AIRBORNE GEOPHYSICS FOR SHALLOW OBJECT DETECTION: TECHNOLOGY UPDATE 2003

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Abstract

A research team, led by Oak Ridge National Laboratory, has developed airborne geophysical systems for mapping and detection of metallic wastes at large sites. The primary focus of this work has been on developing systems for detecting unexploded ordnance (UXO), but the systems are suitable for a wide range of problems where metallic and non-metallic materials need to be mapped over areas of hundreds of hectares and larger. In central and eastern Europe, these low altitude airborne systems can provide detailed maps of large environmental sites that contain UXO, infrastructure, or archaeological features, and high resolution geologic maps of a site.

Introduction

Airborne magnetic and electromagnetic systems have been very effective over the years for mineral prospecting and in support of petroleum exploration. More recently, conventional towed-bird systems, operating at sensor altitudes of 30-50m, have been used in support of environmental investigations (Doll et al., 2000). The towed-bird systems can provide regional data for site investigations, such as locating or delimiting the boundaries of waste areas, identifying geologic contacts that influence environmental issues, or mapping saline intrusion. However, these conventional systems cannot provide the resolution required in many environmental and engineering problems because the distance between sensors and target objects is too great. Ground-based surveys are often suitable for addressing these problems, but for many sites, the size of the area can be too large to be expediently addressed with surface geophysics. Contamination of government land with unexploded ordnance (UXO) is one such large-scale problem.

In the 1990s, two of the coauthors of this paper, Holladay and Gamey, began to address the UXO problem while working at the former Aerodat Ltd. in Toronto. They devised a 3-magnetometer system, the HM-3 ™, in which the sensors were mounted in booms attached directly to the helicopter (Gamey and Mahler, 1999). This architecture provided an opportunity for the pilot to safely fly much closer to the surface. During subsequent joint projects with ORNL researchers, both system and operational parameters were adjusted, and a successful demonstration of the HM-3™ system for UXO as small as 4 kg was completed in September 1999. Since that time, we have developed improved magnetic systems as well as time-domain electromagnetic systems for detection and mapping of UXO and other metallic objects of similar size. These are collectively referred to as the Oak Ridge Airborne Geophysical System (ORAGS).

Figure 1. The ORAGS-Arrowhead total field magnetometer system in operation.

The most recent of the total field magnetometer systems is the ORAGS-Arrowhead system (Figure 1). The sidebooms and foreboom house a total of eight cesium vapor magnetometers at a nominal spacing of 1.7m, with two magnetometers each at the ends of the sidebooms and four spaced evenly across the v-shaped foreboom. Boom-mounting allows operation at altitudes as low as 1-2m above ground level (AGL), much lower than is possible with conventional towed-bird systems. This provides resolution approaching that of ground-based systems.

The sensor positioning within the booms is designed to minimize noise from the helicopter rotor and other sources while maintaining a weight distribution that optimizes flight performance, and above all, safety. All data are recorded on a PC-based console that samples the magnetometers and key analog inputs (such as a fluxgate magnetometer) at 1.2 kHz and records laser-derived altitude and GPS position at the full output rates of those devices. The magnetometer data are downsampled, typically to 120 Hz, and the other data are interpolated to the same sample frequency as the downsampled magnetometer data. Navigation is directed by an Agnav RT-DGPS system with Racal satellite real-time correction. Aircraft position is recorded on the system console and updated by post-processing with a DGPS base station to provide accuracy of 0.2m or better. Under optimal flight conditions, the system acquires data over a 12m swath at 1.7m sensor spacing at a flight height of 1.5m. An Ashtech ADU-2 GPS-based system is used to monitor the attitude of the system to provide accurate positioning for each sensor. The ORAGS systems are typically operated at an air speed in excess of 50 knots. This allows full coverage acquisition of a rate of about 30-40 hectares per hour under favorable conditions.

