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UNIVERSIDAD NACIONAL DE TRUJILLO
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UNIVERSIDAD NACIONAL
SANTIAGO ANTÚNEZ DE MAYOLO
"Una Nueva Universidad para el Desarrollo"

Geophysics in the field of groundwater modeling and archaeological exploration

- Geophysical imaging in Majes I & II for geology, water, cemented subsoils, & landslide risks
 - Archaeo-geophysical investigations at Huacas de Moche in Trujillo
-

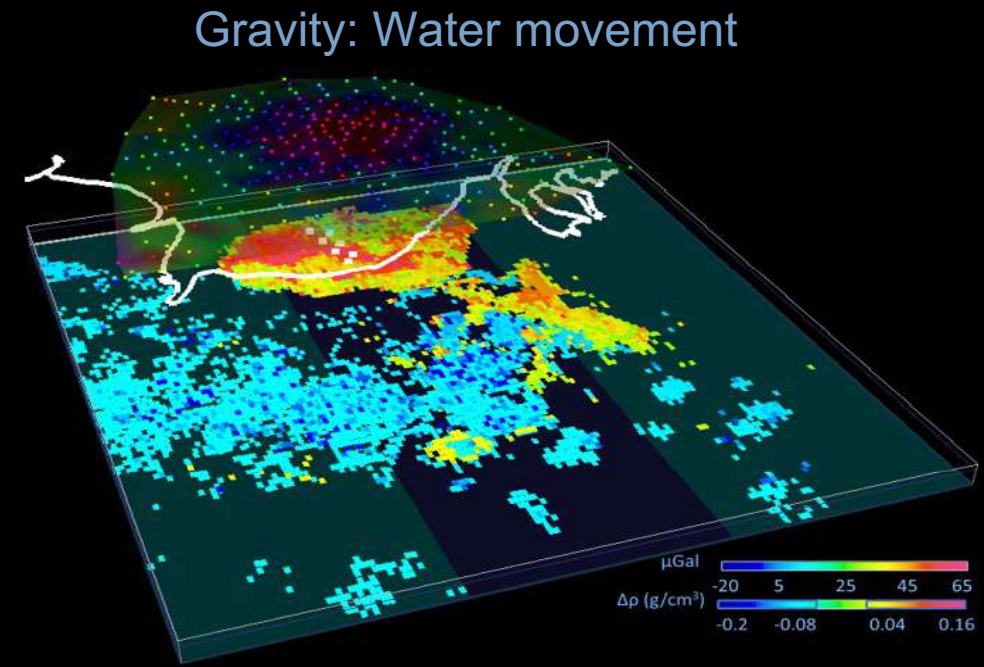
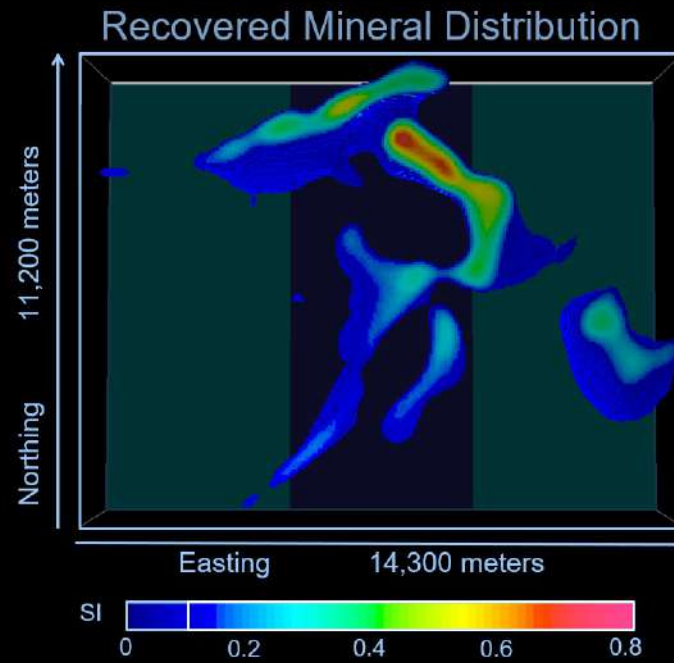
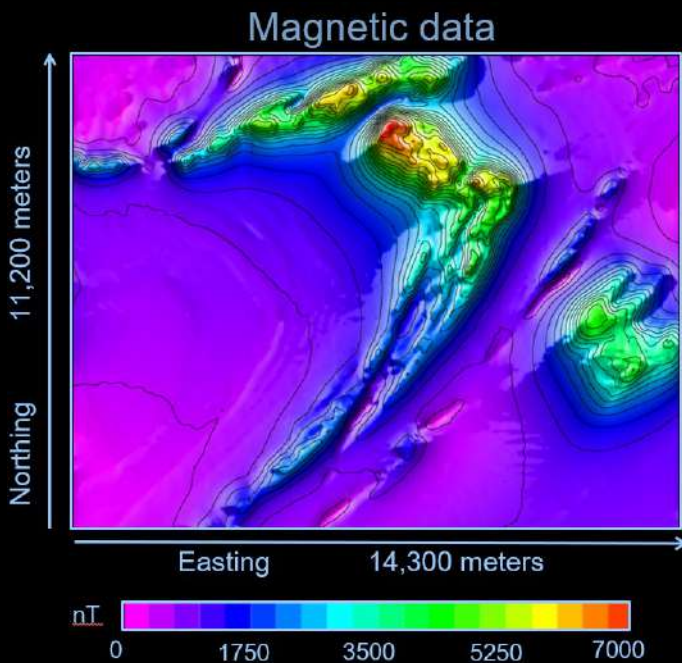
Richard Krahenbuhl

- Research Assoc. Prof: Department of Geophysics
- Director: Humanitarian Engineering & Science - IGP

What is Geophysics? How is it useful?

