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RARE EARTH ELEMENTS AND CRITICAL MINERALS IN THE SAN JUAN AND RATON COAL BASINS IN NORTHERN NEW MEXICO

M. N. Badonie, New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico
V. T. McLemore, New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico
J. Newcomer, New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico
D. Shaver, New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico
E. Owen, New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico

ABSTRACT

Rare earth elements and critical minerals have recently become of great economic interest because of their necessity for many new technologies and recent geopolitical unrest affecting the supply and import of resources. The San Juan and Raton basins in northern New Mexico are two structural coal basins that contain elevated concentrations of rare earth elements and critical minerals. These two New Mexican coal basins will be assessed geochemically and petrographically to identify vectors of the rare earth element and critical mineral enrichment. Coalbeds, coal seams, overlying, and underlying rock units will be sampled and characterized to determine any economic viability. Historic data will be compiled into a new and comprehensive coal geochemical database, which will grow with new analyses, and serve as the dataset for this project; this coal resource database will be made available to the public.

INTRODUCTION

Rare earth elements (REE) are comprised of 17 elements from the periodic table. REE has multiple and various highly specialized applications from industrial uses to electronic devices. Examples of these include flat panel monitor displays, diverse types of batteries and magnets, as well as additional applications where there are no other known substitutes [1]. REE are highly valued for their uses in green technology and the continued development of green energy technologies. The demand for REE has increased in the past years, spurring the re-examination of REE and critical mineral (CM) potential in New Mexico coal basins.

Critical minerals are minerals needed for military, industrial, or commercial purposes that are essential to the economical and national well-being of a country whose sources are vulnerable to disruption. Examples of this include, the production of renewable energy, electronics, agricultural production, and common household items [2]. Critical minerals are used in wind turbines, electric vehicles, hydrogen electrolysis, and thermoelectrics. Like REE, they are crucial to the development and expansion of green energy technologies. REE and CM are subject to demand fluctuation and disruptions in the supply chain. Multiple reasons can arise, such as natural disasters, labor strife, trade disputes, and conflict. The supply chain of REE and CM in the United States is vulnerable as it relies heavily upon importation from other countries. Since 1988, China has been the global leader and dominant supplier of REE, however, coal deposits occurring throughout the world are known to have elevated REE and CM concentrations [3, 4]. Figure 1 shows the different critical minerals and REE that are found in New Mexico. It also shows which elements have been and are being produced in New Mexico.

The purpose of this study is to assess the REE and CM potential in coal beds and related stratigraphic units of the San Juan and Raton basins located in northern New Mexico (Fig. 2). Whole-rock geochemistry, mineral chemistry, and petrographic analysis will provide insight into the REE and CM concentrations in coal beds and related strata. Sampling New Mexican coals and their underlying and overlying strata for geochemistry can provide a means of evaluating and determining potential economic viability. New Mexico's economy can directly benefit from identifying possible REE and CM resources.

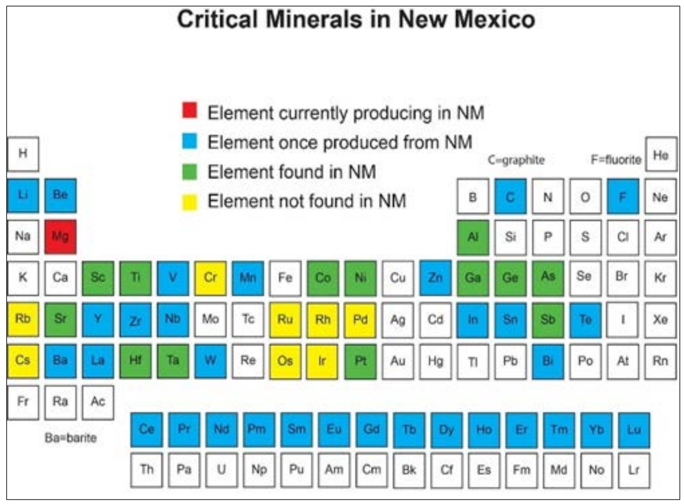

FIGURE 1. Critical Minerals found in New Mexico [15].

