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EXPLORATION OF BEACH-PLACER HEAVY MINERAL DEPOSITS IN THE SAN JUAN BASIN IN NEW MEXICO

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ABSTRACT

The San Juan Basin, New Mexico contains many heavy mineral beach-placer sandstone deposits of Cretaceous age. Beach-placer sandstone deposits are concentrations of heavy minerals that formed by mechanical concentrations (i.e. settling) of heavy minerals on beaches or in longshore bars in a marginal-marine environment. They have high concentrations of several elements, such as Ti, Zr, rare earth elements (REE), Sc, Y, U, Th, Nb, Ta and Fe. These elements are becoming increasingly more important to industry, because they are used in the manufacture of devices our society uses every day, i.e. cell phones, computers, and alternative energy devices, like solar panels. It is unlikely that any of the beach-placer sandstone deposits in the San Juan Basin will be mined in the near future because of small tonnage, low grades, high iron content, and distance to processing plants and markets. However, as the demand for some of these elements increases because of increased demand and short supplies, the dollar value per ton of ore rises, enhancing deposit economics. Current studies at the New Mexico Bureau of Geology and Mineral Resources are focused on the Apache Mesa (formerly Stinking Lake) deposit near Dulce, New Mexico.

INTRODUCTION

Beach-placer sandstone deposits are accumulations of heavy, resistant minerals (i.e. high specific gravity) that form on upper regions of beaches or in long-shore bars in a marginal-marine environment. They form by mechanical concentration (i.e. settling) of heavy minerals by the action of waves, currents, and winds (Fig. 1; Bryan et al., 2007). Modern examples are found along the Atlantic Coast, USA (Koch, 1986; Carpenter and Carpenter, 1991), southeastern Australia (Roy, 1999), and Andhra Pradesh, India (Rao et al., 2008), where they are mined for titanium, zircon, and monazite (a Ce-bearing rare earth, REE, mineral). Detrital heavy minerals comprise approximately 50-60% of these sandstones and typically consist of titanite, zircon, magnetite, ilmenite, monazite, apatite, rutile, xenotime, garnet, and allanite, among other minerals. Most of these minerals have a high specific gravity exceeding 4 and are dark colored, giving the sandstones a dark color, resulting in them being called black sandstones. Although beach-placer sandstone deposits are found in strata of all ages; the deposits in the San Juan Basin in New Mexico are restricted to Late Cretaceous rocks belonging to the Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones (Fig. 2; Table 1; Chenoweth, 1957; Houston and Murphy, 1970, 1977). The beach-placer sandstones are black, dark gray, to olive-brown, resistant to erosion, and radioactive due to radioactive zircon, monazite, apatite, and thorium minerals. Anomalously high concentrations of Ti, Fe, Nb, Th, U, Zr, Sc, Y, and REE are characteristic of these deposits. Similar Upper Cretaceous heavy mineral, beach-placer sandstone deposits are found throughout Montana, Wyoming, Utah, Arizona, and Colorado (Dow and Batty, 1961; Houston and Murphy, 1970, 1977; Zech et al., 1994).

Many of the elements potentially found in beach-placer sandstone deposits, especially Ti and REE (including Y and Sc), are increasingly becoming more important in our technological society and are used in many of our electronic devices, such as cell phones, computer monitors, televisions, wind turbines, etc. As the demand for some of these elements increases because of increased demand and short supplies, the dollar value per ton of ore rises, enhancing deposit economics. Detailed mapping and exploration drilling of these deposits are essential to fully evaluate the economic potential.

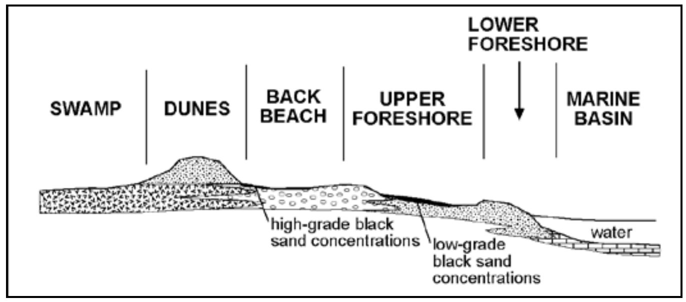

Figure 1. Idealized cross-section of formation of beach-placer sandstone deposits (Houston and Murphy, 1970, 1977).

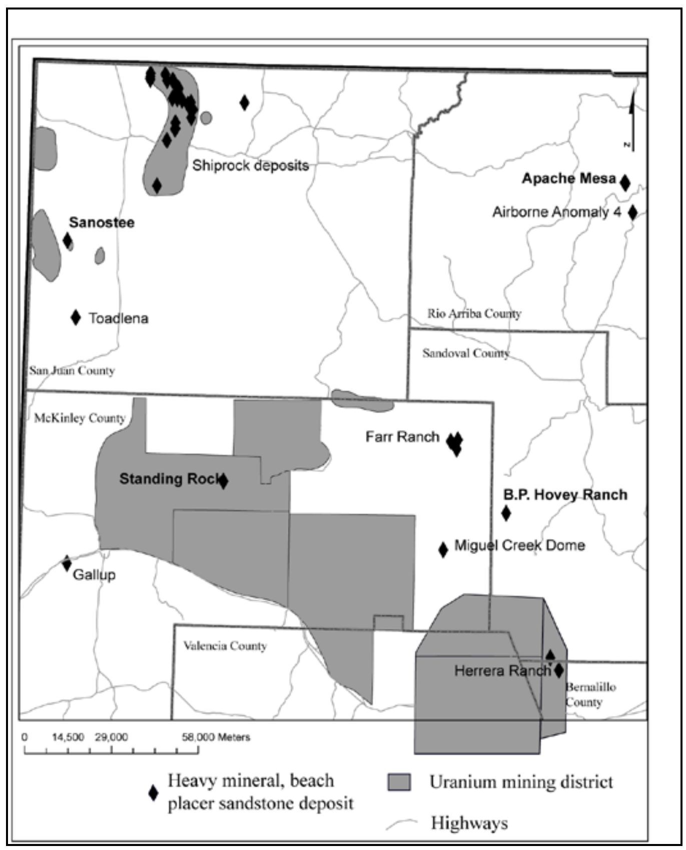

Figure 2. Location of Late Cretaceous heavy mineral, beach-placer sandstone deposits in the San Juan Basin, New Mexico. More detailed location of the Shiprock deposits are in McLemore (2010). Deposits are summarized in Table 1 (see APPENDIX). Deposits in bold are described in this report.