Uses physics to “see” beneath the surface

- Collect data (gravity, magnetics, electrical, electromagnetics, seismic)
- Build models of the subsurface geology and fluids for exploration and production

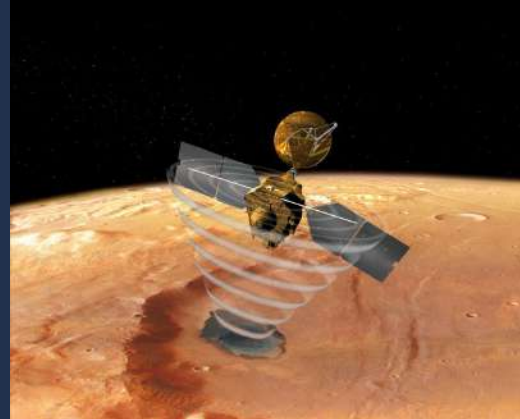


What is Geophysics? How is it useful?

Climate Change



Space



Humanitarian Efforts



Environment



Animas River

Earthquakes



Energy

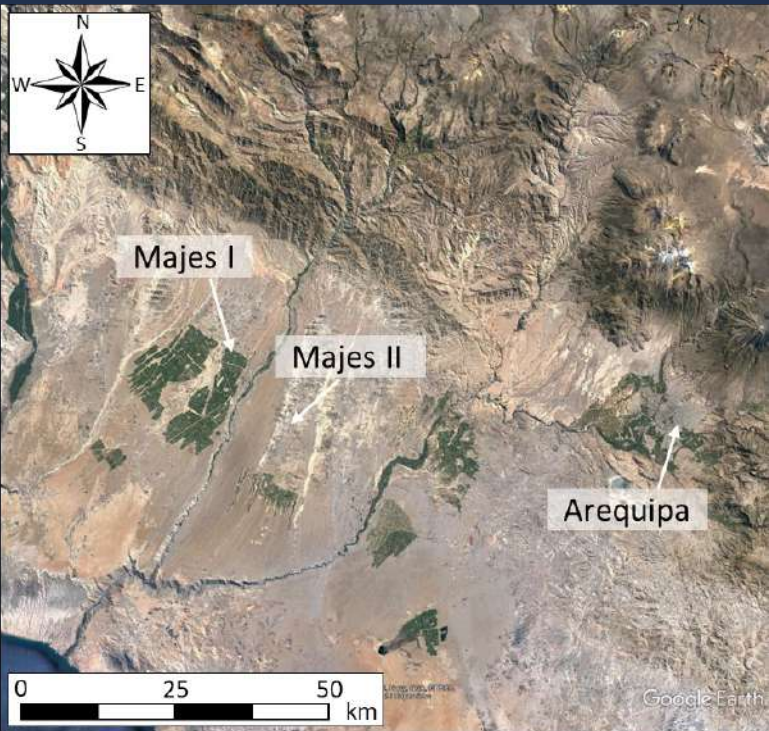


Minerals



Hazards





Southern Peru: Arequipa Region

- Majes I – Current Agricultural Development
- Majes II – Future Agricultural Development

Introduction

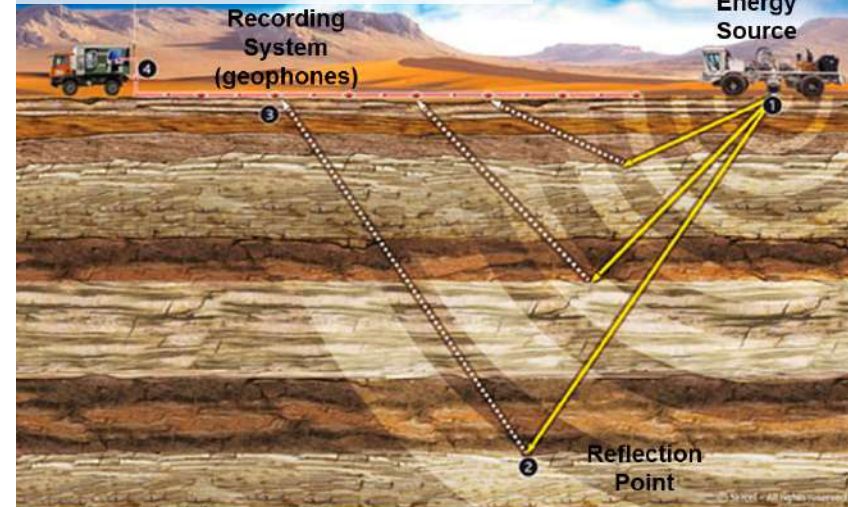
Goals:

- Prove water table at Majes I has risen significantly from inefficient agriculture irrigation
- Incorporate elevated water table into landslide models to show that it has increased landslide activity
- Map larger 3D distribution of geology and water table beneath Majes
- Understand if geophysics can identify/predict locations of possible landslide risk before failure happens
- Map near-surface cemented subsoils (caliche) at Majes II that must be broken up prior to agricultural development

