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Advancing Geothermal Exploration through Airborne Geophysical Technologies: Insights from Japan and Nevada (US) Case Studies

Avances en la Exploración Geotérmica mediante Tecnologías Aerogeofísicas: Experiencias en Japón y Nevada (EE. UU)

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Resumen: Este artículo presenta la aplicación de tecnologías aerogeofísicas en la exploración geotérmica, mediante dos casos de estudio en Japón y en Nevada (EE. UU). Las campañas llevadas a cabo por Xcalibur Smart Mapping, utilizaron electromagnetismo en el dominio del tiempo usando helicóptero (HeliTEM), adquiriendo datos magnéticos simultáneamente en ambas regiones, además de gradientes gravimétricos con la tecnología HeliFalcon AGG en Japón. Estos métodos se aplicaron para investigar sistemas geotérmicos en ambientes tectónicos extensional y magmático-volcánico, respectivamente. El objetivo principal fue detectar y caracterizar reservorios y sellos geotérmicos en el subsuelo mediante el mapeo de anomalías de resistividad y estructuras asociadas a la actividad hidrotermal. En Japón, la interpretación integrada de los datos electromagnéticos, magnéticos y de gradientes gravimétricos reveló múltiples zonas prospectivas. En Nevada, los modelos de resistividad identificaron las estructuras más importantes de la cuenca y rocas sello indicativas del potencial geotérmico. La integración de datos electromagnéticos aerotransportados con la magnetotelúrica terrestre (MT) en Nevada permitió además tener una imagen más detallada de las características del subsuelo críticas para la evaluación de recursos geotérmicos. Estos resultados resaltan el valor de la aerogeofísica para reducir el riesgo en la exploración, orientar estrategias de perforación y acelerar el desarrollo de recursos energéticos geotérmicos sostenibles.

Palabras clave: exploración geotérmica, datos electromagnéticos, gradientes gravimétricos.

Abstract: *This paper presents the application of airborne geophysical technologies in geothermal exploration, demonstrated through two case studies in Japan and Western Nevada (EE. UU). Conducted by Xcalibur Smart Mapping, the surveys utilized Helicopter-borne Time-Domain Electromagnetics (HeliTEM) and magnetic methods in both regions, with Helicopter-borne Gravity Gradiometry (HeliFalcon AGG) additionally deployed in Japan. These technologies were applied to investigate geothermal systems in magmatic-volcanic and extensional tectonic settings, respectively. The primary objective was to detect and characterize hidden or blind geothermal reservoirs by mapping resistivity anomalies and structural features associated with hydrothermal activity. In Japan, the integrated interpretation of electromagnetic, gravity gradiometry, and magnetic data identified significant potential structural and lithological features for geothermal exploration. In Nevada, resistivity models identified key basin structures and cap rocks indicative of geothermal potential. The integration of airborne electromagnetic and ground magnetotelluric (MT) data in Nevada further enhanced imaging of subsurface features critical for geothermal resource assessment. These findings highlight the value of airborne geophysics in reducing exploration risk, advancing drilling strategies, and accelerating the development of sustainable geothermal energy resources.*

Keywords: *geothermal exploration, airborne geophysical data.*

INTRODUCTION

The global transition toward sustainable energy has renewed interest in geothermal resources across a wide range of geological settings. Airborne geophysical technologies provide a transformative approach to exploring these resources, offering rapid, non-invasive, and high-resolution subsurface imaging over large areas. This improves the precision of drilling target selection and reduces the financial risks associated with geothermal development.

This paper presents a synthesis of two major airborne geophysical campaigns conducted in a magmatic-volcanic geothermal environment in Japan and in an extensional domain in Western Nevada (US). Both studies, led by Xcalibur Smart Mapping, deployed Helicopter-borne Time-Domain Electromagnetics (HeliTEM), acquiring magnetic data simultaneously; and in Japan, Helicopter-borne Gravity Gradiometry (HeliFalcon AGG), to image subsurface structures and alteration zones associated with geothermal systems.

OBJECTIVES

The primary goal of both campaigns was to improve the detection and delineation of the elements of the geothermal systems, particularly those hidden beneath sediments or obscured by challenging topography. In Japan, the focus was on mapping low-resistivity zones and characterizing structurally controlled hydrothermal systems along the volcanic chain (Feijth et al., 2018), while in Nevada, the objective was to image low-resistivity clay caps that may overlie geothermal systems in the Basin and Range Province (Matson et al., 2022). In both cases, airborne technologies were used to reduce geological uncertainty and guide drilling strategies.

