Exploring For Lithium Salars Resources With Geophysical Methods

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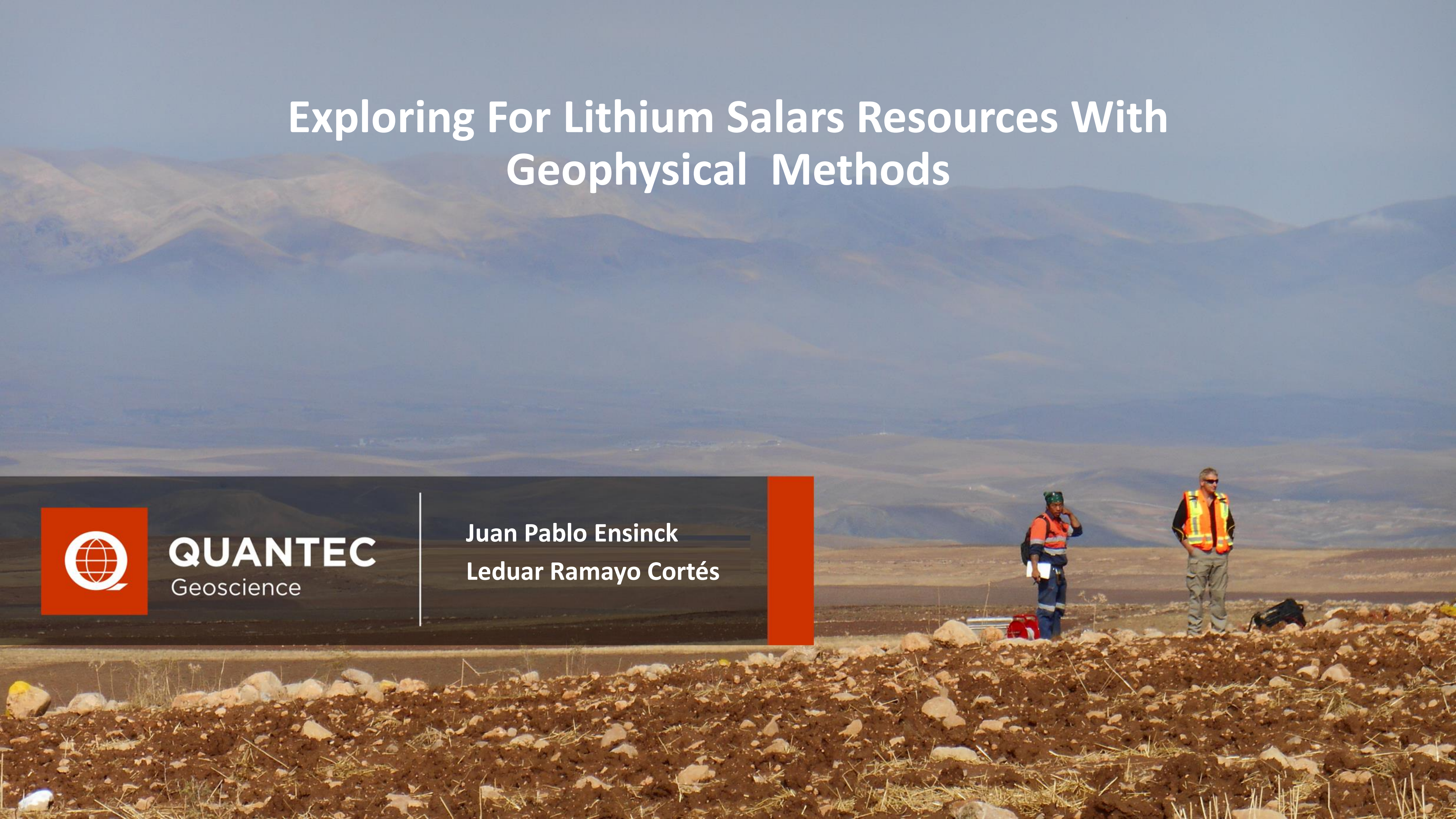


QUANTEC Technology and Services

TITAN

ORION 3D

SPARTAN MT

World Leading Deep Exploration Technology

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

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

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

Broad Range of Expertise and Services

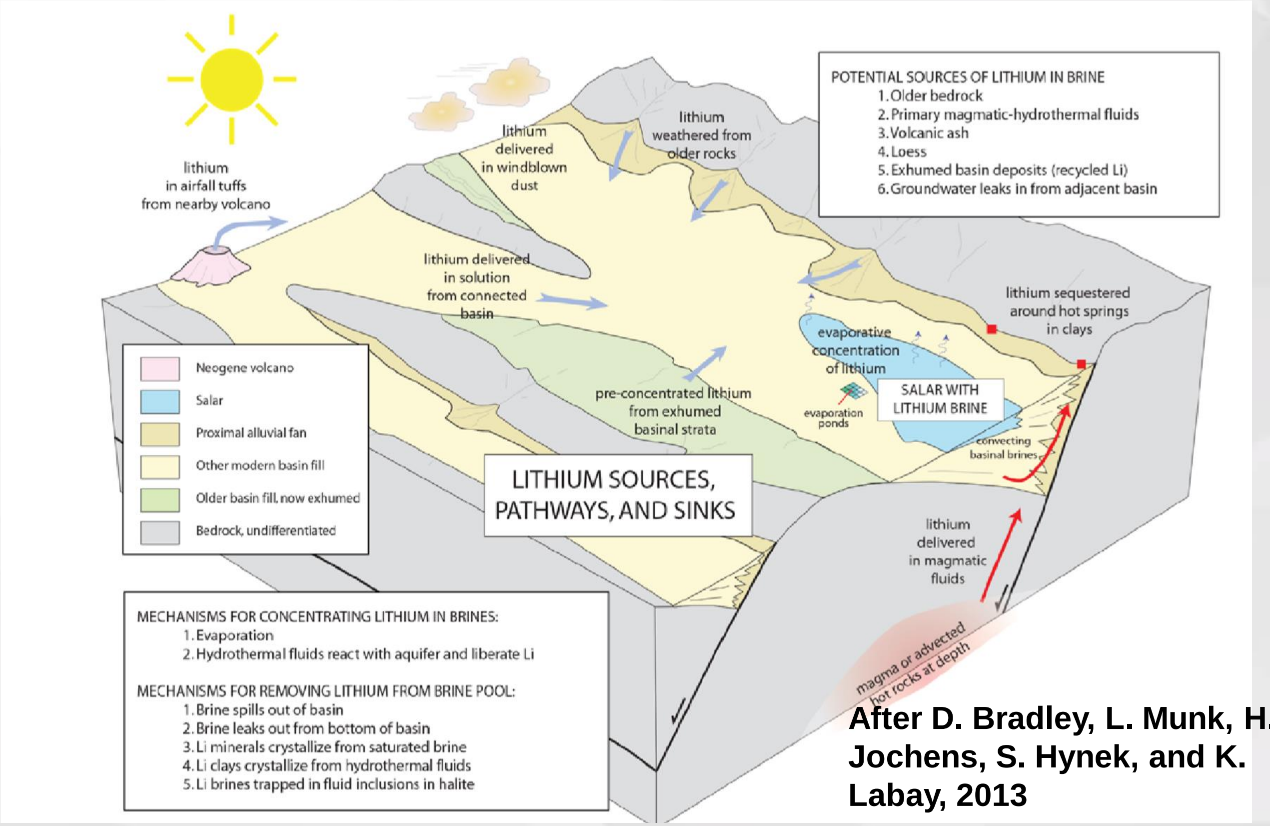
- Survey design, planning, acquisition, QA/QC, interpretation, data integration and consulting services
- Complete suite of conventional ground geophysical surveys including; gravity, magnetic, radiometric, IP (surface and borehole), TEM (surface and borehole), Max-Min, CSAMT and VLF