The purposes of this paper are to describe in detail four heavy mineral, beach-placer sandstone deposits in the San Juan Basin in New Mexico and summarize their economic potential. This report presents new, unpublished geochemical analyses of these four selected deposits (Table 2, see APPENDIX) and builds upon previous reports that have been written describing these deposits and their formation. Detailed mapping of selected deposits by Dow and Batty (1961), Bingler (1963, 1968), Zech et al. (1994), McLemore (2010), and others as cited, including the authors (field work in 2015) is presented to illustrate the regional trend of the deposits.

METHODS OF STUDY

Four sites were examined and sampled in detail in this report: Apache Mesa (formerly Stinking Lake deposit), Sanostee, Standing Rock, and B.P. Hovey Ranch (Fig. 2; Table 1). Exploration drilling occurred at Apache Mesa in August 2015; these results will be presented in more detail in a future report. Each site was mapped and two bags were collected at each location, 3-5 kg of fresh sample for chemical analysis and the other for hand sample and archive. Samples were sent to ALS Laboratory for whole rock chemical analyses by X-ray fluorescence (XRF) and Induced Plasma Spectroscopy (ICP).

Samples of beach-placer sandstones were investigated using a Cameca SX100 electron microprobe at New Mexico Institute of Mining and Technology to characterize compositional, chemical and textural characteristics. Samples chosen for microprobe analysis were selected based on elevated whole-rock concentrations of TiO_2, Zr, U, Th, and REE, and were prepared as 1 inch round mounts and polished to a mirror finish. Samples were then placed in 1 inch round sample mounting cups, set in epoxy, and cured overnight at around 80°C. Once cured, samples were polished using coarse diamond grinding wheels and diamond power suspended in distilled water for the fine polishing. Polished sample surfaces were then cleaned and carbon coated to a 200 angstrom thickness.

The initial observations of the samples were made using backscattered electron imaging (BSE), which allowed observation of sample textures, and location of high mean atomic number (Z) phases that may contain TiO_2, Zr, U, Th, and REE, and other high Z elements. BSE observations were coupled with acquisition of rapid X-ray maps and/or qualitative geochemical scans to help identify different mineral phases.

REGIONAL GEOLOGIC SETTING

During the Late Cretaceous, the present San Juan Basin was on the western edge of the Western Interior seaway (Robinson-Roberts and Kirschbaum, 1995; McLemore, 2010), which extended from the Gulf of Mexico to the Arctic Ocean. Complex fluvial systems transported sediments from the volcanic and metamorphic sources in the Mogollon Highlands to the south and west and possibly the Ancestral Rocky Mountains to the north into the basin. Recycling of sediments was also important. Cyclic transgressions and regressions of the marine seas resulted in a shift of the paleoshorelines (Fig. 3). Most of the heavy mineral, beach-placer deposits define local depositional trends of the beaches at the time of deposition. The shoreface sandstone deposits in the San Juan Basin were formed both during transgression and regression of the western edge of the Western Interior Seaway (Robinson-Roberts and Kirschbaum, 1995; Fassett, 2000) and are similar to modern deposits in Australia (Roy, 1999).

Three of the four deposits described in this report are found in the Point Lookout Sandstone, and the other deposit is in the Gallup Sandstone. Both of these sandstones are regressive marginal marine coastal barrier sandstones and separate the marine facies from nonmarine facies (Fig. 3; Zech, 1982; Devine, 1991). The facies transitions from marine to coastal going up stratigraphically. The Point Lookout Sandstone overlies and can intertongue with the Mancos Formation and is typically overlain by the Menefee Formation (Fig. 3; Hollenshead and Pritchard, 1961). Trough cross beds, evidence of longshore currents, and gently dipping parallel beds are characteristic of both the Point Lookout and Gallup Sandstones. The Gallup Sandstone formed in a similar regressive shallow marine (shoreface) environment (Campbell, 1971, 1979).

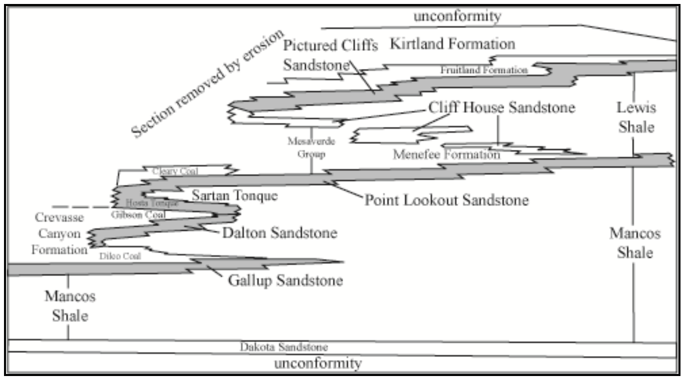

Figure 3. Stratigraphic framework and nomenclature of the Late Cretaceous sedimentary rocks in the San Juan Basin (simplified from Molenaar, 1989; Craigg et al., 1990; Fassett, 2000). Gray-shaded sandstone units are hosts of known beach-placer sandstone deposits in the San Juan Basin.

DESCRIPITONS OF SELECTED BEACH-PLACER SANDSTONE DEPOSITS

Apache Mesa (Stinking Lake), Rio Arriba County (NMRA0001, 2)

The Apache Mesa deposit (Airborne Anomalies 1-3, Stinking Lake) is in section 3, T28N, R1E and section 2, T27N, R1E, on the Jicarilla Apache Reservation in the eastern San Juan Basin (Fig. 1, 4, Table 1) and is in the Point Lookout Sandstone (Bingler, 1968). The original naming of these deposits as airborne anomalies followed by a number is as designated by the original airborne survey.

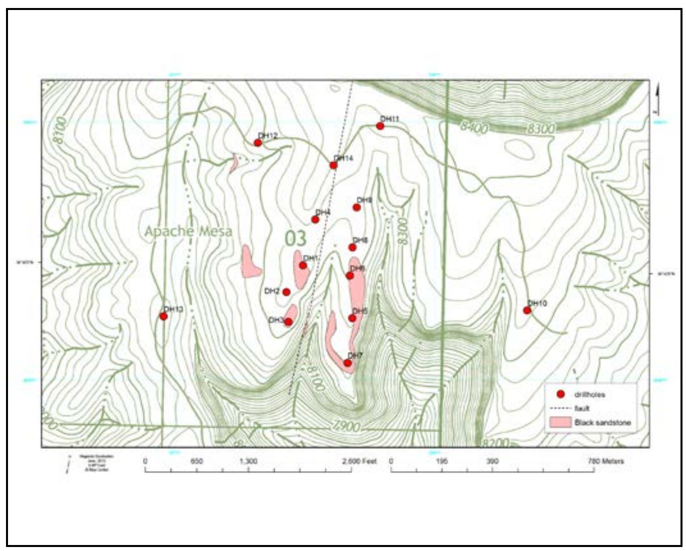

Figure 4. Extent of Apache Mesa beach-placer sandstone deposits and final drill hole map (Apache Mesa quadrangle, Rio Arriba County, New Mexico). The deposits were mapped by the authors in June-September 2015. Future reports will describe the drilling program in detail.

