Improving the understanding of geologic controls of REE deposits at Mountain Pass through 3D geological and geophysical modeling

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Abstract

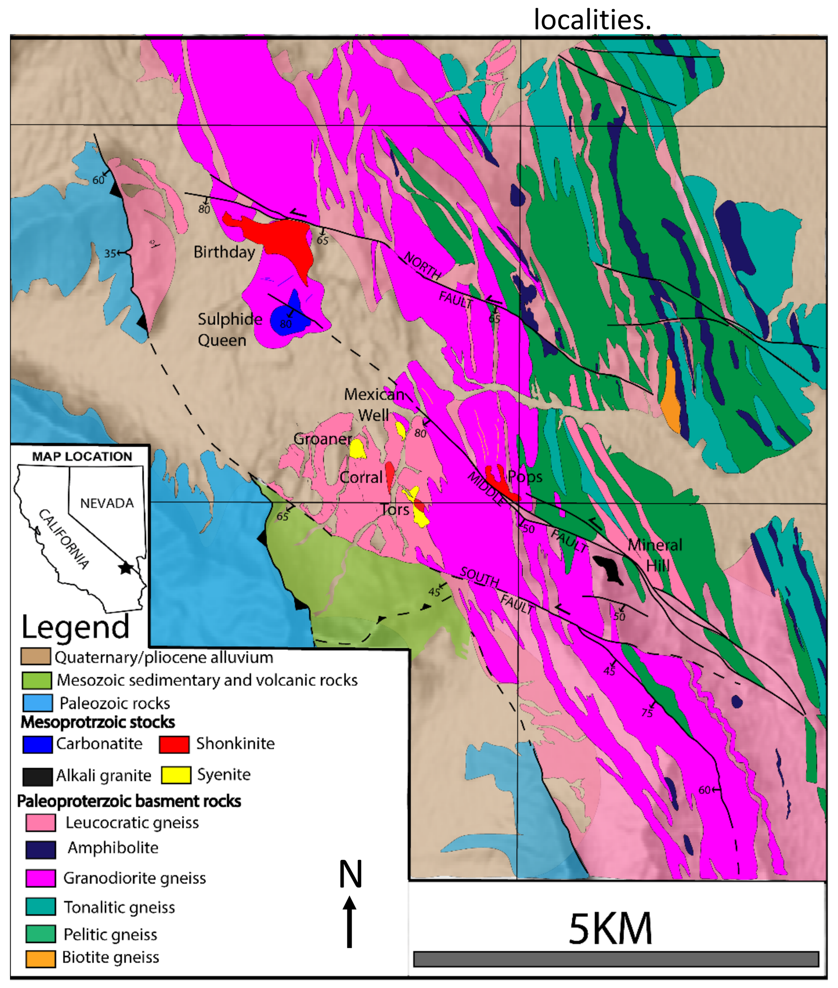
- The Mountain Pass carbonatite deposit in California is a major source of rare earth elements (REEs) for renewable energy, telecommunications, and defense technologies.
- While the Mountain Pass Intrusive Suite (MPIS) has been analyzed in terms of geochemistry, geochronology, and geophysics, new high-resolution airborne geophysical and radiometric data from the USGS provide an opportunity to investigate geologic controls, like faults, in the deposit's formation.
- The research aims to develop a **3D subsurface model by integrating geological mapping with high-resolution geophysical data**, including gravity gradiometry and magnetic measurements.
- By using geological insights to guide and constrain geophysical modeling, the study aims to improve geological interpretations.
- Combining **structural analysis with geophysical imaging** will help clarify the complex geology of Mountain Pass.
- The study is expected to provide an integrated understanding of the geological factors influencing REE mineralization at Mountain Pass, with insights applicable to REE exploration elsewhere.
- Prolonged timelines associated with developing REE mines in the U.S.—averaging nearly 29 years from discovery to production—this study supports more targeted exploration strategies that can reduce uncertainty and accelerate project timelines