QUANTEC Geoscience

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

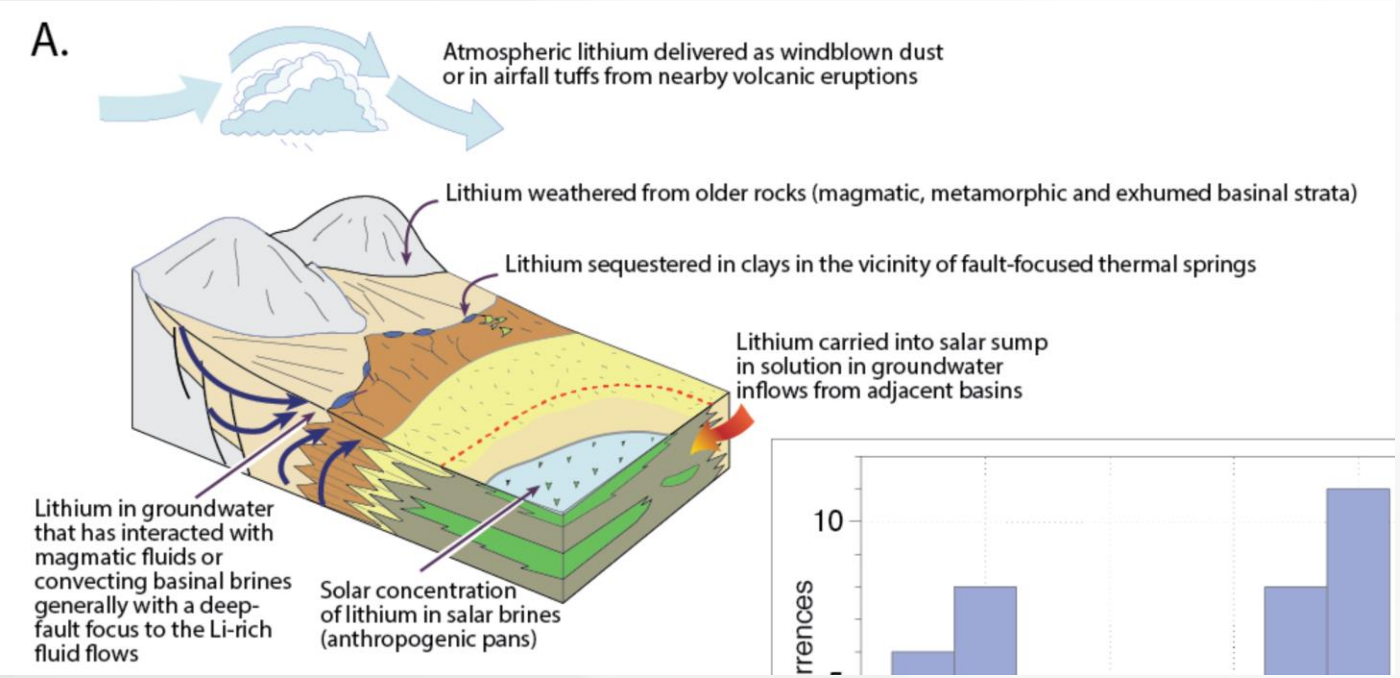


After D. Bradley, L. Munk, H. Jochens, S. Hynek, and K. Labay, 2013

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

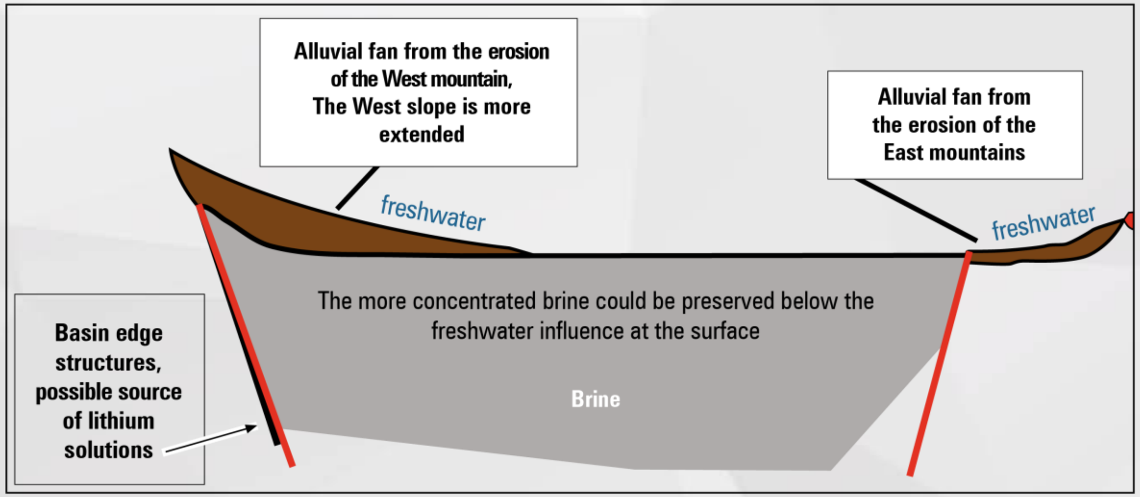
Dynamic Resource

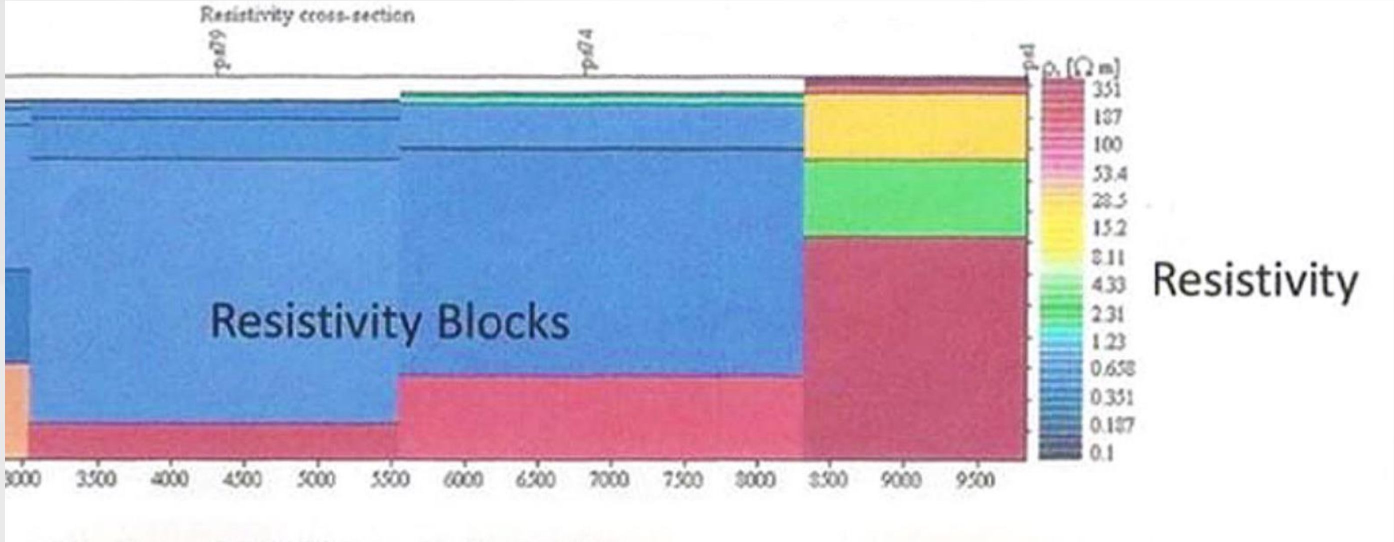
- Resource flows either naturally or by pumping
- Differences in every season



Highly Conductive environment

- Water resistivity decreases with increased salinity





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

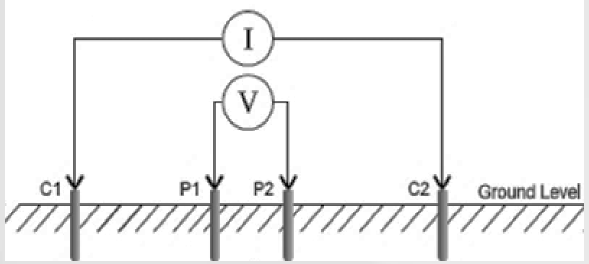
Geophysical Methods

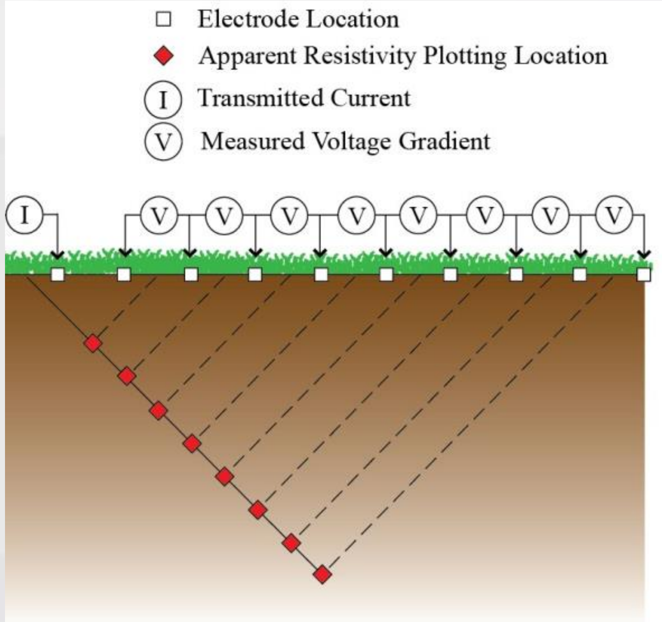
- Geophysical Methods
  - Electrical Resistivity
  - Potential-Fields Gravity and Magnetic
  - Electromagnetic TEM
  - Magnetotellurics CSAMT, AMT, MT
  - Seismic Refraction & Reflection

Electrical Resistivity Methods

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.

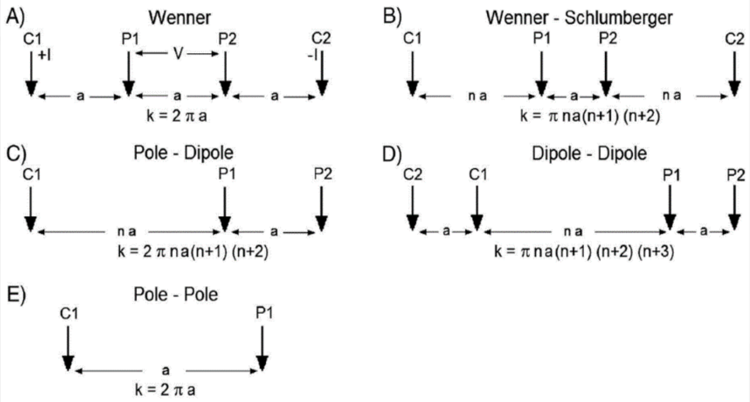
These surveys may be accompanied by induced polarisation (**IP**) measurements.