The Apache Mesa deposits are lenses (Fig. 4), approximately 0-2.4 m thick, and overlie light gray to olive gray, massive to planar cross-bedded, medium- to fine-grained sandstone (Fig. 5). The beach-placer sandstone is reddish-purple to olive-brown to grayish red to black red, moderately to well cemented, medium-grained, and contains iron oxide minerals, leucoxene, zircon, tourmaline, rutile, magnetite, monazite, chromite, ilmenite, and a grain of gold-silver (Bingler, 1968; this study). Locally, the beach-placer sandstone is planar bedded consisting of alternating layers of millimeter to centimeter thick, gray and red to dusky red sandstone.

Figure 5. Beach-placer sandstone at Apache Mesa.

Sanostee deposit, San Juan County (NMSJ0088)

The largest exposed beach-placer sandstone deposit in New Mexico is the Sanostee deposit, which lies along the top of a mesa northwest of Sanostee, New Mexico on the Navajo Indian Reservation (Fig. 1, 6, Table 1; Bingler, 1963; Force, 2000; McLemore, 2010). The Sanostee deposit is in an olive-green-gray to dark brown to black, medium- to fine-grained, well to moderately sorted, heavy mineral sandstone with rounded to subrounded grains and little to no cross bedding that overlies a white to buff, moderately-well cross bedded, medium-grained sandstone, with local rust staining within the Gallup Sandstone (Fig. 7). The deposit trends N30°W, dips 5-10°W, is approximately 2400 m long (Fig. 5), 152-183 m wide, 1-4 m thick, and is overlain by black to gray shale and gray siltstone and sandstone. The deposit occurs in two separate zones forming a resistant, cliff-forming ledge along the mesa (Fig. 4; Force, 2000; V.T. McLemore, field mapping, 2010, 2015). There are local mudcracks in the sandstone beds beneath the heavy mineral sandstone. The deposit contains ilmenite, magnetite, hematite-ilmenite, zircon, tourmaline, garnet, hematite, staurolite, apatite, barite, sphene, monazite, and rutile (Bingler, 1963; Force, 2000; Force et al., 2001; this report).

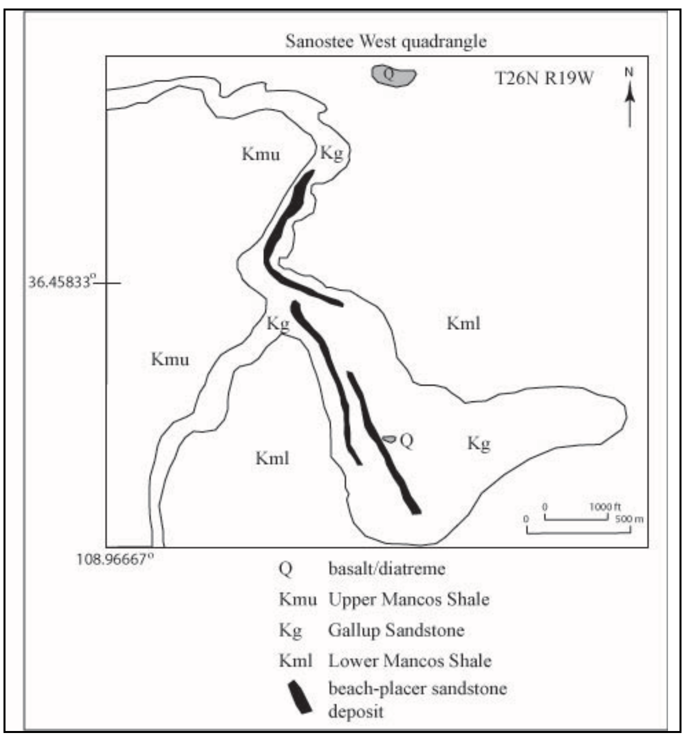

Figure 6. Geologic map of the Sanostee beach-placer sandstone deposits, in section 31, T26N, R19W. Mapping of the deposit was by V.T. McLemore in 2009, modified from Beaumont (1954), Dow and Batty (1961), Bingler (1963), and Force (2000).

Figure 7. Beach-placer sandstone at Sanostee.

Standing Rock (Flat Top Hill) deposit, McKinley County (NMMK0261)

The Standing Rock deposit (also known as Flat Top Hill), in section 35, T18N, R14W, is on the Navajo Indian Reservation (Fig. 1, 8, Table 1), is a dark orange-brown to yellow to red-brown, well-cemented, medium- to fine-grained, well to moderately sorted, sandstone lens with no cross bedding in the Point Lookout Sandstone (Fig. 9). It caps the mesa top of Flat Top Hill (Fig. 8; Chenoweth, 1957; Kirk and Sullivan, 1987) and overlies a tan to buff, cross bedded, medium-grained sandstone. The deposit is as much as 1.5 m thick, 30 m wide, and consists of at least two lenses striking N50°W for approximately 1,500 m. Calcite veining cuts the sandstone deposit locally. The deposit contains monazite, ilmenite, anatase, leucoxene, rutile, zircon, and magnetite. Mud cracks are found along the mesa, indicating subaerial exposure (Fig. 8). Resources are estimated as 635,000 metric tonnes of 4.2% TiO_2, 0.35% ZrO_2 and 0.06% ThO_2 (USBM files).

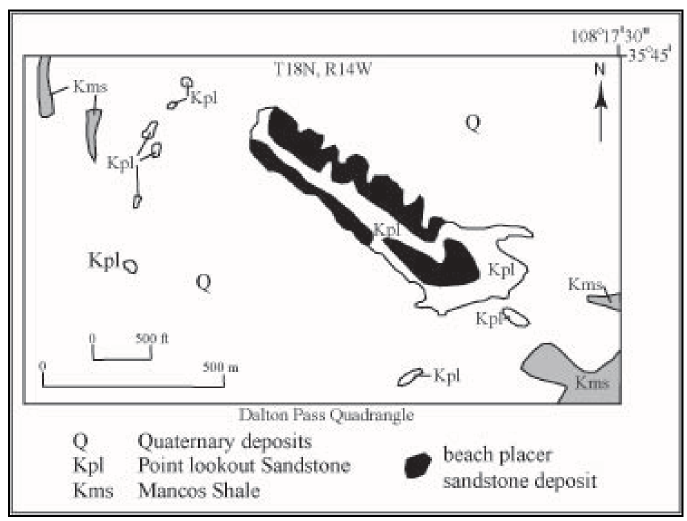

Figure 8. Geologic map of the Standing Rock beach-placer sandstone deposit in section 35, T18N, R14W. Mapping of the deposit was by V.T. McLemore in 2009, sedimentary geology modified from Kirk and Sullivan (1987).

