Geophysical Exploration in Lithium Salars.
Lessons Learned: Exploration Advances Driven by Experience

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TITAN 24

2D Deep earth imaging – distributed data acquisition of multi-parameter geophysics: Resistivity, IP and broad band magnetotellurics (MT resistivity)

ORION 3D

3D Imaging – complete 3D data acquisition for complex environments providing accurate surface to depth imaging of Resistivity, IP and MT

SPARTAN MT

Flexible 2D and 3D deep resistivity imaging utilizing high resolution 24-bit MT

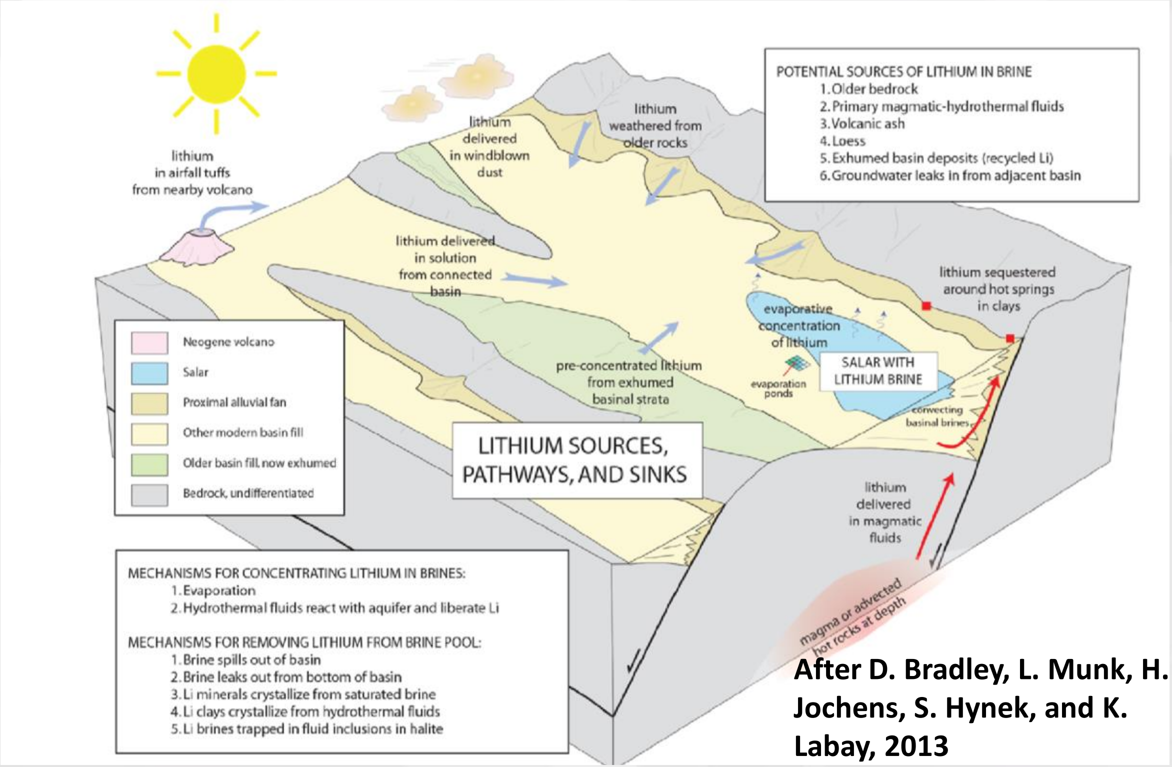
Broad Range of Expertise and Services

- Survey design, planning, acquisition, QA/QC, interpretation, data integration and consulting services
- Complete suite of conventional ground geophysical surveys including; gravity, magnetic, radiometric, IP (surface and borehole), TEM (surface and borehole), Max-Min, CSAMT and VLF

Geophysical Exploration in Lithium Salars. Challenges

- **Geological Complexity**
- **Dynamic Resource**
- **Weather**
- **Highly Conductive environment**
- **Exploration around production or advanced development may encounter cultural noise.**

Geological Complexity

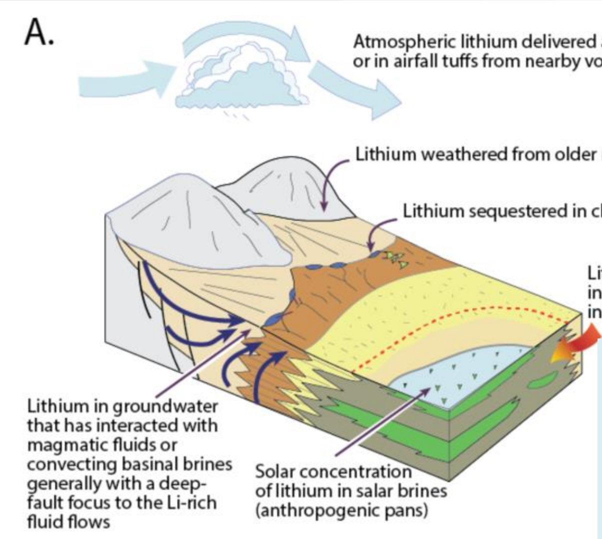


After D. Bradley, L. Munk, H. Jochens, S. Hynek, and K. Labay, 2013

Schematic deposit model for lithium brines showing part of a closed-basin system consisting of interconnected subbasins

Dynamic Resource

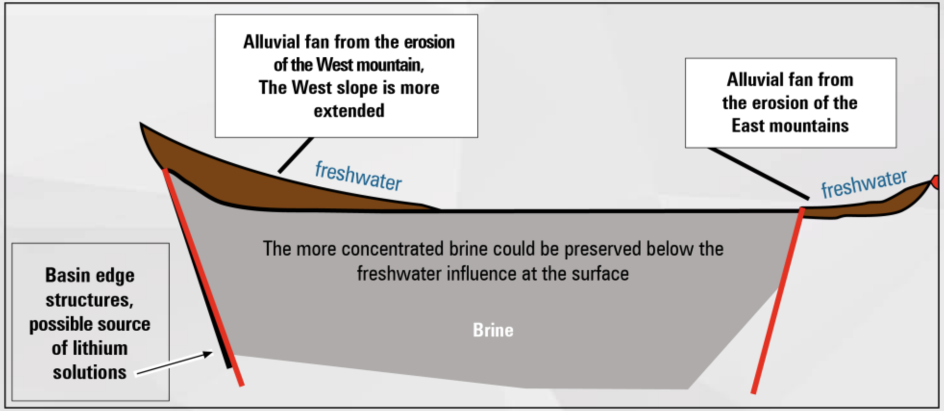
- Resource flows either naturally or by pumping