Introduction

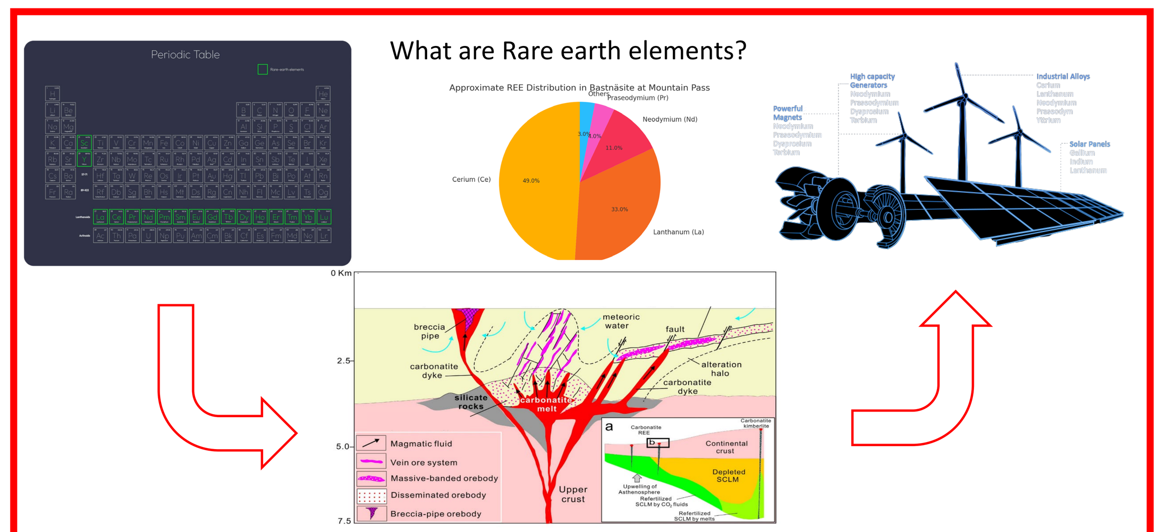
Mountain Pass

(Above) Aerial view of the Mountain Pass Mine in California, one of the world's richest sources of rare earth elements (REEs). Located in the Mojave Desert, the mine plays a critical role in the global supply chain for advanced technologies, including renewable energy systems, defense applications, and electronics.

- The Mountain Pass carbonatite deposit in California has been a major global source of rare earth elements (REEs), supplying up to 80% of the world's REE demand at its peak (1965-1995).
- Technological advancements have increased demand for REEs, essential for manufacturing and maintaining various technologies (e.g., energy-efficient computers, wind turbines, smartphones).
- REEs include the 15 lanthanide elements, along with scandium (Sc) and yttrium (Y), due to their similar occurrence in REE-rich deposits.
- REEs occur in multiple deposit types, each with different geologic origins, such as carbonatites, alkaline igneous systems, ion-adsorption clays, and monazite-bearing placer deposits.
- This study focuses on carbonatite deposits and associated ultrapotassic intrusive rock at Mountain Pass.
- Carbonatites, defined as igneous rocks with over 50% carbonate minerals, are found worldwide in various tectonic settings, with over 600 known localities.



(Left) Composite surface geology map of the Mountain Pass region, California, compiled from legacy geological maps. The map highlights the distribution of Mesoproterozoic carbonatite and syenite intrusions (associated with REE mineralization), Paleoproterozoic basement gneisses, and overlying Mesozoic and Paleozoic formations. Key features include major faults (North, Middle, South) and labeled intrusions such as Sulphide Queen and Birthday, which are central to REE extraction at Mountain Pass