Water table at Majes I



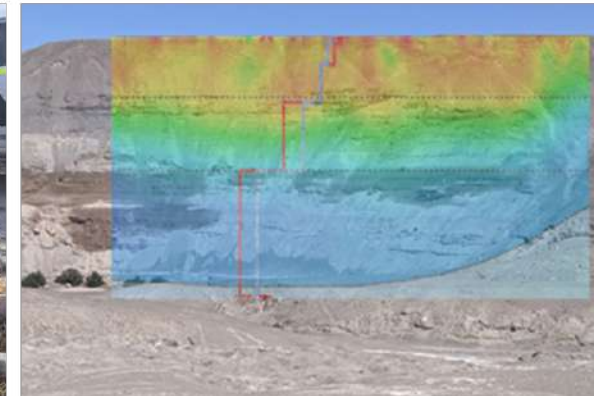
Acquiring geophysical data



Methods & Instrumentation

Large collection of instruments donated to UNSA

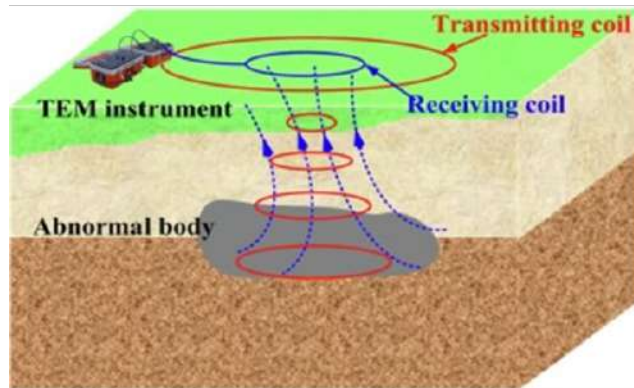
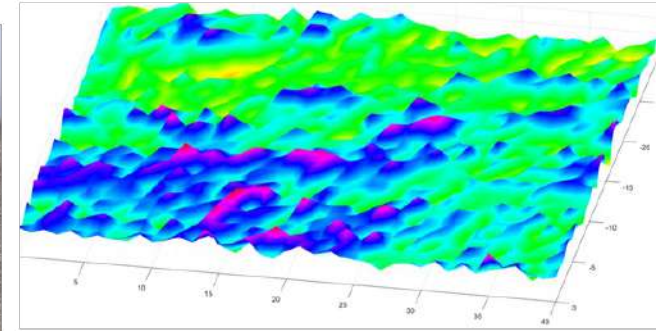
Electrical Resistivity (1.2 km long)



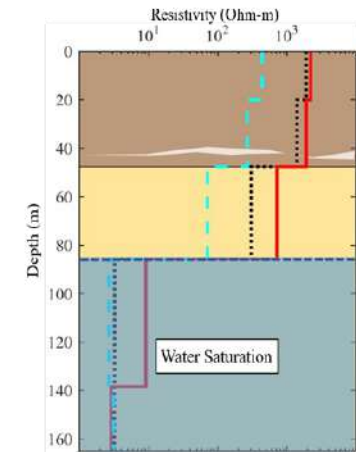
Methods & Instrumentation

Large collection of instruments donated to UNSA

Electromagnetics



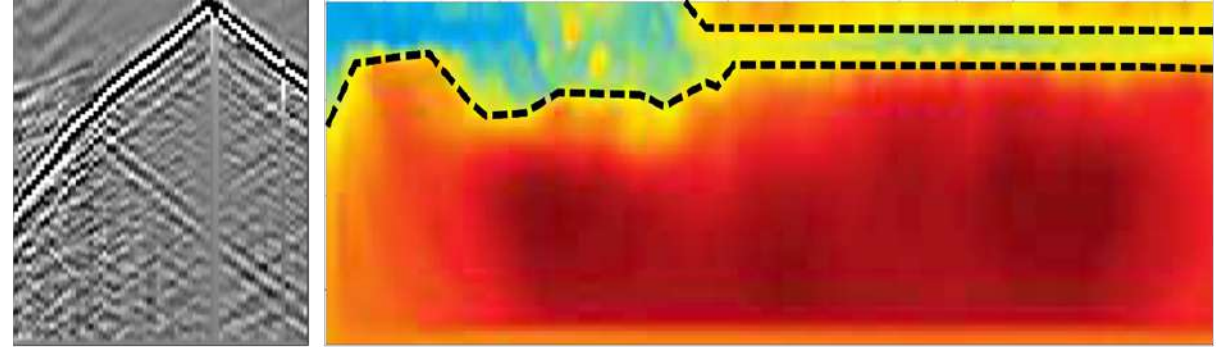
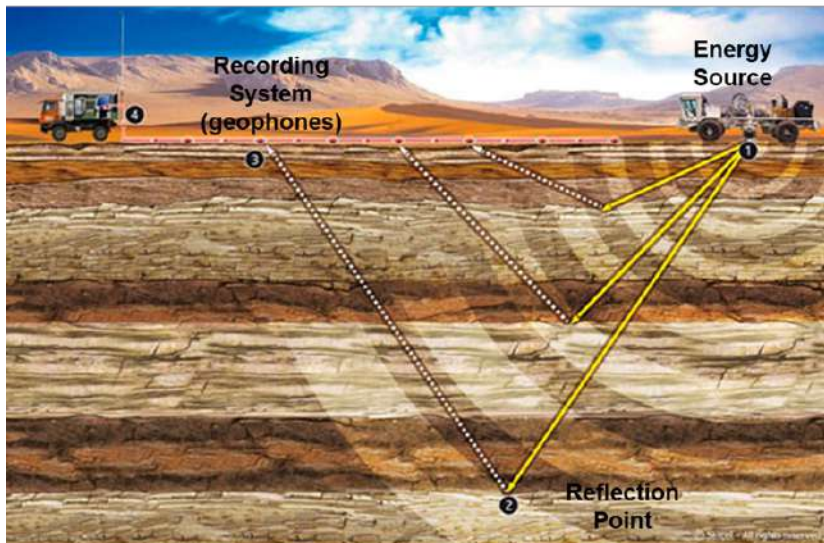
Deep Surveys



