3D GEm: A geophysical exploration breakthrough

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Summary

In exploration, development, and exploitation stages in any renewable and / or non-renewable industry (i.e., geothermal, oil & gas, mineral, coal, etc.), the need to integrate results from geology, geochemistry and geophysics combined with structural and other quantitative analytic methods (e.g., XRD, XRF, fluid inclusions, carbon dating, etc.) might be employed at said stages to ensure the direction one company / agency commits. However, the question of time and cost implementing such activity should be considered depending on the financial capabilities of such companies. In this paper, we will explore the complementing role of **3D GEm technology** in addressing the significance of time efficiency, cost-effectiveness and automatic, unbiased data extraction as exhibited in various case studies.

3DGEm (**3**-**D**imensional **G**eologic Mapping with **E**lectro**m**agnetics) captures ambient Electromagnetic (EM) field waves using triaxial magnetic sensors and biaxial or triaxial electric sensors to create 3D high-definition geological and geophysical images. 3D GEm's proprietary data capture and processing system employs all EM sensor components highlighting: (1) lightweight device that detects ambient data sources, (2) easy deployment compared to other systems, (3) capture triaxial magnetic field readings, & (4) captures biaxial or triaxial electric field readings (**Figure 1**).

This lightweight wireless device allows easy and short deployment time compared to other existing geophysical surveys (e.g., magnetotelluric / resistivity, seismic, magnetic, aeromagnetic, gravity, IP, etc.). In addition, this technology generates high-resolution 3D results enhancing simple interpolation and, thereby, plotting produces self-explaining, high-definition 3D images without the use of traditional modeling methods. This is due to the good instrument-to-data ratio and high resolution employed by 3D GEm which uses the interference of electromagnetic waves recorded at different locations to extract information (e.g., geology, geophysical anomalies, structures, alteration, etc.) within the Earth's subsurface. Depth-wise, this technology likewise employs "data stacking" which increases signal-to-noise (S/N) over time and allows depth penetration to few kilometers (~ 2.5-5.0 km). No electromagnetic (EM) energy is injected into the ground; therefore, this application has a low environmental footprint.

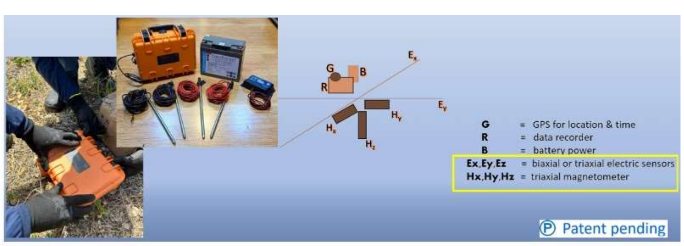

Figure 1. 3D GEm Components and accessories.

Hypothesis

In a typical geophysical survey (e.g., land and/or airborne, etc.), depending on the degree of detail per survey line, range of regional grid distances of 400-800 meters (Alberta Geological Survey, 2024) to semi-detailed range of 100-150 meters to a very detailed 20-50 meters line spacings (Geometrics, 2025) are needed to cover a specific coverage area. Interpretations are mostly presented as two-dimensional; however, third-party applications rely heavily on interpolated / extrapolated data between these survey lines especially when big gaps are identified that finer details are missing between survey lines. Furthermore, continuity of identified two-dimensional geophysical data anomalies throughout the survey lines are difficult to ascertain and, likewise, targeting specific anomalies in 3D space will be on a trial-and-error basis. Costs and time associated by applying these traditional geophysical methods will be more expensive in the long term and will create further strain on the operational activities of the companies and stakeholders involved.

Methodology

3DGEm uses all the five elements in the triaxial magnetic and electric components in its sensors to capture the ambient electromagnetic signals for mapping geologic and geophysical features of the subsurface. This is due to the good instrument-to-data ratio employed by 3D GEm to extract pertinent information about the Earth's subsurface resulting in high-resolution 3D. This is the result of using an arsenal of electromagnetic (EM) sensor combinations that can mimic geophysical anomalies (e.g., resistivity, metal factor, etc.) and focus on geological targets. In addition, the data collection units are portable, battery-operated, and satellite-synchronized, which gives further value to eventual data extraction, correlation and integration.

The layers are automatically traced across the mapped area, avoiding supervised matching of beds across structures/basins implying “self-interpreting” capabilities where automatically assigned EM signatures can be used to find other locations of geological units (or outcrops) on the surface and underground. Thereby, maps and anomalies can be correlated with “existing” surface and subsurface geological and geophysical data.

