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3DGEm for Geothermal Exploration in Latin America

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Abstract

We introduce the 3DGEm method for creating 3D geological maps using electromagnetics. The 3DGEm method captures ambient electric and magnetic data to create high-definition 3D geological maps to present subsurface models in two modes: Mode A features regions of inductance indices that chart lithological units, hydrogeological features or alteration zones; Mode B displays impedance coefficients that uniformly increment with depth, but readily disrupted by faults, sedimentary structures and lithological or geochemical boundaries.

Unlike traditional geophysics which defines quantitative physical anomalies, 3DGEm data reveals qualitative geological models of the subsurface. Mode A images reveal patterns in geological materials that, in geothermal areas, may serve as fluid migration channels. Mode B create detailed images of faults and lithostratigraphic boundaries, unmasking interesting and unexpected structural features of geothermal significance, including mofette structures and Schlieren textures that defined geothermal reservoirs. These 3DGEm data modes can be powerful tools that unravel the complexity of geothermal systems.

We therefore promote 3DGEm as a powerful complement to traditional geological mapping, allowing data from drilling and magnetotellurics to be better understood. Geothermal exploration in Latin America will gain from 3DGEm's low environmental footprint, fast result turn-around, and very competitive costs. However, it is 3DGEm's unique high-resolution 3D geological maps reaching few kilometers into the subsurface that can hasten the development of geothermal resources in Latin America.

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A. Background

Traditionally, geophysical exploration has always aimed at detecting and mapping deviations in physical properties of subsurface materials. 3DGEm employs a number of miniature electromagnetic instruments, and resembling MT, contains triaxial magnetometers and two horizontal electric dipoles in orthogonal geometry. Compared to magnetotellurics, the system covers a shorter frequency range. The main innovation of 3DGEm is in the number of instruments used in surveys. More than 20 units are deployed as a large array covering a few kilometers across to create a dense distribution of EM data.

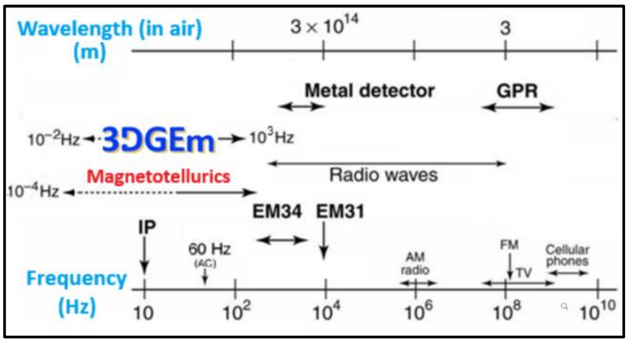

Figure 1: The spectral range of 3DGEm extends from 0.01 Hz to 1kHz, and covers a few orders of magnitude shorter than traditional magnetotellurics system.

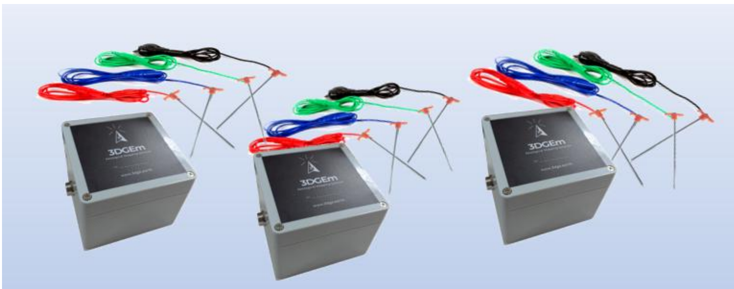

Figure 2: More than 20 units of the portable 3DGEm instruments create an array across an area of few square kilometers. Larger areas may be covered by overlapping surveys can also be used or by stretching the array but while reducing horizontal resolution.

Although the 3DGEm is designed as a geophysical tool, the overall purpose of the system is to create high-definition images of the subsurface, to such extent that the geological elements can be recognized and interpreted. Therefore, rather than producing accurate values of resistivity or magnetic strength, 3DGEm focuses on detecting minute deviations in amplitude, phase, polarity, frequency and other measurable features of numerous waveforms collected over the exploration area. By plotting the subsurface anisotropy and heterogeneity detected by 3DGEm, a 3D image of the geology is created to such detail that the subsurface features are readily recognizable.