Methods & Instrumentation

Large collection of instruments donated to UNSA

Seismic + Source



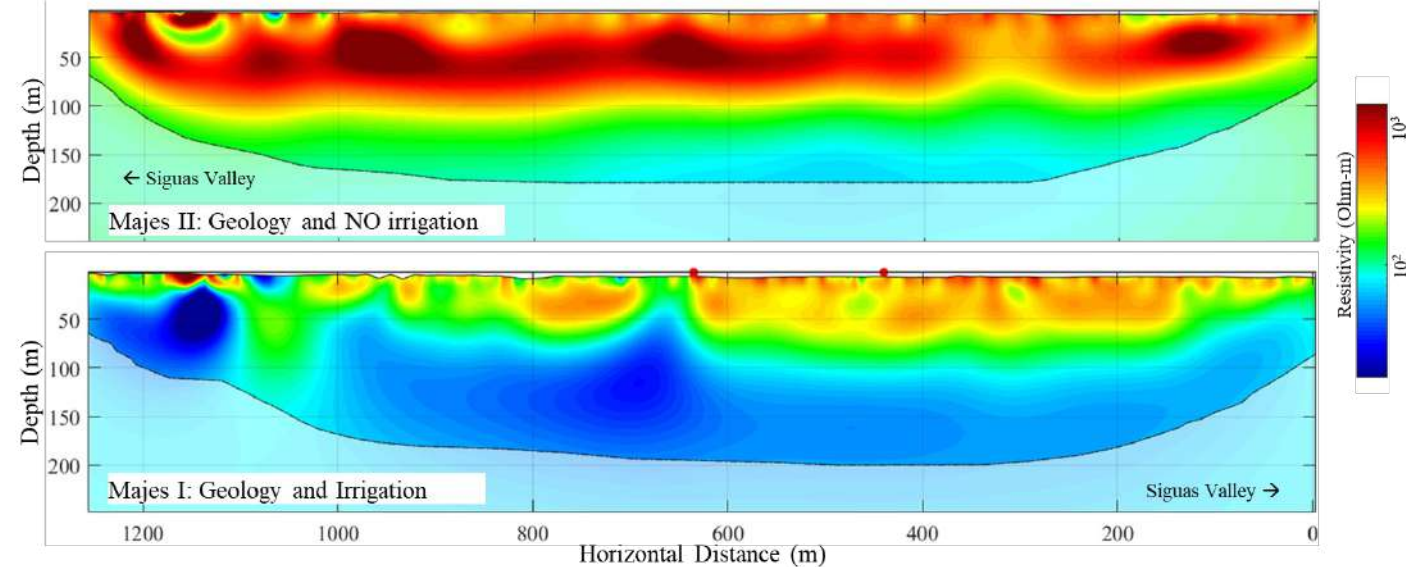
Results

Goal: Prove water table at Majes I has risen significantly from inefficient agriculture irrigation

- Two geophysical survey lines
- 1st: Majes II without agriculture irrigation
- 2nd: Majes I with agriculture irrigation
- Electrical & electromagnetic surveys

Conclusion: Natural water table at Majes II is much deeper. Agriculture irrigation has raised the water table at Majes I as water percolates to depth.

Flamme, Krahenbuhl, Li, Dugan, Shragge, Graber, Sirota, Wilson, Gonzales, Ticona. Minaya (2022).



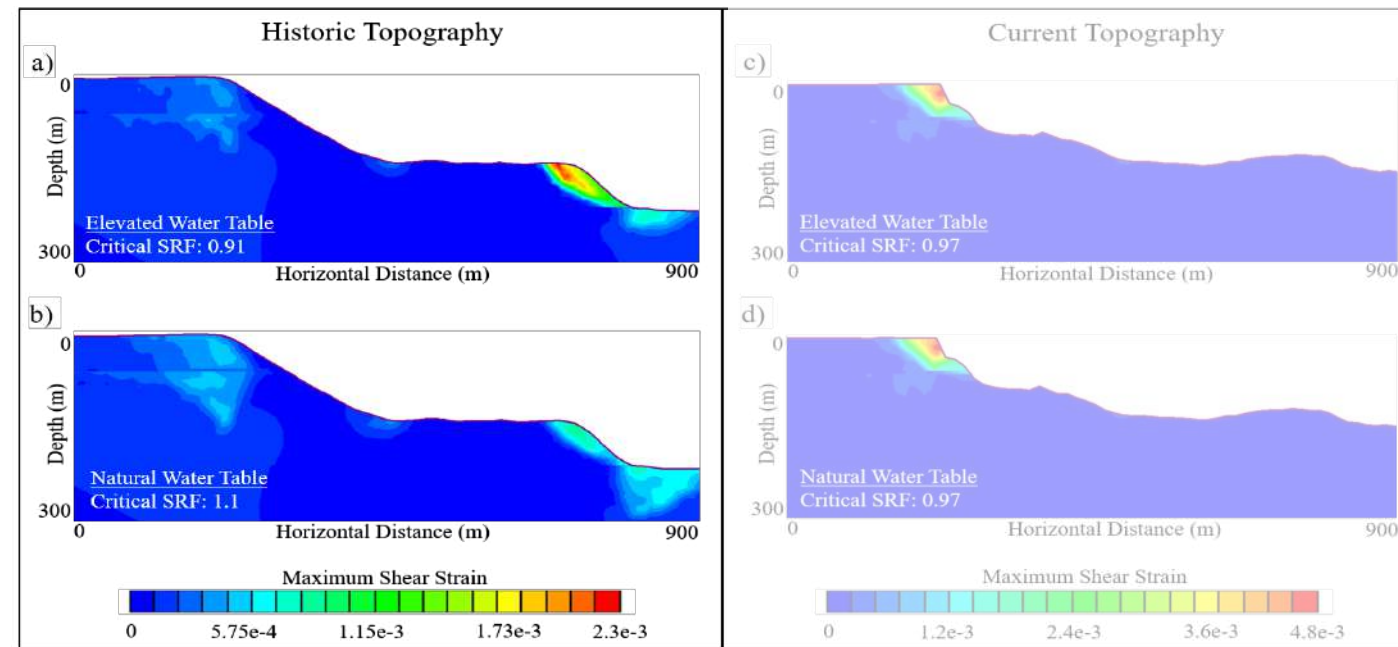
Results

Goal: Incorporate elevated water table determined from geophysical surveys into models to show increased landslide activity