METHODOLOGY

Over 15,000 line-km of high-resolution HeliFalcon AGG, HeliTEM, and magnetic data were collected across rugged terrain in Japan, with elevations from 0 to 2,500 meters and 250-meter line spacing (Fig. 1). In Western Nevada, the survey spanned ~5,000 km², acquiring 1,877 line-km of data over 12 days with 1–2 km line spacing and concurrent magnetic data collection (Fig. 2). Several known geothermal systems were surveyed as calibration and control sites.

A multi-physics approach was employed for interpretation:

- **HeliTEM data** in Japan was used in both regions to map low-resistivity zones associated with hydrothermal alteration, which correspond to clay caps in geothermal systems. (Fig 3).
- **Magnetic data** acquired in Japan was used to map the spatial distribution of lithologies, variations in basement depth, structural features and zones of magnetite destruction caused by hydrothermal alteration (Fig. 4a).
- **HeliFalcon AGG** data flown in Japan, revealed strong subsurface density variations, highlighting lithological contrasts and fine-scale faults critical to understanding fluid migration pathways. (Fig 4b).

HeliTEM data inversion and integration with ground-based geological and magnetotellurics (MT) data in Nevada enabled the construction of three-dimensional resistivity models and interpretation of key geothermal indicators (Sewell, et al., 2023). USGS inversion and standard/conservative depth of investigation (DOI) analysis and cross-validation with MT data confirmed the reliability of airborne resistivity imaging, especially in the top 300–500 meters (Fig. 5).

RESULTS

In Japan, integrated HeliTEM, magnetics and HeliFalcon AGG datasets identified multiple structurally controlled low-resistivity zones some coinciding with known surface manifestations such as fumaroles and hot springs. Four prospective geothermal zones were delineated, each characterized by resistivity anomalies and structural traps suggesting significant migration and potential fluid accumulation (Fig 6). In Nevada, the HeliTEM survey imaged basin-bounding faults, clay-rich cap rocks, and potential outflow zones. The data revealed consistent resistivity patterns corresponding to known geothermal systems and informed a regional conceptual model of hidden geothermal reservoirs with smectite clay caps overlying more resistive hydrothermal zones (Fig. 5).

CONCLUDING REMARKS

These case studies demonstrate the power of airborne geophysics in modern geothermal exploration. The integration of HeliTEM, magnetic with HeliFalcon AGG data (in Japan), and with MT validation (in Nevada), highlights a robust, scalable methodology for characterizing geothermal systems in complex geological contexts. Airborne geophysics enables early-stage targeting, reduces the environmental footprint of exploration, and accelerates resource development timelines.

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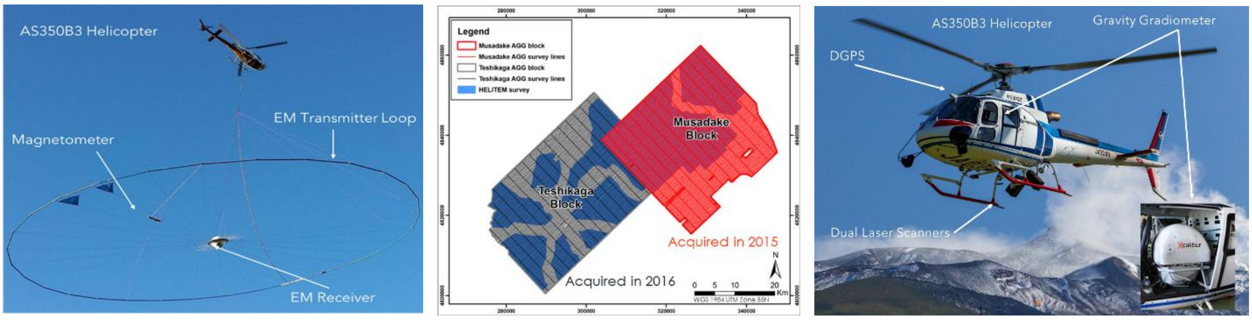

FIGURE 1. HeliTEM system (left), Japan airborne geophysical flight plan (center) and HeliFALCON system (right) (Feijth et al., 2018)