COAL IN NEW MEXICO

New Mexico's coal resources are in the San Juan and Raton basins, in the northern portion of the state (Fig. 2). The San Juan Basin is an asymmetrical depression on the southeast margin of the Colorado Plateau province. It is also the largest coal-bearing region in the state. The Raton basin is a structural basin in north-central New Mexico, which extends into south-central Colorado. The Raton Basin is in the foothills of the Rocky Mountains [5]. Both the San Juan and Raton basins are Laramide structural basins that host important energy and mineral resources that have produced significant amounts of coal, uranium, petroleum, and gas [6]. Coal in the San Juan and Raton basins are Late Cretaceous in age [6]. The San Juan Basin coal is predominantly found in three major coal-bearing sequences, ascending in oldest to youngest stratigraphic order: Crevasse Canyon, Menefee, and Fruitland Formations. The Raton basin has two coal-bearing sequences, the Vermejo and Raton formations [7].

As of October 2022, New Mexico has two operating surface coal mines: El Segundo mine in Grants and the Navajo mine in Fruitland. Figure 2 shows the location of the closed and operating mines in New Mexico. The coal mined is used to generate electricity in New Mexico and Arizona. The San Juan mine was an underground mine that recently closed in October 2022. The Four Corners Generating Station, located in Fruitland, is the only remaining coal-powered power plant that is in operation in New Mexico. In 2021, New Mexico produced 7,693 short tons of coal from the two surface mines and 1,572 short tons from the underground mine [8]. There are no current operating coal mining operations in the Raton coal basin.

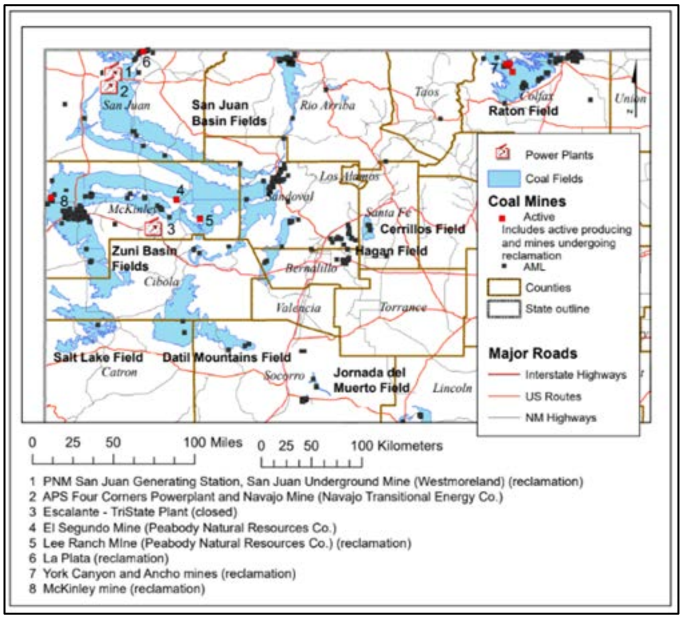

FIGURE 2. Power plants and coal mines, active and abandoned mine locations, San Juan, and Raton coal fields [6].

METHOD OF STUDY

Existing and historical data for sample sites are being integrated into a database. Data includes drill cores, thin sections, geologic maps, hand samples, and past reports. Sampling sites in the San Juan and Raton basin coal fields are being assessed for potential REE and CM. Geological documentation is collected on key sedimentary structures and any post-depositional alteration that may contribute to the concentration of REE and CM. Twenty-two coal fields are being sampled for their REE and CM resource potential.

Samples are being collected from seven sources: (1) coal seams and stratigraphic units above and below the existing coal drill core, (2) field exposures of coal, shale, volcanic ash beds, and humate deposits proximal to coalbeds (3) coal ash, (4) coal refuse and waste piles, (5) acid mine drainage from active and abandoned mine lands, (6) coal and other ore tailings, and (7) boiler slag. Other related strata that will be collected and analyzed include heavy mineral beach-placer sandstones, clay beds, clinker deposits, volcanic ash beds within and adjacent to coal seams, humate deposits, black shales, igneous rocks near coal seams, and uranium deposits. All samples have been labeled, bagged, photographed, and GPS-tagged using the standard operating procedures of the New Mexico Bureau of Geology and Mineral Resources (NMBGMR).

As of November 2022, we have identified 247 legacy samples that have chemical analyses and have collected and analyzed 87 samples. Chemical analysis of coal deposits from legacy literature (including the USGS coal quality database) is not always accurate and needs to be used with caution. This legacy data however still guides sampling and confirms the interpretation of the geochemistry. Samples are collected for whole rock geochemistry, petrographic characterization, and mineral chemistry analysis. Samples collected will be used to analyze and define the depositional relationships between coal beds and REE and CM enrichment. The coal samples have been analyzed by SGS using ASTM methods. ALS has analyzed non-coal samples (see https://www.alsglobal.com/en/Resources-and-downloads). Contact the author for any questions concerning QAQC. The initial stages of geochemical analysis are underway.