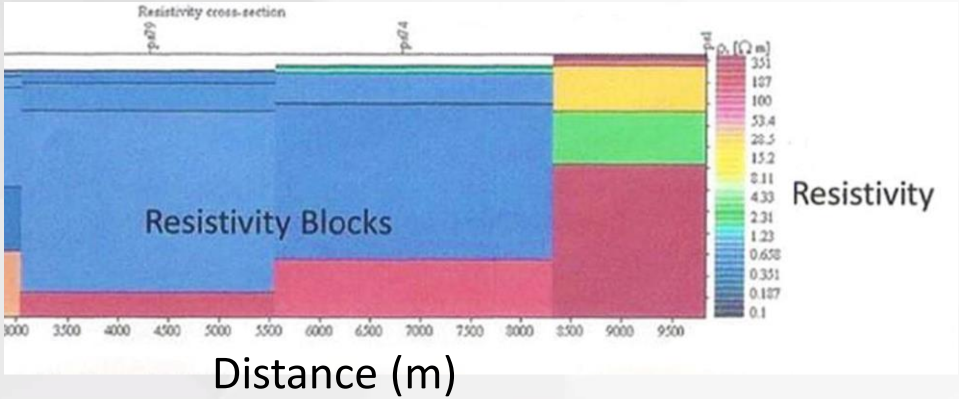


www.saltworkconsultants.com

Highly Conductive environment

Water resistivity decreases with increased salinity





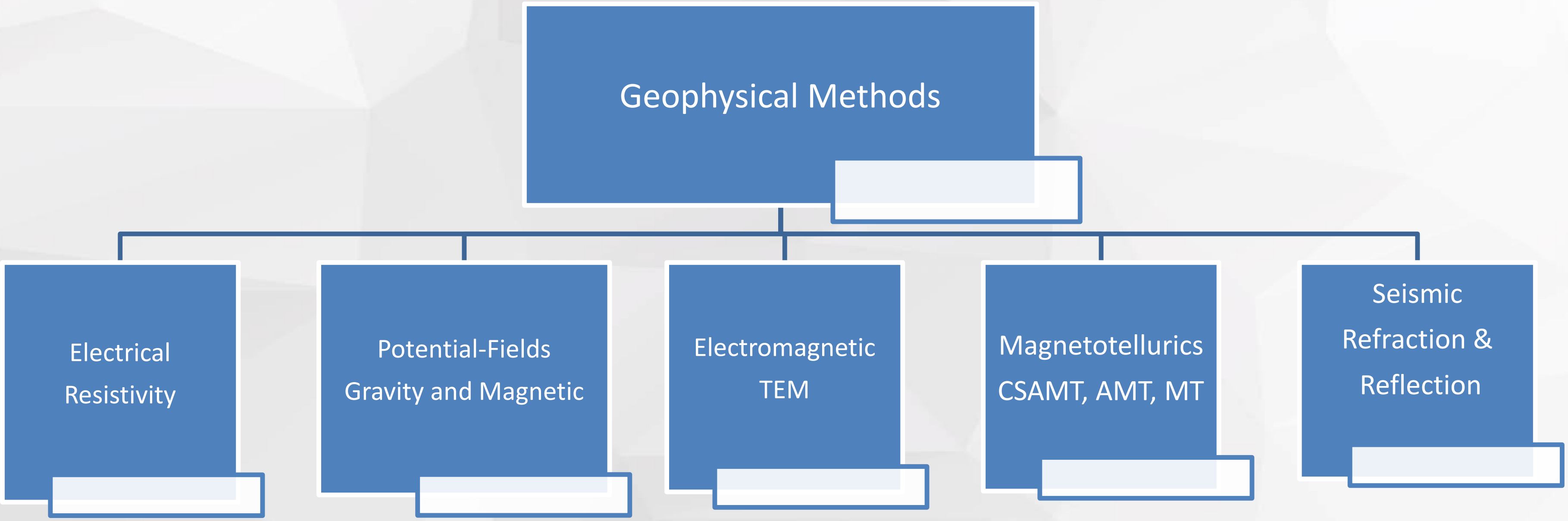
https://libertyonelithium.com

Exploring in and around sites in production

- EM noise – power lines, generators, etc.
- Schedule around mine production
- Access – how to place sensors, and where?
- Health and Safety

Some traditional mineral exploration techniques may be unreliable when faced with production site challenges

Geophysical Methods

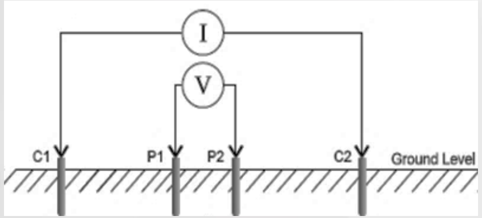


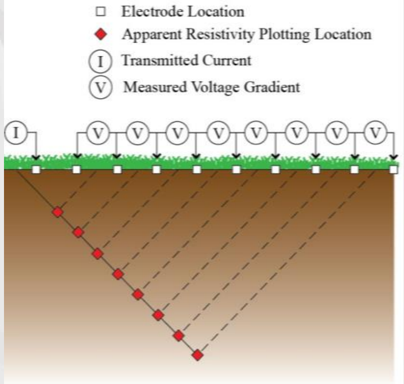
Electrical Resistivity Methods

Resistivity surveys map resistivity/conductivity in the subsurface

Electrical properties are determined by imposing a current in the ground using a transmitter and electrodes (C1-C2). The result is a voltage measured between the potential (receiver) electrodes (P1-P2). Values and interpretability depend on both the electrode configuration and the actual subsurface distribution of the electrical properties with respect to the electrode locations.

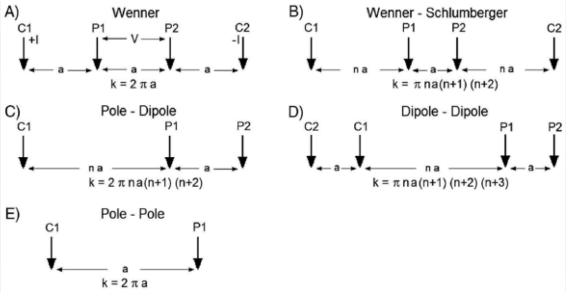
These surveys may be accompanied by induced polarisation (IP) measurements.





