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Recent Developments in Magnetic Method for Hydrocarbon Exploration

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Summary

Technological advancement in magnetometers has resulted in the possibility of measuring the magnetic field with high accuracy; to add to this the improvement in the positioning of the aircrafts using GPS, compensation software / hardware for suppressing airplane noise and gradiometer measurements have led to a sea change in the kind of resolution that can be achieved in the study of aeromagnetic anomalies. This combined with the availability of sophisticated computers and data processing and imaging techniques has made it possible to identify and interpret the miniscule magnetic signatures associated with hydrocarbons. Further, there has been a global surge in geochemical studies to understand magnetic mineralogy, in particular those associated with hydrocarbon seepage and migration that could result in weak magnetic signatures. Thus a combination of recent developments in various fields has resulted in making the Magnetic Method 'a Tool to reckon with', for hydrocarbon exploration. Global examples of the different types of surveys and the resultant improvement in magnetic data interpretation related to hydrocarbon exploration will be presented.

Introduction

The Magnetic Method has for a very long time contributed in assisting oil exploration, mainly as a secondary reconnaissance tool, by helping to define the basement structures that control emplacement of hydrocarbon in overlying sedimentary basins. Although advances made in acquisition, processing and interpretation of aeromagnetic data were being widely applied to the exploration of minerals and geothermal resources, there was a lull in the application of the magnetic method to petroleum exploration in the mid seventies. However, in the recent past, technological advancement in instruments, better data collection procedures, associated data interpretation / imaging techniques and better understanding of magnetic mineralogy has promoted the magnetic method from a reconnaissance tool to a method that a specialist needs to consider seriously for the purpose of hydrocarbon exploration.

Technological Advancement of the Magnetic Method

Improvement in the instrumentation technology has led to the development of accurate magnetometers; the currently available Cesium vapor Magnetometers and Overhauser Magnetometers are able to measure data with an accuracy of 0.001nT. The SQUID magnetometer is one of the most sensitive measurement devices known to man. SQUID or Superconducting Quantum Interference Devices, measure extremely small magnetic fields as small as 10^{-15} Tesla or one femto-Tesla. With the availability of gradiometers measuring horizontal and vertical gradients in the total magnetic field, it is possible to enhance the gradients of the observed weak magnetic anomalies and thereby map lithological / geological structures prospective for hydrocarbon exploration, very accurately. This coupled with precise aircraft positioning using GPS and software / hardware for suppressing airplane noise has resulted in marked improvement in the data acquisition quality and resolution. Blakely (1995) describes in detail the various possible data processing techniques including forward and inverse modeling for analysis of magnetic data. With the availability of sophisticated computers and data processing and imaging techniques, the interpretations have improved manifold and have contributed to a quantum jump in the application of aeromagnetic data to hydrocarbon exploration. Thus, major strides have been made in the acquisition, processing and interpretation of aeromagnetic data.

One of the major problems in the application of magnetic methods is the isolation of weak magnetic anomalies caused by low concentrations of the magnetic minerals in sediments. These weak anomalies are often masked by much stronger magnetic anomalies caused by underlying magnetic rocks and/or by rocks in the sedimentary basin. Proper filtering techniques need to be applied to isolate the signal from the noise; the weak anomalies can be effectively isolated by applying selective band pass filtering filters. It maybe noted that for aeromagnetic data, the along flight data spacing, flight altitude and flight line spacing play an important role in the resolution of the data collected. Available aeromagnetic data over India at the reconnaissance scale (1:250,000) are collected at a flight altitude of around 1.2 km with a flight line spacing of 4 km. with sample spacing of 20m and accuracy of 0.1 nT (Rajaram et al, 2006). Whereas, High Resolution Aeromagnetic (HRAM) data for petroleum exploration are commonly defined as data collected at a flight line spacing of 800m or less at flight heights of 150m or less, at 15 m or less sample spacing along the flight line and at better than 0.1nT accuracy (Glenn and Badgery, 1998). Several countries have repeated their aeromagnetic surveys keeping pace with the technology especially in regions of viable resources. Helicopter mounted system can be used in areas with strong topographic effects as these can be flown while draping the landscape, and as such, minimize the effect of topography. Super HRAM data is collected from a helicopter platform; according to Image Interpretation Technologies Inc. (2005), for SHRAM, typically the data is collected at 30 – 50 m above the ground and with 50 – 200 m flight line spacing. By flying closer to the ground with decreasing flight line spacing, there is a dramatic increase in resolution; the helicopter-borne SHRAM data can detect even the subtlest sedimentary magnetic anomalies that are created in the shallow sedimentary section.

