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Overview

- Petrophysics of Great Basin rocks
- Recent applications of geophysics in the Great Basin
- Future developments in geophysics and their impact in the Great Basin
- Conclusions
**Petrophysics** is a measure of the physical properties of rocks

**Petrophysical generalizations** for Great Basin rocks are:

<table>
<thead>
<tr>
<th>Rock type</th>
<th>Magnetization</th>
<th>Density</th>
<th>Conductivity</th>
<th>Chargeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Plate</td>
<td>(L)</td>
<td>(M-H)</td>
<td>(M)</td>
<td>(L)</td>
</tr>
<tr>
<td>Upper Plate</td>
<td>(L)</td>
<td>(M)</td>
<td>(M)</td>
<td>(L)</td>
</tr>
<tr>
<td>Pen-Perm overlap</td>
<td>(L)</td>
<td>(M)</td>
<td>(M)</td>
<td>(L)</td>
</tr>
<tr>
<td>Intrusive stocks</td>
<td>(M - H)</td>
<td>(M)</td>
<td>(M)</td>
<td>(L)</td>
</tr>
<tr>
<td>Dykes related to stocks</td>
<td>(L-M)</td>
<td>(M)</td>
<td>(H) (clays)</td>
<td>(H) (clays)</td>
</tr>
<tr>
<td>Cover: Alluvial/Colluvial</td>
<td>(L)</td>
<td>(L)</td>
<td>(H)</td>
<td>(L)</td>
</tr>
<tr>
<td>Cover: Volcanic</td>
<td>(H)</td>
<td>(L)</td>
<td>(M)</td>
<td>(L)</td>
</tr>
</tbody>
</table>

\(H = \text{High}, \ M = \text{Moderate}, \ L = \text{Low}\)

- Real world petrophysics are **highly variable** due to overprinting structural, hydrothermal alteration and metamorphic events
- Cannot rely on petrophysical **generalizations**
  - Requires specific **petrophysical studies** for project area
Effective application of geophysics requires:
- specific *petrophysical studies* for project area
- understanding of *geologic controls on mineralization*

Recent examples:
- Magnetics, Goldstrike and Cortez
- Gravity, Stonehouse
- Hardrock Seismic, Cortez
- MT/CSAMT, Ruby Hill
- IP/Resistivity, Bald Mountain
- Remains the most effective reconnaissance mapping tool
  - Despite **limited developments** in acquisition technology
  - Lower cost, better processing tools, better geologic integration

- Stippled **high-low volcanic signature**
  - **Magnetite** in primary composition
  - Variable **remnant** and **normally** magnetized Basalt flows

- Intrusive stock **high**
  - **Magnetite** in primary composition
  - **Remnant** and **normally** magnetized

*Also consider*
- **high** from **Monoclinic Pyrrhotite** in magnetic skarn surrounding intrusion
- Gold Acres Stock: buried intrusion exposed only in Gold Acres Pit

- Quartz Monzonite is **weakly magnetic** (below 2.0 x 10^{-3} SI)

- Skarn surrounding stock is **moderate to highly magnetic** (<46.1 x 10^{-3} SI)

- Peak magnetic response is outside bounds of intrusion

- Consider skarn in interpretations!
Detailed Gravity

- Extensively applied in the Great Basin
  - Map **dense** Lower Plate vs. Upper Plate
  - Map **alteration and metamorphism** in uniform sediments
  - Map bedrock structure **beneath cover**

- **Stonehouse example**
  - Immediately north of Lone Tree mine
  - Wayne Zone is structurally controlled on high-angle (75° W) fault
  - Use gravity to map extension of Wayne Zone structure beneath I-80 highway

- **Significant cover thickness (>500ft)**
  - 1000ft gravity station spacing is sufficient resolution
Residual gravity maps density contrasts in upper 2000ft

Mapping bedrock horst beneath pediment
- 1500ft wide, 3 miles long

Gravity modeling to define geometry and quantify offset
- Simple 2-layer earth model
- Bedrock vs. cover
Detailed Gravity - Stonehouse

- Simple two-layer* 2D gravity model (Encom ModelVision)

*Tertiary Basalt layers of unknown thickness are not accounted for in modeling
Hardrock Seismic