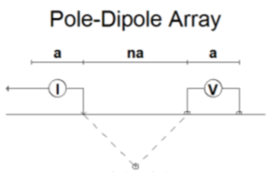
- Advantages
  - A variety of electrode arrays are available and selection depending on the survey objectives and target characteristics
  - Resistivity models may be calculated by inversion and presented as 2D sections and 3D volumes
  - Arrays may be combined to improve data quality and target response
  - More sensitive than EM methods when mapping changes in resistivity
- Disadvantages
  - Galvanic contacts required
  - Remote electrodes needed for some array configurations
  - Depth of investigation (DOI) limited to about 1 km
  - Data need to be inverted for accurate interpretation

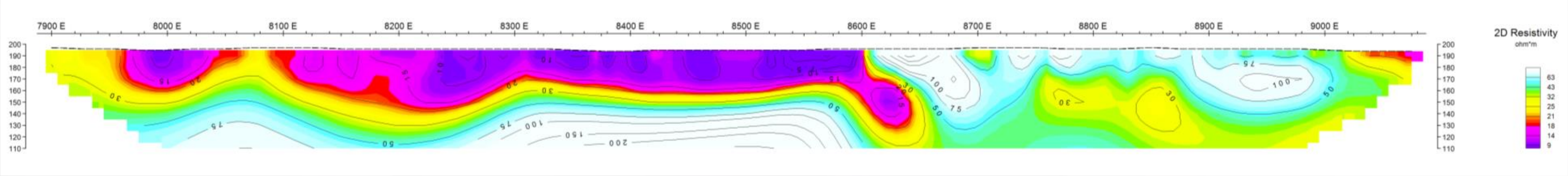
Commonly used electrode arrays and their geometric factors k

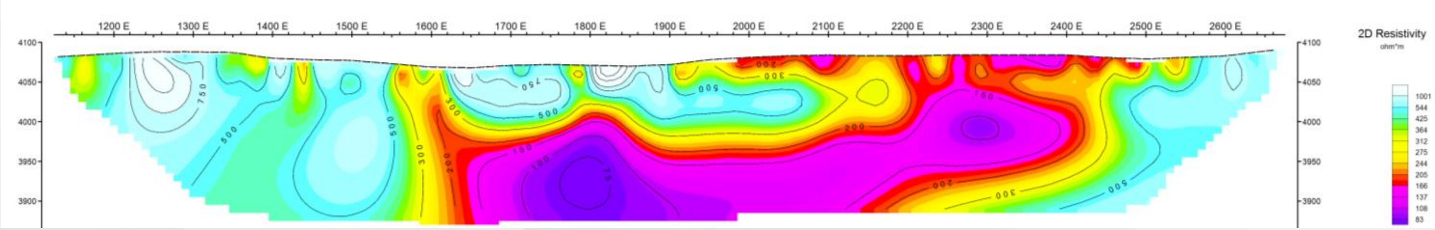


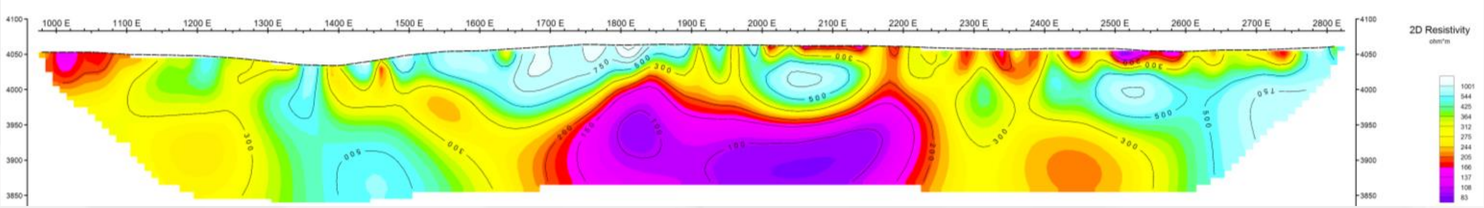
Electrical Resistivity Methods – 2D models

Resistivity survey – Pole Dipole array - 2D Models







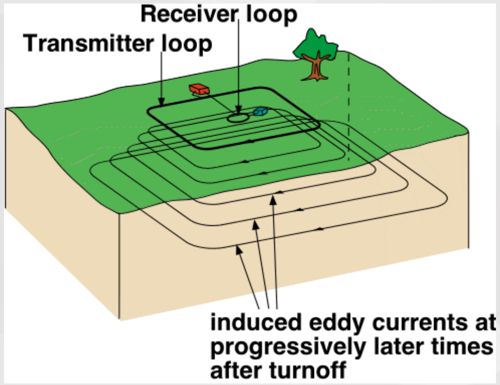


Courtesy Litio Minera Argentina S.A.

Transient Electromagnetics (TEM)

EM Surveys detect conductors. Very suitable for brine detection

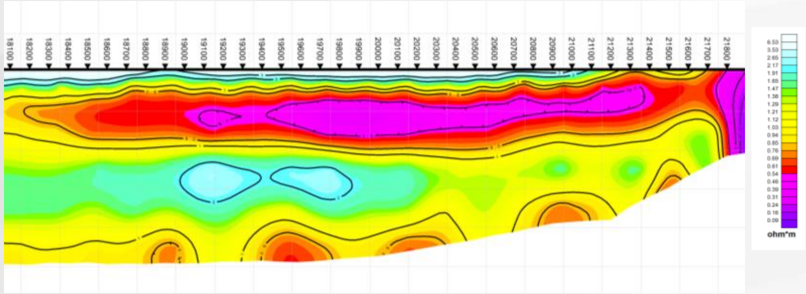
- In-loop configuration
- Sensitive to the immediate vicinity of the transmitter loop
- 1D Resistivity vs depth model
- Up to 600 m depth of investigation (DOI)



– Advantages
  - Maximum field strength throughout the survey area
  - Maximum depth of exploration
  - Maximum sensitivity to small targets
  - Independent of direct contact with surficial soil
  - Better detection of conductive targets than other methods