Figure 9. Beach-placer sandstone at Standing Rock.

B.P. Hovey Ranch, Sandoval County (NMSA0028)

The P.B. Hovey Ranch deposit (also known as the Torreon Wash deposit) is in section 34, T17W, R4W (Fig. 1, 10, Table 1). The deposit is in brown- to olive-gray, medium grained, well to moderately sorted sandstone and is approximately 100 m long and 0.6-1.5 m thick (Fig. 11). There are two zones of beach-placer deposits at the B.P. Hovey Ranch locality (McLemore, 1983). Drilling suggests that this deposit continues to the northwest (Chenoweth, 1957).

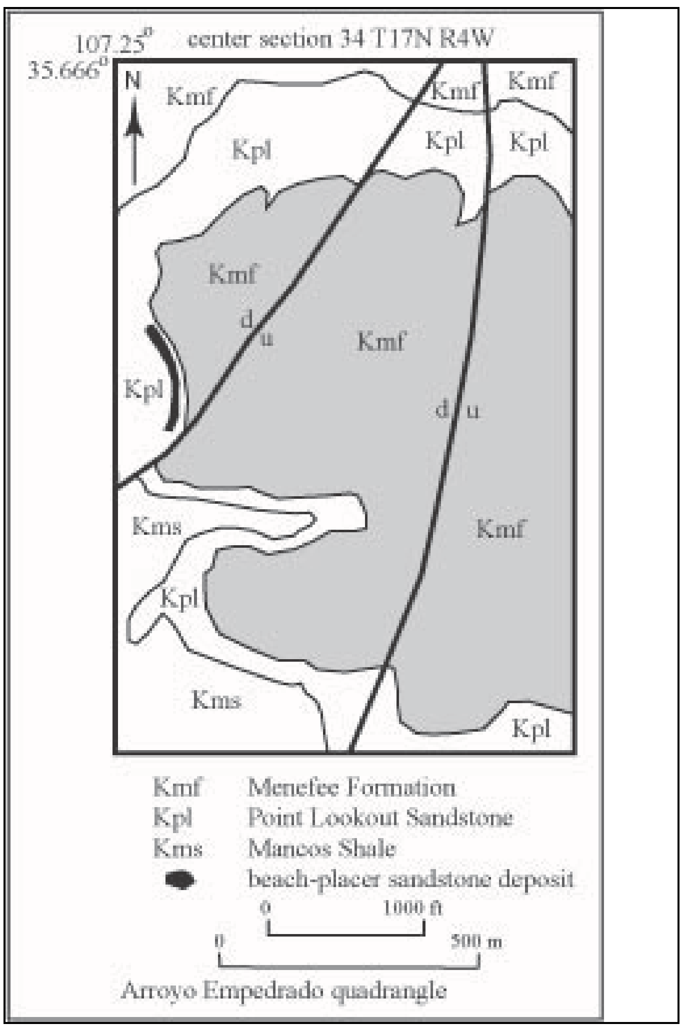

Figure 10. Geologic map of the B.P. Hovey beach-placer sandstone deposit. Mapping of the deposit was by V.T. McLemore in 1981 and 2015. Sedimentary geology is modified from Tabet and Frost (1979).

Figure 11. Beach-placer sandstone at B.P. Hovey.

ELECTRON MICROPROBE STUDIES

Electron microprobe results confirmed the presence of ilmenite, rutile, zircon, monazite, xenotime, garnet and illite in these beach-placer sandstone deposits (Fig. 12, 13). A few grains of chromite and one grain of gold with a silver rim are found in the Apache Mesa deposit. More electron microprobe work needs to be completed. Much of the ilmenite is either altered partially to hematite or is in solid solution series with hematite

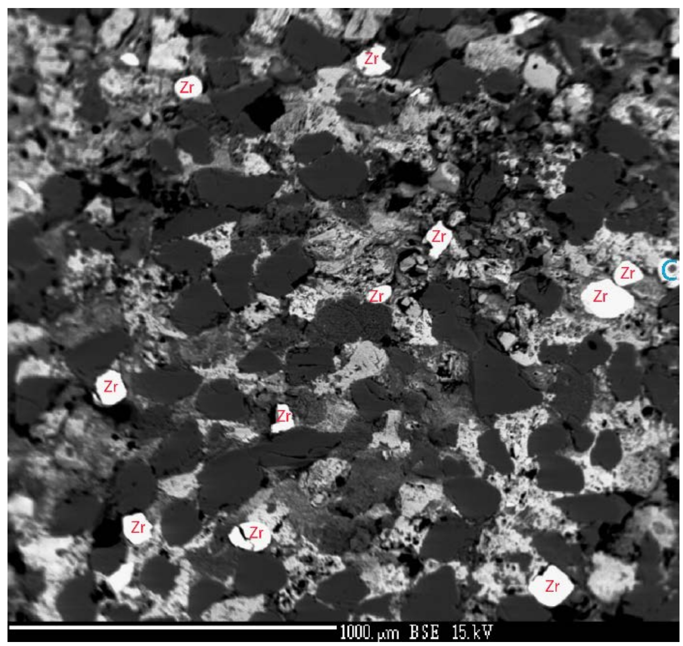

Figure 12. Electron microprobe picture of sample SL 16 (Apache Mesa). Zircon grains are labeled in red. Chromite is labeled in blue. Mottled, lighter colored cement are iron oxide (hematite). Dark grains are mainly quartz.

GEOCHEMISTRY

Selected chemical analyses of selected beach-placer sandstone deposits are in Table 2. Local high concentrations of Ti, Fe, Cr, Nb, Th, U, Zr, Sc, and REE are found in in these four deposits. The REE plots exhibit light-REE chondrite-normalized enriched patterns, typically with negative Eu anomalies (Fig. 14). TiO_2 and Zr show a strong correlation (Fig. 15) and U and Th show a strong correlation (Fig. 16), indicating these elements are found in similar minerals concentrated in the beach-placer sandstones.

