GUADELOUPE ARCHIPELAGO IN FRENCH WEST INDIES

MAGIS for Geothermal Application

For a long time magnetic surveys have been under-used because of their limited usefulness. In recent years technology has advanced considerably and magnetic recording can now be performed simultaneously with other geophysical data acquisition, even though the survey has not been specifically designed for magnetic acquisition. Magnetometers can adapt easily to a large variety of survey configurations (high speed, irregular survey lines path) and still produce high-resolution results.

A marine survey was carried out off the western side of the Guadeloupe archipelago (French West Indies) in November 2003 by the BRGM (French Geological Survey). The Guadeloupe Archipelago is composed of four islands (westward of 61.10 Â° W, Figure 1). Basse-Terre Island, the largest and most western one, belongs to the volcanic arc comprising active volcanic edifices such as the SoufriÃ¨re hills, Montagne PelÃ©e and Kick'em Jenny. Together with Les Saintes Island (southward), they constitute the most recent and highest relief. Hydrothermal venting along the western coast of Basse-Terre Island has been known for a long time. More recently, submarine hydrothermal manifestations have been observed during dives in Bouillante Bay. Along with other geological evidence, these submarine hydrothermal manifestations suggest a marine extension of the geothermal field exploited since 1996 by GEOTHERMIE BOUILLANTE.

This project, supported by ADEME1, aimed to establish a structural geological map of the continental plateau focusing on the submerged part of the Bouillante Bay. The survey was originally planned to use high-resolution seismic equipment only.

IXSEA lent its marine magnetometer, MAGIS, in order to record Earth magnetic variations simultaneously with the seismic data. MAGIS is based on Magnetic Nuclear Resonance (RMN) technology with a proprietary sensor design allowing anisotropic measurement of the magnetic field. Its originality lies in the combination with Dynamic Nuclear Polarization (DNP), a principle discovered by A. Abragham, which permits the preservation of high sensitivity even at high sampling rates. Until recently this technology was used exclusively for defence and space magnetic applications.

The MAGIS magnetometer operates in the Earth's field from 25,000nT to 75,000nT. The resolution is 0.01nT with a noise level of 0.0035nT/Hz1/2. All these performances are achieved with a sampling rate of ten samples per second. Its power consumption - less than 10 Watts and weight in water - around 3kg - allow efficient use in many conditions.

The Bouillante Bay survey was carried out over seven days, on a 10- metre launch. More than 325km of magnetic and seismic data were recorded (Figure 1). The seismic equipment consisted of a 48m-long streamer made up of six traces and a Sparker type source (SIG1000). Shots were performed every 4 metres. The Sparker power ranged from 250 to 1,000J, depending on the expected features to be imaged. The recording system was a 6-channel Delph recorder system. Seismic equipment (source and streamer) and magnetometer were towed respectively at a distance of 50m and 40m behind the launch, at a depth of 3m. The average boat speed was around 5 knots, allowing 1 record per 20cm along the survey line. The magnetometer depth was also recorded with magnetic values for later correction.

The Sparker electric shots necessary for the seismic recordings induced an electro-magnetic field in the magnetometer (Figure 2). These shots appear on the magnetic recordings as spikes (blue line on Figure 2). The spikes never exceed 25nT in amplitude and twenty samples in width. They were easy to remove by a non-linear filter. The magnetic profile after filtering (red line on Figure 2) may then be used with confidence for further processing.
The post-cruise processing of magnetic data performed using dedicated software included de-spiking to remove the electro-magnetic effect of the Sparker, diurnal variation, lag corrections and statistical or micro levelling.
The sensor anisotropy (heading error) of the MAGIS magnetometer is less than 0.5nT p-p. This advantage allows freeing of processing from heading corrections that are tricky to evaluate in marine surveys. In the same way, no care has to be taken with survey lines orientation versus the Earth magnetic field.

For diurnal corrections, we used data recorded at a fixed magnetic base station on Basse-Terre Island belonging to the IPGP (Institut de Physique du Globe de Paris, France) Volcanological Observatory. Lag time comprises both experimental (cable length) and instrumental lag. The instrumental lag of MAGIS, intrinsic to the RMN sensor, is about 1.4s.