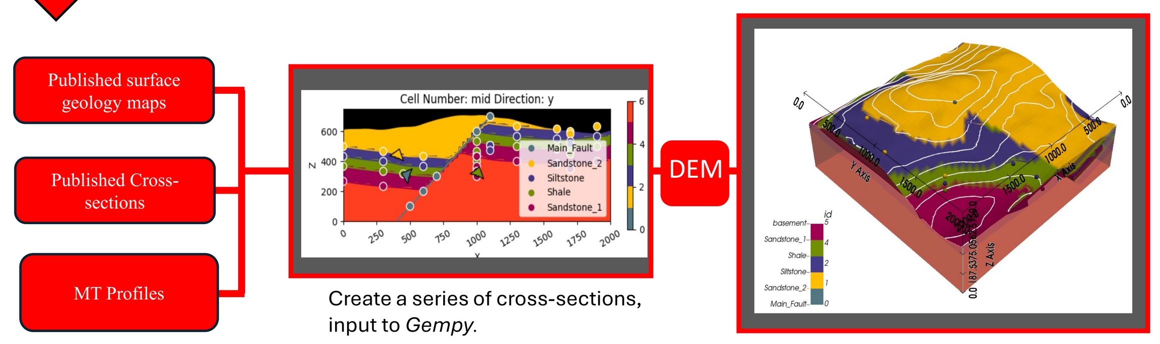


(Above) Schematic illustration of geological processes responsible for the concentration of rare earth elements (REEs) in a carbonatite system. Carbonatite melts intrude the upper crust, forming dykes and breccia pipes enriched in REEs through magmatic and hydrothermal processes. Vein-type, massive-banded, and disseminated orebodies develop in association with fault zones, meteoric water circulation, and alteration halos. The inset (a) shows the mantle source and upwelling of metasomatized sub-continental lithospheric mantle (SCLM) fluids, contributing to carbonatite genesis and REE enrichment.

Method

Step 1 — 3D Block Model

Construct a series of cross sections incorporate geologic maps and MT data. Export the block model to constrain geophysical model.



Create a series of cross-sections, input to *Gempy*.

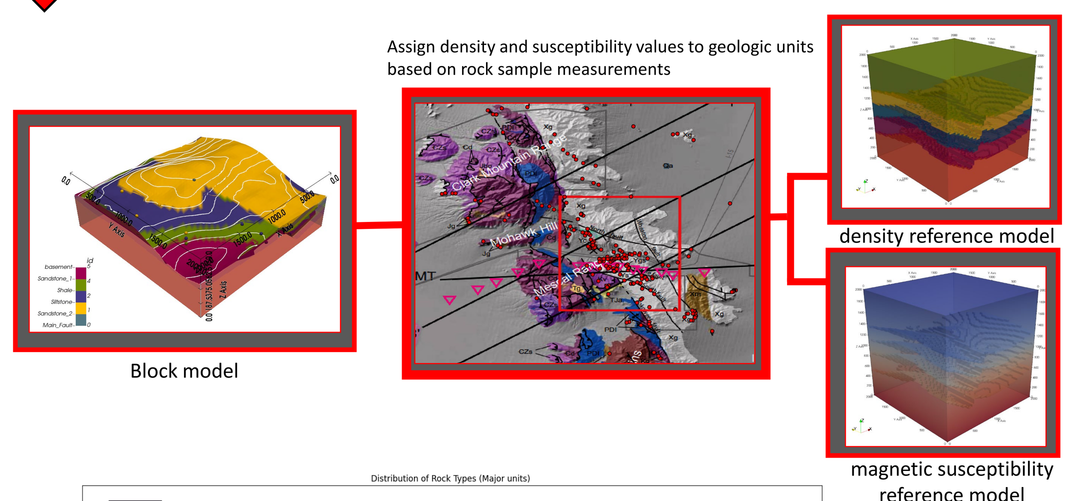
Gempy converts cross-sections to block model.

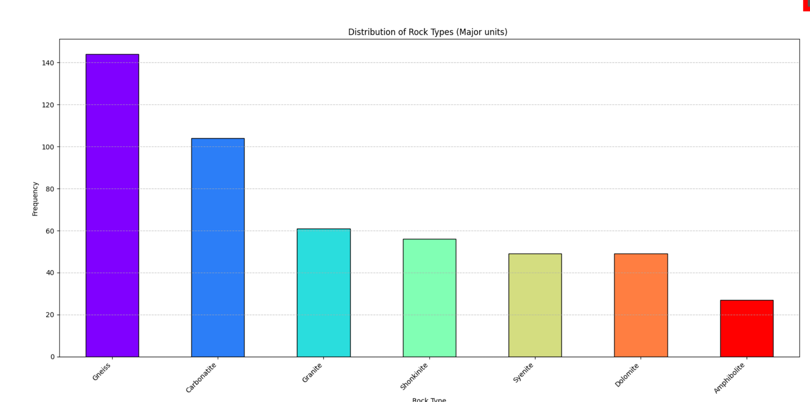
Visualizing Geological Uncertainty

- Multiple Scenarios: GemPy creates many versions of the subsurface based on your data, not just one "best guess."
- Probability Maps: Each block in the model shows how likely it is to contain a specific rock type.
- Confidence Indicators: Areas of high uncertainty are highlighted—helping geologists focus where data is weak.
- Informed Decision-Making: This approach helps reduce risk in exploration, drilling, and planning.

