GLASS EARTH® TECHNOLOGY: 3D SUBSURFACE GEOPHYSICAL IMAGING FOR NATURAL RESOURCE EXPLORATION

Michael Zhdanov, a Distinguished Professor and Director of CEMI at the University of Utah, outlines the potential of Glass Earth® technology in improving geological interpretation, leading to better management and exploration of critical natural resources

Sustainable development of energy, mineral, and water resources is a global priority. Geophysics plays a central role in this effort by providing non-invasive methods for imaging the subsurface and characterizing geological structures that control the distribution of natural resources.

Extensive legacy geophysical datasets – including gravity, magnetic, electromagnetic, and other potential-field surveys – exist across many prospective regions. Although these datasets contain valuable geological information, much of their potential remains unrealized. Modern 3D inversion and multi-physics integration can extract significantly more information from both legacy and newly acquired data. These technologies help identify concealed structures, lithologic variations, alteration zones, fluid pathways, and prospective areas for geothermal energy, groundwater, and critical minerals, including lithium, rare earth elements, copper, nickel, cobalt, and graphite.

Advanced methodology for 3D inversion of multi-physics data

Researchers at the University of Utah's Consortium for Electromagnetic Modeling and Inversion (CEMI), together with TechnoImaging LLC, have developed advanced methods for three-dimensional modeling and inversion of diverse geophysical datasets. These tools enable integrated geological interpretation within a unified quantitative framework. (1,2) The objective is to make the upper crust effectively 'transparent' by recovering quantitative 3D models of subsurface physical properties, including electrical conductivity, chargeability, density, magnetic susceptibility, induced magnetization, and remanent magnetization. This integrated representation of rock physical properties is referred to as the Glass Earth® model.

The key components of this technology include the moving sensitivity domain (MSD) method; joint inversion using Gramian constraints; massively parallelized algorithms; simultaneous inversion of electromagnetic data for conductivity and induced polarization; and magnetic inversion for induced and remanent magnetization. (3,4,5,6,7,8)

The MSD technique is based on the observation that the dominant contribution to geophysical responses commonly arises near the measuring instrument. For moving platforms, particularly airborne systems, this enables efficient inversion of large high-resolution datasets. (4,5)

The Gramian constraint methodology provides a rigorous framework for coupling multiple geophysical datasets in joint inversion. Different geophysical methods respond to different physical properties, but the resulting models should be consistent with the same underlying geology. The Gramian approach enforces meaningful relationships between model parameters, including structural similarity, property correlation, and co-location of geophysical boundaries. This reduces ambiguity and improves geological coherence. (1,2)

Magnetic data have traditionally been inverted mainly for magnetic susceptibility, representing induced magnetization in the present geomagnetic field. However, many geological units contain significant remanent magnetization acquired in ancient magnetic fields. Ignoring this component can lead to incorrect interpretation of magnetic anomalies. TechnoImaging has therefore developed magnetic inversion technology that separates induced and remanent magnetizations. (8)

Geophysical imaging for geothermal and critical mineral resources

One example is geophysical imaging for geothermal and lithium resources in Dixie Valley, Nevada. Between 2021 and 2024, the US Department of Energy–supported BRIDGE project acquired a comprehensive multi-physics dataset, including HeliTEM, magnetotelluric, gravity, and legacy aeromagnetic data, complemented by temperature probes, geochemistry, LiDAR, and fault mapping. (9) Using this data, researchers at TechnoImaging applied a multi-physics inversion workflow that integrates complementary information into a unified 3D geological interpretation.

The resulting density, susceptibility, and resistivity models reveal sedimentary basins characterized by low density, low magnetization, and low resistivity.[10] These signatures are consistent with hydrothermal alteration, magnetite destruction, conductive alteration zones, and fault-controlled fluid circulation. Such features are important for evaluating geothermal systems and assessing the potential for associated critical mineral resources.

Airborne geophysical imaging of the freshwater reservoir beneath the Great Salt Lake

Another example is the application of airborne geophysical imaging to investigate a large freshwater reservoir beneath the Great Salt Lake, the largest inland saline water body in the Western Hemisphere. An airborne electromagnetic survey was conducted to image the electrical resistivity structure beneath the lake. The inversion results reveal a laterally extensive resistive layer beneath the highly conductive brine, interpreted as freshwater-saturated sediments. [11]

Complementing electromagnetic inversion, magnetic inversion, which accounts for both induced and remanent magnetization, provides insight into deeper basement structures. The remanent magnetization model indicates that the basement depth increases rapidly beneath Farmington Bay to more than 3km. This deeper region, interpreted as freshwater-bearing sediments, represents a significant potential freshwater storage zone beneath the Great Salt Lake basin.

