54% REE, and a second sample containing 0.874% U_3O_8, 0.63% ThO_2 and 6.81% rare earth oxide (REO).

Volborth (1962) was the first to mention the REE potential of southern Clark County in a widely read journal. Writing in *Economic Geology* he stated:

> *"Allanite pegmatites similar to the Red Rock pegmatites are abundant near the California-Nevada border in the Precambrian schists and gneisses of the Ivanpah quadrangle mapped by Hewett, and in the Precambrian porphyritic granites of the Gold Butte area north of Lake Mead.*

> *A remarkable concentration of allanite pegmatites occurs on the northwestern slopes of the central New York Mountains about 2 miles southwest of Moore, California. Here six allanite pegmatite bodies were found in an area about one-half mile square in Precambrian biotite schists, migmatites, gneisses, and chlorite-bearing biotite schists.........*
>
> *Some fine-grained allanite was found in the xenotime-monazite dikes of the Crescent Peak area, which lies approximately 8 miles northeast of the NewYork Mountains allanite pegmatites also in Precambrian schists, close to a granite contact. An allanite-like mineral was also found in an aplitic dike near the Neppeno mine near Crescent Peak. Three more probable allanite occurrences are known in this vicinity. According to Mr. R. Lopez, they are in the northwestern part of the McCullough Range; in the southeastern part of the same range, and in the northern part of the Newberry Dead Mountains".*

The REE prospecting history of southern Clark County in largely unknown, but most likely dates from the discovery of U-Th outcrops in the 1950's. The flanks of the New York Mountains are dotted with prospect pits and bulldozer trenches. Old claim markers abound. Molycorp briefly examined the area sometime in the 1970's or early 1980's, but engaged in no significant exploration activity.

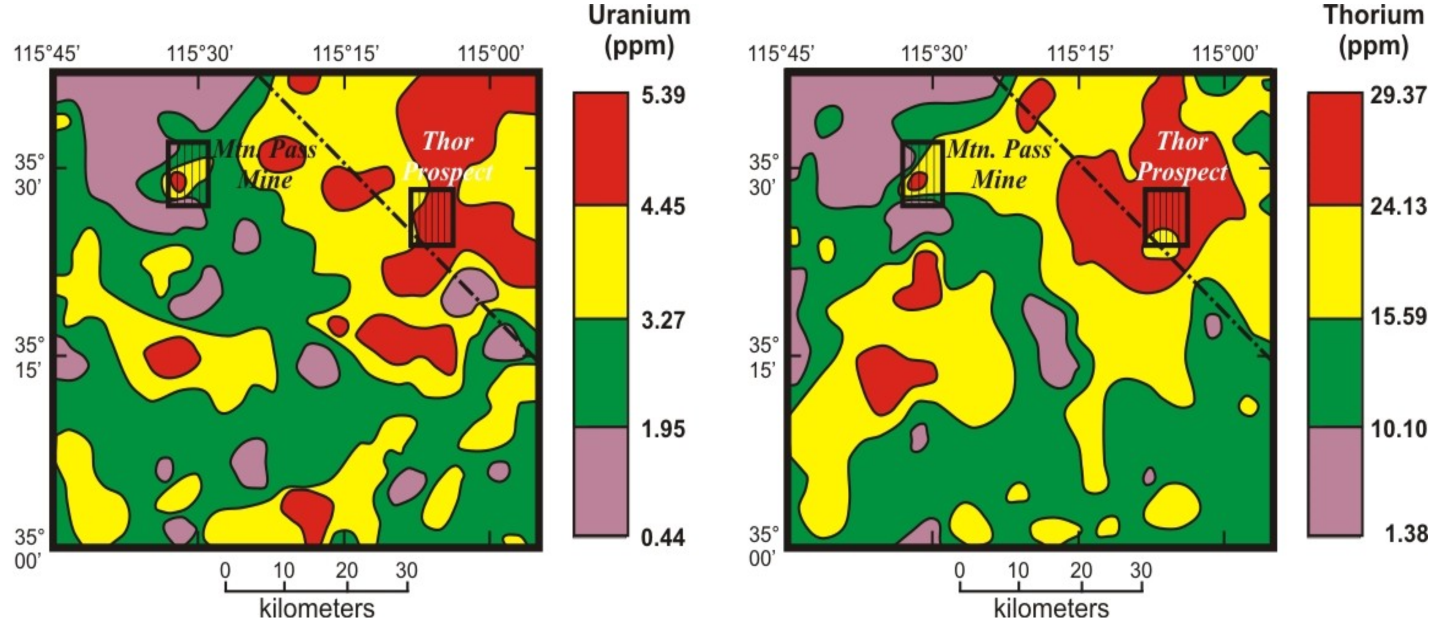

Figure 4. Contoured chemical composition values, derived from aerial gamma-ray surveys, of rocks in the eastern Mojave Desert; representative data for thorium and uranium in parts per million. Boxes show locations of Mountain Pass Mine and the Thor Prospect. Data from USDOE (1979, 1980).

From the mid-1970's to early-1980's, a broad-scale airborne radiometric survey was flown over the Mojave Desert Region as part of the NURE Program (National Uranium Resources Evaluation) by the U.S. Department of Energy. Contoured plots of measured Th and U concentrations from this data were compiled by Duval and others (1989,1990) and made available in digital format in 2005 (Figure 4). These plots renewed interest in the rare earth potential of southern Clark County as a significant U-Th anomaly is present in the New York Mountains, similar to the smaller U-Th anomaly associated with the Mountain Pass rare earth deposit.

In 2009, Elissa Resources Limited staked much of the area covered by historic prospecting and named the claim block the Thor Property. They have conducted an airborne magnetic survey, detailed radiometric survey and extensive geochemical sampling of outcrops and prospect pits. Results were reported by Hogge and others (2010). Plans are in the works for additional geophysical surveys and exploratory drilling.

GEOLOGY

Regional

All known rare earth mineralization lies within the northeastern Mojave Desert (Fig. 5), a large physiographic province whose boundaries are defined by its Tertiary geologic history. To the south and west, the San Andreas Fault separates the Transverse and Coastal Ranges from the Mojave Desert, while to the north the Garlock Fault marks the southern end of the Sierra Nevada Mountains. The eastern margin of the Mojave Desert is more loosely defined, some suggesting the Las Vegas-Sonora megashear while others simply prefer the transition to Basin and Range physiography.

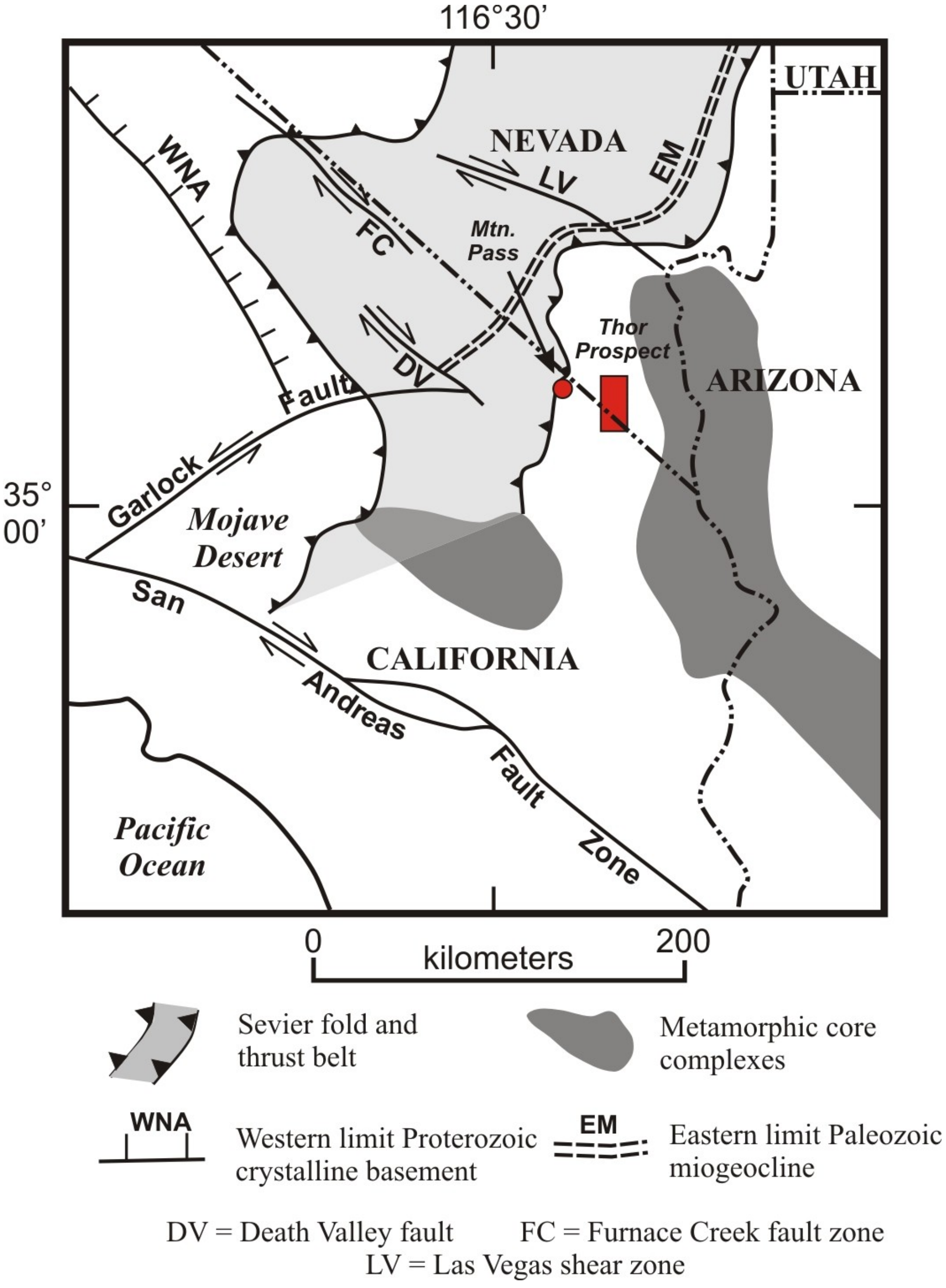

Figure 5. Tectonic map of southeastern California and adjacent regions, showing relationships among major structural and paleogeographic elements. Modified from Burchfiel and Davis (1988).

The diverse geologic history of the eastern Mojave Desert spans more than 1,760 million years (Tosdal, 2007). The oldest rocks are high grade Early Proterozoic gneisses that underwent metamorphism at around 1,700 Ma. The gneisses were then intruded by granitoidal rocks from about 1780 to 1,650 Ma, again by granitic rocks at 1,400 Ma, and by the diabase of the Crystal Spring Formation at about 1,100 Ma. Carbonatite and alkaline igneous rocks compose a part of the 1,400-Ma intrusive suite near Mountain Pass, California. Sedimentary strata of late Proterozoic, Paleozoic, and early Mesozoic age were deposited unconformably on the Proterozoic basement rocks throughout the east Mojave Desert. The sedimentary rocks formed in marine and continental environments along the western edge of the North America craton. They represent the transition from cratonal sedimentary rocks to the southeast, to miogeoclinal units to the northwest (Fig. 5)(Burchfiel and Davis, 1981).