Step 2 — Converting the 3D geological model to 3D reference geophysical models

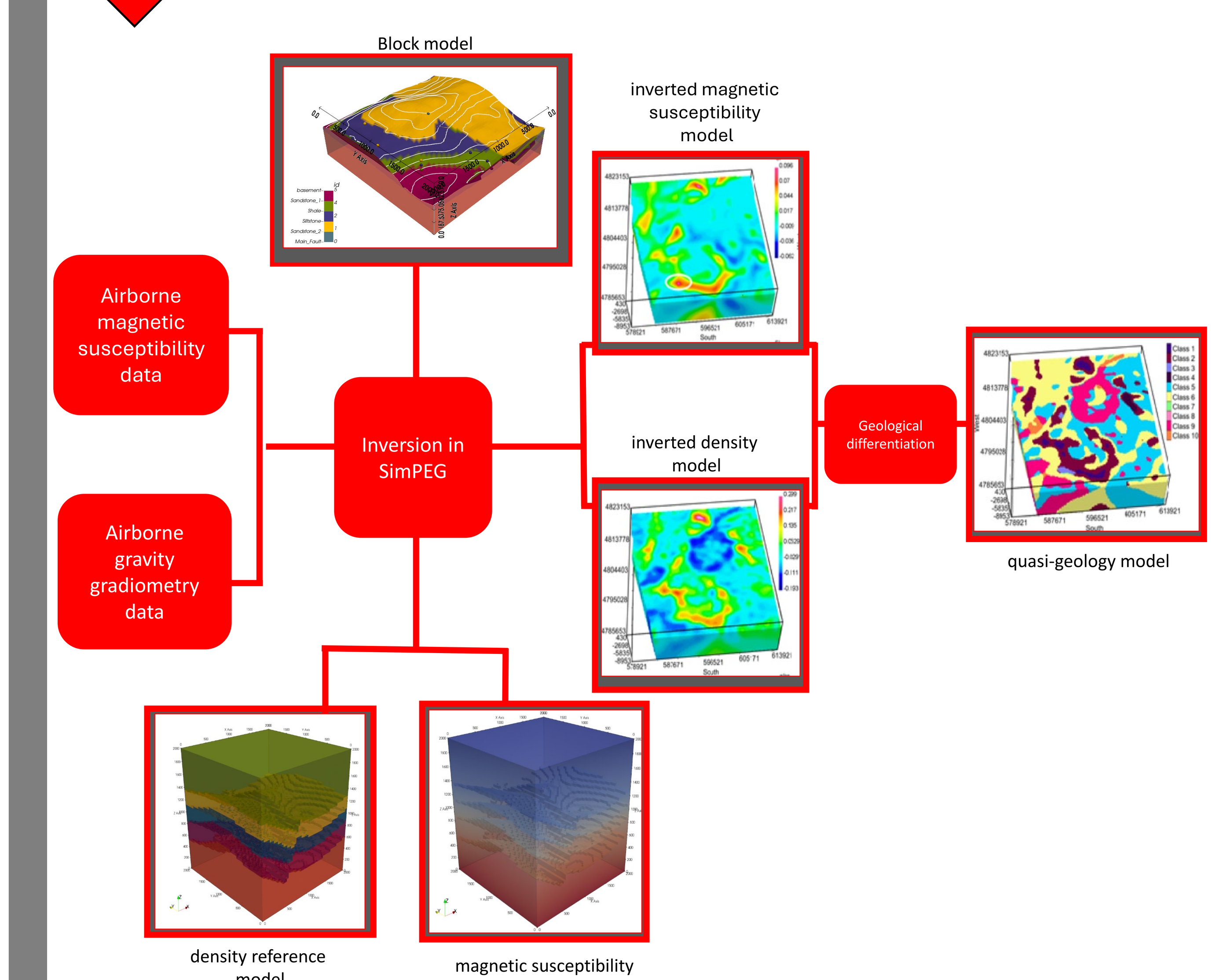
Models based on the 600+ rock samples that measure bulk density and magnetic susceptibility