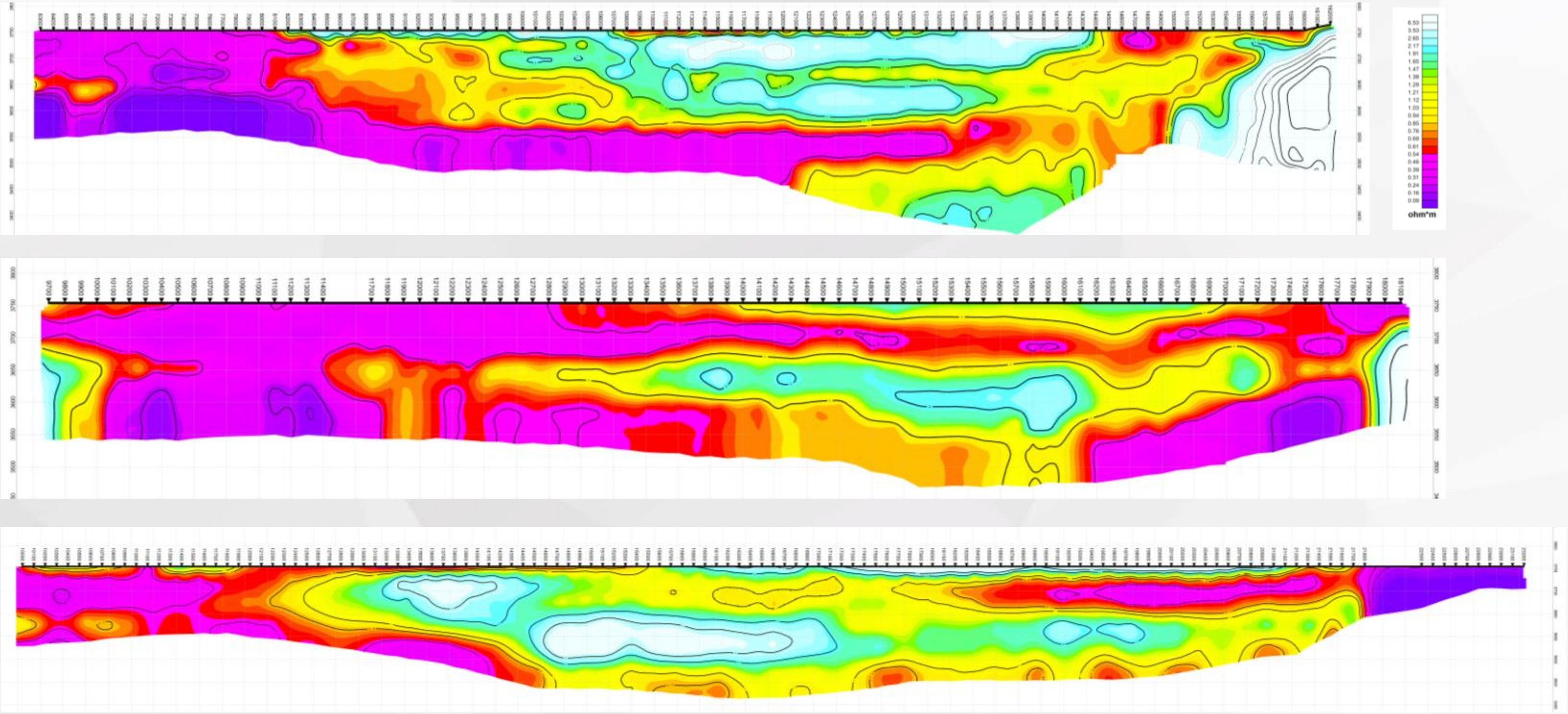
– Disadvantages
  - In-loop configuration is insensitive to vertical bodies (other configurations are available)
  - complex interpretation
  - 1D (layered earth) assumptions

Example Profile: stitched 1D discrete layered model (Mariana Project, LMA)



TEM: Mariana Project

Profiles: stitched 1D discrete layered model

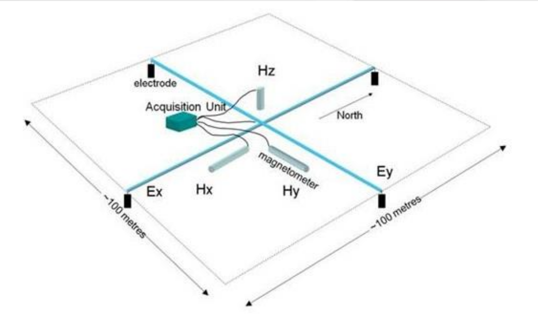


(Courtesy of Litio Minera Argentina S.A.)

Magnetotellurics (CSAMT, AMT, MT)

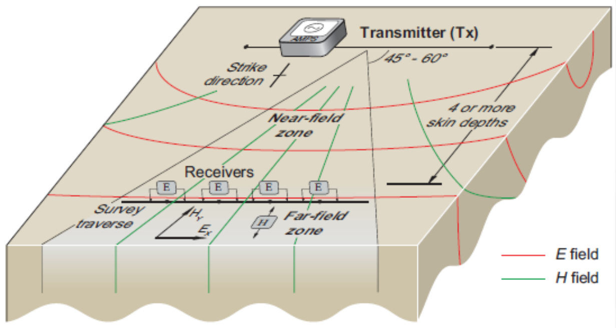
MT surveys map resistivity & conductivity deep in the subsurface

- Passive methods (MT, AMT) use EM signals originating from the magnetosphere and distant thunderstorm activity as the signal source
- Active methods (CSAMT) uses the signal transmitted from a large dipole or loop located at distance from the survey area.
- Frequency-based sounding measurements
- Electrical soundings are obtained that map variations in electrical properties with depth
- DOI depends on frequencies measured and the resistivity of the subsurface

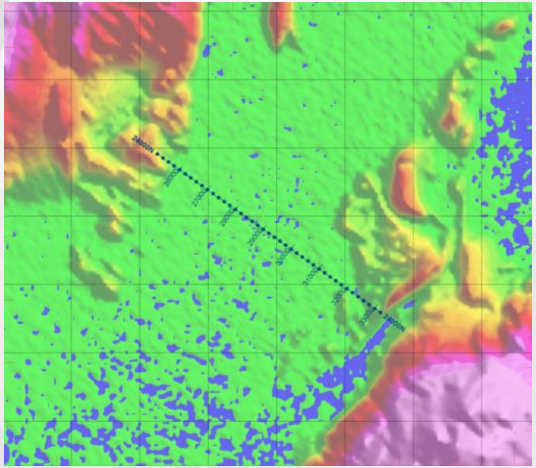


– Advantages
  - DOI from a few 10' s of meters to several km is possible
  - Inversion models provide 2D sections and 3D resistivity volumes
  - Wide frequency ranges are available
  - Short recording period for CSAMT
– Disadvantages
  - Remote measurements needed for denoising (MT)
  - Long recording periods may be required (MT, AMT)
  - CSAMT survey design may be limited due to bipole location