NMBGMR has a collection of published and unpublished data on mining districts, workings, deposits, occurrences, and mills since its inception in 1927 [9, 10] NMBGMR has drill cores of coal deposits from 146 various locations throughout the San Juan and Raton basins. Although this project will focus on coal-bearing strata, the NMBGMR has additional chemical and mineralogical data from other REE and CM deposits in the San Juan and Raton basins. Hoffman [6, 11] compiled a coal field database in the San Juan and Raton basins; data collected are available in the New Mexico Mines Database. Figure 3 shows the locations of the legacy drill core in relation to the location of the San Juan and Raton coal basins.

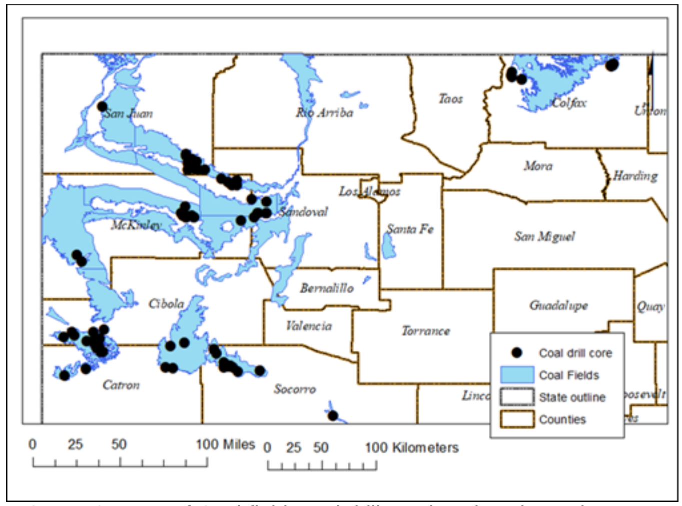

FIGURE 3. Map of Coal fields and drillcore locations in northern, New Mexico. [10].

The United States Geological Survey Coal Quality (USGS COALQAL) database contains the geochemistry of over 50 coal samples from the San Juan Basin. These samples were collected between 1970 and 1980 and were analyzed for REE and other critical minerals. Some samples have shown anomalously high total REE values. Legacy geochemical data of the coal deposits are from several sources [12, 13, 14].

PRELIMINARY RESULTS

Samples have been collected (87), with 58 samples from the San Juan Basin, and 23 from the Raton Basin. The Fruitland Formation, is the most sampled formation from the San Juan Basin, with the Menefee Formation following next. The Vermejo and Raton formations were both sampled from the Raton basin. Of the 22 coal districts (fields) found in both the San Juan and Raton basins, seven of the coal districts (fields) have been sampled. Eight of the samples do not come from either the San Juan or Raton basins but do pertain to furthering the identification of REE and critical minerals in similar rocks adjacent to the basins. Table 1 (see APPENDIX A) lists the samples that have been collected by coal districts. Of the 22 major coal districts, only eight districts have been sampled.

Figure 4 is an REE chondrite normalized plot from the legacy data from the San Juan Basin. The data are from several references [12, 13, 14]. Araya and Baker's data was reported in their master thesis, where the data was analyzed at New Mexico Tech. There is light REE enrichment.

Figure 5 is another REE chondrite normalized plot of new data from the San Juan Basin. This data are based on the newest samples collected, and it's important to note that the coal ash samples are greater than 200 ppm total REE. These samples have light REE enrichment.

In the San Juan basin, Li and Zr have slightly elevated concentrations at 89 ppm and 283 ppm respectively. Salt Lake coal field had the highest Li concentration with as much as 89 ppm. In APPENDIX 1, Figure A1, it's observed that the Salt Lake filed also had large ranges of concentrations of all the sampled coal fields. In APPENDIX 1, Figure A2, the Salt Lake coal field also has elevated concentrations in Zr as much as 281 ppm. Star Lake also had a high elevated concentration at 283 ppm.

