Reducing geologic risk uncertainty for carbon sequestration using modern gravity surveys and modeling in Iron County, Utah

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PROJECT OVERVIEW

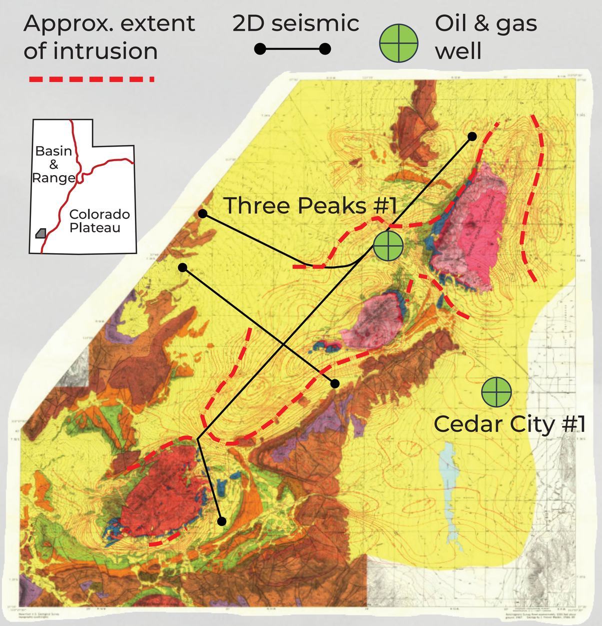
The Iron Springs mining district in southwest Utah is one of the largest sources of iron ore in the United States. Steel from this ore is currently manufactured overseas, resulting in significant business costs and an undesirable carbon footprint. To reduce waste and domesticate production, proposals exist to build a direct-reduced iron plant and develop a carbon capture and storage site to inject ≥500,000 metric tons of CO_2 per year into an adjacent basin. The local subsurface has multiple reservoir/seal packages at depths suitable for CO_2 storage. However, there is considerable geologic risk involved with injection due to complex and poorly constrained subsurface conditions.

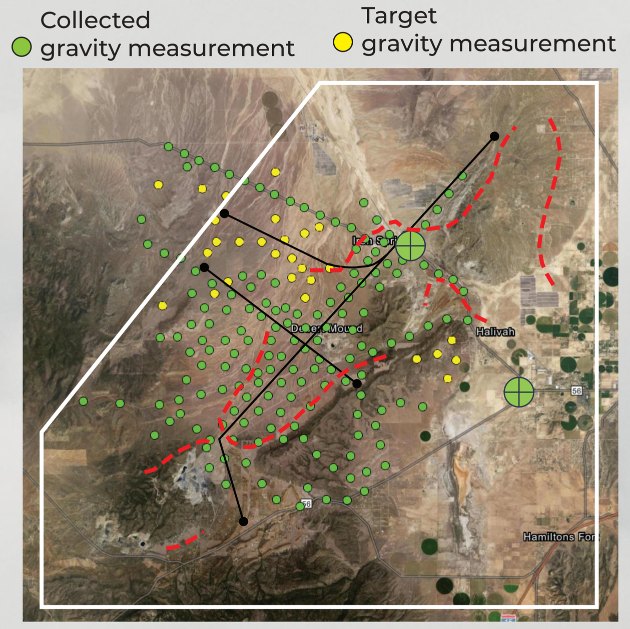
GEOLOGIC CONTEXT

The Iron Springs District in southwest Utah lies at the eastern boundary of the Basin and Range Province as it transitions into the Colorado Plateau. The region comprises north-northeast-trending basement-cored uplifts and grabens that juxtapose thick sequences of Paleozoic and Mesozoic strata and extensive Eocene and younger volcanics, all of which have been heavily faulted.

Physiographically, it is bordered to the west by the Antelope Range, bordered to the south and to the east by intrusive bodies of the "Iron Axis" Magmatic Province that parallel the Iron Springs Thrust Fault system, and opens to the north to the Escalante Desert.

Deposition of thick sequences of carbonate and siliciclastic strata during the Paleozoic and early Mesozoic preceded several structural deformation phases, including the Sevier and Laramide orogenies (~160-50 Ma and ~80-40 Ma, respectively), widespread Oligocene-Miocene calc-alkalic igneous activity ~35-22 Ma that include the quartz monzonite intrusions of the "Iron Axis" Magmatic Province that generally along the trend of the Sevier orogenic front, post-volcanic thermal subsidence, and Basin & Range extension that began in the late Miocene around 10 Ma.