- Two landslide model scenarios with historical topography (before El Zarzal)
- 1st: Natural water table elevation
- 2nd: Elevated water table from agriculture irrigation

Conclusion: Modeling shows shear strain and landslide likelihood increased after irrigation increased the water table

Flamme, Krahenbuhl, Li, Dugan, Shragge, Graber, Sirota, Wilson, Gonzales, Ticona. Minaya (2022).



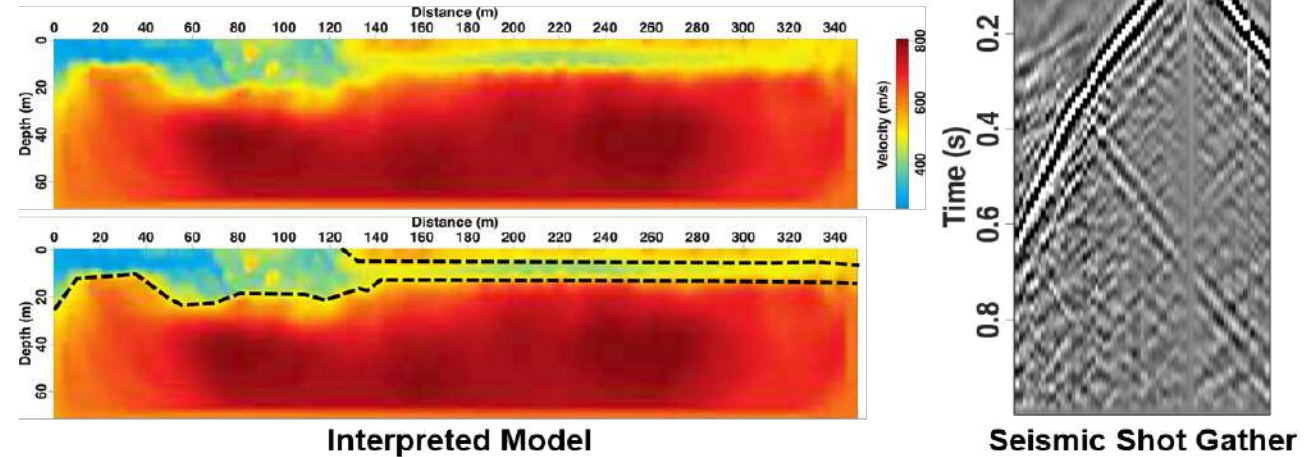
Results

Goal: Understand if geophysics can identify locations of possible landslide risk before failure

- Geophysical surveys above the 'Weeping Cliff' where water percolates out of rocks
- Seismic, electrical & electromagnetic methods
- Identify if sharp changes in electrical resistivity and seismic velocity are present above the weeping cliff

Conclusion: Data indicate reduced shear modulus values with potentially less compacted materials above weeping cliff. Processing / data integration in progress.

Yang, J.; Shragge, J.; Girard, A.J.; Gonzales, E.; Ticona, J.; Minaya, A.; Krahenbuhl, R. Seismic Characterization of a Landslide Complex: A Case History from Majes, Peru. *Sustainability* 2023



Results

Goal: Map near-surface cemented subsoils (caliche) at Majes II that must be broken up prior to agricultural development

- Establish small “test-bed” at Majes II with outcropping caliche
- Electromagnetic, seismic and georadar methods
- Evaluate individual and integrated interpretation to map caliche
- Determine what combination of methods is most efficient to map cemented subsoils at Majes II prior to agricultural development

Conclusion: Georadar & Electromagnetics appears to correlate and identify caliche distribution

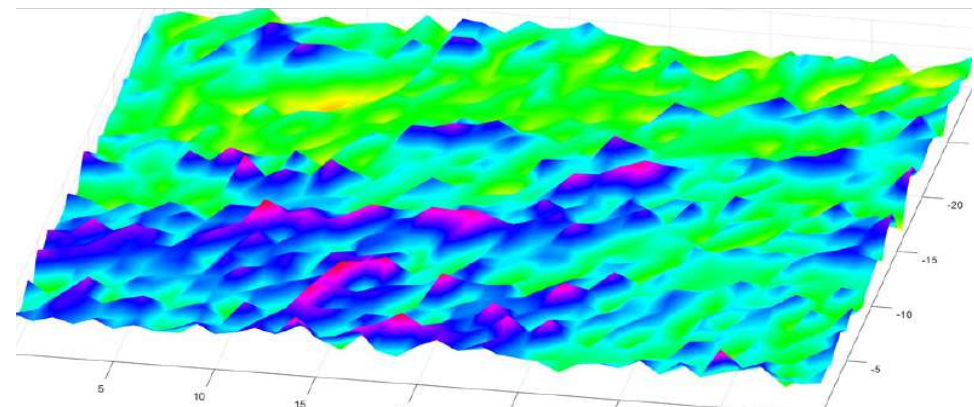
Caliche Outcrop



Electromagnetic Survey



Surface map from electromagnetic survey:



Note: Only a small subset of the 3D field data are shown here



Northern Peru: Trujillo

- Huacas de Moche Archaeology Site

Introduction

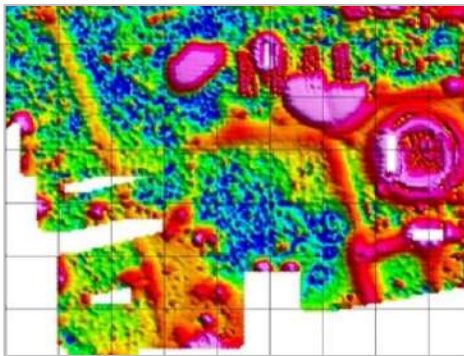
Goals:

- Evaluate application of geophysics at Huacas de Moche
 - Walls
 - Burials / Tombs
 - Floors / Platforms
- Establish small test areas
- Collect, process, and interpret multiple geophysical datasets
- Make recommendations to significantly expand the project



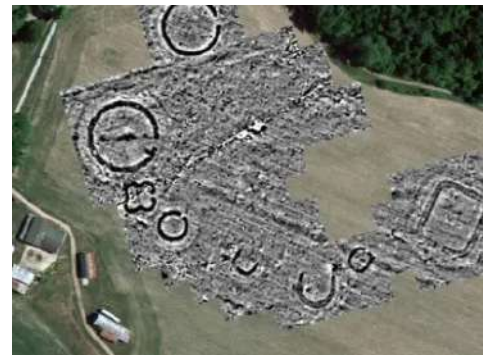
Methods & Instrumentation

Electromagnético



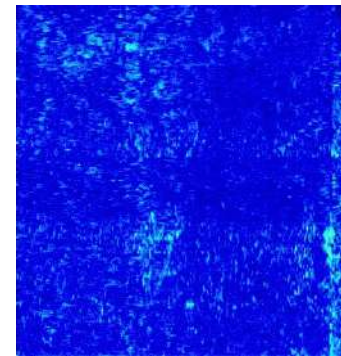
<http://www.geophex.com/Downloads/GEM2%20brochure.pdf>

Magnético



<https://bonebroke.org/2015/02/27/how-do-archaeologists-find-sites/>

Georadar

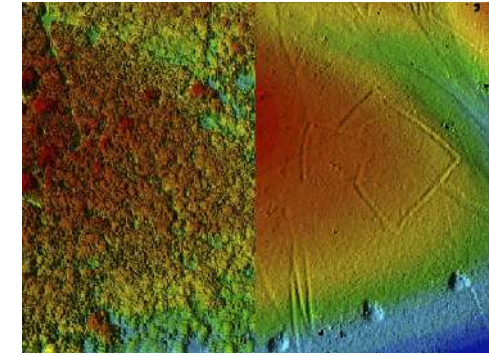


<https://www.archaeological.org/fieldwork/applied-field-geophysics-workshop-ground-penetrating-radar-gpr-applications/>

Drone



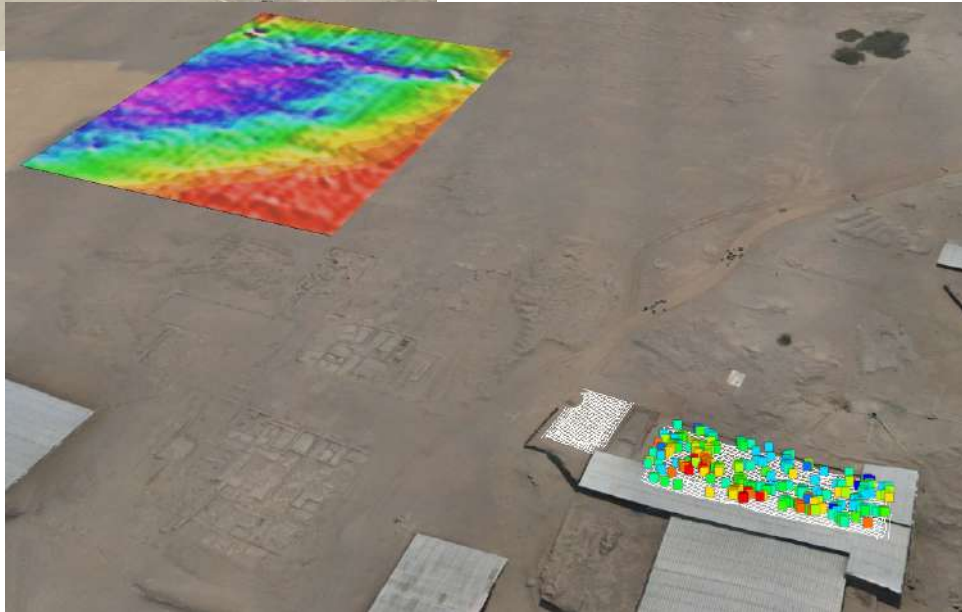
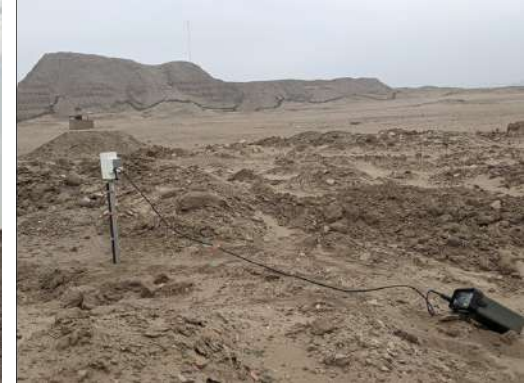
<https://www.emesent.io/2020/06/22/hovermap-supercharges-the-dji-matrice-300-rtk-drone/>



