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Three Dimensional Gradient Magnetics – Geologic Applications

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Abstract

Airborne magnetic mapping has been in use for petroleum exploration for decades, with the last 5 years having seen a renaissance in the use of the magnetic technique. Newer surveys have focused on measuring the weakly magnetic faults and lithologies of the sedimentary sequence, near surface paleo-channels, and the size and shape of salt intrusions, all in addition to the basement structure.

Hood (1965) was the first to describe and quantify the benefits of acquiring magnetic gradient data from an airborne platform. Since that time, magnetometer sensor technology has developed significantly, and new attempts are being made to usefully acquire and interpret the additional information held within the three dimensional magnetic gradients of the magnetic field. Gravity data acquisition, the other potential field method, has also recently seen a move towards use of gradient arrays (Pawlowski 1998). In the systems currently operational, the full gravity gradient tensor is measured. The increased amount of information gathered about the gravitational field within the sedimentary sequence has been used very successfully to enhance the exploration process.

Three dimensional magnetic gradient systems are currently in use for the detection and detailed mapping of oil field infrastructure (pipelines, well heads and other hazards), thereby assisting in the safety and planning of 3D Seismic surveying. At the same time that these operations are under way, the systems have been observed as well to provide an impressive amount of information about the background geology of the oil field.

This helicopter-borne three dimensional magnetic gradient technology has recently been used to collect 50 meter line spacing data in several key exploration areas in both the plains and fold belt regions of the Western Canada Sedimentary Basin. The purpose of this paper is to describe the technology and geologic applications of the system. Case histories will be presented to show the increased information content of the gradients versus the total field.

INTRODUCTION

The three dimensional magnetic gradient system used on these test areas in the Western Canada Sedimentary Basin was the 3D-GM ™ sensor developed by Scintrex. The sensor system consists of three (3) Scintrex CS-2 cesium vapor magnetometers mounted in a towed bird of triangular configuration. Magnetometer separation is three meters in all directions. The system measures the three dimensional gradients (G_x, G_y and G_z) of the local magnetic field, in addition to the total field intensity, at an along line sample interval of 2.5 meters. The exact position and attitude of the sensor bird is measured using geodetic quality differential GPS, a laser altimeter and pitch, roll and yaw sensors, all mounted on the bird.

Corrections are made for heading error and bird orientation, resulting in overall system noise levels in the range of 2 picoTeslas per meter. The laser altimeter on the bird yields a height-above-ground accuracy in the centimeter range, and the differentially corrected GPS data positions the bird to within less than one meter of true location.

Figure 1: Three Dimensional Magnetic Gradient sensor in flight.

Processing of the data post-flight provides a number of useful products, including; geo-referenced flight path video, along-line digital terrain profiles, total magnetic intensity, and the across-line, along-line and vertical magnetic gradients. One of the most useful interpretation tools is the measured total gradient, $G_T = \sqrt{G_x^2+G_y^2+G_z^2}$, also known as the measured analytic signal. The total gradient has a number of advantages over the simple total field and individual gradient measurements. It is independent of normal magnetic diurnal variations, it is independent of sensor orientation errors, it is independent of magnetic latitude variables and of the effect of remnant magnetization. The total gradient is always positive, and always peaks right over top of the causative body, making interpretation and precise positioning a relatively simple process.

The helicopter towed bird is flown over the area of the oil field at an altitude of 30 meters above ground, draping the terrain contours. Flight lines are spaced at 50 meters. Tie lines are flown in an orthogonal direction at 500 meter spacing.

The magnetic gradient information collected by the system provides an omni-directional measurement of the magnetic field, minimizing the directional aliasing prevalent in standard magnetic surveys. It also provides a much higher resolution measurement of the sedimentary magnetic anomaly due to its low flight altitude and the tight line spacing used. The result is a product that provides structural geologists and potential field geophysicists with the most detailed map yet of the local sedimentary geology, as depicted through its magnetic susceptibility properties. The best geological results are achieved when the magnetic data interpretation is combined with a high quality interpretation of satellite imagery.

CASE HISTORY DESCRIPTION:

The test sites presented in this paper were designed to address several critical issues which are related to the exploration application of 3D-gradient magnetic data. First and foremost, we wanted to test the hypothesis that the improved line spacing of the magnetic survey, and the availability of three dimensional magnetic gradient capabilities, will improve our ability to map near surface geological features. Of particular interest are faults and fracture systems that control the development of reservoir rocks in the test areas. Second, we wanted to improve our ability to use 3D-gradient magnetic surveys in areas that are infested with cultural noise, especially pipelines and well heads. Third, we wanted to improve our ability to conduct 3D-gradient magnetic surveys in the rugged areas of the fold belt. Forth, and finally, we wanted to test the hypothesis that with the improved resolution of the 3D-gradient magnetic data we might be able to detect fault related hydrothermal dolomites or perhaps directly detect the presence of micromagnetic signature of hydrocarbon reservoirs.

DISCUSSION OF RESULTS:

Preliminary results of this project are very promising. For example, the new 3D-gradient magnetic data of the Parkland field clearly depicts a major dolomitizing fault that resulted in the development of the two prolific Wabamun-producing wells of this field. The new survey also allow us to clearly separate between cultural noise and near surface geological and geomorphological features. In the deep basin area it is possible to map, with a fine level of detail, a major fault zone that appears to control Chevron’s recent Maserau discovery. Additionally, our new survey of the Colman field shows that the field is compartmented by a series of major northwest trending fault and fracture systems that originate in the basement but were reactivated during the Laramide thrusting event.

CONCLUSIONS:

The sedimentary rock sequences within oil-bearing basins worldwide have been shown to be amenable to the airborne mapping of geologically significant magnetic susceptibility contrasts. The use of three dimensional gradient magnetics, particularly in an environmentally quiet towed bird configuration, is now seen to expand upon these capabilities, and to allow access to more rugged terrain

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