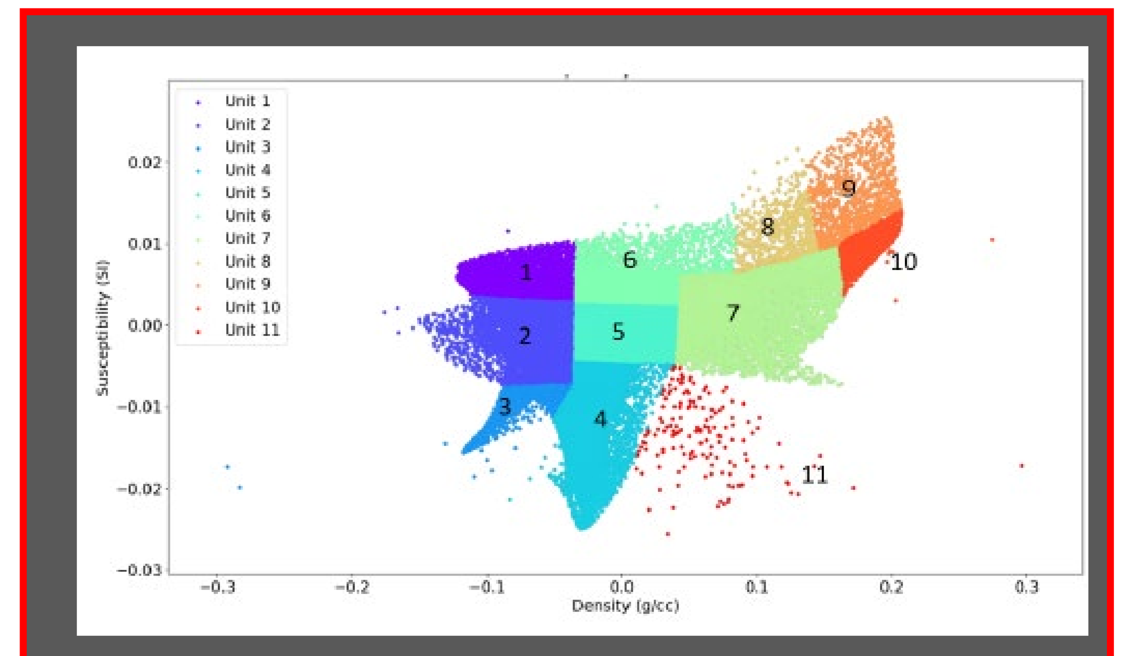


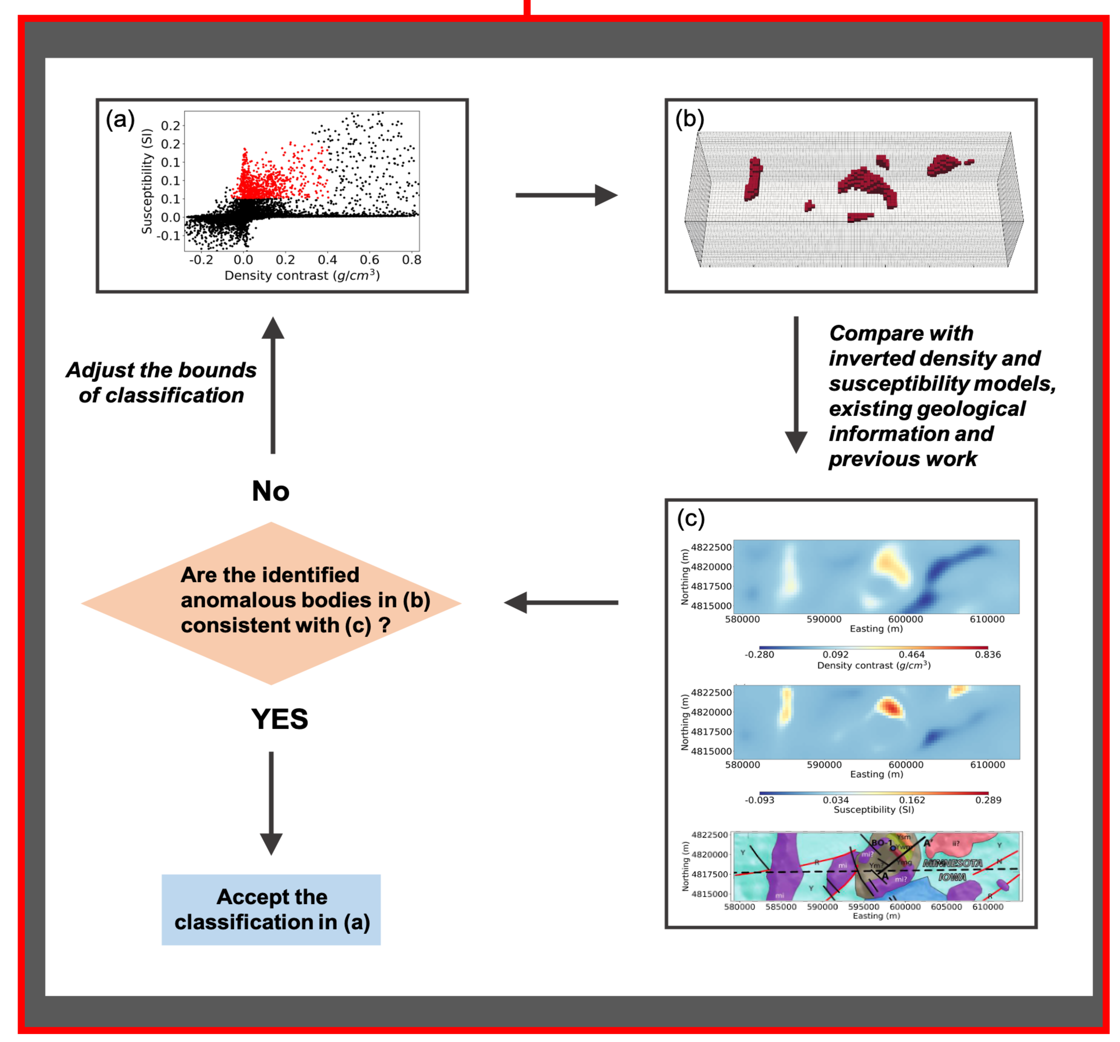
Step 3 — 3D density & magnetic susceptibility inversion models

Apply Geologic differentiation to inverted values to create quasi-geologic model.



