

## AIRBORNE EM DATA COMPLEMENT MAGNETICS IN AN UNEXPECTED WAY

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### Abstract

In the fall of 2008, a low-altitude airborne geophysical survey was carried out at a military installation in Australia, the primary goal of which was detection and mapping of infrastructure, buried wastes, and other buried and surface metallic objects within a 1738 hectare area. The primary survey system was the Battelle VG-16 vertical magnetic gradient system. Because the base is active, the time frame for conducting the survey was limited to a few weeks. The short time frame and the added expense of an additional system were factors against adding on an electromagnetic survey. However, the Australian Department of Defence suggested that there might be non-ferrous targets of significance that the magnetic system would not detect. Moreover, the base was located some tens of kilometers from a field of extinct volcanoes, presenting the possibility of magnetic geology in the form of mafic igneous units. Therefore, it was determined that an airborne transient electromagnetic system should be included in the project.

The added electromagnetic system proved valuable, but not in the way that was expected. Concentrations of strong anomalies appeared in the magnetic data, the sources of which could be either buried debris or geological. The TEM-8 system was flown over some of the more dense concentrations of magnetic anomalies. In some of these areas the TEM data showed very few anomalies, indicating that either the VG-16 anomalies are associated with magnetic rock types, or that the metallic sources detected by the VG-16 system are too deeply buried to be detected with the TEM-8 system. A few carefully located excavations indicated that the sources of the magnetic anomaly concentrations without associated electromagnetic anomalies were localized concentrations of very magnetic iron-bearing rock.

### Introduction

This report describes the results of a low-altitude helicopter geophysical survey carried out for the purpose of detecting and mapping infrastructure, buried wastes, and other buried and surface metallic objects within a 1738 hectare area at an Australian military installation. By low-altitude, we mean survey heights of one to three meters above ground level, where possible. To achieve such low survey altitudes, sensors are mounted on booms which are fixed to the frame of the helicopter, rather than being slung beneath the helicopter on tethers. Figure 1 shows the two Battelle boom-mounted systems used in the survey: the VG-16 (Doll et al, 2008), which measures the vertical magnetic gradient at eight evenly-spaced gradient pods, and the TEM-8, a transient electromagnetic system with two 3m x 4m transmitter loops (Doll et al, 2009). Each loop surrounds four receiver coils. Although these systems were originally designed for wide-area unexploded ordnance surveys, their exceptionally high resolution, effectively equivalent to that of a ground survey, has made the systems attractive for mineral exploration (Gamey et al, 2009) and engineering/infrastructure applications (Beard et al, 2009).



**Figure 1:** Battelle VG-16 vertical magnetic gradient system (left) and TEM-8 transient electromagnetic system (right) used for low-altitude (<2m) surveys.