During the Mesozoic widespread magmatism affected the region. Triassic volcanic rocks are the oldest evidence of this magmatism. Subsequent Jurassic volcanism and plutonism produced alkalic rocks along the east edge of the magmatic arc (Tosdal, 2007). By Cretaceous time plutonic and volcanic rocks had become calc-alkaline, consistent with a mature arc. During the middle to late Mesozoic, the interior of the arc complex underwent as much as 60-100 kilometers of shortening along the Sevier fold and thrust belt (Burchfiel and Davis, 1988) (lightly shaded area Fig.5). Thrust slices within this belt involve the cratonal Proterozoic basement and, locally, Mesozoic plutonic rocks (Burchfiel and Davis, 1988).

During the Miocene, volcanism became widespread along the southern and eastern margins of the Mojave Desert. Significant extensional deformation occurred in metamorphic core complexes along the lower Colorado River to the east and in the central Mojave Desert to the southwest (darkly shaded areas, Fig. 5). This deformation is characterized by an upper plate of intensely faulted, upper-crustal rocks and a lower plate of mylonitic, midcrustal rocks juxtaposed by shallowly-dipping detachment faults. While extensional deformation was having dramatic effects to the south and west, much of the east Mojave Desert escaped the most intense extension.

Cenozoic high-angle faults locally cut several ranges, many having undergone multiple periods of movement. These faults have often been the subject of detailed mapping and study, as they were thought to control formation of various kinds of ore bodies. Despite the study, their significance and genesis remains controversial.

In the Neogene, erosion produced broad pediment domes in the northwestern part of the area. Alkali-basaltic volcanism of the Cima volcanic field followed pediment formation. Erosion during the Quaternary has continued to supply sediment to adjacent valleys.

Mountain Pass

Middle Proterozoic alkaline rocks and carbonatite crop out within an elongate block of crystalline basement rocks approximately 60 km long extending from Kokoweef Peak, in the northeastern Ivanpah Mountains, northwestward to Mesquite Pass. This block is comprised largely of Early Proterozoic gneisses and pegmatites often termed the Fenner Gneiss and assigned an age of 1700-1800 Ma (Wooden and Miller, 1990). These rocks are intruded by Middle Proterozoic alkaline rocks and carbonatite. This block of Proterozoic rocks is bounded on the west by the Cretaceous Keaney-Mollusk thrust and on the east by an inferred high-angle fault beneath the western Ivanpah Valley, the Ivanpah Fault (Hewitt, 1956; Burchfiel and Davis, 1971, 1981). The Proterozoic rocks are cut locally by Tertiary andesite and rhyolite dikes.

The alkaline rocks and carbonatite are restricted to an area extending from approximately 2 km northwest of the Mountain Pass Mine to approximately 5 km southeast of the deposit (Fig. 6). This belt of alkaline rocks appears to be truncated to both the north and south by northwest-striking high-angle faults (Olson and others, 1954). The alkaline igneous rocks at Mountain Pass include shonkinite, syenite, and alkali granite. These rocks form hundreds of thin dikes and seven larger intrusive bodies. The largest intrusive bodies are oval-shaped in map view and range from 200 to 1,800 meters in the longest dimension (Olson and others, 1954). The largest of the intrusive outcrops lies north of the Mountain Pass Mine. Carbonatite, considerably less widespread than the alkaline rocks forms about 200 small dikes and one large intrusive body intruding both Early Proterozoic gneiss and the Middle Proterozoic shonkinite, syenite, and granite. The single largest carbonatite body, called the Sulphide Queen carbonatite, strikes approximately north-south and dips about 40° W (Barnum, 1989). Its principal map dimensions are approximately 700 by 200 meters.

The general intrusive sequence of rock types in the Mountain Pass area is, from oldest to youngest, (1) the main shonkinite bodies, (2) syenite, (3) quartz syenite, (4) alkali granite, (5) late shonkinite dikes, and (6) carbonatite

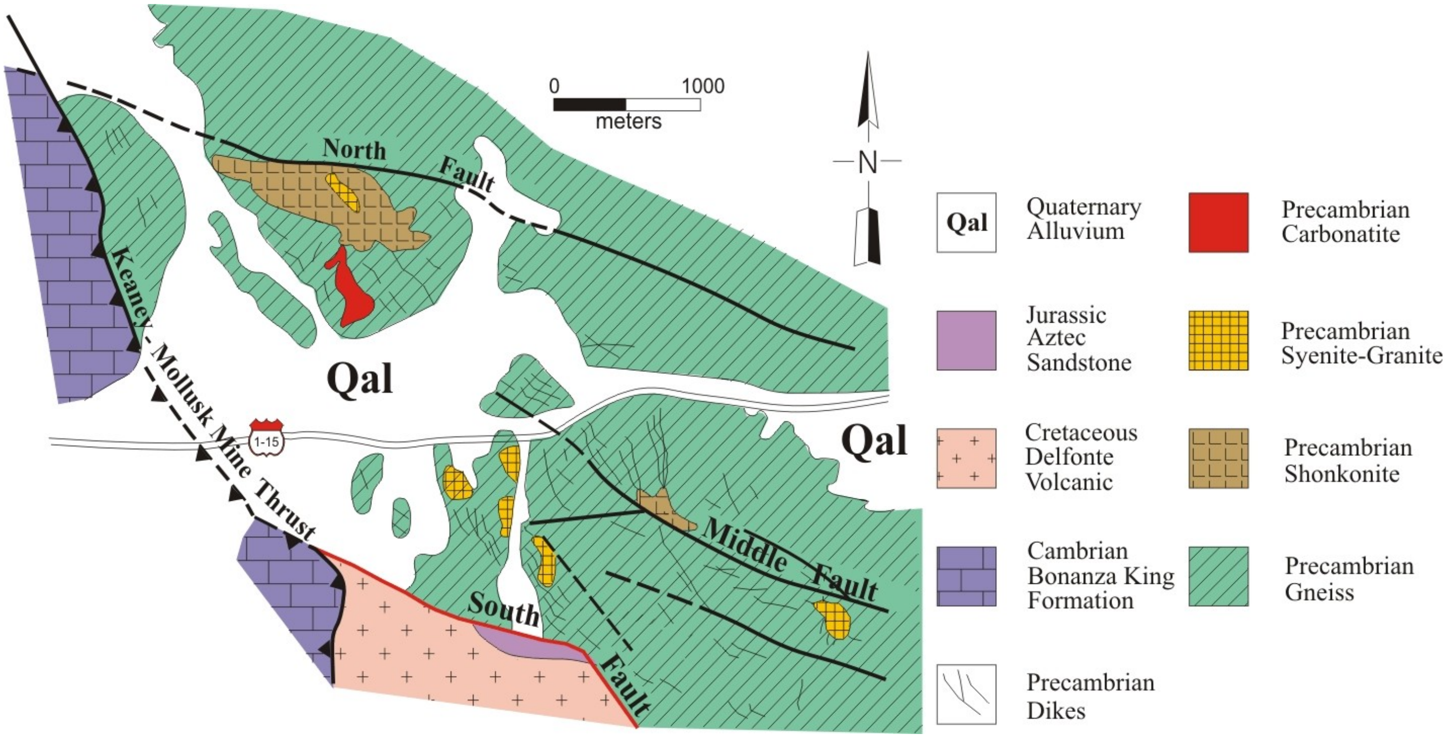

Figure 6. Simplified geologic map of the Mountain Pass carbonatite complex. Modified from Olson and others, 1954.

intrusions, including dikes and the Sulphide Queen body. DeWitt and others (1987) conducted a comprehensive U-Th-Pb and 40Ar/39Ar geochronologic study of the intrusive complex. The shonkenite yielded U-Pb ages of 1,410-1400 Ma; the syenite 1,403 Ma and the carbonatite 1,375 Ma. Collectively, these data indicate that the ultrapotassic rocks at Mountain Pass are approximately 1,410 to 1,400 Ma and that the related carbonatite probably was emplaced some 15 to 25 million years later (Haxel, 2007).

The following summary of the petrography of the carbonatite complex is taken from the seminal paper by Olson and others (1954). Shonkinite consists typically of greater than 50% biotite with subequal proportions of microcline, pyroxene, and sodic amphibole (Fig. 7A). Perthitic exsolution of albite is common within the microcline. Quartz is absent. The pyroxenes are augite and aegirine. With decreasing biotite content and increasing feldspar and pyroxene, shonkinite grades into syenite. Typical syenite contains approximately 65% to 75% alkali feldspar (microcline and /or orthoclase, commonly perthitic); less than 10% plagioclase; with the remainder aegirine, biotite and less commonly amphibole (Fig. 7B). Quartz syenite, gradational in character between syenite and granite, is petrographically similar to syenite but contains 5-10% quartz. The granites of the Mountain Pass often contain large and easily recognizable pink alkali-feldspar phenocrysts. The plagioclase is quite sodic (An6). Mafic minerals Include biotite, hornblende, and sodic amphibole.

The carbonatite body is comprised of three units (oldest to youngest): ferruginous dolomite carbonatite (beforsite) (Fig. 7C), barite-calcite carbonatite (sövite) (Fig. 7D), and silicified carbonatite. Barite-calcite carbonatite is the most abundant rock type within the Sulphide Queen body. Sövite consists of 40 to 75% calcite, 15 to 50% barite, and 5 to 15% bastnaesite (rare earth fluorocarbonate). The rock typically has a fine-grained groundmass surrounding barite phenocrysts 1 to 4 cm in diameter. The dolomite carbonatite is fine grained, consisting predominantly of dolomite and barite with accessory calcite, bastnaesite, magnetite, and pyrite. The silicified carbonatite is texturally similar to the barite-calcite carbonatite but has abundant quartz. The silicified carbonatite consists of bastnaesite, barite, and