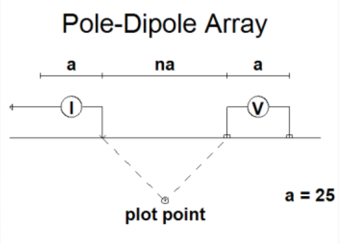
- Advantages
  - A variety of electrode **arrays** are available and selection depending on the survey objectives and target characteristics
  - Resistivity models may be calculated by inversion and presented as **2D** sections and **3D** volumes
  - **Arrays** may be **combined** to improve data quality 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

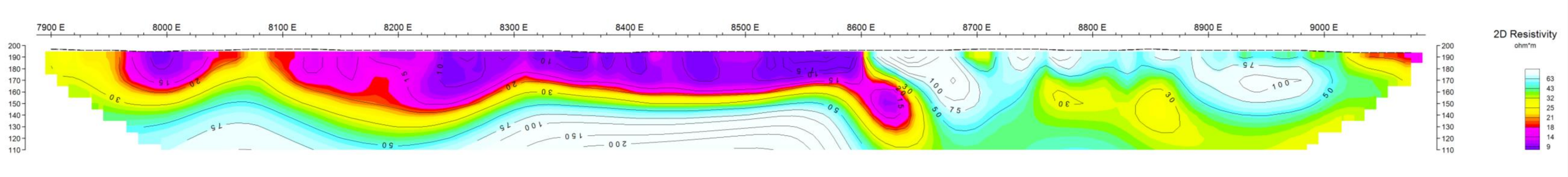
Commonly used electrode arrays and their geometric factors k

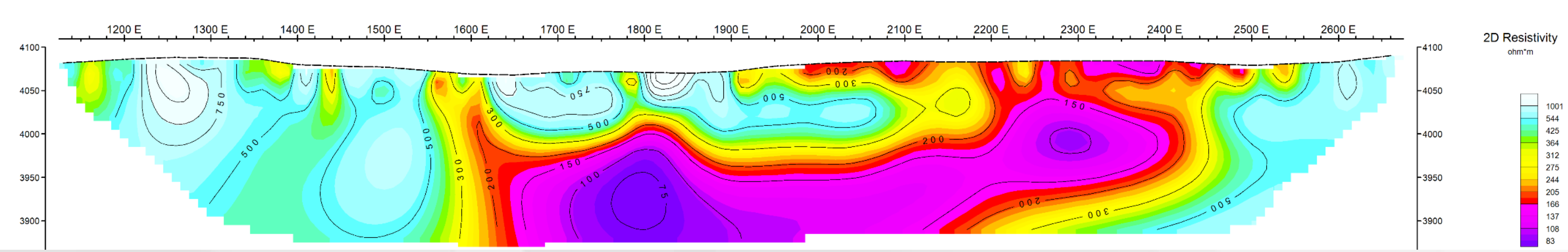


Electrical Resistivity Methods – 2D models

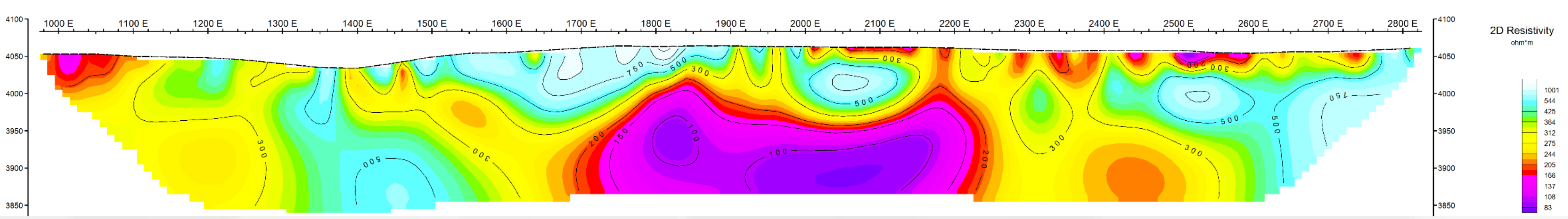
Resistivity survey – Pole Dipole array - 2D Models







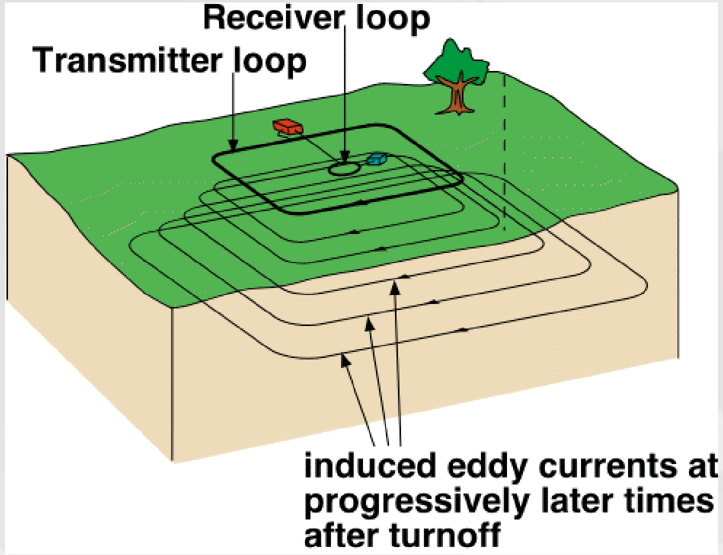
Courtesy Litio Minera Argentina S.A.



Transient Electromagnetics (TEM)

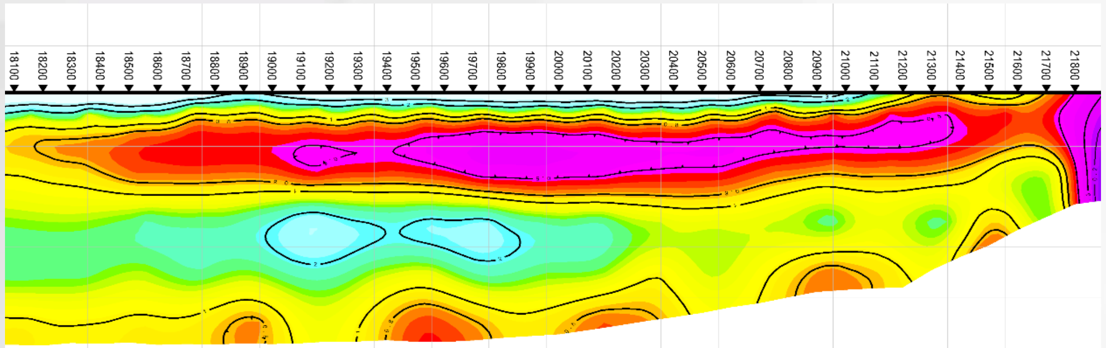
EM Surveys detect conductors. Very suitable for brine detection

- 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)



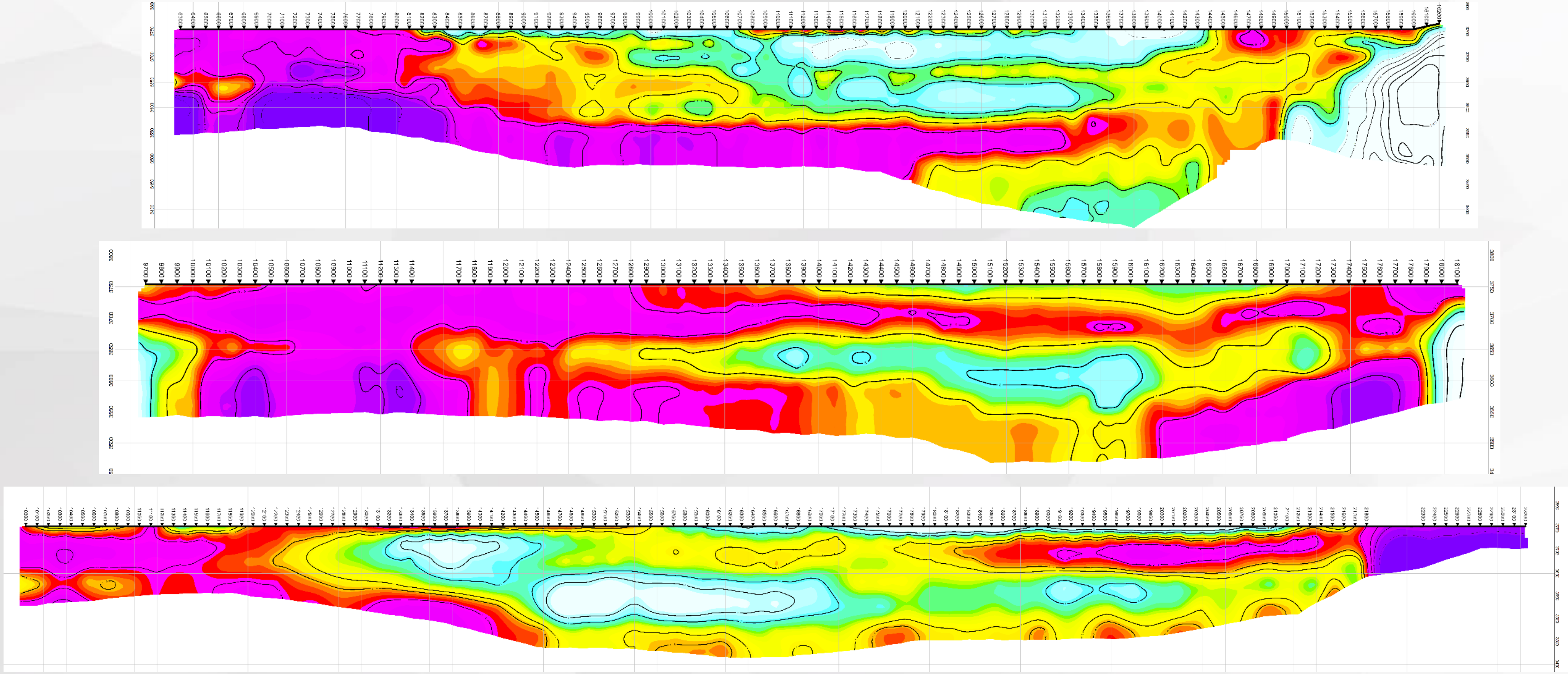
- Advantages
  - Maximum field strength throughout the survey area
  - Maximum depth of exploration
  - Maximum sensitivity to small targets
  - Independent of direct contact with surficial soil
  - Better detection of conductive targets than other methods
- Disadvantages
  - Complex interpretation
  - In-loop configuration is insensitive to vertical bodies (other configurations are available)
  - 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.)