- Softrock seismic - un lithified, sedimentary basin (Hydrocarbons)
- **Hardrock** seismic - lithified, crystalline rock (Ore deposits)

**Hardrock Challenges**
- Complex 3D geology (scattering)
- Higher intrinsic velocities
- Non-homogeneous near-surface

**Variations for Hardrock**
- High resolution: spatial and temporal
- High fold (spatial stacking) >120
- Specific processing considerations
  - Statics corrections for topography
  - Accurate velocity models for depth

**Interpretation**
- Integrate with drilling
- 2D structural interpretation
- Update geologic model
- Direct drill targets
Petrophysics considerations
– Seismic reflections from **acoustic impedance contrasts**: > lithologies > deposition facies > structure

Low-angle structural architecture (<45°)

Covered targets
– Alluvium
– Upper Plate

‘Oil-trap’ targets
– anticlines
– thrust stacking
– over-thickening
- Location of Gold Acres seismic line
Hardrock Seismic - Cortez

Upper Plate siliciclastics
Intrusive
Metamorphic halo
Lower Plate carbonates

Blue = drillholes

Depth conversion from downhole velocity work
MT/CSAMT Resistivity

- Resistivity and Electromagnetic applications increased through advancements in distributed array systems
  - e.g. Titan 24, MIMDAS

- Controlled source for improved resolution in upper 1000ft
  - Supplements data in the “dead band” of natural energy fields
  - Inherent technical issues with CSAMT surveying over cover
    - No bedrock information

- Petrophysics studies and base level geology imperative
  - Large resistivity variations between lithologies, metamorphism and alteration
  - Easy to make inaccurate interpretations
MT - Ruby Hill

- Unconstrained 2D inversion of MT profile
- E-W section, S of East Archimedes Pit. Pink is conductive
- Black: Modeled geology – MT maps structure very well
- Red: Anomalous gold – MT maps mineralization on gradients
Limited use in the Great Basin due to geological ‘noise’:
- Chargeable graphitic shales
- Remobilized carbon outbound of contact metamorphic aureole
- Diagenetic pyrite not associated with mineralization

Applied on case by case basis depending on geologic setting

Advanced applications of traditional IP techniques
- Distributed array systems
- 3D inversion
- Downhole IP experiments
Bald Mt example

- RBM dipole-dipole IP Survey

*Lee to resupply with elevation colour stretch for plan map – not hot/cold
Future: Great Basin geophysics

- Geophysics will play an increasing role in Great Basin exploration in the future

- Blind deposits
  - beneath alluvial or volcanic cover
  - No surface geochemical expression

- Following section describes developments expected in the next 5 to 10 years in:
  - Acquisition
  - Processing and inversion
  - Geological integration
Future: Acquisition

- Distributed array electrical methods
  - Multiple source-receiver combinations
  - Reduce non-uniqueness in inversions
  - Higher interpretability, more accurate

- 3D Hardrock Seismic
  - Better images complex 3D geology
  - More affordable in past decade
  - Wireless receivers with built in GPS locators for formidable terrain

- Airborne gravity
  - Noise levels **down** roughly an order of magnitude in the past decade
  - **Drape** over mountains in the Great Basin will be an issue for the large aircraft required
Future: Processing and Inversion

- 3D survey planning
  - 3D seismic / 3D MT station planning to best ‘illuminate’ target

- 3D inversion
  - Faster algorithms e.g. UBC MUMPS algorithm
  - More complex geophysical methods e.g. 3D EM inversion

- Example: 3D IP inversion
  - Gold Hill, Round Mt, NV
  - Quantec trial
  - Replicated 2D results
Future: Geological Integration

- Integration of geophysical, geochemical and geologic data
- Common earth models populated with multidisciplinary data

From J. Katseanes (Barrick)
Conclusions

- Variability in physical properties of Great Basin rocks warrants petrophysical studies in individual survey areas.

- Recent advances in geophysics have played a major role in more accurately identifying host rock lithologies, alteration and structure associated with gold mineralization.

- Presented examples where geophysics has assisted the exploration program.

- Future is in distributed array, 3D seismic and tools for better processing, inversion, and geologic integration.