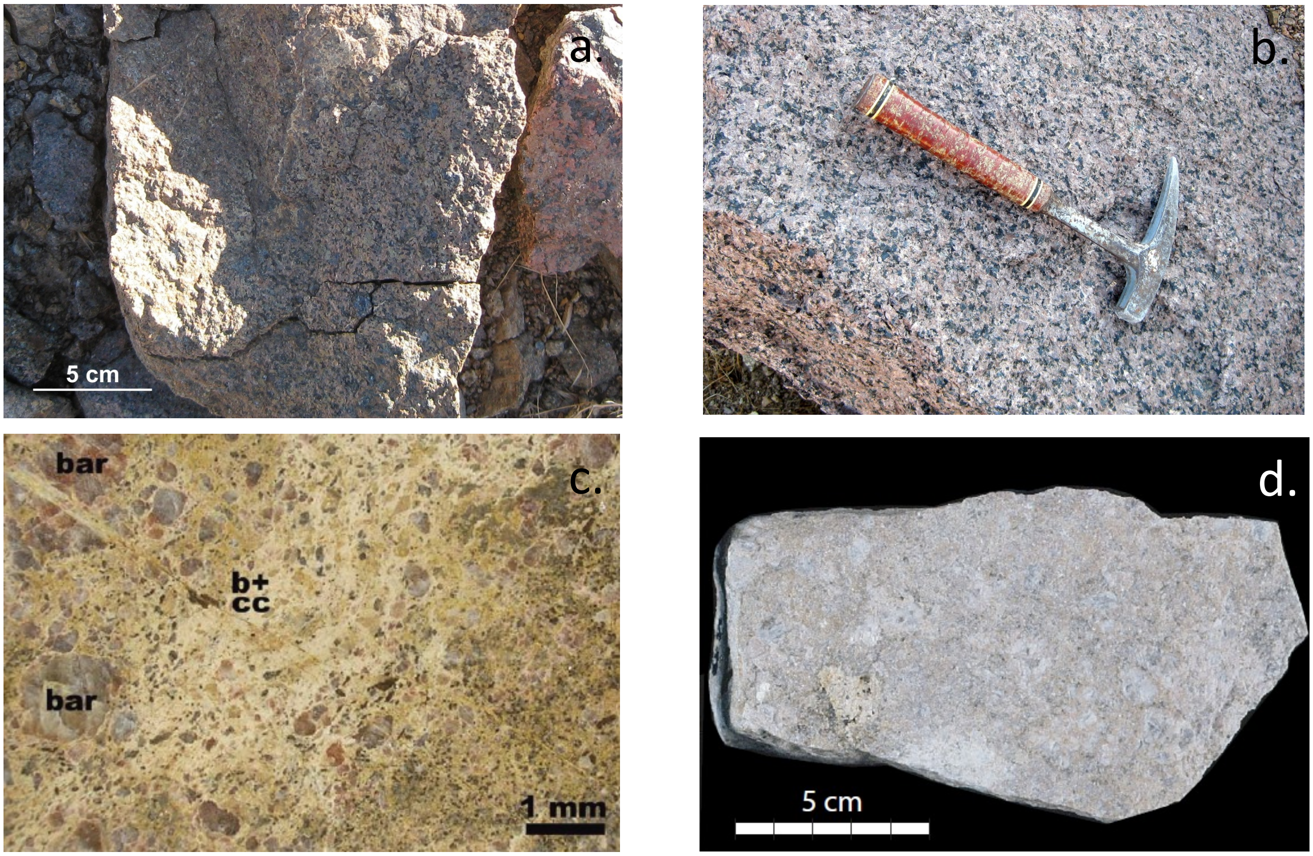

Fig. 7a. Biotite shonkenite from the Birthday Claim. 7b. Syenite from near Mineral Hill. 7c. Beforsite, (dolomite carbonatite) from the Sulphide Queen orebody (Long and others, 2010). Barite phenocrysts (bar), fine-grained bastnaesite mixed with calcite (b+cc) and brown to yellow mineral is dolomite. 7d. Sövite (calcite carbonatite) from the Sulphide Queen stock (Castor and Hedrick, 2006),. Abundant, tabular to irregular, light-gray to cream phenocrysts of barite surrounded by a medium-grained matrix composed of calcite, barite, and bastnaesite (Haxel, 2005).

quartz, with subordinate calcite, hematite and goethite. Bastnaesite content is as much as 60%.

Fenitization (alkali metasomatism) is widespread in and around the alkaline rocks and carbonatite bodies. Fenitization appears to have resulted in enrichment of host rocks in K_2O with lesser Na_2O and depletion of CaO. Alteration minerals include microcline, albite, biotite, riebeckite, aegirine, and chlorite. The net result has been to alter host rocks to a rock petrographically similar to a syenite.

New York Mountains

The eastern Mojave Desert region is underlain by Precambrian crystalline basement rocks that represented the western margin of the North American craton during the Early Proterozoic, 1600 to 2500 Ma. The region is dominated by an 1800 Ma sedimentary and volcanic rock complex that was intruded and metamorphosed at 1780 Ma, 1730 Ma and 1700 Ma, and intruded again from 1690 to 1650 Ma by granitic plutons along a north-south zone in the New York and McCullough Mountains (Miller and Wooden, 1994). During the Paleozoic, the eastern Mojave Desert became part of a geosynclinal trough into which large volumes of marine sediments were deposited. Subsequently, the region was uplifted and deformed by the Antler, Sonoma, Nevadan and Laramide orogenies from the late Paleozoic through the Mesozoic (Burchfiel and Davis, 1988).

The rare earth mineralization lies near the northern end of the New York Mountains, part of a 50 km long, NE-trending chain of mountain ranges that extend across the eastern Mojave Desert from California into southern Nevada. At the northern end of the range, it bends northwestward merging with the McCullough Mountains to the west.

The oldest rocks in the area are high-grade metamorphic rocks, mostly granite gneiss, schist and mylonite that are strongly foliated, with the foliation trending generally NNE and dipping 30-60° NW (Hogge and others, 2010). A 1680-1650 Ma biotite granite pluton intrudes the older metamorphic suite. The intrusive complex forms the crest of New York Mountains and consists largely of leucocratic granite together with smaller bodies of coarser-grained granodiorite (Fig. 8). These rock units are only locally foliated and rarely gneissic. The lower slopes of the New York Mountains and flanking alluvial-filled valleys are mantled by late-Cenozoic gravels and sands (Longwell and others, 1965). Miocene andesitic volcanic rocks occur at the southwest end of the Thor claim block (in California) and along the extreme east side of the study area. A Cretaceous-age (94 Ma) granitic stock underlies Crescent Peak. The Crescent Peak stock has produced alteration zones of silicification and sericite as well as breccias, including a west-elongate intrusion breccia (Archbold and Santos, 1962; Miller and Wooden, 1994)

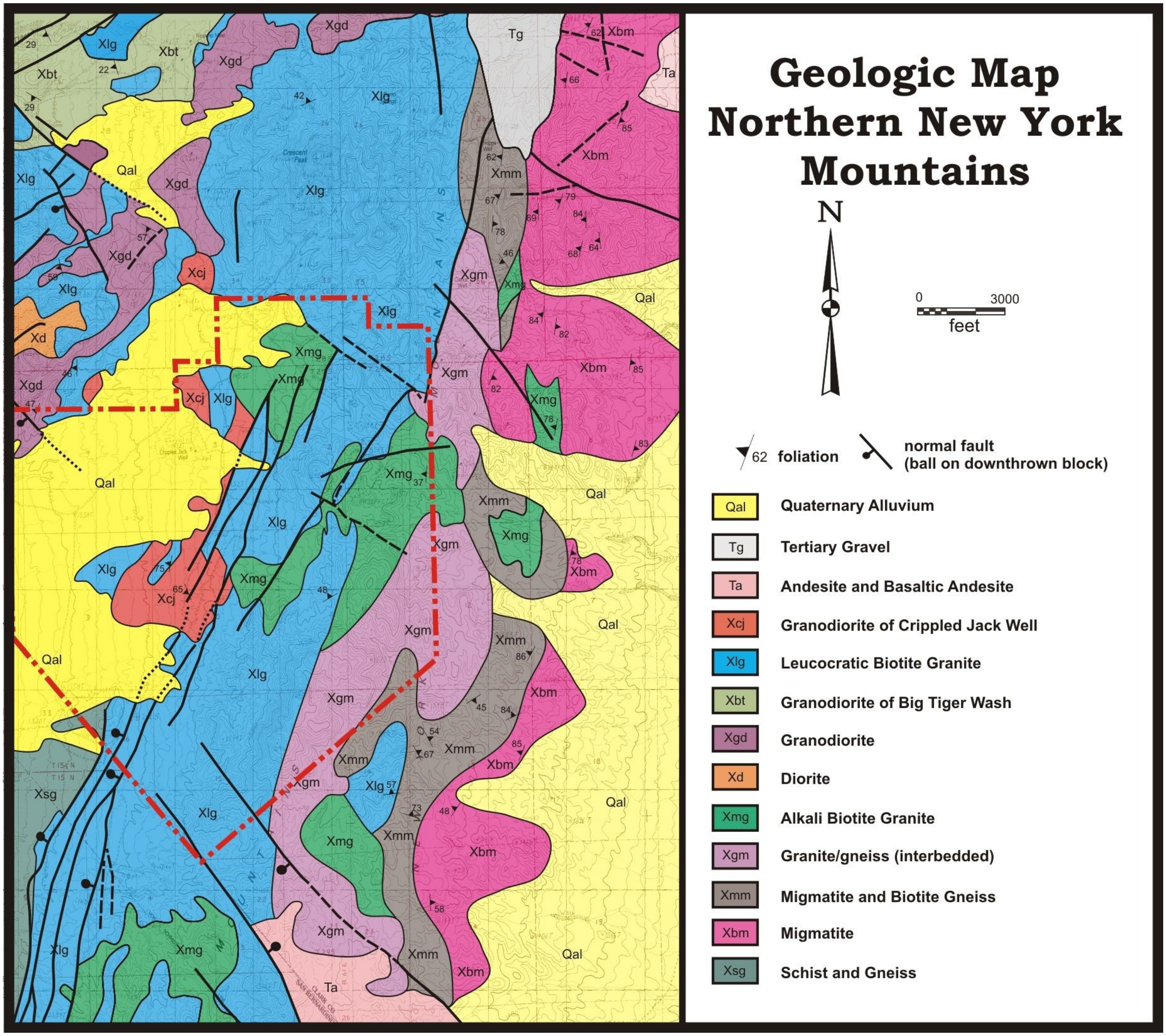

Figure 8. Geologic map of the northern New York Mountains, Modified from Miller and Wooden (1993)/ Dashed red line outlines the approximate area of the Elissa Resources Thor claim block.

Figure 9. Typical outcrop of leucocratic biotite granite from the north end of the Thor Property. It is comprised of subequal amounts of plagioclase, K-feldspar and quartz with lesser biotite.

RARE EARTH MINERALIZATION

No systematic study has been undertaken, and little appears in publication, regarding the rare earth mineralization of southern Clark County, Nevada. It is unclear when the rare earth mineralization was discovered, but Volborth (1962) credits R. Lopez, a local uranium prospector from the 1950's, in his discussion of the rare earth occurrence, Volborth states that the rare earth occurrence consists of a series of steeply-dipping pegmatite dikes up to one meter in width near Crescent Peak. The main rare earth mineral is allanite ($(Ce,Ca,Y,La)_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$), a rare earth-bearing variety of epidote, occurring as euhedral crystals 1-4 cm length. The allanite-rich parts of the dikes have a typical reddish-brown color. Allanite represents 5 to 15% of the dikes. Further to the south rare earth-bearing, fine-grained, brecciated dikes up to two meters wide, follow a fault zone for 4-6 kilometers. These dikes contain xenotime (YPO_4) and monazite ($(Ce,La)PO_4$) with minor allanite. Volborth notes the nearby rare earth deposit at Mountain Pass, California and characterizes the eastern Mojave Desert as a rare earth province.

Miller and others (1986) briefly mention the rare earth deposits of the New York Mountains stating that rare earth-bearing pegmatites are common within the Early Proterozoic gneissic terrane and that minor amounts of thorium and rare earths had been mined from them (Note: field observations cast doubt on their claim that any organized mining activity ever occurred.). They conclude that the allanite-bearing pegmatites are older, presumably Early Proterozoic, and unrelated to the Middle Proterozoic carbonatite system at Mountain Pass.

Hogge and others (2010), state that the Thor claim block consists of monazite-apatite ($Ca_5(PO_4)_3(F,Cl,OH)$)-xenotime veins hosted in Proterozoic-age granitic rocks associated with a fault/shear zone. The trend is at least 2.5 km long and up to 150 m wide. REE+Y assays as high as 10.6% combined REE were reported with some thorium (0.1% to 1.45%) but little uranium. They believe the rare earth zone extends the length of the trend, following a fault contact. It is comprised of altered granitic rocks and includes two different styles of mineralization: (a) veins, 0.5-3.0 meters wide, that occur in stringers and interstitial masses along strike of the trend; and (b) lenses or pods of biotite-rich quartz diorite that are associated with hematitic alteration. These elongate bodies parallel the foliation and possibly represent dikes, sills or xenoliths.