3DGEm embodies a system for data collection, processing and visualization that employs various electric and magnetic sensors to create 3D maps of the geology. The hardware is compact and very portable, and multiple units are deployed as uneven grid over the target area. Time series soundings capture data that reach a few kilometers below the instrument network. Data processing and visualization are designed to image faults, folds, and bedding structures, in one mode, and the rocks and various materials that compose the Earth’s subsurface in another data mode.

B. 3DGEm in geothermal exploration

Geothermal sites are a complex mixture of rocks and fluids traversed by structures and heat source that provides the chemical and thermal factors further complicate matters. In this complexity, the rational approach for a greenfield exploration area using 3DGEm is first to define the structures from Mode B data, and, after the structural framework is visualized, images of the geologic materials from Mode A may be overlaid. The structures are more readily appreciated, providing logic on why certain geological materials are in such locations. For example, faults (seen in Mode B) may connect to streams on the surface (seen in topography) leading to recharge (seen in Mode A as linear streaks) that follow the mapped structures. It is this interplay between the structures—mapped in Mode B, and the materials—mapped in Mode A, that create the logical geologic picture that explains the geothermal field. The structural features seem to be unique to geothermal systems as illustrated in actual geothermal field data in **Figure 3.**

In studying geothermal systems, the circulation of fluids is often desired to be known such that it can be tapped for production of steam, or fed with the reinjection fluid aiming for an effective recirculation. **Figure 4** illustrates what 3DGEm can accomplish – isolating and displaying the geothermal fluids in 3D, using the EM signature contained in Mode A data.

C. Summary and conclusions

3D geologic maps by 3DGEm have been created under varying settings, including sedimentary and volcanic situations, and in mineralized areas. Its ability to create detailed 3D maps led more to discoveries than to questions. This is despite the lack of a comprehensive labels or legends which tags colors to specific geologic formations. It appears therefore that the appreciation of geological features in any map is dependent primarily on the structural detail that can be viewed, and secondarily on the nature of materials inside each color or material category. This observation is therefore indicative that subsurface data is best appreciated when presented with good spatial and structural detail, and that the interpretation on the material or process becomes lower priority. A corollary conclusion to this is that any form of geophysical data, if presented in such 3D detail, can always lead to better appreciation of the underlying geology.