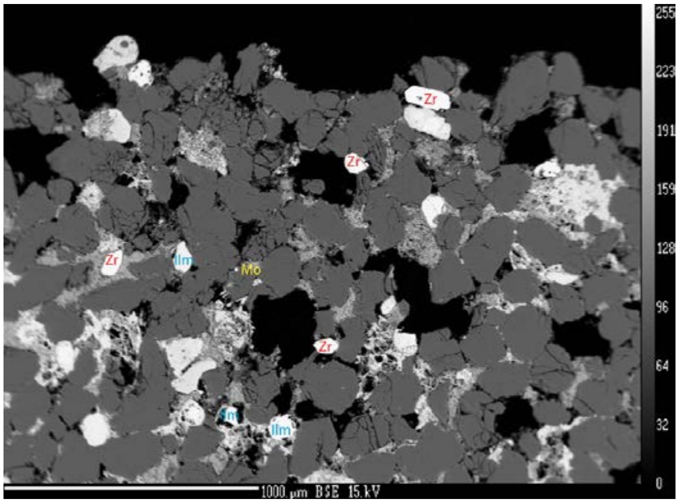

Figure 13. Electron microprobe photo showing distribution of zircon, ilmenite and monazite grains in sample SAN 6 (Sanostee). Zircon grains are labeled in red, ilmenite in blue, and monazite in yellow. Mottled, lighter colored cement is iron oxide (hematite). Dark grey grains are mainly quartz. Black areas are pore spaces.

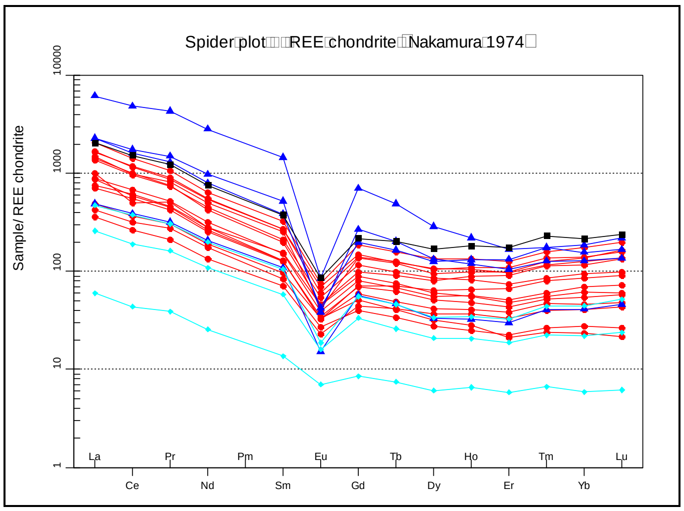

Figure 14. Chondrite-normalized REE plot of selected beach-placer deposits, Apache Mesa (red), Standing Rock (light blue), Sanostee (dark blue), and B.P. Hovey (black), San Juan Basin, New Mexico. Chemical analyses are in Table 2. Chondrite values are from Nakamura (1974).

MINERAL RESOURCE POTENTIAL

Many beach-placer sandstone deposits in the San Juan Basin contain local high concentrations of Ti, Zr, REE, U, Th, Nb, Ta, Fe, Sc, Y, and other elements (Table 2; McLemore, 2010). Additional deposits probably remain undiscovered in the San Juan Basin; at least three drill holes are suspected of having similar deposits (Chenoweth, 1957).

Titanium-bearing minerals (ilmenite, rutile, leucoxene, brookite) are the more important of the economic minerals in these beach-placer sandstone deposits; the major uses of titanium are in pigments (i.e. coatings and paints, plastics, cosmetics, textiles, glazes, etc.), metal alloys, and other applications. A titanium resource typically contains 1% or more ilmenite or rutile at recoverable grain size, typically in unconsolidated (i.e., easily mined) deposits (Force, 2000). Zirconium, REE, and Fe could be by-product minerals. Titanium is found in concentrations from 1% to 16% TiO_2 in these four deposits in the San Juan Basin (Table 2) and is found in ilmenite, titanomagnetite, titanohematite, rutile, anatase, and brookite. Much of the ilmenite is either altered partially to hematite or is in solid solution series with hematite**,** which complicates processing (Force et al., 2001). Force (2000) estimated the contained titanium resource of the Sanostee deposit as 700,000 metric tonnes of Ti ore.

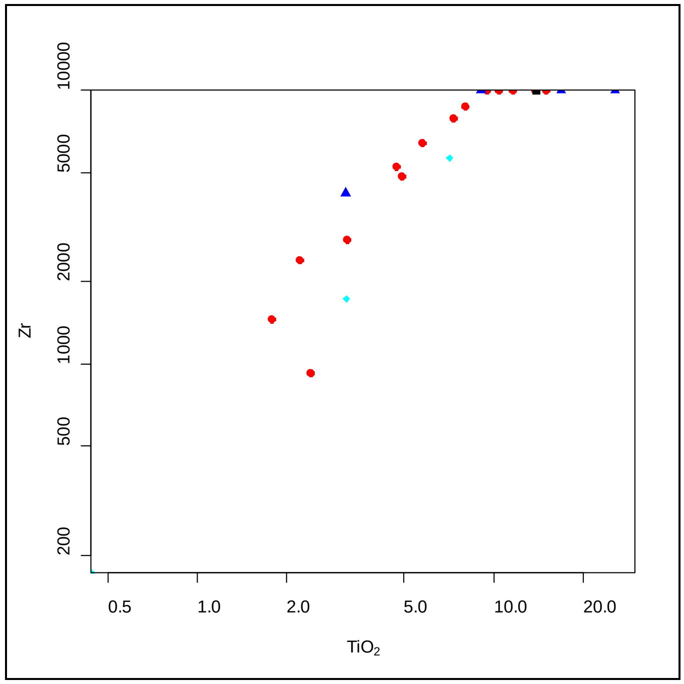

Figure 15. Zr-TiO_2 plot of selected beach-placer deposits, Apache Mesa (red), Standing Rock (light blue), Sanostee (dark blue), and B.P. Hovey (black), San Juan Basin, New Mexico. Chemical analyses are in Table 2.