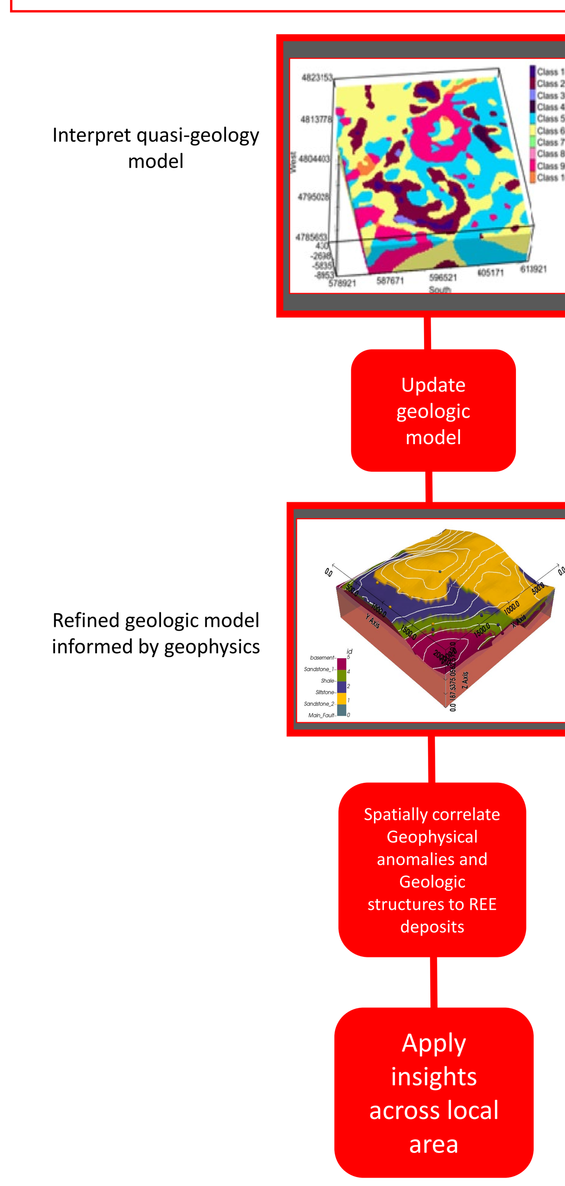
Geologic differentiation





Step 4 — Interpret quasi-geology model

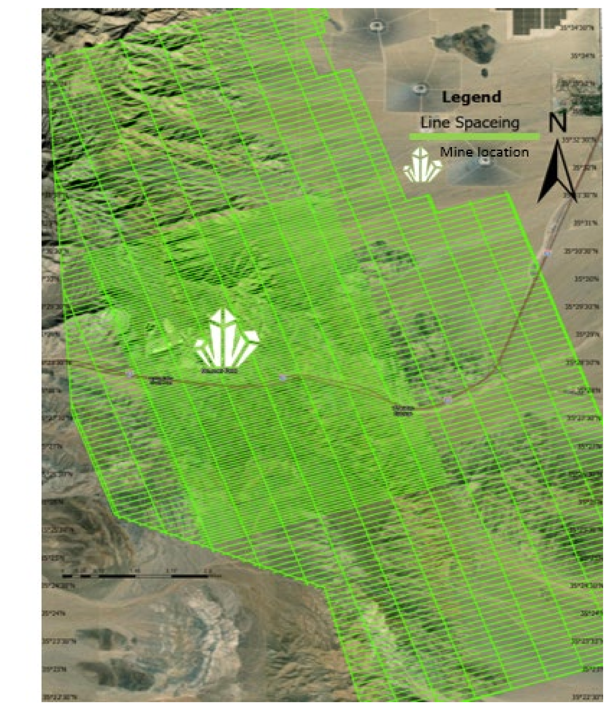
Identified structures and physical properties that characterize the carbonatite and ultrapotassic intrusive stocks.