<https://geoawesomeness.com/lidar-pushes-archaeological-revolution/>

Results

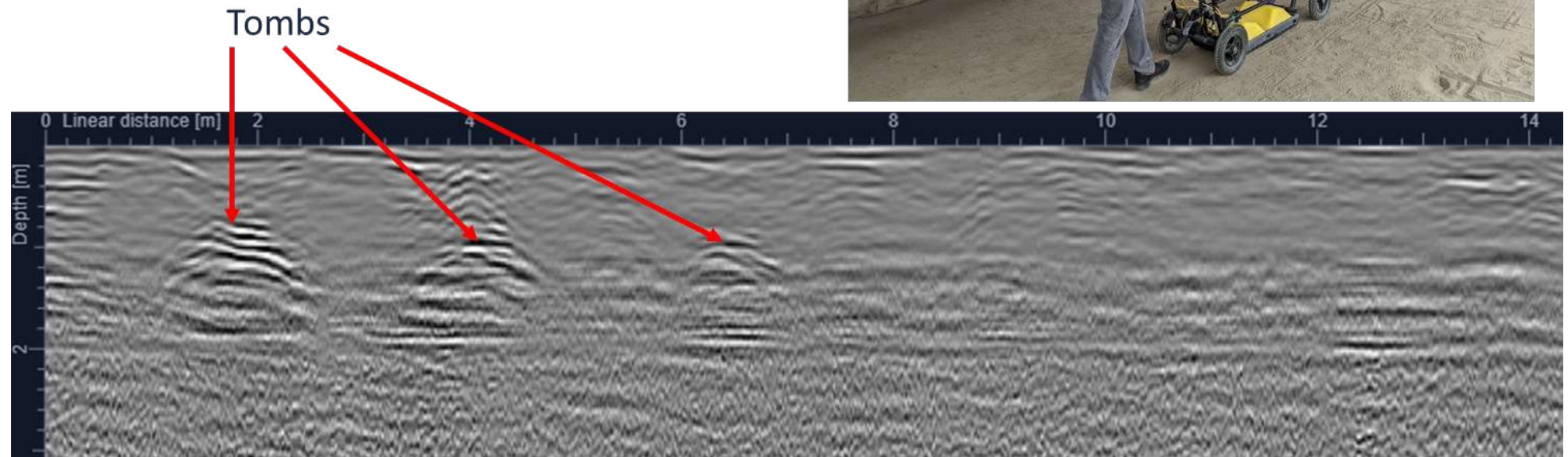
Two Test Areas



Results

Conclusions: Geophysics works exceptionally well at Huacas de Moche

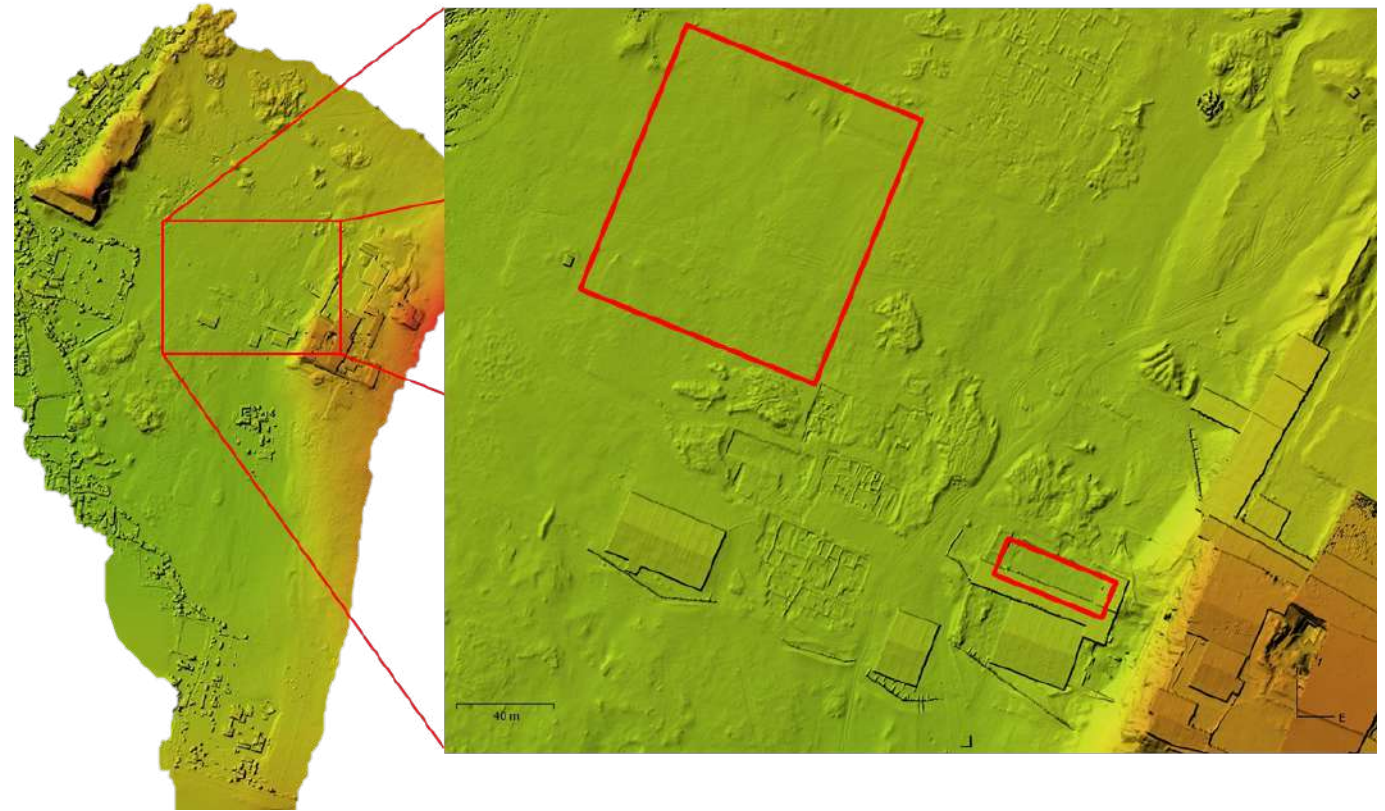
- Geophysics works exceptionally well at HdM