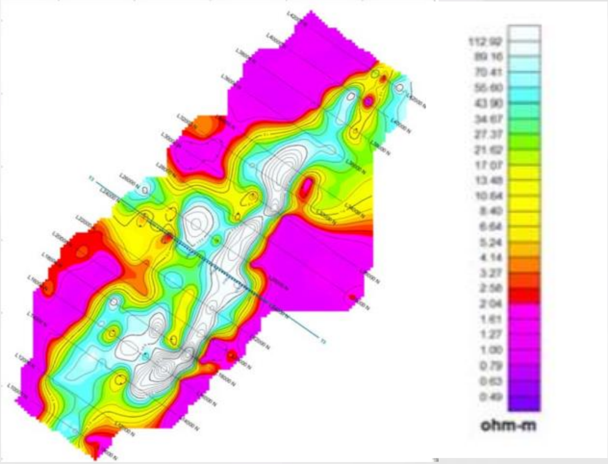
CSAMT survey arrangement



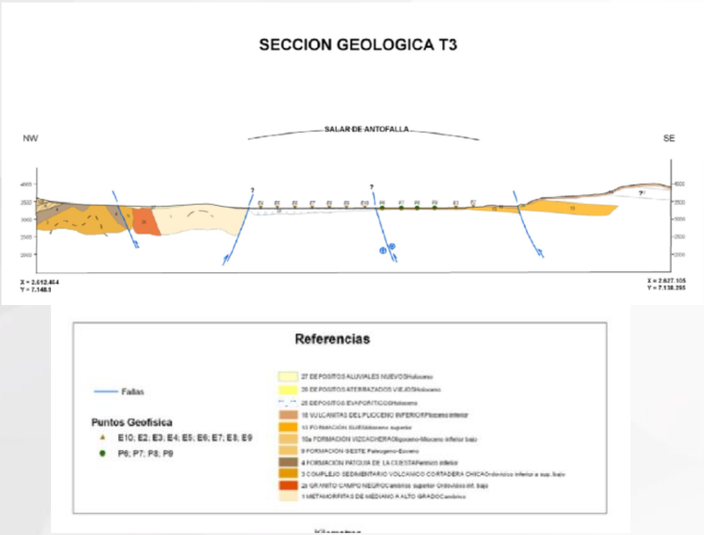
Magnetotellurics (MT). Salar de Antofalla



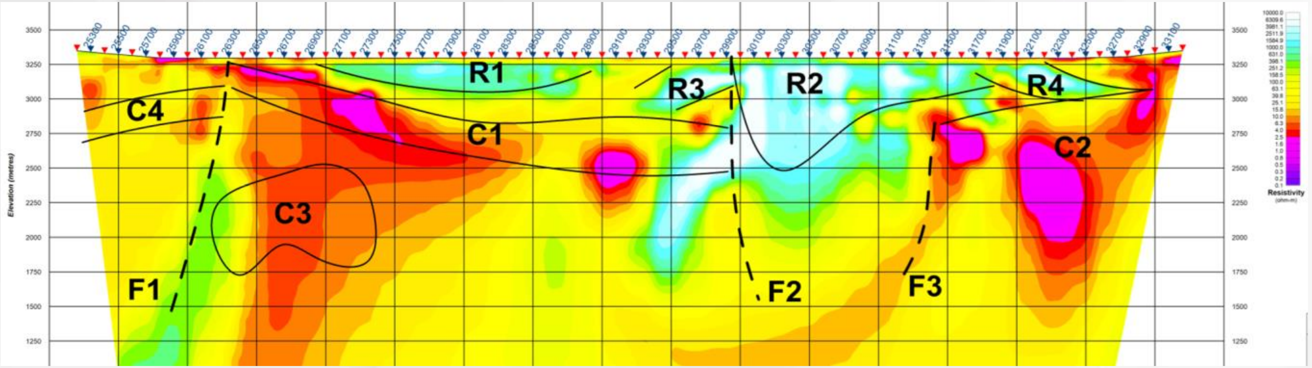
Survey Location Map with topography



TEM resistivity from discrete layer plots at 3250 m elevation

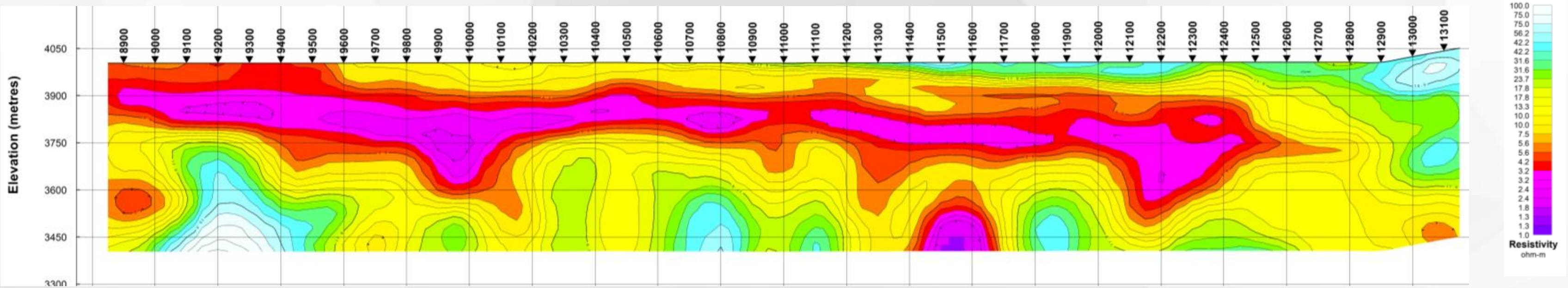


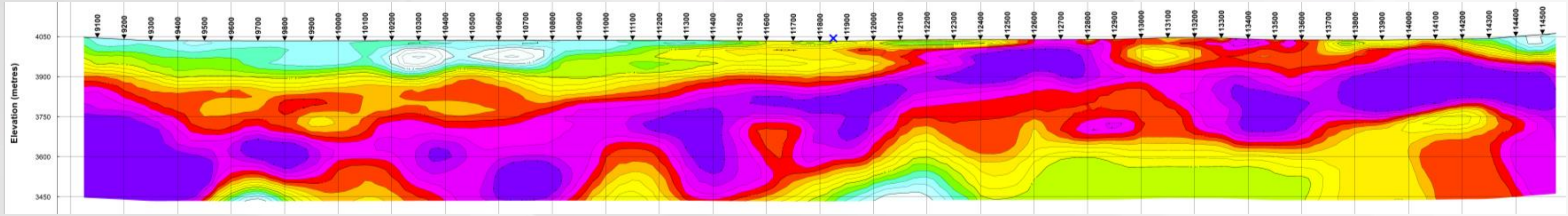
MT 2D results with Interpretation



Magnetotellurics (CSAMT): Salar de Hombre Muerto

CSAMT Resistivity sections – 100 m dipole size -





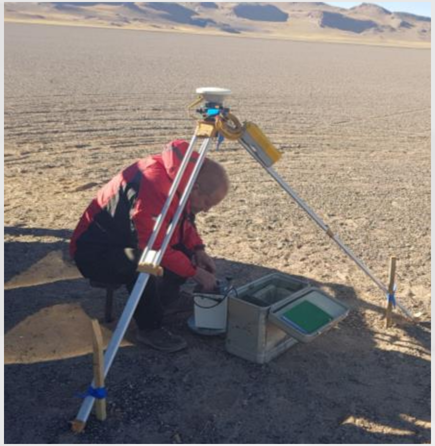
(Courtesy of Dempsey Minerals Limited)