RESEARCH

Data Acquisition and Analysis

A number of techniques were utilized in this research. Thin sections were prepared by Quality Thin Sections of Tucson, Arizona. The sections were examined and photographed with a Nikon polarizing microscope equipped with a digital camera. Samples for x-ray fluorescence (XRF) analysis were prepared using techniques developed by Anderson (2005) and analyzed in the Geological Sciences Department at Cal Poly Pomona with a Philips (PANanalytical) x-ray fluorescence spectrophotometer (Appendix A). Data acquisition employed SuperQ software and whole rock and trace element subroutines created by Geosciences faculty. While XRF provides accurate results for major elements and most minor and trace elements it is deemed inferior to ICP-MS (Inductively coupled plasma mass spectrometry**)** for the analysis of rare earth elements. For this reason, high grade samples were collected from prospect pits by the geology staff at Elissa Resources and sent to ActLabs, Ontario, Canada for analysis (Appendix B). The results were made available for this research. Raw data from XRF and ICP-MS were entered into IgPet 2006 and Excel 2010 for scrutiny and visualization.

Samples were also prepared for x-ray diffraction (XRD) analysis. Since the purpose of the XRD study is to identify unknown mineral phases it was important to employ high purity samples. To insure this, a series of samples were collected from prospect pits and analyzed with XRF. The highest grade samples were then crushed and, where possible, obvious impurities (feldspar and mica) removed by handpicking. The remaining sample was reground to -60 microns and pressed into a sample holder. Analysis employed a Philips XRD utilizing X'Pert software. Unfortunately due to hardware constraints only the resultant diffraction patterns and mineral phase identifications were available for this thesis.

Host Rock Petrology

Elissa Resources staked the Thor Property on the possibility that an undiscovered carbonatite body similar to Mountain Pass might be present. Their field mapping, along with that of Dr. David Jessey, failed to identify any such body at the surface. However, the question remained as to whether the exposed rare earth veins are a manifestation of a buried, subcropping carbonatite body. To perhaps answer that question it is necessary to compare the intrusive suite at Mountain Pass to that of the New York Mountains.

Miller and Wooden (1993) mapped the northern New York Mountains and briefly discussed the rocks in a guidebook (Miller and Wooden, 1994). They characterized the intrusives as generally granitic to granodioritic in composition, but did not discuss either thin section petrology or geochemistry. This did not allow for a comparison to Mountain Pass. For that purpose, 18 samples were collected from unaltered rock outcrops and analyzed. Each sample was examined with a binocular microscope and rough estimates were made of the modal mineral percentages. However, as any two estimates from the same rock often varied significantly a more quantitative approach was deemed essential to eliminate human bias. Therefore, each rock was analyzed with XRF and the major element percentages determined. These were then converted into a CIPW normative analysis and plotted on a standard IUGS diagram. The CIPW norm is not the most desirable method of plotting phaneritic rocks, however comparisons to estimated modal mineralogy suggests it is reasonably accurate. Furthermore the determination of rock chemistry allows for comparisons that simply cannot be made solely on the basis of modal mineralogy.

Figures 10 a-c plot the Thor samples on diagrams commonly utilized to characterize suites of igneous rocks. Figure 10a, a plot of total alkalis verses silica indicates that the bulk of the Thor samples are subalkaline, a distinct con-

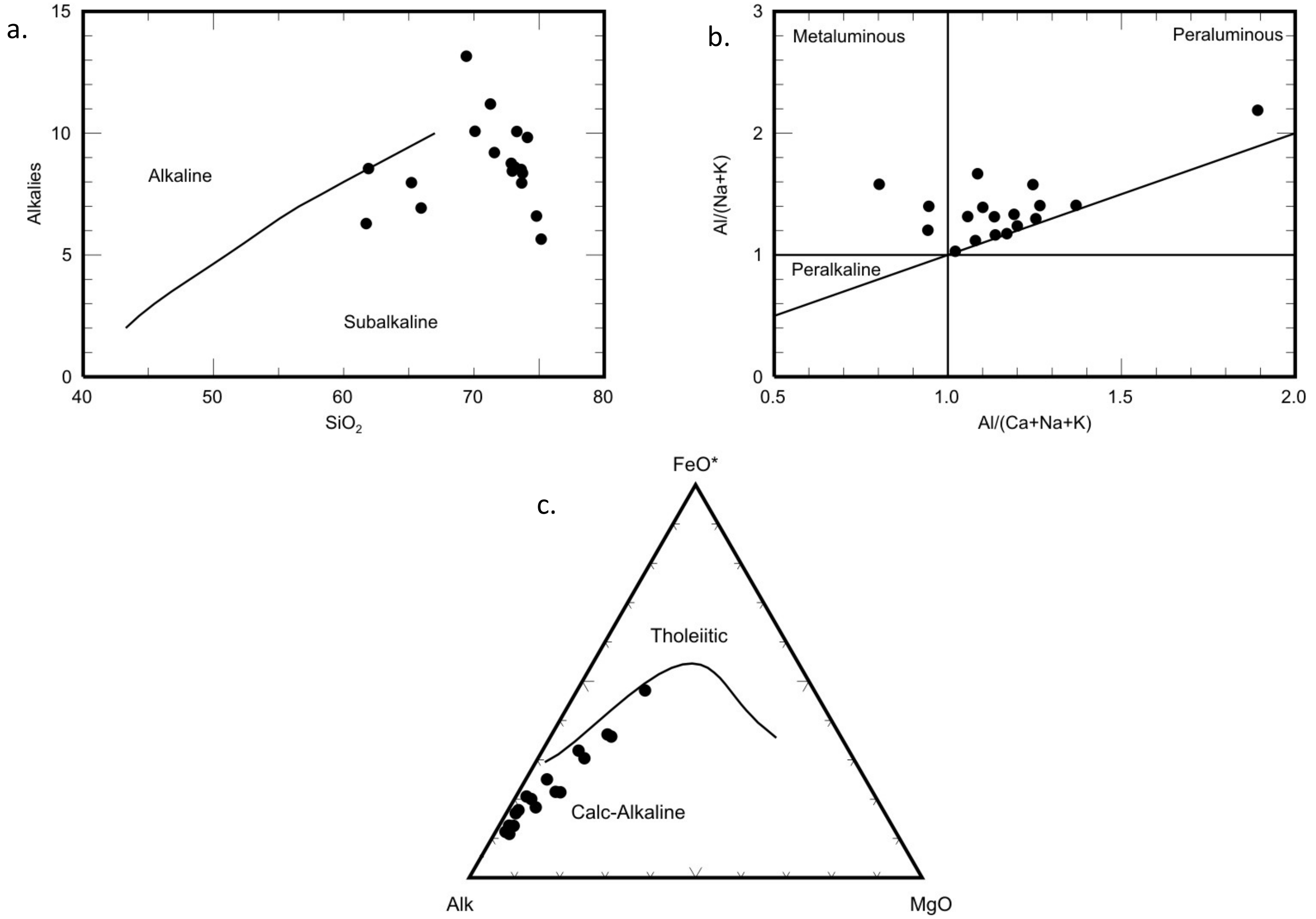

Figure 10a. Plot of total alkalis vs. silica (After Irvine and Baragar, 1971). 10b. Shand's alumina saturation index (After Shand, 1927). 10c. AFM diagram (After Irvine and Baragar, 1971).

trast to the alkaline suite that characterizes carbonatite complexes. Figure 10b and 10c, Shand's Silica Saturation Index and an AFM diagram respectively, reveal that the rocks are generally peraluminous, calc-alkaline granitoids. These are the typical S-type granites associated with continental arcs. While the tectonic setting of the Early Proterozoic of the east Mojave Desert is uncertain, Miller and others (2007) state that the consensus is the Early Proterozoic crust represents continental material that is either indigenous to the North American craton or that was accreted during the Ivanpah orogeny and that the granites of the east Mojave Desert were emplaced into this block of continental crust. This is consistent with the interpretation from Figure 10.

While Figure 10 provides a general framework for characterizing the plutonic suite of the New York Mountains, it is more definitive to undertake a direct

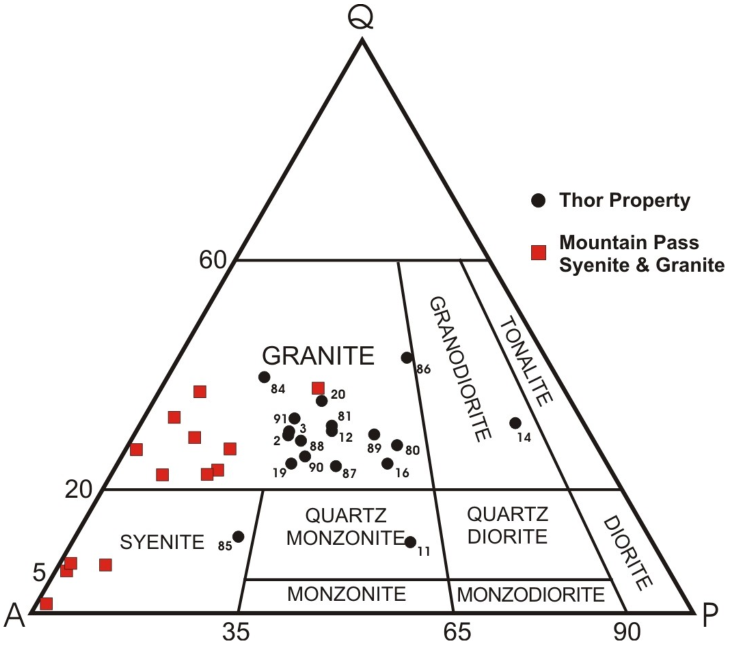

Figure 11, IUGS diagram for the Thor host rocks (black circles), and syenites and granites of Mountain Pass (red squares). Mountain Pass data from Haxel (2007).

Table 2. Comparison of Thor samples to an "Average Granite" (wt%).

	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
Ave. Thor	71.88	0.22	14.76	2.65	0.03	0.61	0.72	2.69	6.06	0.11
Ave. All Granites*	72.04	0.30	14.42	2.90	0.05	0.71	1.82	3.69	4.12	0.12

*** Average Granite from Blatt and Tracy, 1997.**

comparison with Mountain Pass. Figure 11 is an IUGS diagram for the Thor suite compared to the granites and syenites of Mountain Pass. As stated above, the Thor samples are plotted from normative mineralogy while those for Mountain Pass are the result of modal analyses (Haxel, 2007). Even allowing for the uncertainty of plotting normative minerals, it can be clearly seen that the Thor samples are generally much closer to typical granites than the distinctly more alkaline Mountain Pass samples.

Since there is some uncertainty in the normative IUGS plot, Table 2 was prepared showing the average concentrations (weight percent) for major elements of the Thor suite and those for the "average" granite of Blatt and Tracy (1977). The IUGS classification system requires that the An content of plagioclase be determined. If albite (An_{0-10}) is present it is combined with k-feldspar to determine the value for the *A* corner of the IUGS ternary diagram. This normally requires a thin section, thus presenting a problem with normative mineralogy based upon chemical analysis. However, if one assumes that most or all of the measured CaO and Na_2O are present within plagioclase, a reasonable assumption, then the ratio of concentration of CaO to Na_2O provides at least an approximation of An content. For the Thor suite this yields a value of An_{20-25} indicative of oligoclase. Hence, it would be appropriate to ignore albite when calculating the value for the *A* corner from normative mineralogy.