Figure 2 is an analytic signal map of a bombing target in New Mexico, derived from ORAGS-Arrowhead data. Most of the anomalies in this map are associated with M-38 sand- and concrete-filled practice bombs with spotting charges, or other intact or fragmented ordnance. These are sheet metal bombs, about 0.8m long with ferrous steel content of about 10 kg. Anomaly picks for this target were selected with a threshold of about 1.5 nT/m, corresponding to a few kg of ferrous metal. Many of the bombs and fragments are at or near the surface (Figure 3), but some are buried at depths that usually don't exceed 1m. The 900m-diameter ring about the center of the target is associated with a berm of soil that was plowed so that the target could be seen from the air. This is a standard feature at many bombing targets.

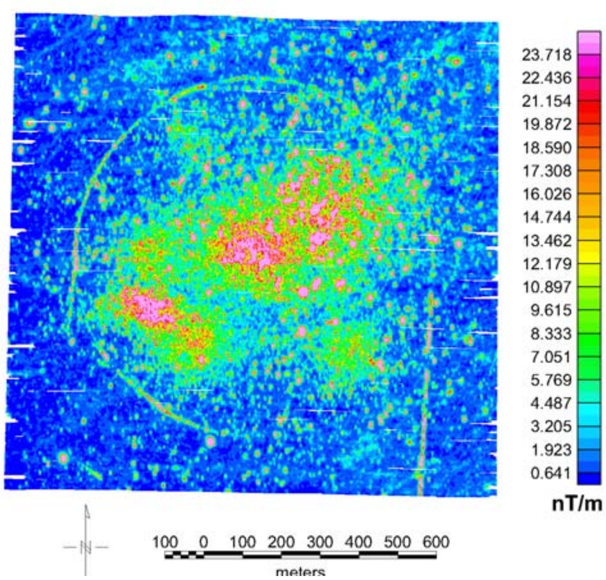


Figure 2. Analytic signal map of a bombing target in New Mexico, derived from airborne magnetic data.

Figure 3. Photograph of the M-38 practice bombs in New Mexico.

Non-UXO Applications for This Technology

Previous work has demonstrated that the ORAGS boom-mounted magnetometer system is suitable for mapping geologic features and infrastructure. Figure 4 shows an analytic signal map for a site in Maryland where many previous ground-based geophysical surveys had been conducted. The airborne data set delineated a spider web of underground pipes that had been overlooked in the preparation and interpretation of ground-based surveys. Such a network of conductors has almost certainly had a negative impact on the processing and interpretation of the ground surveys. The network would not have been detected with a conventional airborne survey at conventional altitudes. This demonstrates the value of using a boom-mounted airborne survey in the early stages of a site investigation to provide a backdrop for subsequent ground-based surveys. Infrastructure mapping is an appropriate task for these airborne systems at many large government and industrial sites.

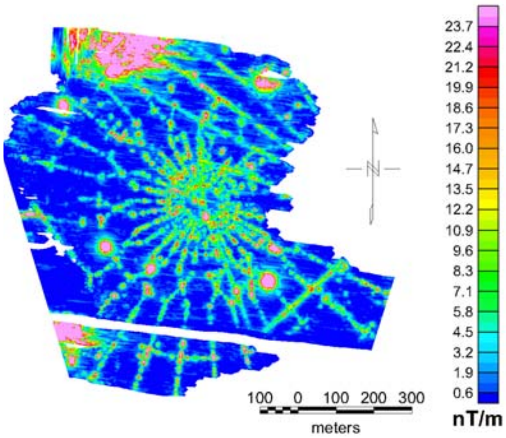


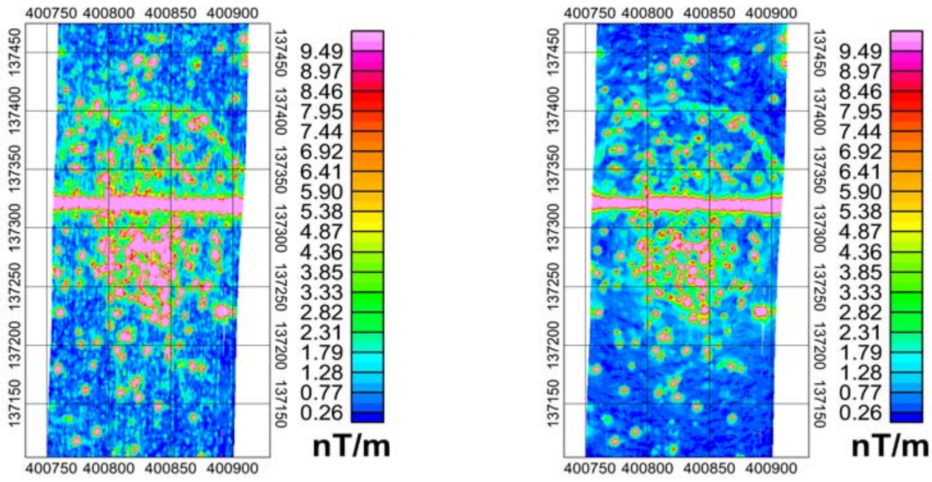
Figure 4. Analytic signal map for a site in Maryland showing anomalies associated with a network of piping that had been overlooked in more localized ground-based surveys.