Potential Methods: Gravity Method

Gravity surveys map variations in subsurface density

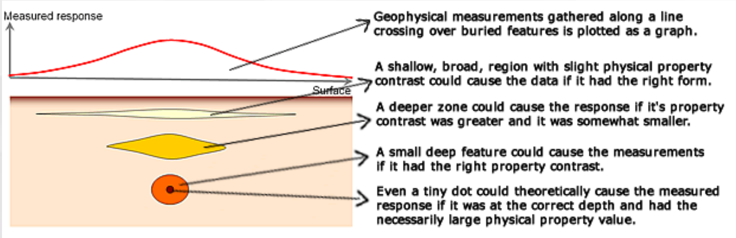
Variations in subsurface density cause variations in the Earth's gravitational field. Relative measurements of the vertical component of the Earth's gravity field are made using a gravity meter.

The reduction of gravity data involves a series of corrections to remove temporal, latitude, height and terrain effects that all have significantly higher amplitude than the signal.



– Advantages
  - Relatively independent of terrain conditions except in the presence of extreme topography
  - Field procedures are fast and require only a small field crew (2-3)
  - Precise measurements
  - Direct correlation with geology may be possible if density data are available

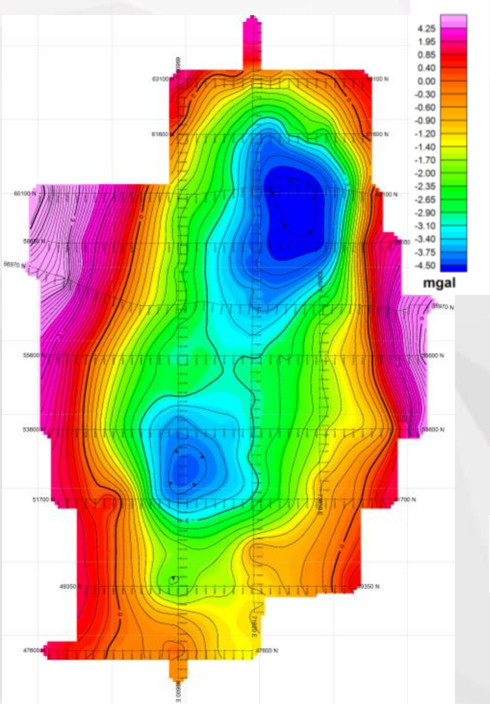
– Disadvantages
  - A complementary DGPS survey must be run along with gravity survey to measure precise positions and elevations
  - The effects of terrain variations surrounding the survey area may be significant and are sometimes difficult to remove
  - Sophisticated inverse modelling methods are available, but the results are non-unique. This may be reduced with petrophysical data and other geological information.



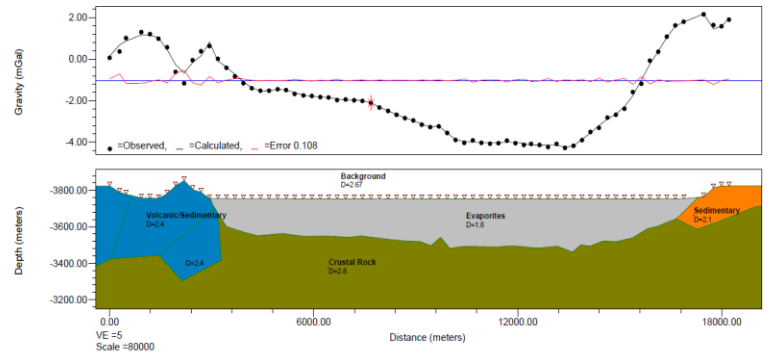
https://www.eoas.ubc.ca

Gravity

Residual Bouguer Anomaly Map - Mariana Project (Litio Minera Argentina S.A.)

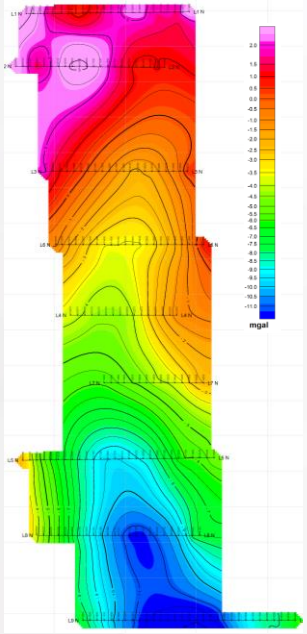


2D geological preliminary model of one transect - Mariana Project (Litio Minera Argentina S.A.)



LITIO MINERA ARGENTINA

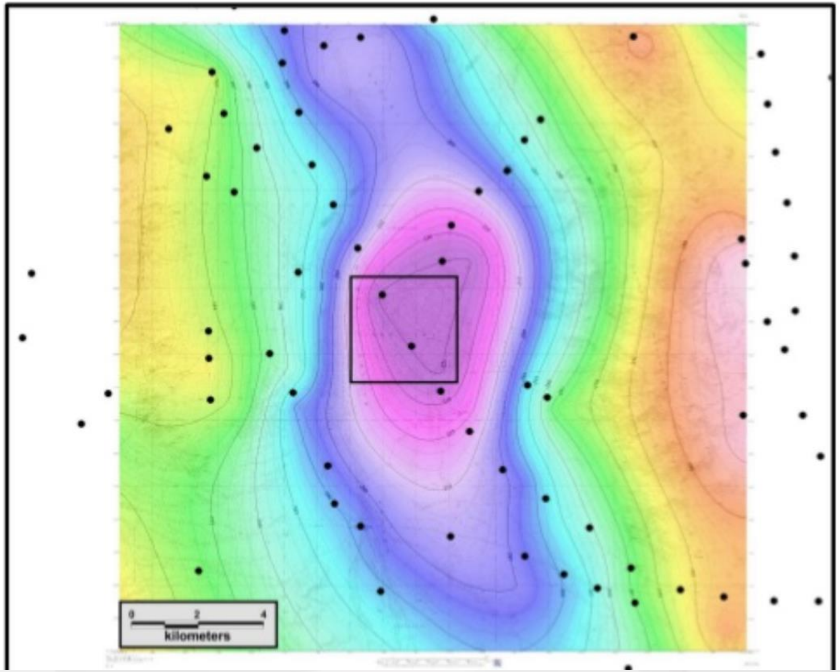
Residual Bouguer Anomaly Map – Salar de Hombre Muerto (Dempsey Minerals Limited)