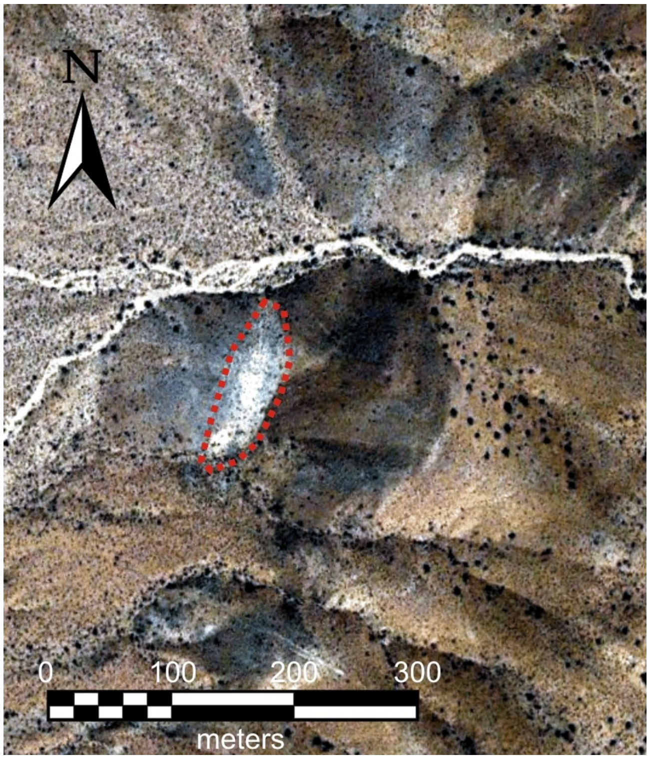

Figure 12. Google Earth image of pegmatite outcropping near the south end of the Thor claim block (shown by the red dashed line). Pegmatite strikes N10-20°E paralleling regional foliation.

A second interesting trend can be seen in Table 2 when comparing Thor granites to the "average" granite. While Thor samples are slightly enriched in alkalis ($Na_2O + K_2O$, shown in orange), they show a significant depletion in CaO (yellow) relative to the average granite. Thus, as stated above, although the Thor rocks do not show the marked alkalinity of a carbonatite suite, they are nonetheless somewhat more alkaline than the "average" crustal granite and perhaps should be characterized as "alkalic" granites. Since rare earth mineralization and alkaline magmatism are invariably related in time and space, it appears that the conclusion of Miller and others (2007) that the rare earth mineralization of the New York Mountains is cogenetic with host rocks and older than the carbonatite at Mountain Pass may be valid (See Discussion Section).

Volborth (1962) stated that the rare earth mineralization generally occurred within a series of pegmatite bodies or dikes. Miller and others (2007) concurred and added that the pegmatite dikes and pods were subparallel to regional foliation of the host rocks. However, neither publication speculated as to the mineralogy of the pegmatites. This is perhaps because pegmatites exposed in prospect pits have been altered to the

Figure 13. Outcrop of the unaltered albitite dike shown on the Google Earth satellite image (Fig. 12).

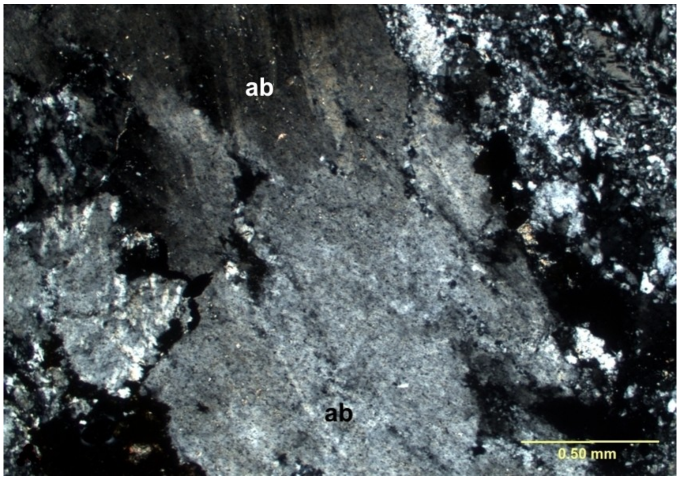

Figure 14. Thin section photomicrograph of albitite dike. Albite grains (ab) are slightly to moderately altered to the Na-clay (beidellite).

consistency of a coarse sand by subsequent rare earth mineralizing fluids, and perhaps weathering, such as to make the original petrography of the pegmatites difficult to determine.

In 2009 geologists from Elissa Resources discovered a large pegmatite dike near the south end of the Thor claim block, clearly visible on satellite imagery (Fig. 12). Believing this to be a potential exploration target it was extensively sampled on outcrop. The rare earth assays were modest, but ICP-MS indicated the dike contained over 20% Na_2O (Klohn, pers. comm., 2010). This was highly unusual in that no common silicate minerals contain greater than 12% Na_2O. Since ICP is less accurate for the lighter elements, Jessey and Baltzer (2010) resampled the pegmatite and analyzed it with XRF. They reported 20.44% Na_2O confirming the ICP analysis.

The author examined this pegmatite during field work in 2011. Unlike other pegmatites, it was found to be largely unaltered by rare earth-bearing fluids (Fig. 13) and therefore a good candidate for petrographic study. A sample was crushed and examined with XRD. It reported nearly pure albite. Thin section analysis confirmed the XRD data and gave an An content of $An_{5\text{-}8}$ (Fig. 14). However, this did not explain Na_2O assays in excess of 20%, as albite can contain no more than 12% Na_2O. Re-examining the thin section revealed that much of the albite was altered. XRD analysis had suggested that the Na-clay beidellite ($Na_{0.5}Al_2(Si_{3.5}Al_{0.5})O_{10}(OH)_2 \bullet n(H_2O)$) might be present in small amounts. This may account for the remaining Na_2O in the samples. No other mineral phases were detected in greater than trace amounts in the samples. This leads to the conclusion that unaltered pegmatite dikes are comprised almost entirely of albite and are best termed albitite dikes. A search of the available literature revealed that the association of albitite dikes with anomalous concentrations of rare earth elements is not uncommon. The best known example is on the island of Sardinia (Palomba, 2004), but other occurrences have been reported in Kurdistan (Mohammad and others, 2007) and China (Fei and others, 2005).

Alteration

Fenitization was first described from the carbonatite intrusion at Fen in southern Norway. It is a distinct form of alkali metasomatism in which surrounding rocks show intense chemical alteration, marked by the appearance of new sodium and potassium minerals replacing the primary ones (Heinrich, 1966). It was soon recognized that fenitization was a common feature of not only carbonatite complexes, but many other rare earth occurrences. It was also ap-

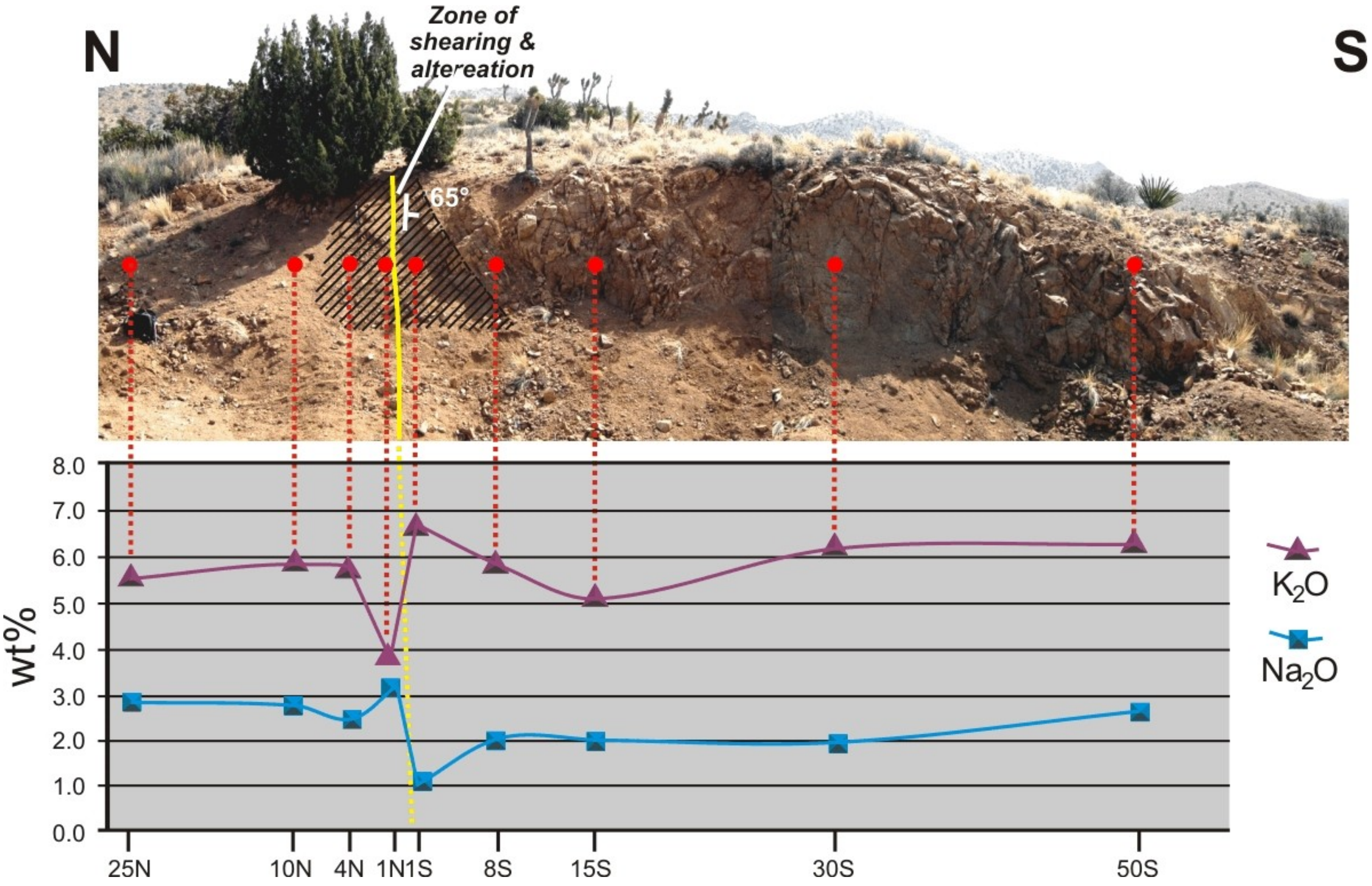

Figure 15. North-south panoramic view of a highly mineralized rare earth prospect pit. The yellow line marks the approximate trace of a N75°W striking fault that dips 65° SW. The red dots are the approximate location of samples collected north and south of the fault, with the purple triangles the K_2O content and the blue squares that for Na_2O.

parent that although fenitization at Fen involved the addition of both K_2O and Na_2O to host rocks, this is not always the case. Some rare earth occurrences are characterized almost exclusively by K metasomatism while others are restricted to Na metasomatism. At Mountain Pass, for instance, Haxel (2007) found that two granite samples had very high K_2O:Na_2O ratios of 37 and 45 and that these fenitized granites were moderately enriched in K_2O and depleted in Na_2O relative to unfenitized granites.

To examine the alteration at the Thor property a series of samples were collected from a pit containing high grade rare earth mineralization (Fig. 15). The pit follows the general strike of foliation and that of the rare earth-bearing pegmatite/dike zone. It is cut by a fault striking N75°W (shown in yellow on Figure 15) that appears to control emplacement of rare earth mineralization. South of the fault the granite is only weakly altered and rare earth concentrations not significantly above background. North of the fault the rock is thoroughly altered with combined rare earth's exceeding 10%. A series on nine samples were collected along pit strike, both north and south of the fault. The sample number designation indicates approximate distance from the fault (e.g., 8S was collected eight feet south of the fault). North of the fault Na_2O increases from 1.5-2.0% to approximately 3%. In contrast, altered rock north of the fault experiences decreases in K_2O content from an average of 6.5% to about 5%. To put this in perspective, Na_2O nearly doubles north of the fault while K_2O content decreases by about 25%. This suggests that Thor alteration is characterized by Na metasomatism and depletion of K_2O, a complete contrast to the metasomatism at Mountain Pass. This alteration trend is in general agreement with Na enrichment and K depletion observed for the very similar rare earth occurrence on Sardinia (Palomba, 2004).