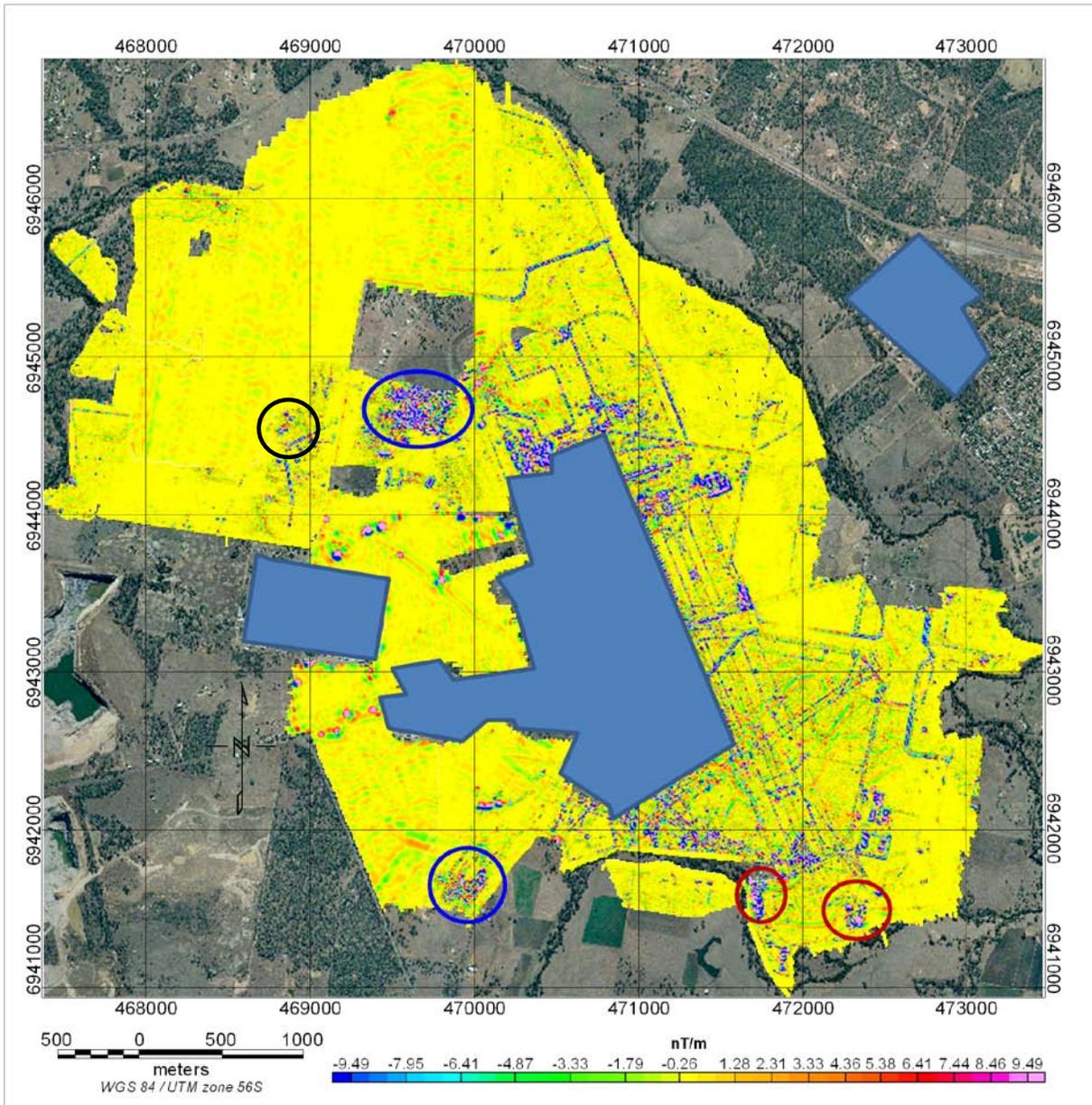
The need for a geophysical survey arose from planned expansion of the base, which was used by Allied forces in World War II, and has been in continual use since that time. In the rapid demobilization of forces after the defeat of Japan, military supplies were sometimes disposed of hastily, and there was concern that undocumented items could be buried on or near the base, and could pose a hazard to construction workers. The choice of airborne methods for geophysical surveying of the base was driven by the size of the area to be surveyed—over 1700 hectares—and time constraints for getting the survey done because of ongoing military trainings, daily logistical operations, and current and planned base expansion activities.

Although the primary survey method was to be measured vertical magnetic gradient using the Battelle VG-16 system, it was ultimately decided that the Battelle TEM-8 electromagnetic system should also be included. The Australian Department of Defence argued that some of the buried items could be non-ferrous and therefore undetectable with the VG-16. It was also pointed out that extinct volcanoes exist in the near vicinity (within tens of km) of the base, and there was some possibility on that account of magnetic geology.

About 70 percent of the 1738 hectares were flown with the VG-16 system at low-altitudes. The mean altitude in these areas was 1.4 meters above ground level. A total of 9786 vertical gradient (VG) anomalies were identified above a 5 nT/m threshold. Of these, 1960 were classified as point-source anomalies of unknown origin. TEM-8 data were collected over 290 hectares, all in the low-altitude VG areas. A total of 1893 anomalies were detected above a 3 mV threshold. Of these, 458 were classified as point source anomalies of unknown origin. The overwhelming majority of TEM anomalies had an accompanying VG anomaly, indicative of metal.