DEMPSEY MINERALS LTD

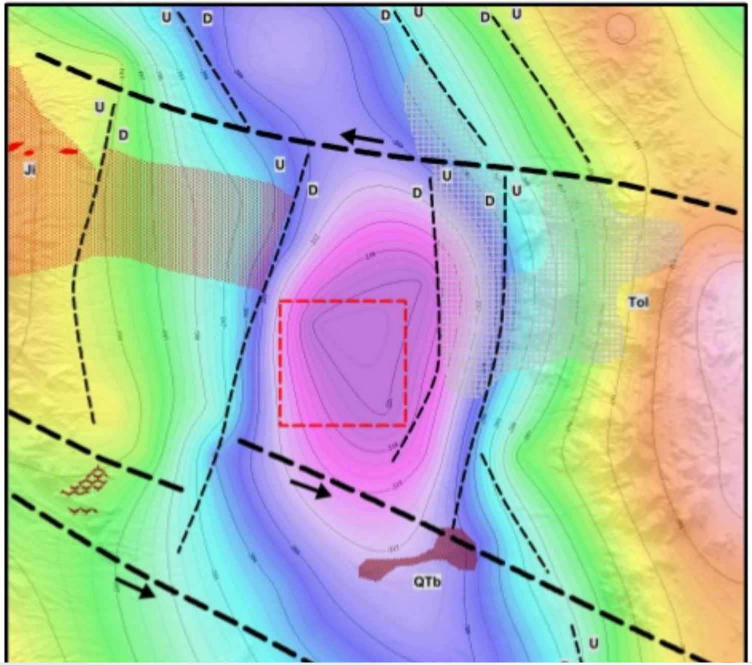
Kibby Basin NV - Belmont Resources Inc: Gravity

Figure 2 presents the complete Bouguer anomaly of gravity at 2.50 g/cc over the topography. The current property position is shown as a black rectangle. A prominent gravity low, as expected, correlates with the basin center flanked by highs in the outcrop areas to the east and west. Average station spacing is variable but on the order of two kilometers with significant gaps. Such coverage is adequate for large scale analysis but completely inadequate for property scale work.



basin. Between the two lateral displacement structures is a zone of extension typified by at least four high angle normal faults oriented approximately north-northeast. High angle normal displacement along these structures is interpreted to have formed the main central basin. Such fault geometry is indicative of an overall trans tensional environment and termed a pull-apart basin. Figure 8 shows a three dimensional block diagram of such a basin's formation.

A large area of **QTb** is mapped within the basin near the southern lateral fault. The occurrence of a large area of **QTb** within the basin indicates additional **QTb** could well be encased with the basin fill and possibly play a role in ponding and/or controlling the distribution of lithium brines.



Potential Methods: Magnetic Method

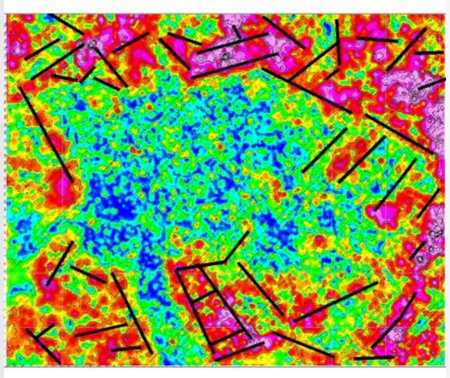
Magnetic surveys map the local magnetic field

Variations in rock magnetism are mostly controlled by a physical property called magnetic susceptibility which responds to the earth's magnetic field. Remanent magnetization also plays a role.

The reduction of magnetic data involves a series of corrections to remove temporal, levelling and other effects.

Maps of Total Magnetic Field can be easily obtained, as well as many related magnetic measures and filters.

- Advantages
  - Relative inexpensive (quick, small crew)
  - Very large areas may be covered in a short time
  - Provides an overall idea of the regional structure & geology
  - Direct results without complex data processing
  - Possibility to invert data to get 2D & 3D models
- Disadvantages
  - Cultural debris and noise can reduce quality or prevent some areas from being surveyed
  - Discrimination between geological units depends on a consistent magnetic contrast. Magnetic susceptibility within units is often highly variable
  - Corrections for temporal variation are required



Analytic Signal Map with interpretation

Kibby Basin NV - Belmont Resources Inc: Magnetics

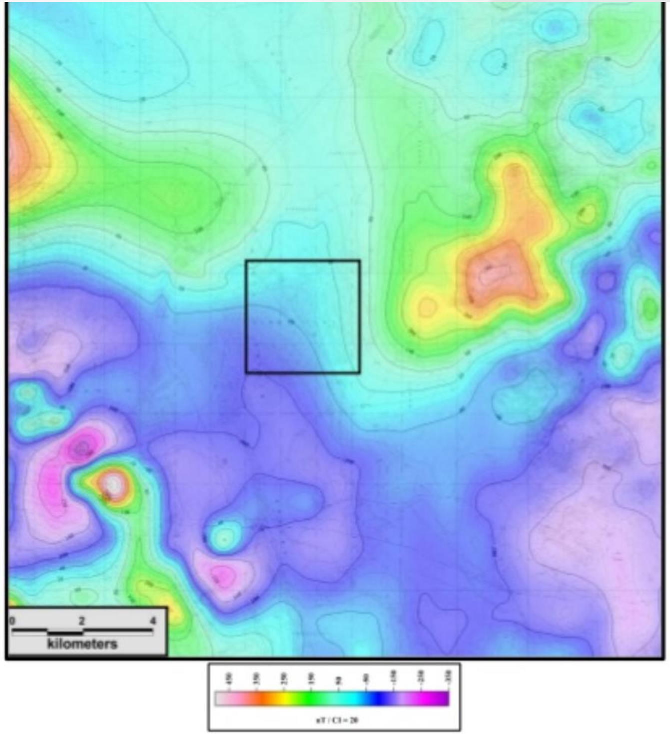


FIGURE 4: RTP Magnetics over Topography

Processing of the merged data included generation of the total magnetic intensity (TMI) grid, which was then reduced-to-pole (RTP) with a USGS algorithm. Figure 4 presents the RTP image over topography. The Kibby Basin property is depicted with a black rectangle. The basin is revealed as a gap in the band of east-west elevated magnetic values.