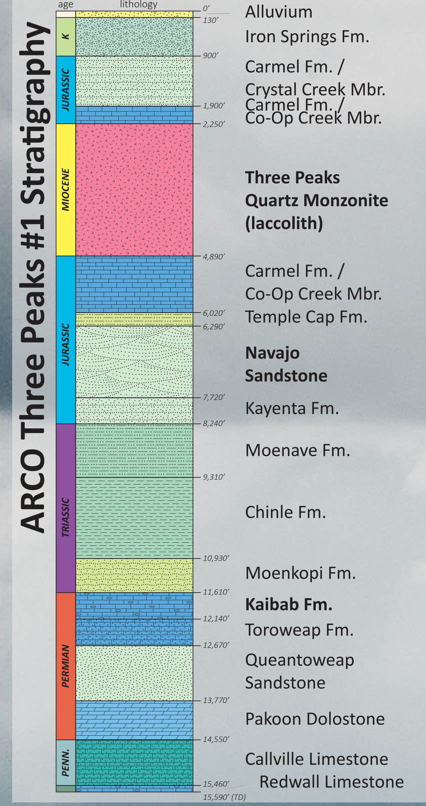




LEFT: Generalized geologic maps of the greater Iron Springs District, Utah showing the location of wells and schematic outline of laccolith (modified from Blank and Mackin, 1967).

RIGHT: satellite imagery of the same area with gravity survey points superimposed.

CO_2 SEQUESTRATION TARGET



As part of a multidisciplinary site characterization, the Utah Geological Survey is conducting **geophysical surveys and geologic data acquisition to characterize subsurface geology and reduce structural, seal, and reservoir risk uncertainty.**

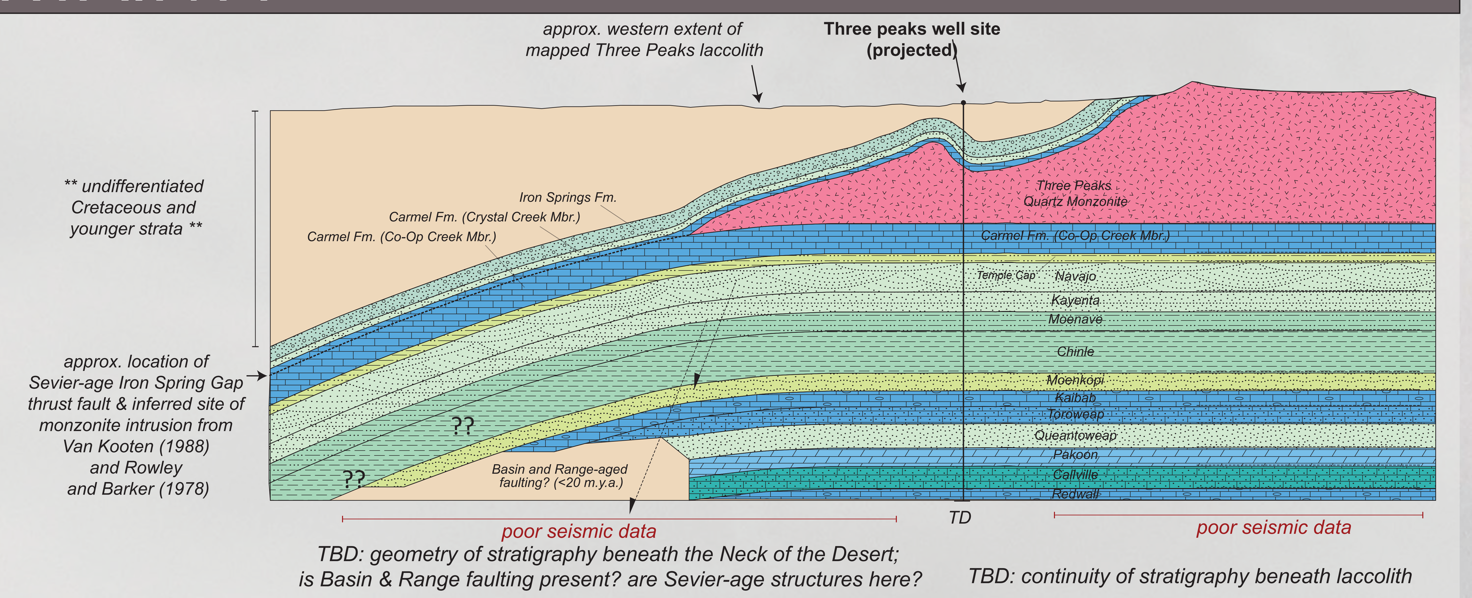
Within the Paleozoic and Mesozoic strata are a series of favorable reservoir/seal pairs that are desirable sequestration targets due to their demonstrated reservoir properties in other parts of Utah.[1,2]

The two key reservoir/seal pairs are (1) the **Jurassic Navajo Formation sandstone** that is stratigraphically sealed by overlying unconformable Carmel gypsiferous shale & gypsum beds and, in certain areas, sealed by the Three Peaks quartz monzonite which intruded the Carmel Formation in Oliogene-Miocene time and (2) the **Permian Kaibab Formation** limestone with (potentially) self-sealing intraformational gypsum layers and overlain by the Triassic Chinle Formation.