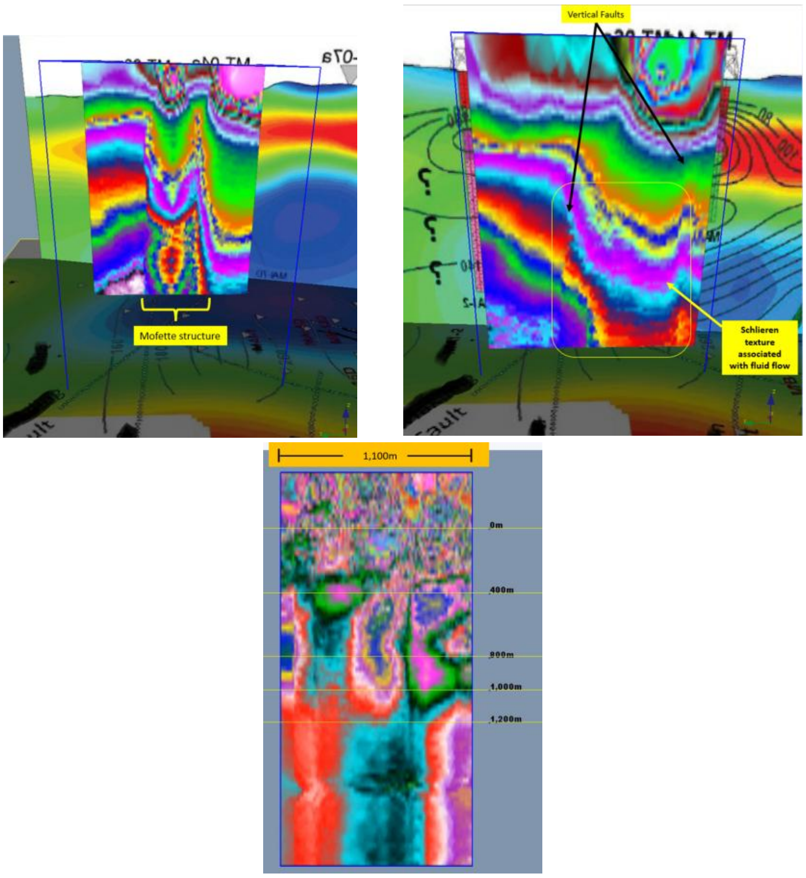

Figure 4: Features that were unique to geothermal areas include mofette structures (left) that manifest the occurrence of volcanic processes at the site, the Schlieren texture (center) that is common around the geothermal reservoir, and the prevalence of apparent fluid-filled structures (right). It is also notable that Mode B bands of impedance coefficient sags or drops along structures around the reservoir area. This is interpreted to suggest the lowering of resistivity (or impedance) and magnetic field strength of the surroundings.

A workflow for use in an exploration campaign is presented in **Figure 5**, and may be suitable as new sites for geothermal energy are being explored. The structural features uniquely observed in geothermal systems may be helpful in defining the position of the geothermal reservoir, and the structures that may be facilitating the vertical migration of fluids. We emphasize that 3DGEm cannot take on the exploration on its own. It is therefore best as a complement to other more traditional methods of exploration. There are yet more that needs to be learned about the 3DGEm data—the other forms of its EM signals are still to be investigated. The same situation can be said about the Earth's subsurface.

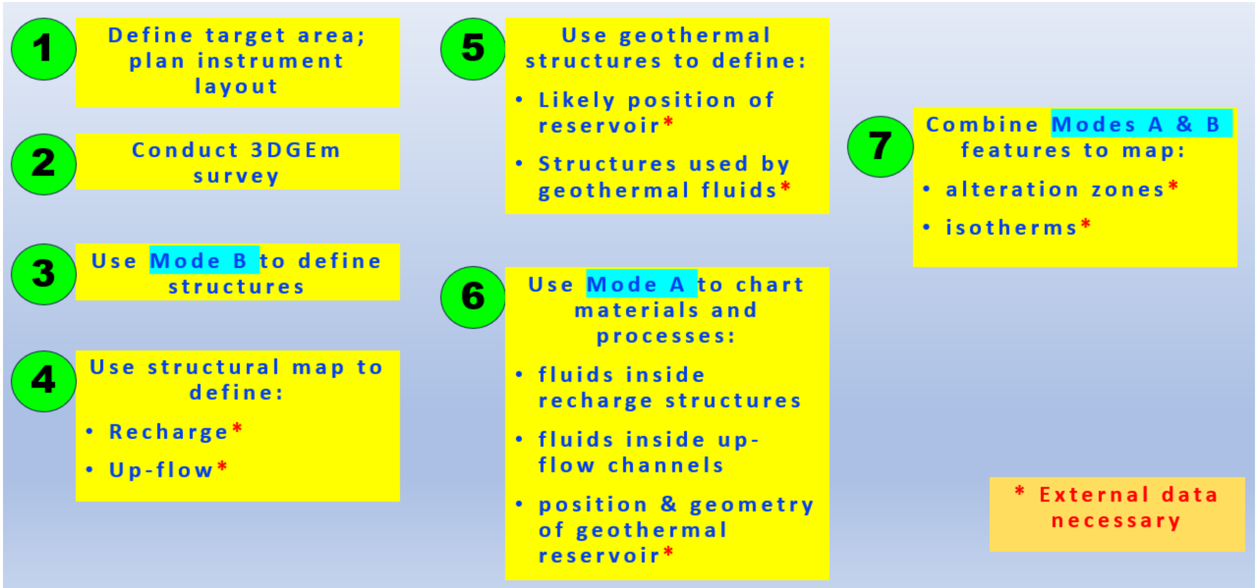

Figure 5: Workflow for using 3DGEm as a complementary tool in a greenfield geothermal exploration. In many stages, the need to use external data to validate 3DGEm results is implied.