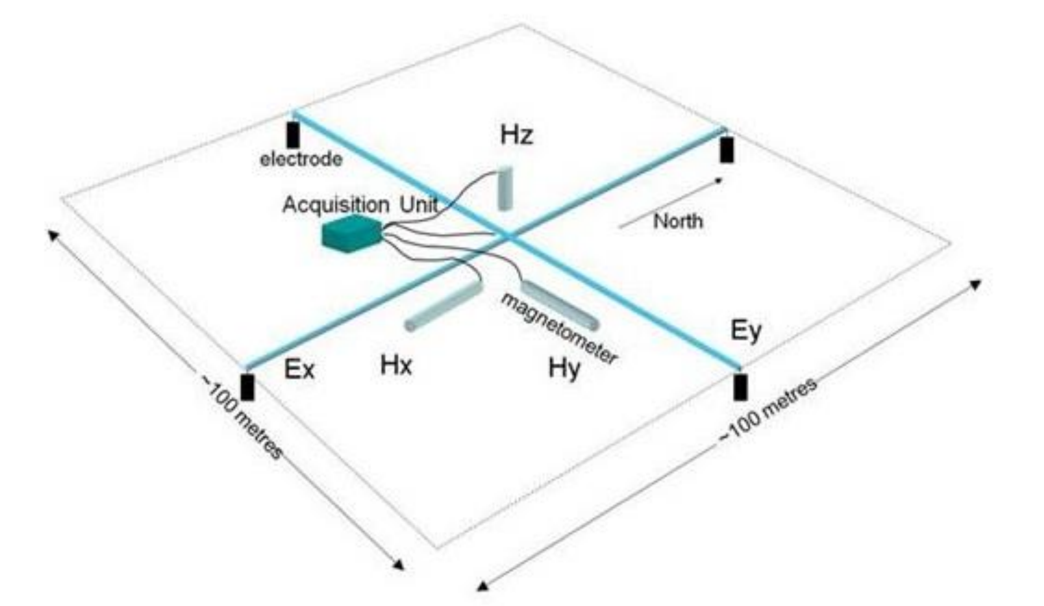
Magnetotellurics (MT, AMT)

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. NO CURRENT INJECTIONS NEEDED.
- 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
  - Wide frequency ranges are available
  - Full tensor acquisition that enables application of 1D, 2D and full 3D resistivity inversion methodologies.
- Disadvantages
  - Remote measurements needed for denoising (MT)
  - Long recording periods may be required (MT, AMT)

MT/AMT survey arrangement



Magnetotellurics (Spartan MT). Kibby Basin NV - Belmont Resources Inc

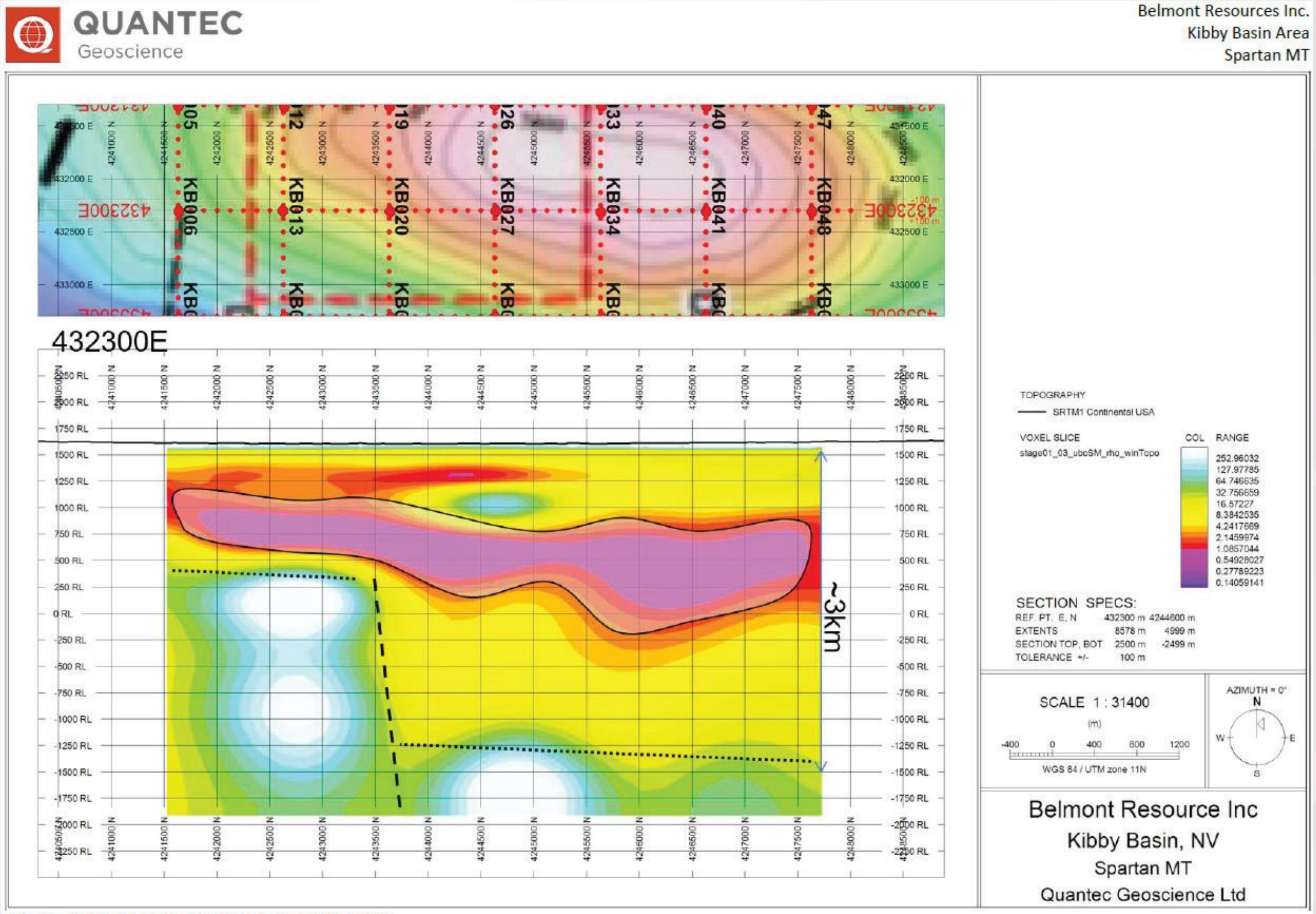


Figure 6-19: MT 3D results along L432300E.