Results

Conclusions: Geophysics works exceptionally well at Huacas de Moche

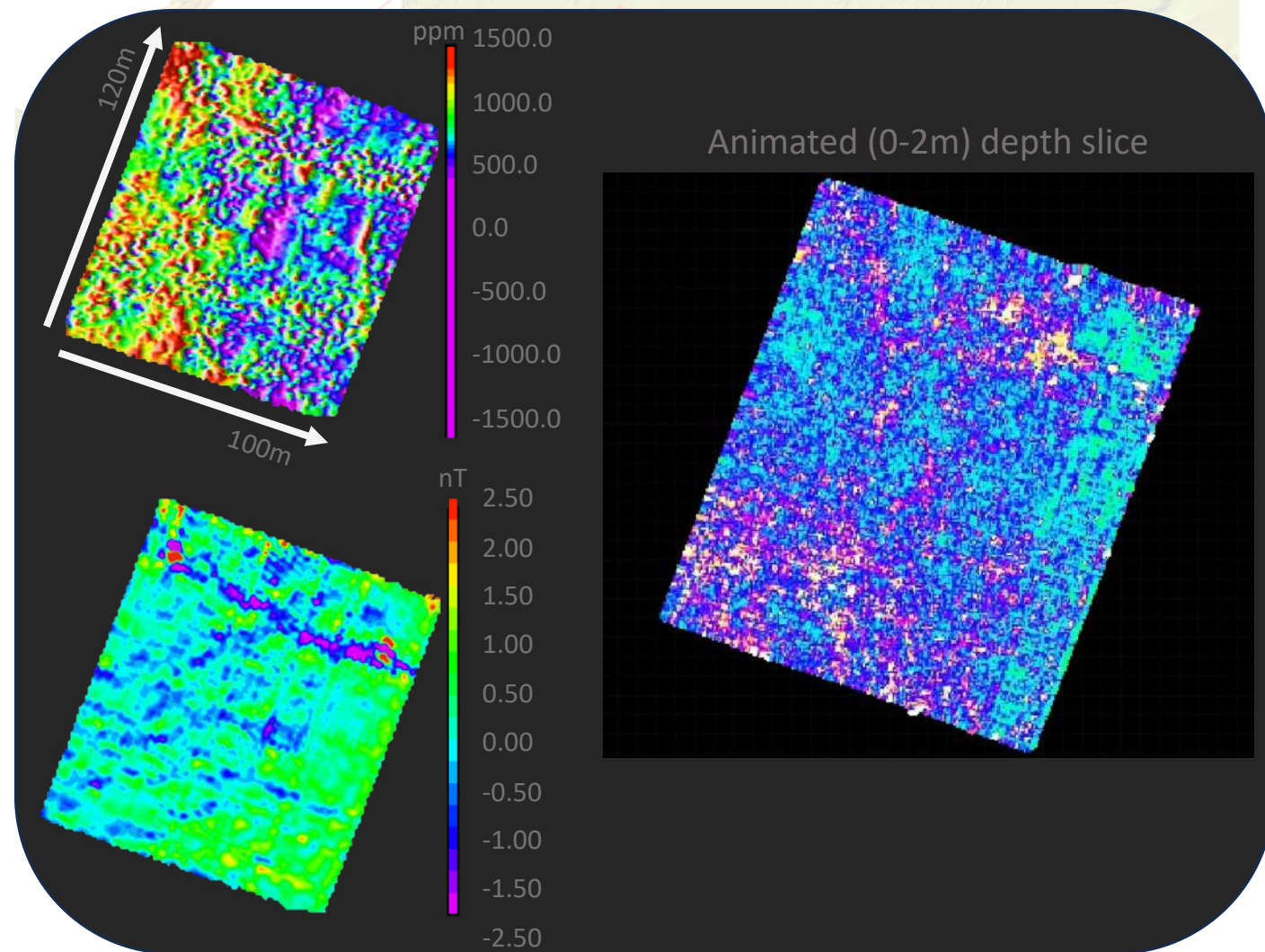
- Geophysics works exceptionally well at HdM
- Drone surveys
 - Provide greatly improved high-resolution orthomosaic maps of the site
 - Map very subtle surface changes that are hard to map on the ground



Results

Conclusions: Geophysics works exceptionally well at Huacas de Moche

- Geophysics works exceptionally well at HdM
- Drone surveys
 - Provide greatly improved high-resolution orthomosaic maps of the site
 - Map very subtle surface changes that are hard to map on the ground
- Magnetics & electromagnetics
 - quickly provide ground maps where there are changes in the subsurface
- Georadar
 - Provide images at depth of walls, tombs, floors
- Recommendation
 - Future surveys for full site should continue



Conclusions

- Geophysics project in Peru

Conclusions

General:

- Many exciting problems to address in Peru, both shallow and deep. Geophysics collaborations with Peruvian Universities contributed significant information to understand these topics

Majes I & II: Geology, Water, Agriculture

- Geophysical instruments donated to universities have worked well for both shallow and deep investigations at Majes (geology & water)
- Proven water table is elevated from agriculture irrigation, and this has increased landslide risk
- Near-surface cemented subsoils (caliche) is a burden for agricultural development, and it can be mapped with geophysical georadar and electromagnetics

Trujillo, Huacas de Moche: Archaeology

- Magnetics, electromagnetics, georadar, and drone data detect and map buried features for archaeologists: burials/tombs, walls, and floors