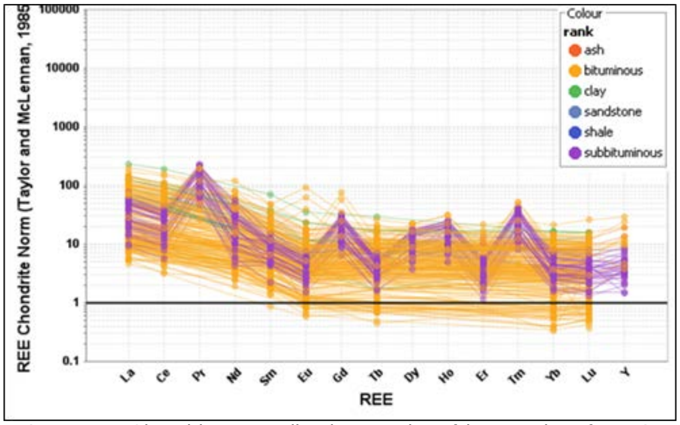

FIGURE 4. Chondrite normalized REE plot of legacy data from San Juan and Raton basins. Coal, shale, and ash deposits have low concentrations of REE, Zr, Ti, N. Data from several sources [12, 13, 14]. Chondrite concentrations from 18.

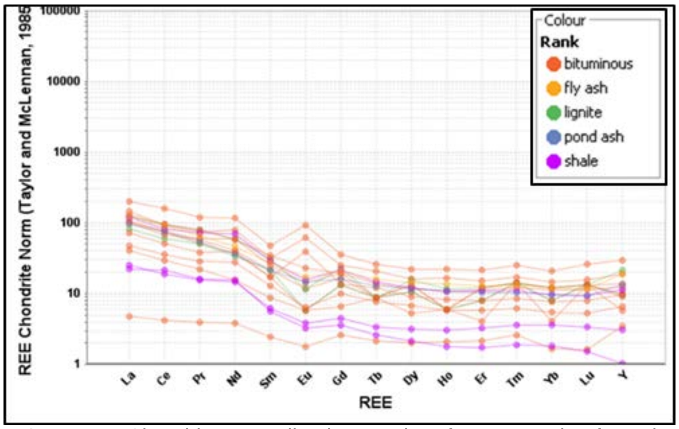

FIGURE 5. Chondrite normalized REE plot of new samples from the San Juan basin, including coal, shale, and ash deposits. Note that coal ash samples have greater than 200 ppm total REE. Chondrite concentrations from 18

PRELIMINARY CONCLUSIONS

- REE in the San Juan and Raton basins coal deposits are relatively low in concentration.
- Other critical minerals, such as Li and Zr, are slightly elevated and could have future potential in the San Juan basin.
- Ash is a product of burning coal, and REE and perhaps some critical minerals can be recovered from the ash, especially if there are additional industrial uses for the ash (additional study underway).
- The economic potential of REE and critical minerals in coal deposits in New Mexico will depend upon the production of more than one commodity from more than one type of deposit.
- REE and CM are low compared to commercial deposits, but significant in terms of coal volume and production.
- CM has variable concentrations between coal districts and seams, and there needs to be thorough sampling.

FUTURE WORK

Future work plans include collecting more samples and ensuring that coal samples are collected from each coal seam in the San Juan and Raton coal basins. Sampling was delayed due to restrictions due to the COVID-19 pandemic, the closure of Federal land due to fire danger, and poor weather. Plans also include continuing geochemical, mineralogical, and other characterization analysis upon receiving geochemistry from labs. As well as, identifying sources of REE and other critical minerals, and evaluating the mineral-resource potential of both the San Juan and Raton coal basins.

ACKNOWLEDGMENTS

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APPENDIX A

TABLE 1. Coal fields in New Mexico that have been sampled, do not include any legacy data. Red bolded words are coal fields that don't have any chemical analyses.