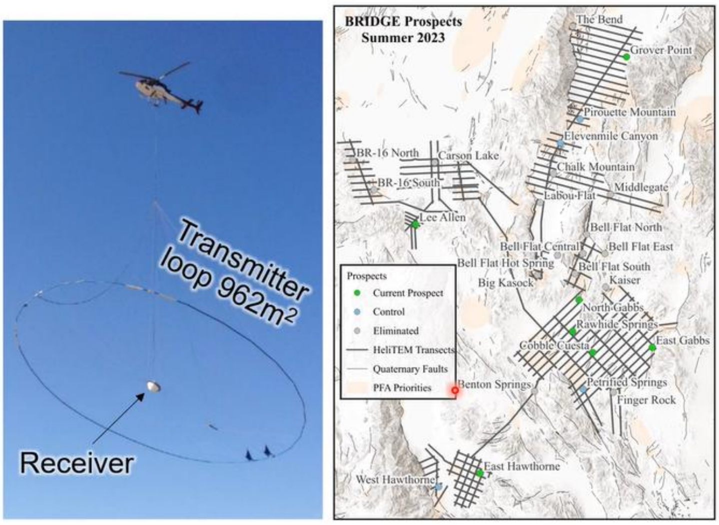

FIGURE 2. Nevada airborne geophysical survey (Folsom M., et al, 2024): HeliTEM system (left) and flight plan (right) (Sewell et al., 2023)

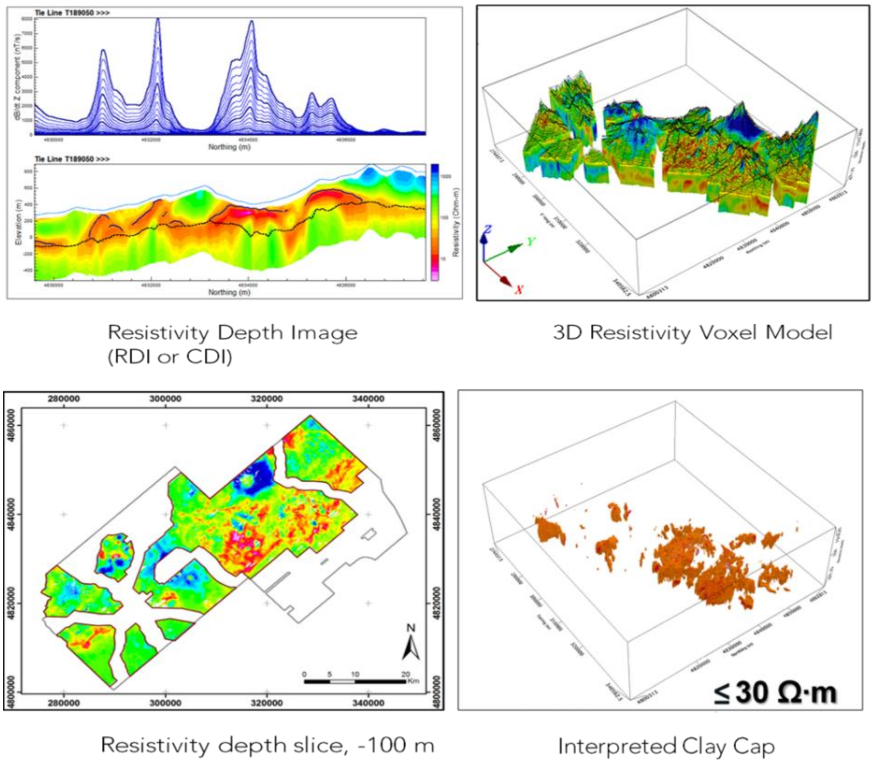

FIGURE 3. Japan HeliTEM electromagnetic data: image of a 2D resistivity profile (top left), 3D resistivity voxel model (top right), resistivity slice at 100 depth (bottom left) and 3D model of the interpreted clay cap (bottom right) (Feijth et al., 2018)