Revised ARCO 3 Peaks #1 well log: Originally interpreted by Van Kooten (1988), the Jurassic & Triassic stratigraphy were revised with control from local wells, outcrop & open mine pits (Sprinkel, pers. comm).

GEOLOGIC UNCERTAINTY

The igneous intrusion has historically been interpreted as a continuous, sheet-like intrusion which migrated by way of an old fault plane. Questions remain about the orientation and extent of the laccolith due to the limitations of the legacy seismic data. The extent of faulting and complexities from regional tectonism are also unknown at depth and could impact seal integrity.



A MULTIDISCIPLINARY SITE CHARACTERIZATION

LEGACY DATA

LEGACY GEOPHYSICAL DATA

A total-intensity aeromagnetic map roughly delineates the three bodies of quartz monzonite porphyry exposed in the district – the Three Peaks, Granite Mountain, and Iron Mountain Intrusions. **It is uncertain if the intrusions are separate events or a continuous laccolith.** There is magnetic and aerial gravity evidence for a considerable, though poorly constrained, southwestern extension of the monzonite intrusion.[3,4]

LEGACY 2D SEISMIC DATA

Several seismic lines show the quartz monzonite intrusion overlies relatively undeformed Paleozoic & Mesozoic sedimentary strata, while the growth and inflation of the laccolith folded and faulted the overlying strata to significant degrees.[5] Repocessed seismic data indicate promising laterally continuous reflectors and several viable structural and stratigraphic trap styles. **The degree and extent of faulting is unknown.**

LEGACY PETROPHYSICAL DATA

Two exploration wells tested Paleozoic and Mesozoic targets: Cedar City #1 (11,700 ft.) drilled to Devonian carbonates; and ARCO Three Peaks #1 (15,590 ft.) drilled to Mississippian Redwall Limestone, and yielded a set of well cuttings which may be used to characterize CO_2 injection targets.

MODERN DATA

SURFACE GEOLOGICAL DATA

Outcrops will be used to evaluate seal and reservoir physical properties. Geologic mapping will be used to provide surface control for structural modeling.

MODERN GRAVITY DATA

Gravity surveying is a cost-effective and non-invasive technique used to **quantify changes in material density** at depth and **delineate subsurface geometries,** adding independent checks on data interpretation from other geophysical methods and rock property analyses. We designed the gravity survey to maximize the potential of defining subsurface basin geometry and subsurface unit architecture

Relative gravity measurements were made using a terrestrial gravimeter and tied to absolute gravity stations. Measurements were focused on the inferred axis of the laccolith (see: Geologic Context) and build on pre-existing, regional scale data collected primarily in the 1970s by the Pan American Center for Earth and Environmental Studies (PACES).[6]

Gravity measurements were tied to high precision GPS with elevation control of 10 cm or better which equates to uncertainties in the gravity field of 0.03 mGal or better.[7]

ABOVE: Gravity survey equipment (CG-5 gravimeter and GPS tripod) with Iron Mountain in the background

GRAVITY WORKFLOW

DATA COLLECTION

Gravity and GPS data are collected in a series of field work campaigns. Measurements are attempted at even spacing while navigating land access and terrain constraints. Files are examined for QA/QC and processed using the methods of Gettings et al. (2008).