Sub-horizontal conductive (brine?) layer in a pull apart basin style

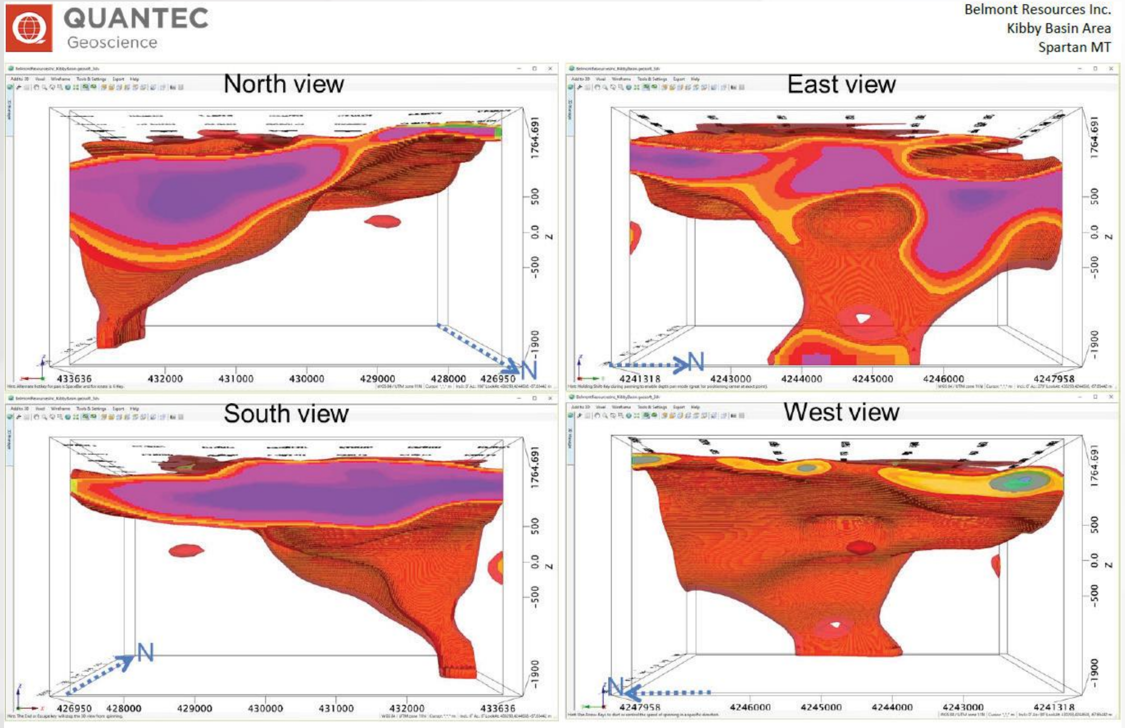
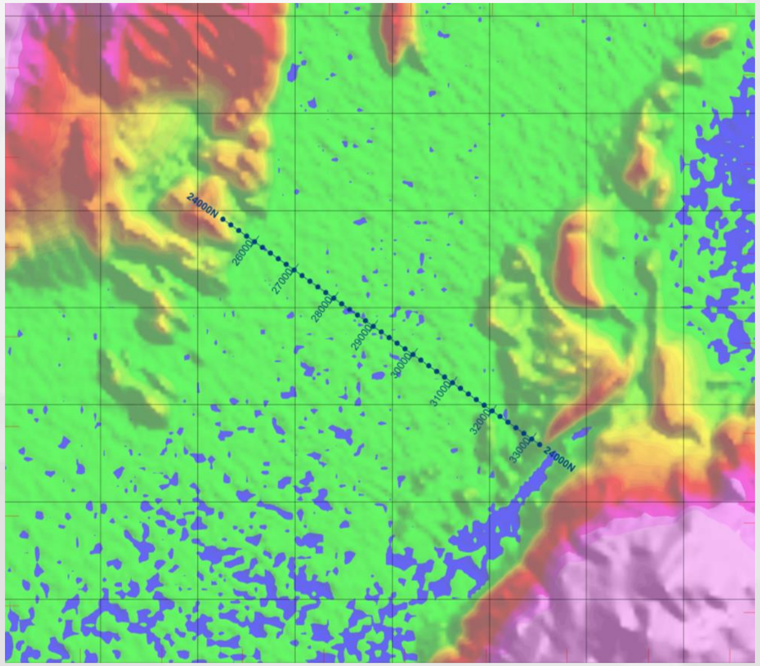


Figure 6-6: View from North, South, East, and West of the 3D resistivity values lower than 10 Ohm-m from the 3D MT model.

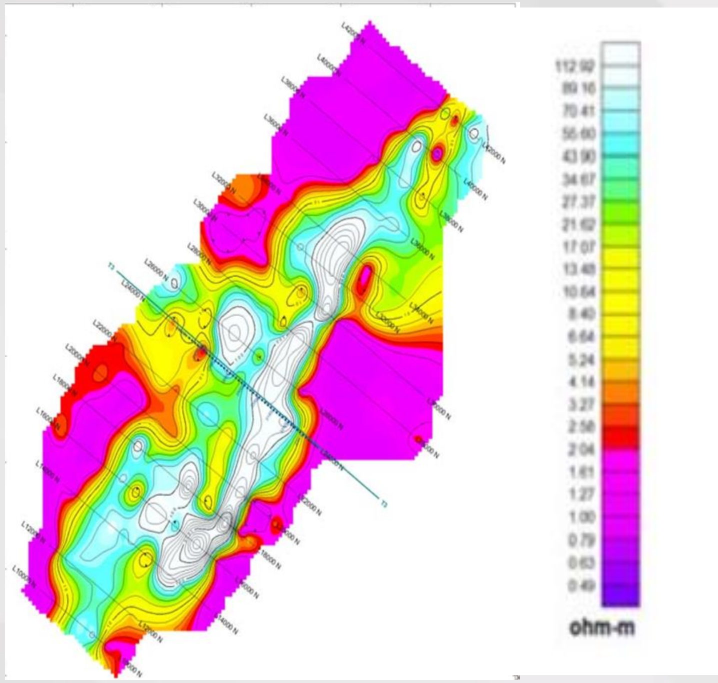
3D view of resistivity values lower than 10 ohm*m

SPARTAN MT

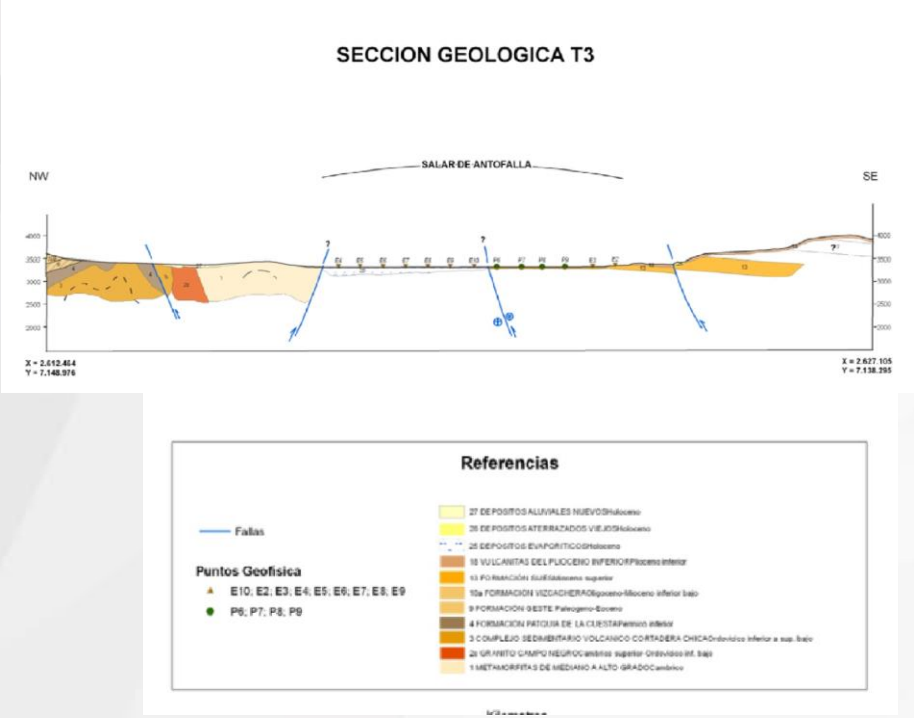
Magnetotellurics (MT). Salar de Antofalla