Built upon the principle of magneto-telluric geophysical surveys, 3D GEm employs “data stacking” which increases signal-to-noise (S/N) over time and allows depth penetration to deeper levels. A rectangular grid of instruments spaced evenly and centered over the exploration target is a good layout where spacing can be 4 instruments per km^2. For moderate coverage, 16 instruments for 2 km × 2 km while a more detailed with a denser layout, or less detailed by using less, or just enlarging the area. The detail is better in the middle and fades outward of the center. Four (4) hours of common time data for all instruments is good for 250-to-500-meter depths, while 24 hours is good down to 2 kilometers. For deeper data depths, around 48 hours or more can reach levels of ~ 5 kilometers.

In order to test the applicability of this new-found technology, case studies will be presented on fault & geological ground-truthing (Case 1); cavity hazard mapping (Case 2); dam construction design (Case 3); tunnel design (Case 4); and, lastly, geothermal exploration (Case 5).

Results & Observations

Case 1: Fault & geological ground-truthing (**Figure 2**). The site was selected because geology (conglomerate beds mapped as colored bands) can be observed inside ~60m vertical shafts in three of the 70m X 70m by 250 m high geophysical anomaly columns. "Listric faulting" is evident showing vertical traces at its flanks and curves into a flat structure at its bottom sections. 2D resistivity confirms fault deformation suggested by 3D GEm implying uplift at the flanks. These data, gathered on different days and different but adjacent sites, illustrate the consistency in time and space of 3D GEm data.

Case 2: Karst geology showing cavity hazards mapping (**Figure 3**). The site is a karst terrain specifically with cavity-populated, reefal limestone. There is good correspondence between 2D resistivity charts and 3DGEM map of resistivity anomalies showing multiple cavities and reverse faulting (confirmed by the fault-uplifted terrain shown by the topography and Google Earth data). Note that no modelling is involved here but automatic data plotting.

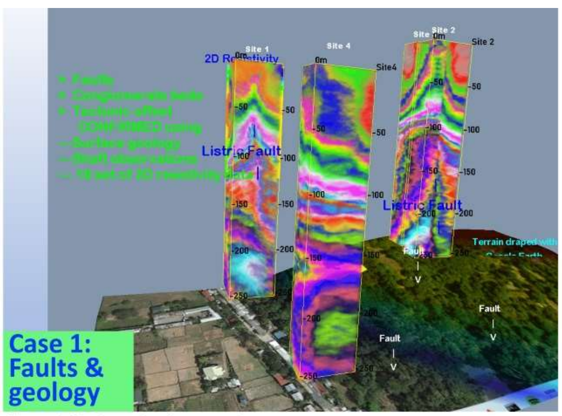

Figure 2. Faults and geology mapping.

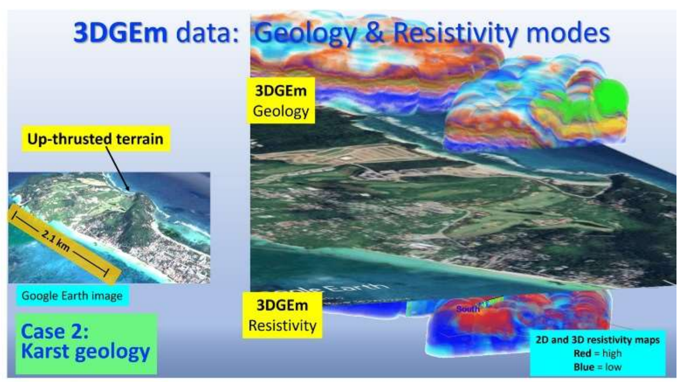

Figure 3. Karst geology showing cavity hazard mapping.

Case 3: 3D geologic mapping for dam construction design (**Figure 4**). The site is a hilly area traversed by a river where a dam is proposed. Detailed geologic mapping was made around the dam site where two sets of 2D resistivity charts were made on left and right banks of the river (at dam abutment) showing curved anomalies. 3DGEM data reveals synclines mimicking the curved resistivity anomalies which are consistent with the strike and dip data from geologic maps. Same data was tested for deep level features, revealing that 3DGEm can map down to a few kilometers deep (~ 2.5 kilometers).

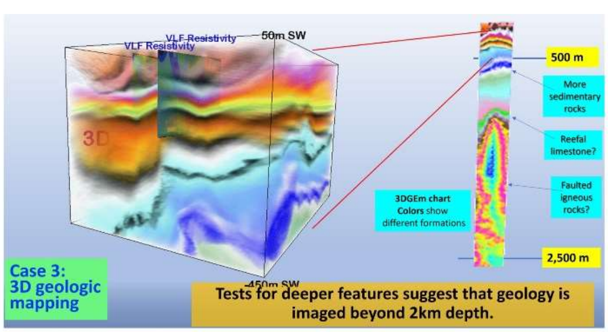

Figure 4. 3D Geologic Mapping for dam construction design.