There is an important consideration that will be discussed in more detail in the following section. That is the relationship of the NW-striking fault to mineralization. Specifically, is the fault pre, syn or post rare earth emplacement? If the fault is post mineralization, then the observed major element trends may be merely a reflection of the juxtaposing of two different rock types. Field evidence, particularly creation of the albitite dikes, suggests this is unlikely and that the fault is most like pre-syn mineralization (see Rare Earth Mineralization discussion below).

Rare Earth Mineralization

Bastnaesite (Ce,La,Y,CO_3F), a rare earth fluorocarboante, is the principle ore mineral in the Mountain Pass carbonatite (Castor and Hedrick, 2006). Monazite is known to be present and apatite may also be present (Warhol, 1980). Molycorp has not released details of ore grade, but the carbonatite is thought to contain about 10% bastnaesite (Olsen and others, 1954). Monazite is likely present only as an accessory and apatite no more than a trace. It is doubtful either was recovered in any quantity during ore processing.

Rare earth mineralization of southern Clark County has never been studied in detail. Volborth (1962) states that allanite and xenotime, a yttrium phosphate, are present and that there also might be small amounts of monazite. Miller and others (2007) mention both allanite and monazite. Elissa Resources collected a series of samples from prospect pits, many assaying in excess of 10% combined REEs (Appendix B). This piqued their interest in identifying the rare earth mineral species. This research sought to answer that question.

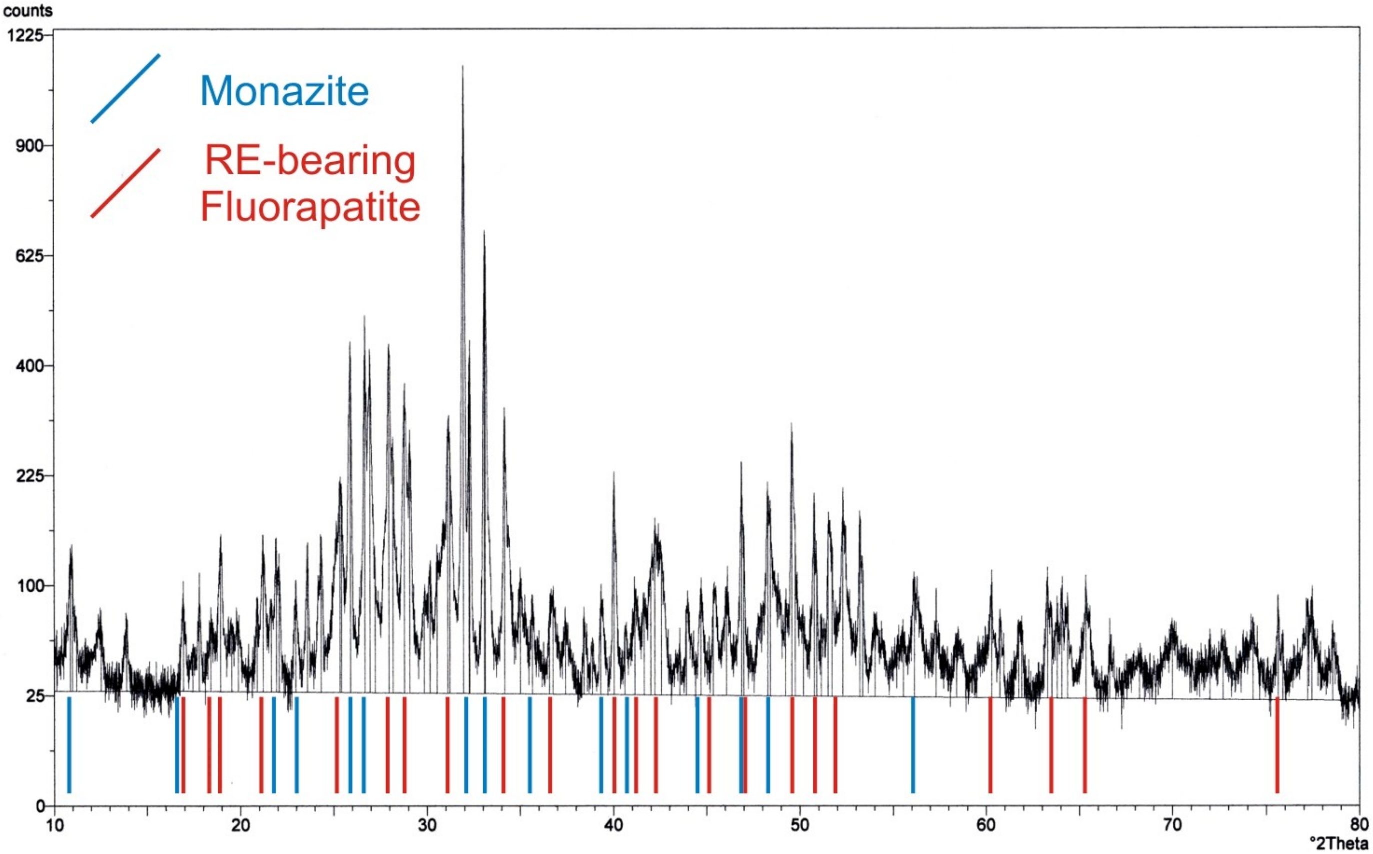

Figure 16. X-ray diffraction scan of a sample collected from the high grade zone of rare earth mineralization in the New York Mountains. Fluorapatite peaks are indexed in red and those for monazite in blue. Peaks that have not been indexed belong either to these two minerals or plagioclase feldspar.

The first step was to analyze a high grade sample with XRF utilizing SemiQ software. As the name implies the analysis is only semiquantitative, but it is designed to look at all of the elements of the periodic table and report those that are present in detectable amounts. Table 3 presents the results of that analysis. (Note that quantitative XRF and ICP-MS are far more accurate for the REEs and that REEs reported in Table 3 are not necessarily the only ones present in the sample.)

Table 3. SemiQ XRF analysis of a high grade sample from the Thor Property (wt%).

Al_2O_3	CaO	FeO*	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2			
6.71	21.64	2.45	0.61	1.13	0.16	2.41	25.24	15.27	0.19			
Cl	F	Ba	Ce	La	Nd	Gd	Sr	Sc	Y	Zr	Sm	Ru
0.04	4.64	0.01	3.01	1.78	13.01	0.20	0.03	0.01	0.77	0.67	0.01	0.01

The high concentrations of REEs, CaO, P_2O_5 and F stand out, suggesting one or more phosphate minerals. The Na_2O, K_2O, Al_2O_3 and SiO_2 are present in amounts indicative of the presence of feldspar and/or clay.

The high grade sample was then analyzed with a Philips x-ray diffractometer running X'Pert Analysis software. Figure 16 shows the results of that x-ray scan. The software identified rare earth-bearing fluorapatite ($(Ca_{5-x}REE_x(PO_4)_3F$) and monazite ($(Ce, La, Pr, Nd, Th, Y)PO_4$) as the two dominant mineral species. The indexed fluorapitite peaks are shown in blue and those for monazite in red. The remaining non-indexed peaks are most likely secondary and tertiary peaks for these two minerals. However, the software also suggested a low probability for the presence of plagioclase feldspar.

The sample was also examined petrographically. Both fluorapatite and monazite were readily recognizable (Fig. 17). They occur as small, 0.2-0.3 mm grains in 1-3 cm wide veins cutting the highly altered host rock. Visual estimates suggest veins are comprised of about 65% fluorapatite and 35% monazite. The veins are pervasive and interconnected forming a stockwork. Interestingly, the fluorapatite grains, in particular, often appear flattened or elongated suggesting foliation. Neither xenotime nor bastnaesite, the dominant rare earth mineral at Mountain Pass, were present. One hand simple contained a few dark green grains which may have been allanite, but its presence could not be confirmed by XRD or thin section observation.

The dark material, in thin section, that hosts the rare earth veins was so highly altered and murky that it was impossible to identify with confidence. In places where light passed through there appeared to be remnants of zoning

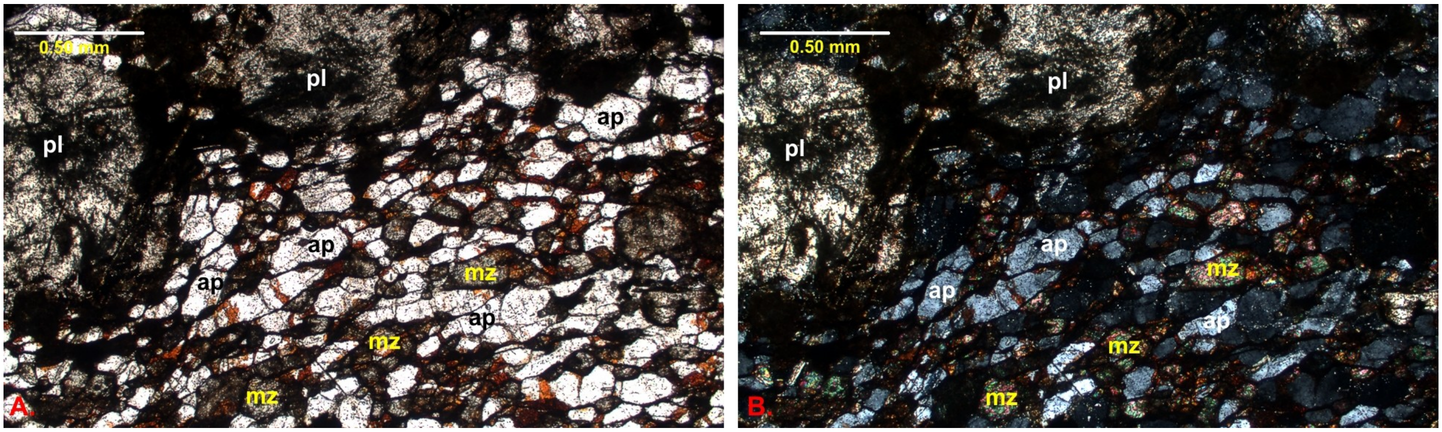

Figure 17. Thin section photomicrographs of high grade rare earth sample; plane polarized light on the left and crossed nicols on the right. Ap = fluorapatite; mz = monazite and pl = heavily altered plagioclase.

typical of plagioclase. This coupled with the XRD suggestion of the presence of plagioclase and the results of the XRF analysis leads to the tentative conclusion that the host rock is largely altered plagioclase (i.e., albitite).

One important question remains unresolved, the relationship of the rare earth veins to the host rock. Miller and others (2007) suggest the rare earth veins and the pegmatites/dikes are cogenetic. Volborth (1962) seems to imply the same relationship. The pegmatites follow the strike of mapped faults and also that of regional metamorphic foliation (N10-30°E). However, field observations indicate that not all of the pegmatites have been mineralized. For instance, the large pegmatite body near the south end of the property contains only trace quantities of rare earths. Those areas hosting high grade mineralization are often characterized by faults that intersect the pegmatite zone at nearly a right angle (N65-80°W), or zones of intense shearing and brecciation. This leads to speculation that rare earth mineralization could have involved a two-step process. The first step was the introduction of pegmatites or dikes, comprised largely of albite (Na metasomatism), along NE-striking faults or perhaps even metamorphic foliation. This was followed in time and space by rare earth-bearing fluids that utilized the NW-striking faults as conduits. When the fluids came into contact with rock that was more easily replaced, i.e. the albitite dikes, deposition of rare earths transpired. The quartz-rich granitic plutons, in contrast, resisted replacement and hence contain only small quantities of REEs. The question of when these two events may have occurred will be taken up in the Discussion section to follow.