## Comparison of Anomalies

Figure 2 shows a map of the vertical gradient anomalies of the base and its immediate surroundings. Although the VG-16 survey produced about 9800 anomalies, two anomalous areas stood out as areas of concern. These areas are circled in blue in Figure 2. They were areas of multiple overlapping anomalies of relatively high amplitudes, and were in appearance similar to documented areas containing buried debris, shown circled in red in Figure 2.



**Figure 2:** Vertical gradient anomaly map of base. Red circles indicate sites of known buried waste. Blue circles indicate areas with similar anomaly pattern as the known sites, but with unknown sources. Black circle is an area where exploratory excavations took place. Blue polygons represent collections of base buildings.

Upon completion of the VG-16 survey, it was determined, based partly on the presence of the two unknown areas in Figure 2, to use the TEM-8 system to survey portions of the base comprising in total about 290 hectares. These areas are shown in dark blue in Figure 3.

Figure 4 shows close up views of the two documented buried debris sites (in Figure 2, circled in red). Although superficially similar to the two unknown areas, in detail there were differences. The two known buried waste sites had visual cues in satellite imagery. They both had some degree of topographic expression visible in satellite photos. The texture of the ground was subtly different from

surrounding undisturbed earth, and one of the sites is encompassed by roads. In contrast, neither of the unknown sites showed evidence of disturbed earth. Both were in large open fields, one on the base proper, the second on farmland leased out by the base.

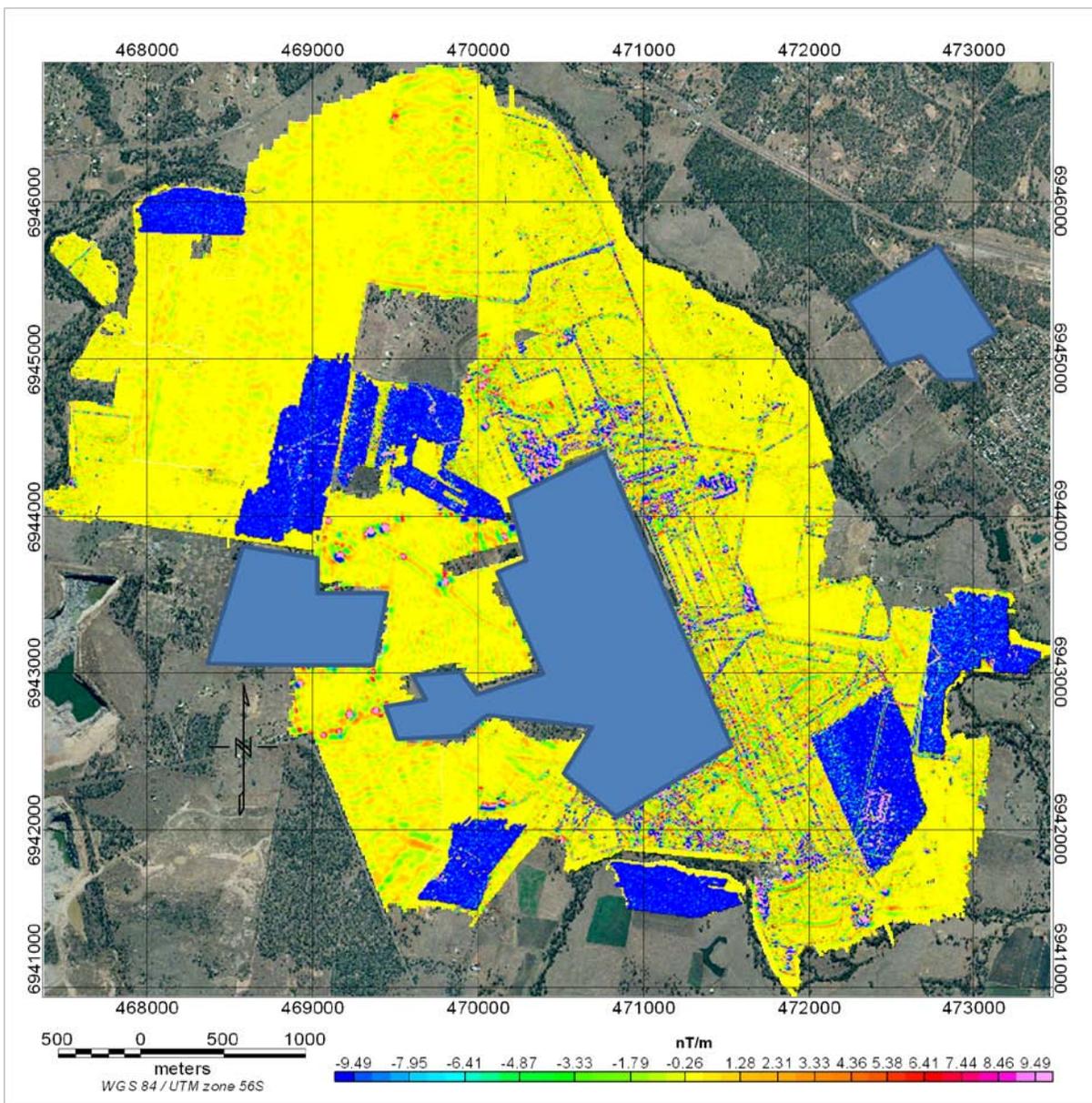
The magnetic anomalies of the known burial areas, although numerous and overlapping, appeared to have a measure of coherent magnetic “structure.” In both areas, there are large positive magnetic anomalies alternating with negative in a more or less N-S pattern, as can be seen in Figure 4. In contrast to the known burial areas, the magnetic anomaly patterns of the two unknown areas have a more random appearance, with positive and negative magnetic lobes being smaller in area and adjoining one another in a variety of directions. This difference can be clearly seen in Figure 5, which shows the VG-16 anomalies of the more northerly unknown anomaly group.