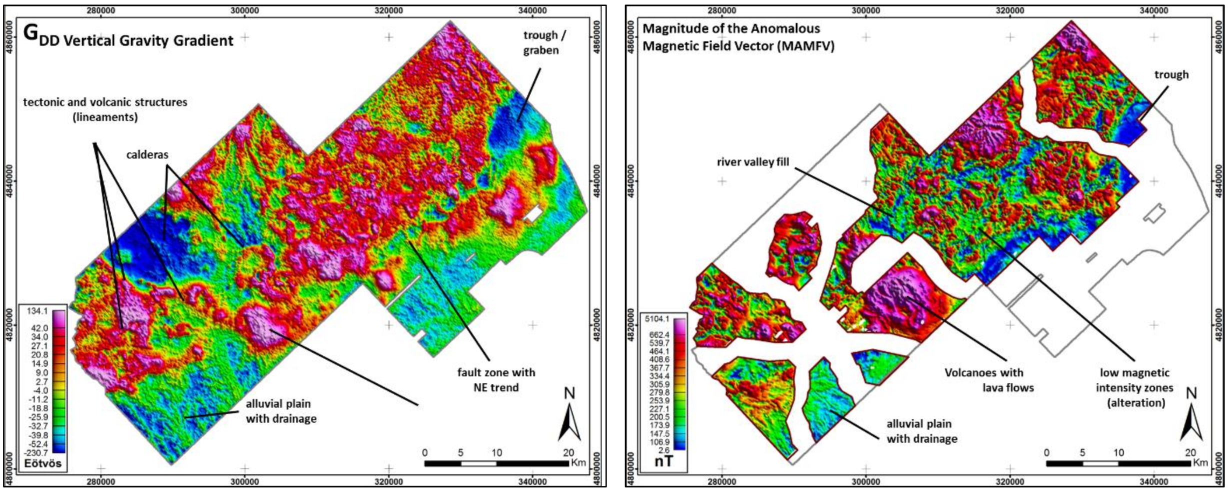

FIGURE 4. Litho-structural interpretation in Japan: A) HeiFalcon AGG data (left) and B) HeliTEM magnetic data (right) (Feijth et al., 2018)

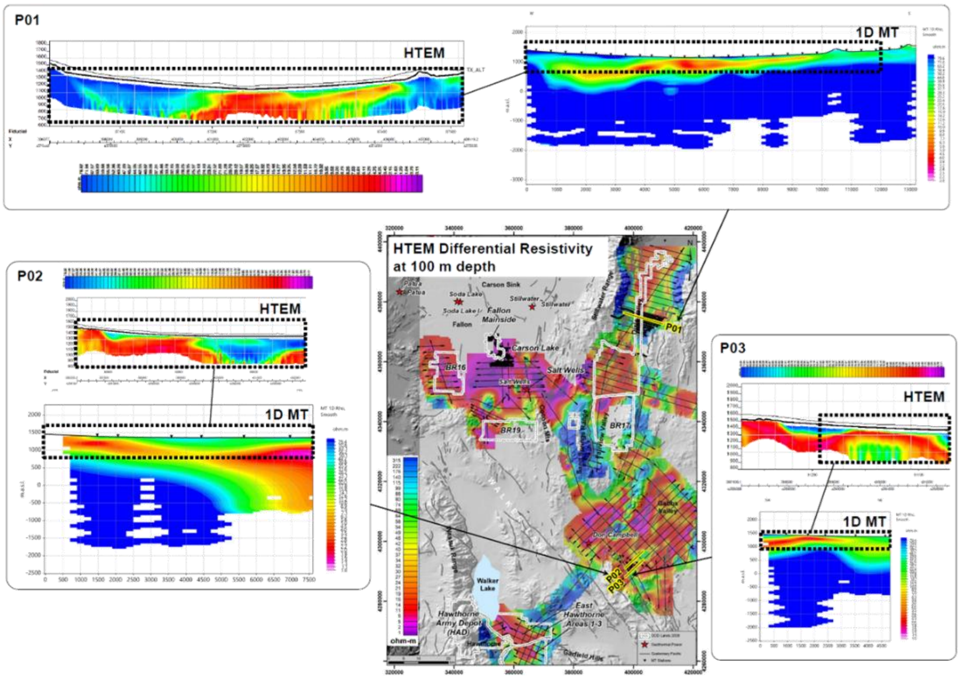

Figure 5. Nevada HeliTEM data: MT and HeliTEM results show good agreement at depths where HeliTEM differential resistivity is reliable (e.g., P01, P02, P03). HeliTEM effectively images the edges of conductive basin sediments in contact with resistive basement rocks (Matson et al., 2022)

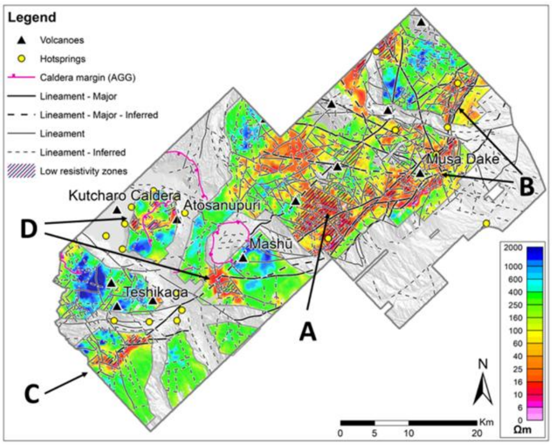

Figure 6. Integrated interpretation of HeliFalcon AGG, magnetic, and HeliTEM data on a HeliTEM resistivity map, highlighting low-resistivity zones and structural controls relevant to geothermal potential in Japan (Feijth et al., 2018).