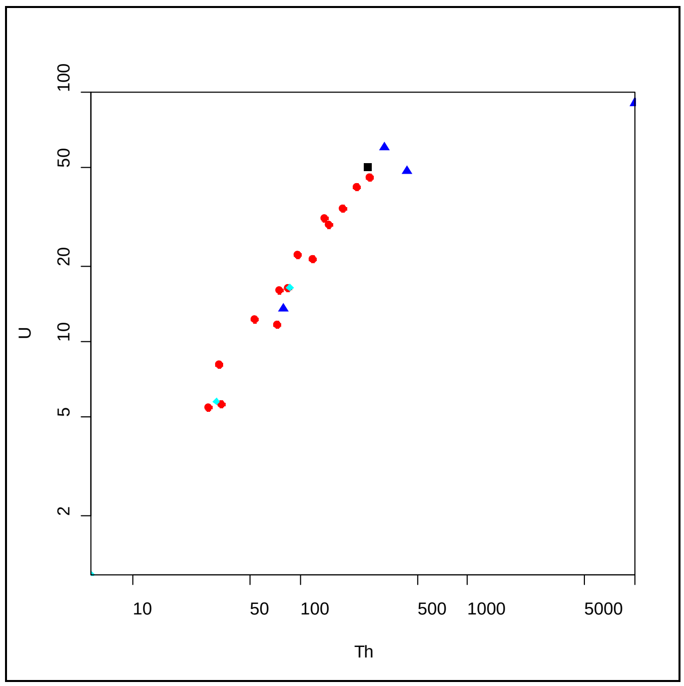

Figure 16. U-Th plot of selected beach-placer deposits, Apache Mesa (red), Standing Rock (light blue), Sanostee (dark blue), and B.P. Hovey (black), San Juan Basin, New Mexico. Chemical analyses are in Table 2.

Zirconium is another potentially important economic element and is mostly found in zircon and, locally ilmenite. Zirconium is used in abrasives, ceramics, refractories, foundry applications, welding rod coatings, nuclear fuel industry applications, and other applications. Most of the deposits in the San Juan Basin contain zircon (Table 2; McLemore, 2010), which could be recovered for some applications only as a by-product. Impurities in zircon include Th, U, REE, and hafnium.

Rare earth elements (REE) include the 15 lanthanide elements (atomic number 57-71), yttrium (Y, atomic number 39), and scandium (Sc). REE are lithophile elements (or elements enriched in the crust) that have similar physical and chemical properties, and, therefore, occur together in nature. REE (including Y and Sc) are increasingly becoming more important in our technological society and are used in many of our electronic devices. 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. However, the projected increase in demand for REE in China, India, the United States, and other countries could result in increased exploration and ultimate production from future deposits in the U.S. and elsewhere (McLemore, 2015). Furthermore, individual REE of high purity and mixtures of specific REE are becoming more economically important. Recently, the Chinese government announced that it is examining the economic feasibility of continuing to export REE from their deposits. Modern beach-placer sand deposits in Australia, India, South Africa, and the U.S. contain 0.1-2% monazite and some are mined for REE (Morteani, 1991).

In the San Juan Basin deposits, the REE are mostly found in monazite, although apatite, zircon, sphene, xenotime, allanite, and epidote also contain minor amounts of REE (McLemore, 2010, 2015). However, the grades and tonnages of the San Juan Basin deposits are currently too low for commercial deposits (Table 2), but the REE could be recovered as by-products, especially if the deposits contain higher concentrations of a specific HREE (McLemore, 2010, 2015).

CONCLUDING REMARKS

Although, local high concentrations of Ti, Zr, U, Th, and REE are found in some heavy mineral, beach-placer sandstone deposits in the San Juan Basin (Table 2; McLemore, 2010), it is unlikely that any of these heavy mineral, beach-placer sandstone deposits in the San Juan Basin will be mined in the near future because of small tonnage (Fig. 4, 6, 8, 10), high degree of cementation through lithification, high iron content (Table 2), and distance to processing plants and markets, mostly in California or on the east coast. However, as the demand for some of these elements increases because of increased demand and short supplies, the dollar value per ton of ore may rise, enhancing deposit economics. Exploration drilling of the Apache Mesa deposit occurred in August 2015 and results are pending. Exploration drilling of some of the other larger deposits, especially the Sanostee deposit and the deposits on the Ute Mountain Ute Indian Reservation in the northern San Juan Basin could be warranted in the future to fully evaluate the economic potential. Ultimately, economic potential will most likely depend upon production of more than one commodity.

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Table 1. Heavy mineral, beach-placer sandstone deposits in the San Juan Basin, New Mexico (U.S. Bureau of Mines and U.S. Atomic Energy unpublished files; Chenoweth, 1957; Dow and Batty, 1961; Houston and Murphy, 1970, 1977; Brookins, 1977; McLemore, 1983, 2010). PRR are Preliminary Reconnaissance Reports of the U.S. Atomic Energy Commission, on file at the New Mexico Bureau of Geology and Mineral Resources. New geologic mapping has occurred since the deposits were first described and, therefore, the locations and host sandstone could be different than first described. The mine identification number (Mine id) is from the New Mexico Mines Database (McLemore et al., 2005a, b). Deposits in bold are described in this report.