The above-mentioned differences led us to suspect a geological origin for the unknowns, and the TEM-8 data, shown in Figure 6 for the northern unknown, supported that view. The TEM-8 data showed no large electromagnetic responses indicative of buried metal over the area of dense magnetic anomalies. The system detected known collections of metal near the site, and therefore the lack of response was not instrument insensitivity. Of note is a known area of waste soil deposited in rows at the ground surface, and shown in the lower right corner of Figure 5. The soil rows contain little metal, but nonetheless appear as small amplitude lineations in the vertical gradient data with a few small magnetic anomalies from metallic objects. The magnetic lineations show the sensitivity of the VG-16 to magnetic susceptibility changes in soil. The TEM-8 system covered only a portion of the site, but as can be seen in Figure 6, the buried metal appears as small TEM anomalies in the northwest corner of the soil rows, but otherwise there is no EM response in this area.

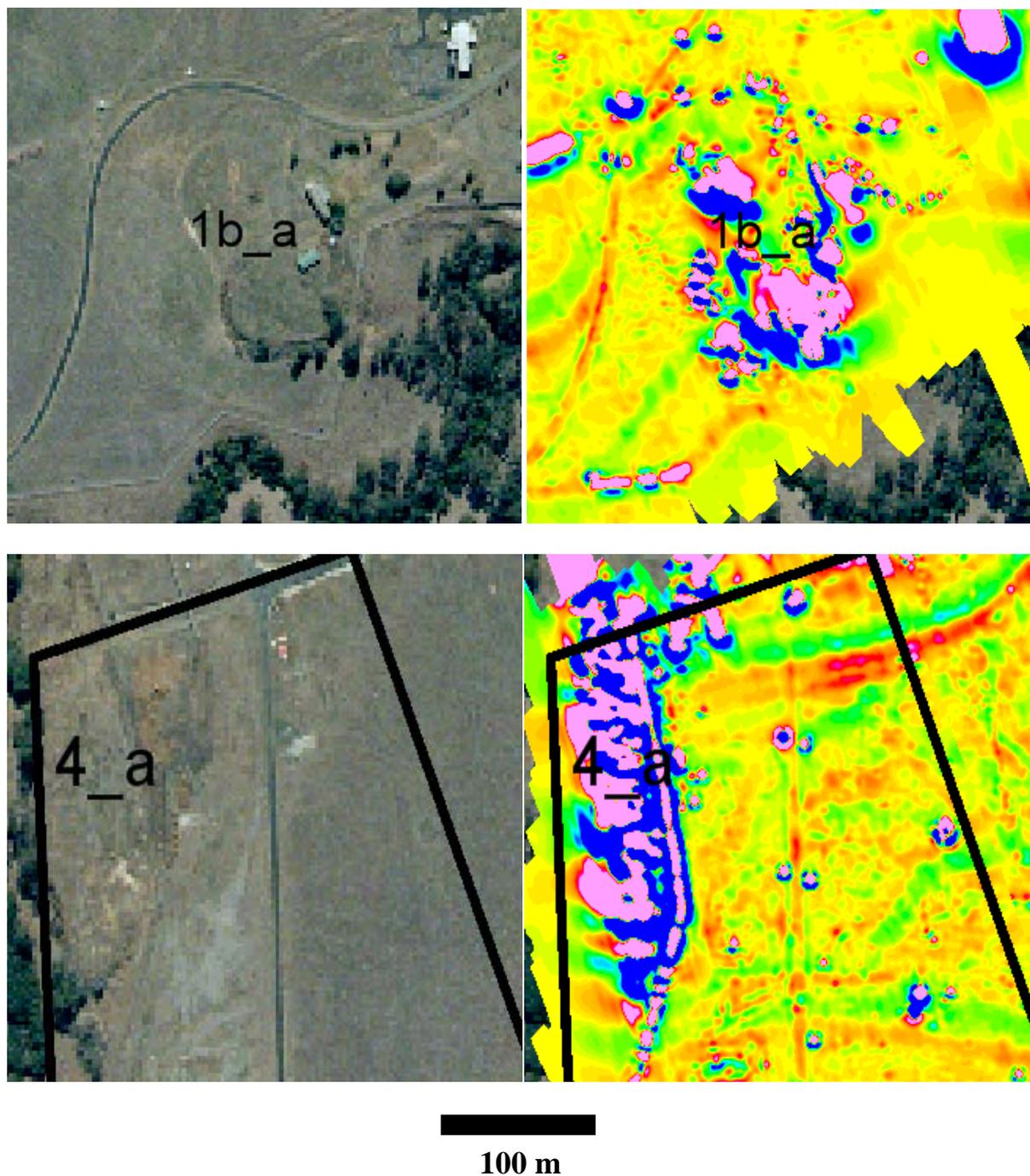
However, because the TEM-8 has limited depth detection ability, a remote possibility existed that metal debris was too deeply buried for the TEM-8 to detect. Two trenches, spaced about 70m apart and located near the center of the magnetic anomalies, were excavated to depths of over 2m. In both trenches, the field notes describe undisturbed silty clays to the bottom of the trenches. Magnetic susceptibility measurements on the silty clays at the trench sites yielded susceptibilities on the order of  $10^{-3}$  SI, not particularly magnetic and typical of clays and sedimentary formations.

The source of the magnetic anomalies remained a mystery until examination of a second magnetic anomaly collection, labeled 17\_a in Figure 7. As in the previous example, it also showed no TEM anomalies (Figure 8). In this instance, anthills in the area with magnetic anomalies were covered with bits of red rock excavated by the ants. The magnetic susceptibilities of the anthills measured approximately 0.03 SI, putting them somewhat above the average magnetic susceptibility for basic igneous rocks (Table 3.1, Telford et al, 1990).