Survey Location Map with topography

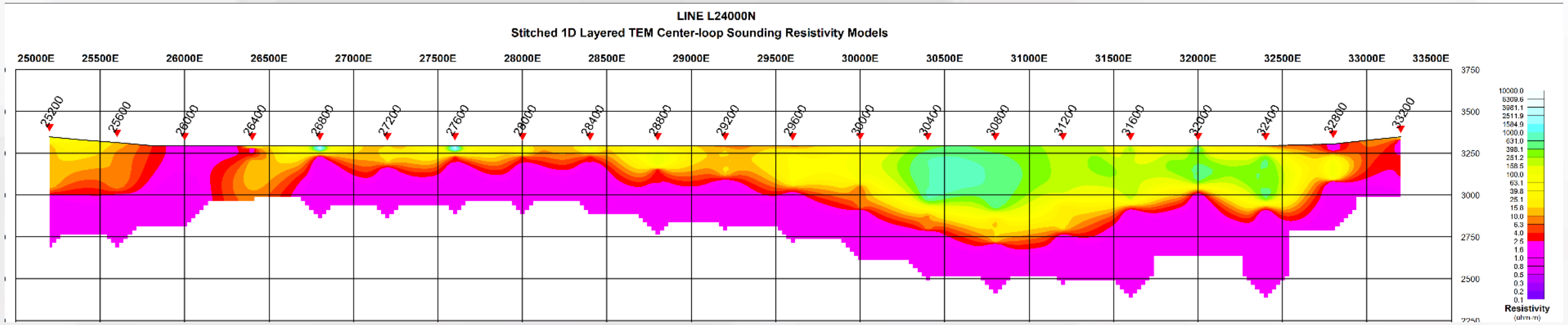


TEM resistivity from discrete layer plots at 3250 m elevation

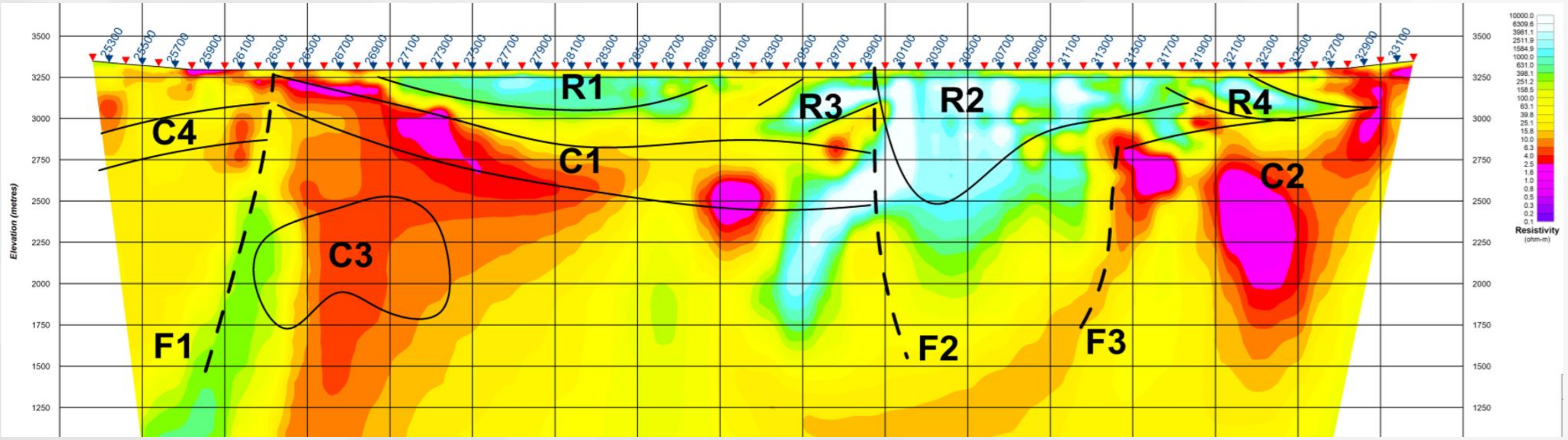


Magnetotellurics (MT vs TEM). Salar de Antofalla

TEM Stitched 1D results



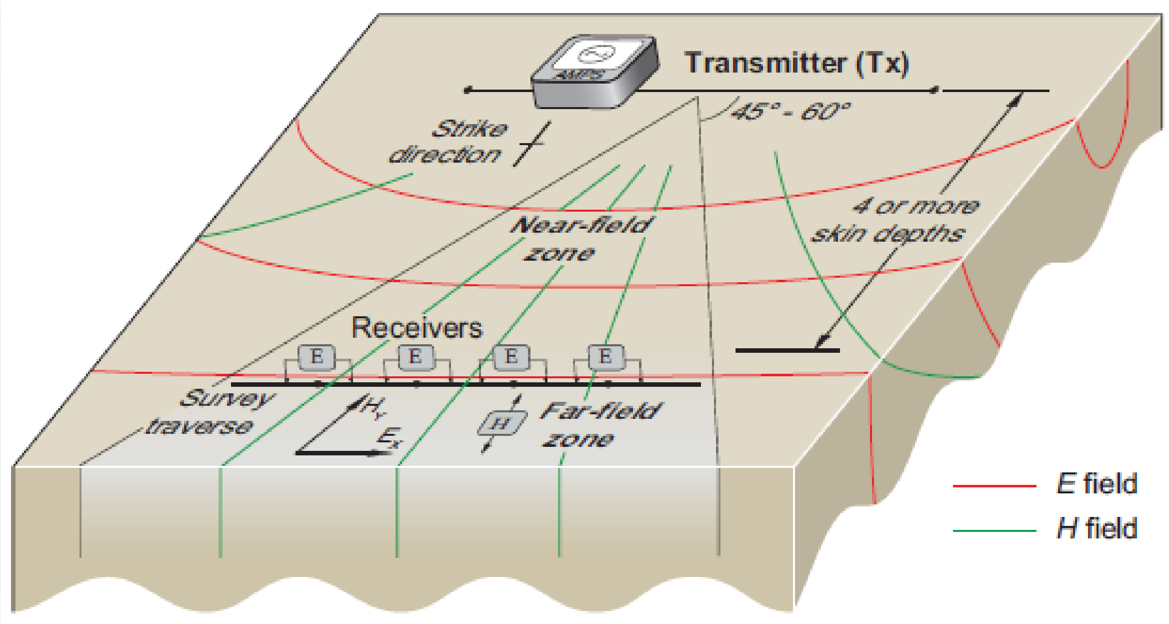
MT 2D results with Interpretation (2000m DOI)



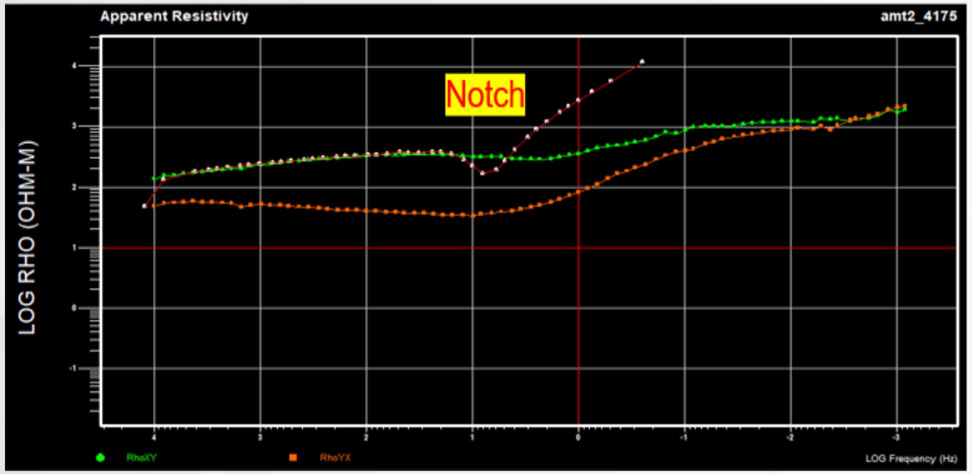
Controlled source Magnetotellurics (CSAMT)

- **Active** method. 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, the resistivity of the subsurface, and the distance to the transmit source.

CSAMT survey arrangement



- Advantages
  - DOI from a few 10's of meters to several 100's of meters – maybe approaching **800 m**
  - Inversion models provide **2D** sections
- Disadvantages
  - **Limited** frequency **ranges** and short recording period
  - Survey design may be limited due to **bipole** location
  - Transmit source **effects** inevitably prevent CSAMT from achieving the same DOI capabilities as AMT



CSAMT: Salar de Hombre Muerto

GALAN
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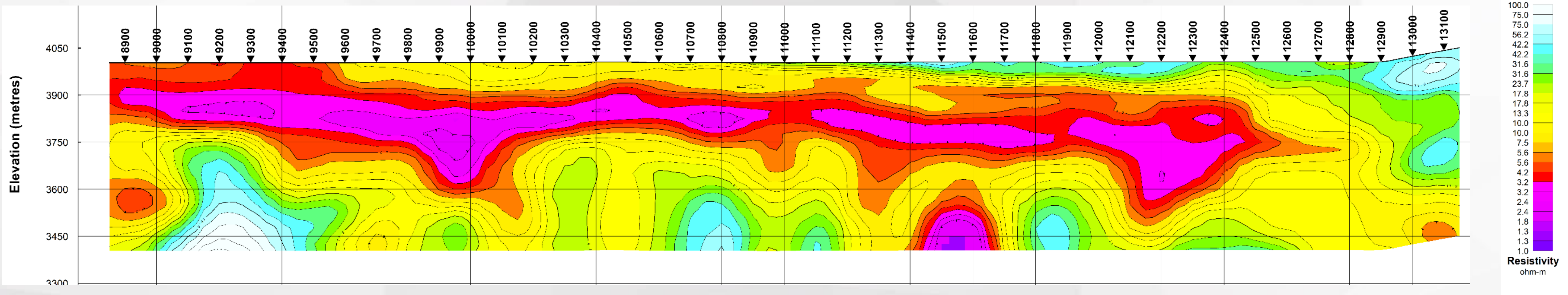
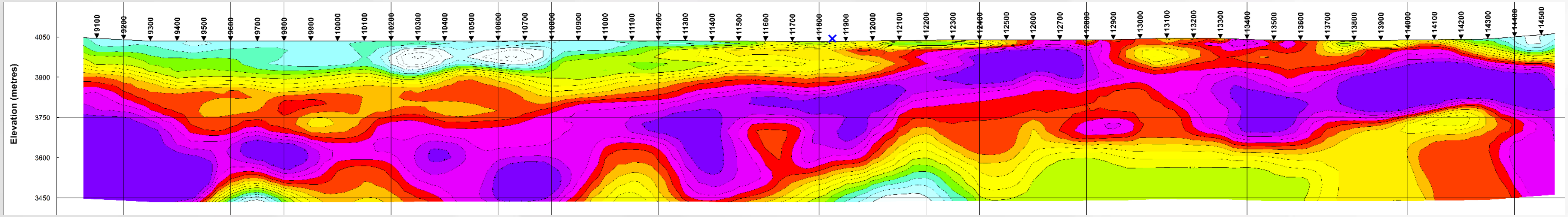
CSAMT Resistivity sections – 100 m dipole size -





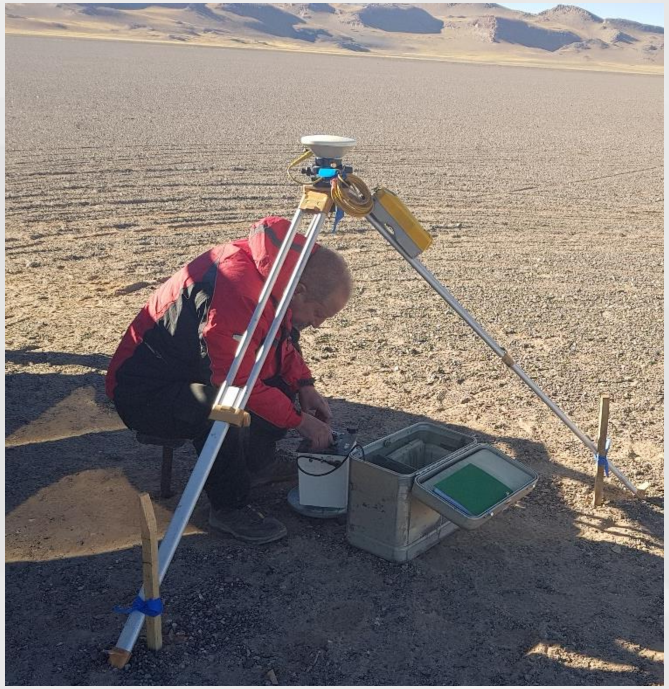
(Courtesy of Galan Lithium Limited)