Discussion

Four objectives were outlined in the Introduction:

1. Examine host rock lithology and alteration.
2. Identify the rare earth-bearing mineral species.
3. Compare the Clark County occurrences to the “better known” Mountain Pass deposit.
4. Create a genetic model relating the two districts.

For the sake of Discussion objectives 1-3 will be considered together. Objective 4 will be considered separately.

Both the Mountain Pass ore body and rare earth veins of southern Clark County occur within Early Proterozoic gneissic rocks, termed Fenner Gneiss (1800-1600 Ma). However, the similarity stops there. While Mountain Pass lies within this Early Proterozoic block, the actual ore deposit is a carbonatite that is part of suite of alkaline intrusions that began around 1410 Ma and culminated with intrusion of the carbonatite at 1375 Ma (Haxel, 2007). The suite varies in composition from alkali granite to syenite and shonkenite (biotite + k-feldspar ± Na pyroxene) as well as the carbonatite. The alkalinity of the complex is well depicted on a standard QAP ternary (Fig. 11).

In contrast, the rare earth occurrences of southern Clark County lie within granitoidal rocks intruded between 1800 and 1650 Ma (Miller and Wooden, 1994). Those rocks outline an area in Figure 11 near the center of the diagram suggesting a more silica-rich parent magma. Various petrographic indices depicted in Figure 10 support this conclusion and suggest the host rocks are typical S-type granites often associated with continental arcs. The only hint of alkalinity comes from a comparison of bulk rock chemistry (Table 2). It can be seen that Thor granites are depleted in CaO and slightly enriched in alkalis (Na_2O + K_2O) relative to the “average” crustal granite leading the author to suggest alkalic granite for the Thor suite.

In general, Mountain Pass host rocks are markedly different from those of the Thor property. There is no carbonatite at Thor and the intrusives are at best only slightly alkaline, while at Mountain Pass they are strongly alkaline. It should be noted that the Thor granites are also thought to be at least 250 million years older. However, as will be discussed below, the age of the Thor granites may not be representative of either the age of the actual pegmatite hosts or of the rare earth mineralization itself. Thus, the apparent age difference between Mountain Pass and Thor must be considered in that light.

Fenitization (alkali metasomatism) is associated with all types of significant rare earth mineralization. At Mountain Pass, Haxel (2007) concluded fenitization results in the addition of potassium (K) and the depletion of sodium (Na). This is verified by field observation. Mountain Pass fenites are generally comprised of >75% k-feldspar with lesser biotite, aegirine/augite, barite and minor quartz and plagioclase. At the Thor property in southern Clark County alkali metasomatism had the opposite effect, resulting in the addition of sodium and the depletion of potassium (Fig. 15). The result was the formation of dikes and pegmatite bodies comprised almost entirely of albite (albitites).

There is also a significant difference in the general character of the altering fluid. Heinrich’s (1966) study of carbonatites demonstrated that fenitization and the formation of a carbonate magma were interrelated. Fenitization occurs when silicate magmas become critically undersaturated. This undersaturation results in an immiscible liquid segregation, yielding an alkaline silicate magma which forms the fenite and a carbonate magma generating the carbonatite intrusive. Therefore, both the fenitization and the carbonatite are of true igneous origin, representing separate distinct phases of the intrusive complex. In other words, one creates the other.

However, the Thor rare earth mineralization has many of the characteristics of hydrothermal vein deposits, requiring an important aqueous component. The nature of the pegmatite host is uncertain. Most geologists see pegmatites as something of a hybrid, being neither true hydrothermal veins nor igneous intrusives. However exotic minerals, such as those hosting the rare earths almost certainly require an aqueous component for transport and deposition.

Ignoring geochronology and assuming Mountain Pass and Thor alteration are of the same age, is it possible that the fluids could have had a common origin? The differences in chemistry, K-rich for Mountain Pass and Na-rich for Thor; as well as origin, magmatic for Mountain Pass and aqueous for Thor are difficult to rationalize by a single model. The only common feature is the general alkali metasomatism itself, but studies have shown that alkali metasomatism is a common feature of rare earth deposits formed under a diverse set of circumstances.

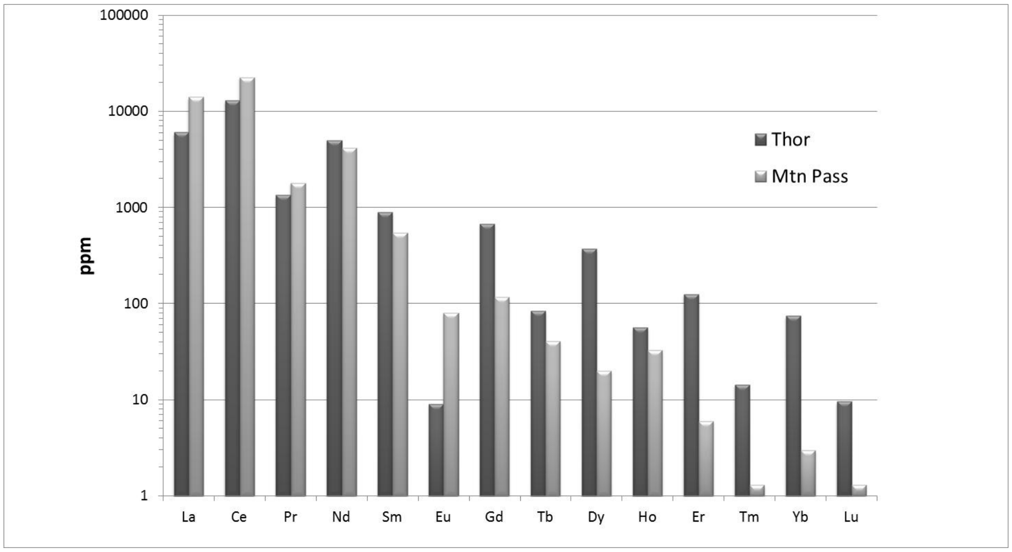

Figure 18. Average rare earth concentrations (ppm) for high grade samples from the Thor and Mountain Pass rare earth deposits. Thor analyses from ActLabs, Ontario, Canada. Mountain Pass data from Haxel (2007).

The mineralogy of Mountain Pass and the southern Nevada rare earth occurrences is quite different. At Mountain Pass, bastnaesite, a fluorocarbonate, is the chief ore mineral. Monazite and perhaps apatite are present but only in minor to trace amounts. Barite, celestite, ankerite and siderite are important gangue minerals. The rare earth minerals in southern Clark County are dominantly phosphates, fluorapatite and monazite (Figs. 16, 17). Minor allanite, a silicate, has also been reported. Bastnaesite is not present. The only gangue minerals are iron oxides and minor thorianite.

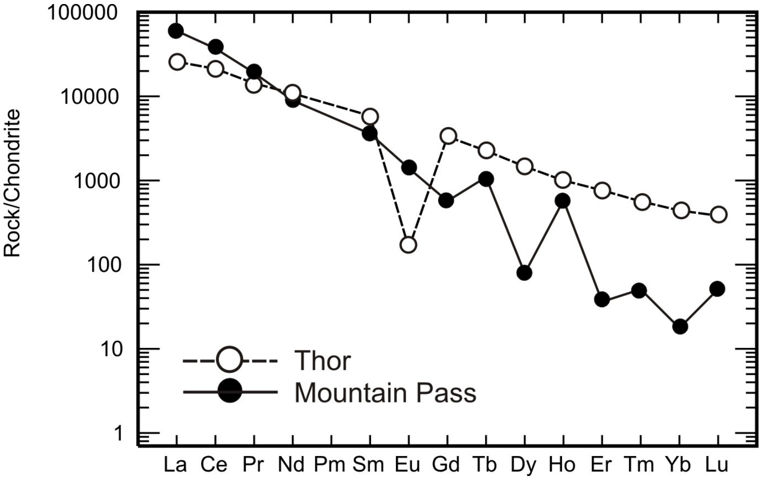

Figure 19. Chondrite normalized rare earth diagram for Thor and Mountain Pass. Cl chondrite standard from Sun and McDonough, 1989.

One aspect of the mineralization has not been previously discussed, the rare earth element geochemistry. Elissa Resources has extensively sampled and analyzed the mineralized zone. Their analyses utilized ICP-MS providing highly accurate and detailed results for rare earths. Those analyses were made available to this author (Appendix B). Similar analyses are available for Mountain Pass (Haxel, 2007). Figures 18 and 19 compare the two districts.

Figure 18 is a simple Excel graph comparing the reported average concentrations of REEs. In general, Mountain Pass shows a noticeable enrichment in the light REEs (La, Ce, Pr, Eu) while the Thor property is enriched in the heavy REEs (Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu). Since the abundance of REEs varies as a consequence of odd verses even atomic number (Oddo-Harkins Effect), geochemists have taken to standardizing analyses in the form of a Spider Diagram. Figure 19 is a chondrite normalized rare earth diagram for Mountain Pass and Thor. The light verses heavy trend of Figure 18 is obvious, but this diagram also reveals a prominent europium anomaly for the Thor samples.

The Thor negative europium (Eu) anomaly requires a little explanation. Europium is the only REE that can occur in the +2 valence state, the others are +3 and rarely +4. As such, Eu readily substitutes for Sr^{+2} and Ca^{+2} in plagioclase. When a plagioclase-bearing source rock is melted to produce magma and the plagioclase does not melt, remaining as a residual solid phase, the resultant magma will be Eu depleted. This manifests itself as a negative Eu anomaly on the chondrite normalized rare earth diagram. This has been taken as an indicator of plagioclase in the parent rock that yielded the ore fluid(s). Under pressure, plagioclase converts to spinel at depths of 20-30 kilometers. Hence, if the rare earth deposit displays a negative Eu anomaly the ore fluid must have been generated from the crust (less than 30 kms). In contrast, an ore body, such as Mountain Pass, which does not display a Eu anomaly has probably originated from a mantle-derived source. This was one of the most powerful arguments for a mantle origin for carbonatite magmas. While the origin of the Thor and Mountain Pass rare earth mineralization is open to conjecture, clearly the presence of an Eu anomaly at Thor and its absence at Mountain Pass, as well as the differing enrichments in light vs. heavy REEs does not argue for a common genesis.

Taken together, the differences in parent rock, alteration, mineralogy and rare earth geochemistry make a compelling argument for the lack of any close genetic relationship between the two occurrences. The only similarity is age of the basement rock and the close geographic proximity. Ignoring the geochronologic disparity, the best that can be said is that Thor represents some sort of a distal relative of Mountain Pass and that perhaps the relationship is a function of their location within the hypothesized “southern Nevada rare earth province” of Volborth (1962).

Objective 4 is the creation of a genetic model linking Mountain Pass and the rare earth mineralization of southern Clark County. Since the preponderance of evidence suggests, at best, a peripheral relationship between the two deposits, this discussion will center solely on the genesis of the southern Nevada rare earth occurrences.