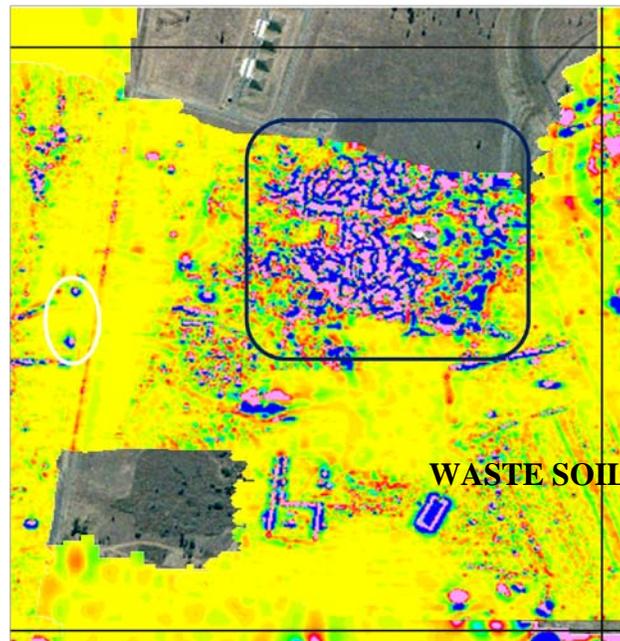
At a third site, located about 500m west of the SW corner of the anomaly collection in Figure 5, and circled in black in Figure 2, two distinct types of magnetic anomalies appeared, as shown in Figure 9. One was a single, strong, very dipolar anomaly of several hundreds of nT/m in the north part of the area, and the second a collection of anomalies having magnitudes of tens of nT/m, and similar in pattern to those mentioned above. Based on prior excavations, we expected to find metal in the north area and magnetic geology in the south. Upon excavation, the predictions turned out to be accurate. A sizeable amount of buried metal debris was uncovered in the north (Figure 10, right panel), and in the south a red layer of sand and gravel having thickness of about 80 cm was uncovered at a depth of about 0.5 m (Figure 10, left panel). The gravelly soil had magnetic susceptibilities in excess of 100 SI, and a bright red piece (Figure 10, center panel) measured over 300 SI, which was effectively the same susceptibility as was measured on the steel frame of our field vehicle.



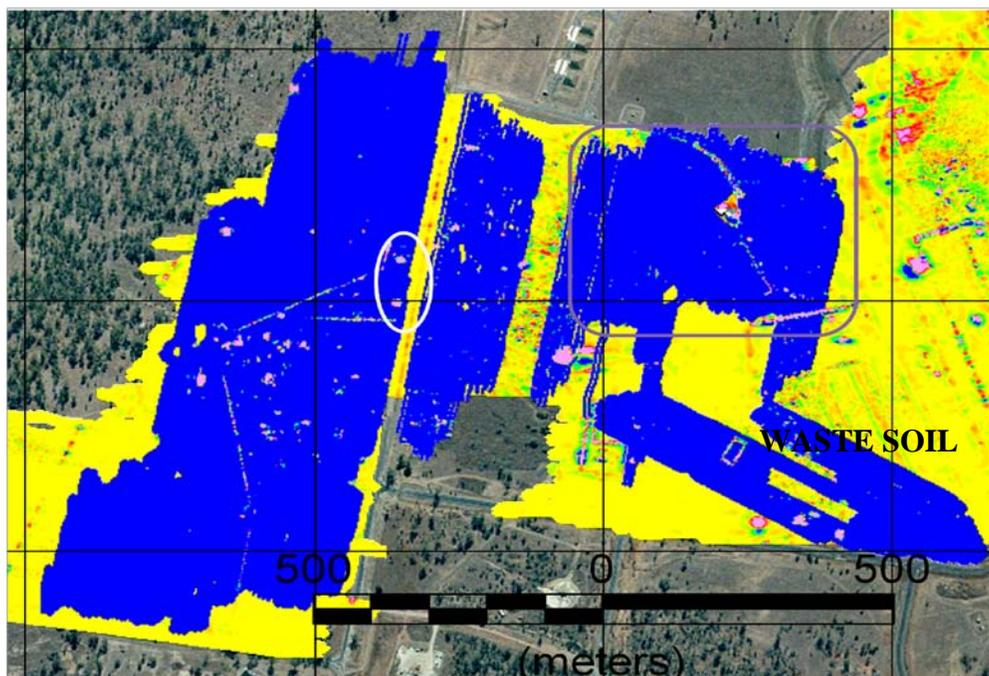
**Figure 3:** Areas (in blue) where TEM-8 was flown to complement the VG-16 survey. The areas included the anomalous areas circled in blue in Figure 2.