District id	District (coal field)	Year of Discovery	Year of Initial Production	Year of Last Production	Estimated Cumulative Production	Formation	Number of samples collected
DIS257	**Barker Creek**	1882		1905		Menefee	
DIS150	Bisti	1961	1980	1988	$40,075,148.00	Fruitland	5
DIS259	**Chaco Canyon**	1905	1905			Menefee	
DIS260	Chacra Mesa	1922		1945		Menefee	3
DIS174	La Ventana	1884	1904	1983		Menefee	4
DIS118	**Crownpoint**	1905	1914	1951	$20,758.00	Crevasse Canyon	
DIS155	Fruitland	1889	1889	2001	$3,137,957,050	Fruitland	1
DIS119	**Gallup**	1881	1882	2001	$121,522,629,885	Crevasse Canyon	
DIS156	**Hogback**	1907	1907	1971	$301,237.00	Menefee	
DIS146	**Monero**	1882	1882	1970	$5,277,552.00	Menefee	
DIS016	Mount Taylor	1936	1952	1953	$69,948.00	Crevasse Canyon	8
DIS157	**Navajo**	1933	1963	9999	$4,714,689,147	Fruitland	
DIS258	**Newcomb**	1955				Menefee	
DIS021	Raton	1820	1898	2002	$954,470,032.00	Vermejo, Raton	23
DIS003	**Rio Puerco**	1901	1937	1944	$139,555.00	Crevasse Canyon	
DIS009	Salt Lake	1980	1987	1987	$100,000.00	Moreno Hill	2
DIS121	**San Mateo**	1905	1983	2001	$1,678,742,326	Menefee	
DIS261	**Standing Rock**	1934	1952	1958		Menefee	1
DIS158	Star Lake	1907			$0.00	Fruitland	30
DIS263	**Tierra Amarilla**	1935	1955	1955		Menefee	
DIS159	**Toadlena**	1950			$0.00	Menefee	
DIS124	**Zuni**	1916	1908	1926	$16,010.00	Crevasse Canyon	
	Other samples						8
	Total samples						87

APPENDIX 1 Chemical plots of critical minerals of samples from the San Juan Basin.