Potential Methods: Gravity Method

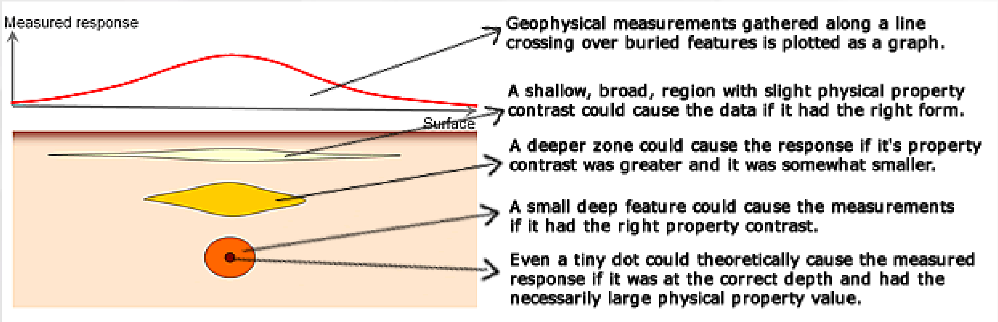
Gravity surveys map variations in subsurface density

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.



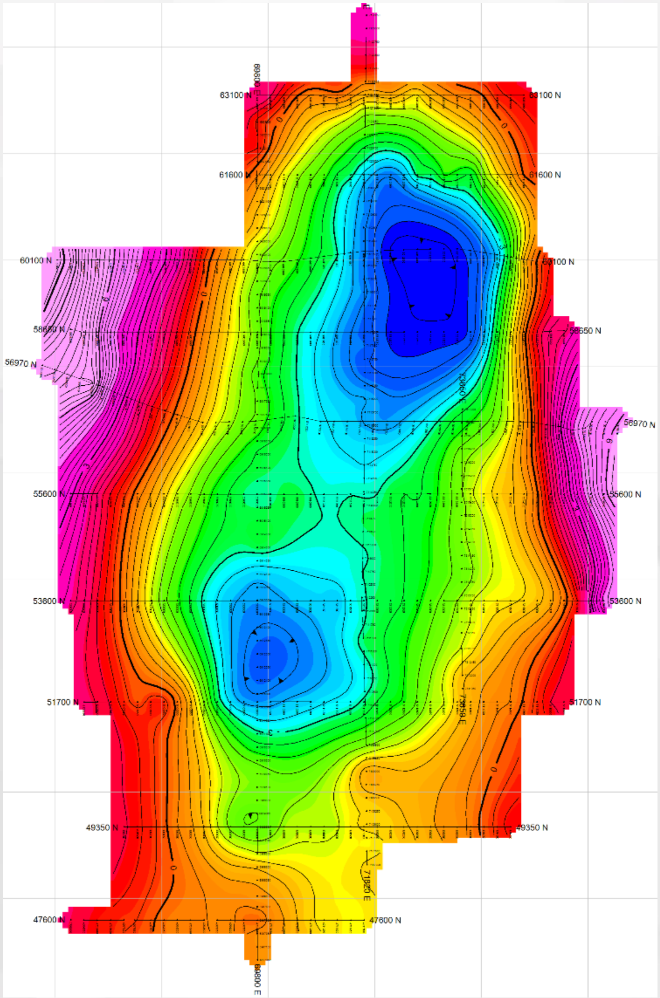
- Advantages
  - Relatively independent of terrain conditions except in the presence of extreme topography
  - Field procedures are **fast** and require only a **small** field **crew** (2-3)
  - **Precise** measurements
  - Direct **correlation** with geology may be possible if density data are available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



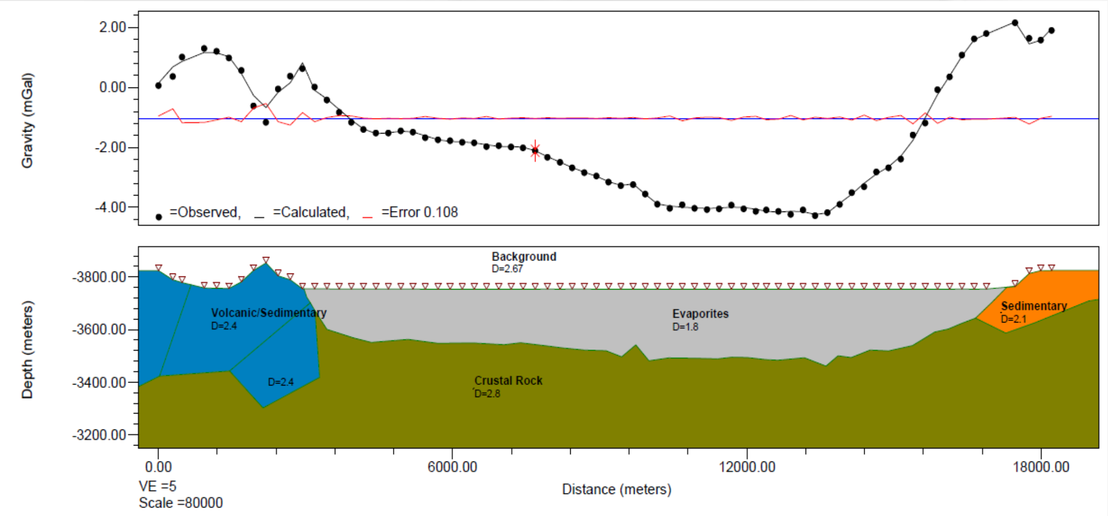
https://www.eoas.ubc.ca

Gravity

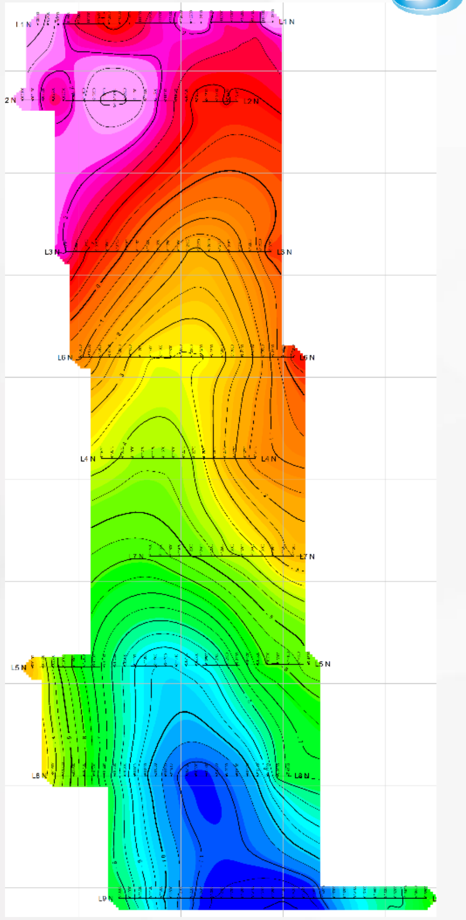
Residual Bouguer Anomaly Map - Mariana Project (Litio Minera Argentina S.A.)



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



Residual Bouguer Anomaly Map – Salar de Hombre Muerto (Galan Lithium Limited)



Potential Methods: Magnetic Method

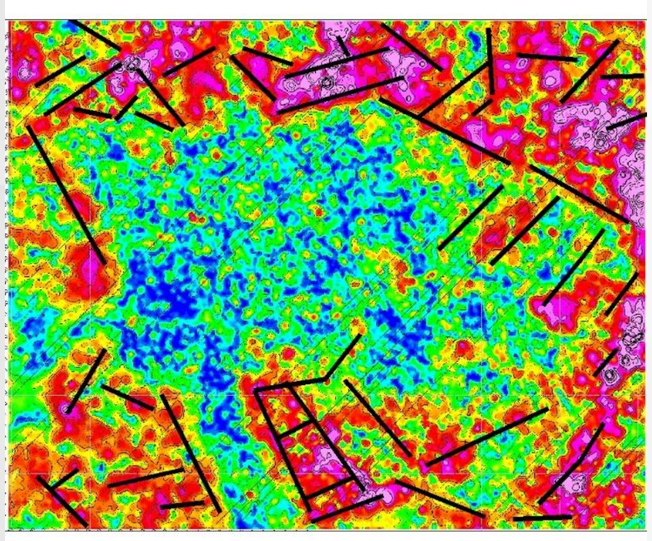
Magnetic surveys map the local magnetic field