Mine id	County	Name	Latitude	Longitude	Host formation	References
NMBE0005	Bernalillo	Herrera Ranch	35.187111	107.050083	Point Lookout Sandstone (?)	McLemore (1983), Chenoweth (1957)
NMMK0060	McKinley	Farr Ranch (Star Lake)	35.880167	107.434778	Pictured Cliffs Sandstone	McLemore (1983), Green et al. (1980, no. 271, 272), Scott et al. (1980), Chenoweth (1957)
NMMK0061	McKinley	Farr Ranch (Star Lake)	35.875139	107.461444	Pictured Cliffs Sandstone	McLemore (1983), Scott et al. (1980), Dow and Batty (1961), USBM files
NMMK0062	McKinley	Farr Ranch (Star Lake)	35.857444	107.443472	Pictured Cliffs Sandstone	McLemore (1983), Chenoweth (1957), PRR ED-R-458 (1955)
NMMK0063	McKinley	Farr Ranch (Star Lake)	35.852611	107.438889	Pictured Cliffs Sandstone	McLemore (1983), Green et al. (1980, no. 273, 274), Chenoweth (1957)
NMMK0072	McKinley	Gallup (Defiance, Torrivio Anticline)	35.481639	108.870778	Mancos Formation-Gallup Sandstone	McLemore (1983), Houston and Murphy (1977), Overstreet (1967), Dow and Batty (1961, p. 37), Sun and Allen (1957), Chenoweth (1957), Allen (1956)
NMMK0108	McKinley	Miguel Creek Dome	35.546028	107.482889	Crevasse Creek Formation-Dalton Sandstone Member	McLemore (1983), Chenoweth (1957), USBM files
NMMK0261	**McKinley**	**Standing Rock (Flat Top Hill)**	**35.745389**	**108.301667**	**Point Lookout Sandstone**	**McLemore (1983), Green et al. (1980, no. 133, 134), Brookins (1977), Dow and Batty (1961), Chenoweth (1957)**
NMRA0001	**Rio Arriba**	**Apache Mesa (Airborne Anomaly 1, Stinking Lake)**	**36.665**	**106.825417**	**Point Lookout Sandstone**	**McLemore (1983), Bingler (1968), Chenoweth (1957), PRR ED-R-604 (1956)**
NMRA0002	Rio Arriba	Airborne Anomaly 3 (Stinking Lake)	36.574028	106.793944	Point Lookout Sandstone	McLemore (1983), Bingler (1968), Chenoweth (1957), PRR ED-R-606 (1956)
NMRA0003	**Rio Arriba**	**Apache Mesa (Airborne Anomaly 2, Stinking Lake)**	**36.662528**	**106.821278**	**Point Lookout Sandstone**	**McLemore (1983), Bingler (1968), Chenoweth (1957), PRR-R-606 (1956)**
NMSA0028	**Sandoval**	**B.P. Hovey Ranch (Torreon Wash)**	**35.659444**	**107.252639**	**Point Lookout Sandstone**	**McLemore (1983), Green et al. (1989, no. 330), Tabet and Frost(1979), Chenoweth (1957), PPR ED-R-552, 554 (1956), USAEC files**
NMSA0049	Sandoval	Herrera Ranch	35.224111	107.082667	Gallup Sandstone	McLemore (1983), Chenoweth (1957); PRR ED-R-661 (1956); USAEC files
NMSJ0002	San Juan	Airborne Anomaly 4 (Barker Dome)	36.892313	108.25757	Pictured Cliffs Sandstone	Chenoweth (1957), PRR ED-R-413 (1955)
NMSJ0003	San Juan	Airborne Anomaly 5	36.772	108.545667	Point Lookout Sandstone	Chenoweth (1975), PRR ED-R-449 (1955), ED-R-432 (1955), USBM files
NMSJ0004	San Juan	Airborne Anomaly 6	36.826306	108.515417	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-445 (1955), ED-R-450 (1955), USBM Files
NMSJ0005	San Juan	Airborne Anomaly 7	36.883444	108.470806	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-435 (1955)
NMSJ0006	San Juan	Airborne Anomalies 8, 9	36.867737	108.450994	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-433 (1955), USBM files
NMSJ0007	San Juan	Airborne Anomalies 10, 11	36.869902	108.458037	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-434 (1955), USBM files
NMSJ0008	San Juan	Airborne Anomaly 12	36.86586	108.457431	Point Lookout Sandstone	Chenoweth (1955), PRR ED-R-436 (1955), USBM files
NMSJ0009	San Juan	Airborne Anomaly 13, 14, 15	36.888611	108.458889	Point Lookout Sandstone	Green et al. (1980, No. 2), Hilpert (1969), Chenoweth (1955), PRR ED-R-451, 452, 453 (1955), USBM files
NMSJ0010	San Juan	Airborne Anomaly 16, 17, 18	36.894806	108.492639	Point Lookout Sandstone	PRR ED-E-437 (1955), USBM files
NMSJ0011	San Juan	Airborne Anomaly 19, 20	36.899306	108.511028	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-438 (1955), USBM files
NMSJ0012	San Juan	Airborne Anomaly 21	36.92325	108.511083	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-439 (1955), USBM files
NMSJ0013	San Juan	unknown	36.92975	108.506778	Point Lookout Sandstone	Chenoweth (1957); PRR ED-R-473 (1955); ED-R-437 (1955)
NMSJ0014	San Juan	Airborne Anomaly 22, 23 (Salt Creek Wash)	36.953889	108.530278	Point Lookout Sandstone	Green et al. (1980, no. 332); Houston and Murphy (1977), Dow and Batty (1961), Chenoweth (1957), PRR ED-R-454, 455 (1955), USBM files
NMSJ0015	San Juan	unknown	36.951222	108.526472	Point Lookout Sandstone	PRR ED-R-472 (1955)
NMSJ0016	San Juan	Airborne Anomaly 24	36.953639	108.551722	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-486 (1955), USBM files
NMSJ0017	San Juan	Airborne Anomaly 32	36.955474	108.614891	Point Lookout Sandstone	PRR ED-R-487 (1955), USBM files
NMSJ0018	San Juan	Airborne Anomaly 33	36.973486	108.614159	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-488 (1955), USBM files

Mine id	County	Name	Latitude	Longitude	Host formation	References
NMSJ0019	San Juan	Airborne Anomaly 34	36.957985	108.615112	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-489 (1955), USBM files
NMSJ0020	San Juan	Airborne Anomaly 35	36.964092	108.614879	Point Lookout Sandstone	Chenoweth (1957c), PRR ED-R-490 (1955), USBM files
NMSJ0021	San Juan	Airborne Anomaly 36	36.899472	108.529639	Point Lookout Sandstone	PRR ED-R-440 (1955)
NMSJ0022	San Juan	Airborne Anomaly 37	36.911278	108.509611	Point Lookout Sandstone	Chenoweth (1957), PRR ED-R-441 (1955)
NMSJ0023	San Juan	Airborne Anomaly 46	36.634045	108.577897	Point Lookout Sandstone	PRR ED-R-491 (1955)
NMSJ0037	San Juan	Deposit 2	36.971746	108.559063	Point Lookout Sandstone	USBM files
NMSJ0038	San Juan	Deposit X-Y	36.84282	108.456884	Point Lookout Sandstone	USBM files
NMSJ0054	San Juan	Hogback	36.809722	108.516667	Lower Menefee Formation	Green et al. (1980, No. 3), Hilpert (1969), Chenoweth (1957), PRR ED-R-456(1955), ED-R-273(1954), USAEC files
NMSJ0088	**San Juan**	**Sanostee**	**36.44894**	**108.898049**	**Gallup Sandstone**	**Bingler (1963), Chenoweth (1957), PRR ED-R-621 (1956), USBM files, USAEC files**
NMSJ0095	San Juan	Toadlena	36.227892	108.867162	Gallup Sandstone	Chenoweth (1957), Archer (1957), USBM files

Table 2. Selected chemical analyses (new, not previously published) of heavy mineral, beach-placer sandstone deposits in the San Juan Basin, New Mexico. TiO_2 and Fe_2O_3T (total iron reported as Fe_2O_3) are in percent (%) and the remaining elements are in parts per million. Additional published analyses are in McLemore (2010) and the complete whole rock chemical analyses will be reported in future reports.