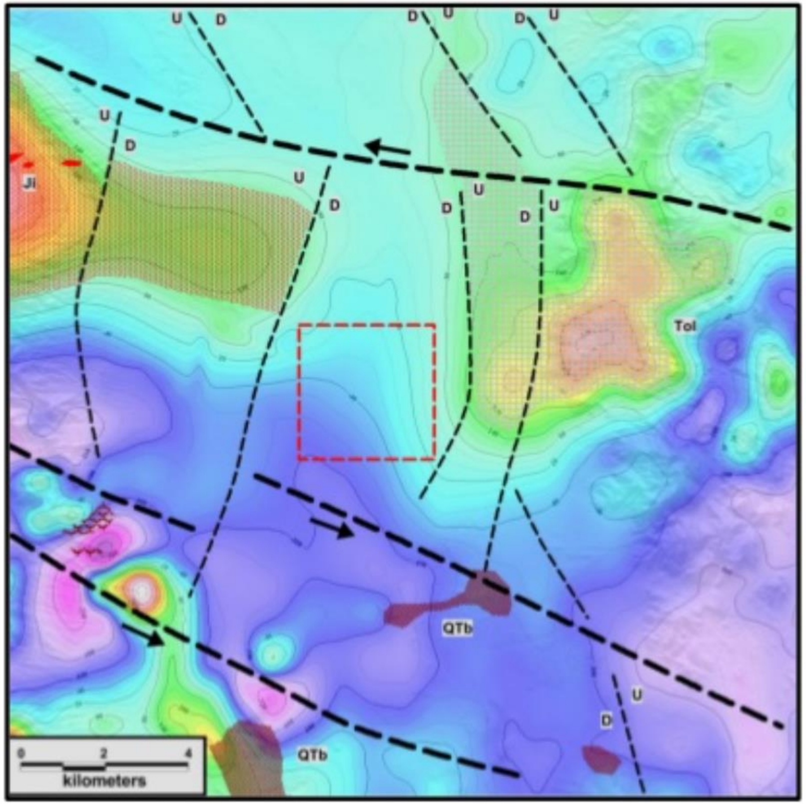


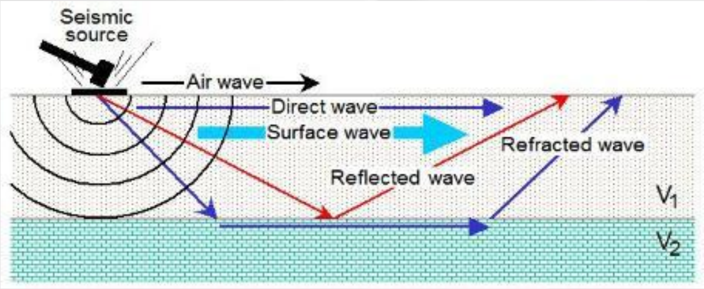
FIGURE 7: RTP Magnetics overlain by Interpretation

Seismic Methods

Seismic methods use reflection and refraction of elastic waves to determine the structure of the subsurface

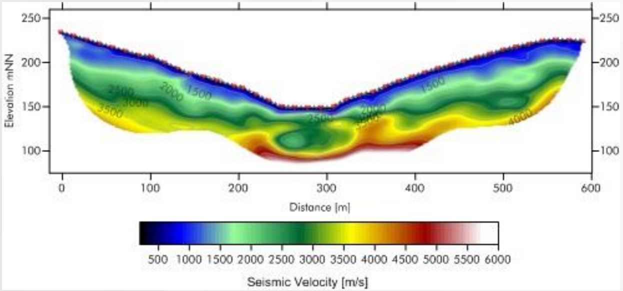
Waves are created by a source and propagate through the subsurface before being recorded by detectors that measure deformation of the ground

The path of the waves from source to detector is controlled by the elastic properties of the material through which they travel. Discontinuities in the elastic properties deflect and divide the seismic waves. Spatially dispersed detectors (geophones) record a series of waves that have taken different paths through the subsurface.



http://parkseismic.com/Whatisseismicsurvey.html

- Advantages
  - Seismic reflection surveys may produce the most detailed images of a deep and sub-horizontal subsurface of any geophysical method.
  - Many seismic methods available for different objectives
  - The output image resembles stratified geology in certain environments and if the proper information is available
  - Seismic refraction surveys may be ideal for shallow, simple layering (10-300 m and 1-5 layers)
- Disadvantages
  - Complex data acquisition and processing are required in order to detect and resolve the weak signals in seismic reflection data
  - Field labor for reflection surveys is complex and may be quite expensive
  - An energetic broadband source can be destructive (dynamite)



http://geotomographie.de

Methods summary: applications in a salar environment

Geophysical Method	Applications in salares	Prior information needed
CSAMT, MT, AMT	Brine layer/basement detection and characterization	Not necessary. Conductivity or depths useful for constrained modelling
Gravity and magnetics	Understanding of the basin/regional structure	Density values or depths to build 2D/3D meaningful models
Electrical Resistivity	Fresh water detection/small structures, resistivity contrasts	Not necessary. Conductivity or depths useful for constrained modelling
TEM	Brine layer detection and characterization	Not necessary. Conductivity or depths useful for constrained and improve models
Seismics	Lithology layering discrimination – Basement detection	Elastic properties of different lithologies to get a meaningful interpretation

Lessons learned

- It is helpful to know the petrophysical properties of the different lithologies or geological targets present in the project area
- Forward modelling may be helpful before conducting surveys
- The survey should cover not only the salar surface but the entire basin if possible
- Structurally controlled environments are very good candidates for exploration using magnetics and gravity
- In highly conductive environments such as salares, the best tools to map brine layers are:
  - TEM (first 300m)
  - MT (300 m + (to more than 1 km))
- A geophysical survey should not end with the delivery of the interpretation report. Whenever there is new geological data it is valuable to return to the geophysical model and improve it. The best way to reduce the ambiguity of a geophysical model is to add geological information

Acknowledgements

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- ❑ Dempsey Minerals Limited
- ❑ Vale
- ❑ Belmont Resources Inc

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Thank you