Magnetic Mineralogical Studies

The International Association of Geomagnetism and Aeronomy has declared the current decade as the Decade of Geopotential Research. Several Satellites dedicated to making measurements of the geomagnetic field have been put in orbit, during this period. This has ushered in a global interest in understanding the cause of the geomagnetic anomalies and resulted in intricate geochemical studies to understand magnetic mineralogy. Of particular interest in this regard is the understanding of the changes in magnetic mineralogy caused by hydrocarbon seepage and migration that could result in weak magnetic signatures. The hydrocarbons leak in varying quantities to the surface and produce, through geochemical interaction, magnetic minerals in the sediments. The process commonly associated with and generated by hydrocarbon micro-seepage include the authigenic precipitation of pore filling carbonate cements, which may decrease permeability of sealing cap rock and the diagenetic, largely microbial conversion process of weakly magnetic hematite parent mineral to strongly magnetic magnetite (Stone et al, 2004). Authigenic magnetite maybe generated in at least two ways: Reduced iron combines with hematite and water to form magnetite and secondly, iron reduced at some depth migrates upwards into an oxidizing zone and oxidation would directly produce magnetite and maghemite (Donovan et al, 1984). The magnetic contrast between sedimentary rocks of normally low magnetic susceptibility and those locally enriched with this epigenetic magnetite results in distinctive magnetic signatures resulting in characteristic "magnetically enhanced zones" which have proven invaluable in hydrocarbon exploration. In China, soil magnetic measurements (susceptibility and hysteretic parameters) and soil hydrocarbon analysis were conducted near the Jingbian gas field and their results provide strong evidences for the formation of highly magnetic minerals in close association with hydrocarbon seepage (Liu et al, 2004). Recognition of such seepage induced magnetic anomalies can be used to facilitate the exploration of oil and gas. Enrichment of magnetic mineralization due to hydrocarbon migration is also a well know phenomenon (see articles in Schumacher and Abrams, 1996).

Urquhart (2004) states that "Bacteria and other microbes play a profound role in the oxidation of migrating hydrocarbons. Their activities are directly or indirectly responsible for many of the diverse surface manifestations of petroleum seepage. These activities, coupled with long-term migration of hydrocarbons, lead to the development of near-surface oxidation-reduction zones that favor the formation of hydrocarbon-induced chemical and mineralogical changes. This seep-induced alteration effect has led to the development of a varied number of geochemical exploration techniques. Some detect hydrocarbons directly in surface and seafloor samples, others detect seep-related microbial activity, and still others measure the secondary effects of hydrocarbon-induced alteration using magnetic techniques". He discusses the Sedimentary Residual Magnetic (SRM) anomaly method which depends on the magnetic properties of the rocks in the sedimentary section being changed by the presence of hydrocarbons at depth; these changes produce magnetic anomalies that are distinguishable from anomalies produced by the magnetic basement and other effects. The test studies show that in practice the method will enhance the success rate of an exploration program where the SRM method is incorporated into the methodology

Examples

An excellent example of the utility of improving resolution of aeromagnetic data is available from the Western Canada Sedimentary Basin (WCSB). The Geological Survey of Canada (GSC) had collected data over WCSB at the reconnaissance scale. Subsequently, magnetic surveys of this Basin have been carried out extensively, at different resolutions. Hassan (2003) of GEDCO, has made a comparison of the HRAM data and GSC data collected over the WSCB and finds that the GSC data does not have adequate frequency content to solve structural problems except on very regional scale while the HRAM data could resolve faults both in the basement and in the sedimentary section and allow one to map the basement. Further, selected areas of WCSB were re-flown using helicopter to collect SHRAM data. Image Interpretation Technologies Inc. (IITech, June 2005) have compared the HRAM and SHRAM data sets; a thrust fault identified in the HRAM data appeared to be offset in a sinistral sense suggesting a tear fault in the sedimentary section. However, the better resolution of the SHRAM data suggested a lateral ramp in the hanging-wall of the thrust, rather than a tear fault.

Several examples to demonstrate the enhanced resolution achieved in the magnetic anomalies that could be used for hydrocarbon exploration purposes, will be presented.

Conclusions

The integrated efforts of Engineers, Geophysicists, Computer Scientists, Petrologists and Geochemists amongst others have resulted in transforming the Magnetic Method for Hydrocarbon exploration from a mere reconnaissance tool to a method that can now provide levels of detail that are compatible to those derived from seismic, well and surface geological data. The Magnetic Method is here to stay!!

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