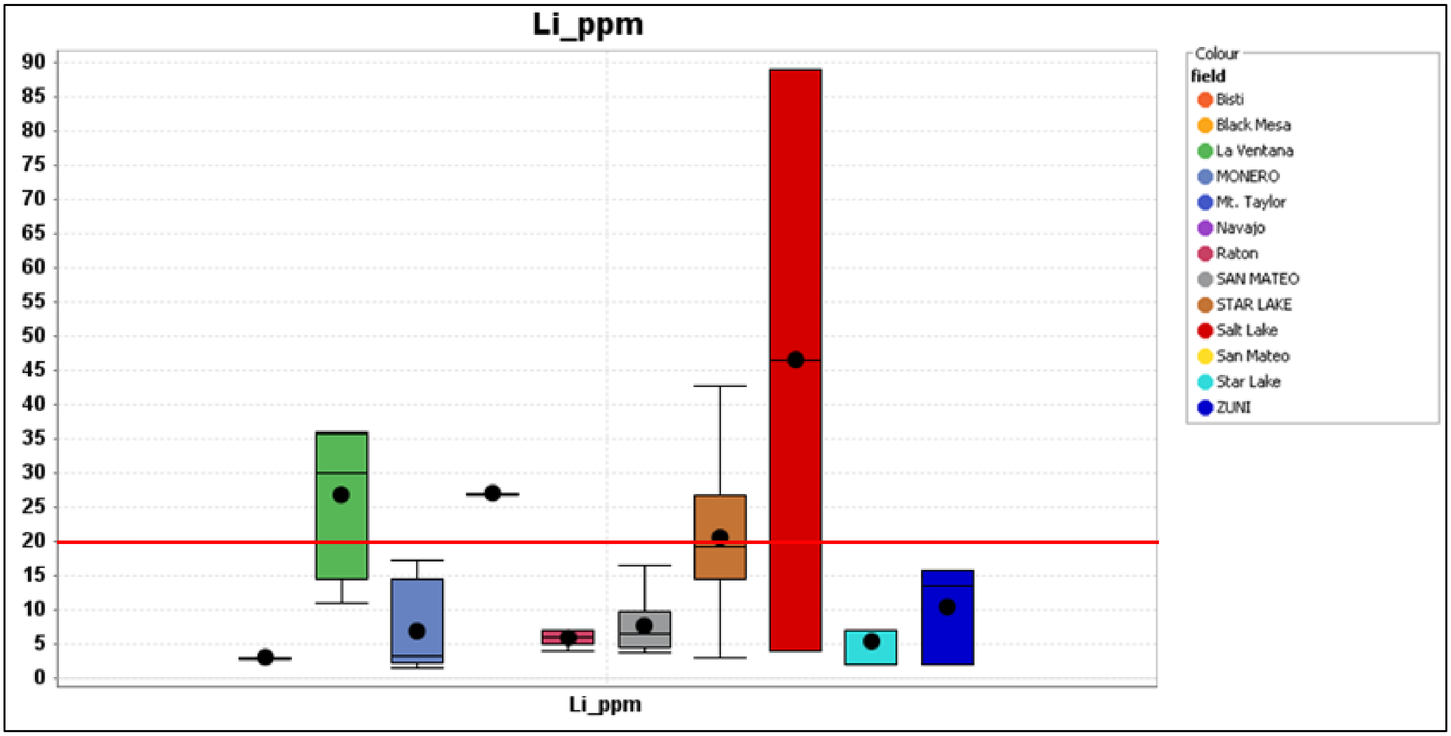

FIGURE A1. Box plot of Li concentrations in the San Juan Basin, classified by coal fields. Red line is average crustal abundance [16].

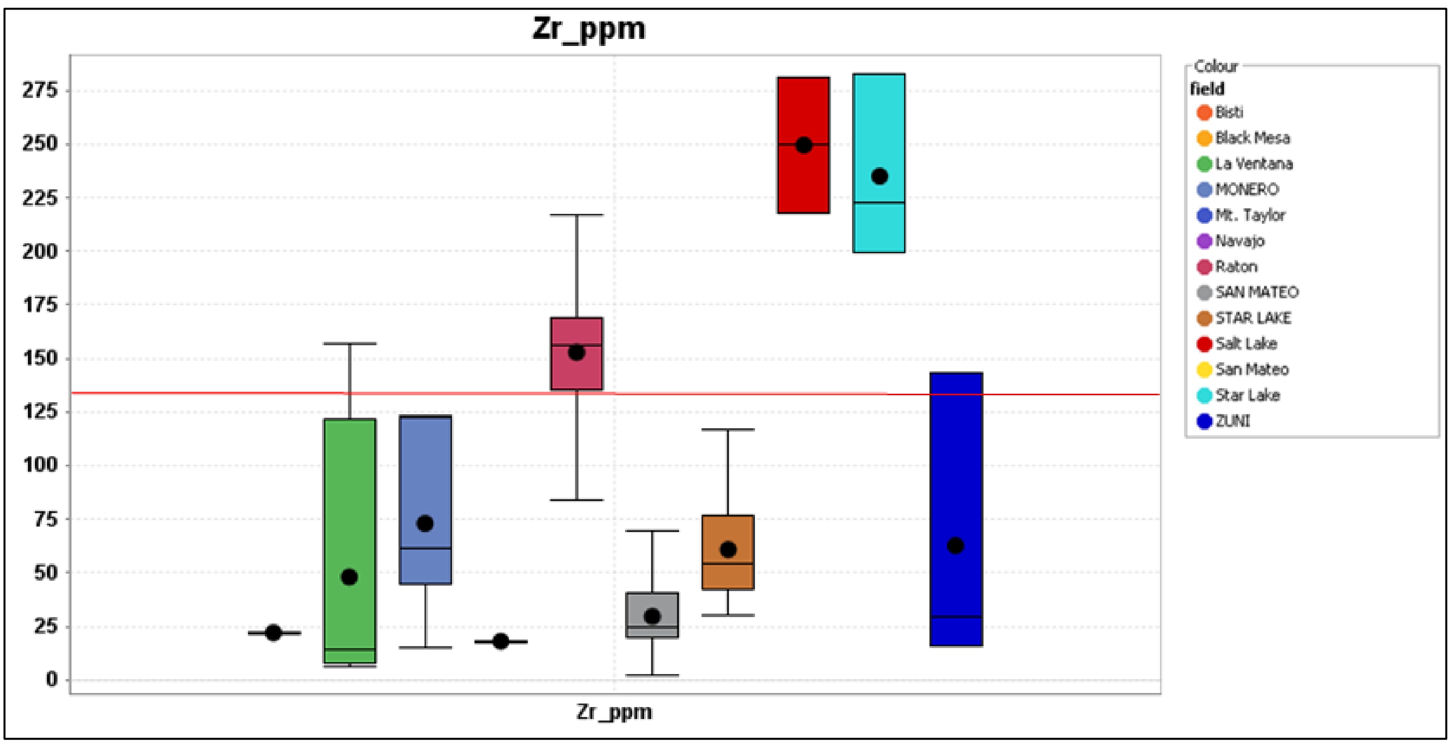

FIGURE A2. Box Plot of Zr Concentrations in the San Juan Basin, classified by coal fields. Red line is average crustal abundance [17].