These results demonstrate the value of integrated airborne electromagnetic and magnetic imaging for mapping groundwater resources in complex saline environments. The approach can be applied not only to the Great Salt Lake but also to other saline lakes, arid basins, coastal aquifers, and environmentally sensitive regions where freshwater resources are difficult to detect using conventional methods.

Broader scientific and practical applications of Glass Earth® technology

The development of Glass Earth® geophysical imaging technology represents an important advancement in quantitative subsurface characterization. By integrating airborne and ground-based geophysical datasets through advanced 3D joint inversion and multi-physics analysis, this technology provides a powerful framework for imaging the physical properties of the Earth's crust with high geological resolution.

The broader scientific significance of this approach lies in its ability to improve our understanding of complex subsurface systems related to energy, mineral, and groundwater resources. From a practical perspective, the technology has direct applications to sustainable energy development and responsible natural resource exploration.

A particularly important advantage of Glass Earth® technology is its ability to add value to existing legacy geophysical datasets. Many countries and exploration companies already possess extensive airborne magnetic, gravity, and electromagnetic data. Reprocessing these datasets using modern 3D inversion and multi-physics integration can yield new geological insights, identify previously unrecognized exploration targets, and reduce the need for costly and environmentally disruptive early-stage exploration programs.

In this sense, Glass Earth® technology provides both a scientific and practical pathway toward more efficient, responsible, and sustainable exploration. It enables better decision-making, reduces geological uncertainty, supports the discovery of critical mineral, energy, and groundwater resources, and contributes to the subsurface knowledge needed for the global transition to clean energy and sustainable resource management.

References

1. Zhdanov, M. S. 2023, Advanced methods of joint inversion and fusion of multiphysics data: Springer Nature.

2. Zhdanov, M. S., 2019, Method of simultaneous imaging of different physical properties using joint inversion of multiple datasets: US Patent No. 10,242,126.

3. Zhdanov, M. S. 2026, Foundations of geophysical electromagnetic theory and methods, 3rd edition: Elsevier

4. Cox, L. H., G. A. Wilson, and M. S. Zhdanov, 2010, 3D inversion of airborne electromagnetic data using a moving footprint: Exploration Geophysics, 41 (4), 250-259.

5. Zhdanov, M. S., and L. Cox, 2017, Method of subsurface imaging using superposition of sensor sensitivities from geophysical data acquisition systems: US Patent No. No. 9,542,359.

6. Cuma, M., and M. S. Zhdanov, 2014, Massively parallel regularized 3D inversion of potential fields on CPUs and GPUs: Computers & Geosciences, V. 62, 80-87.

7. Cuma, M., and M. S. Zhdanov, 2017, Continental-scale joint inversion of Alaska and Yukon gravity and magnetic data: First Break, 35 (9).

8. Zhdanov, M. S., M. Jorgensen, M., and J. J. Keating, 2024, Revealing the Hidden Paleomagnetic Information from the Airborne Total Magnetic Intensity (TMI) data. First Break, 42 (7), 73-78.

9. Downs, C., Schwering, P. C., Kraal, K. O., Folsom, M., Winn, C., Hinz, N., Milton, A., Zimmerman, J., Sabin, A., Sewell, S., Cumming, W., and J. Lopeman, 2025, Basin & Range Investigation for Developing Geothermal Energy (Technical Report SAND--2025-01826). Sandia National Laboratories.

10. Zhdanov, M. S., M. Jorgensen, L. H. Cox, and A. Gribenko, 2026, Joint inversion of multiphysics data to identify geothermal and lithium resources: geophysical strategy for energy transition: KEGS Symposium, Toronto, Canada, February 28, 2026

11. Zhdanov, M. S., Jorgensen, M., Cox, L., Johnson, W. P., and D. K. Solomon, 2026, Airborne geophysical imaging of freshwater reservoir beneath the eastern margin of Great Salt Lake: Scientific Reports, 16, 11287.

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