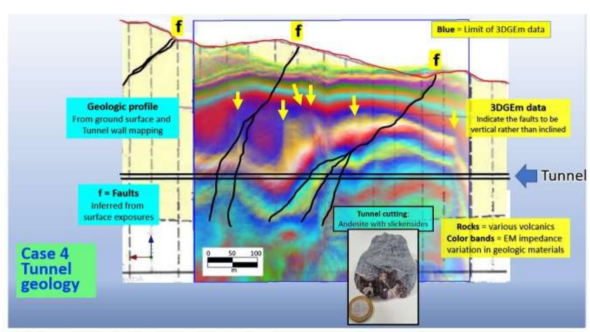

Figure 5. Tunnel geology for engineering design.

Case 4: Tunnel geology for engineering design (**Figure 5**). The Site is a mountainous area where another water conveyance tunnel is proposed. Mapping of geology and faults were needed to prepare tunnel excavation for structural and water influx hazards. 3DGEm data reveal faults to be vertical revealing zones of alteration caused by groundwater along said faults. Google Earth terrain and satellite image reveal straight alignment of faults, confirming their near-vertical geometry. GHD engineers adopted said findings to refine their tunnel construction and management strategies for said site.

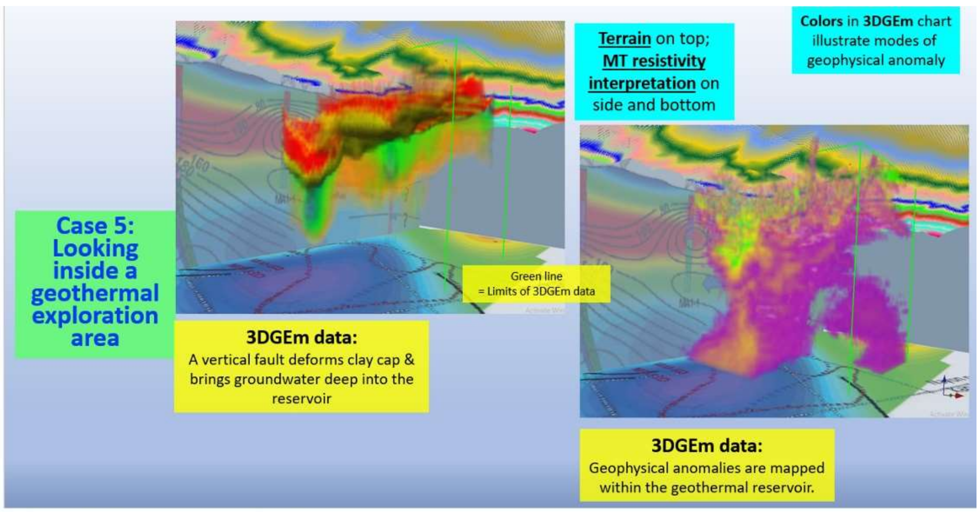

Figure 6. Geothermal exploration mapping.

Case 5: Geothermal exploration mapping (**Figure 6**). The site is an operating geothermal plant where exploration is ongoing. A short and incomplete survey was conducted where 3D GEm data was able to chart the major geological features of the geothermal system. This includes the clay cap, a large fault (where ground water is ushered deep into the reservoir), and potential reservoir zones (where heat up-flow was earlier mapped). In detail, **Figure 6** represents the marginal image of the geothermal reservoir. You can see the faults (sharp vertical boundaries) that coincide with the site's structural map. The N (left) border of the coincides with the mapped N-margin of the geothermal reservoir.

These geology / geophysical anomalies correlate well with existing magnetotellurics, exploration drilling, geology, geochemistry and temperature data on-site which is consistent with their conceptual geothermal model.

Discussions

The complementing role of 3D GEm technology in addressing the significance of time efficiency, cost-effectiveness and automatic, unbiased data extraction / plotting as exhibited in various case studies above show high correlation with existing geology and geophysical data on-site. This is to emphasize that 3D GEm provides outright confidence in interpreting geologic and geophysical anomalies either in a data-populated site or in an unexplored terrain with no data at all. This technology not only shows high resolution, three-dimensional “automatic” plotting of geology /

geophysical signatures, but exhibits clear, distinct stratigraphic continuities and structural discontinuities across any area of interest. This technology has clearly shown great potential for structural studies, hazard mapping, dam construction design, tunnel engineering design and geothermal exploration applications. Future case studies are ongoing right now on various mineral exploration and carbon capture and storage (CCS) studies.

Acknowledgements

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