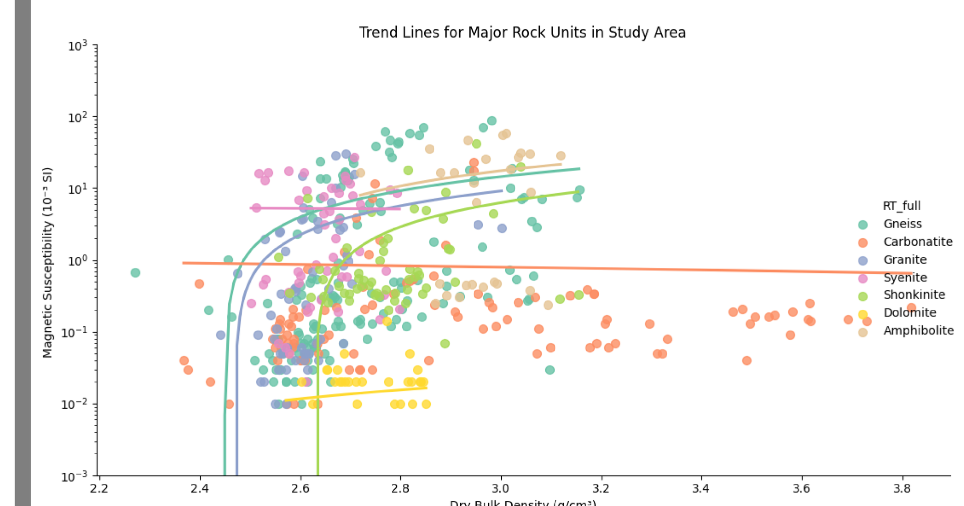


Data

Airborne Survey

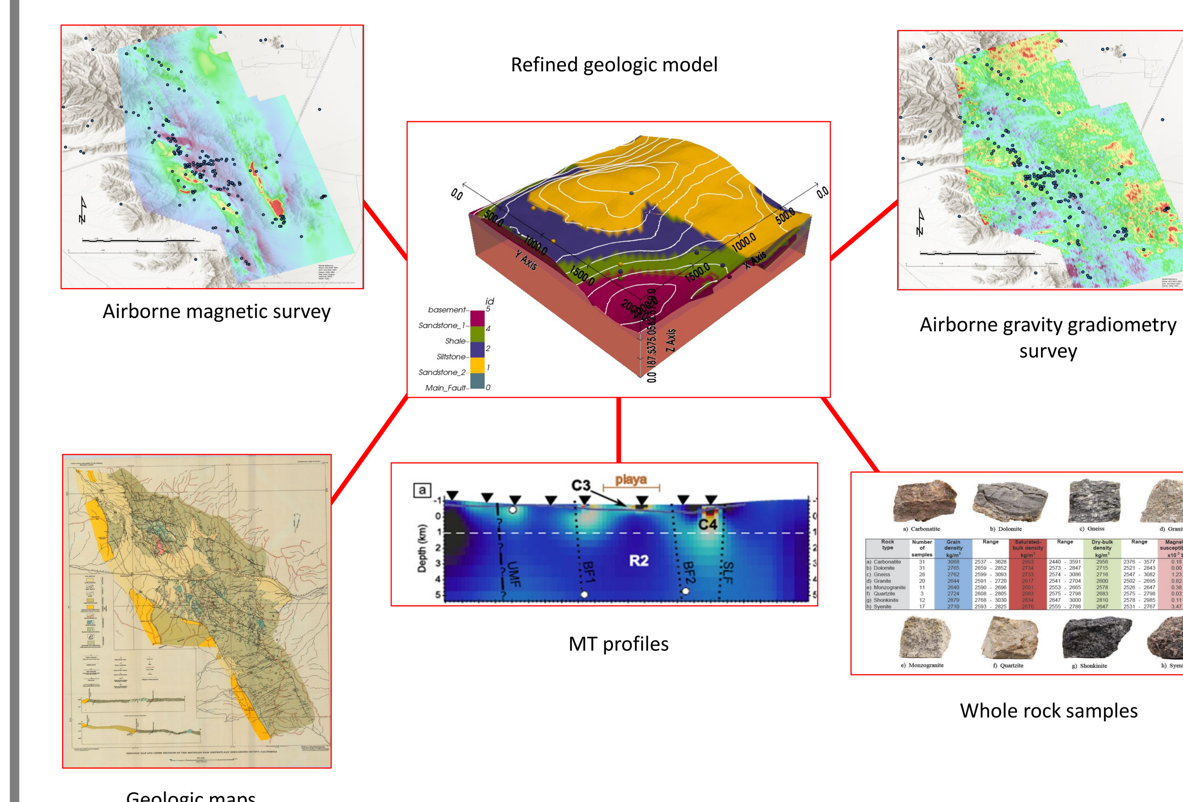
- In 2021 the USGS released a detailed airborne
- Gravity gradiometry survey
- Magnetic survey
- Radiometric survey
- Fight-line spacing of 100m and 200m
- Flight-line elevation above ground of 70m
- 1,814 line-kilometers.





(Left)Cross-plot of magnetic susceptibility versus dry bulk density for major rock units from collected samples in the study area. Distinct lithologies—including carbonatite, syenite, shonkinite, and gneiss—exhibit diagnostic trends, with fitted lines highlighting typical ranges and relationships. This plot helps distinguish lithologic units based on their geophysical signatures, supporting interpretation in the 3D subsurface model.

Expected Contributions



- More **cohesive view of the geologic controls** that influence the emplacement and enrichment of the REE mineralization at Mountain Pass
- **Integrated framework for understanding how the MPIS deposits formed**, contributing valuable insights that can be applied to the exploration of REE deposits elsewhere
- **Demonstrate the effectiveness of combining traditional geologic methods with geophysical data in resolving complex geologic systems**

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