For mineral investigations, the data from the system might be used in two different ways. Where data can be acquired at low altitudes (<5m AGL), the ORAGS system can be used for high-resolution mapping, as with environmental surveys. At higher altitudes, the dense magnetometer configuration could be used to acquire various types of horizontal gradient data (e.g. measured first order, second order, etc). Similarly, the ORAGS system could be used to support petroleum surveys, as a reconnaissance tool for mapping weak magnetic anomalies that might be petroleum indicators or could otherwise influence selection of seismic survey sites. At a survey site in South Dakota, we have observed linear magnetic anomalies in flat-lying sediments that may be associated with chemical alteration or deposition of magnetic minerals along faults or fracture zones. Previous research has focused on developing processing methods to extract weak anomalies from data acquired at higher altitudes, whereas the ORAGS system has the sensitivity to detect these anomalies without advanced processing. The system can also be used as a tool for identifying infrastructure, cultural interference sources, and geologic features within an area that has already been selected for a seismic survey.

Vertical Magnetic Gradient System

For conventional airborne systems, there is an ongoing debate regarding the benefits of measured vertical magnetic gradient vs. calculated vertical magnetic gradient. The latter is derived from gridded total field maps using Fourier analysis or other methods. In previous work (e.g. Doll et al., 2000), we found the calculated gradient to be unsatisfactory for low altitude measurements. Based on encouraging numerical simulations, we developed a vertical gradient system, using gradiometer pods and referred to as the ORAGS-VG system (Figure 5). Various configurations were tested (see Gamey et al., 2003) in addition to the 1m vertical / 1m horizontal magnetometer separations shown in Figure 5. In Figure 6, we show analytic signal maps derived from a) total magnetic field data (calculated vertical gradient) and b) measured vertical gradient, using the 1m x 1m separations shown in Figure 5. An east-trending barbed-wire fence crosses the center of the target. We note that most of the anomalies are better isolated, flight line noise is reduced, and the overall character of the map is significantly quieter on the measured gradient analytic signal map.

Figure 5. ORAGS-VG Vertical magnetic gradient system.



a b

Figure 6. Analytic signal maps for a bombing target in South Dakota. a) Analytic signal derived from total field measurements with the ORAGS-Arrowhead system; b) Analytic signal derived from measured vertical gradient with the ORAGS-VG system. Horizontal scale is in meters.

Electromagnetic System for UXO mapping

We have also developed a boom-mounted airborne time-domain electromagnetic (EM) system, principally for UXO mapping and detection (Beard et al., 2003). There are four primary reasons for this research and development initiative. First, not all UXO is ferrous. An EM system is capable of detecting aluminum, brass, or stainless steel objects where the magnetic system will not. Second, EM systems can perform better than magnetometer systems where geologic interference from basalts or other mafic lithologies is problematic. This has been a factor in sensor selection for ground-based surveys in Hawaii and the southwestern U.S. Third, EM systems provide more opportunities for analyses that aim to distinguish between different types of UXO or between UXO and non-UXO, because they allow more parameters to be measured (e.g. multiple time gates in a time-domain system or multiple frequencies in a frequency-domain system) and subsequently inverted. Finally, the potential for co-acquisition of electromagnetic and magnetic data provides enhanced opportunities for discrimination and ultimately a reduction in the number of anomalies that must be excavated.