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

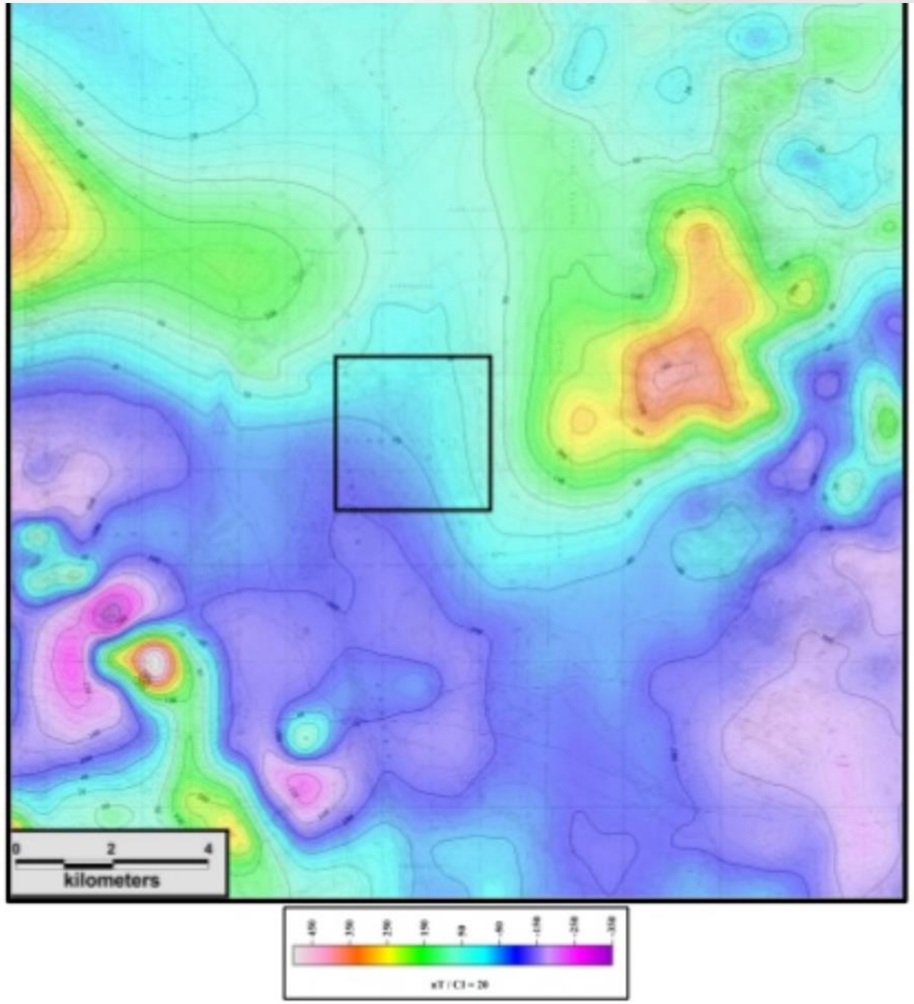


FIGURE 4: RTP Magnetics over Topography

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.

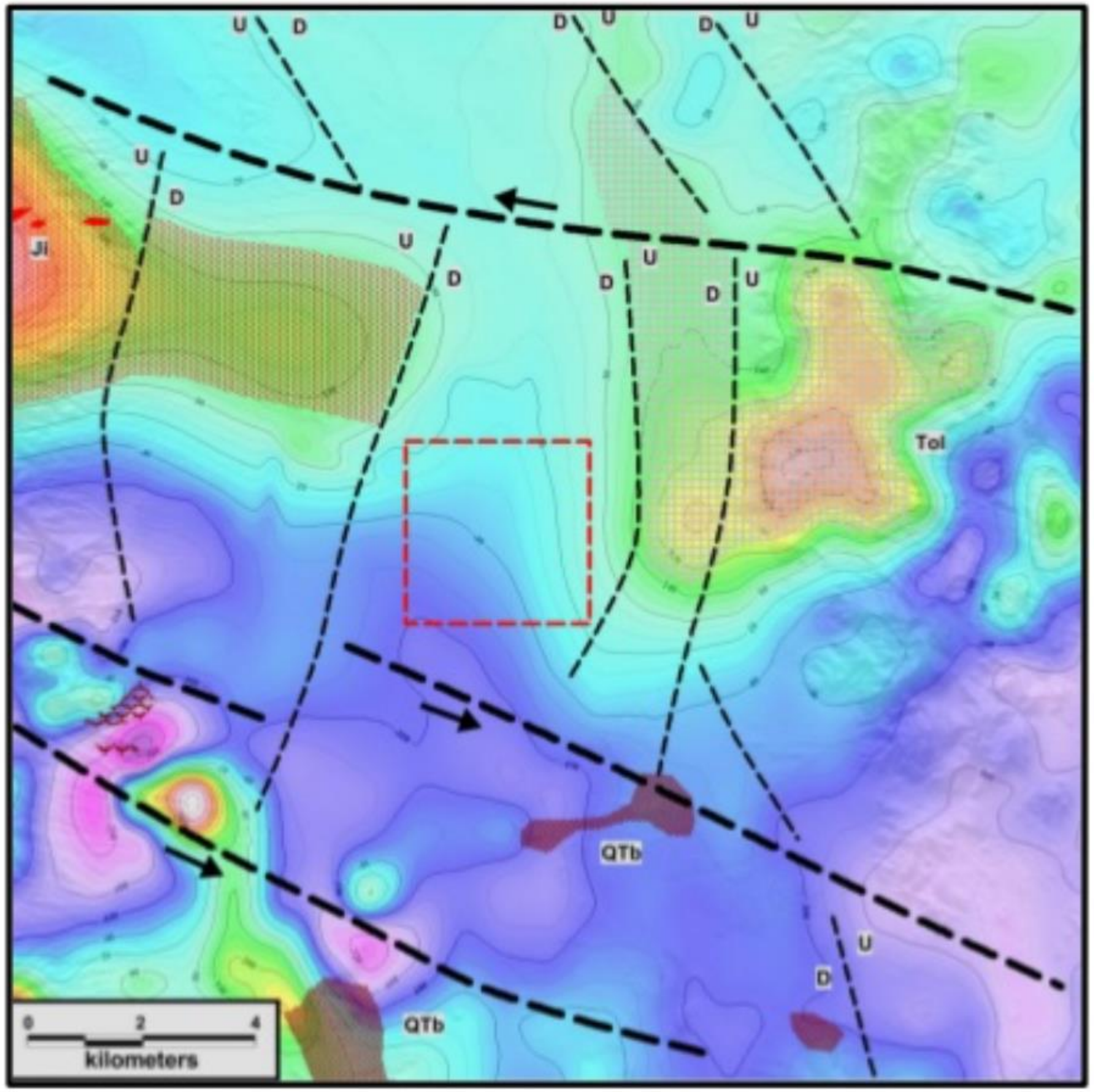


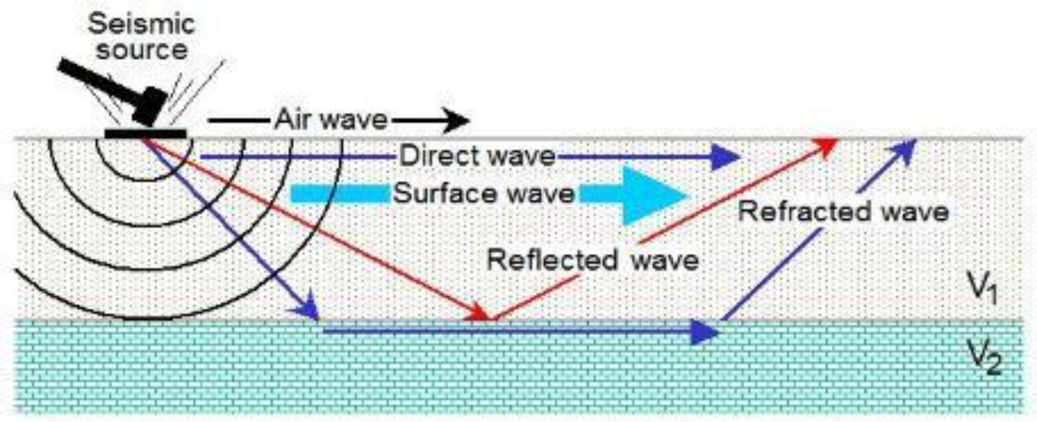
FIGURE 7: RTP Magnetics overlain by Interpretation

Seismic Methods

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

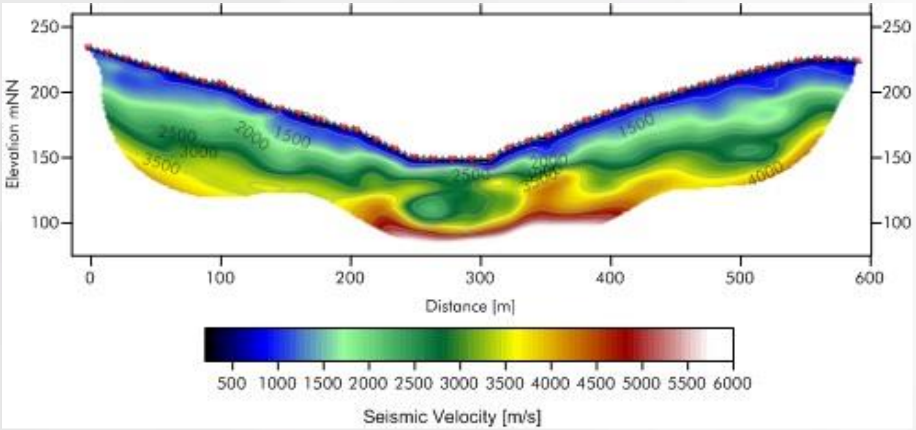
Waves are created by a **source** and propagate through the subsurface before being recorded by **detectors** that measure deformation of the ground

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 salars, the best tools to map brine layers are:
  - TEM (first 300m)
  - MT (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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Thank you !

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