Miller and Wooden (1986) state that the New York Mountains rare earth mineralization is only slightly younger than the host intrusives (1650 Ma). They do not, however, present any compelling evidence to support their statement. If the pegmatites have been emplaced along the northeast striking faults that cut the intrusives this implies they are younger than the granites, but not that they are slightly younger. However, it is also possible that the rare earth bodies were emplaced as a consequence of fluid migration (hydration/dehydration) during metamorphism accompanying the Ivanpah orogeny. As the metamorphic grade decreases to the west-northwest away from the core of the New York Mountains this would account for the strike of the pegmatite zone. It would also require that the mineralization be Early Proterozoic in age. Again evidence is meager to support this hypothesis, but the observed flattening of many fluorapatite grains could be a function of a metamorphic overprint during the Ivanpah orogeny.

To determine the validity of the model it may be useful to examine other districts that have similarities to the New York Mountains. The best known in the United States is the Lehmi Pass District of southern Idaho. Thorianite and rare earths have been emplaced in quartz-feldspar veins within the Proterozoic Belt Series. The host rocks are metasediments. The veins themselves are thought to be Cretaceous to Tertiary in age and related to intrusion of the Idaho Batholith (Austin and others, 1970). Obviously there are significant differences between Lehmi Pass and the New York Mountains, but the former is clearly a case of the rare mineralization being not only younger, but much younger than the host rock.

A better analog to the New York Mountains are the rare earth albitite pegmatites of Sardinia (Palomba, 2004). The albitite bodies occur within Hercynian (300 Ma) granites. Age dates and fluid models have revealed that the mineralization was introduced by hydrothermal fluids at 271 Ma. The tectonic setting for mineralization is thought to have been the Hercynian (Variscan) orogeny that formed the supercontinent of Pangea by collision of Laurasia and Gondwanaland. Although Sardinian rare earth mineralization is slightly younger than the host granites, the Proterozoic New York model is not substantially different.

Finally, comparison can be made to a famous mining district in California, the Mother Lode. There are no known anomalous concentration of rare earths, but Landefeld and Snow (1990) describe a series of albitite dikes along the Melones fault zone. These dikes are related to the "famous" quartz vein that hosts the gold mineralization. Emplacement of the albitites and the gold is thought to be a function of plate convergence and intrusion of the Sierra Nevada batholith. Fluids migrated away from the batholithic core to areas of brecciation and increased permeability like the Melones fault with deposition of the quartz, feldspar and gold. Age of the gold mineralization is uncertain, but almost certainly overlaps that of the Sierra Nevada batholith.

All of these districts have in common the relationship of mineralization to igneous intrusion, although in Sardinia there was a 30 Ma gap. Two of the three are related to plate convergence, the third Basin and Range extension. The Early Proterozoic tectonic setting of the east Mojave is only poorly understood. Miller and others (2007) argue that the basement is comprised of continental sediments metamorphosed by the intrusion of arc granites suggesting a convergent plate boundary. Bennett and DePaolo (1987) prefer a transform plate boundary with over 400 kilometers of sinistral slip.

If the former interpretation is correct, then the Early Proterozoic tectonic setting of the New York Mountains may have been favorable for rare earth mineralization. Intrusion of the granites at 1800-1650 Ma with subsequent normal faulting in a back arc setting would lead to pegmatite formation (≅ 1650 Ma) followed by hydrothermal rare earth mineralization when intrusive activity waned. If Sardinia is a viable analog, the fault conduits and the pegmatites could be younger than the intrusives. Could they be as much as 200 Ma younger and related to Mountain Pass? It seems unlikely that faults could serve as active fluid conduits for such a long period of time.

A model that relates rare earth mineralization to Early Proterozoic tectonics presents one vexing problem. As Guilbert and Park (2007) so elegantly point out, most hydrothermal veins are emplaced at depths of only a few kilometers. This is because permeability and porosity decrease with depth limiting the circulation of aqueous fluids. In contrast, carbonatite magmas are generated in the mantle and although some reach the surface, e.g, Ol Doinyo Lengai in Tanzania, they can theoretically crystallize anywhere within the crust. Keeping in mind that Mountain Pass and the Thor property are only 30 kilometers apart and situated within the same block of basement what are the odds that erosion would expose both at outcrop level? Furthermore, what is the likelihood that erosion since the Early Proterozoic would have removed less than the few kilometers of rock necessary to eliminate the hydrothermal rare earth veins? If the rare earth mineralization is actually significantly younger than the Proterozoic basement the erosion "problem" would disappear. Is this a possibility?

To answer this one needs look no further than the Sevier Fold and Thrust Belt, 25 kilometers to the west (Fig. 5). This belt formed as a consequence of Mesozoic plate convergence. In the eastern Mojave Desert, convergence was coincident with intrusion of the Jurassic-Cretaceous Ivanpah Granite. This would provide the necessary setting for hydrothermal rare earth mineralization. Indeed, the Mother Lode gold deposits are a product of the same convergent event, although they represent fore arc mineralization while the albitite dikes and rare earth mineralization would be a consequence of back arc spreading. Note from Figure 5 that the northeast striking faults and pegmatite zone parallel the trend of the Sevier Belt. Also, this model does not necessarily require that the rare earth mineralization be the same or nearly the same age as the pegmatites. The pegmatites could be Proterozoic with Mesozoic hydrothermal fluids circulating along NW-striking faults and selectively replacing the albitites. Perhaps the best way to test the two disparate models would be a simple age date of the rare earth mineralization. As monazite, as well as thorianite, are common constituents of the deposits this should be an easy task.

CONCLUSIONS

The goal of this research was to examine the rare earth mineralization of southern Clark County, Nevada and compare it to the nearby Mountain Pass rare earth deposit. The following are a brief summary of the conclusions:

- Rare earth mineralization lies within a block of Early Proterozoic (1800-1650 Ma) rocks of largely granitic composition. Geochemistry suggests the granites are typical of continental arcs.
- Alkali metasomatism in the form of Na_2O addition and K_2O depletion is closely associated with the rare earth mineralization. This metasomatism may have been responsible for the formation of numerous dikes and pegmatites comprised largely of albite (albitite) that host the highest grade rare earth mineralization. The dikes are localized along a northeast-striking zone that parallels mapped faults and regional foliation.
- Rare earth mineralization is comprised dominantly of rare earth-bearing apatite and monazite (phosphates) with minor allanite (silicate). High grade pods of REEs often are situated along northwest-striking faults/ fractures.
- Rare earth geochemistry reveals an occurrence that is enriched in HREEs and has a pronounced negative europium anomaly. The latter necessitates a crustal, hydrothermal source for the rare earth elements.
- Two differing models are proposed:
    - ⇒ The preferred model relates rare earth mineralization to the Proterozoic Ivanpah orogeny. The granitic rocks were intruded near the culmination of the orogeny (1650 Ma). A late stage, aqueous phase then migrated along faults to produce the pegmaties and subsequent pods of rare earth mineralization.
    - ⇒ A second possible model links the mineralization, and perhaps pegmatite and dike formation, to Mesozoic plate convergence and the intrusion of the Jurassic-Cretaceous Ivanpah Granite.
    - ⇒ Neither model suggests any close genetic link to the carbonatite body at Mountain Pass.

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Appendix A

XRF whole rock analyses of Thor host rocks (wt%)

Sample No.	SiO2	TiO2	Al2O3	FeO*	MnO	MgO	CaO	Na2O	K2O	P2O5
80	73.729	0.045	14.616	1.456	0.039	0.216	1.492	3.668	4.690	0.049
81	73.145	0.272	13.523	3.012	0.012	1.159	0.191	2.863	5.739	0.084
84	73.666	0.203	13.034	3.144	0.115	0.530	0.564	1.184	6.772	0.157
85	69.418	0.017	16.401	0.845	0.006	0.008	0.073	2.990	10.168	0.066
86	75.165	0.274	12.410	3.213	0.020	0.977	2.191	2.366	3.285	0.098
87	65.203	0.097	15.751	6.344	0.048	1.996	1.467	2.416	5.552	0.288
88	71.573	0.277	15.022	2.396	0.009	0.694	0.740	2.326	6.877	0.084
89	72.946	0.225	14.421	2.461	0.047	0.413	0.956	3.271	5.173	0.088
90	73.291	0.128	14.721	1.515	0.001	0.257	0.028	2.904	7.164	0.046
91	72.865	0.171	15.126	2.473	0.006	0.336	0.164	2.245	6.518	0.096
2	74.109	0.159	13.400	1.722	0.001	0.382	0.234	2.410	7.413	0.170
3	71.264	0.325	15.606	2.658	0.024	0.320	0.178	2.283	8.915	0.066
11	61.910	1.100	15.580	6.760	0.080	2.060	2.940	3.340	5.210	0.280
12	73.630	0.120	12.750	1.230	0.010	0.330	1.610	2.470	6.040	0.100
14	74.800	0.170	14.010	2.290	0.040	0.770	1.460	5.210	1.390	0.110
16	61.730	1.360	12.570	8.920	0.090	2.530	4.240	2.040	4.250	0.780
19	70.080	0.300	16.100	2.250	0.020	0.260	0.240	2.660	7.420	0.060
20	65.950	0.640	18.600	4.170	0.070	0.930	0.730	1.780	5.150	0.090
Ave Thor	71.875	0.224	14.763	2.652	0.032	0.614	0.718	2.692	6.058	0.106

Analyses preformed in the Geochemistry Laboratory at Cal Poly - Pomona using SuperQ and USGS standards.

APPENDIX B

ICP-MS REE analyses of hi-grade sample from the Thor Prospect

	La	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
R468	23500	48500	4940	18100	3010	22.8	2230	272.0	1060	142.0	275.0	27.0	121.0	13.7
BK20	7570	16800	1840	7180	1490	17.6	1220	172.0	841	138.0	324.0	37.2	194.0	24.3
BK17	7270	16200	1750	6830	1400	17.0	1160	158.0	753	120.0	287.0	32.8	169.0	21.6
BK01	8020	16700	1730	6340	1120	8.8	848	105.0	414	56.1	113.0	11.4	52.7	6.6
T4	7310	14800	1520	5160	769	6.0	471	48.3	187	25.6	50.7	5.2	24.2	3.0
T6	6740	14100	1460	5380	927	7.7	662	71.0	286	38.5	71.8	7.4	35.1	4.3
R458	6890	14000	1390	4910	712	5.7	453	43.5	163	21.9	42.3	4.3	20.8	2.6
R468	6130	12800	1330	4890	855	7.1	626	67.5	272	35.7	69.1	7.1	33.4	4.1
BK25	4310	10100	1090	4370	933	11.0	827	115.0	585	100.0	256.0	33.2	187.0	25.9
BK13	4290	9480	995	3600	615	7.8	411	44.5	179	26.1	56.3	6.4	34.4	4.7
R47	3840	8360	855	3050	434	4.4	271	25.7	97	14.1	31.4	3.9	22.3	3.2
BK22	3230	7330	805	3190	687	9.6	611	84.6	417	69.7	167.0	19.8	104.0	13.5
BK26	2970	6800	748	2970	627	8.9	542	73.3	367	62.2	152.0	19.4	110.0	15.1
BK24	2730	6300	691	2760	587	8.1	513	71.0	357	60.0	148.0	18.6	104.0	14.2
BK02	3380	6920	712	2720	442	4.6	327	36.3	149	21.3	44.6	4.5	21.6	2.7
BK08	2910	6170	630	2350	313	3.4	195	18.1	71	10.3	22.8	2.6	14.7	2.2
BK48	2770	5560	562	2120	342	4.2	257	29.8	129	19.0	39.7	4.4	21.6	2.7
Thor Ave,	6109	12995	1355	5054	897	9.1	683	84.4	372	56.5	126.5	14.4	74.7	9.7

Analyses preformed by ActLabs, Ontario, Canada.