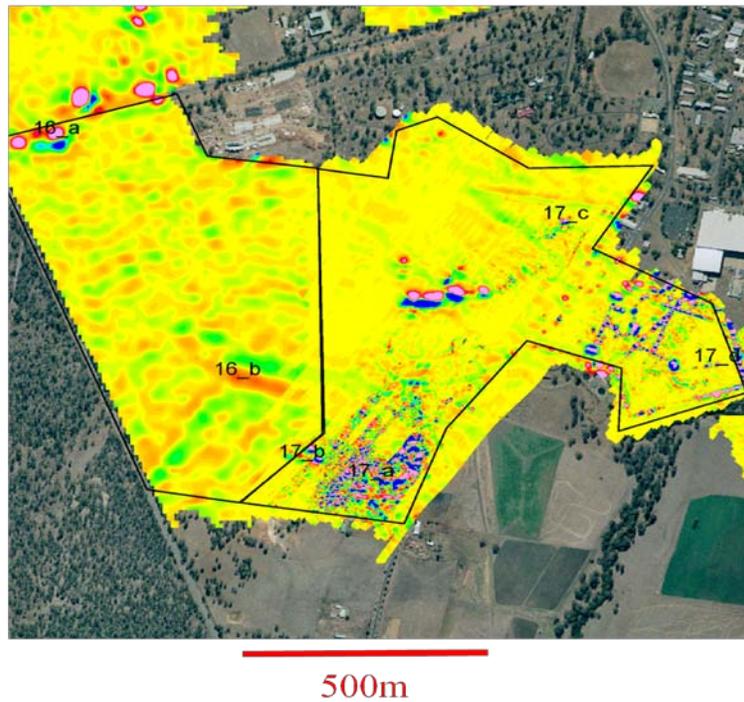
**Figure 4:** VG-16 anomalies over two documented buried debris sites, indicated by the red circles in Figure 2. Color scale is -10 nT/m to +10 nT/m (blue to red).



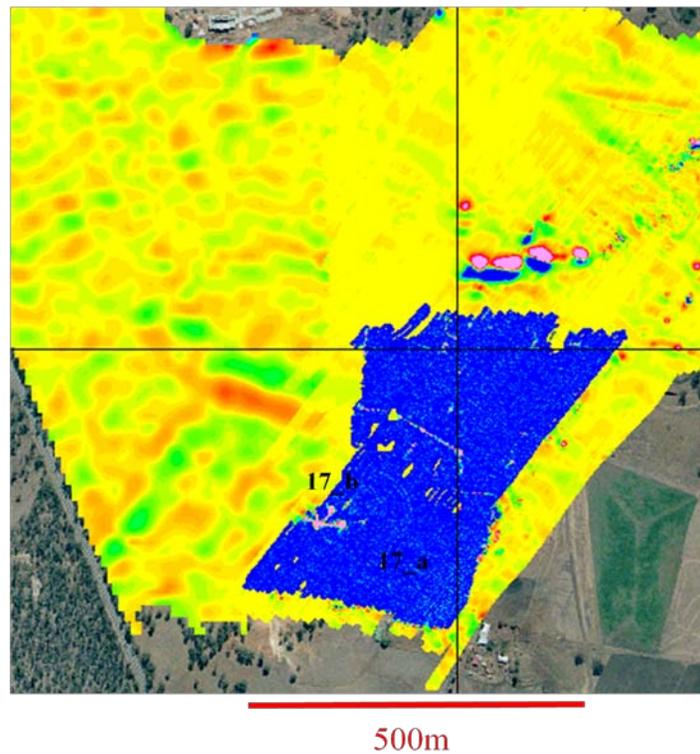
**Figure 5:** VG-16 anomalies of the more northerly of the two unknown areas circled in blue in Figure 2. Rows of waste soil with very little metal are shown by the magnetic lineations in the lower right. Color scale is -10 nT/m to +10 nT/m. Area shown is about 900m x 900m.