Sample	Description	UTM northing	UTM easting	UTM zone	Depth (ft)	Fe_2O_3T	TiO_2	Nb	Th	U	Y	Zr
SL16	Apache Mesa	337494	4059011	13	surface	32.08	13.8	214	258	45.7	182.5	>10000
SL28	Apache Mesa	337751	4058979	13	surface	35.63	11.6	207	178	34.2	203	>10000
DH1-1	Apache Mesa	337543	4059240	13	0-1	20.55	2.22	45.9	32.8	8.12	67.4	2400
DH 3-1	Apache Mesa	337486	4059021	13	0-1	22.54	15	260	218	41.7	243	>10000
DH 3-2	Apache Mesa	337486	4059021	13	1.0-2.0	21.4	10.35	200	147	29.5	186	>10000
DH 3-3	Apache Mesa	337486	4059021	13	2-3.2	26.57	4.91	89	74.4	16.15	93.9	4880
DH 5-3	Apache Mesa	337732	4059035	13	2.8-3.7	3.96	1.79	41.5	28.1	5.43	44.4	1460
DH 5-7	Apache Mesa	337732	4059035	13	7.3-8.1	2.76	2.41	59.4	33.8	5.62	48.2	929
DH 7-1	Apache Mesa	337714	4058862	13	3.3-4.6	3.73	4.7	87.1	72.8	11.7	92.1	5290
SL 59	Apache Mesa	337737	4058881	13	surface	41.87	7.33	130	95.6	22.4	116	7940
SL 60	Apache Mesa	337714	4058862	13	surface	17.62	5.75	102.5	84.6	16.45	102	6420
SL 60b	Apache Mesa	337714	4058862	13	surface	14.14	8.01	145.5	117.5	21.5	152	8780
SL74	Apache Mesa	337637	4058958	13	surface	47.77	9.49	179	138.5	31.2	174	>10000
SL78	Apache Mesa	337504	4059040	13	surface	36.83	3.2	62.6	53.5	12.3	73.4	2840
SAN 1	Sanostee	687655	4036421	12	surface	12.77	3.17	70	79.6	13.5	67.1	4210
SAN 2	Sanostee	687756	4036339	12	surface	9.52	9.1	184.5	433	48.3	229	>10000
SAN 3	Sanostee	687705	4036548	12	surface	19.59	25.7	492	319	60.3	283	>10000
SAN 6	Sanostee	687508	4036825	12	surface	23.48	16.9	400	>1000	90.9	400	>10000
FT3A	Standing Rock	743899	3958985	12	surface	8.08	3.19	34.9	31.6	5.75	41.7	1730
FT3B	Standing Rock	743899	3958985	12	surface	40.33	0.44	6.7	5.65	1.16	12.5	173
FT2	Standing Rock	743945	3958931	12	surface	62.02	7.12	72.8	86.8	16.45	67.5	5650
Hovey 1	Hovey Ranch	296399	3948485	13	surface	11.08	14	266	252	50.1	366	>10000

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
SL16	490	860	91.4	315	51.5	3.2	37.7	5.74	32.4	6.88	22	3.83
SL28	547	1020	101.5	351	55.4	4.6	38.8	5.95	36.4	7.68	24.4	4.11
DH1-1	119	228	23.9	84.1	14.45	1.76	12.35	1.96	12.6	2.6	7.51	1.2
DH 3-1	677	1225	120.5	405	66.2	5.81	51.1	7.51	46.2	9.47	28.5	4.73
DH 3-2	550	1015	98.6	341	55	5.34	41.5	5.87	36.9	7.37	21.6	3.52
DH 3-3	247	529	51.3	178.5	31.2	3.47	24.4	3.54	20.5	3.93	10.9	1.66
DH 5-3	141.5	276	30.9	110	17.15	2.1	11	1.6	9.54	1.76	5.06	0.79
DH 5-7	161	315	34.2	119	19.55	2.57	14.25	1.93	10.85	1.96	4.78	0.72
DH 7-1	236	483	47.8	161	25.5	2.65	19.15	2.93	17.4	3.39	9.68	1.56
SL 59	287	514	50.7	167	26.4	2.52	19.8	3.33	21.9	4.62	15.05	2.39
SL 60	293	593	58.2	199.5	30.7	3.01	22.2	3.2	18.9	3.97	11.6	1.81
SL 60b	453	833	82.1	283	43.1	4.23	32.3	4.6	29.1	5.78	16.55	2.58
SL74	475	868	85.4	267	40.4	3.54	27	4.27	27.8	6.18	20.4	3.44
SL78	333	437	57.1	177.5	26.1	2.52	16.2	2.32	14.25	2.85	8.63	1.41
SAN 1	162	337	35.7	130.5	22	1.18	15.8	2.19	11.3	2.29	6.75	1.22
SAN 2	752	1525	168	616	106.5	2.96	73.9	9.56	46	8.39	23.7	3.83
SAN 3	757	1385	146.5	501	78.3	3.29	54.4	7.78	43.3	9.27	29.9	5.25
SAN 6	2040	4200	484	1785	297	6.55	194.5	23.1	99	15.45	37.6	5.27
FT3A	85.7	163.5	18.25	68.7	11.8	1.23	9.21	1.22	7.14	1.44	4.22	0.67
FT3B	19.8	37.9	4.36	16.2	2.77	0.54	2.35	0.35	2.09	0.46	1.31	0.2
FT2	156	327	34.3	126	21.5	1.44	15.35	2.17	11.6	2.41	7.37	1.32
Hovey 1	677	1320	137.5	477	76.1	6.64	60.1	9.52	58.2	12.75	39.3	6.94

Sample	Yb	Lu	TREE
SL16	30.1	5.64	1955.39
SL28	30.5	5.36	2232.7
DH1-1	8.94	1.48	519.85
DH 3-1	38.5	6.8	2692.32
DH 3-2	27.9	4.66	2214.26
DH 3-3	13.5	2.07	1120.97
DH 5-3	6.12	0.9	614.42
DH 5-7	5.14	0.74	691.69
DH 7-1	11.95	1.95	1023.96
SL 59	18.7	3.11	1136.52
SL 60	15.25	2.46	1256.8
SL 60b	20.8	3.37	1813.51
SL74	25.6	4.55	1858.58
SL78	10.2	1.65	1090.73
SAN 1	9.05	1.58	738.56
SAN 2	28.2	4.65	3368.69
SAN 3	40.9	7.41	3069.3
SAN 6	34.4	5.71	9227.58
FT3A	4.82	0.81	378.71
FT3B	1.29	0.21	89.83
FT2	9.85	1.76	718.07
Hovey 1	47.4	8.05	2936.5