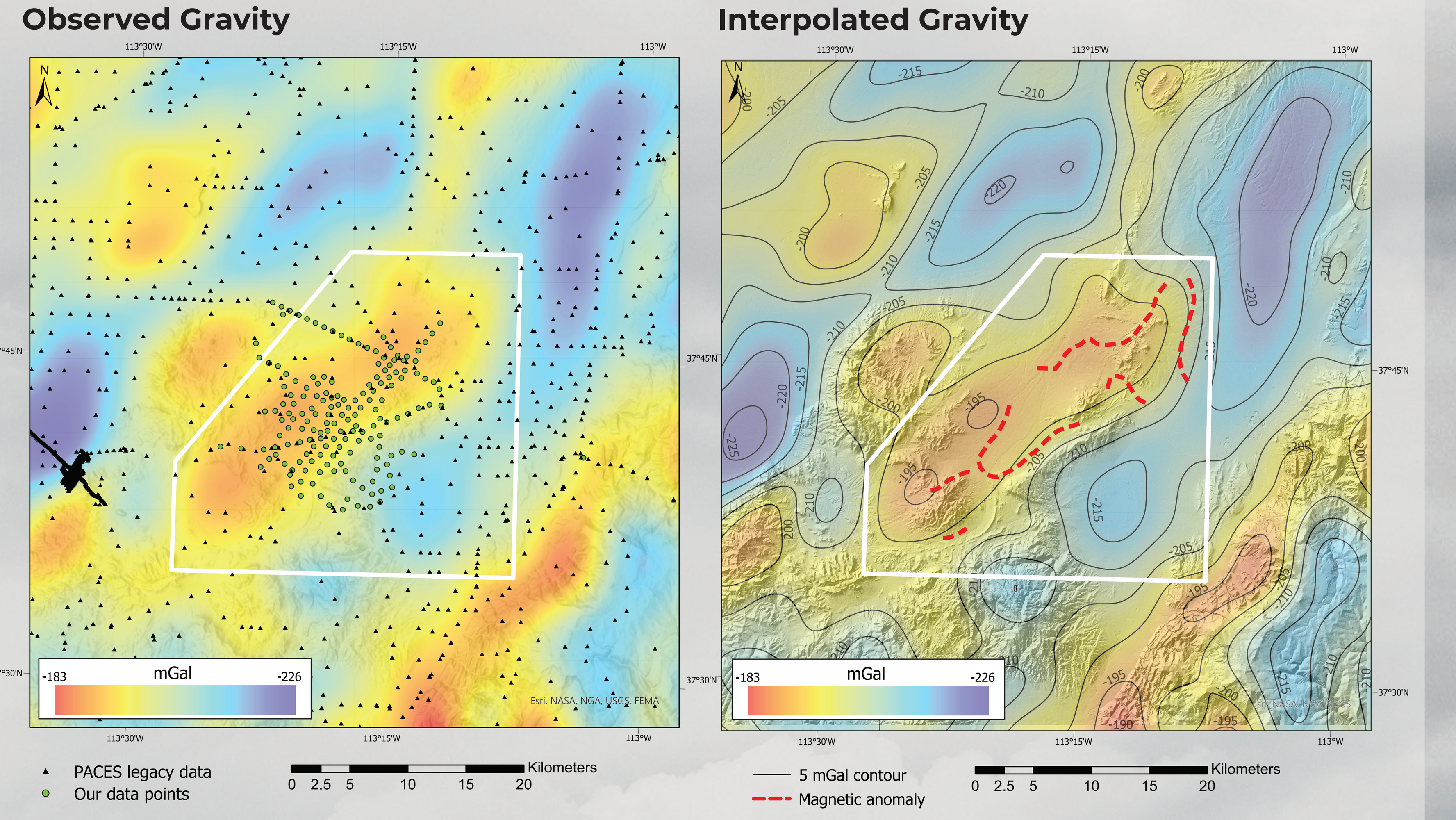
OBSERVED GRAVITY

The fine-scale campaign data are combined with pre-existing regional scale PACES gravity to create an initial Complete Bouguer Gravity Anomaly (CBGA) map of the field area. The map below shows the collected points and the outline of the Blank & Mackin map.

INTERPOLATED GRAVITY

Gravity is interpolated using an equivalent source method which uses block averaging to create a more accurate representation of the gravity field and identify signals that will propagate on a regional scale.[8] The map is layered with a DEM and shows the outline of the magnetic anomaly.

PRELIMINARY MODELING & INTERPRETATION



Our study confirmed the presence of a **large mass excess in the basin and range valley fill which we interpret as a volcanic intrusion**, as expected from legacy geophysical surveys. This is contrary to standard basin and range gravity maps where the ranges are typically gravity highs and basins are gravity lows.[6] The high gravity signal expanding beyond the valley indicate a **greater amount of laccolith injection than others have identified**, however there is a range of intensity throughout the valley (+/- 5 mGal) indicating that the **laccolith geometry may be more complicated than the historical interpretation** of a sheet-like intrusion by way of an old fault plane (see: Geologic Uncertainties). Compared to surrounding mountain ranges and valleys, the laccolith has a gravity signal amplitude of 20-25 mGal. **The gravity signal is orders of magnitude larger than the survey method precision of 0.03 mGal.** Compared to legacy geophysical data, the gravity field looks shifted to the northwest- this may be due to a neighboring deep basin which can pull down the gravity signal.

Future work is planned to collect more data (see: yellow points in Geologic Context) to further constrain the northwest extent of the laccolith. We also plan to create 2D gravity cross sections to understand intrusion geometry and compare to legacy 2D seismic data.

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3: Blank, H. R., Jr., and Mackin, J. H., 1967, Geologic interpretation of an aeromagnetic survey of the Iron Springs district, Utah: U. S. Geol. Survey Prof. Paper 516-B, p. B1-B14

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5: van Kooten, G. K. (1988). Structure and hydrocarbon potential beneath the Iron Springs laccolith, southwestern Utah: Geological Society of America Bulletin, 100(10), 1533-1540.

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Gettings, P., D.S. Chapman, and R.G. Allis., 2008, Techniques, analysis, and noise in a Salt Lake Valley 4D gravity experiment: Geophysics, v.73, WA71-WA82, https://doi.org/10.1190/1.2996303.