As the survey was carried out with primarily seismic objectives, profiles were orientated in all directions, preferentially perpendicular to the geological features. In this context, removing uncompensated diurnal and systematic errors is not so easy. Profiles secant to the others were selected and attributed to tie-lines in order to perform statistical levelling. The fully corrected magnetic data was interpolated with a cell spacing of 100m using a minimum curvature algorithm to generate the total field magnetic map.

The main issue in the project was to map the marine extension of geological features recognised on land, such as large-scale faults and volcanic flows. There are some well-preserved volcanic formation outcrops on the beach of the Bouillante Bay (Figure 3). An undetermined thickness of volcanic breccia (hyaloclastites) has been thrown out to a distance from the volcanoes (brown material on Figure 3). This material has been covered with pebbles and sand during periods of volcanic quietus. Then a new volcanic episode has spilled larva (massive basalt at the top of the geological sequence in Figure 3) over the beach. This recent geological sequence lies in Bouillante Bay, where hydrothermal activity is known. Nevertheless, its extension offshore is unknown.

Ferromagnetic minerals are numerous in volcanic material. However, to locate volcanic structures precisely using the magnetic response is awkward because remnant magnetisation is always present. Magnetic anomalies are then distorted. To be free from such distortion, we computed the amplitude of the 3D analytical signal (A(x,y)) of the magnetic field to locate volcanic magnetic sources.

The analytical signal may be considered to be an energy envelope independent of distance from the magnetic source and remnant magnetisation.
The analytical signal of the magnetic map (Figure 4) delivers important information for the geologist. The photo on Figure 3 was taken on the beach (yellow circle at the bottom-right corner of the rectangle, Figure 4). These geological formations are highly magnetic and extend westward into the sea, as observed on the analytical signal map. The diameter of the surface covered by this volcanic material is greater than 50km. Northward and southward along the coast, high magnetic anomalies are scattered. More westward, the magnetic signal is smoother because the plateau deepens rapidly. As the distance between the magnetometer and the sources increases the magnetic field falls off.

The black rectangle on Figure 4 outlines a higher resolution magnetic survey carried out at the end of the cruise (yellow lines on Figure 1). On the last day, magnetic data only was recorded within a detailed box near Bouillante Bay in order to follow structural features (faults, hydrothermal paleofields) from land to sea. The processing of this survey consisted of diurnal and lag corrections, micro-levelling, grid interpolation (cell size of 25m) and transformation. Even though remnant magnetisation is dominant, reduction to the pole was computed to straighten anomalies induced by most recent volcanic sources (Figure 5). The magnetic field reduced to the pole was draped over detailed bathymetry recorded in 1998 by BRGM and GEOTHERMIE BOUILLANTE. A 140Â¡-orientated trending feature expressed in the bathymetry corresponds to the south-western limit of a well-expressed anomaly. This observation confirms the presence of a structure interpreted in terms of a major fault.

Magnetic anomalies have very high amplitude (more than 1,000nT). The comparison between the analytical signal (Figure 4) and the magnetic field reduced to the pole (Figure 6) gives information about the remnant magnetisation. The anomaly reduced to the pole is very different from the analytical signal, suggesting that the Earth's magnetic field at the time of the volcanic event observed in Figure 3 and extending into the sea is different in direction from the Earth's actual magnetic field. This implies that geological interpretation of these magnetic maps must be done using analytical signal rather than the reduction to the pole transformation.

Conclusion
RMN magnetometers capable of recording at high sampling rate (more than 5Hz) offer unequalled possibilities for magnetic surveys. For a boat speed of 20 knots, data will be recorded every meter. Their low heading error allows independence from survey line geometry. Depending on the number of secant lines crossing the other lines, levelling or micro-levelling can be performed to remove uncompensated diurnal and systematic errors. Finally, their high sensitivity makes them an ideal instrument for a wide variety of applications such as exploration, environmental and archaeological issues.

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Note
1 ADEME: Agence De l'Environnement et de la MaÃ®trise de l'Energie