Our current EM system consists of a large 3m x 12m transmitter loop with two options for receiving coils (Figure 7). Large loop receivers consist of a single turn on the outermost 2.7m x 2.7m portion of the boom. The small diameter multi-turn receiving coils measured 23 x 60 cm, and are positioned midway between the leading and trailing booms. Because the current system is a prototype, it is only a two-channel system. Footprints for the small and large coils are about 1m and 3m respectively when flying at a minimum survey altitude of about 1.0-1.5m. Construction of the ‘production’ six-channel EM system should be completed by 2004.

Figure 7. ORAGS-TEM system in transit near the Black Hills, South Dakota.

Electromagnetic data were acquired with the ORAGS-TEM system for the same target in South Dakota as in Figure 7. These results are shown in Figure 8. The small loop receiver has better resolution than the large loop receiver, but in its current configuration requires more flight passes due to smaller footprint. The 150m-diameter target berm is not seen on the EM map, though it is obvious on the magnetic map. Anomalies in a 15-20m zone straddling the east-trending fence at the

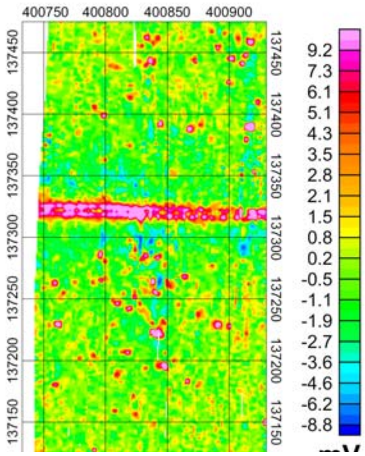


Figure 8. ORAGS-TEM measurements with large loop receiver at a bombing target in South Dakota, corresponding to the magnetic data shown in Figure 6. Data were acquired at 3m flight line spacing. Horizontal scale is in meters.

center of the target are undetected, due to the increased flight height required to pass over the fence.

Conclusions

Three new systems demonstrate that airborne geophysical systems are increasingly effective for UXO detection and other environmental and engineering applications. The ORAGS-Arrowhead system represents a mature stage of development, resulting from fifteen "production" surveys throughout the U.S. The ORAGS-VG and ORAGS-TEM systems have been thoroughly field-tested and are ready to be transitioned into production systems. We anticipate that the use of these systems will be extended beyond UXO surveys to mapping of infrastructure in brownfields, or to other environmental applications, and believe that it can also be extended to a broad range of resource exploration applications where high resolution is desired but unattainable with conventional airborne systems.

Acknowledgements

Most of this work was funded by the Environmental Security Technology Certification Program (ESTCP) under the direction of Dr. Jeffrey Marqusee and Dr. Anne Andrews, in cooperation with D. Scott Millhouse at the U. S. Army Corps of Engineers Engineering and Support Center – Huntsville. Oak Ridge National Laboratory is managed by UT-Battelle, LLC for the U. S. Department of Energy under contract DE-AC05-00OR22725. The submitted manuscript has been authored by a contractor of the U. S. Government. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so for U. S. Government purposes.

References

Beard, L. P., W. E. Doll, T. J. Gamey, J. S. Holladay, and J. L. C. Lee, 2003, Aspects of system design for airborne electromagnetic detection of unexploded ordnance, Extended abstract, SAGEEP 2003, San Antonio, TX, April 6-10, 2003, p. 1445-1454.

Doll, W. E., J. E. Nyquist, L.P. Beard, and T. J. Gamey, 2000, Airborne geophysical surveying for hazardous waste site characterization on the Oak Ridge Reservation, Tennessee, *Geophysics*, v. 65, n. 5, p. 1372-1387.

Gamey, T. J., W. E. Doll, L. P. Beard, and D. T. Bell, 2003, Analysis of Noise Coherence in Airborne Magnetic Gradients for UXO Detection, Extended abstract, SAGEEP 2003, San Antonio, TX, April 6-10, 2003, p. 1387-1398.

Gamey, T. J., and R. Mahler, 1999, Comparison of Towed and Mounted Helicopter Magnetometer Systems for UXO Detection, Extended abstract, SAGEEP 1999, , Oakland CA, March 1999, p. 783-792.