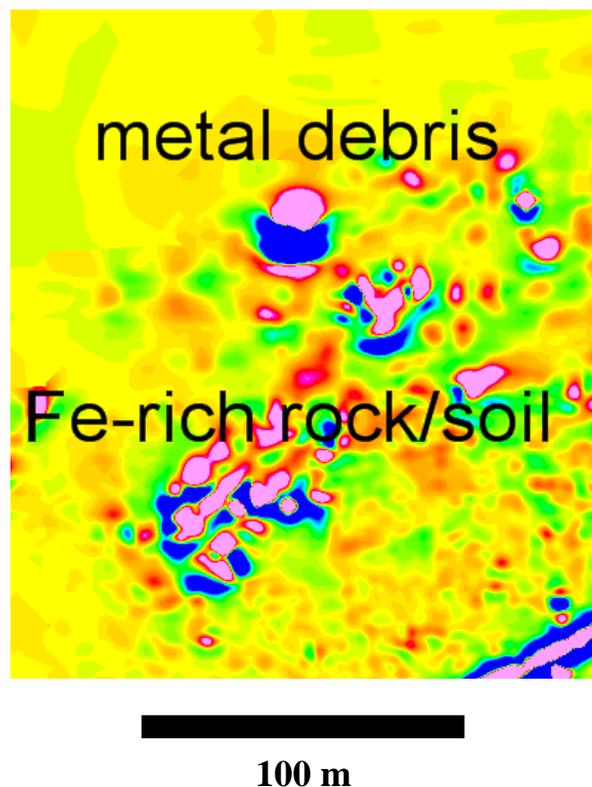
**Figure 6:** TEM-8 anomalies from time gate 2 (250 microseconds after turnoff) of the more northerly of the two unknown areas circled in grey. White oval encompasses two above ground collections of metal. The area of waste soil deposited along rows (shown in Figure 5) is indicated. EM color scale is -5 mV to +5 mV (blue to red).



**Figure 7:** VG-16 anomalies of the southern unknown area, circled in blue in Figure 2. Color scale is -10 nT/m to +10 nT/m.



**Figure 8:** TEM-8 anomalies from time gate 2 (250 microseconds after turnoff) of the southern unknown area. EM color scale is -5 mV to +5 mV.



**Figure 9:** VG-16 anomalies of the exploratory excavation area, circled in black in Figure 2. Color scale is -10 nT/m to +10 nT/m.



**Figure 10:** VG-16 anomalies of the exploratory excavation area, circled in black in Figure 2. Color scale is -10 nT/m to +10 nT/m.

## Conclusions

Although the Battelle airborne magnetic gradient system was the primary system used in a survey of an Australian military base, the Department of Defence requested that electromagnetic data be collected over some portion of the base in case some of the buried items of interest were metallic, but non-ferrous. However, the TEM-8 airborne EM system proved its worth not in detection of buried non-ferrous metal, but in helping the geophysical interpreters to determine whether the sources of sizeable concentrations of magnetic anomalies were metallic or geological. Prior to the survey, there were no strong indicators of magnetic geology in the area. However, subsequent follow-up excavations in areas that showed dense concentrations of magnetic anomalies with no electromagnetic anomalies found a shallow, highly magnetized gravel layer that was most likely responsible for the anomaly pattern. After a few exploratory excavations, we were able to more accurately predict which anomalies were caused by metal and which had geological sources.

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